Contributions and New Methods in Paleontology: Geochemical, Ultrastructural, and Microstructural Characterization of Archean, Proterozoic, and Phanerozoic Fossils

James Daniel Schiffbauer

Dissertation submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Doctor of Philosophy in Geosciences

Committee
Shuhai Xiao, Chair
Michał J. Kowalewski
Kenneth A. Eriksson
Robert J. Bodnar
Stephen E. Scheckler

May 1st 2009
Blacksburg, VA

Keywords: digital paleobiology, acritarchs, ultrastructure, focused ion beam electron microscopy, nanotomography, predator-prey interactions, predatory microtraces, field emission scanning electron microscopy, environmental scanning electron microscopy

Copyright © J.D. Schiffbauer
Contributions and New Methods in Paleontology: Geochemical, Ultrastructural, and Microstructural Characterization of Archean, Proterozoic, and Phanerozoic Fossils

James Daniel Schiffbauer

ABSTRACT

Over the past decade, the study of organismal or systematic paleobiology has been progressing into a new age of digital paleobiology, in which advanced instrumentation is utilized for primary data collection and analyses. Having been progressing throughout this field of study, advanced instruments—commonly electron- and ion- microbeam equipment—have been employed for numerous fossils over the entire range of geologic time, from microfossils to macrofossils and from the Archean (beginning at 3800 Ma) to the Cenozoic (ending at the recent). These techniques, predominantly used for geochemical, morphological, and ultra-/micro-structural analyses, have unlocked an incredible amount of detail contributing to our understanding of fossil organisms, their modes of life, and their biological affinities. But further, as these techniques continue to grow and become popularized in various fields of paleobiological study, they are certain to significantly progress our comprehension and knowledge of the evolution of life through time.

While the chapters presented in this dissertation may not have a unifying theme in terms of a distinct fossil organism or specific time in Earth’s history, furthering the use of electron- and ion- microbeam instrumentation and expanding the paleo-genres to which digital paleobiological approaches may be applied encompasses the fundamental intention of my research. Two of the chapters reported here focus on the geochemical, ultrastructural, and microstructural investigation of organic-walled microfossils, or acritarchs, from the Paleoproterozoic (2500–1600 Ma) and Mesoproterozoic (1600–1000 Ma), using a range of advanced instrumentation including field emission scanning electron microscopy, transmission electron microscopy, laser Raman spectroscopy, electron microprobe, secondary ion mass spectroscopy, and focused ion beam electron microscopy. Moving into the Neoproterozoic (1000–542 Ma), the third primary research chapter utilizes field emission scanning electron microscopy for high-resolution, high magnification imaging and quantitative evaluation of an entire fossil assemblage—from acritarchs and algal fossils to the earliest metazoan embryos. This study was conducted in an effort to examine and describe the phosphatization taphonomic window of the Doushantuo Formation of South China, which is a prime example of exceptional preservation. Finally, the fourth primary research chapter reported here uses field emission scanning electron microscopy and environmental scanning electron microscopy in a field of paleobiology in which advanced instrumentation has been highly underutilized – predatory-prey interactions. This research examines microstructural characteristics of predatory drill holes in both modern and fossil organisms in an attempt to mitigate the identification of predation traces in the fossil record.
DEDICATION

For Danny L. Schiffbauer, who taught me to never stop learning.
ACKNOWLEDGEMENTS

Too many people to thank contributed not only to my development as a scientist but also to my growth into the person that I am today (which, far too often, is overlooked or forgotten). I would like to take this opportunity to briefly acknowledge these exceptional people for all of their support, both professionally and personally, through the years. These are, in no particular order: my parents, Dan and Cindy Schiffbauer, for constant encouragement, life lessons, a little bit of insanity, and certainly fiscal support; my sister, Jenn, for always believing that I could “do it,” whatever “it” happened to be; my wife, Becky, for providing a level of patience with me that I felt was not humanly possible, for keeping me grounded when my mind tried to fight gravity, for leaving the sunny shores of south Florida and the life of a marine biologist for the cold and windy winters of Blacksburg and starting a new career as an ICU nurse, and for always supporting me – even during my most intolerable days (and if you know me at all, I really can be excruciatingly insufferable); Sherman Schiffbauer for lazy Sundays on the couch watching football, for keeping my feet warm during long nights of writing and analyzing, and for being the best quadrupedal friend I could ever have; my in-laws – Alan and Janis Freeland, Matt and Melanie Freeland (and Carson and Connor), Jennifer Freeland and Ryan Leonard, and Michael Freeland – for great vacations at the shore; Mike Rafa and Debbie Rockey for being two of the best educators that I have ever had the opportunity to learn from, and Eddie Vedder for keeping me rockin’ over the past 20 years. I would also like to thank the numerous great faculty and mentors through my academic career, which include, but are certainly not limited to: my undergraduate advisor, Joe Marshall, for encouraging me to pursue graduate studies as well as for giving me opportunities as a teaching assistant early in my academic career; Tom Kammer for opening my eyes to the world of paleontology; my master’s committee, Chuck Messing and Bernardo Vargas-Angel; my master’s advisor, Pat Blackwelder, for giving me invaluable experience with electron microscopy; my PhD committee, Bob Bodnar, Ken Eriksson, and Steve Scheckler; and the entire faculty and staff of the Virginia Tech Department of Geosciences, with a special thanks to Connie Lowe for always listening to my random streams of consciousness. The research presented here could not have been completed without the assistance and guidance of the faculty and staff of the Virginia Tech Institute of Critical Technology and Applied Science Nanoscale Characterization Laboratory (Steve McCartney, John McIntosh, Jerry Hunter, and Bill
Reynolds). I would also like to express my gratitude to my fellow graduate students and friends – Adam Wallace, John Huntley, Troy straight Jers’ Dexter, Ben Rothlisberger, Michelle Casey, Rich the micromill Krause, Jen Stempien, Peter VoiceBot3000, Carrie Tyler, Bing Shen, Lin Dong, Susan Barbour-Wood, Kurt Yano, Roger Clem, and Sean Hope Myer – for good times, cold beers, and most importantly for serving as sounding boards for ideas, rants, and ridiculosity. Lastly, and almost certainly most importantly, I would like to show my enormous appreciation to Michał Kowalewski (or Micha Koweleski) for providing honest opinions, professional guidance, and for believing that I wouldn’t *mess* up too badly; and Shuhai Xiao for professional guidance above and beyond what is required for a PhD advisor and also far ahead of anything that I had expected or anticipated, for giving me a chance, and finally for believing in me even when I didn’t, couldn’t, or chose not to believe in myself.
ATTRIBUTIONS

Several colleagues contributed to the research presented in this dissertation. A brief explanation of their roles in each project follows the description of my doctoral advisory committee. The content of this dissertation was edited and appraised by the following members of my doctoral committee: Shuhai Xiao, Ph.D. (doctoral committee chair, Department of Geosciences, Virginia Tech), Michal Kowalewski, Ph.D. (Department of Geosciences, Virginia Tech), Kenneth A. Eriksson, Ph.D. (Department of Geosciences, Virginia Tech), Robert J. Bodnar, Ph.D. (Department of Geosciences, Virginia Tech), and Stephen E. Scheckler, Ph.D. (Department of Biological Sciences, Virginia Tech). Shuhai Xiao and Michal Kowalewski are both Professors of Geobiology. Shuhai's areas of concentration include, in a few words, Precambrian geobiology, early animal history, Proterozoic algal fossils, Lagerstätten, taphonomy, carbonates, isotope geochemistry, and the fossil record of microbes. Michal’s areas of research focus primarily on collecting paleontological and geological data over a wide range of spatio-temporal scales, which are used to study diverse geobiological topics including ecology, taphonomy, depositional environments, and long-term evolutionary patterns. Kenneth Eriksson is a Professor of Geology and Interim Department Head, whose research has been centered upon the study of siliciclastic sediments in terms of sedimentary processes and depositional environments, stratigraphic architecture, basin analysis and paleogeography, and microbially-induced sedimentary structures. Robert Bodnar is a University Distinguished Professor and C. C. Garvin Professor of Geochemistry, primarily studying the distribution, properties, and role of fluids in planetary processes, and has technical expertise in laser Raman spectroscopy and secondary ion mass spectrometry (SIMS). Stephen Scheckler is a Professor of Biological Sciences and adjunct faculty in the Department of Geosciences, with research interests, broadly, in the realm of Paleozoic paleobotany.

Chapter two, "Ultrastructural and geochemical characterization of Archean–Paleoproterozoic graphite particles: Implications for recognizing traces of life in highly metamorphosed rocks,” was published in Astrobiology (2007), volume 7(4), pages 684–704, by J.D. Schiffbauer, L. Yin, R.J. Bodnar, A.J. Kaufman, F. Meng, J. Hu, B. Shen, X. Yuan, H. Bao, and S. Xiao. Preliminary analyses, supervised by L. Yin, for this project were started at the
Nanjing Institute of Geology and Palaeontology prior to J.D. Schiffbauer’s arrival at Virginia Tech. With positive results from L. Yin’s groundwork, this project became J.D. Schiffbauer’s principal focus for the first two years of his PhD research. J.D. Schiffbauer conducted the primary analyses central to the manuscript, including field collection, acid maceration and extraction of graphitized microfossils, optical microscopy of extracted microfossils and petrographic thin-sections, scanning electron microscopy (SEM) of extracted fossils, laser Raman spectroscopy of both extracted and in-situ fossils, and sample preparation for secondary ion mass spectroscopy (SIMS) analyses. Additionally, J.D. Schiffbauer led the preparation of the manuscript and drafted figures 2 through 10. L. Yin conducted preliminary examination and analyses on material collected prior to J.D. Schiffbauer’s arrival in the Ph.D. program at Virginia Tech, and provided important input on the content of the manuscript. R.J. Bodnar trained J.D. Schiffbauer in Raman spectroscopy, aided in the interpretation of Raman data, and provided notable comments on the structure, organization, and content of the manuscript. A.J. Kaufman and S. Xiao conducted SIMS analyses on microfossils that were extracted and prepared by J.D. Schiffbauer. F. Meng, J. Hu, and B. Shen provided significant field assistance during the collection of the rock samples used for this study, and F. Meng and J. Hu additionally aided in the preliminary fossil analyses conducted by L. Yin, including sample preparation, transmission electron microscopy, and SEM. X. Yuan provided critical logistical support for field collection in the Wutaishan area of North China. H. Bao aided in field collection and data interpretation. S. Xiao provided the majority of the laboratory facilities for the completion of this research, drafted figure 1, supervised the preparation of the manuscript, and also provided intellectual support and invaluable comments on the structure, organization, and content of the manuscript. S. Xiao and J.D. Schiffbauer provided research funds to conduct this research.

Chapter three, “Novel application of focused ion beam electron microscopy (FIB-EM) in preparation and analysis of microfossils ultrastructures: A new view of complexity in early eukaryotic organisms,” by J.D. Schiffbauer and S. Xiao, is currently in press in Palaios. J.D. Schiffbauer conceived and conducted the focused ion beam nanotomography and analyses of extracted organic-walled microfossils, interpreted the resulting data, led preparation of the manuscript, and drafted the figures. S. Xiao conducted the sample collection, oversaw the preparation of the manuscript, and aided in the interpretations of the data. S. Xiao, J.D.
Chapter four, “Microfossil phosphatization and its astrobiological implications,” by S. Xiao and J.D. Schiffbauer, was published in the edited book, From Fossils to Astrobiology: Records of Life on Earth and the search for Extraterrestrial Biosignatures (2008; J. Seckbach and M. Walsh, eds.), as volume 12 of the Cellular Origin, Life in Extreme Habitats and Astrobiology series published by Springer. This project resulted from an invitation to contribute to the aforementioned volume by editor M. Walsh. S. Xiao led the preparation of the manuscript and conducted SEM analyses. J.D. Schiffbauer participated in manuscript preparation, prepared figures 2 through 12, and conducted all aspects of the quantitative analyses. S. Xiao provided research funds.

Chapter five, “The microstructural record of predation: A new approach for identifying predatory drill holes,” was published in Palaios (2008), volume 23(12), pages 810–820, by J.D. Schiffbauer, Y. Yanes, C.L. Tyler, M. Kowalewski, and L.R. Leighton. This project came from the accidental discovery of radular rasping marks on drill holes in limpets from a feeding experiment conducted by Y. Yanes at Friday Harbor Laboratories (University of Washington). The feeding experiment was conducted as part of the 2006 Predator-Prey Interactions Course conducted by M. Kowalewski and L.R. Leighton. J.D. Schiffbauer performed the initial scanning electron microscopy (SEM) that uncovered the radular marks, expanded the project to include SEM micrographs drill holes in mussels from a feeding experiment conducted by M. Kowalewski, drill holes in subfossil (submodern, tidal flat death assemblage) limpet material collected by Y. Yanes, and drill holes in various Miocene bivalves collected by M. Kowalewski and held in the Virginia Tech repository. J.D. Schiffbauer performed all of the SEM work, participated in data collection on the feeding-experiment limpets and subfossil limpets, collected numerical data on the rasp marks from the feeding-experiment mussels and Miocene bivalves, collected numerical data on shell growth microstructures from two of the mussel specimens and one of the Miocene bivalves, and radular tooth width from published literature, conducted quantitative data analyses, led preparation of the manuscript, and drafted the figures. Y. Yanes conducted the limpet feeding experiment, collected and sorted the dead shell assemblage from Schiffbauer, and the Virginia Tech Institute for Critical Technology and Applied Science Nanoscale Characterization and Fabrication Laboratory provided research funds.
the False Bay, led data collection on the feeding-experiment limpets and subfossil limpets, and aided in the preparation of the manuscript. C.L. Tyler provided critical field assistance in the limpet collection as well as assistance in the limpet feeding experiment. M. Kowalewski provided access to repository material, conducted the mussel feeding experiment, oversaw the preparation of the manuscript, and provided significant and detailed comments on the manuscript drafts and insight in data interpretation. L.R. Leighton provided constructive comments on the manuscript, figure drafts, and data interpretation. M. Kowalewski, J.D. Schiffbauer, S.Xiao, and the Virginia Tech Institute for Critical Technology and Applied Science Nanoscale Characterization and Fabrication Laboratory provided research funds.
TABLE OF CONTENTS

ABSTRACT .................................................................................................................................... ii
DEDICATION .................................................................................................................................. iii
ACKNOWLEDGMENTS ................................................................................................................ iv
ATTRIBUTIONS ........................................................................................................................... vi
TABLE OF CONTENTS ................................................................................................................. x
LIST OF MULTIMEDIA OBJECTS ............................................................................................. xv
GRANT INFORMATION ............................................................................................................. xx

CHAPTER 1: A new age in paleobiology: Integrated applications of nanotechnologies for fossil analyses ................................................................................................................................. 1
1.1 INTRODUCTION ..................................................................................................................... 2
1.2 SUMMARY OF RESEARCH ................................................................................................... 3
1.3 REFERENCES .......................................................................................................................... 7

CHAPTER 2: Ultrastructural and geochemical characterization of Archean–Paleoproterozoic graphite particles: Implications for recognizing traces of life in highly metamorphosed rocks ................................................................................................................................. 9
2.1 ABSTRACT ............................................................................................................................. 10
2.2 INTRODUCTION ................................................................................................................... 10
2.3 GEOLOGICAL SETTING ...................................................................................................... 13
2.4 METHODS .............................................................................................................................. 15
  2.4.1 Sample preparation ........................................................................................................ 15
  2.4.2 Analytical techniques ..................................................................................................... 16
2.5 RESULTS ............................................................................................................................... 17
2.6 DISCUSSION .......................................................................................................................... 20
2.7 CONCLUSIONS ..................................................................................................................... 22
  2.7.1 Key morphological features suggest biogenicity ............................................................ 22
  2.7.2 Geochemical evidence inconclusive but consistent with biogenicity ......................... 22
  2.7.3 Jingangku graphite particles have complex origins ....................................................... 23

x
2.7.4 Highly metamorphosed rocks could retain highly altered but morphologically and geochemically recognizable signs of life ................................................................. 24

2.8 ACKNOWLEDGMENTS ........................................................................................................ 24
2.9 TABLES AND TABLE CAPTIONS .................................................................................... 25
2.10 FIGURES AND FIGURE CAPTIONS ............................................................................... 27
2.11 REFERENCES .................................................................................................................. 38
2.12 APPENDIX A ................................................................................................................ 43

CHAPTER 3: Novel application of focused ion beam electron microscopy (FIB-EM) in preparation and analysis of microfossils ultrastructures: A new view of complexity in early eukaryotic organisms ........................................................................................................... 64
3.1 ABSTRACT ....................................................................................................................... 65
3.2 INTRODUCTION ............................................................................................................... 65
3.3 EQUIPMENT, TECHNIQUES, AND PROCEDURES ....................................................... 69
  3.3.1 Brief technical description of FIB-EM system and operational capabilities ....... 69
  3.3.2 Sample description and preparation for FIB-EM nanotomography ................. 71
  3.3.3 FIB-EM nanotomography ..................................................................................... 73
3.4 RESULTS .......................................................................................................................... 76
  3.4.1 Light and scanning electron microscopy ............................................................... 76
  3.4.2 FIB-EM nanotomography of Dictyosphaera delicata ........................................ 76
  3.4.3 FIB-EM nanotomography of Shuiyousphaeridium macroreticulatum .............. 77
  3.4.4 Central body ultrastructure ............................................................................... 77
  3.4.5 Process ultrastructure ...................................................................................... 78
3.5 DISCUSSION .................................................................................................................... 79
3.6 CONCLUSIONS ............................................................................................................... 81
3.6 ACKNOWLEDGMENTS ................................................................................................. 81
3.7 FIGURES AND FIGURE CAPTIONS ........................................................................... 83
3.8 REFERENCES ................................................................................................................... 90
3.9 APPENDIX B .................................................................................................................. 94
CHAPTER 5: The microstructural record of predation: A new approach for identifying predatory drill holes..................................................................................................................... 336

5.1 ABSTRACT ........................................................................................................................... 337

5.2 INTRODUCTION ................................................................................................................. 337

5.3 MATERIALS AND METHODS ........................................................................................... 339

  5.3.1 Laboratory-observed limpets: Sample collection and feeding experiment protocol ............................................................ 339

  5.3.2 Laboratory-observed mussels: Sample collection and feeding experiment protocol ............................................................ 340

  5.3.3 Subfossil limpets: Sample collection ........................................................................ 340

  5.3.4 Miocene bivalves: Sample collection ...................................................................... 341

  5.3.5 Scanning electron microscopy ................................................................................ 341

5.4 RESULTS .............................................................................................................................. 342

  5.4.1 Overview of microtrace morphology ...................................................................... 342

  5.4.2 Drill holes in laboratory-observed limpets ............................................................... 343

  5.4.3 Drill Holes in Laboratory-Observed Mussels ............................................................ 343

  5.4.4 Published Nucella radula micrographs .................................................................. 344

  5.4.5 Drill holes in subfossil limpets ................................................................................ 344

  5.4.6 Drill holes in Miocene bivalves ................................................................................. 345

  5.4.7 Multiple-pass and single-pass micro-rasping marks ..................................................... 345

  5.4.8 Shell Crystalline Microarchitecture ........................................................................ 346

5.5 DISCUSSION ........................................................................................................................ 346

  5.5.1 Primary hypotheses to explain predatory microtrace variations: Predator taxonomy and size-age class ................................................................. 347

  5.5.2 Primary hypotheses to explain predatory microtrace variations: Superimposition of radular passes ................................................................................. 349

  5.5.3 Primary hypotheses to explain predatory microtrace variations: Microtraces and shell crystalline microarchitecture ........................................... 351

5.6 CONCLUSIONS ................................................................................................................... 352

5.7 ACKNOWLEDGMENTS ..................................................................................................... 353

5.8 TABLE AND TABLE CAPTION ......................................................................................... 354
LIST OF MULTIMEDIA OBJECTS

CHAPTER 2

Table 2.1. Published U–Pb zircons ages of the Wutai Metamorphic Complex and the Hutuo Group.............................................................................................................................................25

Table 2.2. $\delta^{13}$C measurements of graphitic disc specimens and Mao standard..........................26

Figure 2.1. Geological map and sample locality...........................................................................27

Figure 2.2. Field photographs of sample horizon......................................................................28

Figure 2.3. Light microscopy and elemental mapping of in-situ and extracted graphite particles..........................................................................................................................................29

Figure 2.4. Size distribution of graphitic discs...........................................................................30

Figure 2.5. Electron microprobe analysis of a Jingangku specimen.........................................31

Figure 2.6. In-situ laser Raman analyses of 8 matrix graphite particles....................................32

Figure 2.7. In-situ laser Raman analyses of 8 clast-hosted graphite particles.............................33

Figure 2.8. Laser Raman spectra of 12 extracted graphite discs.................................................34

Figure 2.9. In-situ rotational analysis of a Jingangku graphite particle in thin section..............35

Figure 2.10. SEM and TEM images of Jingangku graphite discs..............................................36

Figure repository A1. SEM micrographs of graphitic discs.......................................................43–63
CHAPTER 3

Figure 3.1. FIB-EM instrument photographs and sample chamber schematic with labeled components..............................................................................................................................................83

Figure 3.2. Electron micrographs, cross-sectional binary data, and schematic diagram of FIB sample processing..................................................................................................................................................84

Figure 3.3. Electron and light micrographs of Dictyosphaera delicata specimens, focusing on vesicle wall ultrastructures.................................................................................................................................86

Figure 3.4. Representative light, electron, and ion micrographs of single FIB nanotomography-prepared Shuiyousphaeridium macroreticulatum specimen, showing central body, process, and outer membrane ultrastructures..........................................................................................................................87

Figure 3.5. Cross-sectional binary data and 3D renderings of Shuiyousphaeridium macroreticulatum specimen shown in Fig. 3.4.................................................................................................................................88

Figure 3.6. Conceptualization of process ultrastructure and fossil observations..........................89

Figure repository B1. FIB-EM micrographs of acritarch nanotomography preparation and acritarch ultrastructure..........................................................................................................................................................94–140

Figure repository B2. Thresholded nanotomography slices and 3-D renderings.................141–165

CHAPTER 4

Figure 4.1. Schematic summary of preservation resolution, temporal distribution, and environmental distribution of various taphonomic pathways (Butterfield, 2003)......................................................182

Figure 4.2. Phosphatic encrustation on Megasphaera inornata.................................................183
Figure 4.3. Phosphatic encrustation on *Megasphaera inornata* and *Parapandorina rhaphospissa*................................................................................................................................ 185

Figure 4.4. Phosphatic encrustation on *Parapandorina rhaphospissa*, *Megaclonophycus onustus*, and a strongly degraded spheroidal fossil......................................................................................................................................... 186

Figure 4.5. Phosphatic encrustation on organic filaments (mucous strands, bacterial filaments, or fungal hyphae)............................................................................................................................................... 188

Figure 4.6. Phosphatic encrustation on a tubular microfossil (possibly *Sinocyclocyclicus guizhouensis*) and a problematic microfossil........................................................................................................ 189

Figure 4.7. Phosphatization of algal cell walls................................................................................................................................. 191

Figure 4.8. Phosphatic infilling of *Archaeophycus venustus* cells...................................................................................................................... 192

Figure 4.9. Phosphatic infilling in *Meghystrichosphaeridium reticulatum* vesicle, and phosphatic encrustation and impregnation of *Archaeophycus venustus*............................................................................................................ 193

Figure 4.10. Phosphatic rods and granules on a tubular microfossil (possibly *Sinocyclocyclicus guizhouensis*, an unidentified algal fossil, and animal embryo *Parapandorina rhaphospissa*... 194

Figure 4.11. Granules on animal egg/embryo fossil *Megasphaera ornata* and an algal fossil (possibly *Paramecia incognata*)................................................................................................................................................... 195

Figure 4.12. Crystal aspect variation by morphology.......................................................................................................................... 196

Table C1. Crystal aspect variation by morphology......................................................................................................................102–233

Table C2. Bootstrapped crystal aspect variation. Category colors correspond to Fig. 4.12..................................................................................................................................................234
Figure repository C1. SEM micrographs of perpendicularly oriented, micrometric, prismatic apatite ................................................................. 235–258

Figure repository C2. SEM micrographs of tangentially oriented, sub-micrometric, bladed apatite .............................................................................. 259–269

Figure repository C3. SEM micrographs of randomly oriented, sub-micrometric, equant apatite ......................................................................... 270–272

Figure repository C4. SEM micrographs of phosphatic filaments, rods, and granules (with substructures) .................................................................. 273–289

Figure repository C5. Measured SEM micrographs of perpendicularly oriented, micrometric, prismatic apatite. Table C1 image file # in lower right corner ................................................................. 290–303

Figure repository C6. Measured SEM micrographs of tangentially oriented, sub-micrometric, bladed apatite. Table C1 image file # in lower right corner ................................................................. 304–311

Figure repository C7. Measured SEM micrographs of randomly oriented, sub-micrometric, equant apatite. Table C1 image file # in lower right corner ................................................................. 312–316

Figure repository C8. Measured SEM micrographs of phosphatic granule aggregates (C8a) and granules (C8b). Table C1 image file # in lower right corner ................................................................. 317–335

CHAPTER 5
Table 5.1. Descriptive statistics for the quantified predatory microtraces, shell-growth microfabrics, and radular cusp measurements from Rolán et al. (2004) ................................................................. 354

Figure 5.1. Representative micro-rasping marks ................................................................................................................................. 355
Figure 5.2. Predatory microtrace size-frequency distributions and images of corresponding shells............................................................................................................................................. 357

Figure 5.3. Predatory microtrace, shell microstructure, and radular cusp data.................................................359

Figure 5.4. Size differentiation of multiple-pass (overlain) and single-pass predatory microtraces versus distribution of radular cusp widths in *N. lapillus*, as measured from Rolán et al., 2004..............................................................................................................................................360

Table D1. Predatory microtrace spacing measurements.................................................................364–383

Table D2. Crystalline shell microfabric measurements.................................................................................384–388

Table D3. Radular cusp width measurements (Rolán et al., 2004).........................................................389–390

Table D4. Multiple-pass microtrace vs. single-pass microtrace spacing measurements.................................................................391–398

Figure repository D1. SEM micrographs of laboratory-observed limpets..................................399–401

Figure repository D2. SEM micrographs of laboratory-observed mussels.................................402–414

Figure repository D3. SEM micrographs of subfossil limpets..............................................................415–419

Figure repository D4. SEM micrographs of Miocene bivalves..........................................................420–426

Figure repository D5. SEM micrographs of crystalline shell microfabrics and published *Nucella lapillus* radulae...........................................................................................................................................427–428
GRANT INFORMATION


Petroleum Industry Geosciences Endowed Graduate Scholarship, Virginia Tech Department of Geosciences (2008)


David R. Wones Geosciences Graduate Research Award, Virginia Tech Department of Geosciences (2007)

Aerospace Graduate Research Fellowship, Virginia Space Grant Consortium (2005–2008)


C.G. “Jake” Tillman Geosciences Graduate Research Award and Scholarship, Virginia Tech Department of Geosciences (2005–2006)

Graduate Student Research Grant, Geological Society of America (2005)

National Science Foundation, Sedimentary Geology and Paleobiology, EAR-0545135: Ediacara fossils preserved in Ediacaran bituminous limestone

National Aeronautics and Space Administration, Exobiology and Evolutionary Biology Program, NNG056P21G: Probable eukaryote fossils preserved in Archean–Paleoproterozoic shales: A new window onto the early biosphere
CHAPTER 1

A new age in paleobiology: Integrated applications of nanotechnologies for fossil analyses

JAMES D. SCHIFFBAUER

Department of Geosciences, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061, USA
1.1 Introduction

Over the past decade, the study of paleobiology has been progressing into a new age which we can finally say is in the 21st century – this is an age of digital paleobiology. This new mode of paleobiology focuses heavily on the use of tools far more advanced than a soft-rock hammer and an optical microscope for detailed geological, biological, and chemical analyses of a wide range of fossils. For instance, over the past few years we have seen applications of microfocus x-ray computed tomography (microCT) and synchrotron-radiation X-ray tomographic microscopy (SRXTM) for three-dimensional analyses of subcellular and developmental structures in Neoproterozoic and earliest Phanerozoic fossilized embryos (Donoghue et al., 2006; Hagadorn et al., 2006); the utilization of three-dimensional laser-Raman spectroscopy and imaging as well as confocal laser scanning microscopy to reconstruct the morphology and chemistry of earliest microfossils known on the planet (Kudryantsev et al., 2001; Schopf and Kudryantsev, 2005; Schopf et al., 2006); an increase in the use of transmission electron microscopy (TEM) for ultrastructural analyses in an attempt to resolve taxonomic affinities of problematic microfossils (Talyzina and Moczydłowska, 2000; Javaux et al., 2004; Willman and Moczydłowska, 2007); the use of focused ion beam electron microscopy (FIB-EM) to view three-dimensional preservation of fossils in-situ as well as to construct site-specific TEM ultrathin foils of paleontological materials (Kempe et al., 2005; Bernard et al., 2007; Cavalazzi, 2007); more widespread use of secondary ion mass spectrometry (SIMS) for isotopic analyses to understand potential roles of microbes in mineral formation (Kohn et al., 1998; Papineau and Mojzsis, 2006); and even expanded roles of more common advanced instruments, such as field-emission scanning electron microscopy and environmental scanning electron microscopy (FE-SEM and ESEM, respectively), as primary analytical instruments in various fields of paleobiology (Gaines et al., 2008). While the chapters presented in this dissertation may not have a unifying theme in terms of a distinct fossil organism or specific time in Earth’s history, furthering the use of electron- and ion- microbeam instrumentation and expanding the paleo-genres to which digital paleobiological approaches may be applied encompasses the fundamental intention of my research.
1.2 Summary of research

Chapter two, “Ultrastructural and geochemical characterization of Archean–Paleoproterozoic graphite particles: Implications for recognizing traces of life in highly metamorphosed rocks,” was published in *Astrobiology* (Schiffbauer et al., 2007), and focuses on the description and multidisciplinary investigation of late Archean–early Paleoproterozoic (~2500 Ma) graphite discs from the Wutai Metamorphic Complex in the Wutaishan area of North China. These discs, which potentially represent metamorphic products of organic-walled microfossils, were analyzed using a suite of advanced instrumentation, including FE-SEM, TEM, Raman spectroscopy, and SIMS, which potentially represent organic-walled microfossils. Abundant graphite particles occur in amphibolite grade quartzite of the Archean–Paleoproterozoic Wutai Metamorphic Complex in the Wutaishan area of North China. Petrographic thin section observations suggest that the graphite particles occur within and between quartzite clasts, and are heterogeneous in origin. Using HF maceration techniques, the Wutai graphite particles were extracted for further investigation. Laser Raman spectroscopic analysis of a population of extracted graphite discs indicated that they experienced a maximum metamorphic temperature of 513 ± 50 °C, which is consistent with the metamorphic grade of the host rock and supports their indigenicity. Scanning and transmission electron microscopy revealed that the particles bear morphological features (such as hexagonal sheets of graphite crystals) related to metamorphism and crystal growth, but a small fraction of them (graphite discs) are characterized by a circular morphology, distinct marginal concentric folds, surficial wrinkles, and complex nanostructures. Ion microprobe analysis of individual graphite discs showed that their carbon isotope compositions range from −7.4‰ to −35.9‰ V-PDB, with an average of −20.3‰, which is comparable to bulk analysis of extracted carbonaceous material. The range of their size, ultrastructures, and isotopic signatures suggests that the morphology and geochemistry of the Wutai graphite discs were overprinted by metamorphism and their ultimate carbon source probably had diverse origins that include abiotic processes. We considered both biotic and abiotic origins of the carbon source and graphite disc morphologies and cannot falsify the possibility that some circular graphite discs characterized by marginal folds and surficial wrinkles represent deflated, compressed, and subsequently graphitized organic-walled vesicles. Together with reports by other authors of acanthomorphic acritarchs from greenschist-amphibolite grade metamorphic rocks, this study suggests that it is worthwhile to examine
carbonaceous materials preserved in highly metamorphosed rocks for possible evidence of ancient life.

Chapter three, “Novel application of focused ion beam electron microscopy (FIB-EM) in preparation and analysis of microfossils ultrastructures: A new view of complexity in early eukaryotic organisms,” is currently in press at *Palaios* (Schiffbauer and Xiao, in press). This chapter details a new method (FIB nanotomography) for microfossil ultrastructural examination using a relatively new electron- and ion-microbeam instrument, FIB-EM. Coupled dual-beam FIB-EM systems have gained popularity across multiple disciplines over the past decade. Widely utilized as a stand-alone instrument for micromachining and metal/insulator deposition in numerous industries, the submicron-scale ion milling/sectioning capabilities of FIB-EM systems have been well documented in the materials science literature. These capacities make FIB-EM a powerful tool for *in-situ*, site-specific TEM ultrathin foil preparation. Recent advancements in the field-emission guns (FEGs) of FIB-EM systems have provided spatial resolution comparable to that of many high-end scanning electron microscopes, thus providing integrated imaging, material deposition, and material removal capabilities. More recently, FIB-EM preparation techniques have been applied to geological samples to characterize mineral inclusions, grain boundaries, and microfossils. Here, we demonstrate a novel method for analyzing three dimensional (3-D) ultrastructures of microfossils using FIB-EM. Our method, FIB-EM nanotomography, consists of sequential ion milling/sectioning and concurrent SEM imaging. This technique with coupled dual-beam systems allows for real-time, 3-D ultrastructural analysis and compositional mapping with precise site selectivity, and may provide new insights in fossil ultrastructures. Using the FIB-EM nanotomography method, we investigated sphaeromorph and acanthomorph acritarchs (organic-walled microfossils) extracted from the ≥1000 Ma Mesoproterozoic Ruyang Group of North China. The 3-D characteristics of certain important but controversial acritarch features, such as processes and vesicularly-enclosed central bodies, are described. Through these case studies, we demonstrate that FIB-EM nanotomography is a powerful and useful tool for investigating the three-dimensionality of microfossil ultra- and nano-structures.

Chapter four, “Microfossil phosphatization and its astrobiological implications,” was published in the edited book, *From Fossils to Astrobiology: Records of Life on Earth and the search for Extraterrestrial Biosignatures* (Xiao and Schiffbauer, 2008). This chapter utilizes high-
resolution, high-magnification micrographs of exceptionally-well preserved fossil organisms from the famous Doushantuo phosphorites FE-SEM for quantitative evaluation of the phosphatization taphonomic process in an attempt to understand the potential for this preservational window in extraterrestrial environments. One of the major tasks of astrobiological research is to critically examine evidence of past or present ecosystems beyond our planet. Because the Earth is the only planet that is known to have hosted life, it therefore provides the only model for us to learn how traces of life can be preserved and recognized. If past morphological evidence of microbial life exists outside of our planet, it is likely that it would be preserved by taphonomic pathways similar to those we have observed on Earth. In contrast to the Phanerozoic fossil record that is characterized by macroscopic skeletal fossils, the Proterozoic (2500–542 Ma) fossil record is dominated by microscopic, soft-bodied organisms. Thus, from a Phanerozoic point of view, the fossilization of such organisms is regarded as exceptional preservation. Here, we briefly review the exceptional preservation taphonomic pathways in the Proterozoic fossil record, including Bitter Spring-, Doushantuo-, Orsten, Beecher’s trilobite-, and Burgess Shale-type preservational pathways. This is followed by detailed descriptive and quantitative analyses of three-dimensional phosphatization of non-biomineralizing microorganisms in the Neoproterozoic Doushantuo Formation. In our investigation, we recognized four different styles of phosphate mineralization, each characterized by distinct crystal size, orientation, and organization. These are interpreted as different phosphatization processes related to availability of nucleation sites and degradation of organic substrate, and include (1) perpendicularly oriented, prismatic apatite crystals; (2) tangentially oriented, bladed apatite crystals; (3) randomly oriented, equant apatite crystals; and (4) phosphatic filaments, rods, and granules. We focus on describing the phosphatization window of the Doushantuo Formation because it represents one of the most powerful taphonomic pathways through which soft-bodied microorganisms can be preserved, which is highly relevant to astrobiological research.

Chapter five, “The microstructural record of predation: A new approach for identifying predatory drill holes,” was published in *Palaios* (Schiffbauer et al., 2008), and focuses on the utilization of FE-SEM and ESEM for the examination and identification of predatory drill holes, both in modern and fossil ecosystems. Drill holes in prey skeletons are the most common source of data for quantifying predator-prey interactions in the fossil record. To be useful, however,
such drill holes need to be identified correctly. Instead of using site-specificity, size-selectivity, or taxon-based approaches or morphometric strategies for the identification of predatory drill holes, a more explicit approach, the application of FE-SEM and ESEM to directly observe micrometer-scale traces left by the predatory organism during the construction of drill holes, was used to describe and quantify microstructural characteristics of drill holes. Various specimens, including modern limpets and mussels drilled by muricid snails in laboratory experiments, subfossil limpets collected from a tidal flat (San Juan Island, Washington state, USA), and various Miocene bivalves collected from multiple European sites, were examined for microstructural features. The microstructures observed are interpreted here as *Radulichnus*-like micro-rasping marks, or predatory microtraces, made by the radula of drilling gastropod predators. The mean adjacent spacing of these microtraces is notably denser than the spacing of muricid radular teeth determined by measurements taken from the literature. Because the radular marks typically overlie or crosscut each other, the denser spacing of predatory microtraces likely reflects superimposition of scratches from repeated passes of the radula. One incomplete drill hole showed a clear, chemically aided drilling dissolution signature around its outer margin, while a number of other specimens showed similar, but ambiguous, traces of dissolution. The range of organisms examined illustrates the utility of SEM imaging for identifying micro-rasping marks associated with predatory drill holes in both modern and fossil specimens. These distinct microtraces offer promise for augmenting our ability to identify drill holes in the fossil record and to distinguish them from holes produced by non-predatory means.
1.3 References


CHAPTER 2

Ultrastructural and geochemical characterization of Archean–Paleoproterozoic graphite particles: Implications for recognizing traces of life in highly metamorphosed rocks

JAMES D. SCHIFFBAUER1, LEIMING YIN2, ROBERT J. BODNAR1, ALAN J. KAUFMAN3, FANWEI MENG2, JIE Hu2, BING SHEN1, XUNLAI YUAN4, HUIMING BAO5, & SHUHAI XIAO1

1Department of Geosciences, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061, USA
2Nanjing Institute of Geology and Paleontology, Nanjing 210008, China
3Department of Geology, University of Maryland, College Park, Maryland 20742, USA
4State Key Laboratory of Palaeontology and Stratigraphy, Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, Nanjing 210008, China
5Department of Geology and Geophysics, Louisiana State University, Baton Rouge, LA 70803
2.1 Abstract
Abundant graphite particles occur in amphibolite grade quartzite of the Archean–Paleoproterozoic Wutai Metamorphic Complex in the Wutaishan area of North China. Petrographic thin section observations suggest that the graphite particles occur within and between quartzite clasts, and are heterogeneous in origin. Using HF maceration techniques, the Wutai graphite particles were extracted for further investigation. Laser Raman spectroscopic analysis of a population of extracted graphite discs indicated that they experienced a maximum metamorphic temperature of 513 ± 50 °C, which is consistent with the metamorphic grade of the host rock and supports their indigenicity. Scanning and transmission electron microscopy revealed that the particles bear morphological features (such as hexagonal sheets of graphite crystals) related to metamorphism and crystal growth, but a small fraction of them (graphite discs) are characterized by a circular morphology, distinct marginal concentric folds, surficial wrinkles, and complex nanostructures. Ion microprobe analysis of individual graphite discs showed that their carbon isotope compositions range from −7.4‰ to −35.9‰ V-PDB, with an average of −20.3‰, which is comparable to bulk analysis of extracted carbonaceous material.

The range of their size, ultrastructures, and isotopic signatures suggests that the morphology and geochemistry of the Wutai graphite discs were overprinted by metamorphism and their ultimate carbon source probably had diverse origins that include abiotic processes. We considered both biotic and abiotic origins of the carbon source and graphite disc morphologies and cannot falsify the possibility that some circular graphite discs characterized by marginal folds and surficial wrinkles represent deflated, compressed, and subsequently graphitized organic-walled vesicles. Together with reports by other authors of acanthomorphic acritarchs from greenschist-amphibolite grade metamorphic rocks, this study suggests that it is worthwhile to examine carbonaceous materials preserved in highly metamorphosed rocks for possible evidence of ancient life.

2.2 Introduction
When one assesses the early record of life, it quickly becomes apparent that two distinct and incongruent stories are evident: Proterozoic fossils are abundant and widely accepted, but Archean body fossils are few and controversial. Proterozoic acritarchs (a polyphyletic group of organic-walled vesicular microfossils) recovered from relatively unmetamorphosed cherts and
shales provide a great deal of information about the evolution of early cellular life (Knoll et al., 2006). Some Proterozoic acritarchs, such as those recovered from the ~1.5 Ga Ruyang and Roper Groups (Javaux et al., 2001; Javaux et al., 2003; Xiao et al., 1997), have been interpreted to be among the earliest representatives of eukaryotic life in the fossil record. Paleontologists have also been able to identify evolutionary patterns, including both taxonomic diversity and morphological disparity patterns, from the fossil record of Proterozoic acritarchs (Huntley et al., 2006; Huntley et al., 2006; Knoll, 1994; Knoll et al., 2006; Vidal and Moczydlowska-Vidal, 1997).

In contrast, the Archean fossil record is based upon a limited number of often controversial microfossils, biologically mediated sedimentary structures, and isotopic biosignatures. Filamentous structures from ~3.5 Ga low metamorphic grade cherts in Australia have been interpreted as bacterial fossils (Schopf, 1993; Schopf et al., 2002; Schopf and Packer, 1987) or carbonaceous structures shaped by crystal growth (Brasier et al., 2006; Brasier et al., 2002; Brasier et al., 2005), though less controversial microfossils have been known from Neoarchean rocks (Altermann and Schopf, 1995). Similarly, stromatolitic forms have been interpreted as structures produced by either physio-chemical (Grotzinger and Knoll, 1999; Grotzinger and Rothman, 1996; Lowe, 1994) or biological processes (Allwood et al., 2006; Hofmann et al., 1999). Even more controversial are isotopically light graphite particles from ~3.8 Ga amphibolite metamorphic grade banded iron- formations of West Greenland, which have been interpreted as products of early biological activity (Mojzsis et al., 1996; Mojzsis and Harrison, 2000; Rosing, 1999) or metasomatic products of siderite decomposition under high temperature and pressure (Fedo and Whitehouse, 2002; Lepland et al., 2005; van Zuilen et al., 2002; van Zuilen et al., 2003). Adding to the controversy is laboratory demonstration that abiotic pathways such as siderite decomposition and Fischer-Tropsch-type synthesis from CO₂–CH₄ fluids catalyzed by iron may lead to the formation of carbonaceous compounds depleted in ¹³C (Horita, 2005; McCollom and Seewald, 2006; van Zuilen et al., 2002). Thus, the above mentioned complications necessitate a great deal of caution to be implemented and demand multiple lines of evidence (morphological, ultrastructural, and geochemical) to be sought during the interpretation of Archean and early Paleoproterozoic biosignatures.

In addition to the controversies surrounding the geobiological evidence of early life, the study of Archean life is also limited by the predominance of high metamorphic grade rocks. It is
traditionally accepted that high grade metamorphism is detrimental to morphological fossil preservation. Accordingly, Archean microfossils with recognizable biological morphologies previously have been reported only from low grade metacherts (Altermann and Schopf, 1995; Awramik et al., 1983; Knoll and Barghoorn, 1977; Schopf and Walter, 1983; Walsh and Lowe, 1985). However, recent studies of Precambrian and Phanerozoic rocks have shown that *bona fide* filamentous bacteria, organic-walled microfossils (e.g., leiospheres, acanthomorphic acritarchs, and chitinozoans), and possible paraconodonts can be preserved in greenschist grade metamorphic rocks (Kidder and Awramik, 1990; Knoll, 1992; Molyneux, 1998), greenschist-amphibolite grade rocks (Bernard et al., 2007; Squire et al., 2006; Zang, 2007), and gneisses (Hanel et al., 1999).

These recent developments prompted us to explore highly metamorphosed rocks of the Archean–early Paleoproterozoic Wutai Metamorphic Complex in the Wutaishan area of North China, using a combination of light microscopy, electron microscopy, Raman spectroscopy, and ion microprobe techniques. The immediate goal of this study was to characterize the morphological, ultrastructural, and geochemical features of the carbonaceous material recovered from the Wutai Metamorphic Complex. Our study resulted in the recovery of abundant graphite particles from amphibolite grade quartzites of the Wutai Metamorphic Complex in the Wutaishan area of North China. Raman spectroscopy indicated that these graphite particles are indigenous to the host rock. Most graphite particles are irregular in shape and show hexagonal broken edges, but a distinct population of graphite particles can be characterized as circular discs with marginal folds and surficial wrinkles. Although the morphology of these graphite discs must have been overprinted by fragmentation, crystal growth, and other abiotic processes, the presence of marginal folds and surficial wrinkles on circular discs seems to suggest that they may represent deflated, compressed, and subsequently graphitized organic-walled vesicles. Transmission electron microscopy shows that they appear to consist of two graphitized layers separated by an electron-dense material trapped in between. Isotopic analysis of bulk carbonaceous material gave a carbon isotope value of $-21.3\%\text{ V-PDB}$, but ion probe analysis of individual graphite particles gave a range of carbon isotope values between $-7.4\%\text{ and }-35.9\%\text{ V-PDB}$, with an average of $-20.3\%$. At the present, the morphological, ultrastructural, and geochemical evidence for a biological origin is still equivocal, but this study represents a first
attempt to characterize carbonaceous material from highly metamorphosed Archean–early Paleoproterozoic rocks using a combination of analytical tools.

2.3 Geological Setting
The Wutai Metamorphic Complex is located between the Fuping and Hengshan metamorphic complexes, which together compose the middle segment of the Trans-North China Orogen and constitute the Hengshan-Wutai-Fuping mountain belt. The Trans-North China Orogen is a narrow NE-SW zone, also known as the Central Zone, which separates the Eastern and Western blocks of the North China Craton (Fig. 2.1A). Three different tectonic models have been proposed for the development and evolution of the Hengshan-Wutai-Fuping mountain belt. The first suggests that the Fuping and Hengshan complexes were part of a single continental block, and the Wutai complex was formed in a late Archean rift basin between the Fuping and Hengshan complexes (Tian, 1991; Yuan and Zhang, 1993). The second model suggests that the Hengshan-Wutai-Fuping mountain belt represents a late Archean continent-arc-continent collision system, with the Hengshan and Fuping complexes corresponding to two Archean continental blocks, and the Wutai complex representing the trapped intermediate island arc (Bai, 1986; Bai et al., 1992; Li et al., 1990; Wang et al., 1996). As a third model, recent data suggest that these complexes represent a single late Archean to early Paleoproterozoic magmatic arc that underwent deformation, metamorphism, and exhumation, and was subsequently incorporated into the Trans-North China Orogen in the development of the North China Craton (Zhao et al., 2004).

The Wutai Metamorphic Complex is a greenstone terrane that consists of tonalitic-trondhjemitic-granodioritic (TTG) gneisses, granitoids, mafic to felsic volcanic rocks, and metamorphosed volcanic-sedimentary rocks (Polat et al., 2005). On the basis of metamorphic facies and geological mapping, the volcanic-sedimentary package of the Wutai Metamorphic Complex has been classified as the Wutai Group (Fig. 2.1B), which is subdivided into eight formations (Tian, 1991). The lower Wutai Group consists mainly of amphibolite, orthogneiss, and metasedimentary rocks, including banded iron-formation and quartzite metamorphosed to lower amphibolite facies. Petrographic study indicates that the lower Wutai Group was heated to a maximum temperature of 600–650°C and buried to a maximum pressure of 10–12 kbar (Zhao et al., 1999). The middle Wutai Group is composed of greenschist facies tholeiites and felsic
volcanics. The upper Wutai Group consists of greenschist to subgreenschist facies metasediments and metavolcanics. The Wutai Metamorphic Complex is unconformably overlain by the Hutuo group, which is comprised of subgreenschist facies metasediments and minor mafic volcanics, including quartzites, slates, and metabasalts.

Recent geochronological data from SHRIMP U–Pb zircon analyses of samples from the lower, middle, and upper subgroups of the Wutai Group (Wilde et al., 2004a), however, suggest that these units are roughly of similar age. For example, Wilde et al., 2004a reported eight SHRIMP zircon U–Pb ages from intermediate to felsic volcanic rocks of the lower, middle, and upper subgroups. These eight ages range from 2533±8 to 2513±8 Ma, and together they give a weighted mean of 2523±3 Ma. These ages do not support correlation between age and metamorphic grade of the three subgroups as had been previously suggested (Bai, 1986; Tian, 1991). Therefore, metamorphic grade cannot be used as a stratigraphic indicator within the Wutai Group (Wilde et al., 2004a), and the geochronological data cast doubt on the superposition relationship of the units within the Wutai Group (Bai, 1986; Tian, 1991).

Regardless of controversy that surrounds the stratigraphic relationship of the Wutai Group, there is ample geochronological data to suggest that the Wutai Complex and Hutuo Group are Archean–early Paleoproterozoic in age (Table 2.1). The Wutai Group is penetrated by gneissic granitoids and granitoids that were emplaced pre-, syn-, and post-greenstone metamorphism (Tian, 1991; Wilde et al., 2005). Extensive radiometric dating shows three episodes of granite intrusion, during 2560–2540 Ma, 2540–2515 Ma, and 2170–2120 Ma; the 2540–2515 Ma granitoids were interpreted as coeval with felsic volcanism in the Wutai Complex (Wilde et al., 2005). Metavolcanics in the Wutai Group range from 2533 ± 8 Ma to 2513 ± 8 Ma (Wilde et al., 2004a), which further confirms an Archean age for the Wutai Group. A volcanic ash from the overlying Hutuo Group gave a SHRIMP U–Pb zircon age of 2087 ± 9 Ma (Wilde et al., 2004b). Therefore, the age of the Wutai Metamorphic Complex is conservatively constrained from late Archean to early Paleoproterozoic.

Our samples were collected from a 10–30 cm thick bed of carbonaceous quartzite (Fig. 2.2C) in a geological unit mapped as the Jingangku Formation of the Wutai Group, near the village of Shentangpu (39°07.386’N, 113°55.223’E; Fig. 2.2A). The Jingangku Formation consists of ultramafic volcanics, amphibolite, iron-formation (Fig. 2.2B), volcanogenic massive sulfide deposit, and metasedimentary rocks, including micaschist, calc-silicate, and quartzite
(Polat et al., 2005; Tian, 1991). The metavolcanics are interpreted as “remnants of oceanic crust”, whereas the metasedimentary rocks as “stable continental margin sediments” (Polat et al., 2005).

Some geologists (Wang et al., 2000) argue that the geological unit mapped as the Jingangku Formation may entirely or partly belong to the Hutuo Group. Because the Wutai Complex can interfinger with the younger, less severely metamorphosed, Hutuo Group in the Wutaishan area (Wilde et al., 2004b), extreme care has been taken to ensure that our collected samples belong to the Jingangku Formation of the Wutai Complex. Our sampling locality is ca. 25 km northeast of the Wutai-Hutuo interfingering zone (Wilde et al., 2004b). In addition, our sample locale was in close association with amphibolite and banded iron-formation (Fig. 2.2B), which are characteristic lithologies of the Jingangku Formation of the Wutai Complex, but not characteristic of the Hutuo Group. Furthermore, Raman geothermometry of isolated graphite and petrographic analysis of our samples show that they are more akin to the amphibolite grade metamorphism of the Wutai Complex, but inconsistent with the greenschist grade metamorphism of the Hutuo Group in eastern Wutaishan area (Tian, 1991), where our samples were collected. More importantly, samples from the Jingangku Formation near our sampling locality yielded a 2508 ± 2 Ma U–Pb age that is interpreted to date the peak metamorphism of the Jingangku Formation (Table 2.1; Liu et al., 1985). Pyrite from the Jingangku Formation also yields $^{33}$S anomalies (Ding et al., 2004), which are consistent with its Archean age, because $^{33}$S anomalies are not known in geological samples younger than ~2.4 Ga (Bekker et al., 2004). Therefore, our samples likely belong to the Jingangku Formation of the Wutai Complex, rather than any stratigraphic units of the overlying Hutuo Group. Regardless, the conservative age estimate (Archean–Paleoproterozoic) of our samples stands even if they belong to the Hutuo Group (2087 ± 9 Ma; Wilde et al., 2004b).

2.4 Methods

2.4.1 Sample preparation

Standard petrographic thin sections were made from the Jingangku carbonaceous quartzite samples and examined under a microscope using both plain and polarized light. In thin sections, quartzite clasts are set in a fine-grained carbonaceous (primarily graphitic) matrix. Graphite particles occur in both the matrix and clasts (Fig. 2.3A–H), which confirms their indigenericity.
To extract graphite particles (20–220 μm, s.d. = 31 μm, n = 270; Fig. 2.4), ~30–50 g rock chips were immersed in concentrated hydrochloric acid and then 48–51% hydrofluoric acid for a week. Carbonaceous residue (Fig. 2.3I), including abundant graphite particles, was recovered from acid maceration.

2.4.2 Analytical techniques

The carbonaceous nature of extracted graphite particles were confirmed by elemental mapping (Fig. 2.3J–N) and electron microprobe analysis (Fig. 2.5). To verify the indigenicity of the graphite particles, we used Raman spectroscopy to estimate their peak metamorphic temperature, following the method described in Beyssac et al. (2002). Raman microprobe analyses were carried out on both in-situ graphite particles (eight specimens within matrix, Fig. 2.6A–B; eight specimens within clasts, Fig. 2.7A–B) and extracted, subcircular to circular graphite discs (12 specimens, Fig. 2.8A–B). Raman microprobe analysis was performed on a Dilor X-Y Raman microprobe system (Virginia Tech, 514.32 nm laser focused to a diameter of <20 μm under a 40× objective, laser power 100 mW) and a JY LabRam HR800 Raman microprobe system (Virginia Tech, 632.81 nm laser focused to a diameter of <20 μm under a 40× objective, laser power 25 mW). To test whether the orientation of in-situ graphite particles had any effect on Raman microprobe analysis, Raman spectra of the same particles were collected with the thin section rotated at 0°, 90°, 180°, and 270° (Fig. 2.9). Background noise of Raman spectra in Figs. 2.6A–B and 2.7A–B was reduced using the Savitzky-Golay smoothing method (6th order polynomial with 40 points per sample) conducted on GRAMS/AI software.

Extracted graphite particles were examined under a light microscope, and circular to subcircular graphite discs were manually removed from carbonaceous residue for electron microscopy analyses (Fig. 2.10). Scanning electron microscopy (SEM), field emission scanning electron microscopy (FE-SEM), and transmission electron microscopy (TEM) were performed on LEO 1550 FE-SEM (Virginia Tech), JEOL JSM 6300 (Nanjing), LEO 1530 VP (Nanjing), and Zeiss DSM 982 (Maryland) electron microscopes. FE-SEM observations of magnifications up to 200,000× achieved 5-nm resolution. Electron microprobe and elemental mapping analyses were performed on an INCA X-ray EDS system attached to an LEO 1530 VP electron microscope (Nanjing). Several specimens were imbedded in epoxy, and then ultra thin (~60 nm) sections were microtomed for TEM observations (JEOL JEM-1230 in Nanjing).
Carbon isotopes of bulk carbonaceous material (i.e. acid macerates) were analyzed using a conventional combustion method in Nanjing (Finnigan MAT 251 mass spectrometer) and at the University of Maryland (Micromass IsoPrime dual-inlet gas source stable isotope mass spectrometer, coupled with a Eurovector elemental analyzer). Analytical precision was better than 0.1‰ vs. V-PDB. Eleven $\delta^{13}C$ measurements (Table 2.2) were conducted on five specimens using a Cameca 6f ion microprobe (Carnegie Institution of Washington). The magnitude of instrumental mass fractionation (IMF) inherent to surface ionization mass spectrometry was quantified by the repeated analyses of the standard Mao diamond ($\delta^{13}C = -6.5‰$, IMF = $52.9 \pm 0.5‰$, $n = 9$, Table 2.2). The primary $\text{Cs}^+$ beam intensity was 0.5 nA and was focused down to a 20–25 μm spot, which allowed for multiple analyses of the same individual specimen.

2.5 Results

Petrographic analysis of the sampled Jingangku carbonaceous quartzite showed strong brecciation, with angular mm- to cm-sized rock fragments set in finer-grained, carbonaceous matrix (Fig. 2.3A–B). The rock fragments (or clasts) were not elongated or preferentially oriented and consisted of randomly oriented sand- to silt-size quartz minerals (Fig. 2.3A–D), as well as minor carbonate minerals. Most quartz grains showed undulose extinction (Fig. 2.3D), which indicates modification of optical axes by metamorphic stress. The composite clasts require at least two generations of fragmentation; the more recent fragmentation was probably tectonic brecciation because of the strong angularity, whereas the earlier one appears to be sedimentary because of the moderate level of sorting. Heavy mineral analysis is being conducted to test this interpretation.

Our samples are moderately carbonaceous (two measurements of 0.72% and 1.06% TOC weight percentage determined by combustion analyses of one randomly crushed sample, sample weights used for analysis ~30 and ~50 g). The carbonaceous material consisted mostly of graphite particles. Their indigenicity and graphite nature were verified by thin section petrographic observations (Fig. 2.3A–H), elemental mapping (Fig. 2.3J–N), electron and Raman microprobe analyses (Figs. 2.5–2.9), and scanning electron microscopy (Fig. 2.10C–R, U–V). Graphite particles occur abundantly in the matrix between clasts (Fig. 2.3A–D), but less abundantly within clasts (Fig. 2.3E–H). Some clast-hosted graphite particles are circular to elliptical (Fig. 2.3E–H), but the morphology of matrix graphite is difficult to resolve under
petrographic microscope because of the high concentration and the opacity of carbonaceous material in the matrix.

*In-situ* Raman microprobe analyses of matrix graphite showed highly variable spectra (eight spectra collected, Fig. 2.6), often with a disordered D band greater than or comparable to the graphite G band. On the other hand, *in-situ* Raman spectra of clast-hosted graphite (eight spectra collected, Fig. 2.7) were more consistent and illustrated a strong G band and a weak D band. *In-situ* samples were rotated 360°, with Raman spectra collected at each 90° interval; only minor changes occurred in the G and D band intensity, and slightly more so in S band intensity (Fig. 2.9). Overall, all *in-situ* Raman spectra had a relatively strong G band, which suggests a high degree of graphite crystallinity (Wopenka and Pasteris, 1993), though the differences between matrix graphite and clast-hosted graphite may be indicative of their different origins.

Some graphite particles are circular (Fig. 2.10C–U), and we term these particles graphite discs. Raman spectra of extracted graphite discs (Fig. 2.8) are highly consistent, comparable to those of clast-hosted graphite particles. Application of the graphite Raman geothermometer (Beyssac et al., 2002; Rahl et al., 2005; Wopenka and Pasteris, 1993) to these spectra suggests that these graphite discs experienced peak metamorphic temperature of 513 ± 50 °C (n = 12), which is broadly consistent with the amphibolite grade of the host rock, but slightly lower than the 600–650 °C temperature estimate based on mineral association (Zhao et al., 1999). Therefore, the carbonaceous precursors of these graphite discs were likely in place before or during the amphibolite metamorphism.

When observed via scanning electron microscopy, the extracted graphite particles are mostly irregularly shaped, with some discs (Fig. 2.10C–Q) and rare filaments (Fig. 2.10B). The filaments, ca. 1.5 μm in width and tens of μm in length, preserve no evidence for septation. The discs, which average about 60 μm in diameter (20–220 μm, s.d. = 31 μm, n = 270; Fig. 2.4) and 1–3 μm in thickness (Fig. 2.10N, S–T), are circular, ovate, and slightly elliptical in morphology, and they consist of graphite sheets (Fig. 2.10N–P). These discs and filaments are broadly similar in morphology to the acritarchs and filaments from the overlying Paleoproterozoic Hutuo Group in the same geographic region (Sun and Zhu, 1998). However, the Hutuo discs and filaments are poorly characterized, and thus, at present, quantitative morphological comparisons can not be ascertained.
Many specimens bear concentric (Fig. 2.10C–E) or crescentic (Fig. 2.10F–G, Q) marginal folds, with isoclinal (Fig. 2.10F–G, L–M) or anticlinal (Fig. 2.10C–E) slopes. Some folds show plunging termination into the surface of the disc (arrow in Fig. 2.10D). Concentric and crescentic folds do not occur in the center of these discs, which is either flat (Fig. 2.10C, E–F, L, P–Q) or covered with irregularly arranged, fine wrinkles (Fig. 2.10H–J). The folds and wrinkles can be distinguished, on the basis of electron shadows in SEM observations using the secondary electron detector, from steps and kinks resulting from termination or dislocation of graphite sheets. At extremely high magnification, the graphite discs are characterized by nanoscale (10–100 nm) ridges and pores. The nanoridges bifurcate and anastomose (Fig. 2.10R), and their significance is obscure. The nanopores, when viewed with the backscatter detector, appear to be filled with an unidentified material that has an average atomic number greater than graphite (Fig. 2.10U). Similar nanopores (Fig. 2.10V), though an order of magnitude smaller in size, have been found in the vesicle walls of the Mesoproterozoic acritarch *Dictyosphaera delicata*, and are filled with aluminum phosphate minerals (Kaufman and Xiao, 2003).

Transmission electron microscopy showed that some discs appear to consist of two sets of graphite sheets, with a thin layer of electron dense material between the sets (Fig. 2.10T). This is consistent with SEM observation of the naturally broken edge of a graphite disc (Fig. 2.10N), though in the latter specimen the two sets of graphite sheets are separated by a narrow gap.

Some morphological aspects of the graphite discs—and most of the irregular graphite particles—reflect graphite crystallization, overgrowth, inelastic deformation, and fragmentation. For example, the thickness of the discs may be variable due to graphite overgrowth (Fig. 2.10Q). The graphite discs may become somewhat sub-rounded, subhedral, or angular (Fig. 2.10H, L, P–Q), rather than curvilinear (Fig. 2.10C–G). The termination or dislocation of graphite sheets may form steps (arrow in Fig. 2.10P). A few specimens show very sharp bending (long arrow in Fig. 2.10O), kinking (short arrow in Fig. 2.10O), fracturing (long arrow in Fig. 2.10L), and fragmentation (arrows in Fig. 2.10H, K). Some discs consist of two distinct sets of graphite sheets, separated by a gap of <1 μm (Fig. 2.10N); this gap may result from physical separation along tabular cleavages. Features similar to these have been reported from metamorphic graphites from Grenville marbles and interpreted as overgrowths and deformation features (Kretz, 1996).
Five extracted graphite discs were analyzed for carbon isotopic signatures using a Cameca 6f ion microprobe. The results are intriguing but inconclusive (Table 2.2). In most cases, multiple analyzed spots on the same individual disc showed low variability of $\delta^{13}C$ values ($2–3\%_o$, three specimens), but the other specimens demonstrated greater intraspecimen variability ($7–9\%_o$, two specimens). Additionally, the range of values between different individuals spanned from $-7.3$ to $-35.8\%_o$ V-PDB. The mean $\delta^{13}C$ value of all ion probe measurements ($-20.3\%_o$ V-PDB) is similar to the $-21.3\%_o$ V-PDB value determined by standard techniques for bulk kerogen.

2.6 Discussion

Graphite particles are common in Archean and younger metamorphic rocks, such as marbles, schists, and gneisses (Rakovan and Jaszczak, 2002; Satish-Kumar, 2005; Ueno et al., 2002; van Zuilen et al., 2003). Typically, metamorphic graphite is found in a few varying forms: well-developed crystals (Palache, 1941), deformed crystals (Kretz, 1996), crystals with microtopographic growth spirals (Rakovan and Jaszczak, 2002), crystals within graphite veins (along with many other minerals including quartz, sillimanite, ilmenite, and muscovite) (Rumble and Hoering, 1986), and in spheroidal or spherule aggregates (Jaszczak, 1997).

Based on isotopic studies and Raman analyses in conjunction with high resolution transmission electron microscopy, it has been suggested that syngenetic graphite can form within metasedimentary rocks during metamorphic heating from the progressive crystallization of organic carbon within precursor sediments, whereby the original carbonaceous material becomes ordered into crystalline graphite (Rantitsch et al., 2004; Weis et al., 1981; Wopenka and Pasteris, 1993). Alternatively, some graphite forms are more likely to have formed by carbon precipitation from carbon-rich fluids (Jaszczak and Rakovan, 2002; Rumble and Hoering, 1986; Satish-Kumar et al., 2001), by siderite decomposition (Fedo and Whitehouse, 2002; van Zuilen et al., 2002; van Zuilen et al., 2003), or by Fischer–Tropsch precipitation from CO$_2$–CH$_4$ fluids (Horita, 2005; McCollom and Seewald, 2006). Thus, the question arises as to whether the Jingangku Formation graphite discs, characterized by such morphological features as marginal concentric folds, fine surficial wrinkles, and complex nanoridge and nanoporous structures, could have been morphologically shaped by metamorphic processes. If the circular morphology and concentric folds of these discs can be produced by metamorphism alone, then similar morphologies should
be observed in other metamorphic graphite particles as well. However, to the best of our knowledge, no other graphite crystals have been shown to have similar morphological features that so distinctively characterize the Jingangku graphite discs (Jaszczak, 1997; Kretz, 1996; Palache, 1941; Rakovan and Jaszczak, 2002; Satish-Kumar, 2005; Ueno et al., 2002; van Zuilen et al., 2003). Instead, those graphite particles occur as interstitial crystals or inclusions in the common forms mentioned above, and their morphologies are probably unrelated to biology, though their ultimate carbon source may or may not be biological (Fedo and Whitehouse, 2002; Mojzsis et al., 1996; van Zuilen et al., 2003). Thus, it seems as though the morphology, micro-, and nano-scale structures of the Jingangku graphite discs cannot be accounted for by metamorphism alone.

The curvilinear margin of some Jingangku graphite discs is also difficult to account for by metamorphism alone. Abiotic precipitation of graphite is expected to produce hexagonal crystals. Such crystals may be deformed during metamorphism, but circular discs with concentric folds are not to be expected. If the Jingangku graphite discs were derived from amorphous kerogen, graphite overgrowth during metamorphism should reduce rather than enhance the marginal curvilinearity, and concentric folds are not to be expected either. One may argue that gliding of graphite sheets in a directed stress environment could seemingly form crescentic marginal folds as illustrated in Fig. 2.10F–G, but the folds should have much sharper crests (Kretz, 1996; e.g., Fig. 2.10O) and the disc center should show shearing in the same direction and magnitude as the margin. Additionally, bending or gliding of graphite sheets is not expected to generate regular concentric marginal folds.

Our inability to account for all morphologies of the Jingangku graphite discs by metamorphic processes alone compels us to consider other alternative interpretations. Is it possible that the Jingangku discs and filaments are graphitized biological structures? In this alternative interpretation, the filaments may represent filamentous bacteria, and the discs could represent originally spheroidal vesicles with a recalcitrant organic wall, which were subsequently deflated, flattened, and graphitized during compaction, diagenesis, and metamorphism. Their circular to ovate shape, marginal concentric folds, and surficial wrinkles are expected morphologies during the compression and elastic deformation of organic-walled vesicles; these features are commonly observed in compressed organic-walled microfossils in Proterozoic rocks (Schopf and Klein, 1992). Further, the nanoporous structures are similar to those found in
Mesoproterozoic acritarchs, i.e. *Dictyosphaera delicata* (Kaufman and Xiao, 2003). In addition, the gap between two sets of graphite sheets in some specimens (Fig. 2.10N), conservatively interpreted above as related to physical separation along tabular cleavages, may be alternatively interpreted as a gap between two compressed vesicle walls. Moreover, TEM observations show that some specimens have an electron-dense central layer (Fig. 2.10T), rather than a gap; this layer cannot be interpreted as cleavage separation but may represent material trapped within the compressed vesicle. Thus, we tentatively conclude that the graphite discs from the Jingangku Formation may represent deflated, flattened, and graphitized vesicles similar to acritarchs from younger rocks.

### 2.7 Conclusions

#### 2.7.1 Key morphological features suggest biogenicity

Important features such as circular morphology, marginal folds, fine wrinkles, and trapped materials may have resulted from early diagenetic compression of spheroidal vesicles. Although these morphological features must have been altered during metamorphism and graphitization, hints of their presence may still be preservable in a fraction of the Jingangku graphite discs. Indeed, laboratory experiments demonstrate that Mesoproterozoic organic-walled microfossils (such as *Dictyosphaera delicata* and *Shuiyousphaeridium macroreticulatum*) heated within the hosting rock to 500 °C over periods of up to 125 days show signs of graphitization, while retaining such features as discoidal morphology and concentric folds (Schiffbauer et al., 2006).

#### 2.7.2 Geochemical evidence inconclusive but consistent with biogenicity

A biological interpretation on the basis of morphological features described above implies that the ultimate carbon source of the Jingangku graphite discs must be biological as well. Carbonaceous material isolated from one of our samples has a bulk δ¹³C value of −21.3‰ V-PDB, as determined by conventional combustion methods. Individual discs, measured using an ion microprobe (Kaufman and Xiao, 2003), show a wide range of δ¹³C values from −7.4‰ to −35.9‰ V-PDB (mean = −20.3‰; n = 11; Table 2.2). Three of the individually analyzed graphite discs showed low variability (<3‰) of δ¹³C values, but the other two specimens demonstrated much higher intraspecimen variability (7–9‰). These δ¹³C values are inconclusive, given what is known about carbon isotope fractionations associated with abiotic processes. From
experimental analyses, multiple abiotic pathways can lead to the synthesis of carbon compounds with $\delta^{13}C$ values as low as $-60\%$ due to kinetic isotope effects (Horita, 2005); moreover, it has been suggested that carbon compounds with $\delta^{13}C$ values as low as $-30\%$ (previously regarded as recycled sedimentary organic compounds) may be indigenous to the mantle (Horita, 2005). However, it is worth noting that the Jingangku specimens have a much wider $\delta^{13}C$ range and are more depleted in $^{13}C$ than graphite particles found in granulite grade metamorphic rocks (Farquhar et al., 1999; Santosh et al., 2003; Satish-Kumar, 2005), where isotopic homogenization is presumably stronger. The range and heterogeneity of the Jingangku $\delta^{13}C$ values may record partial isotopic exchange during metamorphism (Ueno et al., 2002), and the lowest measured values (e.g., $-35.9\%$) are better approximations of primary $\delta^{13}C$ values. If so, then the measured $\delta^{13}C$ values may be stronger evidence for biological source than they appear.

2.7.3 Jingangku graphite particles have complex origins

It needs to be stressed that, though some irregular graphite particles in the Jingangku samples may be metamorphic or fragmentation products from circular graphite discs, it is unlikely that all of the graphite particles were derived from compressed vesicles. Indeed, carbonaceous extracts from unmetamorphosed fossiliferous rocks of younger age mainly consist of amorphous kerogen, and only a small fraction is represented by morphologically recognizable acritarchs. Nor is the carbon source of all Jingangku graphite particles biological. Petrographic evidence and Raman analyses discussed above suggest diverse origins of Jingangku graphite particles. It appears that the extracted graphite discs may have come from the clasts because of (1) the in-situ observation that some graphite particles in clasts are circular (Fig. 2.3E–H), (2) the similarity between Raman spectra of clast-hosted graphite and extracted graphite discs (Figs. 2.7–2.8), and (3) the possibility that quartzite clasts may provide a shield against shearing deformation. However, this issue cannot be unambiguously resolved because of the limited resolution of in-situ observation using light microscopy and the high concentration of matrix graphite. Thus, the Jingangku graphite particles may have complex origins, and we cannot conclusively disprove the possibility that both abiotic (e.g., decomposition of ferrous carbonate minerals or Fischer–Tropsch precipitation from $CO_2$–$CH_4$ fluids catalyzed by Fe) and biotic processes may have contributed to the carbon source and morphology of the Jingangku graphite particles.
2.7.4 Highly metamorphosed rocks could retain highly altered but morphologically and geochemically recognizable signs of life

Despite the inconclusive nature of our interpretation, this study does suggest that, in our search for evidence of ancient life, more work should be directed to carbonaceous material even in highly metamorphosed rocks. Recent studies of Precambrian and Phanerozoic metamorphic rocks have recovered bona fide filamentous bacteria, organic-walled microfossils (e.g., leiospheres, acanthomorphic acritarchs, chitinozoans, and lychnophyte spores), and possible paraconodonts from greenschist- amphibolite-, and gneiss-grade metamorphic rocks (Bernard et al., 2007; Hanel et al., 1999; Kidder and Awramik, 1990; Knoll, 1992; Molyneux, 1998; Squire et al., 2006; Zang, 2007). Thus, it is worthwhile to explore whether the taphonomic window for Archean life is wider than previously thought.

2.8 Acknowledgments

This research was supported by NASA Exobiology Program, National Science Foundation of China, Chinese Academy of Sciences, Chinese Ministry of Science and Technology, State Key Laboratory of Paleobiology and Stratigraphy of the Chinese Academy of Sciences, Virginia Tech ASPIRES and ICTAS programs, the Virginia Space Grant Consortium, the Paleontological Society, and the Geological Society of America. We thank Y. Tian for field assistance; W. Huang (maceration), C. Wang (TEM), C. Farley (laser Raman microprobe), S. Mutchler (graphical assistance), E. Hauri and J. Wang (ion probe), and Y. Mao, J. Barry, and S. R. F. McCartney (SEM – Virginia Tech Institute for Critical Technologies and Applied Sciences) for technical help; and N. Butterfield, K. Grey, R. Law, R. Tracy, M. Kowalewski, and J.W. Huntley for discussion.
### 2.9 Tables and Table Captions

**Table 2.1.** Published U–Pb zircons ages (conventional or SHRIMP) of the Wutai Metamorphic Complex and the Hutuo Group.

<table>
<thead>
<tr>
<th>Lithology</th>
<th>Geological unit</th>
<th>Locality in Fig. 2B</th>
<th>U–Pb age (Ma)±2σ</th>
<th>Interpretation</th>
<th>Reference</th>
<th>Sample #</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Granitoid</strong></td>
<td><strong>Archean Granitoids in the Wutai Complex</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Granitoid</td>
<td>Ekou granite</td>
<td>1</td>
<td>2566±13</td>
<td>Crystallization age</td>
<td>(Wilde et al., 1997)</td>
<td>95PC34</td>
</tr>
<tr>
<td>Granitoid</td>
<td>Ekou granite</td>
<td>1</td>
<td>2555±6</td>
<td>Crystallization age</td>
<td>(Wilde et al., 1997)</td>
<td>95-19</td>
</tr>
<tr>
<td>Granitoid</td>
<td>Lanzhishan granite</td>
<td>2</td>
<td>2533±8</td>
<td>Crystallization age</td>
<td>(Wilde et al., 1997)</td>
<td>95PC94</td>
</tr>
<tr>
<td>Granitoid</td>
<td>Lanzhishan granite</td>
<td>2</td>
<td>2537±10</td>
<td>Crystallization age</td>
<td>(Wilde et al., 1997)</td>
<td>95PC96</td>
</tr>
<tr>
<td>Granitoid</td>
<td>Lanzhishan granite</td>
<td>2</td>
<td>2560±6</td>
<td>Crystallization age</td>
<td>(Liu et al., 1985)</td>
<td>Ag5-2,5</td>
</tr>
<tr>
<td>Granitoid</td>
<td>Chechang-Beitai granite</td>
<td>3</td>
<td>2538±6</td>
<td>Crystallization age</td>
<td>(Wilde et al., 2005)</td>
<td>WC-5</td>
</tr>
<tr>
<td>Granitoid</td>
<td>Chechang-Beitai granite</td>
<td>3</td>
<td>2546±6</td>
<td>Crystallization age</td>
<td>(Wilde et al., 2005)</td>
<td>WC-6</td>
</tr>
<tr>
<td>Granitoid</td>
<td>Chechang-Beitai granite</td>
<td>4</td>
<td>2552±11</td>
<td>Crystallization age</td>
<td>(Wilde et al., 2005)</td>
<td>WC-7</td>
</tr>
<tr>
<td>Granitoid</td>
<td>Chechang-Beitai granite</td>
<td>3</td>
<td>2551±5</td>
<td>Crystallization age</td>
<td>(Wilde et al., 2005)</td>
<td>95PC6B</td>
</tr>
<tr>
<td>Granitoid</td>
<td>Guangningsi granite</td>
<td>5</td>
<td>2531±5</td>
<td>Crystallization age</td>
<td>(Wilde et al., 2005)</td>
<td>95PC76</td>
</tr>
<tr>
<td>Granitoid</td>
<td>Shifo granite</td>
<td>6</td>
<td>2531±4</td>
<td>Crystallization age</td>
<td>(Wilde et al., 2005)</td>
<td>95PC98</td>
</tr>
<tr>
<td>Granitoid</td>
<td>Wangjiahui granite</td>
<td>7</td>
<td>2520±9</td>
<td>Crystallization age</td>
<td>(Wilde et al., 2005)</td>
<td>95PC62</td>
</tr>
<tr>
<td>Granitoid</td>
<td>Wangjiahui granite</td>
<td>7</td>
<td>2517±12</td>
<td>Crystallization age</td>
<td>(Wilde et al., 2005)</td>
<td>95PC63</td>
</tr>
<tr>
<td><strong>Metasedimentary or metavolcanic rocks of the Wutai Complex/Hutuo Group</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Garnet quartzite</td>
<td>Jingangku Fm*</td>
<td>Hengshan</td>
<td>2527±10</td>
<td>Protolith age</td>
<td>(Wang et al., 2000)</td>
<td>HG-5</td>
</tr>
<tr>
<td>Quartzite</td>
<td>Jingangku Fm*</td>
<td>Hengshan</td>
<td>2501±15</td>
<td>Protolith age</td>
<td>(Wang et al., 2000)</td>
<td>HG-7</td>
</tr>
<tr>
<td>Metavolcanics</td>
<td>Jingangku Fm</td>
<td>8</td>
<td>2438±36</td>
<td>Protolith age</td>
<td>(Bai et al., 1992)</td>
<td>Not reported</td>
</tr>
<tr>
<td>Qtz keratophyre</td>
<td>Hongmenyan Fm</td>
<td></td>
<td>2522±17</td>
<td>Protolith age</td>
<td>(Liu et al., 1985)</td>
<td>Ag6-2</td>
</tr>
<tr>
<td>Metadacite</td>
<td>Hongmenyan Fm</td>
<td>10</td>
<td>2524±8</td>
<td>Protolith age</td>
<td>(Wilde et al., 2004a)</td>
<td>WT-17</td>
</tr>
<tr>
<td>Metavolcanics</td>
<td>Hongmenyan Fm</td>
<td>10</td>
<td>2516±10</td>
<td>Protolith age</td>
<td>(Wilde et al., 2004a)</td>
<td>WT-12</td>
</tr>
<tr>
<td>Metavolcanics</td>
<td>Hongmenyan Fm</td>
<td>10</td>
<td>2533±8</td>
<td>Protolith age</td>
<td>(Wilde et al., 2004a)</td>
<td>WT-13</td>
</tr>
<tr>
<td>Metavolcanics</td>
<td>Hongmenyan Fm</td>
<td>10</td>
<td>2523±9</td>
<td>Protolith age</td>
<td>(Wilde et al., 2004a)</td>
<td>WT-9</td>
</tr>
<tr>
<td>Metavolcanics</td>
<td>Zhuangwang Fm</td>
<td>11</td>
<td>2529±10</td>
<td>Protolith age</td>
<td>(Wilde et al., 2004a)</td>
<td>96PC114</td>
</tr>
<tr>
<td>Metavolcanics</td>
<td>Zhuangwang Fm</td>
<td>12</td>
<td>2513±8</td>
<td>Protolith age</td>
<td>(Wilde et al., 2004a)</td>
<td>95PC119</td>
</tr>
<tr>
<td>Metavolcanics</td>
<td>Baizhiyan Fm</td>
<td>12</td>
<td>2524±10</td>
<td>Protolith age</td>
<td>(Wilde et al., 2004a)</td>
<td>95PC115</td>
</tr>
<tr>
<td>Metavolcanics</td>
<td>Upper Wutai Gp</td>
<td>13</td>
<td>2528±6</td>
<td>Protolith age</td>
<td>(Wilde et al., 2004a)</td>
<td>95PC55C</td>
</tr>
<tr>
<td>Felsic tuff</td>
<td>Upper Wutai Gp</td>
<td>13</td>
<td>2523±18</td>
<td>Protolith age</td>
<td>(Kröner et al., 2005)</td>
<td>95PC30</td>
</tr>
<tr>
<td>Metavolcanics</td>
<td>Hutuo Gp</td>
<td>14</td>
<td>2087±9</td>
<td>Volcanic ash age</td>
<td>(Wilde et al., 2004b)</td>
<td>HTG-10</td>
</tr>
<tr>
<td><strong>Metamorphic age</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metavolcanics</td>
<td>Jingangku Fm</td>
<td>15</td>
<td>2508±2</td>
<td>Metamorphic age</td>
<td>(Liu et al., 1985)</td>
<td>Ag7-7</td>
</tr>
</tbody>
</table>

Sample localities are numbered and marked in Fig. 2B.

*These two sample horizons were considered by the original authors (Wang et al., 2000) as equivalents to the Northern Jingangku Formation in the Hengshan Complex.
Table 2.2. $\delta^{13}$C measurements of graphitic disc specimens and Mao standard (–6.5‰ vs. V-PDB).

<table>
<thead>
<tr>
<th>Analysis #</th>
<th>Sample #</th>
<th>$\delta^{13}$C</th>
<th>Corrected $\delta^{13}$C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mao Standard</td>
<td></td>
<td>–59.83</td>
<td></td>
</tr>
<tr>
<td>4. Sample</td>
<td>A3</td>
<td>–72.22</td>
<td>–19.3</td>
</tr>
<tr>
<td>5. Sample</td>
<td>A3</td>
<td>–70.50</td>
<td>–17.6</td>
</tr>
<tr>
<td>7. Sample</td>
<td>A2</td>
<td>–67.93</td>
<td>–15.0</td>
</tr>
<tr>
<td>8. Sample</td>
<td>A2</td>
<td>–62.91</td>
<td>–10.0</td>
</tr>
<tr>
<td>9. Sample</td>
<td>A2</td>
<td>–60.33</td>
<td>–7.4</td>
</tr>
<tr>
<td>11. Mao Standard</td>
<td></td>
<td>–59.29</td>
<td></td>
</tr>
<tr>
<td>13. Mao Standard</td>
<td></td>
<td>–58.97</td>
<td></td>
</tr>
<tr>
<td>15. Sample</td>
<td>B2</td>
<td>–88.84</td>
<td>–35.9</td>
</tr>
<tr>
<td>16. Sample</td>
<td>B2</td>
<td>–79.68</td>
<td>–26.8</td>
</tr>
<tr>
<td>17. Mao Standard</td>
<td></td>
<td>–59.49</td>
<td></td>
</tr>
<tr>
<td>18. Sample</td>
<td>C2</td>
<td>–78.48</td>
<td>–25.6</td>
</tr>
<tr>
<td>19. Sample</td>
<td>C2</td>
<td>–80.07</td>
<td>–27.1</td>
</tr>
<tr>
<td>20. Sample</td>
<td>C4</td>
<td>–73.48</td>
<td>–20.6</td>
</tr>
<tr>
<td>21. Sample</td>
<td>C4</td>
<td>–71.47</td>
<td>–18.5</td>
</tr>
<tr>
<td>22. Mao Standard</td>
<td></td>
<td>–58.43</td>
<td></td>
</tr>
</tbody>
</table>
2.10 Figures and Figure Captions

**Figure 2.1.** Geological map and sample locality. (A) Location of Wutai Metamorphic Complex in the Central Zone. Insets show the North China Craton (lower left) and the Wutai Complex sandwiched between the Fuping and Hengshan complexes (lower right). (B) Geological map of the Wutai Complex. The eight formations of the Wutai Group are coded and listed in stratigraphic order according to Tian (1991). Numbered dots denote sampling sites of U–Pb radiometric dates (Table 2.1).
Figure 2.2. Field photographs of sample horizon. (A) Field photograph of sample locality (arrow) near Shentangpu (39°07.386’N, 113°55.223’E). (B) Amphibolite (rock hammer) below and weathered iron-formation (arrow) above sample horizon. (C) Close-up of sampled unit of carbonaceous quartzite (arrow).
Figure 2.3. Light microscopy and elemental mapping of in-situ (A–G) and extracted (I–N) graphite particles. 
(A) Angular mm–cm sized clasts (black arrow) set in finer-grained carbonaceous matrix (white arrow). (B) Same as A viewed under cross nicols. Note multiple sand- to silt-sized quartz grains in clasts. (C) Close-up of a clast surrounded by matrix graphite. (D) Same as C viewed under cross nicols to show quartz grains within clast and undulose extinction (white arrow). (E–H) Photomicrographs of clast-hosted circular to elliptical graphite discs in thin sections. Specimen in H lies slightly oblique to the cut of the thin section, where part of the disc was polished away (black arrow). (I) Extracted carbonaceous material, the bulk of which has irregular morphology. Note, at center of image, a circular disc with a diameter of ~60 μm. (J) SEM of uncoated specimen used for elemental maps. (K–N) Carbon (K), calcium (L), oxygen (M), and silicon (N) elemental maps of specimen illustrated in J.
Figure 2.4. Size distribution of graphitic discs (mean = 64 μm; s. d. = 31 μm; n = 270).
Figure 2.5. Electron microprobe analysis of a Jingangku specimen. X-ray energy dispersive spectrum shows a sharp carbon spike. Au peak due to gold coating.
Figure 2.6. *In-situ* laser Raman analyses of 8 matrix graphite particles. Note variation in D band. All spectra have been baseline corrected and smoothed using the Savitzky-Golay method. (A) All spectra superimposed on each other. (B) Individual spectra.
Figure 2.7. *In-situ* laser Raman analyses of 8 clast-hosted graphite particles. Note consistently low intensity of D band. All spectra have been baseline corrected and smoothed using the Savitzky-Golay method. (A) All spectra superimposed on each other. (B) Individual spectra.
Figure 2.8. Laser Raman spectra of 12 extracted graphite discs. Note consistently low intensity of D band and similarity to Raman spectra of clast-hosted graphite particles. Spectra are not baseline corrected. (A) All spectra superimposed on each other. (B) Individual spectra.
Figure 2.9. *In-situ* rotational analysis of a Jingangku graphite particle in thin section. Spectra were collected at 4 orientations: 0°, 90°, 180°, and 270°. The relative intensity of the D and G bands does not change significantly with rotation angles, although the S band shows slight variation. Spectra are not baseline corrected.
Figure 2.10. Caption on following page.
Figure 2.10. SEM and TEM images of Jingangku graphite discs. (A) Vial containing graphitized discs and carbonaceous matter extracted from 30 g rocks. Scale in cm. (B) Representative filament extracted along with graphitized discs. (C) Circular to elliptical disc with concentric marginal folds and amorphous carbonaceous material on surface. (D) Magnified view of arrowed area in (C) showing concentric marginal folds. Arrow points to plunging and tapering fold. (E) Circular to elliptical disc similar to (C) with concentric marginal folds. (F) Elliptical disc with crescentic folds in upper part and featureless graphite sheets in lower part. (G) Detail of crescentic folds in upper right margin of (F). (H) Subhedral specimen with irregular surficial wrinkles and fragmented edge (short arrows). (I) Details of surficial wrinkles in lower right of (H). (J) Lower right edge (rotated) of (H), illustrating marginal folds. (K) Folded, wrinkled, and fragmented (short arrows) disc. (L) Elliptical to subhedral specimen with fracture (long arrow). (M) Marginal folds on lower right margin of (L) (marked by short arrow). (N) Cross-sectional view along fracture in specimen (L) (marked by long arrow). Note central gap between two sets of graphite sheets. (O) Specimen with sharp bending (long arrow) and kinking (short arrow). (P) Flat sub-rounded to subhedral disc with marginal steps (arrow) representing termination of graphite sheets. (Q) Sub-rounded to subhedral disc with crescentic folds along upper half and graphite edge overgrowth in lower half. (R) High magnification SEM showing nanoridges on disc surface. (S) TEM of graphite disc showing poorly defined central gap (arrows). (T) TEM of graphite disc showing electron-dense layer (arrow). (U) High magnification SEM showing nanopores filled with material of high atomic mass. (V) Similar nanopores in vesicle walls of Mesoproterozoic acritarch *Dictyosphaera delicata*. Nanopores filled with aluminum phosphate minerals. (B–R) are SEM photomicrographs collected using secondary electron detector, (U–V) are SEM photomicrographs using back-scattered electron detector, and (S–T) are TEM photomicrographs. Scale bars represent 10 μm unless otherwise noted.
2.11 References


ALTERMANN, W., and SCHOPF, J.W., 1995, Microfossils from the Neoarchean Campbell Group, Griqualand West Sequence of the Transvaal Supergroup, and their paleoenvironmental and evolutionary implications: *Precambrian Research*, v. 75, p. 65–90.


HANEL, M., MONTENARI, M., and KALT, A., 1999, Determining sedimentation ages of high-grade metamorphic gneisses by their palynological record: a case study in the northern


SCHOFF, J.W., and PACKER, B.M., 1987, Early Archean (3.3-billion to 3.5-billion-year-old) microfossils from Warrawoona group, Australia: *Science*, v. 237, p. 70–73.


2.12 Appendix A

Figure repository A1. SEM micrographs of graphitic discs.

Figure A1.1-1

Figure A1.1-2
Figure A1.2-1

Figure A1.2-2
Figure A1.29

Figure A1.30
Figure A1.31

Figure A1.32
CHAPTER 3

Novel application of focused ion beam electron microscopy (FIB-EM) in preparation and analysis of microfossils ultrastructures: A new view of complexity in early eukaryotic organisms

JAMES D. SCHIFFBAUER & SHUHAI XIAO

Department of Geosciences, Virginia Polytechnic Institute and State University, 4044 Derring Hall, Blacksburg Virginia 24061, USA
3.1 Abstract
Coupled dual-beam focused ion beam electron microscopy (FIB-EM) has gained popularity across multiple disciplines over the past decade. Widely utilized as a stand-alone instrument for micromachining and metal or insulator deposition in numerous industries, the submicron-scale ion milling and cutting capabilities of FIB-EM systems have been well documented in the materials science literature. These capacities make FIB-EM a powerful tool for in situ, site-specific transmission electron microscopy (TEM) ultrathin foil preparation. Recent advancements in the field-emission guns (FEGs) of FIB-EM systems have provided spatial resolution comparable to that of many high-end scanning electron microscopes (SEM), thus, providing enhanced imaging capacities with material deposition and material removal capabilities. More recently, FIB-EM preparation techniques have been applied to geological samples to characterize mineral inclusions, grain boundaries, and microfossils. Here, we demonstrate a novel method for analyzing three-dimensional (3D) ultrastructures of microfossils using FIB-EM. Our method, FIB-EM nanotomography, consists of sequential ion milling, or cross-sectioning, and concurrent SEM imaging. This technique with coupled dual-beam systems allows for real-time, 3D ultrastructural analysis and compositional mapping with precise site selectivity, and may provide new insights in fossil ultrastructures. Using the FIB-EM nanotomography method, we investigated sphaeromorphic and acanthomorphic acritarchs (organic-walled microfossils) extracted from the ≥1000 Ma Mesoproterozoic Ruyang Group of North China. The 3D characteristics of such important but controversial acritarch features as processes and vesicularly enclosed central bodies are described. Through these case studies, we demonstrate that FIB-EM nanotomography is a powerful and useful tool for investigating the three-dimensionality of microfossil ultra- and nanostructures.

3.2 Introduction
During the 1950s, argon ion milling techniques became popularized as a means of thinning mineral samples to electron transparency for use in transmission electron microscopy (TEM), revolutionizing the microstructural study of Earth science materials (Castaing and Labourie, 1953; Barber, 1970; Heaney et al., 2001). The increased use of ion milling in preparing rock samples for TEM analysis was a direct result of the inadequacy of standard ultramicrotomy and electropolishing techniques—commonly used for biological samples and alloys or metals,
respectively—when applied to Earth science materials. As many Earth science materials are inherently brittle and friable, argon milling grew into the principal methodology for preparing Earth science TEM samples (Barber, 1999; Heaney et al., 2001 and references therein). Since the 1990s, however, there has been an increasing utilization of a different tool—dual beam FIB-EM workstations. Newer dual-beam FIB-EM workstations are built on standard field emission scanning electron microscopy (FE-SEM) platforms, and couple a high-resolution, high-magnification field emission gun (FEG) with a focused ion beam consisting of a gallium ($\text{Ga}^+$) liquid metal ion source (LMIS). Recent advancements in imaging technologies have resulted in FEGs capable of subnanometer-scale imaging; these technologies are now commonly incorporated into FIB-EM workstations.

TEM sample preparation was the original high-end use for these instruments (e.g., Giannuzzi et al., 1998, 1999; Heaney et al., 2001 among numerous others). The integrated SEM in dual-beam systems allows the operator to have visual control on where and how the sample is milled, as well as perspective when using an integrated micromanipulator probe needle in TEM foil lift-outs. Conversely, single-beam FIB systems rely on the ion beam for both milling and imaging, which is intrinsically detrimental to the sample. The principal advantages of dual-beam systems, therefore, is that they not only allow for simultaneous electron imaging and ion milling but also circumvent surficial damage to the sample caused by extended ion imaging in single-beam systems.

No longer is this instrument considered to be only a TEM sample preparation machine. They are now regarded as comprehensive micromachining platforms and are fully capable of carrying out integrated analyses. While the semiconductor industry has dominated the FIB-EM-use market for the creation and modification of prototype microdevices, the capacities of FIB-EM instruments have promoted their expansion into multiple industrial and research laboratories and have vastly diversified the types of materials examined. The primary functions of FIB-EM instruments are the dissection and deposition of material on the micro- to nanometer scale using controlled and automated $\text{Ga}^+$ focused-ion beam rastering. These systems have been successfully used to prepare site-specific TEM foils of numerous specimens, ranging from metals, alloys, and ceramics, to biological samples, Earth and planetary materials, and fossils (e.g., Giannuzzi et al., 1999; Heaney et al., 2001; Weiss et al., 2002; Lee et al., 2003; Floss et al., 2004; Wirth, 2004; Benzerara et al., 2005; Kempe et al., 2005; Bernard et al., 2007; Cavalazzi, 2007; Marko et al.,
TEM foil preparation with the FIB-EM technique has drastically changed and vastly improved traditional ultramicrotomy-based TEM specimen preparation because it allows site-specific ultrathin foil preparation and introduces no ultramicrotomy-induced deformation artifacts. FIB-EM systems, more so, have also been utilized as stand-alone analytical instruments, and are starting to gradually infiltrate various research fields as they become increasingly accessible.

FIB-EM systems are ideal, all-in-one workstations for analyzing intricate details of microfossils because of their capabilities—whether embedded in their host rock or extracted. Microfossil ultrastructural analysis is certainly not outmoded. Since the early days of systematic microfossil investigation using standard TEM procedures (e.g., Oehler, 1976, 1978; Schopf and Oehler, 1976), the study of microfossil ultrastructure has developed into an integral step in aiding the taxonomic interpretation of Proterozoic and Phanerozoic microfossils (Talyzina and Moczydłowska, 2000; Javaux et al., 2003, 2004; Kempe et al., 2005; Javaux and Marshal, 2006; Willman and Moczydłowska, 2007; Cohen et al., 2009).

In this study, we used a FIB-EM system to examine the ultrastructures of Mesoproterozoic acritarchs from the Beidajian Formation of the Ruyang Group, southern Shanxi, North China (Xiao et al., 1997). While the age of the Ruyang Group is constrained poorly, it is probably <1625 Ma and ≥999 Ma, and likely between 1300–1400 Ma based on C-isotope profiles (Xiao et al., 1997). Acritarchs are organic-walled vesicular microfossils that cannot be placed with confidence into any existing classification (Evitt, 1963). These microfossils undoubtedly have diverse biological affinities and, therefore, should be considered a polyphyletic grouping with no true taxonomic status or rank (Servais, 1996). Predominantly interpreted as planktonic protists, acritarchs are widely known from the Proterozoic Eon. Unambiguous acritarchs are as old as 1600–1800 Ma (Yan, 1982, 1991, 1995; Luo et al., 1985; Zhang, 1986, 1997; Sun and Zhu, 2000), although possible graphitized vesicles from high-grade metamorphic rocks of Australia and China may place their earliest appearance in the late Archean (ca. 2500 Ma) (Schiffbauer et al., 2007; Zang, 2007).

The identification of taxonomically and phylogenetically useful features in acritarchs can be challenging because they may include a diverse range of organisms—diapause egg cases of early metazoans (Yin et al., 2007; Cohen et al., 2009), resting cysts of prasinophyte chlorophytes (Arouri et al., 1999), dinoflagellates (Moldowan and Talyzina, 1998; Meng et al., 2005; Willman
and Moczydłowska, 2007), to various prokaryotes (Javaux et al., 2003). Traditionally, some acritarchs are interpreted as eukaryotic fossils based on their relatively large cell size (Schopf, 1992), and large cell size was also used to support a eukaryotic interpretation for the ~1900 Ma megafossils *Grypania spiralis* (Han and Runnegar, 1992). Then again, size may not be an adequate indicator of taxonomic standing, as some prokaryotes may reach extremely large sizes, such as the 750 µm *Thiomargarita namibiensis* (Schulz et al., 1999). In light of this, microstructures and ultrastructures are often sought to elucidate taxonomic interpretations of acritarchs (Arouri et al., 1999, 2000; Talyzina and Moczydłowska, 2000; Javaux et al., 2004).

For example, micro- and ultrastructural characterization of ~1500 Ma acanthomorphic (or process-bearing) acritarchs using both SEM and TEM techniques has provided unambiguous evidence of cytoskeletal sophistication (Javaux et al., 2001, 2003, 2004), presenting the earliest unquestionable fossil evidence for the presence of eukaryotes.

Both SEM and TEM have their shortcomings, however. SEM only provides surface morphology, and TEM requires time-consuming microtomy that allows little control on the orientation of ultrathin sections relative to the microfossil. The FIB-EM technology offers considerable benefits over TEM, including minimal sample preparation and continuous sectioning in real time with high-precision site-selectivity. Its operational capabilities as a stand-alone analytical instrument, however, remain relatively underutilized outside of materials sciences research and the semiconductor manufacturing industry. Here, we illustrate a novel method for analyzing ultrastructures of fossil specimens using FIB-EM, which entails sequential ion-beam-milled cross-sections imaged via integrated FE-SEM, generating a form of *in-situ* high-resolution three-dimensional microscopy—or FIB nanotomography.

The FIB nanotomography technique is accomplished by sequential ion sectioning and subsequent acquisition of scanning electron micrographs of the each serial section of the structure of interest. The FIB tomographic technique has been widely used in materials sciences to study materials interfaces in, for instance, ceramics, alloys, composites, cements, and particulates (Inkson et al., 2001; Holzer et al., 2004, 2006, 2007; Kubis et al., 2004; Groeber et al., 2006). The interslice spacing for sequential sections in the FIB-tomographic method from the published materials literature typically ranges from 10–300 nm, and are dependent on the size of the features of interest. The most common increments, based on time-efficiency of the ion-sectioning process, are 100–250 nm, although FIB-nanotomography of 100 nm-sized particles
require sectioning as fine as 10 nm for proper three-dimensional (3D) reconstructions (Holzer et al., 2004). The application of the FIB nanotomography technique allows for real-time, three-dimensional ultrastructural analysis and compositional mapping with precise site selectivity, and may create opportunities for microfossil ultrastructural analyses.

3.3 Equipment, techniques, and procedures

3.3.1 Brief technical description of FIB-EM system and operational capabilities

The Virginia Tech Institute of Critical Technology and Applied Science Nanoscale Characterization and Fabrication Laboratory (VT-ICTAS-NCFL) houses a state-of-the-art FIB-EM instrument, the FEI Company’s DualBeam™ Helios 600 NanoLab™ (Fig. 3.1A). The large vacuum chamber of the Helios Nanolab can accommodate samples up to 15 cm in diameter and a Z-depth of 5 cm. Housed within this workstation are the following primary components: a high-resolution, high-magnification Elstar™ Schottky FEG for scanning electron microscopy; multiple electron detectors for image acquisition including a through-the-lens detector (TLD) for ultra-high resolution secondary electron detection (sample surface topography), an Everhart-Thornley detector (ETD) for conventional secondary electron detection, and a backscattered electron detector (BSE; surface composition); a high-resolution Sidewinder™ focused Ga⁺ ion beam column for controlled, nanoscale-material addition and excavation; and a Continuous Dynode Electron Multiplier detector (CDM detector) for ion imaging (Figs. 3.1B–C).

The electron column and ion column are oriented within the workstation so that the electron and ion beams (E-beam and I-beam, respectively) intersect at a 52° angle at their coincident point (Figs. 3.2A–B). Both beams can be active simultaneously and operate independently. The E-beam is normally used for nondestructive imaging, whereas the I-beam is used to volatize material in an operator-defined and controlled pattern. Both the electron column and ion column can be operated at a broad range of beam currents and voltages, allowing for optimal imaging and milling capacities on a wide array of samples. The Elstar™ electron column is capable of 1,000,000× magnification, which can provide image detail at 0.9 nm resolution at a beam voltage of 15 kV and optimum working distance. The Sidewinder™ ion column can also provide high-resolution images of 5.0 nm resolution at 30 kV at coincident working distance. Additionally, both beams are highly capable of operating at lower beam energies. This enhances SEM imaging of surface topography by allowing for charge control. Lower energy of the I-beam
is useful in removing or reducing surface amorphization during ion imaging as well as material removal. Moreover, precise piezo-control of the 5-axes sample stage permits ease of navigation along the x- and y-directions as well as rotational movements. Stage tilting and z-axis movement are motorized so that, at eucentric height of the sample or coincident point of the beams, a precise spot on the sample surface can be positioned perpendicularly to the E- and I-beams for synchronized electron imaging and ion milling purposes.

This FIB-EM instrument is capable of nanoscale lithography, deposition, and tomography; and the integrated Omniprobe™ tungsten micromanipulator probe needle can be utilized for precision probing, straining, moving and placing nanometer sized objects cut from or deposited on larger samples. This specific FIB-EM system also utilizes an integrated three-nozzle gas injection system (GIS, Figs. 3.1B–C) with an organometallic gas for platinum deposition and various other material-specific assist gases (or decorative gases) to enhance specialized ion-milling processes, such as insulator enhanced etching and selective carbon-milling. These GIS nozzles are essentially precisely controlled, 100 µm-diameter hypodermic needles inserted to within 100 µm of the sample surface for delivery of gases in direct proximity to the region of interest. The organometallic platinum gas is crucial for all cutting operations. Platinum is deposited by controlled I-beam volitization of the organic component of the precursor gas, and typically accreted to a thickness of one micron on the surface of the sample region of interest. The deposited platinum layer is essential for defining and protecting the original sample surface from superfluous I-beam damage because the I-beam is parabolically shaped. Furthermore, platinum is also used as a binding glue (to the micromanipulator probe needle) when material biopsies or TEM foil lift-outs are performed or constructed. In addition to the deposition of metals, decorative gases can be used. For example, water vapor augments organic material removal, and xenon difluoride gas is used commonly to enhance the volatization of oxides, similar to standard hydroflouric acid etching.

To aid its use as a stand-alone analytical instrument, the Helios 600 workstation system is equipped with Pegasus XM 4 Integrated Energy Dispersive Spectrometer (EDS) and Electron Backscatter Diffraction (EBSD) packages, with the Genesis EDS x-ray microanalysis system and Hikari EBSD camera. When coordinated with material removal via the ion beam, it is, therefore, possible to create 3D reconstructions of the internal structure, chemistry, and orientation of objects just a few nanometers in size.
The principal tasks conducted by FIB-EM workstations are in situ material deposition, nanometer-scale ion milling, and site-specific sample cross-sectioning, all of which can be easily monitored in real-time via concurrent electron imaging. The FIB-EM’s most common use is TEM ultrathin foil preparation, which consists of cutting an electron-transparent foil through ion material excavation and subsequent moving and attaching the sample to a TEM grid via an integrated micromanipulator probe needle. As these ion-sectioning capabilities have submicron-scale positional accuracy, one can clearly understand the advantages of FIB-EM workstations in TEM ultrathin foil preparation. Additional advantages over standard ultramicrotomy include preserving sample structural integrity that would be otherwise damaged by ultramicrotomy and introducing such physical artifacts to the sample as fissures (microcracks), epoxy resin shatter, and knife chatter. The I-beam itself may also introduce such artifacts during ion imaging and cross-sectioning as sample surface amorphization with consequent loss of microstructural detail, cross-section curtaining, and Ga⁺ impregnation (Prenitzer et al., 2003; Rubanov and Munroe, 2004). Curtaining, however, is easily resolved during the cross-section cleaning process (or thinning in TEM ultrathin foil preparation) and broad surface amorphization can be avoided with careful selection of beam current and minimal usage of I-beam imaging.

Paleobiological TEM sample preparation via standard ultramicrotomy techniques is prone to causing misinterpretation of fossil microstructure, as defects of sample preparation abound. A major advantage of the FIB-EM technique is that it can cut nearly any material with minimal damage and aberration. The FIB-EM can be used to prepare the most challenging samples that are not easily made by microtome or electropolish techniques because the material removed by the I-beam is volatized rather than sheared by physical means. Moreover, because of the subnanometer-scale electron imaging capabilities, integrated ion milling, and submicron-scale positional accuracy, this instrument is highly applicable to in situ, site-specific, nanometer-scale tomographic analyses. While inherently destructive to the samples analyzed, this mode of tomographic analysis offers spatial and composition information beyond the capacities of standard microcomputed X-ray tomographic techniques.

3.3.2 Sample description and preparation for FIB-EM nanotomography
The siliciclastic host rocks containing the acritarchs used for this study were collected from the Mesoproterozoic Beidajian Formation of the Ruyang Group (≥999 Ma) at the Shuiyougou
Section (SYG 6), southern Shanxi, North China (Xiao et al., 1997). Shales and siltstones of the Beidajian Formation contain highly abundant and well-preserved acritarchs, including *Shuiyousphaeridium macroreticulatum*, *Dictyosphaera delicata*, *Valeria lophostriata*, and *Tappania plana*. This study focused on *Dictyosphaera delicata* and *Shuiyousphaeridium macroreticulatum*, the two most abundant species from the Shuiyougou acritarch assemblage. Although the method detailed here is highly applicable to (perhaps better-preserved) microfossils of younger geologic ages as well as modern microorganisms, acritarchs of this antiquity were specifically chosen because ultrastructures of conspecific and morphologically similar acritarchs have been documented using standard TEM techniques (Javaux et al., 2001, 2003, 2004).

To extract acritarchs, ~2 grams of Shuiyougou carbonaceous shale was dissolved using standard hydrofluoric acid digestion techniques, and the resulting carbonaceous macerates were rinsed with distilled deionized water and then vacuum sieved with a 10 µm nylon screen (Vidal, 1988). During inspection of the sieved macerates under stereomicroscopy, numerous individuals of *Shuiyousphaeridium macroreticulatum* and *Dictyosphaera delicata* were isolated, rinsed to remove any attached debris, placed on a glass slide, and photomicrographed. The specimens chosen for analysis ranged in color from orange-brown to brown, and have a corresponding thermal alteration index (TAI) of 3–4, using the TAI scale published by Batten (1996), and consistent with the results reported by Marshall et al. (2005). Specifically selected were specimens that contained vesicularly enclosed central bodies, which have been interpreted as possible nuclear or other organelle remnants as well as vestiges of degraded cytoplasm (Knoll and Barghoorn, 1975; Oehler, 1976, 1978; Golubic and Barghoorn, 1977; Hagadorn et al., 2006).

Following imaging under optical microscopy, the Shuiyougou shale specimens were prepared for FIB analysis. Circumventing such arduous sample preparation techniques as epoxy impregnation of the sample of interest (Heaney et al., 2001; Cavalazzi, 2007), FIB-EM sample preparation is essentially identical to SEM sample preparation. The specimens were placed on a carbon- or copper-tape mount on a standard-sized aluminum SEM stub. Removing a standard depth of material with each I-beam cross-section may excavate into the mounting-tape medium because acritarch vesicle thickness varies both between and among specimens. Copper-tape mounts, therefore, were preferred to maximize compositional differences between the specimen and the mounting adhesive when viewed in cross-section. After mounting the acritarchs, the
aluminum stubs were gold-palladium sputter-coated to a thickness of 20 nm with a Cressington 208 HR (MTM-20 thickness-controller equipped) high-resolution sputter coater.

3.3.3 FIB-EM nanotomography

Subsequent to Au-Pd sputter coating, the stubs were individually secured to the sample stage and inserted into the FIB-EM vacuum chamber. Once under vacuum, the I-beam and GIS warm-up sequences are initiated and the sample surface is scanned and navigated by the E-beam. After a point of interest is determined and the LMIS source is ignited, the sample surface is adjusted to eucentric height where the E-beam and I-beam are coincident, i.e. the region of interest on the sample is effectively the center of the sample chamber universe. I-beam imaging is inherently damaging to the sample but must be utilized to ensure that both beams are focused on the same point of the specimen; accordingly, several additional procedures during imaging are recommended to minimize marring the sample surface. First, lower I-beam currents may be used for imaging purposes, which allow for longer live-viewing times with minimal surficial damage; however, not only is the lower-current I-beam still destructive, the I-beam may also undergo a focal shift when increasing current and thus the I-beam and E-beam may be slightly off coincident focus. Second, sequential I-beam snapshots may be used at higher currents to avoid refocusing the beam; but even with very short viewing times, this technique may result in significant surficial damage. Third, the organometallic platinum gas may be injected into the system without a deposition pattern in place; thus, when scanning the sample in I-beam mode (even at higher currents), a very thin layer of platinum is deposited and the sample surface remains undamaged. This technique is probably the most efficient and commonly used. Finally, if the sample surface is relatively flat, or there is a reasonably large surface area of the sample that is of lesser significance, the I-beam and E-beam can be brought to coincident focus outside of the region of interest.

After coincident focus is reached and the region of interest is determined, a deposition pattern is outlined. With the GIS, organo-metallic gas is injected into the vacuum chamber near the sample surface, and the I-beam is rastered throughout the deposition pattern, depositing the sacrificial platinum layer; other metals can be used, but platinum is the most common for sectioning purposes. Typically for FIB-EM preparation of TEM ultrathin foils, a small rectangular strip is used as the deposition pattern, and larger rectangular step-cutting patterns are
positioned on both sides of this protective layer. After the protective layer is deposited, usually at a thickness of approximately ≤1 μm, the I -beam can be concurrently rastered directly on the sample surface in both of the two cutting patterns to mill material away, leaving an undisturbed cross-section. The entire cutting process can be concurrently monitored via E-beam imaging. Usually after completing the step-cuts, the sectioned surfaces are cleaned with the designated cleaning, or polishing, I-beam function (Fig. 3.2I).

For FIB-EM nanotomography, instead of depositing a protective strip, the entire region of interest should be covered with a thin <1 μm layer of platinum (Figs. 3.2C–F). Again, a step-cutting pattern (Figs. 3.2C, I) is used at the leading edge of the platinum to allow for easy viewing of the cross-sections. Unlike preparation of TEM foils, however, all subsequent ion-cutting patterns are simply very narrow strips, or cleaning-cross-section patterns. After each cut the newly exposed section is imaged and the cutting pattern is advanced sequentially to obtain successive cross sections for the region of interest. The computer interface and concurrent E-beam imaging provide nanometer-scale positional accuracy for sequential cuts. A spatial resolution should be chosen appropriate for the features of interest. If nanometer-scale features are of interest, these cutting strips may be as small as a single nanometer, but if imaging larger regions is desired, the cutting pattern can be lengthened to the micron-scale. Using a trial and error approach, we achieved successful results using variable width, 3–5 μm depth (z-axis; Fig. 3.2I) cleaning-cross-section patterns (Figs. 3.2C, I), which were advanced from 100 nm to 250 nm at a time, the most common thicknesses from the materials literature. To ensure that all of the leading edge material was cleanly and completely removed with each cleaning-cross-section, the patterns were generated at double the length (y-axis, Fig. 3.2I) of the advancement distance. For instance, a 200 nm y-axis length pattern was used for 100 nm length sections; this pattern would only be advanced 100 nm at a time for each sequential section and, therefore, had an extra 100 nm on the trailing edge that would not overlie any material of interest. Although sectioning patterns may be advanced 1 nm at a time, sequential sections of <100 nm long can create surface amorphization complications. The shape of the ion beam is parabolic, and the wider upper portion of the beam can unevenly erode the platinum sacrificial layer above the uncut sample exterior. Performing multiple cleaning-cross-sections over larger z-distances, or increasing the number of tightly spaced sequential cross-sections, therefore, results in a progressively thinner protective platinum layer, which eventually causes sample surface amorphization. The relatively
large depth selection (z-axis) of our cross-sectioning patterns ensured that the entire thickness of the fossil, in addition to the 20 nm gold-palladium coating and the ~1 µm thick platinum sacrificial surface, was completely sectioned. Because the volume of material excavated via the I-beam is directly proportional to time of I-beam rastering, the selection of 100 nm or 250 nm cleaning section advancements was dependent on the total width (x-axis; Fig. 3.2I) of the sectioning pattern. For instance, in cases where the cutting pattern was narrow (≤10 µm), 100 nm length sections were used for optimal spatial resolution, whereas 250 nm length sections were used for wider cross-sections (>10 µm) in an effort to maximize both spatial resolution and time efficiency for three-dimensionally analyzing and reconstructing up to nearly 20 µm of the fossils.

The sequential electron images were first thresholded in Adobe Photoshop® CS2 to black and white binary representations, in order to extract only the pixels corresponding to the sectioned microfossil material (Figs. 3.2G–H). This alteration removes any unwanted image data, such as sections of the mounting tape and platinum protective layer. Additionally, because the sample is tilted 52° below horizontal in order to establish perpendicularity to the I-beam, the SEM micrographs of the ion sections are oriented 142° (rather than perpendicular) to the surface of the sample in order to obtain the best available view of the cross-section. The resultant image data, therefore, inherently contains a y-axis length component (Fig. 3.2G), and the thresholding procedure is a necessary step to reduce the three-dimensionality of the microfossil image to only two dimensions (Fig. 3.2H). These 2-D binary images are then organized into image stacks, and then imported into Kitware, Inc. ParaView 2.6.2 software for three-dimensional rendering. ParaView uses a “marching cubes” algorithm, which extracts a polygonal mesh of an isosurface—a surface that represents points of a constant value, in this case composition of the microfossils—from the two-dimensional image stacks. The individual polygons are then incorporated into 3D surface renderings of the structures of interest. Furthermore, these surface models can be converted to 3D volume renderings by reducing the opacity of the surface contours, which helps to elucidate internally contained structures—an important feature for analyzing complex microfossil ultrastructures.
3.4 Results

3.4.1 Light and scanning electron microscopy

Light and electron microscopy confirm previously published data (Xiao et al., 1997; Javaux et al., 2004) and the results are described briefly here. The vesicles of *Dictyosphaera delicata* and *Shuiyousphaeridium macroreticulatum* are 50–300 µm in diameter (Figs. 3.3F, 3.4A). Vesicle walls consisting of interlocking polygonal (mostly hexagonal) plates characterize both taxa; although *D. delicata* is herkomorphic and lacks processes (spines), whereas *S. macroreticulatum* is acanthomorphic with unevenly distributed extravesicular processes. The hexagonal plates are 1.5–3 µm in maximum width and the plate boundaries correspond to raised ridges on the outer vesicle walls. The raised ridges are 100–300 nm thick and 100–200 nm high. True excystment structures are unknown (Xiao et al., 1997). The processes on *S. macroreticulatum* are flared typically or conspicuously branched, and are on average 10–15 µm long and 2–3 µm in diameter. The processes have been described as hollow and appear to be open at the distal end and flare outward at both the vesicular attachment point and tip, although SEM imaging indicates that some of the processes have rounded or bulbous terminations. In addition, a discontinuous outer membrane, supported by the processes, appears to be present in some specimens. Furthermore, some vesicles of *D. delicata* and *S. macroreticulatum* contain circular opaque internal bodies, which are clearly seen under transmitted light microscopy (Fig. 3.4A).

3.4.2 FIB-EM nanotomography of *Dictyosphaera delicata*

In an effort to refine the FIB sequential ion section technique, a total of 10 *Dictyosphaera delicata* specimens were used as test subjects. From these specimens, numerous FIB ultra-thin sections were constructed (Figs. 3.3A–E) to establish a 2-D baseline for ultrastructures observed using the sequential ion sectioning technique. A total of 90 cross-sections were made at a spacing of 100 nm, covering a distance of approximately 9 µm. These sections were 8.2 µm wide. The ultrastructures of *D. delicata* vesicles are relatively simple. Vesicle walls vary in thickness, but are typically constrained between approximately 200 to 500 nm. The vesicle walls are multilamellar (Figs. 3.3A–E, H–I), similar to the multilayered vesicle walls of *Shuiyousphaeridium macroreticulatum* as reported in TEM ultrastructural analyses (see figs. 5H–J in Javaux et al., 2004). The innermost layer, which shows up in a lighter grayscale with both the ETD and TLD, is approximately 150 nm thick where visible. With sequential ion
sectioning, it was observed that the two vesicle walls contain smaller chambers (maximum diameters from 460 to 548 nm) distinct from the large vesicle cavity (Fig. 3.3K). Moreover, the vesicle walls merge and separate multiple times (Figs. 3.3H–J).

3.4.3 FIB-EM nanotomography of *Shuiyousphaeridium macroreticulatum*

After the nanotomography technique had been refined with *Dictyosphaera* specimens, more complex vesicles of *Shuiyousphaeridium macroreticulatum* were prepared and analyzed. Two features were of primary interest with these acanthomorphic acritarchs for use of FIB nanotomography: the 3D ultrastructures of processes and central bodies. After observation under standard optical microscopy, six specimens with readily identifiable central bodies were prepared for and analyzed via the FIB nanotomographic technique. Under ion imaging, these specimens showed topographically raised regions on the vesicle wall that correspond to the location of the central bodies (Fig. 3.4C). Convenient for our ultrastructural goals, in one specimen, what we interpreted as an extravesicular process was also situated on the outer vesicle wall at the edge of the central body (Figs. 3.4B–C). A total of 70 cross-sections with 250 nm spacing and 15.4 µm widths were conducted in this specimen, occupying a total distance of 17.25 µm. The nanotomography of this specimen serves as the focal case study for both the central body and extravesicular process, which are described below.

3.4.4 Central body ultrastructure

As was expected from the topographic observation with ion imaging, sequential-ion sectioning moving into the vesicularly enclosed central body was accompanied by an overall thickening of the fossil, from a relatively consistent total vesicle thickness of 300–500 nm—individual vesicle wall thickness ranging from ~150 nm to ~250 nm—to a total thickness of approximately 1500 nm. Throughout the analyzed region of the central body, there is no distinction between the vesicle walls and the central body, i.e. no gaps exist between the central body and the vesicle walls. Given that the vesicle walls of compressed acritarchs can merge (Figs. 3.3H–J), it is possible that the compressed vesicle wall and central body can merge during diagenesis as well. No direct measurement, thus, could be made on the thickness of the central body but it is estimated to be 1000 nm by assuming vesicle wall thicknesses of 250 nm—the maximum measured individual wall thickness outside of the central body region. In addition to the overall
thickening of the acritarch, the central body is distinguished by a high incidence of nanometer-scale pores. These nanopores show an order of magnitude in size range, from 5.8 nm at smallest to 58.2 nm at largest (Figs. 3.4D–F). We localized the pores to the central-body region by adding a hypothetical vesicle wall, using 250 nm as individual wall thicknesses to these image slices (Figs. 3.4D–E). At any given image slice of the central body, up to 25 nanopores can be identified in an area of 5120 (field of view width at 25k× magnification) × 1000 nm (total estimated central body thickness) (Figs. 3.4D–E). In one isolated case, one of the larger nanopores shows a tangential extension downward towards the stub mount. This extension covers a length of 575.7 nm, nearly ten times the diameter of the nanopore (Fig. 3.4F), suggesting that this nanopore may be a cylindrical nanotube.

3.4.5 Process ultrastructure

The structure interpreted as an extravesicular process examined via FIB-EM nanotomography was located on the vesicle surface, near the outer boundary of the raised central body region (Figs. 3.4A–C, and B inset). With the site-specificity capabilities of the FIB-EM system, we were able to section laterally through the length of this structure (see Figs. 3.4G–J, 5A–J). A total length of approximately 4.5 µm of the process was cross-sectioned (19 total sections), illustrating a complex structure with multiple chambers rather than a simple hollow or cylindrical process. Moreover, through the 4.5 µm of sectioning, images of two distinct, but conjoined structures were captured—a larger bulbous structure with a maximum diameter of 3.23 µm and ~3.00 µm long, occupying a total of 13 sections (Figs. 3.5A–H), and a smaller stalk-like columnar structure with a maximum diameter of 1.51 µm and ~3.50 µm long, occupying a total of 15 sections (Figs. 3.5C–J). The larger bulbous structure has a rounded central vacuole, with a maximum diameter of 1494 nm, and up to eight smaller, radially adjacent, elliptical to reniform chambers (maximum dimension = 1255 nm). These reniform chambers are laterally extensive, continuing proximally to distally and perpendicular to the plane of the cross-sections. The smaller columnar structure, flanking and briefly contiguous to the larger bulbous structure, does not show the same chamber arrangement. Rather, it consists of a maximum of four axially arranged, predominantly elliptical, and laterally intermittent chambers (maximum dimension = 539 nm) that disappear and reappear suddenly without tapering through the sequential sectioning. The bulbous and columnar structures are conjoined briefly: the columnar structure first joins with the bulbous structure prior
to its midpoint, at only 1.00 µm into the structure, and continues for an additional 1.50 µm past the end of the bulbous structure. Both of these structures maintain attachment to the outer vesicle surface for nearly their entire lengths but show no evidence of communication with the vesicle cavity. Furthermore, a shroud of organic material covers this complex set of structures through nearly the entire sectioning length (Figs. 3.5D–J). This shroud is attached to the bulbous structure at approximately its midpoint, coincident with the start of the columnar structure, and it covers the majority of the smaller columnar structure. Three-dimensional models of these structures, both as a surface rendering and a volume rendering with highlighted continuous chamber space, are shown in Figures 3.5K–N (data from 29 cross-sections included, representing 7.0 µm of material). Conceptual diagrams of the full living view of a *S. macroreticulatum* vesicle, as well as tentative reconstructions of the process structure both in-life and as sectioned from the fossil representative are shown in Figure 3.6. While these diagrams are admittedly speculative, they incorporate key characteristics observed both in previously examined specimens as well information elucidated via the FIB-EM nanotomographic method and, therefore, provide the most comprehensive interpretation possible from the available surficial and ultrastructural data.

### 3.5 Discussion

FIB nanotomography of the Ruyang Group specimens shown here illustrated numerous similarities to previously published ultrastructures detailed from TEM examination of conspecific and morphologically similar Roper Group acritarchs, such as multilayered vesicle walls comprised of reticulate organic plates (Javaux et al., 2001, 2003, 2004). Such similarities to data observed with more extensively tested techniques illustrate the viability of FIB nanotomography as a method for examining microfossil ultrastructures.

The biological origin of the chambers within the vesicle walls of *Dictyosphaera delicata* (Fig. 3.3K) is debatable, as they may be products of taphonomic or thermal alteration, similar to the amalgamation and separation of compressed vesicle walls in the same specimens (Figs. 3.3H–J). Nonetheless, it is important to note that similar chambers, described as rounded voids—maximum diameter of approximately 3 µm, nearly an order of magnitude larger than those observed here—have been observed from TEM ultrastructural examination of younger (~580 Ma) and less thermally mature (TAI=2–3, Willman et al., 2006) leiosphere acritarchs from the
Officer Basin, South Australia (Willman, 2009). Likely in much the same conundrum as ours, however, neither a biological nor a taphonomic interpretation has been offered for the voids in leiosphere walls (Willman, 2009). FIB nanotomography *Shuiyousphaeridium* specimens, on the other hand, illustrated complexities unknown from previous examination. First, the nanoporous structures present in the central bodies may represent nanotubular structures of biological significance. These structures are intriguingly similar to nanoporous structures observed on the vesicle walls of *Dictyosphaera delicata* (see figs. 1D, F of Kaufman and Xiao, 2003), but those observed here are restricted to the central body region and show no evidence of continuing through the outer vesicle walls. There is a great deal of missing data by removing 250 nm of material between cross-sections, however, because the size range of these structures is so small. It is difficult to determine, therefore, whether these nanopores are a network of interconnected nanotubes. In an effort to resolve this problem, we are currently adapting the nanotomography method to remove much less material (10 nm) between sequential ion sections, but this presents the problem of surface amorphization described earlier in the methods section. The two interconnected process-like structures, if they are indeed part of what is commonly recognized as an external process, are far more intricate than hollow cylindrical processes as previously described from these fossils (Xiao et al., 1997). Their relatively consistent fusion with the vesicle wall may draw the process interpretation into question, but this connection throughout nearly the entire length of the process is likely taphonomic—similar to the amalgamation of compressed vesicle walls in *D. delicata*. As is observable in our conceptualized representation of these structures, we interpret the larger bulbous structure as the process termination attached to the vesicle surface by the stalk-like columnar structure. While most processes observed on *S. macroreticulatum* in both light and electron microscopy show flared or branched terminations, bulbous structures have been observed on numerous specimens—although rare. We do not feel that the bulbous process termination is the common form, though it may be more frequent than observed if it is easily damaged or ripped from the processes during maceration and handling. Another feature of note is the shroud of organic material that covers the majority of the process-like structure. We suggest that this shroud potentially represents a fragment of an outer membrane, which has previously been described as a thin organic veil supported by the extravesicular processes (Xiao et al., 1997). The surficial feature observed under electron imaging, therefore, likely reflects this shroud rather than the extravesicular process observed in
FIB nanotomography. The process is obscured underneath and, thus, protected by the outer membrane shroud. Further, one apparent detail that can be resolved from the process ultrastructural reconstruction is the lack of communication between the process—specifically the stalk in our conceptualized view—and the inner vesicle cavity. As a final point, the segmented chambers viewed in the smaller columnar structure and the vacuolated larger bulbous structure illustrate a level of ultrastructural complexity that was not previously documented in Ruyang Group acritarchs and, therefore, should compel further microfossil ultrastructural study via FIB-EM nanotomography.

3.6 Conclusions
In summary, we have illustrated that the FIB-EM technique presents opportunities to examine the three-dimensionality and continuity of microfossil ultrastructures with numerous advantages over standard SEM and TEM techniques. As simply a TEM ultrathin foil preparation tool, FIB-EM workstations offer considerable benefits—predominantly its site-specificity—over standard ultramicrotomy and electropolishing techniques. Perhaps more importantly, as this technique provides a 3D element to the study of microfossil ultrastructures, requires little sample preparation, and introduces few artifacts, the study of microfossils stands much to gain by popularizing the use of FIB nanotomography. An interesting prospect of this 3D ultrastructural technique is to combine with analyses from other such advanced instruments as micro-Fourier transform infrared (FTIR) spectroscopy (e.g., Marshall et al., 2005), for integrated ultrastructural and chemical investigation, which could potentially shed light on taxonomic affinities of problematic microfossils. Further studies that would jointly consider possible modern analogs of acritarchs, such as dinoflagellate cysts and diapause animal eggs, would undoubtedly aid in unlocking some of the taxonomic puzzles surrounding acritarch interpretations.

3.7 Acknowledgments
The research was supported by NASA Exobiology and Evolutionary Biology Program, the Virginia Tech Institute for Critical Technology and Applied Science (ICTAS), and the Virginia Space Grant Consortium. Analyses were conducted at the Virginia Tech ICTAS Nanoscale Characterization and Fabrication Laboratory, with technical help from S.R.F. McCartney and J. McIntosh. 3D renderings were constructed with the assistance of P. Shinpaugh (VT-CAVE,
Visualization and Animation Group of ICTAS); and J. Norton provided conceptual graphical representations of the *Shuiyousphaeridium macroreticulatum* process. We additionally thank T.A. Dexter, PALAIOS coeditor S. T. Hasiotis, associate editor B. Granier, and two anonymous reviewers for critical comments that greatly improved the quality of this report.
3.8 Figures and Figure Captions

Figure 3.1. FIB-EM instrument photographs and sample chamber schematic with labeled components. (A) Photograph of FEI Company’s DualBeam™ Helios 600 NanoLab™. (B) Sample chamber photograph with E-beam, GIS nozzles, CDM detector, and sample stage visible. (C) Schematic diagram of sample chamber with E-beam, I-beam, GIS nozzles, micromanipulator probe needle, and image detectors labeled.
Figure 3.2. Electron micrographs, cross-sectional binary data (BD), and schematic diagram of FIB sample processing. (A–F) *Dictyosphaera delicata* specimens; (G–H) *Shuixousphaeridium macroreticulatum* specimen cross-section and BD of vesicle ultrastructure; (I) Schematic diagram of FIB sample processing. (A) Overview of uncut *D. delicata* specimen perpendicular to E-beam. (B) Overview of same *D. delicata* specimen as shown in (A) oriented perpendicular to I-beam and imaged with E-beam, Pt deposition GIS nozzle visible in upper right corner of frame of view. (C) Side view of step-cut into *D. delicata* specimen with Pt deposition pattern (right black box), step-cut pattern (left black box), and cleaning-cross-section pattern (white box). (D) Standard TEM lift-out FIB preparation of *D. delicata* specimen, consisting of two opposing step-cuts juxtaposed to Pt protective strip. (E) FIB nanotomography preparation of *D. delicata* specimen with initial step-cut at leading edge of Pt deposition. (F) Higher magnification view of initial cross-section shown in (E), additionally showing multilamellar vesicle wall structure. (G) Representative cross-section from FIB nanotomography of *Shuixousphaeridium macroreticulatum* specimen with axes labeled, triple white arrow indicates debris trapped in the adhesive layer. (H) Thresholded BD from cross-section shown in (G), illustrating reduction of 3D to 2D as only cross-section axes x and z are visible. (I) Schematic representation of FIB nanotomography sample processing.
Figure 3.2. (continued) *Note for Figures 3.2–3.4: labeled brackets observed in Fig. 3.2F–G also used in Fig. 3.3 and 3.4 to indicate deposited platinum protective layer, vesicle wall(s), and underlying adhesive. Pt brackets are black and flat-ended; the vesicle brackets are white and terminated by arrows; when visible vesicle wall was too thin to fit a double-sided arrow, horizontal arrow brackets were used and indicated in corresponding figure captions; adhesive brackets are white and flat-ended. Dashed-line brackets indicate entirety of the structure is not visible in the frame of view.
Figure 3.3. Electron and light micrographs of *Dictyosphaera delicata* specimens, focusing on vesicle wall ultrastructures. (A–E) Baseline vesicle wall ultrastructures; (F–K) Single FIB nanotomography-prepared *D. delicata* specimen. (A) Step-cut cross-sectional view. (B) Higher magnification of boxed area in (A), of multilamellar vesicle wall, horizontal white arrow illustrates 20 nm thickness Au-Pd sputter coating. (C) Dual step-cut (TEM-ultrathin section preparation) cross-sectional view of multilamellar vesicle wall, black arrow indicates edge of protective Pt strip, lower white arrow indicates edge of lower vesicle wall edge. (D) Cross-sectional view of multilamellar vesicle wall and inner incisions (arrows) correspond to polygonal plate boundaries. (E) Sequential cross-section (SCS, 100 nm y-length from D) of migration (left arrows in D and E) and termination (right arrows in D and E) of inner incisions due to oblique sectioning through polygonal fields. (F) Light micrograph of *D. delicata* specimen, with FIB-EM images shown in (G–K). (G) Electron micrograph of Pt deposition pattern (box) and direction (arrow) of sequential FIB cross-sections; overall morphology was slightly damaged during transfer to SEM stub. (H) Initial step-cut cross-section showing multilamellar ultrastructure of both vesicle walls; arrows indicates vesicle wall conjunction, although vesicle walls are merged through most of the cross-section. (I) SCS (100 nm from H) of larger spacing between vesicle walls, and slight convergences of vesicle walls and disappearance of multilamellar ultrastructure (arrows). (J) SCS (3100 nm from I) of mostly merged vesicle walls. (K) SCS (1800 nm from J) with three chambers (arrow) on outer edge of vesicle wall, horizontal white arrow bracket illustrates vesicle thickness.
Figure 3.4. Representative light, electron, and ion micrographs of single FIB nanotomography-prepared *Shuiyousphaeridium macroreticulatum* specimen, showing central body, process, and outer membrane ultrastructures. (A) Light micrograph of *S. macroreticulatum* specimen with FIB-EM images shown in (B–J). (B) Electron micrograph of Pt deposition pattern (box) and direction (arrow) of sequential cross-sections, inset electron micrograph shows higher magnification of sectioned surficial process (cross-sections in G–J). (C) Ion micrograph (rotated ~45° counterclockwise from (B) showing central body (upper arrow, cross-sections in D–F) and surficial process (lower arrow). (D) Numerous nanopores in central body, white lines show hypothetical vesicle wall thickness of 250 nm. (E) Sequential cross-section (750 nm y-length from D) of continuance of nanopores through central body, white lines show hypothetical vesicle wall thicknesses of 250 nm. (F) High magnification view of nanopore with tangential extension indicated by arrows. (G) Cross-sectional view of bulbous tip of process, horizontal white arrow brackets indicate vesicle wall thickness (binary data shown in Fig. 3.5E). (H) Cross-sectional view of process stalk, horizontal white arrow brackets indicate vesicle wall thickness. (I) Higher magnification view of (G), showing multiple radial chambers (but no central vacuole) and beginning of columnar stalk to the left. (J) Higher magnification view of (H), showing four axially-arranged circular to elliptical chambers.
Figure 3.5. Cross-sectional binary data (BD) and 3D renderings (3D-R) of Shuiyousphaeridium macroreticulatum specimen shown in Fig. 4. (A–J) BD from FIB nanotomography-prepared S. macroreticulatum specimen; (K–N) 3D-R from FIB nanotomography of specimen in Fig. 3.4. Y-axis length exaggerated ~3:1 for clarity; scale bars accurate for x-width and z-depth measurements. (A) BD of bulbous process termination (bulb) showing large central vacuole (LCV) and one unclosed radial chamber (RC) on lower right. (B) BD (250 nm y-length from A) of bulb with LCV, five small RCs, and hints of outer membrane shroud (OMS) on right. (C) BD (250 nm from B) of bulb with LCV, large elliptical RC on lower right of LCV, and semblance of OMS on right. (D) BD (250 nm from C) of bulb showing LCV, three elliptical RCs on lower edge of LCV, and more continuous OMS. (E) BD (250 nm from D) of bulb with no LCV, six large elliptical RCs (two unclosed RCs on lower left), continuous OMS, and columnar stalk portion of process (stalk) at left edge of bulb. (F) BD (250 nm from E) of bulb showing no LCV, seven large elliptical RCs (two unclosed RCs on lower left), mostly continuous OMS, and stalk at left edge of bulb. (G) BD (250 nm from F) of bulb edge with no LCV, five disorganized RCs (two unclosed RCs on lower left), four smaller RCs in upper bulb, one smaller RC at bulb base, mostly continuous OMS, and more defined stalk at left edge of bulb. (H) BD (250 nm from G) of bulb edge detached from vesicle wall, mostly continuous OMS, and tenuous connection of stalk to outer vesicle surface. (I) BD (750 nm from H) with no bulb visible, mostly continuous OMS, and stalk with four RCs. (J) BD (250 nm from I) with mostly continuous OMS and stalk with two outer edge RCs. (K) Top view surface 3D-R, with darker region representing bulb (ellipse), stalk (rectangle), and part of the OMS (axes applicable for K and L). (L) Top view of volume 3D-R, white inclusions represent continuous RCs or LCV within process (unclosed RCs not included).
Figure 3.6. Conceptualization of process ultrastructure and fossil observations. Left illustration shows living full vesicle depiction with outer membrane, upper slice removed to show process distribution, morphologies, and vesicle surface reticulation; right illustration (following black arrow) shows higher magnification view and hypothetical structural and ultrastructural representation of bulbous-tipped process as it may have appeared during the life of the acritarch; lower illustration (following grey arrow) shows conceptual reconstruction of fossil bulbous-tipped process and outer membrane shroud as sectioned during FIB-EM analyses.
3.8 References


3.9 Appendix B

Figure repository B1. FIB-EM micrographs of acritarch nanotomography preparation and acritarch ultrastructure.

Figure B1.1-1 (Dictyosphaera delicata)

Figure B1.1-2
Figure B1.1-9

Figure B1.2-1 (*Dictyosphaera delicata*)
Figure B1.2-2

Figure B1.2-3
Figure B1.2-4

Figure B1.3-1 (Dictyosphaera delicata)
Figure B1.3-2

Figure B1.3-3
Figure B1.3-4

Figure B1.3-5
Figure B1.3-6

Figure B1.4-1 (Dictyosphaera delicata)
Figure B1.6-1 (*Dictyosphaera delicata*)

Figure B1.6-2

Figure B1.6-3

Figure B1.6-4

Figure B1.6-5

Figure B1.6-6
Figure B1.8-1
(Shuiyouphaeridium macroreticulatum)

Figure B1.8-2

Figure B1.8-3

Figure B1.8-4

Figure B1.8-5

Figure B1.8-6
Figure repository B2. Thresholded nanotomography slices and 3-D renderings.

Figure B2.1-1 (corresponds to Figure B1.8-27)

Figure B2.1-2 (corresponds to Figure B1.8-28)
Figure B2.1-3 (corresponds to Figure B1.8-29)

Figure B2.1-4 (corresponds to Figure B1.8-30)
Figure B2.1-5 (corresponds to Figure B1.8-31)

Figure B2.1-6 (corresponds to Figure B1.8-32)
Figure B2.1-7 (corresponds to Figure B1.8-33)

Figure B2.1-8 (corresponds to Figure B1.8-34)
Figure B2.1-9 (corresponds to Figure B1.8-35)

Figure B2.1-10 (corresponds to Figure B1.8-36)
Figure B2.1-11 (corresponds to Figure B1.8-37)

Figure B2.1-12 (corresponds to Figure B1.8-38)
Figure B2.1-13 (corresponds to Figure B1.8-39)

Figure B2.1-14 (corresponds to Figure B1.8-40)
Figure B2.1-15 (corresponds to Figure B1.8-41)

Figure B1.1-16 (corresponds to Figure B1.8-42)
Figure B2.1-19 (corresponds to Figure B1.8-45)

Figure B2.1-20 (corresponds to Figure B1.8-46)
Figure B2.1-21 (corresponds to Figure B1.8-47)

Figure B2.1-22 (corresponds to Figure B1.8-48)
Figure B2.1-23 (corresponds to Figure B1.8-49)

Figure B2.1-24 (corresponds to Figure B1.8-50)
Figure B2.1-25 (corresponds to Figure B1.8-51)

Figure B2.1-26 (corresponds to Figure B1.8-52)
Figure B2.1-29 (corresponds to Figure B1.8-55)

Figure B2.2-1
Figure B2.3-10

Figure B2.3-11
CHAPTER 4

Microfossil phosphatization and its astrobiological implications

SHUHAI XIAO & JAMES D. SCHIFFBAUER

Department of Geosciences, Virginia Polytechnic Institute and State University, 4044 Derring Hall, Blacksburg Virginia 24061, USA
4.1 Abstract
One of the major tasks of astrobiological research is to critically examine evidence of past or present ecosystems beyond our planet. Because the Earth is the only planet that is known to have hosted life, it therefore provides the only model for us to learn how traces of life can be preserved and recognized. If past morphological evidence of microbial life exists outside of our planet, it is likely that it would be preserved by taphonomic pathways similar to those we have observed on Earth. In contrast to the Phanerozoic fossil record that is characterized by macroscopic skeletal fossils, the Proterozoic (2500–542 Ma) fossil record is dominated by microscopic, soft-bodied organisms. Thus, from a Phanerozoic point of view, the fossilization of such organisms is regarded as exceptional preservation. Here, we briefly review the exceptional preservation taphonomic pathways in the Proterozoic fossil record, including Bitter Spring-, Doushantuo-, Orsten, Beecher’s trilobite-, and Burgess Shale-type preservational pathways. This is followed by detailed descriptive and quantitative analyses of three-dimensional phosphatization of non-biomineralizing microorganisms in the Neoproterozoic Doushantuo Formation. In our investigation, we recognized four different styles of phosphate mineralization, each characterized by distinct crystal size, orientation, and organization. These are interpreted as different phosphatization processes related to availability of nucleation sites and degradation of organic substrate, and include (1) perpendicularly oriented, prismatic apatite crystals; (2) tangentially oriented, bladed apatite crystals; (3) randomly oriented, equant apatite crystals; and (4) phosphatic filaments, rods, and granules. We focus on describing the phosphatization window of the Doushantuo Formation because it represents one of the most powerful taphonomic pathways through which soft-bodied microorganisms can be preserved, which is highly relevant to astrobiological research.

4.2 Introduction
One of the major tasks of astrobiology is to critically examine evidence of past or present ecosystems beyond our planet. As Earth is the only planet that is known to have hosted life, perhaps as early as 3800–3500 Ma as illustrated by biologically-meaningful carbon isotopic signatures and prokaryotic microfossils (Mojzsis et al., 1996; Schopf, 2006; but see Brasier et al., 2006; Fedo et al., 2006; van Zuilen et al., 2002), it provides the only model for us to learn how traces of life can be preserved and recognized. In this contribution, we focus on fossil
preservation through phosphate mineralization and discuss its implications for the identification of possible life (particularly ancient life if it did exist) on other planets.

If cellular organisms had once existed on other planets, by either independent origin or shared descent with life on Earth, they were most likely to be microscopic, soft-bodied life forms akin to microorganisms (microbial life: prokaryotes, protists, and microalgae) that have populated various environments on Earth. This inference is based on two arguments. First, the striking ecological and metabolic diversity of microbial life on Earth (Nisbet and Sleep, 2001) indicates that it has a better chance populating extreme environments on other planets. Second, consideration of phylogeny and morphological complexity requires that the earliest life be represented by simple forms that are microscopic, unicellular (single-celled), and lack skeletons. Indeed, the evolutionary history on Earth shows that non-skeletal microbial life preceded macroscopic life by slightly more than 1500 million years, so that the Archean–Proterozoic biosphere (3500–542 Ma) was entirely dominated by microorganisms. Macro-organisms visible to naked eye (e.g., *Grypania*) did not appear until about 1900 Ma (Fralick et al., 2002; Han and Runnegar, 1992; Schneider et al., 2002) and they did not become ecologically dominant until the Proterozoic–Cambrian transition at about a half billion years ago. Similarly, the Archean-Proterozoic biosphere consisted almost exclusively of non-biomineralizing, soft-bodied organisms; biologically controlled mineralization evolved in only a few Neoproterozoic (1000–542 Ma) taxa (Allison and Hilgert, 1986; Grant, 1990; Grotzinger et al., 2000; Hua et al., 2005; Porter and Knoll, 2000; Wood et al., 2002) and did not become widespread until after the Cambrian Explosion (Bengtson, 1994; Knoll, 2003). Thus, the Precambrian world serves as a plausible model in the search for ancient ecosystems on other planets.

In this contribution, we ask the question how morphological evidence (as opposed to geochemical evidence) of microbial life—if it did exist—would be best preserved in extraterrestrial environments. We approach this question by briefly reviewing the taphonomic pathways in the Proterozoic (2500–542 Ma) fossil record. This is followed by a more detailed analysis of three-dimensional phosphatization of non-biomineralizing microorganisms in the Neoproterozoic Doushantuo Formation. We focus on the phosphatization window of the Doushantuo Formation because it represents one of the most powerful taphonomic pathways through which soft-bodied microorganisms can be preserved. We then close our chapter by discussing the astrobiological relevance of phosphatization.
4.3. Preservation of Proterozoic Fossils

In contrast to the Phanerozoic fossil record that is characterized by macroscopic skeletal fossils, the Precambrian fossil record is dominated by microscopic, soft-bodied organisms. Thus, from a Phanerozoic point of view, the fossilization of such organisms is regarded as exceptional preservation. Butterfield identified six different taphonomic styles of exceptional preservation of Proterozoic–Cambrian non-biomineralizing organisms (briefly reviewed below, Fig. 4.1), which are named after well known biotas that exemplify each of these taphonomic styles (Butterfield, 2003).

Bitter Spring-type preservation is characterized by silicification of microorganisms in peritidal cherts (Knoll, 1985; Schopf, 1968; Zhang et al., 1998). Classical silicified biotas, for instance the Bitter Spring assemblage, typically show evidence of cellular preservation of microbial communities dominated by prokaryotic forms such as cyanobacteria, although unicellular and multicellular eukaryotes are often preserved as well (Xiao, 2004). In marine environments, this taphonomic window was open in its fullest in the Precambrian, particularly in the Proterozoic, most likely because of the higher availability of dissolved silica in marine waters before the rise of silica biomineralizers such as hexactinellid sponges, demosponges, and diatoms (Maliva et al., 1989; Maliva et al., 2005).

Doushantuo-type preservation is known for the exquisite phosphatization of mostly eukaryotic microorganisms that thrived in shallow subtidal environments (Dornbos et al., 2006; Hagadorn et al., 2006; Xiao and Knoll, 1999). Often, labile cellular and subcellular structures are preserved in Doushantuo-type phosphatization. Similar to Doushantuo-type preservation is Orsten-type preservation, which represents a taphonomic pathway in which more recalcitrant tissues, such as ecdysozoan cuticles, are preserved through phosphatization (Müller, 1985; Walossek, 2003). The Orsten biota, however, is distinct from the Doushantuo biota in its carbonate (as opposed to phosphorite) depositional setting and the lack of phosphatization of more labile substrates such as cellular and subcellular structures. Some phosphatized biotas in Cambrian successions (Bengtson and Yue, 1997; Dong et al., 2004; Zhang and Pratt, 1994) may be considered as transitional taphonomic windows that bridge the end members of the Doushantuo and Orsten biotas, because they show evidence of both cellular and cuticular phosphatization. When considered together, the two phosphatization windows seem to be open only in the Ediacaran and early Paleozoic (Donoghue et al., 2006).
Beecher’s trilobite-type preservation represents pyritization of relatively recalcitrant tissues, for example chitinous arthropod cuticles (Briggs et al., 1991) and cellulose-based cell walls (Grimes et al., 2002; Yuan et al., 2001). The preservational resolution of this taphonomic window is limited by crystal size of authigenic pyrite and controlled by the balance between organic degradation through bacterial sulfate reduction (as a source of sulfide) and authigenic precipitation of pyrite. The temporal and environmental occurrences of this taphonomic window are not well characterized, but are potentially widespread given that pyrite formation is sensitive to local geochemical conditions rather than global secular trends (Rickard et al., 2007). Possible Proterozoic examples of this type of preservation include pyritized chuarid vesicles (Yuan et al., 2001) and pyritized tubes (Cai and Hua, 2007) in Ediacaran successions of South China.

The four preservational pathways discussed above are collectively known as permineralization—the preservation of soft tissues with three-dimensional detail by authigenic minerals (Briggs, 2003). In contrast, Burgess Shale-type preservation is characterized by two-dimensional compression and preservation of more recalcitrant tissues as carbonaceous films (Butterfield, 1995; Gaines et al., 2005), typically on bedding planes of fine-grained sediments deposited in deep-water environments below fair weather wave bases. Several mechanisms have been proposed to explain Burgess Shale-type preservation, although these need not to be mutually exclusive. Some argue that authigenic aluminosilicate minerals may have played a role in delaying organic degradation, therefore promoting organic preservation (Butterfield, 1995; Orr et al., 1998). But recent investigation of the Chengjiang biota—an early Cambrian example of Burgess Shale-type preservation—seems to indicate that pyrite mineralization was at least partly responsible for the exceptional preservation of soft tissues (Gabbott et al., 2004; Zhu et al., 2005). These authors argue that the degradation of more labile tissues by sulfate reduction bacteria provides a source of hydrogen sulfide (H₂S), which in the presence of reactive iron (Fe) would promote pyrite mineralization and the preservation of more recalcitrant soft tissues. Burgess Shale-type preservation is most common in the Cambrian, but also occurs in the Proterozoic (Xiao et al., 2002) and post-Cambrian Paleozoic (Butterfield, 1995). The secular trend of Burgess Shale-type preservation may be controlled by several factors, two of primary importance may be clay mineral geochemistry (Butterfield, 1995; Orr et al., 1998) and bioturbation (Allison and Briggs, 1993; Orr et al., 2003).
Finally, the Ediacara-type preservation is a non-actualistic taphonomic window, characterized by the casting and molding of macroscopic organisms in siliciclastic rocks, including sandstones. Microbial mats, through the formation of a “death mask” on degrading Ediacara organisms and the promotion of mineralization beneath microbial mats, may be responsible for the casting and molding of Ediacara fossils in South Australia (Gehling, 1999). Other Ediacara fossils were probably “masked” by volcanic ashes (Narbonne, 2005) or event deposits of fine-grained silts (Xiao et al., 2005). Ediacara-type preservation mostly occurs in Ediacaran rocks, although rare occurrences in Phanerozoic and Mesoproterozoic successions have been reported (Fedonkin and Yochelson, 2002; Hagadorn et al., 2000; Jensen et al., 1998; Zhang and Babcock, 2001).

From an astrobiological perspective, the Bitter Spring-, Doushantuo-, and Orsten-type preservation pathways are most important because of their likelihood of capturing morphological information about microscopic organisms consisting of more labile organic structures. In the following section, we will take a closer look at the Doushantuo-type preservation at its type locality.

4.4. Phosphatization in the Neoproterozoic Doushantuo Formation
The late Neoproterozoic phosphorite of the Doushantuo Formation at Weng’an, South China, hosts some of the best preserved microfossils, providing both cellular and subcellular insights into a variety of eukaryote organisms, including animals and algae (Hagadorn et al., 2006; Xiao et al., 2004). Because the Doushantuo Formation at Weng’an hosts the earliest record of animal life in the form of fossilized metazoan embryos (however, see Bailey et al., 2007 for an alternative interpretation and Xiao et al., 2007 for a rebuttal), past investigations have focused primarily on their evolutionary significance (Xiao et al., 1998). Only a few studies were designed specifically to understand the taphonomy of the Weng’an biota (Dornbos et al., 2005; Dornbos et al., 2006; Xiao and Knoll, 1999). The lack of in-depth understanding of Doushantuo taphonomy not only makes the biological interpretation of certain Doushantuo fossils controversial (Bengtson and Budd, 2004; Chen et al., 2004; Chen et al., 2000; Xiao et al., 2000), but also weakens the role of the Doushantuo biota as a model to guide further exploration of Doushantuo-type preservation in other ages and on other planets.
Previous examination (Xiao and Knoll, 1999) using scanning electron microscopy provided evidence that the preservation of Doushantuo microfossils critically depends on two mineralization processes: (1) encrustation through mineral nucleation and precipitation on organic substrates, such as cell membranes, cell walls, and mucus strands; and (2) impregnation of phosphatic minerals within organic substrates. Recent analysis provides further evidence to substantiate these processes.

In our investigation, we extracted Doushantuo microfossils using the standard acid digestion method (dissolution in 10% acetic acid for 3–6 days). Extracted specimens were gold-palladium (Au-Pd) sputter-coated to ~20 nm in thickness and then observed using scanning electron microscopy. We recognize four different styles of phosphate mineralization, each characterized by distinct crystal size, orientation, and organization. These are interpreted as different phosphatization processes related to availability of nucleation sites and degradation of organic substrate. The following sections explore these four styles of phosphate mineralization (Figs. 4.2–4.11), including (1) perpendicularly oriented, prismatic apatite crystals; (2) tangentially oriented, bladed apatite crystals; (3) randomly oriented, equant apatite crystals; and (4) phosphatic filaments, rods, and granules.

4.5. Perpendicularly oriented, micrometric, prismatic apatite crystals: Phosphatic encrustation on organic and inorganic substrates

4.5.1. Description

We begin by examining one Doushantuo specimen of Megasphaera inornata (Fig. 4.2A), interpreted as a phosphatized animal egg cell encased within an egg envelope. At a closer look, there is abundant evidence for encrusting apatite crystals of micrometric size (Fig. 4.2C, E, H). These crystals are often oriented perpendicular to encrusted surfaces, which can be the egg cell surface (Fig. 4.2B, lower right) or the outer envelope (Fig. 4.2E). The egg cell is eccentrically located within the envelope and entirely covered with apatite botryoids approximately 10–20 μm in size (Fig. 4.2B, lower right). There is evidence that the botryoids overgrow on each other and sometimes aggregate to form cauliflower-like structures (Fig. 4.2B). The botryoids are made of prismatic apatite crystals that are radially oriented. Thus, they appear as hexagonal terminations when viewed distally on botryoid surface (Fig. 4.2C, lower right). The crystals are prismatic euhedra, typically ~0.09–0.85 μm in width and ~0.40–2.25 μm in length (Fig. 4.12).
Similarly, the envelope is covered with both botryoidal (Fig. 4.2D–E) and isopachous apatite cements (Fig. 4.2H). Thus, the apparent thickness of the phosphatic envelope depends on the degree of encrustation and may be significantly different from the thickness of the original organic envelope. In the specimen illustrated in Fig. 4.2, because of the eccentric location of the egg cell and asymmetrical encrustation, its phosphatic envelope is strongly uneven in thickness. Indeed, the phosphatic envelope splits into two parts, creating a cavity between what appear to be layers of phosphatic encrustation (Fig. 4.2A, upper right). Phosphatic encrustation occurs on all surfaces—the inner and outer envelope surfaces, as well as the walls defining the cavity. These apatite crystals are also approximately 0.09–0.85 μm in width (Fig. 4.12). They terminate and increase in size toward the cavity (Fig. 4.2D–E), toward the egg cell (Fig. 4.2F, H), and away from the envelope, indicating that they grew as cavity infillings and surface encrustations.

Similar isopachous and botryoidal encrustation occurs in virtually all Doushantuo animal eggs/embryos (Figs. 4.3–4.5), tubular fossils (Fig. 4.6A–D), and multicellular algae (Fig. 4.7). Apatite crystals are perpendicularly oriented on egg envelope surfaces (Figs. 4.3B, D, H, 4.4B), egg/embryo cell surfaces (Figs. 4.3E, G, 4.4E), filaments (possibly mucus strands, bacterial filaments, or fungal hyphae; Fig. 4.5B, D), the surface of a problematic fossil (Fig. 4.6H), and algal cell walls (Fig. 4.7C).

It appears that botryoidal and isopachous cementation is selective with respect to encrusted substrate. Botryoidal cements tend to occur on egg/embryo cell surfaces or cell interiors. In some Megasphaera specimens, the egg cell was significantly reduced (Fig. 4.3A, C) or strongly degraded beyond recognition (Fig. 4.4G). However, their cell surface, regardless of the degree of degradation, is often completely covered with botryoidal apatite cements. Similar botryoidal cements also occur on the cell surfaces of Parapandorina rhaphospissa (Figs. 4.4A, 4.5A), interpreted as blastula-stage embryos (Xiao and Knoll, 2000). These botryoidal cements are sometimes continuous with phosphatic filaments (Fig. 4.5). The cells of Megaclonophycus onustus, interpreted as possible blastula-stage embryos (Xiao and Knoll, 2000), are also covered with cements (Fig. 4.4C–E), although these are more isopachous than botryoidal. However, in the same specimen, abundant botryoidal cements occur within cells, as revealed by natural fractures of the cells (Fig. 4.4F). Additionally, some botryoidal cements also occur on the inner surfaces of egg envelopes (Fig. 4.2C–E).
In contrast, isopachous cements preferentially occur on egg envelopes, both on the inner and outer surfaces, with perpendicularly oriented crystals growing inward (Fig. 4.3B, D, H) or outward (Fig. 4.4B), respectively. Occasionally a thin veneer of isopachous cement overlies phosphatic substrate consisting of smaller, randomly oriented crystals (Figs. 4.6C, F, 4.9E). Finally, some algal cell walls appear to be phosphatized by poorly oriented, relatively small (sub-micrometric) apatite crystals (Fig. 4.7).

4.5.2. Interpretation
Phosphatic encrustation is interpreted as a relatively late diagenetic process. This is supported by the following observations: (1) it consists of relatively larger (micrometric) crystals and (2) it mantles early diagenetic phosphate that consists of smaller (sub-micrometric) and randomly oriented crystals (Figs. 4.6C, F, 4.9E). It is interesting to note that, with some exceptions, botryoidal cements tend to occur on animal egg/embryo cell surfaces and inner surfaces of egg envelopes, whereas isopachous cements tend to occur on envelopes or mantle early diagenetic phosphate. It is likely these two types of cements represent two generations of cementation that were controlled by nucleation processes (e.g., nucleation on small isolated particles vs. surfaces). We hypothesize that more recalcitrant substrates (e.g., envelope) can maintain their integrity and provide coherent surfaces on which late diagenetic, isopachous cements nucleate and grow. In contrast, more labile substrates (e.g., cytoplasm, cell membranes) were easily degraded into organic particles or macromolecules that served as isolated nucleation sites for the growth of early diagenetic botryoidal cements.

4.6. Tangentially oriented, sub-micrometric, bladed apatite crystals: Phosphatic infilling of intracellular space
4.6.1. Description
Tangentially oriented, sub-micrometer-sized apatite crystals occur in a number of Archaeophycus venustus (=Paratetraphycus giganteus) specimens, interpreted as algal fossils (Zhang et al., 1998). Archaeophycus venustus cells are polyhedral in shape and approximately 10–30 μm in size (Figs. 4.8, 4.9D–H). They are often packed into sarcinoidal clusters. The cells are phosphatized by tangentially oriented, sub-micrometric (<0.20 μm in width, ~0.20–0.55 μm in length; see Fig. 4.12), apatite crystals—many of which with long axes parallel to the cell
surface (Fig. 4.8B, E, H). One polyhedral cell has two of its facets exposed (Fig. 4.8H), and it can be observed from this cell that exposed crystals on both facets are tangentially oriented. Tangentially oriented crystals also occur in the acritarch *Meghystrichosphaeridium reticulatum* (Xiao and Knoll, 1999), whose vesicle surface is defined by sub-micrometric crystals that lie parallel to its vesicle surface (Fig. 4.9A–C). With a mean width of ~0.10 μm (ranging from 0.07–0.15 μm), tangentially oriented crystals are more slender than the perpendicular crystals in botryoidal and isopachous cements (Fig. 4.12). Moreover, they are often bladed and less euhedral than the prismatic crystals in botryoidal and isopachous cements.

4.6.2. Interpretation

Tangentially oriented apatite blades exclusively occur in algal and acritarch fossils, but not in phosphatized animal embryo cells or embryonic envelopes, which are typically characterized by botryoidal and isopachous cements, respectively. The tangential orientation of the crystals indicates that they did not nucleate on cell walls; instead, their orientation seems to be constrained by cell walls. We hypothesize that these tangential crystals grew on floating nuclei within algal cells or acritarch vesicles and were pushed against the cell/vesicle walls, essentially making an internal mold of the cells or vesicles.

It is uncertain why tangentially oriented crystals are not present in animal embryo cells or envelopes. It is possible that nucleation sites within algal cells and acritarch vesicles were abundant, so that randomly nucleated crystals tend to be smaller and their tangential orientation was constrained by the relatively recalcitrant algal cell walls and acritarch vesicle walls. In contrast, the space between animal egg/embryo cells and egg/embryonic envelopes is usually significant (partly because of shrinkage of egg/embryo cells), and nucleation sites may have been relatively rare in this space, thus nucleation was focused on egg/embryo cell surfaces and egg/embryonic envelopes. The ample space between egg/embryo cells and encasing envelopes allowed apatite crystals to grow larger than tangentially oriented crystals.
4.7. Randomly oriented, sub-micrometric, equant apatite crystals: Phosphatic impregnation

4.7.1. Description
Some Doushantuo fossils were preserved through the precipitation of randomly oriented, sub-micrometric, equant apatite crystals. Such sub-micrometric crystals occur on the tube walls of *Sinocyclocyclicus guizhouensis* (Fig. 4.6D), the phosphatic wall of a spherical fossil (Fig. 6G), and cell surfaces of *Archaeophycus venustus* (Fig. 4.9F, H). In all cases, the randomly oriented crystals are subsequently mantled by isopachous cements of larger and perpendicularly oriented apatite crystals. Like the tangentially oriented crystals described above, the randomly oriented crystals are less euhedral and smaller (~0.08–0.30 μm in width, ~0.10–0.35 μm in length; see Fig. 4.12) than the perpendicularly oriented crystals, but they are equant rather than bladed.

4.7.2. Interpretation
Clearly, precipitation of the randomly oriented crystals predates the perpendicularly oriented crystals. Thus, randomly oriented crystals have the greatest potential to replicate the most labile organic structures. We hypothesize that the tube walls and cell walls were impregnated with microcrystals after only minimal degradation. In the impregnation process, crystal orientation and morphology are constrained by available “interstitial” space within the organic structures being impregnated. Of course, subsequent crystal overgrowth after complete degradation of organic structure is likely, so that the “interstitial” space is unlikely to have been faithfully replicated by the sub-micrometric crystals.

4.8. Phosphatic filaments, rods, and granules: Evidence for microbial activities?

4.8.1. Description
Phosphatic filaments, described above (Fig. 4.5), are typically 10–20 μm in diameter and up to 100 μm in length, and often form pillars or networks in the space between shrunken eggs/embryos and envelopes. At closer look, they consist of radially oriented crystals that form botryoidal or isopachous cements. Crystals in the axial region (~0.1 μm in width) are much smaller than in the peripheral region (0.3–2.0 μm in width). Similar phosphatic filaments have been found in Phanerozoic phosphatized biotas (Bengtson, 1976; Conway Morris and Chen, 1992; Ding et al., 1992; Duncan and Briggs, 1996; Duncan et al., 1998; Martill and Wilby, 1994;
Müller and Hinz-Schallreuter, 1993; Yue and Bengtson, 1999). Some of these (e.g., fig. 9D of Yue and Bengtson, 1999) have an axial lumen surrounded by isopachs or botryoids of radially oriented and outward growing crystals. The Doushantuo filaments do not have an axial lumen (Fig. 4.5D); instead, the axial region is characterized by much smaller crystals.

One specimen of the tubular microfossil *Sinocyclocyclicus guizhouensis* (Liu *et al.*, in press) bears rare phosphatic rods (Fig. 4.10A–B). The rods are slightly curved, about 0.2 μm in diameter and up to approximately 1.3 μm in length. Furthermore, these phosphatic rods consist of small granular sub-structures that are approximately 0.05–0.08 μm in size. It is uncertain whether they have a central lumen but they appear to have distally closed ends.

Some (but not all) Doushantuo fossils are covered with a granular texture (Figs. 4.10C–H, 4.11). Such granular texture occurs on the surface of multicellular algae (Fig. 4.10C–D), animal embryo cells (Fig. 4.10F), and egg envelopes (Fig. 4.11A). The texture consists of granules of relatively uniform size, on average about 0.05 μm in width and 0.09 μm in length (range of ~0.03-0.09 μm and ~0.06–0.15 μm, respectively). The granules forms aggregates about 0.30–0.70 μm in length and 0.08–0.15μm in width (Figs. 4.11E–F, 4.12) or cover the surface of individual crystals (Fig. 4.11G–H). The occurrence of such granules on larger euhedral crystals (Fig. 4.11H) indicates that they postdate such euhedral crystals and are likely late diagenetic in origin. But it is uncertain whether the granular aggregates (Fig. 4.10D, 4.11F) and the granules on extremely small crystals (Fig. 4.11C) were also of late diagenetic origin, because they may or may not share the same origin with the granules on large euhedral crystals.

### 4.8.2. Interpretation

We interpret the phosphatic filaments, rods, and granules—in order of decreasing confidence—as possible evidence of microbial activities. The phosphatic filaments are almost identical in morphology to silicified microbial filaments in modern hot-spring environments (Jones *et al.*, 2004; Jones *et al.*, 1997; Renaut *et al.*, 1998). Microbial filaments in modern hot-spring environments are rapidly encased by opal-A microspheres, often leaving an axial lumen (fig. 10M of Jones *et al.*, 1997) similar to those described by Yue and Bengtson (1999, their fig. 9D). Jones *et al.* (2004) also showed that extremely thin mucus strands can serve as nucleation substrates for the nucleation of opal-A microspheres, which upon growth can be coalesced to form siliceous pseudofilaments. These siliceous filaments are plausible modern analogs for the
phosphatic filaments from the Doushantuo Formation. Although Doushantuo filaments do not have a well defined axial lumen, the extremely small apatite crystals in the axial region (as compared with crystals in the peripheral regions) suggest the former presence of an organic or microbial filament, which either escaped from entombment or degraded after being entombed, and the former axial lumen was then filled with diagenetic phosphate. The phylogenetic affinity of the microbial filaments, however, is more difficult to determine. They can be bacterial filaments, fungal hyphae, or simply mucous strands produced by any microbes (Xiao and Knoll, 1999). Bailey et al. (2007) suggested that the filaments may represent symbiotic epibionts, but they can also be interpreted as saprophytic bacteria given that such filaments typically occur on shrunken and degraded cells (Fig. 4.5; Xiao and Knoll, 1999).

Doushantuo phosphatic rods (Fig. 4.10B) can also be interpreted as phosphatized bacteria. Indeed, their morphology and granular texture is very similar to silicified bacterial rods reported in Jones et al. (1997, their fig. 5G), except they are about five times smaller. Their smaller size (about 0.2 μm in diameter and 1.3 μm in length), however, does not preclude a bacterial interpretation (Southam and Donald, 1999).

Doushantuo phosphatic granules (0.09 μm in length and 0.05 μm in width; Fig. 4.11E–H), on the other hand, may approach the size limit of cellular life (Nealson, 1997; Southam and Donald, 1999). Structures of similar size and shape have been interpreted as nanobacterial fossils (Folk, 1999; Folk and Rasbury, 2002), but this interpretation has been met with skepticism because their extremely small size may not be sufficient to house necessary metabolic machineries (Nealson, 1997; Southam and Donald, 1999). A recent report describes granular-textured sheets from Triassic stromatolites (Perri and Tucker, 2007). These granular-textured surfaces in Triassic stromatolites are strikingly similar to those in the Doushantuo Formation (compare Fig. 4.11G–H with figs. 2C, 3B, and 4C in Perri and Tucker, 2007), and a similar origin for both occurrences is plausible. Perri and Tucker (2007) interpreted the Triassic granular-textured sheets as mineralized extracellular polymeric substances (EPS), on the basis of their similarity to the sub-polygonal honeycomb structure of modern EPS. This interpretation may also be applicable to the Doushantuo Formation, but more research is needed to test the possibility that the granular texture in the Doushantuo Formation may be abiotic precipitation formed during acetic acid treatment in the laboratory or, less likely due to their irregular nature, artifacts resulting from excessive Au-Pd coating during sputtering.
4.9. Quantitative evaluation

To quantify the crystal aspect variability, we conducted detailed imaging and statistical analyses on high resolution scanning electron micrographs of the four crystal morphologies described above. For each crystal type, the dimensions of length and width were measured. The raw results are presented in Fig. 4.12A. The figure also shows the length and width of granule aggregates (red color). A total of 1075 randomly chosen crystals (specifically 350 perpendicularly oriented prismatic apatite crystals; 200 tangentially oriented bladed apatite crystals; 125 randomly oriented equant apatite crystals; 325 phosphatic granule aggregates; and 75 granules) were measured on scanning electron micrographs using Adobe Photoshop CS2. The data were analyzed using SAS 9.1 and plotted using DeltaGraph 5.0. Fig. 4.12A illustrates the length–width plots of all four different types of crystal morphology. Fig. 4.12B–C shows less obscured view of the four crystal morphologies—including measurements of granule aggregates.

To estimate the confidence intervals, the data were subject to a naïve bootstrapping analysis (Efron, 1981; Kowalewski et al., 1998), with 1000 iterations (SAS code written by M. Kowalewski and modified by R. Krause). Means and corresponding 95% confidence intervals of the lengths, widths, and aspect ratios for each of the above-described crystal morphologies are presented in Fig. 4.12D–E. The quantitative analysis shows that perpendicularly oriented, prismatic crystals are significantly larger than tangentially oriented, bladed crystals (Fig. 4.12D), although they have similar length:width ratios (Fig. 4.12E). The randomly oriented equant crystals and phosphatic granules are even smaller, and as expected have smaller aspect ratios. Thus, these four crystal morphologies are distinct in both shape and size. And the distinction of these crystal morphologies may aid in understanding factors affecting nucleation and growth of crystals in varying regions of multiple fossil taxa during the phosphatization process.

4.10 Summary

To summarize, we recognize several different phosphatic textures, probably indicating different phosphatization processes responsible for the preservation of Doushantuo microfossils. Phosphatic encrustation by micrometric, perpendicularly oriented crystals is most pervasive in the Doushantuo Formation. It occurs as botryoidal and isopachous cements on a variety of substrates, including animal egg/embryo cell surfaces, egg/embryonic envelopes, algal cell walls, organic filaments, as well as secondary coatings on pre-existing phosphatic surfaces. Phosphatic
infilling of intracellular space by sub-micrometric, tangentially oriented crystals was probably driven by abundant random nucleation within algal cells or acritarch vesicles. These random crystals probably became tangentially oriented when pushed against the relatively recalcitrant algal cell walls and acritarch vesicle walls. In essence, the cells and acritarchs were molded by crystals growing inside. Tangentially aligned crystals do not occur in animal cells perhaps because animal cell membranes were more labile and would be deflated and degraded before cell lumens were completely phosphatized. Phosphatic impregnation by sub-micrometric, randomly oriented crystals occurred when nucleation was initiated within organic substrates (such as more recalcitrant tube walls and cell walls) after only minimal degradation. Finally, there is tentative evidence for bacterial (or nanobacterial) activities preserved in the Doushantuo microfossils. At the present, the exact taphonomic roles of these bacterial activities are still uncertain.

Our analysis shows that the preservational quality and taphonomic resolution of phosphatic impregnation and intracellular infilling is much better than phosphatic encrustation. This is because the former processes tend to preserve more recalcitrant structures, during earlier diagenesis, after less degradation, by smaller crystals. Thus, analysis of Doushantuo microfossils suggests that the recalcitrance, degree of degradation, and crystal size all play a significant, controlling role in phosphatization of soft-bodied microorganisms (Briggs, 2003).

4.11. Relevance to astrobiology

As discussed in the opening section, any extraterrestrial ecosystems likely started with a biosphere dominated by soft-bodied microorganisms. Additionally, from a practical point of view, the amount of extraterrestrial samples available for astropaleobiological investigation is likely small (even if a Mars sample return mission is conceivable in the near future). Thus, the astropaleobiological focus has been and must continue to be on microscopic fossils, and the Precambrian biosphere is the most suitable analog for such investigation. Among all of the taphonomic pathways discussed in the introduction section, Bitter Spring-type (silicification) and Doushantuo/Orsten-type preservation (phosphatization) hold the greatest potential in astropaleobiological investigation. Beecher’s trilobite-type preservation (pyritization) has poor resolution because of the large size of pyrite crystals and its intrinsic dependence on organic degradation and destruction as a source of sulfide. Burgess Shale-type preservation and Ediacara-type preservation tend to preserve macroscopic organisms. In addition, the two-
dimensional compression in Burgess Shale-type preservation also decreases its taphonomic fidelity, and instability of organic carbon in many strongly oxidative extraterrestrial environments also makes Burgess Shale-type preservation less relevant. Thus, in the search for ancient extraterrestrial ecosystems, we need to follow the silica and phosphate. Detailed investigation of silicified and phosphatized biotas preserved in ancient rocks on the Earth, together with an experimental approach to better understand of the molecular and geochemical processes of silicification and phosphatization (Martin et al., 2003; Raff et al., 2006), will certainly help us to more effectively choose astrobiological landing/sampling sites.

4.12. Acknowledgments
We would like to acknowledge the NASA Exobiology Program, NSF Sedimentary Geology and Paleobiology Program, Petroleum Research Fund, National Natural Science Foundation of China, and Chinese Ministry of Science and Technology for support. We thank Stefan Bengtson, Phil Donoghue, James W. Hagadorn, John W. Huntley, Michał Kowalewski, Richard A. Krause, Xunlai Yuan, and Chuanming Zhou for discussion. Steve Dornbos and an anonymous reviewer provided constructive comments on an earlier version of this contribution.
4.13. Figures and Figure Captions

Figure 4.1. Schematic summary of preservation resolution, temporal distribution, and environmental distribution of various taphonomic pathways (Butterfield, 2003).
Figure 4.2. Caption on following page.
Figure 4.2. Phosphatic encrustation on *Megasphaera inornata*. (A) Eccentric egg cell and phosphatic envelope with uneven thickness. Boxed areas magnified in (B, D, and F). (B) Botryoidal cements on cell surface and in space between cell and envelope. (C) Magnification of (B) showing crystal terminations (lower right) and inward growing crystals (upper left). (D–E) Botryoids with inward growing crystals. Arrowed area in (D) magnified in (E). (F–H) Isopachs with inward growing crystals (H) and randomly oriented prismatic crystals (G). Arrowed areas in (F) magnified in (G) and (H).
Figure 4.3. Phosphatic encrustation on *Megasphaera inornata* (A–E) and *Parapandorina rhaphospissa* (F–H). (B, D, and H) are magnified views of boxed areas in (A, C, and F), showing isopachous cements with inward growing crystals on inner surface of envelope. (E and G) are magnified views of cell surface in (C and F), showing distal views of hexagonal crystal terminations.
Figure 4.4. Caption on following page.
Figure 4.4. Phosphatic encrustation on Parapandorina rhaphospissa (A–B), Megaclonophycus onustus (C–F), and a strongly degraded spheroidal fossil (G–H). (B and D) are magnified views of boxed areas in (A and C), showing isopachous cements on both inner and outer surfaces of envelope/membrane, with crystals growing centrifugally from the original organic envelope that may be represented only by the gap between centrifugally growing cements. (D) is further magnified in (E and F), showing botryoidal cements within cells as well as isopachous cements on membrane. (H) is magnified view of (G), showing crystal terminations and botryoidal cements on strongly degraded cellular content.
Figure 4.5. Phosphatic encrustation on organic filaments (mucous strands, bacterial filaments, or fungal hyphae). (B and D) are magnified views of (A and B), showing external and cross section views of phosphatic filaments. Crystals are oriented radially and coarsen centrifugally.
Figure 4.6. Caption on following page.
Figure 4.6. Phosphatic encrustation on a tubular microfossil (possibly *Sinocyclocyclicus guizhouensis*; A–D) and a problematic microfossil (E–H). (B, C, D) are successively magnified views of (A), showing phosphatic encrustation (with perpendicularly oriented crystals) overlying small randomly oriented crystals (D), interpreted as phosphatic impregnation of organic tube walls. (F, G, and H) are successively magnified views of (E), showing phosphatic encrustation (H, distal view) mantling small randomly oriented crystals (G).
Figure 4.7. Phosphatization of algal cell walls. (B and C) are successively magnified views of (A), showing fractured algal thallus with cellular preservation. Small apatite crystals nucleated on cell walls. (E and F) are successively magnified views of (D), showing poorly organized crystals on cell walls.
Figure 4.8. Phosphatic infilling of *Archaeophycus venustus* cells. (B) is magnified view of (A), (D and E) are successive magnifications of (C), and (G and H) are magnified views of (F), showing tangentially oriented crystals.
Figure 4.9. Phosphatic infilling in *Meghystrichosphaeridium reticulatum* vesicle (A–C), and phosphatic encrustation (E, white arrow) and impregnation (F, H) of *Archaeophycus venustus* (D–H). (B and C) are successive magnifications of (A), showing tangentially oriented crystals. (E and F) are successive magnifications of (D), and (H) is magnified view of (G), showing randomly oriented sub-micrometric crystals.
Figure 4.10. Phosphatic rods (B, arrow) and granules (D–E, G–H) on a tubular microfossil (possibly *Sinocyclocyclicus guizhouensis*, A–B), an unidentified algal fossil (C–E), and animal embryo *Parapandorina rhaphospissa* (F–H). (B) is magnified view of (A), (D and E) magnified views of (C), and (G and H) magnified views of (F). Note granular texture in (D–E, G–H).
Figure 4.11. Granules on animal egg/embryo fossil *Megasphaera ornata* (A–C) and an algal fossil (possibly *Paramecia incognata*, D–H). (B and C) are successive magnifications of (A). (E and G) are magnifications of (D), and are further magnified in (F and H), respectively. Granular texture best seen in (F and H).
Figure 4.12. Crystal aspect variation by morphology. (A) Length–width plot of four crystal morphologies. Examples of crystal morphologies with marked dimensions and color coding are shown to the right in figure key. (B) Length–width plot of perpendicular prismatic apatite crystals. (C) Length–width plot of comparatively smaller crystal morphologies (tangential blades, random equant crystals, granule aggregates, and granules). (D) Bootstrapped mean crystal length versus mean crystal width, with 95% confidence intervals. (E) Bootstrapped length:width ratio with 95% confidence intervals.
4.14. References


Knoll, A.H., 2003, Biomineralization and evolutionary history: Reviews in Mineralogy and Geochemistry, v. 54, p. 329-356.


### 4.15 Appendix C

**Table C1.** Crystal aspect variation by morphology.

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Image file #</th>
<th>Crystal # on image</th>
<th>Scale true length (µm)</th>
<th>Image scale length (pix)</th>
<th>Image crystal length (pix)</th>
<th>Image crystal width (pix)</th>
<th>Crystal true length (µm)</th>
<th>Crystal true width (µm)</th>
<th>L:W ratio</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>648</td>
<td>1</td>
<td>136.2</td>
<td>27.4</td>
<td>6.6</td>
<td>1.00587</td>
<td>0.24229</td>
<td>4.15152</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>648</td>
<td>2</td>
<td>136.2</td>
<td>16.3</td>
<td>5.0</td>
<td>0.59838</td>
<td>0.18355</td>
<td>3.26000</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>648</td>
<td>3</td>
<td>136.2</td>
<td>24.4</td>
<td>9.4</td>
<td>0.89574</td>
<td>0.34508</td>
<td>2.59574</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>648</td>
<td>4</td>
<td>136.2</td>
<td>13.2</td>
<td>4.3</td>
<td>0.48458</td>
<td>0.15786</td>
<td>3.06977</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>648</td>
<td>5</td>
<td>136.2</td>
<td>18.9</td>
<td>7.3</td>
<td>0.69383</td>
<td>0.26799</td>
<td>2.58904</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>648</td>
<td>6</td>
<td>136.2</td>
<td>18.2</td>
<td>7.9</td>
<td>0.66814</td>
<td>0.29001</td>
<td>2.30380</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>648</td>
<td>7</td>
<td>136.2</td>
<td>20.6</td>
<td>5.6</td>
<td>0.75624</td>
<td>0.20558</td>
<td>3.67857</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>648</td>
<td>8</td>
<td>136.2</td>
<td>22.6</td>
<td>8.4</td>
<td>0.82966</td>
<td>0.30837</td>
<td>2.69048</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>648</td>
<td>9</td>
<td>136.2</td>
<td>22.4</td>
<td>5.8</td>
<td>0.82232</td>
<td>0.21292</td>
<td>3.86207</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>648</td>
<td>10</td>
<td>136.2</td>
<td>22.4</td>
<td>8.7</td>
<td>0.82232</td>
<td>0.31938</td>
<td>2.57471</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>648</td>
<td>11</td>
<td>136.2</td>
<td>19.5</td>
<td>4.4</td>
<td>0.71586</td>
<td>0.16153</td>
<td>4.43182</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>648</td>
<td>12</td>
<td>136.2</td>
<td>15.8</td>
<td>5.2</td>
<td>0.58003</td>
<td>0.19090</td>
<td>3.03846</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>648</td>
<td>13</td>
<td>136.2</td>
<td>18.8</td>
<td>5.5</td>
<td>0.69016</td>
<td>0.20191</td>
<td>3.41818</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>648</td>
<td>14</td>
<td>136.2</td>
<td>23.0</td>
<td>5.3</td>
<td>0.84435</td>
<td>0.19457</td>
<td>4.33962</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>648</td>
<td>15</td>
<td>136.2</td>
<td>33.2</td>
<td>12.3</td>
<td>1.21880</td>
<td>0.45154</td>
<td>2.69919</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>648</td>
<td>16</td>
<td>136.2</td>
<td>23.8</td>
<td>7.4</td>
<td>0.87372</td>
<td>0.27166</td>
<td>3.21622</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>648</td>
<td>17</td>
<td>136.2</td>
<td>21.4</td>
<td>6.0</td>
<td>0.78561</td>
<td>0.22026</td>
<td>3.56667</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>648</td>
<td>18</td>
<td>136.2</td>
<td>31.4</td>
<td>7.2</td>
<td>1.15272</td>
<td>0.26432</td>
<td>4.36111</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>648</td>
<td>19</td>
<td>136.2</td>
<td>17.1</td>
<td>7.3</td>
<td>0.62775</td>
<td>0.26799</td>
<td>2.34247</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>648</td>
<td>20</td>
<td>136.2</td>
<td>11.4</td>
<td>5.4</td>
<td>0.41850</td>
<td>0.19824</td>
<td>2.11111</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>648</td>
<td>21</td>
<td>136.2</td>
<td>27.8</td>
<td>8.2</td>
<td>1.02056</td>
<td>0.30103</td>
<td>3.39024</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>648</td>
<td>22</td>
<td>136.2</td>
<td>15.7</td>
<td>6.0</td>
<td>0.57636</td>
<td>0.22026</td>
<td>2.61667</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>648</td>
<td>23</td>
<td>136.2</td>
<td>18.6</td>
<td>7.6</td>
<td>0.68282</td>
<td>0.27900</td>
<td>2.44737</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>648</td>
<td>24</td>
<td>136.2</td>
<td>21.7</td>
<td>9.6</td>
<td>0.79662</td>
<td>0.35242</td>
<td>2.26042</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>648</td>
<td>25</td>
<td>136.2</td>
<td>19.8</td>
<td>7.9</td>
<td>0.72687</td>
<td>0.29001</td>
<td>2.50633</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>669</td>
<td>1</td>
<td>136.2</td>
<td>15.5</td>
<td>3.7</td>
<td>0.56902</td>
<td>0.13583</td>
<td>4.18919</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>669</td>
<td>2</td>
<td>136.2</td>
<td>19.3</td>
<td>4.5</td>
<td>0.70852</td>
<td>0.16520</td>
<td>4.28899</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>669</td>
<td>3</td>
<td>136.2</td>
<td>15.8</td>
<td>4.1</td>
<td>0.58003</td>
<td>0.15051</td>
<td>3.85366</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>669</td>
<td>4</td>
<td>136.2</td>
<td>14.6</td>
<td>3.9</td>
<td>0.53598</td>
<td>0.14317</td>
<td>3.74359</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>669</td>
<td>5</td>
<td>136.2</td>
<td>14.2</td>
<td>3.5</td>
<td>0.52129</td>
<td>0.12849</td>
<td>4.05714</td>
<td>perpendicular prismatic</td>
<td></td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
<td>L:W ratio</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>-------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>---------------------------</td>
<td>--------------------------</td>
<td>-------------------------</td>
<td>-------------------------</td>
<td>-----------</td>
<td>----------</td>
</tr>
<tr>
<td>31</td>
<td>669</td>
<td>6</td>
<td>5</td>
<td>136.2</td>
<td>22.1</td>
<td>4.0</td>
<td>0.81131</td>
<td>0.14684</td>
<td>5.52500</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>32</td>
<td>669</td>
<td>7</td>
<td>5</td>
<td>136.2</td>
<td>21.4</td>
<td>3.8</td>
<td>0.78561</td>
<td>0.13950</td>
<td>5.63158</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>33</td>
<td>669</td>
<td>8</td>
<td>5</td>
<td>136.2</td>
<td>14.0</td>
<td>4.7</td>
<td>0.51395</td>
<td>0.17254</td>
<td>2.97872</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>34</td>
<td>669</td>
<td>9</td>
<td>5</td>
<td>136.2</td>
<td>16.7</td>
<td>4.8</td>
<td>0.61307</td>
<td>0.17621</td>
<td>3.47917</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>35</td>
<td>669</td>
<td>10</td>
<td>5</td>
<td>136.2</td>
<td>16.5</td>
<td>6.7</td>
<td>0.60573</td>
<td>0.24596</td>
<td>2.46269</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>36</td>
<td>669</td>
<td>11</td>
<td>5</td>
<td>136.2</td>
<td>12.6</td>
<td>2.5</td>
<td>0.46256</td>
<td>0.09178</td>
<td>5.04000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>37</td>
<td>669</td>
<td>12</td>
<td>5</td>
<td>136.2</td>
<td>21.2</td>
<td>5.5</td>
<td>0.77827</td>
<td>0.20191</td>
<td>3.85455</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>38</td>
<td>669</td>
<td>13</td>
<td>5</td>
<td>136.2</td>
<td>20.6</td>
<td>5.9</td>
<td>0.75624</td>
<td>0.21659</td>
<td>3.49153</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>39</td>
<td>669</td>
<td>14</td>
<td>5</td>
<td>136.2</td>
<td>23.0</td>
<td>8.4</td>
<td>0.84435</td>
<td>0.30837</td>
<td>2.73810</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>40</td>
<td>669</td>
<td>15</td>
<td>5</td>
<td>136.2</td>
<td>17.0</td>
<td>6.4</td>
<td>0.62408</td>
<td>0.23495</td>
<td>2.65625</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>41</td>
<td>669</td>
<td>16</td>
<td>5</td>
<td>136.2</td>
<td>18.0</td>
<td>4.3</td>
<td>0.66079</td>
<td>0.15786</td>
<td>4.18605</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>42</td>
<td>669</td>
<td>17</td>
<td>5</td>
<td>136.2</td>
<td>12.2</td>
<td>5.0</td>
<td>0.44787</td>
<td>0.18355</td>
<td>2.44000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>43</td>
<td>669</td>
<td>18</td>
<td>5</td>
<td>136.2</td>
<td>17.2</td>
<td>3.3</td>
<td>0.63142</td>
<td>0.12115</td>
<td>5.21212</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>44</td>
<td>669</td>
<td>19</td>
<td>5</td>
<td>136.2</td>
<td>12.5</td>
<td>3.9</td>
<td>0.45888</td>
<td>0.14317</td>
<td>3.20513</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>45</td>
<td>669</td>
<td>20</td>
<td>5</td>
<td>136.2</td>
<td>12.6</td>
<td>3.2</td>
<td>0.46256</td>
<td>0.11747</td>
<td>3.93750</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>46</td>
<td>669</td>
<td>21</td>
<td>5</td>
<td>136.2</td>
<td>20.5</td>
<td>5.2</td>
<td>0.75257</td>
<td>0.19090</td>
<td>3.94231</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>47</td>
<td>669</td>
<td>22</td>
<td>5</td>
<td>136.2</td>
<td>11.9</td>
<td>4.6</td>
<td>0.43686</td>
<td>0.16887</td>
<td>2.58696</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>48</td>
<td>669</td>
<td>23</td>
<td>5</td>
<td>136.2</td>
<td>20.6</td>
<td>7.3</td>
<td>0.75624</td>
<td>0.26799</td>
<td>2.82192</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>49</td>
<td>669</td>
<td>24</td>
<td>5</td>
<td>136.2</td>
<td>15.9</td>
<td>7.0</td>
<td>0.58370</td>
<td>0.25698</td>
<td>2.27143</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>50</td>
<td>669</td>
<td>25</td>
<td>5</td>
<td>136.2</td>
<td>24.7</td>
<td>10.6</td>
<td>0.90675</td>
<td>0.38913</td>
<td>2.33019</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>51</td>
<td>789</td>
<td>1</td>
<td>5</td>
<td>34.4</td>
<td>6.7</td>
<td>1.8</td>
<td>0.97384</td>
<td>0.26163</td>
<td>3.72222</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>52</td>
<td>789</td>
<td>2</td>
<td>5</td>
<td>34.4</td>
<td>5.2</td>
<td>2.5</td>
<td>0.75581</td>
<td>0.36337</td>
<td>2.08000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>53</td>
<td>789</td>
<td>3</td>
<td>5</td>
<td>34.4</td>
<td>6.9</td>
<td>1.7</td>
<td>1.00291</td>
<td>0.24709</td>
<td>4.05882</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>54</td>
<td>789</td>
<td>4</td>
<td>5</td>
<td>34.4</td>
<td>6.5</td>
<td>2.0</td>
<td>0.94477</td>
<td>0.29070</td>
<td>3.25000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>55</td>
<td>789</td>
<td>5</td>
<td>5</td>
<td>34.4</td>
<td>7.2</td>
<td>1.9</td>
<td>1.04651</td>
<td>0.27616</td>
<td>3.78947</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>56</td>
<td>789</td>
<td>6</td>
<td>5</td>
<td>34.4</td>
<td>8.2</td>
<td>2.1</td>
<td>1.19186</td>
<td>0.30523</td>
<td>3.90476</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>57</td>
<td>789</td>
<td>7</td>
<td>5</td>
<td>34.4</td>
<td>4.5</td>
<td>2.2</td>
<td>0.65407</td>
<td>0.31977</td>
<td>2.04545</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>58</td>
<td>789</td>
<td>8</td>
<td>5</td>
<td>34.4</td>
<td>5.6</td>
<td>1.9</td>
<td>0.81395</td>
<td>0.27616</td>
<td>2.94737</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>59</td>
<td>789</td>
<td>9</td>
<td>5</td>
<td>34.4</td>
<td>7.2</td>
<td>2.5</td>
<td>1.04651</td>
<td>0.36337</td>
<td>2.88000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>60</td>
<td>789</td>
<td>10</td>
<td>5</td>
<td>34.4</td>
<td>4.4</td>
<td>2.2</td>
<td>0.63953</td>
<td>0.31977</td>
<td>2.00000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>61</td>
<td>789</td>
<td>11</td>
<td>5</td>
<td>34.4</td>
<td>5.3</td>
<td>1.9</td>
<td>0.77035</td>
<td>0.27616</td>
<td>2.78947</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>62</td>
<td>789</td>
<td>12</td>
<td>5</td>
<td>34.4</td>
<td>4.7</td>
<td>1.7</td>
<td>0.68314</td>
<td>0.24709</td>
<td>2.76471</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>63</td>
<td>789</td>
<td>13</td>
<td>5</td>
<td>34.4</td>
<td>8.4</td>
<td>2.7</td>
<td>1.22093</td>
<td>0.39244</td>
<td>3.11111</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>64</td>
<td>789</td>
<td>14</td>
<td>5</td>
<td>34.4</td>
<td>4.8</td>
<td>1.4</td>
<td>0.69767</td>
<td>0.20349</td>
<td>3.42857</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
<td>L/W ratio</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>-------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>---------------------------</td>
<td>-------------------------</td>
<td>-------------------------</td>
<td>-------------------------</td>
<td>-----------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>65</td>
<td>789</td>
<td>15</td>
<td>5</td>
<td>34.4</td>
<td>4.8</td>
<td>1.5</td>
<td>0.69767</td>
<td>0.21802</td>
<td>3.20000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>66</td>
<td>789</td>
<td>16</td>
<td>5</td>
<td>34.4</td>
<td>3.2</td>
<td>1.7</td>
<td>0.46512</td>
<td>0.24709</td>
<td>1.88235</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>67</td>
<td>789</td>
<td>17</td>
<td>5</td>
<td>34.4</td>
<td>3.9</td>
<td>1.5</td>
<td>0.56686</td>
<td>0.21802</td>
<td>2.60000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>68</td>
<td>789</td>
<td>18</td>
<td>5</td>
<td>34.4</td>
<td>6.3</td>
<td>2.1</td>
<td>0.91570</td>
<td>0.30523</td>
<td>3.00000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>69</td>
<td>789</td>
<td>19</td>
<td>5</td>
<td>34.4</td>
<td>5.0</td>
<td>2.0</td>
<td>0.72674</td>
<td>0.29070</td>
<td>2.50000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>70</td>
<td>789</td>
<td>20</td>
<td>5</td>
<td>34.4</td>
<td>7.7</td>
<td>3.1</td>
<td>1.11919</td>
<td>0.45058</td>
<td>2.48387</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>71</td>
<td>789</td>
<td>21</td>
<td>5</td>
<td>34.4</td>
<td>4.8</td>
<td>1.7</td>
<td>0.69767</td>
<td>0.24709</td>
<td>2.82353</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>72</td>
<td>789</td>
<td>22</td>
<td>5</td>
<td>34.4</td>
<td>5.2</td>
<td>2.3</td>
<td>0.75581</td>
<td>0.33430</td>
<td>2.26087</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>73</td>
<td>789</td>
<td>23</td>
<td>5</td>
<td>34.4</td>
<td>5.9</td>
<td>1.7</td>
<td>0.85756</td>
<td>0.24709</td>
<td>3.47059</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>74</td>
<td>789</td>
<td>24</td>
<td>5</td>
<td>34.4</td>
<td>4.3</td>
<td>1.8</td>
<td>0.62500</td>
<td>0.26163</td>
<td>2.38889</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>75</td>
<td>789</td>
<td>25</td>
<td>5</td>
<td>34.4</td>
<td>5.8</td>
<td>2.1</td>
<td>0.84302</td>
<td>0.30523</td>
<td>2.76190</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>76</td>
<td>791</td>
<td>1</td>
<td>5</td>
<td>34.4</td>
<td>10.0</td>
<td>3.0</td>
<td>1.45349</td>
<td>0.43605</td>
<td>3.33333</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>77</td>
<td>791</td>
<td>2</td>
<td>5</td>
<td>34.4</td>
<td>8.1</td>
<td>3.0</td>
<td>1.17733</td>
<td>0.43605</td>
<td>2.70000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>78</td>
<td>791</td>
<td>3</td>
<td>5</td>
<td>34.4</td>
<td>10.3</td>
<td>3.0</td>
<td>1.49709</td>
<td>0.43605</td>
<td>3.43333</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>79</td>
<td>791</td>
<td>4</td>
<td>5</td>
<td>34.4</td>
<td>10.9</td>
<td>3.2</td>
<td>1.58430</td>
<td>0.46512</td>
<td>3.40625</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>80</td>
<td>791</td>
<td>5</td>
<td>5</td>
<td>34.4</td>
<td>8.0</td>
<td>3.4</td>
<td>1.16279</td>
<td>0.49419</td>
<td>2.35294</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>81</td>
<td>791</td>
<td>6</td>
<td>5</td>
<td>34.4</td>
<td>11.4</td>
<td>4.0</td>
<td>1.65698</td>
<td>0.58140</td>
<td>2.85000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>82</td>
<td>791</td>
<td>7</td>
<td>5</td>
<td>34.4</td>
<td>8.5</td>
<td>3.0</td>
<td>1.23547</td>
<td>0.43605</td>
<td>2.83333</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>83</td>
<td>791</td>
<td>8</td>
<td>5</td>
<td>34.4</td>
<td>8.1</td>
<td>3.2</td>
<td>1.17733</td>
<td>0.46512</td>
<td>2.53125</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>84</td>
<td>791</td>
<td>9</td>
<td>5</td>
<td>34.4</td>
<td>9.7</td>
<td>2.8</td>
<td>1.40988</td>
<td>0.40698</td>
<td>3.46429</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>85</td>
<td>791</td>
<td>10</td>
<td>5</td>
<td>34.4</td>
<td>7.2</td>
<td>1.6</td>
<td>1.04651</td>
<td>0.23256</td>
<td>4.50000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>86</td>
<td>791</td>
<td>11</td>
<td>5</td>
<td>34.4</td>
<td>6.3</td>
<td>2.0</td>
<td>0.91570</td>
<td>0.29070</td>
<td>3.15000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>87</td>
<td>791</td>
<td>12</td>
<td>5</td>
<td>34.4</td>
<td>6.6</td>
<td>1.8</td>
<td>0.95930</td>
<td>0.26163</td>
<td>3.66667</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>88</td>
<td>791</td>
<td>13</td>
<td>5</td>
<td>34.4</td>
<td>6.4</td>
<td>1.7</td>
<td>0.93023</td>
<td>0.24709</td>
<td>3.76471</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>89</td>
<td>791</td>
<td>14</td>
<td>5</td>
<td>34.4</td>
<td>5.3</td>
<td>1.8</td>
<td>0.77035</td>
<td>0.26163</td>
<td>2.94444</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>90</td>
<td>791</td>
<td>15</td>
<td>5</td>
<td>34.4</td>
<td>7.3</td>
<td>1.9</td>
<td>1.06105</td>
<td>0.27616</td>
<td>3.84211</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>91</td>
<td>791</td>
<td>16</td>
<td>5</td>
<td>34.4</td>
<td>7.5</td>
<td>2.2</td>
<td>1.09012</td>
<td>0.31977</td>
<td>3.40909</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>92</td>
<td>791</td>
<td>17</td>
<td>5</td>
<td>34.4</td>
<td>5.6</td>
<td>2.3</td>
<td>0.81395</td>
<td>0.33430</td>
<td>2.43478</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>93</td>
<td>791</td>
<td>18</td>
<td>5</td>
<td>34.4</td>
<td>5.9</td>
<td>2.0</td>
<td>0.85756</td>
<td>0.29070</td>
<td>2.95000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>94</td>
<td>791</td>
<td>19</td>
<td>5</td>
<td>34.4</td>
<td>6.5</td>
<td>1.6</td>
<td>0.94477</td>
<td>0.23256</td>
<td>4.06250</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>95</td>
<td>791</td>
<td>20</td>
<td>5</td>
<td>34.4</td>
<td>8.4</td>
<td>1.8</td>
<td>1.22093</td>
<td>0.26163</td>
<td>4.66667</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>96</td>
<td>791</td>
<td>21</td>
<td>5</td>
<td>34.4</td>
<td>7.4</td>
<td>1.7</td>
<td>1.07558</td>
<td>0.24709</td>
<td>4.35294</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>97</td>
<td>791</td>
<td>22</td>
<td>5</td>
<td>34.4</td>
<td>10.2</td>
<td>3.0</td>
<td>1.48256</td>
<td>0.43605</td>
<td>3.40000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>98</td>
<td>791</td>
<td>23</td>
<td>5</td>
<td>34.4</td>
<td>7.2</td>
<td>2.8</td>
<td>1.04651</td>
<td>0.40698</td>
<td>2.57143</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
<td>L:W ratio</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>--------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>---------------------------</td>
<td>---------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>-----------</td>
<td>------------------------</td>
</tr>
<tr>
<td>99</td>
<td>791</td>
<td>24</td>
<td>5</td>
<td>34.4</td>
<td>7.3</td>
<td>2.4</td>
<td>1.06105</td>
<td>0.34884</td>
<td>3.04167</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>100</td>
<td>791</td>
<td>25</td>
<td>5</td>
<td>34.4</td>
<td>7.3</td>
<td>2.6</td>
<td>1.06105</td>
<td>0.37791</td>
<td>2.80769</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>101</td>
<td>793</td>
<td>1</td>
<td>10</td>
<td>41.0</td>
<td>6.9</td>
<td>1.5</td>
<td>1.68293</td>
<td>0.36585</td>
<td>4.60000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>102</td>
<td>793</td>
<td>2</td>
<td>10</td>
<td>41.0</td>
<td>7.0</td>
<td>2.2</td>
<td>1.70732</td>
<td>0.53659</td>
<td>3.18182</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>103</td>
<td>793</td>
<td>3</td>
<td>10</td>
<td>41.0</td>
<td>6.1</td>
<td>1.4</td>
<td>1.48780</td>
<td>0.34146</td>
<td>4.55714</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>104</td>
<td>793</td>
<td>4</td>
<td>10</td>
<td>41.0</td>
<td>5.1</td>
<td>1.4</td>
<td>1.24390</td>
<td>0.34146</td>
<td>3.64286</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>105</td>
<td>793</td>
<td>5</td>
<td>10</td>
<td>41.0</td>
<td>5.2</td>
<td>1.3</td>
<td>1.26289</td>
<td>0.31707</td>
<td>4.00000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>106</td>
<td>793</td>
<td>6</td>
<td>10</td>
<td>41.0</td>
<td>5.9</td>
<td>1.6</td>
<td>1.43902</td>
<td>0.39024</td>
<td>3.68750</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>107</td>
<td>793</td>
<td>7</td>
<td>10</td>
<td>41.0</td>
<td>6.9</td>
<td>1.8</td>
<td>1.68293</td>
<td>0.43902</td>
<td>3.83333</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>108</td>
<td>793</td>
<td>8</td>
<td>10</td>
<td>41.0</td>
<td>7.2</td>
<td>1.9</td>
<td>1.75610</td>
<td>0.46341</td>
<td>3.78947</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>109</td>
<td>793</td>
<td>9</td>
<td>10</td>
<td>41.0</td>
<td>6.3</td>
<td>1.4</td>
<td>1.53659</td>
<td>0.34146</td>
<td>4.50000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>110</td>
<td>793</td>
<td>10</td>
<td>10</td>
<td>41.0</td>
<td>5.7</td>
<td>1.6</td>
<td>1.39024</td>
<td>0.39024</td>
<td>3.56250</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>111</td>
<td>793</td>
<td>11</td>
<td>10</td>
<td>41.0</td>
<td>5.0</td>
<td>1.2</td>
<td>1.21951</td>
<td>0.29268</td>
<td>4.16667</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>112</td>
<td>793</td>
<td>12</td>
<td>10</td>
<td>41.0</td>
<td>4.6</td>
<td>1.2</td>
<td>1.12195</td>
<td>0.29268</td>
<td>3.83333</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>113</td>
<td>793</td>
<td>13</td>
<td>10</td>
<td>41.0</td>
<td>4.8</td>
<td>1.3</td>
<td>1.17073</td>
<td>0.31707</td>
<td>3.69231</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>114</td>
<td>793</td>
<td>14</td>
<td>10</td>
<td>41.0</td>
<td>5.0</td>
<td>1.7</td>
<td>1.21951</td>
<td>0.41463</td>
<td>2.94118</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>115</td>
<td>793</td>
<td>15</td>
<td>10</td>
<td>41.0</td>
<td>5.7</td>
<td>1.6</td>
<td>1.39024</td>
<td>0.39024</td>
<td>3.56250</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>116</td>
<td>793</td>
<td>16</td>
<td>10</td>
<td>41.0</td>
<td>4.9</td>
<td>1.4</td>
<td>1.19512</td>
<td>0.34146</td>
<td>3.50000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>117</td>
<td>793</td>
<td>17</td>
<td>10</td>
<td>41.0</td>
<td>5.1</td>
<td>2.0</td>
<td>1.24390</td>
<td>0.48780</td>
<td>2.55000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>118</td>
<td>793</td>
<td>18</td>
<td>10</td>
<td>41.0</td>
<td>5.7</td>
<td>1.8</td>
<td>1.39024</td>
<td>0.43902</td>
<td>3.16667</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>119</td>
<td>793</td>
<td>19</td>
<td>10</td>
<td>41.0</td>
<td>5.1</td>
<td>1.5</td>
<td>1.24390</td>
<td>0.36585</td>
<td>3.40000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>120</td>
<td>793</td>
<td>20</td>
<td>10</td>
<td>41.0</td>
<td>5.4</td>
<td>1.8</td>
<td>1.31707</td>
<td>0.43902</td>
<td>3.00000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>121</td>
<td>793</td>
<td>21</td>
<td>10</td>
<td>41.0</td>
<td>4.7</td>
<td>1.2</td>
<td>1.14634</td>
<td>0.29268</td>
<td>3.91667</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>122</td>
<td>793</td>
<td>22</td>
<td>10</td>
<td>41.0</td>
<td>6.7</td>
<td>2.1</td>
<td>1.63415</td>
<td>0.51220</td>
<td>3.19048</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>123</td>
<td>793</td>
<td>23</td>
<td>10</td>
<td>41.0</td>
<td>3.9</td>
<td>1.2</td>
<td>0.95122</td>
<td>0.29268</td>
<td>3.25000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>124</td>
<td>793</td>
<td>24</td>
<td>10</td>
<td>41.0</td>
<td>5.6</td>
<td>1.7</td>
<td>1.36585</td>
<td>0.41463</td>
<td>3.29412</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>125</td>
<td>793</td>
<td>25</td>
<td>10</td>
<td>41.0</td>
<td>5.7</td>
<td>2.1</td>
<td>1.39024</td>
<td>0.51220</td>
<td>2.71429</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>126</td>
<td>796</td>
<td>1</td>
<td>5</td>
<td>34.4</td>
<td>8.9</td>
<td>2.3</td>
<td>1.29360</td>
<td>0.33430</td>
<td>3.86957</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>127</td>
<td>796</td>
<td>2</td>
<td>5</td>
<td>34.4</td>
<td>8.7</td>
<td>2.6</td>
<td>1.26453</td>
<td>0.37791</td>
<td>3.34615</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>128</td>
<td>796</td>
<td>3</td>
<td>5</td>
<td>34.4</td>
<td>7.8</td>
<td>2.2</td>
<td>1.13372</td>
<td>0.31977</td>
<td>3.54545</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>129</td>
<td>796</td>
<td>4</td>
<td>5</td>
<td>34.4</td>
<td>6.7</td>
<td>2.1</td>
<td>0.97384</td>
<td>0.30523</td>
<td>3.19048</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>130</td>
<td>796</td>
<td>5</td>
<td>5</td>
<td>34.4</td>
<td>4.8</td>
<td>1.8</td>
<td>0.69767</td>
<td>0.26163</td>
<td>2.66667</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>131</td>
<td>796</td>
<td>6</td>
<td>5</td>
<td>34.4</td>
<td>5.0</td>
<td>1.8</td>
<td>0.72674</td>
<td>0.26163</td>
<td>2.77778</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>132</td>
<td>796</td>
<td>7</td>
<td>5</td>
<td>34.4</td>
<td>5.5</td>
<td>2.0</td>
<td>0.79942</td>
<td>0.29070</td>
<td>2.75000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
<td>L:W ratio</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>--------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>---------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>----------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>133</td>
<td>796</td>
<td>8</td>
<td>5</td>
<td>34.4</td>
<td>7.6</td>
<td>2.1</td>
<td>1.10465</td>
<td>0.30523</td>
<td>3.61905</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>134</td>
<td>796</td>
<td>9</td>
<td>5</td>
<td>34.4</td>
<td>5.8</td>
<td>1.7</td>
<td>0.84302</td>
<td>0.24709</td>
<td>3.41176</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>135</td>
<td>796</td>
<td>10</td>
<td>5</td>
<td>34.4</td>
<td>8.4</td>
<td>2.3</td>
<td>1.22093</td>
<td>0.33430</td>
<td>3.65217</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>136</td>
<td>796</td>
<td>11</td>
<td>5</td>
<td>34.4</td>
<td>7.4</td>
<td>1.9</td>
<td>1.07558</td>
<td>0.27616</td>
<td>3.89474</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>137</td>
<td>796</td>
<td>12</td>
<td>5</td>
<td>34.4</td>
<td>5.1</td>
<td>2.0</td>
<td>0.74128</td>
<td>0.29070</td>
<td>2.55000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>138</td>
<td>796</td>
<td>13</td>
<td>5</td>
<td>34.4</td>
<td>7.1</td>
<td>2.0</td>
<td>1.03198</td>
<td>0.29070</td>
<td>3.55000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>139</td>
<td>796</td>
<td>14</td>
<td>5</td>
<td>34.4</td>
<td>8.8</td>
<td>3.5</td>
<td>1.27907</td>
<td>0.50872</td>
<td>2.51429</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>140</td>
<td>796</td>
<td>15</td>
<td>5</td>
<td>34.4</td>
<td>7.9</td>
<td>2.2</td>
<td>1.14826</td>
<td>0.31977</td>
<td>3.59091</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>141</td>
<td>796</td>
<td>16</td>
<td>5</td>
<td>34.4</td>
<td>8.3</td>
<td>2.9</td>
<td>1.20640</td>
<td>0.42151</td>
<td>2.86207</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>142</td>
<td>796</td>
<td>17</td>
<td>5</td>
<td>34.4</td>
<td>7.5</td>
<td>2.3</td>
<td>1.09012</td>
<td>0.33430</td>
<td>3.26087</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>143</td>
<td>796</td>
<td>18</td>
<td>5</td>
<td>34.4</td>
<td>4.1</td>
<td>1.5</td>
<td>0.59593</td>
<td>0.21802</td>
<td>2.73333</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>144</td>
<td>796</td>
<td>19</td>
<td>5</td>
<td>34.4</td>
<td>6.2</td>
<td>1.7</td>
<td>0.90116</td>
<td>0.24709</td>
<td>3.64706</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>145</td>
<td>796</td>
<td>20</td>
<td>5</td>
<td>34.4</td>
<td>6.6</td>
<td>2.2</td>
<td>0.95930</td>
<td>0.31977</td>
<td>3.00000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>146</td>
<td>796</td>
<td>21</td>
<td>5</td>
<td>34.4</td>
<td>5.3</td>
<td>1.4</td>
<td>0.77035</td>
<td>0.20349</td>
<td>3.78571</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>147</td>
<td>796</td>
<td>22</td>
<td>5</td>
<td>34.4</td>
<td>5.2</td>
<td>2.0</td>
<td>0.75581</td>
<td>0.29070</td>
<td>2.60000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>148</td>
<td>796</td>
<td>23</td>
<td>5</td>
<td>34.4</td>
<td>4.5</td>
<td>1.3</td>
<td>0.65407</td>
<td>0.18895</td>
<td>3.46154</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>149</td>
<td>796</td>
<td>24</td>
<td>5</td>
<td>34.4</td>
<td>6.8</td>
<td>1.9</td>
<td>0.98837</td>
<td>0.27616</td>
<td>3.57895</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>150</td>
<td>796</td>
<td>25</td>
<td>5</td>
<td>34.4</td>
<td>4.9</td>
<td>2.0</td>
<td>0.71221</td>
<td>0.29070</td>
<td>2.45000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>151</td>
<td>797</td>
<td>1</td>
<td>5</td>
<td>34.4</td>
<td>7.9</td>
<td>2.1</td>
<td>1.14826</td>
<td>0.30523</td>
<td>3.76190</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>152</td>
<td>797</td>
<td>2</td>
<td>5</td>
<td>34.4</td>
<td>11.6</td>
<td>2.6</td>
<td>1.68605</td>
<td>0.37791</td>
<td>4.46154</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>153</td>
<td>797</td>
<td>3</td>
<td>5</td>
<td>34.4</td>
<td>12.7</td>
<td>3.0</td>
<td>1.84593</td>
<td>0.43605</td>
<td>4.23333</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>154</td>
<td>797</td>
<td>4</td>
<td>5</td>
<td>34.4</td>
<td>6.4</td>
<td>1.5</td>
<td>0.93023</td>
<td>0.21802</td>
<td>4.26667</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>155</td>
<td>797</td>
<td>5</td>
<td>5</td>
<td>34.4</td>
<td>6.5</td>
<td>1.9</td>
<td>0.94477</td>
<td>0.27616</td>
<td>3.42105</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>156</td>
<td>797</td>
<td>6</td>
<td>5</td>
<td>34.4</td>
<td>5.8</td>
<td>2.0</td>
<td>0.84302</td>
<td>0.29070</td>
<td>2.90000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>157</td>
<td>797</td>
<td>7</td>
<td>5</td>
<td>34.4</td>
<td>7.9</td>
<td>2.4</td>
<td>1.14826</td>
<td>0.34884</td>
<td>3.29167</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>158</td>
<td>797</td>
<td>8</td>
<td>5</td>
<td>34.4</td>
<td>5.7</td>
<td>1.6</td>
<td>0.82849</td>
<td>0.23256</td>
<td>3.56250</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>159</td>
<td>797</td>
<td>9</td>
<td>5</td>
<td>34.4</td>
<td>7.0</td>
<td>1.9</td>
<td>1.01744</td>
<td>0.27616</td>
<td>3.68421</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>160</td>
<td>797</td>
<td>10</td>
<td>5</td>
<td>34.4</td>
<td>6.6</td>
<td>2.3</td>
<td>0.95930</td>
<td>0.33430</td>
<td>2.86957</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>161</td>
<td>797</td>
<td>11</td>
<td>5</td>
<td>34.4</td>
<td>11.8</td>
<td>2.8</td>
<td>1.71512</td>
<td>0.40698</td>
<td>4.21429</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>162</td>
<td>797</td>
<td>12</td>
<td>5</td>
<td>34.4</td>
<td>9.4</td>
<td>2.4</td>
<td>1.36628</td>
<td>0.34884</td>
<td>3.91667</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>163</td>
<td>797</td>
<td>13</td>
<td>5</td>
<td>34.4</td>
<td>11.4</td>
<td>3.2</td>
<td>1.65698</td>
<td>0.46512</td>
<td>3.56250</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>164</td>
<td>797</td>
<td>14</td>
<td>5</td>
<td>34.4</td>
<td>6.9</td>
<td>2.0</td>
<td>1.00291</td>
<td>0.29070</td>
<td>3.45000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>165</td>
<td>797</td>
<td>15</td>
<td>5</td>
<td>34.4</td>
<td>9.4</td>
<td>2.6</td>
<td>1.36628</td>
<td>0.37791</td>
<td>3.61538</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>166</td>
<td>797</td>
<td>16</td>
<td>5</td>
<td>34.4</td>
<td>6.6</td>
<td>1.7</td>
<td>0.95930</td>
<td>0.24709</td>
<td>3.88235</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
<td>L:W ratio</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>--------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>---------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>-----------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>167</td>
<td>797</td>
<td>17</td>
<td>5</td>
<td>34.4</td>
<td>6.0</td>
<td>1.7</td>
<td>0.87209</td>
<td>0.24709</td>
<td>3.52941</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>168</td>
<td>797</td>
<td>18</td>
<td>5</td>
<td>34.4</td>
<td>5.8</td>
<td>1.6</td>
<td>0.84302</td>
<td>0.23256</td>
<td>3.62500</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>169</td>
<td>797</td>
<td>19</td>
<td>5</td>
<td>34.4</td>
<td>5.6</td>
<td>2.3</td>
<td>0.81395</td>
<td>0.33430</td>
<td>2.43478</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>170</td>
<td>797</td>
<td>20</td>
<td>5</td>
<td>34.4</td>
<td>7.1</td>
<td>2.0</td>
<td>1.03198</td>
<td>0.29070</td>
<td>3.55000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>171</td>
<td>797</td>
<td>21</td>
<td>5</td>
<td>34.4</td>
<td>7.0</td>
<td>1.8</td>
<td>1.01744</td>
<td>0.26163</td>
<td>3.88889</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>172</td>
<td>797</td>
<td>22</td>
<td>5</td>
<td>34.4</td>
<td>5.6</td>
<td>1.5</td>
<td>0.81395</td>
<td>0.21802</td>
<td>3.73333</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>173</td>
<td>797</td>
<td>23</td>
<td>5</td>
<td>34.4</td>
<td>5.2</td>
<td>1.9</td>
<td>0.75581</td>
<td>0.27616</td>
<td>2.73684</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>174</td>
<td>797</td>
<td>24</td>
<td>5</td>
<td>34.4</td>
<td>7.8</td>
<td>2.0</td>
<td>1.13372</td>
<td>0.29070</td>
<td>3.90000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>175</td>
<td>797</td>
<td>25</td>
<td>5</td>
<td>34.4</td>
<td>9.7</td>
<td>2.4</td>
<td>1.40988</td>
<td>0.34884</td>
<td>4.04167</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>176</td>
<td>974</td>
<td>1</td>
<td>2</td>
<td>27.4</td>
<td>8.3</td>
<td>2.9</td>
<td>0.60584</td>
<td>0.21168</td>
<td>2.86207</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>177</td>
<td>974</td>
<td>2</td>
<td>2</td>
<td>27.4</td>
<td>12.2</td>
<td>3.0</td>
<td>0.89051</td>
<td>0.21898</td>
<td>4.06667</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>178</td>
<td>974</td>
<td>3</td>
<td>2</td>
<td>27.4</td>
<td>7.4</td>
<td>1.8</td>
<td>0.54015</td>
<td>0.13139</td>
<td>4.11111</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>179</td>
<td>974</td>
<td>4</td>
<td>2</td>
<td>27.4</td>
<td>7.2</td>
<td>1.5</td>
<td>0.52555</td>
<td>0.10949</td>
<td>4.80000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>180</td>
<td>974</td>
<td>5</td>
<td>2</td>
<td>27.4</td>
<td>14.3</td>
<td>3.1</td>
<td>1.04380</td>
<td>0.22628</td>
<td>4.61290</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>181</td>
<td>974</td>
<td>6</td>
<td>2</td>
<td>27.4</td>
<td>8.5</td>
<td>2.1</td>
<td>0.62044</td>
<td>0.15328</td>
<td>4.04762</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>182</td>
<td>974</td>
<td>7</td>
<td>2</td>
<td>27.4</td>
<td>7.6</td>
<td>2.3</td>
<td>0.55474</td>
<td>0.16788</td>
<td>3.30435</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>183</td>
<td>974</td>
<td>8</td>
<td>2</td>
<td>27.4</td>
<td>6.6</td>
<td>1.6</td>
<td>0.48175</td>
<td>0.11679</td>
<td>4.12500</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>184</td>
<td>974</td>
<td>9</td>
<td>2</td>
<td>27.4</td>
<td>5.8</td>
<td>2.1</td>
<td>0.42336</td>
<td>0.15328</td>
<td>2.76190</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>185</td>
<td>974</td>
<td>10</td>
<td>2</td>
<td>27.4</td>
<td>7.2</td>
<td>1.9</td>
<td>0.52555</td>
<td>0.13869</td>
<td>3.78947</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>186</td>
<td>974</td>
<td>11</td>
<td>2</td>
<td>27.4</td>
<td>6.2</td>
<td>1.5</td>
<td>0.45255</td>
<td>0.10949</td>
<td>4.13333</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>187</td>
<td>974</td>
<td>12</td>
<td>2</td>
<td>27.4</td>
<td>8.4</td>
<td>2.2</td>
<td>0.61314</td>
<td>0.16058</td>
<td>3.81818</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>188</td>
<td>974</td>
<td>13</td>
<td>2</td>
<td>27.4</td>
<td>6.9</td>
<td>2.3</td>
<td>0.50365</td>
<td>0.16788</td>
<td>3.00000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>189</td>
<td>974</td>
<td>14</td>
<td>2</td>
<td>27.4</td>
<td>5.8</td>
<td>2.1</td>
<td>0.42336</td>
<td>0.15328</td>
<td>2.76190</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>190</td>
<td>974</td>
<td>15</td>
<td>2</td>
<td>27.4</td>
<td>6.1</td>
<td>2.2</td>
<td>0.44526</td>
<td>0.16058</td>
<td>2.77273</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>191</td>
<td>974</td>
<td>16</td>
<td>2</td>
<td>27.4</td>
<td>6.4</td>
<td>2.5</td>
<td>0.46715</td>
<td>0.18248</td>
<td>2.56000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>192</td>
<td>974</td>
<td>17</td>
<td>2</td>
<td>27.4</td>
<td>7.2</td>
<td>2.2</td>
<td>0.52555</td>
<td>0.16058</td>
<td>3.27273</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>193</td>
<td>974</td>
<td>18</td>
<td>2</td>
<td>27.4</td>
<td>11.9</td>
<td>4.0</td>
<td>0.86861</td>
<td>0.29197</td>
<td>2.97500</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>194</td>
<td>974</td>
<td>19</td>
<td>2</td>
<td>27.4</td>
<td>6.9</td>
<td>2.5</td>
<td>0.50365</td>
<td>0.18248</td>
<td>2.76000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>195</td>
<td>974</td>
<td>20</td>
<td>2</td>
<td>27.4</td>
<td>7.7</td>
<td>2.4</td>
<td>0.56204</td>
<td>0.17518</td>
<td>3.20833</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>196</td>
<td>974</td>
<td>21</td>
<td>2</td>
<td>27.4</td>
<td>7.0</td>
<td>2.0</td>
<td>0.51095</td>
<td>0.14599</td>
<td>3.50000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>197</td>
<td>974</td>
<td>22</td>
<td>2</td>
<td>27.4</td>
<td>7.2</td>
<td>2.3</td>
<td>0.52555</td>
<td>0.16788</td>
<td>3.13043</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>198</td>
<td>974</td>
<td>23</td>
<td>2</td>
<td>27.4</td>
<td>9.0</td>
<td>2.6</td>
<td>0.65693</td>
<td>0.18978</td>
<td>3.46154</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>199</td>
<td>974</td>
<td>24</td>
<td>2</td>
<td>27.4</td>
<td>5.5</td>
<td>1.8</td>
<td>0.40146</td>
<td>0.13139</td>
<td>3.05556</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>200</td>
<td>974</td>
<td>25</td>
<td>2</td>
<td>27.4</td>
<td>11.5</td>
<td>2.5</td>
<td>0.83942</td>
<td>0.18248</td>
<td>4.60000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
<td>L:W ratio</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>--------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>---------------------------</td>
<td>-------------------------</td>
<td>-------------------------</td>
<td>-------------------------</td>
<td>-----------</td>
<td>----------------</td>
</tr>
<tr>
<td>201</td>
<td>976</td>
<td>1</td>
<td>10</td>
<td>41.0</td>
<td>8.5</td>
<td>2.6</td>
<td>2.07317</td>
<td>0.63415</td>
<td>3.26923</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>202</td>
<td>976</td>
<td>2</td>
<td>10</td>
<td>41.0</td>
<td>6.8</td>
<td>2.3</td>
<td>1.65854</td>
<td>0.56098</td>
<td>2.95652</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>203</td>
<td>976</td>
<td>3</td>
<td>10</td>
<td>41.0</td>
<td>6.1</td>
<td>2.1</td>
<td>1.48780</td>
<td>0.51220</td>
<td>2.90476</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>204</td>
<td>976</td>
<td>4</td>
<td>10</td>
<td>41.0</td>
<td>5.6</td>
<td>1.7</td>
<td>1.36585</td>
<td>0.41463</td>
<td>3.29412</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>205</td>
<td>976</td>
<td>5</td>
<td>10</td>
<td>41.0</td>
<td>4.9</td>
<td>1.6</td>
<td>1.19512</td>
<td>0.39024</td>
<td>3.06250</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>206</td>
<td>976</td>
<td>6</td>
<td>10</td>
<td>41.0</td>
<td>6.5</td>
<td>1.6</td>
<td>1.58537</td>
<td>0.39024</td>
<td>4.06250</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>207</td>
<td>976</td>
<td>7</td>
<td>10</td>
<td>41.0</td>
<td>5.4</td>
<td>1.9</td>
<td>1.31707</td>
<td>0.46341</td>
<td>2.84211</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>208</td>
<td>976</td>
<td>8</td>
<td>10</td>
<td>41.0</td>
<td>7.2</td>
<td>2.1</td>
<td>1.75610</td>
<td>0.51220</td>
<td>3.42857</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>209</td>
<td>976</td>
<td>9</td>
<td>10</td>
<td>41.0</td>
<td>7.4</td>
<td>3.0</td>
<td>1.80488</td>
<td>0.73171</td>
<td>2.46667</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>210</td>
<td>976</td>
<td>10</td>
<td>10</td>
<td>41.0</td>
<td>6.5</td>
<td>2.7</td>
<td>1.58537</td>
<td>0.65854</td>
<td>2.40741</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>211</td>
<td>976</td>
<td>11</td>
<td>10</td>
<td>41.0</td>
<td>5.8</td>
<td>2.0</td>
<td>1.41463</td>
<td>0.48780</td>
<td>2.90000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>212</td>
<td>976</td>
<td>12</td>
<td>10</td>
<td>41.0</td>
<td>6.8</td>
<td>2.6</td>
<td>1.65854</td>
<td>0.63415</td>
<td>2.61538</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>213</td>
<td>976</td>
<td>13</td>
<td>10</td>
<td>41.0</td>
<td>4.6</td>
<td>1.7</td>
<td>1.12195</td>
<td>0.41463</td>
<td>2.70588</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>214</td>
<td>976</td>
<td>14</td>
<td>10</td>
<td>41.0</td>
<td>5.6</td>
<td>2.2</td>
<td>1.36585</td>
<td>0.53659</td>
<td>2.54545</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>215</td>
<td>976</td>
<td>15</td>
<td>10</td>
<td>41.0</td>
<td>8.2</td>
<td>2.5</td>
<td>2.00000</td>
<td>0.60976</td>
<td>3.28000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>216</td>
<td>976</td>
<td>16</td>
<td>10</td>
<td>41.0</td>
<td>7.7</td>
<td>1.8</td>
<td>1.87805</td>
<td>0.43902</td>
<td>4.27778</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>217</td>
<td>976</td>
<td>17</td>
<td>10</td>
<td>41.0</td>
<td>5.8</td>
<td>1.4</td>
<td>1.41463</td>
<td>0.34146</td>
<td>4.14286</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>218</td>
<td>976</td>
<td>18</td>
<td>10</td>
<td>41.0</td>
<td>5.1</td>
<td>2.2</td>
<td>1.24390</td>
<td>0.53659</td>
<td>2.31818</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>219</td>
<td>976</td>
<td>19</td>
<td>10</td>
<td>41.0</td>
<td>7.5</td>
<td>2.6</td>
<td>1.82927</td>
<td>0.63415</td>
<td>2.88462</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>220</td>
<td>976</td>
<td>20</td>
<td>10</td>
<td>41.0</td>
<td>6.1</td>
<td>2.0</td>
<td>1.48780</td>
<td>0.48780</td>
<td>3.05000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>221</td>
<td>976</td>
<td>21</td>
<td>10</td>
<td>41.0</td>
<td>8.3</td>
<td>3.1</td>
<td>2.02439</td>
<td>0.75610</td>
<td>2.67742</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>222</td>
<td>976</td>
<td>22</td>
<td>10</td>
<td>41.0</td>
<td>7.8</td>
<td>2.6</td>
<td>1.90244</td>
<td>0.63415</td>
<td>3.00000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>223</td>
<td>976</td>
<td>23</td>
<td>10</td>
<td>41.0</td>
<td>4.7</td>
<td>1.5</td>
<td>1.14634</td>
<td>0.36585</td>
<td>3.13333</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>224</td>
<td>976</td>
<td>24</td>
<td>10</td>
<td>41.0</td>
<td>4.9</td>
<td>1.7</td>
<td>1.19512</td>
<td>0.41463</td>
<td>2.88235</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>225</td>
<td>976</td>
<td>25</td>
<td>10</td>
<td>41.0</td>
<td>5.7</td>
<td>2.1</td>
<td>1.39024</td>
<td>0.51220</td>
<td>2.71429</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>226</td>
<td>1009</td>
<td>1</td>
<td>5</td>
<td>34.4</td>
<td>7.6</td>
<td>2.7</td>
<td>1.10465</td>
<td>0.39244</td>
<td>2.81481</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>227</td>
<td>1009</td>
<td>2</td>
<td>5</td>
<td>34.4</td>
<td>6.8</td>
<td>1.7</td>
<td>0.98837</td>
<td>0.24709</td>
<td>4.00000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>228</td>
<td>1009</td>
<td>3</td>
<td>5</td>
<td>34.4</td>
<td>10.8</td>
<td>4.2</td>
<td>1.56977</td>
<td>0.61047</td>
<td>2.57143</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>229</td>
<td>1009</td>
<td>4</td>
<td>5</td>
<td>34.4</td>
<td>9.9</td>
<td>2.9</td>
<td>1.43895</td>
<td>0.42151</td>
<td>3.41379</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>230</td>
<td>1009</td>
<td>5</td>
<td>5</td>
<td>34.4</td>
<td>8.4</td>
<td>2.3</td>
<td>1.22093</td>
<td>0.33430</td>
<td>3.65217</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>231</td>
<td>1009</td>
<td>6</td>
<td>5</td>
<td>34.4</td>
<td>12.2</td>
<td>3.7</td>
<td>1.77326</td>
<td>0.53779</td>
<td>3.29730</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>232</td>
<td>1009</td>
<td>7</td>
<td>5</td>
<td>34.4</td>
<td>9.4</td>
<td>2.3</td>
<td>1.36628</td>
<td>0.33430</td>
<td>4.08696</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>233</td>
<td>1009</td>
<td>8</td>
<td>5</td>
<td>34.4</td>
<td>7.9</td>
<td>1.9</td>
<td>1.14826</td>
<td>0.27616</td>
<td>4.15789</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>234</td>
<td>1009</td>
<td>9</td>
<td>5</td>
<td>34.4</td>
<td>6.2</td>
<td>2.3</td>
<td>0.90116</td>
<td>0.33430</td>
<td>2.69565</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
<td>L:W ratio</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>--------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>---------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>-----------</td>
<td>----------</td>
</tr>
<tr>
<td>235</td>
<td>1009</td>
<td>10</td>
<td>5</td>
<td>34.4</td>
<td>8.3</td>
<td>3.4</td>
<td>1.20640</td>
<td>0.49419</td>
<td>2.44118</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>236</td>
<td>1009</td>
<td>11</td>
<td>5</td>
<td>34.4</td>
<td>9.2</td>
<td>2.9</td>
<td>1.33721</td>
<td>0.42151</td>
<td>3.17241</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>237</td>
<td>1009</td>
<td>12</td>
<td>5</td>
<td>34.4</td>
<td>10.5</td>
<td>3.2</td>
<td>1.52616</td>
<td>0.46512</td>
<td>3.28125</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>238</td>
<td>1009</td>
<td>13</td>
<td>5</td>
<td>34.4</td>
<td>6.5</td>
<td>2.0</td>
<td>0.94477</td>
<td>0.29070</td>
<td>3.25000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>239</td>
<td>1009</td>
<td>14</td>
<td>5</td>
<td>34.4</td>
<td>6.1</td>
<td>2.0</td>
<td>0.88663</td>
<td>0.29070</td>
<td>3.05000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>240</td>
<td>1009</td>
<td>15</td>
<td>5</td>
<td>34.4</td>
<td>7.5</td>
<td>2.2</td>
<td>1.09012</td>
<td>0.31977</td>
<td>3.40909</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>241</td>
<td>1009</td>
<td>16</td>
<td>5</td>
<td>34.4</td>
<td>7.3</td>
<td>2.8</td>
<td>1.06105</td>
<td>0.40698</td>
<td>2.60714</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>242</td>
<td>1009</td>
<td>17</td>
<td>5</td>
<td>34.4</td>
<td>6.8</td>
<td>1.6</td>
<td>0.98837</td>
<td>0.23256</td>
<td>4.25000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>243</td>
<td>1009</td>
<td>18</td>
<td>5</td>
<td>34.4</td>
<td>9.0</td>
<td>2.5</td>
<td>1.30814</td>
<td>0.36337</td>
<td>3.60000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>244</td>
<td>1009</td>
<td>19</td>
<td>5</td>
<td>34.4</td>
<td>8.4</td>
<td>2.8</td>
<td>1.22093</td>
<td>0.40698</td>
<td>3.00000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>245</td>
<td>1009</td>
<td>20</td>
<td>5</td>
<td>34.4</td>
<td>4.7</td>
<td>1.5</td>
<td>0.68314</td>
<td>0.21802</td>
<td>3.13333</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>246</td>
<td>1009</td>
<td>21</td>
<td>5</td>
<td>34.4</td>
<td>4.8</td>
<td>1.8</td>
<td>0.69767</td>
<td>0.26163</td>
<td>2.66667</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>247</td>
<td>1009</td>
<td>22</td>
<td>5</td>
<td>34.4</td>
<td>4.9</td>
<td>2.0</td>
<td>0.71221</td>
<td>0.29070</td>
<td>2.45000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>248</td>
<td>1009</td>
<td>23</td>
<td>5</td>
<td>34.4</td>
<td>6.0</td>
<td>1.9</td>
<td>0.87209</td>
<td>0.27616</td>
<td>3.15789</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>249</td>
<td>1009</td>
<td>24</td>
<td>5</td>
<td>34.4</td>
<td>6.5</td>
<td>2.3</td>
<td>0.94477</td>
<td>0.33430</td>
<td>2.82609</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>250</td>
<td>1009</td>
<td>25</td>
<td>5</td>
<td>34.4</td>
<td>7.3</td>
<td>2.5</td>
<td>1.06105</td>
<td>0.36337</td>
<td>2.92000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>251</td>
<td>1023</td>
<td>1</td>
<td>20</td>
<td>54.5</td>
<td>3.8</td>
<td>1.8</td>
<td>1.39450</td>
<td>0.66055</td>
<td>2.11111</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>252</td>
<td>1023</td>
<td>2</td>
<td>20</td>
<td>54.5</td>
<td>4.5</td>
<td>1.5</td>
<td>1.65138</td>
<td>0.55046</td>
<td>3.00000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>253</td>
<td>1023</td>
<td>3</td>
<td>20</td>
<td>54.5</td>
<td>5.2</td>
<td>1.6</td>
<td>1.90826</td>
<td>0.58716</td>
<td>3.25000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>254</td>
<td>1023</td>
<td>4</td>
<td>20</td>
<td>54.5</td>
<td>4.1</td>
<td>1.6</td>
<td>1.50459</td>
<td>0.58716</td>
<td>2.56250</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>255</td>
<td>1023</td>
<td>5</td>
<td>20</td>
<td>54.5</td>
<td>4.3</td>
<td>1.7</td>
<td>1.57798</td>
<td>0.62385</td>
<td>2.52941</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>256</td>
<td>1023</td>
<td>6</td>
<td>20</td>
<td>54.5</td>
<td>4.4</td>
<td>2.2</td>
<td>1.61468</td>
<td>0.80734</td>
<td>2.00000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>257</td>
<td>1023</td>
<td>7</td>
<td>20</td>
<td>54.5</td>
<td>4.6</td>
<td>1.8</td>
<td>1.68807</td>
<td>0.66055</td>
<td>2.55556</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>258</td>
<td>1023</td>
<td>8</td>
<td>20</td>
<td>54.5</td>
<td>4.6</td>
<td>2.3</td>
<td>1.68807</td>
<td>0.84404</td>
<td>2.00000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>259</td>
<td>1023</td>
<td>9</td>
<td>20</td>
<td>54.5</td>
<td>3.9</td>
<td>1.6</td>
<td>1.43119</td>
<td>0.58716</td>
<td>2.43750</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>260</td>
<td>1023</td>
<td>10</td>
<td>20</td>
<td>54.5</td>
<td>4.8</td>
<td>2.0</td>
<td>1.76147</td>
<td>0.73394</td>
<td>2.40000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>261</td>
<td>1023</td>
<td>11</td>
<td>20</td>
<td>54.5</td>
<td>5.1</td>
<td>1.8</td>
<td>1.87156</td>
<td>0.66055</td>
<td>2.83333</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>262</td>
<td>1023</td>
<td>12</td>
<td>20</td>
<td>54.5</td>
<td>3.5</td>
<td>1.5</td>
<td>1.28440</td>
<td>0.55046</td>
<td>2.33333</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>263</td>
<td>1023</td>
<td>13</td>
<td>20</td>
<td>54.5</td>
<td>3.4</td>
<td>1.2</td>
<td>1.24771</td>
<td>0.44037</td>
<td>2.83333</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>264</td>
<td>1023</td>
<td>14</td>
<td>20</td>
<td>54.5</td>
<td>4.1</td>
<td>1.5</td>
<td>1.50459</td>
<td>0.55046</td>
<td>2.73333</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>265</td>
<td>1023</td>
<td>15</td>
<td>20</td>
<td>54.5</td>
<td>4.2</td>
<td>1.8</td>
<td>1.54128</td>
<td>0.66055</td>
<td>2.33333</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>266</td>
<td>1023</td>
<td>16</td>
<td>20</td>
<td>54.5</td>
<td>3.7</td>
<td>1.4</td>
<td>1.35780</td>
<td>0.51376</td>
<td>2.64286</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>267</td>
<td>1023</td>
<td>17</td>
<td>20</td>
<td>54.5</td>
<td>3.3</td>
<td>1.6</td>
<td>1.21101</td>
<td>0.58716</td>
<td>2.06250</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>268</td>
<td>1023</td>
<td>18</td>
<td>20</td>
<td>54.5</td>
<td>3.2</td>
<td>1.3</td>
<td>1.17431</td>
<td>0.47706</td>
<td>2.46154</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
<td>L/W ratio</td>
<td>Category</td>
</tr>
<tr>
<td>---------</td>
<td>--------------</td>
<td>--------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>---------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>-----------</td>
<td>------------------------</td>
</tr>
<tr>
<td>269</td>
<td>1023</td>
<td>19</td>
<td>20</td>
<td>54.5</td>
<td>3.4</td>
<td>1.7</td>
<td>1.24771</td>
<td>0.62385</td>
<td>2.00000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>270</td>
<td>1023</td>
<td>20</td>
<td>20</td>
<td>54.5</td>
<td>3.3</td>
<td>1.5</td>
<td>1.21101</td>
<td>0.55046</td>
<td>2.20000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>271</td>
<td>1023</td>
<td>21</td>
<td>20</td>
<td>54.5</td>
<td>3.8</td>
<td>1.4</td>
<td>1.39450</td>
<td>0.51376</td>
<td>2.71429</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>272</td>
<td>1023</td>
<td>22</td>
<td>20</td>
<td>54.5</td>
<td>4.7</td>
<td>1.7</td>
<td>1.72477</td>
<td>0.62385</td>
<td>2.76471</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>273</td>
<td>1023</td>
<td>23</td>
<td>20</td>
<td>54.5</td>
<td>5.3</td>
<td>1.6</td>
<td>1.94495</td>
<td>0.58716</td>
<td>3.31250</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>274</td>
<td>1023</td>
<td>24</td>
<td>20</td>
<td>54.5</td>
<td>4.2</td>
<td>2.0</td>
<td>1.54122</td>
<td>0.73394</td>
<td>2.10000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>275</td>
<td>1023</td>
<td>25</td>
<td>20</td>
<td>54.5</td>
<td>4.4</td>
<td>2.1</td>
<td>1.61468</td>
<td>0.77064</td>
<td>2.09524</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>276</td>
<td>1126</td>
<td>1</td>
<td>5</td>
<td>34.4</td>
<td>9.4</td>
<td>4.5</td>
<td>1.36628</td>
<td>0.65407</td>
<td>2.08889</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>277</td>
<td>1126</td>
<td>2</td>
<td>5</td>
<td>34.4</td>
<td>7.6</td>
<td>2.2</td>
<td>1.10465</td>
<td>0.31977</td>
<td>3.45455</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>278</td>
<td>1126</td>
<td>3</td>
<td>5</td>
<td>34.4</td>
<td>8.6</td>
<td>2.0</td>
<td>1.25000</td>
<td>0.29070</td>
<td>4.30000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>279</td>
<td>1126</td>
<td>4</td>
<td>5</td>
<td>34.4</td>
<td>8.9</td>
<td>2.0</td>
<td>1.29360</td>
<td>0.29070</td>
<td>4.45000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>280</td>
<td>1126</td>
<td>5</td>
<td>5</td>
<td>34.4</td>
<td>8.7</td>
<td>1.8</td>
<td>1.26453</td>
<td>0.26163</td>
<td>4.83333</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>281</td>
<td>1126</td>
<td>6</td>
<td>5</td>
<td>34.4</td>
<td>11.5</td>
<td>4.8</td>
<td>1.67151</td>
<td>0.69767</td>
<td>2.39583</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>282</td>
<td>1126</td>
<td>7</td>
<td>5</td>
<td>34.4</td>
<td>8.9</td>
<td>2.6</td>
<td>1.29360</td>
<td>0.37791</td>
<td>3.42308</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>283</td>
<td>1126</td>
<td>8</td>
<td>5</td>
<td>34.4</td>
<td>8.6</td>
<td>2.4</td>
<td>1.25000</td>
<td>0.34884</td>
<td>3.58333</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>284</td>
<td>1126</td>
<td>9</td>
<td>5</td>
<td>34.4</td>
<td>10.2</td>
<td>3.2</td>
<td>1.48256</td>
<td>0.46512</td>
<td>3.18750</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>285</td>
<td>1126</td>
<td>10</td>
<td>5</td>
<td>34.4</td>
<td>10.0</td>
<td>2.9</td>
<td>1.45349</td>
<td>0.42151</td>
<td>3.44828</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>286</td>
<td>1126</td>
<td>11</td>
<td>5</td>
<td>34.4</td>
<td>7.3</td>
<td>3.6</td>
<td>1.06105</td>
<td>0.52326</td>
<td>2.02778</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>287</td>
<td>1126</td>
<td>12</td>
<td>5</td>
<td>34.4</td>
<td>9.8</td>
<td>2.8</td>
<td>1.42442</td>
<td>0.40698</td>
<td>3.50000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>288</td>
<td>1126</td>
<td>13</td>
<td>5</td>
<td>34.4</td>
<td>8.1</td>
<td>2.0</td>
<td>1.17733</td>
<td>0.29070</td>
<td>4.05000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>289</td>
<td>1126</td>
<td>14</td>
<td>5</td>
<td>34.4</td>
<td>7.4</td>
<td>2.0</td>
<td>1.07558</td>
<td>0.29070</td>
<td>3.70000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>290</td>
<td>1126</td>
<td>15</td>
<td>5</td>
<td>34.4</td>
<td>9.5</td>
<td>3.1</td>
<td>1.38081</td>
<td>0.45058</td>
<td>3.06452</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>291</td>
<td>1126</td>
<td>16</td>
<td>5</td>
<td>34.4</td>
<td>6.8</td>
<td>2.7</td>
<td>0.98837</td>
<td>0.39244</td>
<td>2.51852</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>292</td>
<td>1126</td>
<td>17</td>
<td>5</td>
<td>34.4</td>
<td>6.5</td>
<td>1.8</td>
<td>0.94477</td>
<td>0.26163</td>
<td>3.61111</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>293</td>
<td>1126</td>
<td>18</td>
<td>5</td>
<td>34.4</td>
<td>7.4</td>
<td>2.2</td>
<td>1.07558</td>
<td>0.31977</td>
<td>3.36364</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>294</td>
<td>1126</td>
<td>19</td>
<td>5</td>
<td>34.4</td>
<td>8.9</td>
<td>3.9</td>
<td>1.29360</td>
<td>0.56686</td>
<td>2.28205</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>295</td>
<td>1126</td>
<td>20</td>
<td>5</td>
<td>34.4</td>
<td>9.4</td>
<td>4.0</td>
<td>1.36628</td>
<td>0.58140</td>
<td>2.35000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>296</td>
<td>1126</td>
<td>21</td>
<td>5</td>
<td>34.4</td>
<td>5.3</td>
<td>2.4</td>
<td>0.77035</td>
<td>0.34884</td>
<td>2.20833</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>297</td>
<td>1126</td>
<td>22</td>
<td>5</td>
<td>34.4</td>
<td>4.9</td>
<td>1.3</td>
<td>0.71221</td>
<td>0.18895</td>
<td>3.76923</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>298</td>
<td>1126</td>
<td>23</td>
<td>5</td>
<td>34.4</td>
<td>5.4</td>
<td>1.9</td>
<td>0.78488</td>
<td>0.27616</td>
<td>2.84211</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>299</td>
<td>1126</td>
<td>24</td>
<td>5</td>
<td>34.4</td>
<td>6.8</td>
<td>1.5</td>
<td>0.98837</td>
<td>0.21802</td>
<td>4.53333</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>300</td>
<td>1126</td>
<td>25</td>
<td>5</td>
<td>34.4</td>
<td>6.3</td>
<td>2.2</td>
<td>0.91570</td>
<td>0.31977</td>
<td>2.86364</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>301</td>
<td>1126</td>
<td>26</td>
<td>5</td>
<td>34.4</td>
<td>4.1</td>
<td>2.3</td>
<td>0.48787</td>
<td>0.56098</td>
<td>3.65217</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>302</td>
<td>1126</td>
<td>27</td>
<td>5</td>
<td>34.4</td>
<td>4.1</td>
<td>2.5</td>
<td>2.21951</td>
<td>0.60976</td>
<td>3.64000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
<td>L:W ratio</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>-------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>----------------------------</td>
<td>--------------------------</td>
<td>------------------------</td>
<td>------------------------</td>
<td>-----------</td>
<td>----------</td>
</tr>
<tr>
<td>303</td>
<td>1129</td>
<td>3</td>
<td>10</td>
<td>41.0</td>
<td>6.9</td>
<td>1.9</td>
<td>1.68293</td>
<td>0.46341</td>
<td>3.63158</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>304</td>
<td>1129</td>
<td>4</td>
<td>10</td>
<td>41.0</td>
<td>7.4</td>
<td>1.9</td>
<td>1.80488</td>
<td>0.46341</td>
<td>3.89474</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>305</td>
<td>1129</td>
<td>5</td>
<td>10</td>
<td>41.0</td>
<td>8.0</td>
<td>2.7</td>
<td>1.95122</td>
<td>0.65854</td>
<td>2.96296</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>306</td>
<td>1129</td>
<td>6</td>
<td>10</td>
<td>41.0</td>
<td>8.7</td>
<td>2.3</td>
<td>2.12195</td>
<td>0.56098</td>
<td>3.78261</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>307</td>
<td>1129</td>
<td>7</td>
<td>10</td>
<td>41.0</td>
<td>7.1</td>
<td>1.7</td>
<td>1.73171</td>
<td>0.41463</td>
<td>4.17647</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>308</td>
<td>1129</td>
<td>8</td>
<td>10</td>
<td>41.0</td>
<td>8.0</td>
<td>2.8</td>
<td>1.95122</td>
<td>0.68293</td>
<td>2.85714</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>309</td>
<td>1129</td>
<td>9</td>
<td>10</td>
<td>41.0</td>
<td>7.0</td>
<td>2.2</td>
<td>1.70732</td>
<td>0.53659</td>
<td>3.18182</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>310</td>
<td>1129</td>
<td>10</td>
<td>10</td>
<td>41.0</td>
<td>7.7</td>
<td>2.1</td>
<td>1.87805</td>
<td>0.51220</td>
<td>3.66667</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>311</td>
<td>1129</td>
<td>11</td>
<td>10</td>
<td>41.0</td>
<td>8.8</td>
<td>2.2</td>
<td>2.14634</td>
<td>0.53659</td>
<td>4.00000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>312</td>
<td>1129</td>
<td>12</td>
<td>10</td>
<td>41.0</td>
<td>7.0</td>
<td>2.0</td>
<td>1.70732</td>
<td>0.48780</td>
<td>3.50000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>313</td>
<td>1129</td>
<td>13</td>
<td>10</td>
<td>41.0</td>
<td>9.2</td>
<td>2.3</td>
<td>2.24390</td>
<td>0.56098</td>
<td>4.00000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>314</td>
<td>1129</td>
<td>14</td>
<td>10</td>
<td>41.0</td>
<td>6.2</td>
<td>1.7</td>
<td>1.51220</td>
<td>0.41463</td>
<td>3.64706</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>315</td>
<td>1129</td>
<td>15</td>
<td>10</td>
<td>41.0</td>
<td>7.5</td>
<td>2.5</td>
<td>1.82927</td>
<td>0.60976</td>
<td>3.00000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>316</td>
<td>1129</td>
<td>16</td>
<td>10</td>
<td>41.0</td>
<td>6.6</td>
<td>1.9</td>
<td>1.60976</td>
<td>0.46341</td>
<td>3.47368</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>317</td>
<td>1129</td>
<td>17</td>
<td>10</td>
<td>41.0</td>
<td>7.2</td>
<td>2.2</td>
<td>1.75610</td>
<td>0.53659</td>
<td>3.27273</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>318</td>
<td>1129</td>
<td>18</td>
<td>10</td>
<td>41.0</td>
<td>6.2</td>
<td>1.7</td>
<td>1.51220</td>
<td>0.41463</td>
<td>3.64706</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>319</td>
<td>1129</td>
<td>19</td>
<td>10</td>
<td>41.0</td>
<td>8.3</td>
<td>1.9</td>
<td>2.02439</td>
<td>0.46341</td>
<td>4.36842</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>320</td>
<td>1129</td>
<td>20</td>
<td>10</td>
<td>41.0</td>
<td>7.9</td>
<td>1.8</td>
<td>1.92683</td>
<td>0.43902</td>
<td>4.38889</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>321</td>
<td>1129</td>
<td>21</td>
<td>10</td>
<td>41.0</td>
<td>5.0</td>
<td>1.6</td>
<td>1.21951</td>
<td>0.39024</td>
<td>3.12500</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>322</td>
<td>1129</td>
<td>22</td>
<td>10</td>
<td>41.0</td>
<td>5.6</td>
<td>1.7</td>
<td>1.36585</td>
<td>0.41463</td>
<td>3.29412</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>323</td>
<td>1129</td>
<td>23</td>
<td>10</td>
<td>41.0</td>
<td>5.7</td>
<td>1.8</td>
<td>1.39024</td>
<td>0.43902</td>
<td>3.16667</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>324</td>
<td>1129</td>
<td>24</td>
<td>10</td>
<td>41.0</td>
<td>6.8</td>
<td>2.2</td>
<td>1.65854</td>
<td>0.53659</td>
<td>3.09091</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>325</td>
<td>1129</td>
<td>25</td>
<td>10</td>
<td>41.0</td>
<td>5.6</td>
<td>1.6</td>
<td>1.36585</td>
<td>0.39024</td>
<td>3.50000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>326</td>
<td>1148</td>
<td>1</td>
<td>2</td>
<td>27.4</td>
<td>13.9</td>
<td>3.0</td>
<td>1.01460</td>
<td>0.21898</td>
<td>4.63333</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>327</td>
<td>1148</td>
<td>2</td>
<td>2</td>
<td>27.4</td>
<td>6.4</td>
<td>1.8</td>
<td>0.46715</td>
<td>0.13139</td>
<td>3.55556</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>328</td>
<td>1148</td>
<td>3</td>
<td>2</td>
<td>27.4</td>
<td>8.2</td>
<td>1.9</td>
<td>0.59854</td>
<td>0.13869</td>
<td>4.31579</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>329</td>
<td>1148</td>
<td>4</td>
<td>2</td>
<td>27.4</td>
<td>10.8</td>
<td>3.4</td>
<td>0.78832</td>
<td>0.24818</td>
<td>3.17647</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>330</td>
<td>1148</td>
<td>5</td>
<td>2</td>
<td>27.4</td>
<td>7.9</td>
<td>2.6</td>
<td>0.57664</td>
<td>0.18978</td>
<td>3.03846</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>331</td>
<td>1148</td>
<td>6</td>
<td>2</td>
<td>27.4</td>
<td>9.0</td>
<td>3.0</td>
<td>0.65693</td>
<td>0.21898</td>
<td>3.00000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>332</td>
<td>1148</td>
<td>7</td>
<td>2</td>
<td>27.4</td>
<td>12.3</td>
<td>3.6</td>
<td>0.89781</td>
<td>0.26277</td>
<td>3.41667</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>333</td>
<td>1148</td>
<td>8</td>
<td>2</td>
<td>27.4</td>
<td>15.9</td>
<td>4.3</td>
<td>1.16058</td>
<td>0.31387</td>
<td>3.69767</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>334</td>
<td>1148</td>
<td>9</td>
<td>2</td>
<td>27.4</td>
<td>8.1</td>
<td>2.5</td>
<td>0.59124</td>
<td>0.18248</td>
<td>3.24000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>335</td>
<td>1148</td>
<td>10</td>
<td>2</td>
<td>27.4</td>
<td>9.2</td>
<td>2.9</td>
<td>0.67153</td>
<td>0.21168</td>
<td>3.17241</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>336</td>
<td>1148</td>
<td>11</td>
<td>2</td>
<td>27.4</td>
<td>9.4</td>
<td>3.2</td>
<td>0.68613</td>
<td>0.23358</td>
<td>2.93750</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
<td>L:W ratio</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>-------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>---------------------------</td>
<td>--------------------------</td>
<td>-------------------------</td>
<td>-------------------------</td>
<td>-----------</td>
<td>----------</td>
</tr>
<tr>
<td>337</td>
<td>1148</td>
<td>12</td>
<td>2</td>
<td>27.4</td>
<td>9.3</td>
<td>3.5</td>
<td>0.67883</td>
<td>0.25547</td>
<td>2.65714</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>338</td>
<td>1148</td>
<td>13</td>
<td>2</td>
<td>27.4</td>
<td>7.7</td>
<td>2.4</td>
<td>0.56204</td>
<td>0.17518</td>
<td>3.20833</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>339</td>
<td>1148</td>
<td>14</td>
<td>2</td>
<td>27.4</td>
<td>6.4</td>
<td>1.5</td>
<td>0.46715</td>
<td>0.10949</td>
<td>4.26667</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>340</td>
<td>1148</td>
<td>15</td>
<td>2</td>
<td>27.4</td>
<td>6.7</td>
<td>2.1</td>
<td>0.48905</td>
<td>0.15328</td>
<td>3.19048</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>341</td>
<td>1148</td>
<td>16</td>
<td>2</td>
<td>27.4</td>
<td>5.7</td>
<td>2.1</td>
<td>0.41606</td>
<td>0.15328</td>
<td>2.71429</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>342</td>
<td>1148</td>
<td>17</td>
<td>2</td>
<td>27.4</td>
<td>12.3</td>
<td>5.0</td>
<td>0.89781</td>
<td>0.36496</td>
<td>2.46000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>343</td>
<td>1148</td>
<td>18</td>
<td>2</td>
<td>27.4</td>
<td>8.6</td>
<td>3.2</td>
<td>0.62774</td>
<td>0.23358</td>
<td>2.68750</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>344</td>
<td>1148</td>
<td>19</td>
<td>2</td>
<td>27.4</td>
<td>9.9</td>
<td>3.0</td>
<td>0.72263</td>
<td>0.21898</td>
<td>3.30000</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>345</td>
<td>1148</td>
<td>20</td>
<td>2</td>
<td>27.4</td>
<td>7.5</td>
<td>2.3</td>
<td>0.54745</td>
<td>0.16788</td>
<td>3.26087</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>346</td>
<td>1148</td>
<td>21</td>
<td>2</td>
<td>27.4</td>
<td>8.9</td>
<td>2.4</td>
<td>0.64964</td>
<td>0.17518</td>
<td>3.70833</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>347</td>
<td>1148</td>
<td>22</td>
<td>2</td>
<td>27.4</td>
<td>8.3</td>
<td>2.2</td>
<td>0.60584</td>
<td>0.16058</td>
<td>3.77273</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>348</td>
<td>1148</td>
<td>23</td>
<td>2</td>
<td>27.4</td>
<td>8.7</td>
<td>2.2</td>
<td>0.63504</td>
<td>0.16058</td>
<td>3.95455</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>349</td>
<td>1148</td>
<td>24</td>
<td>2</td>
<td>27.4</td>
<td>8.2</td>
<td>3.4</td>
<td>0.59854</td>
<td>0.24818</td>
<td>2.41176</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>350</td>
<td>1148</td>
<td>25</td>
<td>2</td>
<td>27.4</td>
<td>7.0</td>
<td>2.3</td>
<td>0.51095</td>
<td>0.16788</td>
<td>3.04348</td>
<td>perpendicular prismatic</td>
</tr>
<tr>
<td>1</td>
<td>607</td>
<td>1</td>
<td>2</td>
<td>108.8</td>
<td>27.9</td>
<td>6.4</td>
<td>0.51287</td>
<td>0.11765</td>
<td>4.35938</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>2</td>
<td>607</td>
<td>2</td>
<td>2</td>
<td>108.8</td>
<td>21.9</td>
<td>5.1</td>
<td>0.40257</td>
<td>0.09375</td>
<td>4.29412</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>3</td>
<td>607</td>
<td>3</td>
<td>2</td>
<td>108.8</td>
<td>17.2</td>
<td>5.5</td>
<td>0.31618</td>
<td>0.10110</td>
<td>3.12727</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>4</td>
<td>607</td>
<td>4</td>
<td>2</td>
<td>108.8</td>
<td>15.9</td>
<td>5.3</td>
<td>0.29228</td>
<td>0.09743</td>
<td>3.00000</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>5</td>
<td>607</td>
<td>5</td>
<td>2</td>
<td>108.8</td>
<td>16.6</td>
<td>5.8</td>
<td>0.30515</td>
<td>0.10662</td>
<td>2.86207</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>6</td>
<td>607</td>
<td>6</td>
<td>2</td>
<td>108.8</td>
<td>19.2</td>
<td>5.4</td>
<td>0.35294</td>
<td>0.09926</td>
<td>3.55556</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>7</td>
<td>607</td>
<td>7</td>
<td>2</td>
<td>108.8</td>
<td>17.7</td>
<td>5.3</td>
<td>0.32537</td>
<td>0.09743</td>
<td>3.33962</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>8</td>
<td>607</td>
<td>8</td>
<td>2</td>
<td>108.8</td>
<td>28.5</td>
<td>7.7</td>
<td>0.52390</td>
<td>0.14154</td>
<td>3.70130</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>9</td>
<td>607</td>
<td>9</td>
<td>2</td>
<td>108.8</td>
<td>23.0</td>
<td>7.9</td>
<td>0.42279</td>
<td>0.14522</td>
<td>2.91139</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>10</td>
<td>607</td>
<td>10</td>
<td>2</td>
<td>108.8</td>
<td>21.9</td>
<td>4.8</td>
<td>0.40257</td>
<td>0.08824</td>
<td>4.56250</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>11</td>
<td>607</td>
<td>11</td>
<td>2</td>
<td>108.8</td>
<td>19.9</td>
<td>6.0</td>
<td>0.36581</td>
<td>0.11029</td>
<td>3.31667</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>12</td>
<td>607</td>
<td>12</td>
<td>2</td>
<td>108.8</td>
<td>26.0</td>
<td>8.0</td>
<td>0.47794</td>
<td>0.14706</td>
<td>3.25000</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>13</td>
<td>607</td>
<td>13</td>
<td>2</td>
<td>108.8</td>
<td>26.8</td>
<td>8.5</td>
<td>0.49265</td>
<td>0.15625</td>
<td>3.15294</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>14</td>
<td>607</td>
<td>14</td>
<td>2</td>
<td>108.8</td>
<td>21.9</td>
<td>6.0</td>
<td>0.40257</td>
<td>0.11029</td>
<td>3.65000</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>15</td>
<td>607</td>
<td>15</td>
<td>2</td>
<td>108.8</td>
<td>21.6</td>
<td>6.7</td>
<td>0.39706</td>
<td>0.12316</td>
<td>3.22388</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>16</td>
<td>607</td>
<td>16</td>
<td>2</td>
<td>108.8</td>
<td>17.2</td>
<td>5.2</td>
<td>0.31618</td>
<td>0.09559</td>
<td>3.30769</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>17</td>
<td>607</td>
<td>17</td>
<td>2</td>
<td>108.8</td>
<td>15.3</td>
<td>4.5</td>
<td>0.28125</td>
<td>0.08272</td>
<td>3.40000</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>18</td>
<td>607</td>
<td>18</td>
<td>2</td>
<td>108.8</td>
<td>16.8</td>
<td>4.6</td>
<td>0.30882</td>
<td>0.08456</td>
<td>3.65217</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>19</td>
<td>607</td>
<td>19</td>
<td>2</td>
<td>108.8</td>
<td>23.3</td>
<td>5.9</td>
<td>0.42831</td>
<td>0.10846</td>
<td>3.94915</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>20</td>
<td>607</td>
<td>20</td>
<td>2</td>
<td>108.8</td>
<td>23.9</td>
<td>5.2</td>
<td>0.43934</td>
<td>0.09559</td>
<td>4.59615</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
<td>L:W ratio</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>-------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>---------------------------</td>
<td>--------------------------</td>
<td>-------------------------</td>
<td>-------------------------</td>
<td>----------</td>
<td>------------------</td>
</tr>
<tr>
<td>21</td>
<td>607</td>
<td>21</td>
<td>2</td>
<td>108.8</td>
<td>21.4</td>
<td>5.2</td>
<td>0.39338</td>
<td>0.09559</td>
<td>4.11538</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>22</td>
<td>607</td>
<td>22</td>
<td>2</td>
<td>108.8</td>
<td>18.4</td>
<td>4.7</td>
<td>0.33824</td>
<td>0.08640</td>
<td>3.91489</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>23</td>
<td>607</td>
<td>23</td>
<td>2</td>
<td>108.8</td>
<td>25.6</td>
<td>8.2</td>
<td>0.47059</td>
<td>0.15074</td>
<td>3.12195</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>24</td>
<td>607</td>
<td>24</td>
<td>2</td>
<td>108.8</td>
<td>15.7</td>
<td>4.8</td>
<td>0.28860</td>
<td>0.08824</td>
<td>3.27083</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>25</td>
<td>607</td>
<td>25</td>
<td>2</td>
<td>108.8</td>
<td>17.1</td>
<td>4.8</td>
<td>0.31434</td>
<td>0.08824</td>
<td>3.56250</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>26</td>
<td>729</td>
<td>1</td>
<td>2</td>
<td>108.8</td>
<td>18.9</td>
<td>6.3</td>
<td>0.34743</td>
<td>0.11581</td>
<td>3.00000</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>27</td>
<td>729</td>
<td>2</td>
<td>2</td>
<td>108.8</td>
<td>21.8</td>
<td>6.1</td>
<td>0.40074</td>
<td>0.11213</td>
<td>3.57377</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>28</td>
<td>729</td>
<td>3</td>
<td>2</td>
<td>108.8</td>
<td>20.5</td>
<td>6.9</td>
<td>0.37684</td>
<td>0.12684</td>
<td>2.97101</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>29</td>
<td>729</td>
<td>4</td>
<td>2</td>
<td>108.8</td>
<td>18.7</td>
<td>5.7</td>
<td>0.34375</td>
<td>0.10478</td>
<td>3.28070</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>30</td>
<td>729</td>
<td>5</td>
<td>2</td>
<td>108.8</td>
<td>20.9</td>
<td>7.9</td>
<td>0.38419</td>
<td>0.14522</td>
<td>2.64557</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>31</td>
<td>729</td>
<td>6</td>
<td>2</td>
<td>108.8</td>
<td>25.9</td>
<td>6.0</td>
<td>0.47610</td>
<td>0.11029</td>
<td>4.31667</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>32</td>
<td>729</td>
<td>7</td>
<td>2</td>
<td>108.8</td>
<td>19.3</td>
<td>5.6</td>
<td>0.35478</td>
<td>0.10294</td>
<td>3.44643</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>33</td>
<td>729</td>
<td>8</td>
<td>2</td>
<td>108.8</td>
<td>22.6</td>
<td>5.7</td>
<td>0.41544</td>
<td>0.10478</td>
<td>3.96491</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>34</td>
<td>729</td>
<td>9</td>
<td>2</td>
<td>108.8</td>
<td>18.6</td>
<td>4.3</td>
<td>0.34191</td>
<td>0.07904</td>
<td>4.32558</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>35</td>
<td>729</td>
<td>10</td>
<td>2</td>
<td>108.8</td>
<td>16.8</td>
<td>5.6</td>
<td>0.30882</td>
<td>0.10294</td>
<td>3.00000</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>36</td>
<td>729</td>
<td>11</td>
<td>2</td>
<td>108.8</td>
<td>16.3</td>
<td>5.6</td>
<td>0.29963</td>
<td>0.10294</td>
<td>2.91071</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>37</td>
<td>729</td>
<td>12</td>
<td>2</td>
<td>108.8</td>
<td>18.2</td>
<td>6.2</td>
<td>0.33456</td>
<td>0.11397</td>
<td>2.93548</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>38</td>
<td>729</td>
<td>13</td>
<td>2</td>
<td>108.8</td>
<td>24.9</td>
<td>6.8</td>
<td>0.45772</td>
<td>0.12500</td>
<td>3.66176</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>39</td>
<td>729</td>
<td>14</td>
<td>2</td>
<td>108.8</td>
<td>25.4</td>
<td>7.1</td>
<td>0.46961</td>
<td>0.13051</td>
<td>3.57746</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>40</td>
<td>729</td>
<td>15</td>
<td>2</td>
<td>108.8</td>
<td>18.8</td>
<td>6.5</td>
<td>0.34559</td>
<td>0.11949</td>
<td>2.89231</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>41</td>
<td>729</td>
<td>16</td>
<td>2</td>
<td>108.8</td>
<td>14.4</td>
<td>5.0</td>
<td>0.26471</td>
<td>0.09191</td>
<td>2.88000</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>42</td>
<td>729</td>
<td>17</td>
<td>2</td>
<td>108.8</td>
<td>19.9</td>
<td>6.8</td>
<td>0.36581</td>
<td>0.12500</td>
<td>2.92647</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>43</td>
<td>729</td>
<td>18</td>
<td>2</td>
<td>108.8</td>
<td>20.7</td>
<td>5.7</td>
<td>0.38051</td>
<td>0.10478</td>
<td>3.63158</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>44</td>
<td>729</td>
<td>19</td>
<td>2</td>
<td>108.8</td>
<td>16.8</td>
<td>5.9</td>
<td>0.30882</td>
<td>0.10846</td>
<td>2.84746</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>45</td>
<td>729</td>
<td>20</td>
<td>2</td>
<td>108.8</td>
<td>20.8</td>
<td>7.2</td>
<td>0.38235</td>
<td>0.13235</td>
<td>2.88889</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>46</td>
<td>729</td>
<td>21</td>
<td>2</td>
<td>108.8</td>
<td>17.3</td>
<td>6.2</td>
<td>0.31801</td>
<td>0.11397</td>
<td>2.79032</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>47</td>
<td>729</td>
<td>22</td>
<td>2</td>
<td>108.8</td>
<td>18.1</td>
<td>4.7</td>
<td>0.33272</td>
<td>0.08640</td>
<td>3.85106</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>48</td>
<td>729</td>
<td>23</td>
<td>2</td>
<td>108.8</td>
<td>18.3</td>
<td>6.4</td>
<td>0.33640</td>
<td>0.11765</td>
<td>2.85938</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>49</td>
<td>729</td>
<td>24</td>
<td>2</td>
<td>108.8</td>
<td>16.3</td>
<td>5.6</td>
<td>0.29963</td>
<td>0.10294</td>
<td>2.91071</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>50</td>
<td>729</td>
<td>25</td>
<td>2</td>
<td>108.8</td>
<td>18.3</td>
<td>6.3</td>
<td>0.33640</td>
<td>0.11581</td>
<td>2.90476</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>51</td>
<td>730</td>
<td>1</td>
<td>2</td>
<td>108.8</td>
<td>17.9</td>
<td>6.3</td>
<td>0.32904</td>
<td>0.11581</td>
<td>2.84127</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>52</td>
<td>730</td>
<td>2</td>
<td>2</td>
<td>108.8</td>
<td>12.9</td>
<td>4.0</td>
<td>0.23713</td>
<td>0.07353</td>
<td>3.22500</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>53</td>
<td>730</td>
<td>3</td>
<td>2</td>
<td>108.8</td>
<td>19.6</td>
<td>5.2</td>
<td>0.36029</td>
<td>0.09559</td>
<td>3.76923</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>54</td>
<td>730</td>
<td>4</td>
<td>2</td>
<td>108.8</td>
<td>21.3</td>
<td>7.4</td>
<td>0.39154</td>
<td>0.13603</td>
<td>2.87838</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
<td>L:W ratio</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>--------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>---------------------------</td>
<td>----------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>------------</td>
<td>----------</td>
</tr>
<tr>
<td>55</td>
<td>730</td>
<td>5</td>
<td>2</td>
<td>108.8</td>
<td>22.2</td>
<td>7.2</td>
<td>0.40809</td>
<td>0.13235</td>
<td>3.0833</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>56</td>
<td>730</td>
<td>6</td>
<td>2</td>
<td>108.8</td>
<td>21.2</td>
<td>6.8</td>
<td>0.38971</td>
<td>0.12500</td>
<td>3.11765</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>57</td>
<td>730</td>
<td>7</td>
<td>2</td>
<td>108.8</td>
<td>19.3</td>
<td>5.7</td>
<td>0.35478</td>
<td>0.10478</td>
<td>3.38596</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>58</td>
<td>730</td>
<td>8</td>
<td>2</td>
<td>108.8</td>
<td>24.9</td>
<td>7.0</td>
<td>0.45772</td>
<td>0.12868</td>
<td>3.55714</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>59</td>
<td>730</td>
<td>9</td>
<td>2</td>
<td>108.8</td>
<td>14.6</td>
<td>4.3</td>
<td>0.26838</td>
<td>0.07904</td>
<td>3.39535</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>60</td>
<td>730</td>
<td>10</td>
<td>2</td>
<td>108.8</td>
<td>23.6</td>
<td>7.2</td>
<td>0.43382</td>
<td>0.13235</td>
<td>3.27778</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>61</td>
<td>730</td>
<td>11</td>
<td>2</td>
<td>108.8</td>
<td>19.3</td>
<td>4.1</td>
<td>0.26654</td>
<td>0.07537</td>
<td>3.53659</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>62</td>
<td>730</td>
<td>12</td>
<td>2</td>
<td>108.8</td>
<td>15.0</td>
<td>4.1</td>
<td>0.27574</td>
<td>0.07537</td>
<td>3.65854</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>63</td>
<td>730</td>
<td>13</td>
<td>2</td>
<td>108.8</td>
<td>15.4</td>
<td>4.5</td>
<td>0.28309</td>
<td>0.08272</td>
<td>3.42222</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>64</td>
<td>730</td>
<td>14</td>
<td>2</td>
<td>108.8</td>
<td>16.1</td>
<td>5.1</td>
<td>0.29596</td>
<td>0.09375</td>
<td>3.15686</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>65</td>
<td>730</td>
<td>15</td>
<td>2</td>
<td>108.8</td>
<td>15.8</td>
<td>4.9</td>
<td>0.29044</td>
<td>0.09007</td>
<td>3.22449</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>66</td>
<td>730</td>
<td>16</td>
<td>2</td>
<td>108.8</td>
<td>12.5</td>
<td>4.6</td>
<td>0.22978</td>
<td>0.08456</td>
<td>2.71739</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>67</td>
<td>730</td>
<td>17</td>
<td>2</td>
<td>108.8</td>
<td>14.1</td>
<td>4.5</td>
<td>0.25919</td>
<td>0.08272</td>
<td>3.13333</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>68</td>
<td>730</td>
<td>18</td>
<td>2</td>
<td>108.8</td>
<td>14.1</td>
<td>4.8</td>
<td>0.25919</td>
<td>0.08824</td>
<td>2.93750</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>69</td>
<td>730</td>
<td>19</td>
<td>2</td>
<td>108.8</td>
<td>14.9</td>
<td>4.6</td>
<td>0.27390</td>
<td>0.08456</td>
<td>3.23913</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>70</td>
<td>730</td>
<td>20</td>
<td>2</td>
<td>108.8</td>
<td>13.6</td>
<td>4.0</td>
<td>0.25000</td>
<td>0.07353</td>
<td>3.40000</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>71</td>
<td>730</td>
<td>21</td>
<td>2</td>
<td>108.8</td>
<td>14.6</td>
<td>4.7</td>
<td>0.26838</td>
<td>0.08640</td>
<td>3.10638</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>72</td>
<td>730</td>
<td>22</td>
<td>2</td>
<td>108.8</td>
<td>15.6</td>
<td>5.3</td>
<td>0.28676</td>
<td>0.09743</td>
<td>2.94340</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>73</td>
<td>730</td>
<td>23</td>
<td>2</td>
<td>108.8</td>
<td>16.3</td>
<td>5.7</td>
<td>0.29963</td>
<td>0.10478</td>
<td>2.85965</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>74</td>
<td>730</td>
<td>24</td>
<td>2</td>
<td>108.8</td>
<td>12.2</td>
<td>4.1</td>
<td>0.22426</td>
<td>0.07537</td>
<td>2.97561</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>75</td>
<td>730</td>
<td>25</td>
<td>2</td>
<td>108.8</td>
<td>22.6</td>
<td>6.9</td>
<td>0.41544</td>
<td>0.12684</td>
<td>3.27536</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>76</td>
<td>839</td>
<td>1</td>
<td>2</td>
<td>54.5</td>
<td>8.4</td>
<td>2.8</td>
<td>0.30826</td>
<td>0.10275</td>
<td>3.00000</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>77</td>
<td>839</td>
<td>2</td>
<td>2</td>
<td>54.5</td>
<td>6.4</td>
<td>2.7</td>
<td>0.23486</td>
<td>0.09908</td>
<td>2.37037</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>78</td>
<td>839</td>
<td>3</td>
<td>2</td>
<td>54.5</td>
<td>8.7</td>
<td>3.3</td>
<td>0.31927</td>
<td>0.12110</td>
<td>2.63636</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>79</td>
<td>839</td>
<td>4</td>
<td>2</td>
<td>54.5</td>
<td>10.5</td>
<td>3.2</td>
<td>0.38532</td>
<td>0.11743</td>
<td>3.28125</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>80</td>
<td>839</td>
<td>5</td>
<td>2</td>
<td>54.5</td>
<td>7.5</td>
<td>2.4</td>
<td>0.27523</td>
<td>0.08807</td>
<td>3.12500</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>81</td>
<td>839</td>
<td>6</td>
<td>2</td>
<td>54.5</td>
<td>6.8</td>
<td>2.4</td>
<td>0.24954</td>
<td>0.08807</td>
<td>2.83333</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>82</td>
<td>839</td>
<td>7</td>
<td>2</td>
<td>54.5</td>
<td>11.0</td>
<td>3.0</td>
<td>0.40367</td>
<td>0.11009</td>
<td>3.66667</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>83</td>
<td>839</td>
<td>8</td>
<td>2</td>
<td>54.5</td>
<td>10.5</td>
<td>2.7</td>
<td>0.38532</td>
<td>0.09908</td>
<td>3.88889</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>84</td>
<td>839</td>
<td>9</td>
<td>2</td>
<td>54.5</td>
<td>8.1</td>
<td>2.8</td>
<td>0.29725</td>
<td>0.10275</td>
<td>2.89286</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>85</td>
<td>839</td>
<td>10</td>
<td>2</td>
<td>54.5</td>
<td>7.5</td>
<td>2.7</td>
<td>0.27523</td>
<td>0.09908</td>
<td>2.77778</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>86</td>
<td>839</td>
<td>11</td>
<td>2</td>
<td>54.5</td>
<td>7.6</td>
<td>2.9</td>
<td>0.27890</td>
<td>0.10642</td>
<td>2.62069</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>87</td>
<td>839</td>
<td>12</td>
<td>2</td>
<td>54.5</td>
<td>10.0</td>
<td>2.6</td>
<td>0.36697</td>
<td>0.09541</td>
<td>3.84615</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>88</td>
<td>839</td>
<td>13</td>
<td>2</td>
<td>54.5</td>
<td>7.1</td>
<td>2.8</td>
<td>0.26055</td>
<td>0.10275</td>
<td>2.53571</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
<td>L:W ratio</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>-------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>---------------------------</td>
<td>--------------------------</td>
<td>-------------------------</td>
<td>-------------------------</td>
<td>-----------</td>
<td>------------------</td>
</tr>
<tr>
<td>89</td>
<td>839</td>
<td>14</td>
<td>2</td>
<td>54.5</td>
<td>6.5</td>
<td>2.2</td>
<td>0.23853</td>
<td>0.08073</td>
<td>2.95455</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>90</td>
<td>839</td>
<td>15</td>
<td>2</td>
<td>54.5</td>
<td>8.3</td>
<td>2.7</td>
<td>0.30459</td>
<td>0.09908</td>
<td>3.07407</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>91</td>
<td>839</td>
<td>16</td>
<td>2</td>
<td>54.5</td>
<td>7.2</td>
<td>2.6</td>
<td>0.26422</td>
<td>0.09541</td>
<td>2.76923</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>92</td>
<td>839</td>
<td>17</td>
<td>2</td>
<td>54.5</td>
<td>7.4</td>
<td>2.6</td>
<td>0.27156</td>
<td>0.09541</td>
<td>2.84615</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>93</td>
<td>839</td>
<td>18</td>
<td>2</td>
<td>54.5</td>
<td>8.2</td>
<td>2.5</td>
<td>0.30092</td>
<td>0.09174</td>
<td>3.28000</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>94</td>
<td>839</td>
<td>19</td>
<td>2</td>
<td>54.5</td>
<td>6.9</td>
<td>2.8</td>
<td>0.25321</td>
<td>0.10275</td>
<td>2.46429</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>95</td>
<td>839</td>
<td>20</td>
<td>2</td>
<td>54.5</td>
<td>8.4</td>
<td>3.1</td>
<td>0.30826</td>
<td>0.11376</td>
<td>2.70968</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>96</td>
<td>839</td>
<td>21</td>
<td>2</td>
<td>54.5</td>
<td>6.4</td>
<td>2.0</td>
<td>0.23486</td>
<td>0.07339</td>
<td>3.20000</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>97</td>
<td>839</td>
<td>22</td>
<td>2</td>
<td>54.5</td>
<td>8.0</td>
<td>2.6</td>
<td>0.29358</td>
<td>0.09541</td>
<td>3.07692</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>98</td>
<td>839</td>
<td>23</td>
<td>2</td>
<td>54.5</td>
<td>7.2</td>
<td>2.4</td>
<td>0.26422</td>
<td>0.08807</td>
<td>3.00000</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>99</td>
<td>839</td>
<td>24</td>
<td>2</td>
<td>54.5</td>
<td>6.5</td>
<td>2.3</td>
<td>0.23853</td>
<td>0.08440</td>
<td>2.82609</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>100</td>
<td>839</td>
<td>25</td>
<td>2</td>
<td>54.5</td>
<td>6.3</td>
<td>2.2</td>
<td>0.23119</td>
<td>0.08073</td>
<td>2.86364</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>101</td>
<td>855</td>
<td>1</td>
<td>2</td>
<td>54.5</td>
<td>9.3</td>
<td>3.5</td>
<td>0.34128</td>
<td>0.12844</td>
<td>2.65714</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>102</td>
<td>855</td>
<td>2</td>
<td>2</td>
<td>54.5</td>
<td>7.0</td>
<td>2.7</td>
<td>0.25688</td>
<td>0.09908</td>
<td>2.59259</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>103</td>
<td>855</td>
<td>3</td>
<td>2</td>
<td>54.5</td>
<td>7.3</td>
<td>2.6</td>
<td>0.26789</td>
<td>0.09541</td>
<td>2.80769</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>104</td>
<td>855</td>
<td>4</td>
<td>2</td>
<td>54.5</td>
<td>7.6</td>
<td>2.8</td>
<td>0.27890</td>
<td>0.10275</td>
<td>2.71429</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>105</td>
<td>855</td>
<td>5</td>
<td>2</td>
<td>54.5</td>
<td>8.2</td>
<td>3.3</td>
<td>0.30092</td>
<td>0.12110</td>
<td>2.48485</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>106</td>
<td>855</td>
<td>6</td>
<td>2</td>
<td>54.5</td>
<td>7.0</td>
<td>2.7</td>
<td>0.25688</td>
<td>0.09908</td>
<td>2.59259</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>107</td>
<td>855</td>
<td>7</td>
<td>2</td>
<td>54.5</td>
<td>10.7</td>
<td>3.3</td>
<td>0.39266</td>
<td>0.12110</td>
<td>3.24242</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>108</td>
<td>855</td>
<td>8</td>
<td>2</td>
<td>54.5</td>
<td>12.7</td>
<td>3.1</td>
<td>0.46606</td>
<td>0.11376</td>
<td>4.09677</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>109</td>
<td>855</td>
<td>9</td>
<td>2</td>
<td>54.5</td>
<td>8.7</td>
<td>3.1</td>
<td>0.31927</td>
<td>0.11376</td>
<td>2.80645</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>110</td>
<td>855</td>
<td>10</td>
<td>2</td>
<td>54.5</td>
<td>7.7</td>
<td>2.8</td>
<td>0.28257</td>
<td>0.10275</td>
<td>2.75000</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>111</td>
<td>855</td>
<td>11</td>
<td>2</td>
<td>54.5</td>
<td>7.3</td>
<td>2.9</td>
<td>0.26789</td>
<td>0.10642</td>
<td>2.51724</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>112</td>
<td>855</td>
<td>12</td>
<td>2</td>
<td>54.5</td>
<td>7.6</td>
<td>2.9</td>
<td>0.27890</td>
<td>0.10642</td>
<td>2.62069</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>113</td>
<td>855</td>
<td>13</td>
<td>2</td>
<td>54.5</td>
<td>10.5</td>
<td>3.2</td>
<td>0.38532</td>
<td>0.11743</td>
<td>3.28125</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>114</td>
<td>855</td>
<td>14</td>
<td>2</td>
<td>54.5</td>
<td>7.7</td>
<td>2.9</td>
<td>0.28257</td>
<td>0.10642</td>
<td>2.65517</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>115</td>
<td>855</td>
<td>15</td>
<td>2</td>
<td>54.5</td>
<td>8.0</td>
<td>2.8</td>
<td>0.29358</td>
<td>0.10275</td>
<td>2.85714</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>116</td>
<td>855</td>
<td>16</td>
<td>2</td>
<td>54.5</td>
<td>9.3</td>
<td>2.8</td>
<td>0.34128</td>
<td>0.10275</td>
<td>3.32143</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>117</td>
<td>855</td>
<td>17</td>
<td>2</td>
<td>54.5</td>
<td>8.5</td>
<td>3.0</td>
<td>0.31193</td>
<td>0.11009</td>
<td>2.83333</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>118</td>
<td>855</td>
<td>18</td>
<td>2</td>
<td>54.5</td>
<td>7.1</td>
<td>2.7</td>
<td>0.26055</td>
<td>0.09908</td>
<td>2.62963</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>119</td>
<td>855</td>
<td>19</td>
<td>2</td>
<td>54.5</td>
<td>7.4</td>
<td>2.5</td>
<td>0.27156</td>
<td>0.09174</td>
<td>2.90000</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>120</td>
<td>855</td>
<td>20</td>
<td>2</td>
<td>54.5</td>
<td>10.1</td>
<td>3.3</td>
<td>0.37064</td>
<td>0.12110</td>
<td>3.06061</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>121</td>
<td>855</td>
<td>21</td>
<td>2</td>
<td>54.5</td>
<td>7.1</td>
<td>2.8</td>
<td>0.26055</td>
<td>0.10275</td>
<td>2.53571</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>122</td>
<td>855</td>
<td>22</td>
<td>2</td>
<td>54.5</td>
<td>8.0</td>
<td>2.8</td>
<td>0.29358</td>
<td>0.10275</td>
<td>2.85714</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
<td>L:W ratio</td>
<td>Category</td>
</tr>
<tr>
<td>---------</td>
<td>--------------</td>
<td>-------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>---------------------------</td>
<td>--------------------------</td>
<td>-------------------------</td>
<td>--------------------------</td>
<td>----------------</td>
<td>------------------</td>
</tr>
<tr>
<td>123</td>
<td>855</td>
<td>23</td>
<td>2</td>
<td>54.5</td>
<td>7.3</td>
<td>3.0</td>
<td>0.26789</td>
<td>0.11009</td>
<td>2.43333</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>124</td>
<td>855</td>
<td>24</td>
<td>2</td>
<td>54.5</td>
<td>6.6</td>
<td>2.5</td>
<td>0.24220</td>
<td>0.09174</td>
<td>2.64000</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>125</td>
<td>855</td>
<td>25</td>
<td>2</td>
<td>54.5</td>
<td>8.5</td>
<td>3.2</td>
<td>0.31193</td>
<td>0.11743</td>
<td>2.65625</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>126</td>
<td>885</td>
<td>1</td>
<td>2</td>
<td>27.4</td>
<td>4.9</td>
<td>1.8</td>
<td>0.35766</td>
<td>0.13139</td>
<td>2.72222</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>127</td>
<td>885</td>
<td>2</td>
<td>2</td>
<td>27.4</td>
<td>4.7</td>
<td>1.6</td>
<td>0.34307</td>
<td>0.11679</td>
<td>2.93750</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>128</td>
<td>885</td>
<td>3</td>
<td>2</td>
<td>27.4</td>
<td>5.8</td>
<td>1.8</td>
<td>0.42336</td>
<td>0.13139</td>
<td>3.22222</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>129</td>
<td>885</td>
<td>4</td>
<td>2</td>
<td>27.4</td>
<td>5.5</td>
<td>1.7</td>
<td>0.40146</td>
<td>0.12409</td>
<td>3.23529</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>130</td>
<td>885</td>
<td>5</td>
<td>2</td>
<td>27.4</td>
<td>4.6</td>
<td>1.7</td>
<td>0.33577</td>
<td>0.12409</td>
<td>2.70588</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>131</td>
<td>885</td>
<td>6</td>
<td>2</td>
<td>27.4</td>
<td>4.0</td>
<td>1.5</td>
<td>0.29197</td>
<td>0.10949</td>
<td>2.66667</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>132</td>
<td>885</td>
<td>7</td>
<td>2</td>
<td>27.4</td>
<td>4.1</td>
<td>1.6</td>
<td>0.29927</td>
<td>0.11679</td>
<td>2.56250</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>133</td>
<td>885</td>
<td>8</td>
<td>2</td>
<td>27.4</td>
<td>4.4</td>
<td>1.8</td>
<td>0.32117</td>
<td>0.13139</td>
<td>2.44444</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>134</td>
<td>885</td>
<td>9</td>
<td>2</td>
<td>27.4</td>
<td>4.5</td>
<td>1.7</td>
<td>0.32847</td>
<td>0.12409</td>
<td>2.64706</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>135</td>
<td>885</td>
<td>10</td>
<td>2</td>
<td>27.4</td>
<td>4.0</td>
<td>1.5</td>
<td>0.29197</td>
<td>0.10949</td>
<td>2.66667</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>136</td>
<td>885</td>
<td>11</td>
<td>2</td>
<td>27.4</td>
<td>4.0</td>
<td>1.6</td>
<td>0.29197</td>
<td>0.11679</td>
<td>2.50000</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>137</td>
<td>885</td>
<td>12</td>
<td>2</td>
<td>27.4</td>
<td>3.4</td>
<td>1.2</td>
<td>0.24818</td>
<td>0.08759</td>
<td>2.83333</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>138</td>
<td>885</td>
<td>13</td>
<td>2</td>
<td>27.4</td>
<td>5.2</td>
<td>1.5</td>
<td>0.37956</td>
<td>0.10949</td>
<td>3.46667</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>139</td>
<td>885</td>
<td>14</td>
<td>2</td>
<td>27.4</td>
<td>4.1</td>
<td>1.7</td>
<td>0.29927</td>
<td>0.12409</td>
<td>2.41176</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>140</td>
<td>885</td>
<td>15</td>
<td>2</td>
<td>27.4</td>
<td>5.8</td>
<td>2.1</td>
<td>0.42336</td>
<td>0.15328</td>
<td>2.76190</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>141</td>
<td>885</td>
<td>16</td>
<td>2</td>
<td>27.4</td>
<td>5.2</td>
<td>2.0</td>
<td>0.37956</td>
<td>0.14599</td>
<td>2.60000</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>142</td>
<td>885</td>
<td>17</td>
<td>2</td>
<td>27.4</td>
<td>3.9</td>
<td>1.4</td>
<td>0.28467</td>
<td>0.10219</td>
<td>2.78571</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>143</td>
<td>885</td>
<td>18</td>
<td>2</td>
<td>27.4</td>
<td>4.2</td>
<td>1.6</td>
<td>0.30657</td>
<td>0.11679</td>
<td>2.62500</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>144</td>
<td>885</td>
<td>19</td>
<td>2</td>
<td>27.4</td>
<td>3.7</td>
<td>1.3</td>
<td>0.27007</td>
<td>0.09489</td>
<td>2.84615</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>145</td>
<td>885</td>
<td>20</td>
<td>2</td>
<td>27.4</td>
<td>5.9</td>
<td>1.8</td>
<td>0.43066</td>
<td>0.13139</td>
<td>3.27778</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>146</td>
<td>885</td>
<td>21</td>
<td>2</td>
<td>27.4</td>
<td>5.4</td>
<td>2.1</td>
<td>0.39416</td>
<td>0.15328</td>
<td>2.57143</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>147</td>
<td>885</td>
<td>22</td>
<td>2</td>
<td>27.4</td>
<td>4.7</td>
<td>1.5</td>
<td>0.34307</td>
<td>0.10949</td>
<td>3.13333</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>148</td>
<td>885</td>
<td>23</td>
<td>2</td>
<td>27.4</td>
<td>3.8</td>
<td>1.4</td>
<td>0.27737</td>
<td>0.10219</td>
<td>2.71429</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>149</td>
<td>885</td>
<td>24</td>
<td>2</td>
<td>27.4</td>
<td>4.0</td>
<td>1.5</td>
<td>0.29197</td>
<td>0.10949</td>
<td>2.66667</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>150</td>
<td>885</td>
<td>25</td>
<td>2</td>
<td>27.4</td>
<td>4.3</td>
<td>1.7</td>
<td>0.31387</td>
<td>0.12409</td>
<td>2.52941</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>151</td>
<td>890</td>
<td>1</td>
<td>2</td>
<td>54.5</td>
<td>8.2</td>
<td>3.5</td>
<td>0.30092</td>
<td>0.12844</td>
<td>2.34286</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>152</td>
<td>890</td>
<td>2</td>
<td>2</td>
<td>54.5</td>
<td>9.7</td>
<td>3.5</td>
<td>0.35596</td>
<td>0.12844</td>
<td>2.77143</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>153</td>
<td>890</td>
<td>3</td>
<td>2</td>
<td>54.5</td>
<td>10.4</td>
<td>3.0</td>
<td>0.38165</td>
<td>0.11009</td>
<td>3.46667</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>154</td>
<td>890</td>
<td>4</td>
<td>2</td>
<td>54.5</td>
<td>6.8</td>
<td>2.6</td>
<td>0.24954</td>
<td>0.09541</td>
<td>2.61538</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>155</td>
<td>890</td>
<td>5</td>
<td>2</td>
<td>54.5</td>
<td>7.1</td>
<td>2.8</td>
<td>0.26055</td>
<td>0.10275</td>
<td>2.53571</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>156</td>
<td>890</td>
<td>6</td>
<td>2</td>
<td>54.5</td>
<td>6.6</td>
<td>2.4</td>
<td>0.24220</td>
<td>0.08807</td>
<td>2.75000</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
<td>L:W ratio</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>-------------------</td>
<td>-----------------------</td>
<td>--------------------------</td>
<td>----------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>-----------</td>
<td>------------------------</td>
</tr>
<tr>
<td>157</td>
<td>890</td>
<td>7</td>
<td>2</td>
<td>54.5</td>
<td>7.1</td>
<td>2.6</td>
<td>0.26055</td>
<td>0.09541</td>
<td>2.73077</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>158</td>
<td>890</td>
<td>8</td>
<td>2</td>
<td>54.5</td>
<td>6.3</td>
<td>2.3</td>
<td>0.23119</td>
<td>0.08440</td>
<td>2.73913</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>159</td>
<td>890</td>
<td>9</td>
<td>2</td>
<td>54.5</td>
<td>6.5</td>
<td>2.7</td>
<td>0.23853</td>
<td>0.09908</td>
<td>2.40741</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>160</td>
<td>890</td>
<td>10</td>
<td>2</td>
<td>54.5</td>
<td>8.4</td>
<td>2.9</td>
<td>0.30826</td>
<td>0.10642</td>
<td>2.89655</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>161</td>
<td>890</td>
<td>11</td>
<td>2</td>
<td>54.5</td>
<td>10.4</td>
<td>2.9</td>
<td>0.38165</td>
<td>0.10642</td>
<td>3.58621</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>162</td>
<td>890</td>
<td>12</td>
<td>2</td>
<td>54.5</td>
<td>8.9</td>
<td>2.7</td>
<td>0.32661</td>
<td>0.09908</td>
<td>3.29630</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>163</td>
<td>890</td>
<td>13</td>
<td>2</td>
<td>54.5</td>
<td>7.6</td>
<td>2.3</td>
<td>0.27890</td>
<td>0.08440</td>
<td>3.30435</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>164</td>
<td>890</td>
<td>14</td>
<td>2</td>
<td>54.5</td>
<td>9.0</td>
<td>3.3</td>
<td>0.33028</td>
<td>0.12110</td>
<td>2.72727</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>165</td>
<td>890</td>
<td>15</td>
<td>2</td>
<td>54.5</td>
<td>8.0</td>
<td>2.8</td>
<td>0.29358</td>
<td>0.10275</td>
<td>2.85714</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>166</td>
<td>890</td>
<td>16</td>
<td>2</td>
<td>54.5</td>
<td>10.3</td>
<td>3.4</td>
<td>0.37798</td>
<td>0.12477</td>
<td>3.02941</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>167</td>
<td>890</td>
<td>17</td>
<td>2</td>
<td>54.5</td>
<td>7.1</td>
<td>2.4</td>
<td>0.26055</td>
<td>0.08807</td>
<td>2.95833</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>168</td>
<td>890</td>
<td>18</td>
<td>2</td>
<td>54.5</td>
<td>7.5</td>
<td>2.6</td>
<td>0.27523</td>
<td>0.09541</td>
<td>2.88462</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>169</td>
<td>890</td>
<td>19</td>
<td>2</td>
<td>54.5</td>
<td>8.0</td>
<td>2.9</td>
<td>0.29358</td>
<td>0.10642</td>
<td>2.75862</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>170</td>
<td>890</td>
<td>20</td>
<td>2</td>
<td>54.5</td>
<td>8.3</td>
<td>2.3</td>
<td>0.30459</td>
<td>0.08440</td>
<td>3.60870</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>171</td>
<td>890</td>
<td>21</td>
<td>2</td>
<td>54.5</td>
<td>7.7</td>
<td>2.8</td>
<td>0.28257</td>
<td>0.10275</td>
<td>2.75000</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>172</td>
<td>890</td>
<td>22</td>
<td>2</td>
<td>54.5</td>
<td>7.3</td>
<td>2.6</td>
<td>0.26789</td>
<td>0.09541</td>
<td>2.80769</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>173</td>
<td>890</td>
<td>23</td>
<td>2</td>
<td>54.5</td>
<td>7.1</td>
<td>2.8</td>
<td>0.26055</td>
<td>0.10275</td>
<td>2.53571</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>174</td>
<td>890</td>
<td>24</td>
<td>2</td>
<td>54.5</td>
<td>7.1</td>
<td>2.8</td>
<td>0.26055</td>
<td>0.10275</td>
<td>2.53571</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>175</td>
<td>890</td>
<td>25</td>
<td>2</td>
<td>54.5</td>
<td>6.4</td>
<td>2.4</td>
<td>0.23486</td>
<td>0.08807</td>
<td>2.66667</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>176</td>
<td>1152</td>
<td>1</td>
<td>2</td>
<td>54.5</td>
<td>8.5</td>
<td>2.9</td>
<td>0.31193</td>
<td>0.10642</td>
<td>2.93103</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>177</td>
<td>1152</td>
<td>2</td>
<td>2</td>
<td>54.5</td>
<td>6.4</td>
<td>2.3</td>
<td>0.23486</td>
<td>0.08440</td>
<td>2.78261</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>178</td>
<td>1152</td>
<td>3</td>
<td>2</td>
<td>54.5</td>
<td>9.9</td>
<td>3.2</td>
<td>0.36330</td>
<td>0.11743</td>
<td>3.09375</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>179</td>
<td>1152</td>
<td>4</td>
<td>2</td>
<td>54.5</td>
<td>7.5</td>
<td>2.5</td>
<td>0.27523</td>
<td>0.09174</td>
<td>3.00000</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>180</td>
<td>1152</td>
<td>5</td>
<td>2</td>
<td>54.5</td>
<td>9.5</td>
<td>3.2</td>
<td>0.34862</td>
<td>0.11743</td>
<td>2.96875</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>181</td>
<td>1152</td>
<td>6</td>
<td>2</td>
<td>54.5</td>
<td>7.0</td>
<td>2.2</td>
<td>0.25688</td>
<td>0.08073</td>
<td>3.18182</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>182</td>
<td>1152</td>
<td>7</td>
<td>2</td>
<td>54.5</td>
<td>5.9</td>
<td>1.9</td>
<td>0.21651</td>
<td>0.06972</td>
<td>3.10526</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>183</td>
<td>1152</td>
<td>8</td>
<td>2</td>
<td>54.5</td>
<td>6.9</td>
<td>2.3</td>
<td>0.25321</td>
<td>0.08440</td>
<td>3.00000</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>184</td>
<td>1152</td>
<td>9</td>
<td>2</td>
<td>54.5</td>
<td>8.8</td>
<td>2.4</td>
<td>0.32294</td>
<td>0.08807</td>
<td>3.66667</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>185</td>
<td>1152</td>
<td>10</td>
<td>2</td>
<td>54.5</td>
<td>7.7</td>
<td>2.9</td>
<td>0.28257</td>
<td>0.10642</td>
<td>2.65517</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>186</td>
<td>1152</td>
<td>11</td>
<td>2</td>
<td>54.5</td>
<td>7.0</td>
<td>2.7</td>
<td>0.25688</td>
<td>0.09908</td>
<td>2.59259</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>187</td>
<td>1152</td>
<td>12</td>
<td>2</td>
<td>54.5</td>
<td>5.8</td>
<td>2.2</td>
<td>0.21284</td>
<td>0.08073</td>
<td>2.63636</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>188</td>
<td>1152</td>
<td>13</td>
<td>2</td>
<td>54.5</td>
<td>7.5</td>
<td>2.6</td>
<td>0.27523</td>
<td>0.09541</td>
<td>2.88462</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>189</td>
<td>1152</td>
<td>14</td>
<td>2</td>
<td>54.5</td>
<td>8.8</td>
<td>3.2</td>
<td>0.32294</td>
<td>0.11743</td>
<td>2.75000</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>190</td>
<td>1152</td>
<td>15</td>
<td>2</td>
<td>54.5</td>
<td>9.7</td>
<td>2.7</td>
<td>0.35596</td>
<td>0.09908</td>
<td>3.59259</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
<td>L:W ratio</td>
<td>Category</td>
</tr>
<tr>
<td>---------</td>
<td>--------------</td>
<td>-------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>----------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>-----------</td>
<td>-------------------</td>
</tr>
<tr>
<td>191</td>
<td>1152</td>
<td>16</td>
<td>2</td>
<td>54.5</td>
<td>9.1</td>
<td>2.7</td>
<td>0.33394</td>
<td>0.09908</td>
<td>3.37037</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>192</td>
<td>1152</td>
<td>17</td>
<td>2</td>
<td>54.5</td>
<td>6.5</td>
<td>2.2</td>
<td>0.23853</td>
<td>0.08073</td>
<td>2.95455</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>193</td>
<td>1152</td>
<td>18</td>
<td>2</td>
<td>54.5</td>
<td>7.4</td>
<td>2.6</td>
<td>0.27156</td>
<td>0.09541</td>
<td>2.84615</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>194</td>
<td>1152</td>
<td>19</td>
<td>2</td>
<td>54.5</td>
<td>8.6</td>
<td>2.7</td>
<td>0.31560</td>
<td>0.09908</td>
<td>3.18519</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>195</td>
<td>1152</td>
<td>20</td>
<td>2</td>
<td>54.5</td>
<td>8.4</td>
<td>2.9</td>
<td>0.30826</td>
<td>0.10642</td>
<td>2.89655</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>196</td>
<td>1152</td>
<td>21</td>
<td>2</td>
<td>54.5</td>
<td>6.4</td>
<td>2.1</td>
<td>0.23486</td>
<td>0.07706</td>
<td>3.04762</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>197</td>
<td>1152</td>
<td>22</td>
<td>2</td>
<td>54.5</td>
<td>8.3</td>
<td>2.7</td>
<td>0.30459</td>
<td>0.09908</td>
<td>3.07407</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>198</td>
<td>1152</td>
<td>23</td>
<td>2</td>
<td>54.5</td>
<td>5.0</td>
<td>2.0</td>
<td>0.18349</td>
<td>0.07339</td>
<td>2.50000</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>199</td>
<td>1152</td>
<td>24</td>
<td>2</td>
<td>54.5</td>
<td>8.2</td>
<td>2.8</td>
<td>0.30092</td>
<td>0.10275</td>
<td>2.92857</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>200</td>
<td>1152</td>
<td>25</td>
<td>2</td>
<td>54.5</td>
<td>7.0</td>
<td>2.4</td>
<td>0.25688</td>
<td>0.08807</td>
<td>2.91667</td>
<td>tangential bladed</td>
</tr>
<tr>
<td>1</td>
<td>690</td>
<td>1</td>
<td>1</td>
<td>163.1</td>
<td>22.2</td>
<td>21.0</td>
<td>0.13611</td>
<td>0.12876</td>
<td>1.05714</td>
<td>random equant</td>
</tr>
<tr>
<td>2</td>
<td>690</td>
<td>2</td>
<td>1</td>
<td>163.1</td>
<td>23.2</td>
<td>22.9</td>
<td>0.14224</td>
<td>0.14040</td>
<td>1.01310</td>
<td>random equant</td>
</tr>
<tr>
<td>3</td>
<td>690</td>
<td>3</td>
<td>1</td>
<td>163.1</td>
<td>21.7</td>
<td>16.9</td>
<td>0.13305</td>
<td>0.10362</td>
<td>1.28402</td>
<td>random equant</td>
</tr>
<tr>
<td>4</td>
<td>690</td>
<td>4</td>
<td>1</td>
<td>163.1</td>
<td>21.7</td>
<td>19.6</td>
<td>0.13305</td>
<td>0.12017</td>
<td>1.10714</td>
<td>random equant</td>
</tr>
<tr>
<td>5</td>
<td>690</td>
<td>5</td>
<td>1</td>
<td>163.1</td>
<td>21.8</td>
<td>21.7</td>
<td>0.13366</td>
<td>0.13305</td>
<td>1.00461</td>
<td>random equant</td>
</tr>
<tr>
<td>6</td>
<td>690</td>
<td>6</td>
<td>1</td>
<td>163.1</td>
<td>19.8</td>
<td>18.9</td>
<td>0.12140</td>
<td>0.11588</td>
<td>1.04762</td>
<td>random equant</td>
</tr>
<tr>
<td>7</td>
<td>690</td>
<td>7</td>
<td>1</td>
<td>163.1</td>
<td>17.1</td>
<td>15.9</td>
<td>0.10484</td>
<td>0.09749</td>
<td>1.07547</td>
<td>random equant</td>
</tr>
<tr>
<td>8</td>
<td>690</td>
<td>8</td>
<td>1</td>
<td>163.1</td>
<td>17.3</td>
<td>13.6</td>
<td>0.10607</td>
<td>0.08338</td>
<td>1.27206</td>
<td>random equant</td>
</tr>
<tr>
<td>9</td>
<td>690</td>
<td>9</td>
<td>1</td>
<td>163.1</td>
<td>17.8</td>
<td>15.9</td>
<td>0.10914</td>
<td>0.09749</td>
<td>1.11950</td>
<td>random equant</td>
</tr>
<tr>
<td>10</td>
<td>690</td>
<td>10</td>
<td>1</td>
<td>163.1</td>
<td>22.3</td>
<td>21.5</td>
<td>0.13673</td>
<td>0.13182</td>
<td>1.03721</td>
<td>random equant</td>
</tr>
<tr>
<td>11</td>
<td>690</td>
<td>11</td>
<td>1</td>
<td>163.1</td>
<td>22.1</td>
<td>17.8</td>
<td>0.13550</td>
<td>0.10914</td>
<td>1.24157</td>
<td>random equant</td>
</tr>
<tr>
<td>12</td>
<td>690</td>
<td>12</td>
<td>1</td>
<td>163.1</td>
<td>21.8</td>
<td>19.9</td>
<td>0.13366</td>
<td>0.12201</td>
<td>1.09548</td>
<td>random equant</td>
</tr>
<tr>
<td>13</td>
<td>690</td>
<td>13</td>
<td>1</td>
<td>163.1</td>
<td>26.6</td>
<td>23.3</td>
<td>0.16309</td>
<td>0.14286</td>
<td>1.14163</td>
<td>random equant</td>
</tr>
<tr>
<td>14</td>
<td>690</td>
<td>14</td>
<td>1</td>
<td>163.1</td>
<td>23.6</td>
<td>21.3</td>
<td>0.14470</td>
<td>0.13059</td>
<td>1.10798</td>
<td>random equant</td>
</tr>
<tr>
<td>15</td>
<td>690</td>
<td>15</td>
<td>1</td>
<td>163.1</td>
<td>23.5</td>
<td>22.8</td>
<td>0.14408</td>
<td>0.13979</td>
<td>1.03070</td>
<td>random equant</td>
</tr>
<tr>
<td>16</td>
<td>690</td>
<td>16</td>
<td>1</td>
<td>163.1</td>
<td>18.7</td>
<td>18.2</td>
<td>0.11465</td>
<td>0.11159</td>
<td>1.02747</td>
<td>random equant</td>
</tr>
<tr>
<td>17</td>
<td>690</td>
<td>17</td>
<td>1</td>
<td>163.1</td>
<td>17.4</td>
<td>17.3</td>
<td>0.10668</td>
<td>0.10607</td>
<td>1.00578</td>
<td>random equant</td>
</tr>
<tr>
<td>18</td>
<td>690</td>
<td>18</td>
<td>1</td>
<td>163.1</td>
<td>21.8</td>
<td>16.2</td>
<td>0.13366</td>
<td>0.09933</td>
<td>1.34568</td>
<td>random equant</td>
</tr>
<tr>
<td>19</td>
<td>690</td>
<td>19</td>
<td>1</td>
<td>163.1</td>
<td>25.6</td>
<td>22.6</td>
<td>0.15696</td>
<td>0.13857</td>
<td>1.13274</td>
<td>random equant</td>
</tr>
<tr>
<td>20</td>
<td>690</td>
<td>20</td>
<td>1</td>
<td>163.1</td>
<td>22.9</td>
<td>16.9</td>
<td>0.14040</td>
<td>0.10362</td>
<td>1.35503</td>
<td>random equant</td>
</tr>
<tr>
<td>21</td>
<td>690</td>
<td>21</td>
<td>1</td>
<td>163.1</td>
<td>28.3</td>
<td>22.8</td>
<td>0.17351</td>
<td>0.13979</td>
<td>1.24123</td>
<td>random equant</td>
</tr>
<tr>
<td>22</td>
<td>690</td>
<td>22</td>
<td>1</td>
<td>163.1</td>
<td>20.5</td>
<td>17.3</td>
<td>0.12569</td>
<td>0.10607</td>
<td>1.18497</td>
<td>random equant</td>
</tr>
<tr>
<td>23</td>
<td>690</td>
<td>23</td>
<td>1</td>
<td>163.1</td>
<td>23.6</td>
<td>19.7</td>
<td>0.14470</td>
<td>0.12078</td>
<td>1.19797</td>
<td>random equant</td>
</tr>
<tr>
<td>24</td>
<td>690</td>
<td>24</td>
<td>1</td>
<td>163.1</td>
<td>18.0</td>
<td>16.0</td>
<td>0.11036</td>
<td>0.09810</td>
<td>1.12500</td>
<td>random equant</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
<td>L:W ratio</td>
<td>Category</td>
</tr>
<tr>
<td>---------</td>
<td>--------------</td>
<td>-------------------</td>
<td>-----------------------</td>
<td>--------------------------</td>
<td>---------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>-----------</td>
<td>------------------------</td>
</tr>
<tr>
<td>25</td>
<td>690</td>
<td>25</td>
<td>1</td>
<td>163.1</td>
<td>17.3</td>
<td>14.2</td>
<td>0.10607</td>
<td>0.08706</td>
<td>1.21831</td>
<td>random equant</td>
</tr>
<tr>
<td>26</td>
<td>776</td>
<td>1</td>
<td>2</td>
<td>27.4</td>
<td>2.7</td>
<td>2.6</td>
<td>0.19708</td>
<td>0.18978</td>
<td>1.03846</td>
<td>random equant</td>
</tr>
<tr>
<td>27</td>
<td>776</td>
<td>2</td>
<td>2</td>
<td>27.4</td>
<td>3.5</td>
<td>2.4</td>
<td>0.25547</td>
<td>0.17518</td>
<td>1.45833</td>
<td>random equant</td>
</tr>
<tr>
<td>28</td>
<td>776</td>
<td>3</td>
<td>2</td>
<td>27.4</td>
<td>4.0</td>
<td>3.3</td>
<td>0.29197</td>
<td>0.24088</td>
<td>1.21212</td>
<td>random equant</td>
</tr>
<tr>
<td>29</td>
<td>776</td>
<td>4</td>
<td>2</td>
<td>27.4</td>
<td>4.4</td>
<td>3.2</td>
<td>0.32117</td>
<td>0.23358</td>
<td>1.37500</td>
<td>random equant</td>
</tr>
<tr>
<td>30</td>
<td>776</td>
<td>5</td>
<td>2</td>
<td>27.4</td>
<td>4.1</td>
<td>3.3</td>
<td>0.29927</td>
<td>0.24088</td>
<td>1.24242</td>
<td>random equant</td>
</tr>
<tr>
<td>31</td>
<td>776</td>
<td>6</td>
<td>2</td>
<td>27.4</td>
<td>3.4</td>
<td>3.0</td>
<td>0.24818</td>
<td>0.21898</td>
<td>1.13333</td>
<td>random equant</td>
</tr>
<tr>
<td>32</td>
<td>776</td>
<td>7</td>
<td>2</td>
<td>27.4</td>
<td>4.0</td>
<td>2.5</td>
<td>0.29197</td>
<td>0.18248</td>
<td>1.60000</td>
<td>random equant</td>
</tr>
<tr>
<td>33</td>
<td>776</td>
<td>8</td>
<td>2</td>
<td>27.4</td>
<td>3.4</td>
<td>2.9</td>
<td>0.24818</td>
<td>0.21168</td>
<td>1.17241</td>
<td>random equant</td>
</tr>
<tr>
<td>34</td>
<td>776</td>
<td>9</td>
<td>2</td>
<td>27.4</td>
<td>3.5</td>
<td>3.0</td>
<td>0.25547</td>
<td>0.21898</td>
<td>1.16667</td>
<td>random equant</td>
</tr>
<tr>
<td>35</td>
<td>776</td>
<td>10</td>
<td>2</td>
<td>27.4</td>
<td>3.8</td>
<td>3.4</td>
<td>0.27737</td>
<td>0.24818</td>
<td>1.11765</td>
<td>random equant</td>
</tr>
<tr>
<td>36</td>
<td>776</td>
<td>11</td>
<td>2</td>
<td>27.4</td>
<td>3.1</td>
<td>2.7</td>
<td>0.22628</td>
<td>0.19708</td>
<td>1.14815</td>
<td>random equant</td>
</tr>
<tr>
<td>37</td>
<td>776</td>
<td>12</td>
<td>2</td>
<td>27.4</td>
<td>2.9</td>
<td>2.3</td>
<td>0.21168</td>
<td>0.16788</td>
<td>1.26087</td>
<td>random equant</td>
</tr>
<tr>
<td>38</td>
<td>776</td>
<td>13</td>
<td>2</td>
<td>27.4</td>
<td>3.7</td>
<td>2.6</td>
<td>0.27007</td>
<td>0.18978</td>
<td>1.42308</td>
<td>random equant</td>
</tr>
<tr>
<td>39</td>
<td>776</td>
<td>14</td>
<td>2</td>
<td>27.4</td>
<td>3.7</td>
<td>2.9</td>
<td>0.27007</td>
<td>0.21168</td>
<td>1.27586</td>
<td>random equant</td>
</tr>
<tr>
<td>40</td>
<td>776</td>
<td>15</td>
<td>2</td>
<td>27.4</td>
<td>3.0</td>
<td>2.5</td>
<td>0.21898</td>
<td>0.18248</td>
<td>1.20000</td>
<td>random equant</td>
</tr>
<tr>
<td>41</td>
<td>776</td>
<td>16</td>
<td>2</td>
<td>27.4</td>
<td>4.3</td>
<td>3.4</td>
<td>0.31387</td>
<td>0.24818</td>
<td>1.26471</td>
<td>random equant</td>
</tr>
<tr>
<td>42</td>
<td>776</td>
<td>17</td>
<td>2</td>
<td>27.4</td>
<td>3.9</td>
<td>3.6</td>
<td>0.28467</td>
<td>0.26277</td>
<td>1.08333</td>
<td>random equant</td>
</tr>
<tr>
<td>43</td>
<td>776</td>
<td>18</td>
<td>2</td>
<td>27.4</td>
<td>3.5</td>
<td>2.6</td>
<td>0.25547</td>
<td>0.18978</td>
<td>1.34615</td>
<td>random equant</td>
</tr>
<tr>
<td>44</td>
<td>776</td>
<td>19</td>
<td>2</td>
<td>27.4</td>
<td>3.7</td>
<td>3.3</td>
<td>0.27007</td>
<td>0.24088</td>
<td>1.12121</td>
<td>random equant</td>
</tr>
<tr>
<td>45</td>
<td>776</td>
<td>20</td>
<td>2</td>
<td>27.4</td>
<td>3.9</td>
<td>2.8</td>
<td>0.28467</td>
<td>0.20438</td>
<td>1.39286</td>
<td>random equant</td>
</tr>
<tr>
<td>46</td>
<td>776</td>
<td>21</td>
<td>2</td>
<td>27.4</td>
<td>3.8</td>
<td>3.4</td>
<td>0.27737</td>
<td>0.24818</td>
<td>1.11765</td>
<td>random equant</td>
</tr>
<tr>
<td>47</td>
<td>776</td>
<td>22</td>
<td>2</td>
<td>27.4</td>
<td>3.6</td>
<td>2.5</td>
<td>0.26277</td>
<td>0.18248</td>
<td>1.44000</td>
<td>random equant</td>
</tr>
<tr>
<td>48</td>
<td>776</td>
<td>23</td>
<td>2</td>
<td>27.4</td>
<td>4.1</td>
<td>3.7</td>
<td>0.29927</td>
<td>0.27007</td>
<td>1.10811</td>
<td>random equant</td>
</tr>
<tr>
<td>49</td>
<td>776</td>
<td>24</td>
<td>2</td>
<td>27.4</td>
<td>3.1</td>
<td>2.5</td>
<td>0.22628</td>
<td>0.18248</td>
<td>1.24000</td>
<td>random equant</td>
</tr>
<tr>
<td>50</td>
<td>776</td>
<td>25</td>
<td>2</td>
<td>27.4</td>
<td>4.1</td>
<td>2.6</td>
<td>0.29927</td>
<td>0.18978</td>
<td>1.57692</td>
<td>random equant</td>
</tr>
<tr>
<td>51</td>
<td>835</td>
<td>1</td>
<td>2</td>
<td>54.5</td>
<td>5.1</td>
<td>3.7</td>
<td>0.18716</td>
<td>0.13578</td>
<td>1.37838</td>
<td>random equant</td>
</tr>
<tr>
<td>52</td>
<td>835</td>
<td>2</td>
<td>2</td>
<td>54.5</td>
<td>5.1</td>
<td>4.1</td>
<td>0.18716</td>
<td>0.15046</td>
<td>1.24390</td>
<td>random equant</td>
</tr>
<tr>
<td>53</td>
<td>835</td>
<td>3</td>
<td>2</td>
<td>54.5</td>
<td>5.5</td>
<td>4.4</td>
<td>0.20183</td>
<td>0.16147</td>
<td>1.25000</td>
<td>random equant</td>
</tr>
<tr>
<td>54</td>
<td>835</td>
<td>4</td>
<td>2</td>
<td>54.5</td>
<td>4.8</td>
<td>4.2</td>
<td>0.17615</td>
<td>0.15413</td>
<td>1.14286</td>
<td>random equant</td>
</tr>
<tr>
<td>55</td>
<td>835</td>
<td>5</td>
<td>2</td>
<td>54.5</td>
<td>4.9</td>
<td>3.6</td>
<td>0.17982</td>
<td>0.13211</td>
<td>1.36111</td>
<td>random equant</td>
</tr>
<tr>
<td>56</td>
<td>835</td>
<td>6</td>
<td>2</td>
<td>54.5</td>
<td>6.7</td>
<td>5.0</td>
<td>0.24587</td>
<td>0.18349</td>
<td>1.34000</td>
<td>random equant</td>
</tr>
<tr>
<td>57</td>
<td>835</td>
<td>7</td>
<td>2</td>
<td>54.5</td>
<td>5.0</td>
<td>4.9</td>
<td>0.18349</td>
<td>0.17982</td>
<td>1.02041</td>
<td>random equant</td>
</tr>
<tr>
<td>58</td>
<td>835</td>
<td>8</td>
<td>2</td>
<td>54.5</td>
<td>5.0</td>
<td>4.0</td>
<td>0.18349</td>
<td>0.14679</td>
<td>1.25000</td>
<td>random equant</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
<td>L:W ratio</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>--------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>---------------------------</td>
<td>--------------------------</td>
<td>-------------------------</td>
<td>-------------------------</td>
<td>-----------</td>
<td>----------------</td>
</tr>
<tr>
<td>59</td>
<td>835</td>
<td>9</td>
<td>2</td>
<td>54.5</td>
<td>6.6</td>
<td>6.2</td>
<td>0.24220</td>
<td>0.22752</td>
<td>1.06452</td>
<td>random equant</td>
</tr>
<tr>
<td>60</td>
<td>835</td>
<td>10</td>
<td>2</td>
<td>54.5</td>
<td>4.2</td>
<td>3.6</td>
<td>0.15413</td>
<td>0.13211</td>
<td>1.16667</td>
<td>random equant</td>
</tr>
<tr>
<td>61</td>
<td>835</td>
<td>11</td>
<td>2</td>
<td>54.5</td>
<td>4.0</td>
<td>3.1</td>
<td>0.14679</td>
<td>0.11376</td>
<td>1.29032</td>
<td>random equant</td>
</tr>
<tr>
<td>62</td>
<td>835</td>
<td>12</td>
<td>2</td>
<td>54.5</td>
<td>5.1</td>
<td>3.8</td>
<td>0.18716</td>
<td>0.13945</td>
<td>1.34211</td>
<td>random equant</td>
</tr>
<tr>
<td>63</td>
<td>835</td>
<td>13</td>
<td>2</td>
<td>54.5</td>
<td>3.3</td>
<td>3.0</td>
<td>0.12110</td>
<td>0.11009</td>
<td>1.10000</td>
<td>random equant</td>
</tr>
<tr>
<td>64</td>
<td>835</td>
<td>14</td>
<td>2</td>
<td>54.5</td>
<td>5.2</td>
<td>4.7</td>
<td>0.19083</td>
<td>0.17248</td>
<td>1.10638</td>
<td>random equant</td>
</tr>
<tr>
<td>65</td>
<td>835</td>
<td>15</td>
<td>2</td>
<td>54.5</td>
<td>3.8</td>
<td>3.5</td>
<td>0.13945</td>
<td>0.12844</td>
<td>1.08571</td>
<td>random equant</td>
</tr>
<tr>
<td>66</td>
<td>835</td>
<td>16</td>
<td>2</td>
<td>54.5</td>
<td>4.8</td>
<td>3.9</td>
<td>0.17615</td>
<td>0.14312</td>
<td>1.23077</td>
<td>random equant</td>
</tr>
<tr>
<td>67</td>
<td>835</td>
<td>17</td>
<td>2</td>
<td>54.5</td>
<td>4.2</td>
<td>3.6</td>
<td>0.15413</td>
<td>0.13211</td>
<td>1.16667</td>
<td>random equant</td>
</tr>
<tr>
<td>68</td>
<td>835</td>
<td>18</td>
<td>2</td>
<td>54.5</td>
<td>4.3</td>
<td>3.5</td>
<td>0.15780</td>
<td>0.12844</td>
<td>1.22857</td>
<td>random equant</td>
</tr>
<tr>
<td>69</td>
<td>835</td>
<td>19</td>
<td>2</td>
<td>54.5</td>
<td>3.9</td>
<td>3.1</td>
<td>0.14312</td>
<td>0.11376</td>
<td>1.25806</td>
<td>random equant</td>
</tr>
<tr>
<td>70</td>
<td>835</td>
<td>20</td>
<td>2</td>
<td>54.5</td>
<td>4.7</td>
<td>3.6</td>
<td>0.17248</td>
<td>0.13211</td>
<td>1.30556</td>
<td>random equant</td>
</tr>
<tr>
<td>71</td>
<td>835</td>
<td>21</td>
<td>2</td>
<td>54.5</td>
<td>4.8</td>
<td>4.0</td>
<td>0.17615</td>
<td>0.14679</td>
<td>1.20000</td>
<td>random equant</td>
</tr>
<tr>
<td>72</td>
<td>835</td>
<td>22</td>
<td>2</td>
<td>54.5</td>
<td>4.0</td>
<td>3.6</td>
<td>0.14679</td>
<td>0.13211</td>
<td>1.11111</td>
<td>random equant</td>
</tr>
<tr>
<td>73</td>
<td>835</td>
<td>23</td>
<td>2</td>
<td>54.5</td>
<td>3.9</td>
<td>3.2</td>
<td>0.14312</td>
<td>0.11743</td>
<td>1.21875</td>
<td>random equant</td>
</tr>
<tr>
<td>74</td>
<td>835</td>
<td>24</td>
<td>2</td>
<td>54.5</td>
<td>4.7</td>
<td>4.4</td>
<td>0.17248</td>
<td>0.16147</td>
<td>1.06818</td>
<td>random equant</td>
</tr>
<tr>
<td>75</td>
<td>835</td>
<td>25</td>
<td>2</td>
<td>54.5</td>
<td>4.7</td>
<td>4.0</td>
<td>0.17248</td>
<td>0.14679</td>
<td>1.17500</td>
<td>random equant</td>
</tr>
<tr>
<td>76</td>
<td>1149</td>
<td>1</td>
<td>1</td>
<td>41.0</td>
<td>5.8</td>
<td>4.7</td>
<td>0.14146</td>
<td>0.11463</td>
<td>1.23404</td>
<td>random equant</td>
</tr>
<tr>
<td>77</td>
<td>1149</td>
<td>2</td>
<td>1</td>
<td>41.0</td>
<td>5.9</td>
<td>4.3</td>
<td>0.14390</td>
<td>0.10488</td>
<td>1.37209</td>
<td>random equant</td>
</tr>
<tr>
<td>78</td>
<td>1149</td>
<td>3</td>
<td>1</td>
<td>41.0</td>
<td>5.6</td>
<td>4.1</td>
<td>0.13659</td>
<td>0.10000</td>
<td>1.36585</td>
<td>random equant</td>
</tr>
<tr>
<td>79</td>
<td>1149</td>
<td>4</td>
<td>1</td>
<td>41.0</td>
<td>5.1</td>
<td>4.7</td>
<td>0.12439</td>
<td>0.11463</td>
<td>1.08511</td>
<td>random equant</td>
</tr>
<tr>
<td>80</td>
<td>1149</td>
<td>5</td>
<td>1</td>
<td>41.0</td>
<td>6.9</td>
<td>4.5</td>
<td>0.16829</td>
<td>0.10976</td>
<td>1.53333</td>
<td>random equant</td>
</tr>
<tr>
<td>81</td>
<td>1149</td>
<td>6</td>
<td>1</td>
<td>41.0</td>
<td>5.2</td>
<td>4.8</td>
<td>0.12683</td>
<td>0.11707</td>
<td>1.08333</td>
<td>random equant</td>
</tr>
<tr>
<td>82</td>
<td>1149</td>
<td>7</td>
<td>1</td>
<td>41.0</td>
<td>6.8</td>
<td>5.0</td>
<td>0.16585</td>
<td>0.12195</td>
<td>1.36000</td>
<td>random equant</td>
</tr>
<tr>
<td>83</td>
<td>1149</td>
<td>8</td>
<td>1</td>
<td>41.0</td>
<td>10.2</td>
<td>8.2</td>
<td>0.24878</td>
<td>0.20000</td>
<td>1.24390</td>
<td>random equant</td>
</tr>
<tr>
<td>84</td>
<td>1149</td>
<td>9</td>
<td>1</td>
<td>41.0</td>
<td>6.7</td>
<td>5.3</td>
<td>0.16341</td>
<td>0.12927</td>
<td>1.26415</td>
<td>random equant</td>
</tr>
<tr>
<td>85</td>
<td>1149</td>
<td>10</td>
<td>1</td>
<td>41.0</td>
<td>6.8</td>
<td>5.0</td>
<td>0.16585</td>
<td>0.12195</td>
<td>1.36000</td>
<td>random equant</td>
</tr>
<tr>
<td>86</td>
<td>1149</td>
<td>11</td>
<td>1</td>
<td>41.0</td>
<td>7.4</td>
<td>5.9</td>
<td>0.18049</td>
<td>0.14390</td>
<td>1.25424</td>
<td>random equant</td>
</tr>
<tr>
<td>87</td>
<td>1149</td>
<td>12</td>
<td>1</td>
<td>41.0</td>
<td>5.7</td>
<td>4.9</td>
<td>0.13902</td>
<td>0.11951</td>
<td>1.16327</td>
<td>random equant</td>
</tr>
<tr>
<td>88</td>
<td>1149</td>
<td>13</td>
<td>1</td>
<td>41.0</td>
<td>9.1</td>
<td>5.5</td>
<td>0.22195</td>
<td>0.13415</td>
<td>1.65455</td>
<td>random equant</td>
</tr>
<tr>
<td>89</td>
<td>1149</td>
<td>14</td>
<td>1</td>
<td>41.0</td>
<td>6.7</td>
<td>4.7</td>
<td>0.16341</td>
<td>0.11463</td>
<td>1.42553</td>
<td>random equant</td>
</tr>
<tr>
<td>90</td>
<td>1149</td>
<td>15</td>
<td>1</td>
<td>41.0</td>
<td>8.2</td>
<td>5.6</td>
<td>0.20000</td>
<td>0.13659</td>
<td>1.46429</td>
<td>random equant</td>
</tr>
<tr>
<td>91</td>
<td>1149</td>
<td>16</td>
<td>1</td>
<td>41.0</td>
<td>7.4</td>
<td>6.2</td>
<td>0.18049</td>
<td>0.15122</td>
<td>1.19355</td>
<td>random equant</td>
</tr>
<tr>
<td>92</td>
<td>1149</td>
<td>17</td>
<td>1</td>
<td>41.0</td>
<td>6.1</td>
<td>4.1</td>
<td>0.14878</td>
<td>0.10000</td>
<td>1.48780</td>
<td>random equant</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
<td>L:W ratio</td>
<td>Category</td>
</tr>
<tr>
<td>---------</td>
<td>--------------</td>
<td>--------------------</td>
<td>-----------------------</td>
<td>--------------------------</td>
<td>----------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>-----------</td>
<td>----------</td>
</tr>
<tr>
<td>93</td>
<td>1149</td>
<td>18</td>
<td>1</td>
<td>41.0</td>
<td>6.0</td>
<td>5.6</td>
<td>0.14634</td>
<td>0.13659</td>
<td>1.07143</td>
<td>random equant</td>
</tr>
<tr>
<td>94</td>
<td>1149</td>
<td>19</td>
<td>1</td>
<td>41.0</td>
<td>5.2</td>
<td>4.4</td>
<td>0.12683</td>
<td>0.10732</td>
<td>1.18182</td>
<td>random equant</td>
</tr>
<tr>
<td>95</td>
<td>1149</td>
<td>20</td>
<td>1</td>
<td>41.0</td>
<td>5.5</td>
<td>5.0</td>
<td>0.13415</td>
<td>0.12195</td>
<td>1.10000</td>
<td>random equant</td>
</tr>
<tr>
<td>96</td>
<td>1149</td>
<td>21</td>
<td>1</td>
<td>41.0</td>
<td>6.3</td>
<td>5.5</td>
<td>0.15366</td>
<td>0.13415</td>
<td>1.14545</td>
<td>random equant</td>
</tr>
<tr>
<td>97</td>
<td>1149</td>
<td>22</td>
<td>1</td>
<td>41.0</td>
<td>7.3</td>
<td>6.9</td>
<td>0.17805</td>
<td>0.16829</td>
<td>1.05797</td>
<td>random equant</td>
</tr>
<tr>
<td>98</td>
<td>1149</td>
<td>23</td>
<td>1</td>
<td>41.0</td>
<td>8.4</td>
<td>6.2</td>
<td>0.20488</td>
<td>0.15122</td>
<td>1.35484</td>
<td>random equant</td>
</tr>
<tr>
<td>99</td>
<td>1149</td>
<td>24</td>
<td>1</td>
<td>41.0</td>
<td>6.3</td>
<td>5.2</td>
<td>0.15366</td>
<td>0.12683</td>
<td>1.21154</td>
<td>random equant</td>
</tr>
<tr>
<td>100</td>
<td>1149</td>
<td>25</td>
<td>1</td>
<td>41.0</td>
<td>5.4</td>
<td>4.3</td>
<td>0.13171</td>
<td>0.10488</td>
<td>1.25581</td>
<td>random equant</td>
</tr>
<tr>
<td>101</td>
<td>1032</td>
<td>1</td>
<td>2</td>
<td>54.5</td>
<td>5.5</td>
<td>4.9</td>
<td>0.20183</td>
<td>0.17982</td>
<td>1.12245</td>
<td>random equant</td>
</tr>
<tr>
<td>102</td>
<td>1032</td>
<td>2</td>
<td>2</td>
<td>54.5</td>
<td>7.7</td>
<td>5.2</td>
<td>0.28257</td>
<td>0.19083</td>
<td>1.48077</td>
<td>random equant</td>
</tr>
<tr>
<td>103</td>
<td>1032</td>
<td>3</td>
<td>2</td>
<td>54.5</td>
<td>4.0</td>
<td>3.9</td>
<td>0.14679</td>
<td>0.14312</td>
<td>1.02564</td>
<td>random equant</td>
</tr>
<tr>
<td>104</td>
<td>1032</td>
<td>4</td>
<td>2</td>
<td>54.5</td>
<td>3.4</td>
<td>3.1</td>
<td>0.12477</td>
<td>0.11376</td>
<td>1.09677</td>
<td>random equant</td>
</tr>
<tr>
<td>105</td>
<td>1032</td>
<td>5</td>
<td>2</td>
<td>54.5</td>
<td>5.1</td>
<td>4.0</td>
<td>0.18716</td>
<td>0.14679</td>
<td>1.27500</td>
<td>random equant</td>
</tr>
<tr>
<td>106</td>
<td>1032</td>
<td>6</td>
<td>2</td>
<td>54.5</td>
<td>3.9</td>
<td>3.8</td>
<td>0.14312</td>
<td>0.13945</td>
<td>1.02632</td>
<td>random equant</td>
</tr>
<tr>
<td>107</td>
<td>1032</td>
<td>7</td>
<td>2</td>
<td>54.5</td>
<td>4.4</td>
<td>3.4</td>
<td>0.16147</td>
<td>0.12477</td>
<td>1.29412</td>
<td>random equant</td>
</tr>
<tr>
<td>108</td>
<td>1032</td>
<td>8</td>
<td>2</td>
<td>54.5</td>
<td>5.8</td>
<td>4.7</td>
<td>0.21284</td>
<td>0.17248</td>
<td>1.23404</td>
<td>random equant</td>
</tr>
<tr>
<td>109</td>
<td>1032</td>
<td>9</td>
<td>2</td>
<td>54.5</td>
<td>4.9</td>
<td>4.1</td>
<td>0.17982</td>
<td>0.15046</td>
<td>1.19512</td>
<td>random equant</td>
</tr>
<tr>
<td>110</td>
<td>1032</td>
<td>10</td>
<td>2</td>
<td>54.5</td>
<td>5.0</td>
<td>4.0</td>
<td>0.18349</td>
<td>0.14679</td>
<td>1.25000</td>
<td>random equant</td>
</tr>
<tr>
<td>111</td>
<td>1032</td>
<td>11</td>
<td>2</td>
<td>54.5</td>
<td>5.1</td>
<td>3.9</td>
<td>0.18716</td>
<td>0.14312</td>
<td>1.30769</td>
<td>random equant</td>
</tr>
<tr>
<td>112</td>
<td>1032</td>
<td>12</td>
<td>2</td>
<td>54.5</td>
<td>5.0</td>
<td>3.7</td>
<td>0.18349</td>
<td>0.13578</td>
<td>1.35135</td>
<td>random equant</td>
</tr>
<tr>
<td>113</td>
<td>1032</td>
<td>13</td>
<td>2</td>
<td>54.5</td>
<td>5.1</td>
<td>4.2</td>
<td>0.18716</td>
<td>0.15413</td>
<td>1.21429</td>
<td>random equant</td>
</tr>
<tr>
<td>114</td>
<td>1032</td>
<td>14</td>
<td>2</td>
<td>54.5</td>
<td>4.6</td>
<td>3.8</td>
<td>0.16881</td>
<td>0.13945</td>
<td>1.21053</td>
<td>random equant</td>
</tr>
<tr>
<td>115</td>
<td>1032</td>
<td>15</td>
<td>2</td>
<td>54.5</td>
<td>4.8</td>
<td>4.1</td>
<td>0.17615</td>
<td>0.15046</td>
<td>1.17073</td>
<td>random equant</td>
</tr>
<tr>
<td>116</td>
<td>1032</td>
<td>16</td>
<td>2</td>
<td>54.5</td>
<td>4.2</td>
<td>3.5</td>
<td>0.15413</td>
<td>0.12844</td>
<td>1.20000</td>
<td>random equant</td>
</tr>
<tr>
<td>117</td>
<td>1032</td>
<td>17</td>
<td>2</td>
<td>54.5</td>
<td>4.4</td>
<td>4.1</td>
<td>0.16147</td>
<td>0.15046</td>
<td>1.07317</td>
<td>random equant</td>
</tr>
<tr>
<td>118</td>
<td>1032</td>
<td>18</td>
<td>2</td>
<td>54.5</td>
<td>4.3</td>
<td>3.7</td>
<td>0.15780</td>
<td>0.13578</td>
<td>1.16216</td>
<td>random equant</td>
</tr>
<tr>
<td>119</td>
<td>1032</td>
<td>19</td>
<td>2</td>
<td>54.5</td>
<td>5.1</td>
<td>4.1</td>
<td>0.18716</td>
<td>0.15046</td>
<td>1.24390</td>
<td>random equant</td>
</tr>
<tr>
<td>120</td>
<td>1032</td>
<td>20</td>
<td>2</td>
<td>54.5</td>
<td>4.6</td>
<td>4.3</td>
<td>0.16881</td>
<td>0.15780</td>
<td>1.06977</td>
<td>random equant</td>
</tr>
<tr>
<td>121</td>
<td>1032</td>
<td>21</td>
<td>2</td>
<td>54.5</td>
<td>4.5</td>
<td>4.1</td>
<td>0.16514</td>
<td>0.15046</td>
<td>1.09756</td>
<td>random equant</td>
</tr>
<tr>
<td>122</td>
<td>1032</td>
<td>22</td>
<td>2</td>
<td>54.5</td>
<td>5.6</td>
<td>4.2</td>
<td>0.20550</td>
<td>0.15413</td>
<td>1.33333</td>
<td>random equant</td>
</tr>
<tr>
<td>123</td>
<td>1032</td>
<td>23</td>
<td>2</td>
<td>54.5</td>
<td>4.5</td>
<td>3.3</td>
<td>0.16514</td>
<td>0.12110</td>
<td>1.36364</td>
<td>random equant</td>
</tr>
<tr>
<td>124</td>
<td>1032</td>
<td>24</td>
<td>2</td>
<td>54.5</td>
<td>4.9</td>
<td>3.5</td>
<td>0.17982</td>
<td>0.12844</td>
<td>1.40000</td>
<td>random equant</td>
</tr>
<tr>
<td>125</td>
<td>1032</td>
<td>25</td>
<td>2</td>
<td>54.5</td>
<td>5.9</td>
<td>5.5</td>
<td>0.21651</td>
<td>0.20183</td>
<td>1.07273</td>
<td>random equant</td>
</tr>
<tr>
<td>1</td>
<td>683</td>
<td>0.5</td>
<td>1</td>
<td>136.2</td>
<td>85.5</td>
<td>42.2</td>
<td>0.31388</td>
<td>0.15492</td>
<td>2.02607</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
<td>L:\W ratio</td>
<td>Category</td>
</tr>
<tr>
<td>---------</td>
<td>--------------</td>
<td>--------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>---------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>-------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>2</td>
<td>683</td>
<td>2</td>
<td>0.5</td>
<td>136.2</td>
<td>71.2</td>
<td>34.4</td>
<td>0.26138</td>
<td>0.12628</td>
<td>2.06977</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>3</td>
<td>683</td>
<td>3</td>
<td>0.5</td>
<td>136.2</td>
<td>119.5</td>
<td>55.7</td>
<td>0.43869</td>
<td>0.20448</td>
<td>2.14542</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>4</td>
<td>683</td>
<td>4</td>
<td>0.5</td>
<td>136.2</td>
<td>63.4</td>
<td>46.3</td>
<td>0.23275</td>
<td>0.16997</td>
<td>1.36933</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>5</td>
<td>683</td>
<td>5</td>
<td>0.5</td>
<td>136.2</td>
<td>73.1</td>
<td>39.6</td>
<td>0.26836</td>
<td>0.14537</td>
<td>1.84596</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>6</td>
<td>683</td>
<td>6</td>
<td>0.5</td>
<td>136.2</td>
<td>54.5</td>
<td>32.8</td>
<td>0.20007</td>
<td>0.12041</td>
<td>1.66159</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>7</td>
<td>683</td>
<td>7</td>
<td>0.5</td>
<td>136.2</td>
<td>67.6</td>
<td>43.8</td>
<td>0.24816</td>
<td>0.16079</td>
<td>1.54338</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>8</td>
<td>683</td>
<td>8</td>
<td>0.5</td>
<td>136.2</td>
<td>75.5</td>
<td>29.7</td>
<td>0.27717</td>
<td>0.10903</td>
<td>2.54209</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>9</td>
<td>683</td>
<td>9</td>
<td>0.5</td>
<td>136.2</td>
<td>61.4</td>
<td>34.9</td>
<td>0.22540</td>
<td>0.12812</td>
<td>1.75931</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>10</td>
<td>683</td>
<td>10</td>
<td>0.5</td>
<td>136.2</td>
<td>55.1</td>
<td>38.0</td>
<td>0.20228</td>
<td>0.13950</td>
<td>1.45000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>11</td>
<td>683</td>
<td>11</td>
<td>0.5</td>
<td>136.2</td>
<td>63.9</td>
<td>38.5</td>
<td>0.23458</td>
<td>0.14134</td>
<td>1.65974</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>12</td>
<td>683</td>
<td>12</td>
<td>0.5</td>
<td>136.2</td>
<td>50.1</td>
<td>26.0</td>
<td>0.18392</td>
<td>0.09545</td>
<td>1.92692</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>13</td>
<td>683</td>
<td>13</td>
<td>0.5</td>
<td>136.2</td>
<td>66.9</td>
<td>32.7</td>
<td>0.24559</td>
<td>0.12004</td>
<td>2.04587</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>14</td>
<td>683</td>
<td>14</td>
<td>0.5</td>
<td>136.2</td>
<td>49.8</td>
<td>25.2</td>
<td>0.18282</td>
<td>0.09251</td>
<td>1.97619</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>15</td>
<td>683</td>
<td>15</td>
<td>0.5</td>
<td>136.2</td>
<td>54.2</td>
<td>28.4</td>
<td>0.19897</td>
<td>0.10426</td>
<td>1.90845</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>16</td>
<td>683</td>
<td>16</td>
<td>0.5</td>
<td>136.2</td>
<td>61.4</td>
<td>32.7</td>
<td>0.22540</td>
<td>0.12004</td>
<td>1.87768</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>17</td>
<td>683</td>
<td>17</td>
<td>0.5</td>
<td>136.2</td>
<td>67.8</td>
<td>26.8</td>
<td>0.24890</td>
<td>0.09838</td>
<td>2.52985</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>18</td>
<td>683</td>
<td>18</td>
<td>0.5</td>
<td>136.2</td>
<td>47.1</td>
<td>26.3</td>
<td>0.17291</td>
<td>0.09655</td>
<td>1.79087</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>19</td>
<td>683</td>
<td>19</td>
<td>0.5</td>
<td>136.2</td>
<td>70.8</td>
<td>27.8</td>
<td>0.25991</td>
<td>0.10206</td>
<td>2.54676</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>20</td>
<td>683</td>
<td>20</td>
<td>0.5</td>
<td>136.2</td>
<td>74.9</td>
<td>31.3</td>
<td>0.27496</td>
<td>0.11490</td>
<td>2.39297</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>21</td>
<td>683</td>
<td>21</td>
<td>0.5</td>
<td>136.2</td>
<td>59.0</td>
<td>26.7</td>
<td>0.21659</td>
<td>0.09802</td>
<td>2.20974</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>22</td>
<td>683</td>
<td>22</td>
<td>0.5</td>
<td>136.2</td>
<td>50.6</td>
<td>31.9</td>
<td>0.18576</td>
<td>0.11711</td>
<td>1.58621</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>23</td>
<td>683</td>
<td>23</td>
<td>0.5</td>
<td>136.2</td>
<td>47.8</td>
<td>30.8</td>
<td>0.17548</td>
<td>0.11307</td>
<td>1.55195</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>24</td>
<td>683</td>
<td>24</td>
<td>0.5</td>
<td>136.2</td>
<td>53.1</td>
<td>27.0</td>
<td>0.19493</td>
<td>0.09912</td>
<td>1.96667</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>25</td>
<td>683</td>
<td>25</td>
<td>0.5</td>
<td>136.2</td>
<td>65.1</td>
<td>35.9</td>
<td>0.23899</td>
<td>0.13179</td>
<td>1.81337</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>26</td>
<td>684</td>
<td>1</td>
<td>1</td>
<td>163.1</td>
<td>44.4</td>
<td>25.4</td>
<td>0.27223</td>
<td>0.15573</td>
<td>1.74803</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>27</td>
<td>684</td>
<td>2</td>
<td>1</td>
<td>163.1</td>
<td>34.7</td>
<td>23.7</td>
<td>0.21275</td>
<td>0.14531</td>
<td>1.46414</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>28</td>
<td>684</td>
<td>3</td>
<td>1</td>
<td>163.1</td>
<td>39.4</td>
<td>18.7</td>
<td>0.24157</td>
<td>0.11465</td>
<td>2.10695</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>29</td>
<td>684</td>
<td>4</td>
<td>1</td>
<td>163.1</td>
<td>33.8</td>
<td>18.7</td>
<td>0.20723</td>
<td>0.11465</td>
<td>1.80749</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>30</td>
<td>684</td>
<td>5</td>
<td>1</td>
<td>163.1</td>
<td>37.9</td>
<td>23.7</td>
<td>0.23237</td>
<td>0.14531</td>
<td>1.59916</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>31</td>
<td>684</td>
<td>6</td>
<td>1</td>
<td>163.1</td>
<td>33.6</td>
<td>25.0</td>
<td>0.20601</td>
<td>0.15328</td>
<td>1.34400</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>32</td>
<td>684</td>
<td>7</td>
<td>1</td>
<td>163.1</td>
<td>35.1</td>
<td>26.5</td>
<td>0.21521</td>
<td>0.16248</td>
<td>1.32453</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>33</td>
<td>684</td>
<td>8</td>
<td>1</td>
<td>163.1</td>
<td>40.8</td>
<td>23.5</td>
<td>0.25015</td>
<td>0.14408</td>
<td>1.73617</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>34</td>
<td>684</td>
<td>9</td>
<td>1</td>
<td>163.1</td>
<td>41.5</td>
<td>27.2</td>
<td>0.25445</td>
<td>0.16677</td>
<td>1.52574</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>35</td>
<td>684</td>
<td>10</td>
<td>1</td>
<td>163.1</td>
<td>35.4</td>
<td>20.6</td>
<td>0.21704</td>
<td>0.12630</td>
<td>1.71845</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
<td>L/W ratio</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>-------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>---------------------------</td>
<td>--------------------------</td>
<td>-------------------------</td>
<td>-------------------------</td>
<td>------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>36</td>
<td>684</td>
<td>11</td>
<td>1</td>
<td>163.1</td>
<td>33.1</td>
<td>25.0</td>
<td>0.20294</td>
<td>0.15328</td>
<td>1.32400</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>37</td>
<td>684</td>
<td>12</td>
<td>1</td>
<td>163.1</td>
<td>32.1</td>
<td>20.7</td>
<td>0.19681</td>
<td>0.12692</td>
<td>1.55072</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>38</td>
<td>684</td>
<td>13</td>
<td>1</td>
<td>163.1</td>
<td>36.6</td>
<td>17.2</td>
<td>0.22440</td>
<td>0.10546</td>
<td>2.12791</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>39</td>
<td>684</td>
<td>14</td>
<td>1</td>
<td>163.1</td>
<td>33.9</td>
<td>22.1</td>
<td>0.20785</td>
<td>0.13550</td>
<td>1.53394</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>40</td>
<td>684</td>
<td>15</td>
<td>1</td>
<td>163.1</td>
<td>25.5</td>
<td>14.6</td>
<td>0.15635</td>
<td>0.08952</td>
<td>1.74658</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>41</td>
<td>684</td>
<td>16</td>
<td>1</td>
<td>163.1</td>
<td>38.6</td>
<td>14.4</td>
<td>0.23666</td>
<td>0.08829</td>
<td>2.68056</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>42</td>
<td>684</td>
<td>17</td>
<td>1</td>
<td>163.1</td>
<td>31.1</td>
<td>21.1</td>
<td>0.19068</td>
<td>0.12937</td>
<td>1.47393</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>43</td>
<td>684</td>
<td>18</td>
<td>1</td>
<td>163.1</td>
<td>23.6</td>
<td>15.7</td>
<td>0.14470</td>
<td>0.09626</td>
<td>1.50318</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>44</td>
<td>684</td>
<td>19</td>
<td>1</td>
<td>163.1</td>
<td>36.3</td>
<td>23.7</td>
<td>0.22256</td>
<td>0.14531</td>
<td>1.53165</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>45</td>
<td>684</td>
<td>20</td>
<td>1</td>
<td>163.1</td>
<td>30.9</td>
<td>17.6</td>
<td>0.18945</td>
<td>0.10791</td>
<td>1.75568</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>46</td>
<td>684</td>
<td>21</td>
<td>1</td>
<td>163.1</td>
<td>35.5</td>
<td>20.9</td>
<td>0.21766</td>
<td>0.12814</td>
<td>1.69856</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>47</td>
<td>684</td>
<td>22</td>
<td>1</td>
<td>163.1</td>
<td>32.7</td>
<td>18.7</td>
<td>0.20049</td>
<td>0.11465</td>
<td>1.74866</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>48</td>
<td>684</td>
<td>23</td>
<td>1</td>
<td>163.1</td>
<td>46.4</td>
<td>25.0</td>
<td>0.28449</td>
<td>0.15328</td>
<td>1.85600</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>49</td>
<td>684</td>
<td>24</td>
<td>1</td>
<td>163.1</td>
<td>41.4</td>
<td>27.6</td>
<td>0.25383</td>
<td>0.16922</td>
<td>1.50000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>50</td>
<td>684</td>
<td>25</td>
<td>1</td>
<td>163.1</td>
<td>35.0</td>
<td>20.4</td>
<td>0.21459</td>
<td>0.12508</td>
<td>1.71569</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>51</td>
<td>739</td>
<td>1</td>
<td>2</td>
<td>54.5</td>
<td>7.2</td>
<td>3.7</td>
<td>0.26422</td>
<td>0.13578</td>
<td>1.94595</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>52</td>
<td>739</td>
<td>2</td>
<td>2</td>
<td>54.5</td>
<td>6.3</td>
<td>3.7</td>
<td>0.23119</td>
<td>0.13578</td>
<td>1.70270</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>53</td>
<td>739</td>
<td>3</td>
<td>2</td>
<td>54.5</td>
<td>8.2</td>
<td>4.6</td>
<td>0.30092</td>
<td>0.16881</td>
<td>1.78261</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>54</td>
<td>739</td>
<td>4</td>
<td>2</td>
<td>54.5</td>
<td>6.5</td>
<td>3.7</td>
<td>0.23853</td>
<td>0.13578</td>
<td>1.75676</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>55</td>
<td>739</td>
<td>5</td>
<td>2</td>
<td>54.5</td>
<td>9.8</td>
<td>4.4</td>
<td>0.35963</td>
<td>0.16147</td>
<td>2.22727</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>56</td>
<td>739</td>
<td>6</td>
<td>2</td>
<td>54.5</td>
<td>7.6</td>
<td>3.9</td>
<td>0.27890</td>
<td>0.14312</td>
<td>1.94872</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>57</td>
<td>739</td>
<td>7</td>
<td>2</td>
<td>54.5</td>
<td>7.5</td>
<td>4.2</td>
<td>0.27523</td>
<td>0.15413</td>
<td>1.78571</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>58</td>
<td>739</td>
<td>8</td>
<td>2</td>
<td>54.5</td>
<td>7.3</td>
<td>4.4</td>
<td>0.26789</td>
<td>0.16147</td>
<td>1.65909</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>59</td>
<td>739</td>
<td>9</td>
<td>2</td>
<td>54.5</td>
<td>8.7</td>
<td>4.6</td>
<td>0.31927</td>
<td>0.16881</td>
<td>1.89130</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>60</td>
<td>739</td>
<td>10</td>
<td>2</td>
<td>54.5</td>
<td>7.7</td>
<td>3.7</td>
<td>0.28257</td>
<td>0.13578</td>
<td>2.08108</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>61</td>
<td>739</td>
<td>11</td>
<td>2</td>
<td>54.5</td>
<td>11.1</td>
<td>5.0</td>
<td>0.40734</td>
<td>0.18349</td>
<td>2.22000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>62</td>
<td>739</td>
<td>12</td>
<td>2</td>
<td>54.5</td>
<td>8.8</td>
<td>5.3</td>
<td>0.32924</td>
<td>0.19450</td>
<td>1.66038</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>63</td>
<td>739</td>
<td>13</td>
<td>2</td>
<td>54.5</td>
<td>7.3</td>
<td>4.1</td>
<td>0.26789</td>
<td>0.15046</td>
<td>1.78049</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>64</td>
<td>739</td>
<td>14</td>
<td>2</td>
<td>54.5</td>
<td>7.3</td>
<td>3.9</td>
<td>0.26789</td>
<td>0.14312</td>
<td>1.87179</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>65</td>
<td>739</td>
<td>15</td>
<td>2</td>
<td>54.5</td>
<td>9.3</td>
<td>4.9</td>
<td>0.34128</td>
<td>0.17982</td>
<td>1.89796</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>66</td>
<td>739</td>
<td>16</td>
<td>2</td>
<td>54.5</td>
<td>7.7</td>
<td>3.9</td>
<td>0.28257</td>
<td>0.14312</td>
<td>1.97436</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>67</td>
<td>739</td>
<td>17</td>
<td>2</td>
<td>54.5</td>
<td>6.7</td>
<td>3.4</td>
<td>0.24587</td>
<td>0.12477</td>
<td>1.97059</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>68</td>
<td>739</td>
<td>18</td>
<td>2</td>
<td>54.5</td>
<td>6.6</td>
<td>3.3</td>
<td>0.24220</td>
<td>0.12110</td>
<td>2.00000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>69</td>
<td>739</td>
<td>19</td>
<td>2</td>
<td>54.5</td>
<td>6.9</td>
<td>3.8</td>
<td>0.25321</td>
<td>0.13945</td>
<td>1.81579</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
<td>L:W ratio</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>-------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>------------------------</td>
<td>------------------------</td>
<td>-----------</td>
<td>----------------</td>
</tr>
<tr>
<td>70</td>
<td>739</td>
<td>20</td>
<td>2</td>
<td>54.5</td>
<td>9.3</td>
<td>3.8</td>
<td>0.34128</td>
<td>0.13945</td>
<td>2.44737</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>71</td>
<td>739</td>
<td>21</td>
<td>2</td>
<td>54.5</td>
<td>9.1</td>
<td>4.8</td>
<td>0.33394</td>
<td>0.17615</td>
<td>1.89583</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>72</td>
<td>739</td>
<td>22</td>
<td>2</td>
<td>54.5</td>
<td>7.1</td>
<td>3.3</td>
<td>0.26055</td>
<td>0.12110</td>
<td>2.15152</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>73</td>
<td>739</td>
<td>23</td>
<td>2</td>
<td>54.5</td>
<td>10.0</td>
<td>4.8</td>
<td>0.36697</td>
<td>0.17615</td>
<td>2.08333</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>74</td>
<td>739</td>
<td>24</td>
<td>2</td>
<td>54.5</td>
<td>8.3</td>
<td>3.8</td>
<td>0.30459</td>
<td>0.13945</td>
<td>2.18421</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>75</td>
<td>739</td>
<td>25</td>
<td>2</td>
<td>54.5</td>
<td>8.9</td>
<td>4.7</td>
<td>0.32661</td>
<td>0.17248</td>
<td>1.89362</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>76</td>
<td>740</td>
<td>1</td>
<td>2</td>
<td>27.4</td>
<td>4.9</td>
<td>2.7</td>
<td>0.35766</td>
<td>0.19708</td>
<td>1.81481</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>77</td>
<td>740</td>
<td>2</td>
<td>2</td>
<td>27.4</td>
<td>7.5</td>
<td>2.8</td>
<td>0.54745</td>
<td>0.20438</td>
<td>2.67857</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>78</td>
<td>740</td>
<td>3</td>
<td>2</td>
<td>27.4</td>
<td>6.5</td>
<td>2.2</td>
<td>0.47445</td>
<td>0.16058</td>
<td>2.95455</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>79</td>
<td>740</td>
<td>4</td>
<td>2</td>
<td>27.4</td>
<td>6.2</td>
<td>2.9</td>
<td>0.45255</td>
<td>0.21168</td>
<td>2.13793</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>80</td>
<td>740</td>
<td>5</td>
<td>2</td>
<td>27.4</td>
<td>4.2</td>
<td>2.4</td>
<td>0.30657</td>
<td>0.17518</td>
<td>1.75000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>81</td>
<td>740</td>
<td>6</td>
<td>2</td>
<td>27.4</td>
<td>4.3</td>
<td>2.2</td>
<td>0.31387</td>
<td>0.16058</td>
<td>1.95455</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>82</td>
<td>740</td>
<td>7</td>
<td>2</td>
<td>27.4</td>
<td>4.7</td>
<td>1.9</td>
<td>0.34307</td>
<td>0.13869</td>
<td>2.47368</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>83</td>
<td>740</td>
<td>8</td>
<td>2</td>
<td>27.4</td>
<td>4.3</td>
<td>2.0</td>
<td>0.31387</td>
<td>0.14599</td>
<td>2.15000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>84</td>
<td>740</td>
<td>9</td>
<td>2</td>
<td>27.4</td>
<td>5.9</td>
<td>2.8</td>
<td>0.43066</td>
<td>0.20438</td>
<td>2.10714</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>85</td>
<td>740</td>
<td>10</td>
<td>2</td>
<td>27.4</td>
<td>4.2</td>
<td>1.7</td>
<td>0.30657</td>
<td>0.12409</td>
<td>2.47059</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>86</td>
<td>740</td>
<td>11</td>
<td>2</td>
<td>27.4</td>
<td>5.0</td>
<td>2.7</td>
<td>0.36496</td>
<td>0.19708</td>
<td>1.85185</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>87</td>
<td>740</td>
<td>12</td>
<td>2</td>
<td>27.4</td>
<td>5.3</td>
<td>3.0</td>
<td>0.38686</td>
<td>0.21898</td>
<td>1.76667</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>88</td>
<td>740</td>
<td>13</td>
<td>2</td>
<td>27.4</td>
<td>7.2</td>
<td>3.6</td>
<td>0.52555</td>
<td>0.26277</td>
<td>2.00000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>89</td>
<td>740</td>
<td>14</td>
<td>2</td>
<td>27.4</td>
<td>6.1</td>
<td>2.4</td>
<td>0.44526</td>
<td>0.17518</td>
<td>2.54167</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>90</td>
<td>740</td>
<td>15</td>
<td>2</td>
<td>27.4</td>
<td>4.6</td>
<td>2.5</td>
<td>0.33577</td>
<td>0.18248</td>
<td>1.84000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>91</td>
<td>740</td>
<td>16</td>
<td>2</td>
<td>27.4</td>
<td>6.9</td>
<td>3.3</td>
<td>0.50365</td>
<td>0.24088</td>
<td>2.09091</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>92</td>
<td>740</td>
<td>17</td>
<td>2</td>
<td>27.4</td>
<td>7.1</td>
<td>3.1</td>
<td>0.51825</td>
<td>0.22628</td>
<td>2.29032</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>93</td>
<td>740</td>
<td>18</td>
<td>2</td>
<td>27.4</td>
<td>4.9</td>
<td>2.8</td>
<td>0.35766</td>
<td>0.20438</td>
<td>1.75000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>94</td>
<td>740</td>
<td>19</td>
<td>2</td>
<td>27.4</td>
<td>6.1</td>
<td>2.4</td>
<td>0.44526</td>
<td>0.17518</td>
<td>2.54167</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>95</td>
<td>740</td>
<td>20</td>
<td>2</td>
<td>27.4</td>
<td>5.4</td>
<td>2.6</td>
<td>0.39416</td>
<td>0.18978</td>
<td>2.07692</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>96</td>
<td>740</td>
<td>21</td>
<td>2</td>
<td>27.4</td>
<td>4.4</td>
<td>2.0</td>
<td>0.32117</td>
<td>0.14599</td>
<td>2.20000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>97</td>
<td>740</td>
<td>22</td>
<td>2</td>
<td>27.4</td>
<td>5.2</td>
<td>2.7</td>
<td>0.37956</td>
<td>0.19708</td>
<td>1.92593</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>98</td>
<td>740</td>
<td>23</td>
<td>2</td>
<td>27.4</td>
<td>7.4</td>
<td>2.9</td>
<td>0.54015</td>
<td>0.21168</td>
<td>2.55172</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>99</td>
<td>740</td>
<td>24</td>
<td>2</td>
<td>27.4</td>
<td>5.2</td>
<td>2.4</td>
<td>0.37956</td>
<td>0.17518</td>
<td>2.16667</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>100</td>
<td>740</td>
<td>25</td>
<td>2</td>
<td>27.4</td>
<td>5.6</td>
<td>2.2</td>
<td>0.40876</td>
<td>0.16058</td>
<td>2.54545</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>101</td>
<td>931</td>
<td>1</td>
<td>2</td>
<td>54.5</td>
<td>10.7</td>
<td>5.6</td>
<td>0.39266</td>
<td>0.20550</td>
<td>1.91071</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>102</td>
<td>931</td>
<td>2</td>
<td>2</td>
<td>54.5</td>
<td>12.4</td>
<td>7.2</td>
<td>0.45505</td>
<td>0.26422</td>
<td>1.72222</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>103</td>
<td>931</td>
<td>3</td>
<td>2</td>
<td>54.5</td>
<td>11.4</td>
<td>5.0</td>
<td>0.41835</td>
<td>0.18349</td>
<td>2.28000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
<td>L:W ratio</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>--------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>---------------------------</td>
<td>----------------------------</td>
<td>----------------------------</td>
<td>----------------------------</td>
<td>-----------</td>
<td>------------------</td>
</tr>
<tr>
<td>104</td>
<td>931</td>
<td>4</td>
<td>2</td>
<td>54.5</td>
<td>7.1</td>
<td>4.0</td>
<td>0.26055</td>
<td>0.14679</td>
<td>1.77500</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>105</td>
<td>931</td>
<td>5</td>
<td>2</td>
<td>54.5</td>
<td>8.9</td>
<td>4.6</td>
<td>0.32661</td>
<td>0.16881</td>
<td>1.93478</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>106</td>
<td>931</td>
<td>6</td>
<td>2</td>
<td>54.5</td>
<td>12.5</td>
<td>7.2</td>
<td>0.45872</td>
<td>0.26422</td>
<td>1.73611</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>107</td>
<td>931</td>
<td>7</td>
<td>2</td>
<td>54.5</td>
<td>10.5</td>
<td>5.1</td>
<td>0.38532</td>
<td>0.18716</td>
<td>2.05882</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>108</td>
<td>931</td>
<td>8</td>
<td>2</td>
<td>54.5</td>
<td>13.4</td>
<td>5.3</td>
<td>0.49174</td>
<td>0.19450</td>
<td>2.52830</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>109</td>
<td>931</td>
<td>9</td>
<td>2</td>
<td>54.5</td>
<td>8.6</td>
<td>4.1</td>
<td>0.31560</td>
<td>0.15046</td>
<td>2.09756</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>110</td>
<td>931</td>
<td>10</td>
<td>2</td>
<td>54.5</td>
<td>8.9</td>
<td>4.3</td>
<td>0.32661</td>
<td>0.15780</td>
<td>2.06977</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>111</td>
<td>931</td>
<td>11</td>
<td>2</td>
<td>54.5</td>
<td>9.1</td>
<td>5.0</td>
<td>0.33394</td>
<td>0.18349</td>
<td>1.82000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>112</td>
<td>931</td>
<td>12</td>
<td>2</td>
<td>54.5</td>
<td>11.0</td>
<td>4.4</td>
<td>0.40367</td>
<td>0.16147</td>
<td>2.50000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>113</td>
<td>931</td>
<td>13</td>
<td>2</td>
<td>54.5</td>
<td>9.2</td>
<td>4.2</td>
<td>0.33761</td>
<td>0.15413</td>
<td>2.19048</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>114</td>
<td>931</td>
<td>14</td>
<td>2</td>
<td>54.5</td>
<td>8.8</td>
<td>5.4</td>
<td>0.32294</td>
<td>0.19817</td>
<td>1.62963</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>115</td>
<td>931</td>
<td>15</td>
<td>2</td>
<td>54.5</td>
<td>11.6</td>
<td>5.4</td>
<td>0.42569</td>
<td>0.19817</td>
<td>2.14815</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>116</td>
<td>931</td>
<td>16</td>
<td>2</td>
<td>54.5</td>
<td>7.9</td>
<td>4.8</td>
<td>0.28991</td>
<td>0.17615</td>
<td>1.64583</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>117</td>
<td>931</td>
<td>17</td>
<td>2</td>
<td>54.5</td>
<td>7.2</td>
<td>4.6</td>
<td>0.26422</td>
<td>0.16881</td>
<td>1.56252</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>118</td>
<td>931</td>
<td>18</td>
<td>2</td>
<td>54.5</td>
<td>11.0</td>
<td>5.0</td>
<td>0.40367</td>
<td>0.18349</td>
<td>2.20000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>119</td>
<td>931</td>
<td>19</td>
<td>2</td>
<td>54.5</td>
<td>8.1</td>
<td>2.8</td>
<td>0.29725</td>
<td>0.10275</td>
<td>2.89286</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>120</td>
<td>931</td>
<td>20</td>
<td>2</td>
<td>54.5</td>
<td>7.6</td>
<td>3.8</td>
<td>0.27890</td>
<td>0.13945</td>
<td>2.00000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>121</td>
<td>931</td>
<td>21</td>
<td>2</td>
<td>54.5</td>
<td>7.5</td>
<td>4.0</td>
<td>0.27523</td>
<td>0.14679</td>
<td>1.87500</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>122</td>
<td>931</td>
<td>22</td>
<td>2</td>
<td>54.5</td>
<td>10.8</td>
<td>3.9</td>
<td>0.39633</td>
<td>0.14312</td>
<td>2.76923</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>123</td>
<td>931</td>
<td>23</td>
<td>2</td>
<td>54.5</td>
<td>8.6</td>
<td>3.4</td>
<td>0.31560</td>
<td>0.12477</td>
<td>2.52941</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>124</td>
<td>931</td>
<td>24</td>
<td>2</td>
<td>54.5</td>
<td>11.4</td>
<td>4.7</td>
<td>0.41835</td>
<td>0.17248</td>
<td>2.42553</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>125</td>
<td>931</td>
<td>25</td>
<td>2</td>
<td>54.5</td>
<td>7.6</td>
<td>3.7</td>
<td>0.27890</td>
<td>0.13578</td>
<td>2.05405</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>126</td>
<td>932</td>
<td>1</td>
<td>2</td>
<td>54.5</td>
<td>11.1</td>
<td>4.7</td>
<td>0.40734</td>
<td>0.17248</td>
<td>2.36170</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>127</td>
<td>932</td>
<td>2</td>
<td>2</td>
<td>54.5</td>
<td>11.7</td>
<td>4.5</td>
<td>0.42936</td>
<td>0.16514</td>
<td>2.60000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>128</td>
<td>932</td>
<td>3</td>
<td>2</td>
<td>54.5</td>
<td>10.1</td>
<td>4.5</td>
<td>0.37064</td>
<td>0.16514</td>
<td>2.24444</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>129</td>
<td>932</td>
<td>4</td>
<td>2</td>
<td>54.5</td>
<td>9.6</td>
<td>3.7</td>
<td>0.35229</td>
<td>0.13578</td>
<td>2.59459</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>130</td>
<td>932</td>
<td>5</td>
<td>2</td>
<td>54.5</td>
<td>9.9</td>
<td>5.3</td>
<td>0.36330</td>
<td>0.19450</td>
<td>1.86792</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>131</td>
<td>932</td>
<td>6</td>
<td>2</td>
<td>54.5</td>
<td>8.1</td>
<td>4.1</td>
<td>0.29725</td>
<td>0.15046</td>
<td>1.97561</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>132</td>
<td>932</td>
<td>7</td>
<td>2</td>
<td>54.5</td>
<td>9.1</td>
<td>6.0</td>
<td>0.33394</td>
<td>0.22018</td>
<td>1.51667</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>133</td>
<td>932</td>
<td>8</td>
<td>2</td>
<td>54.5</td>
<td>10.0</td>
<td>4.3</td>
<td>0.36697</td>
<td>0.15780</td>
<td>2.32558</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>134</td>
<td>932</td>
<td>9</td>
<td>2</td>
<td>54.5</td>
<td>12.6</td>
<td>6.0</td>
<td>0.46239</td>
<td>0.22018</td>
<td>2.10000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>135</td>
<td>932</td>
<td>10</td>
<td>2</td>
<td>54.5</td>
<td>10.3</td>
<td>4.6</td>
<td>0.37798</td>
<td>0.16881</td>
<td>2.23913</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>136</td>
<td>932</td>
<td>11</td>
<td>2</td>
<td>54.5</td>
<td>12.5</td>
<td>6.4</td>
<td>0.45872</td>
<td>0.23486</td>
<td>1.95313</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>137</td>
<td>932</td>
<td>12</td>
<td>2</td>
<td>54.5</td>
<td>13.1</td>
<td>5.5</td>
<td>0.48073</td>
<td>0.20183</td>
<td>2.38182</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Scale true length (pix)</td>
<td>Image scale length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (µm)</td>
<td>Image crystal length (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>--------------------</td>
<td>------------------------</td>
<td>-------------------------</td>
<td>-------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>138</td>
<td>932</td>
<td>13</td>
<td>2</td>
<td>54.5</td>
<td>7.3</td>
<td>3.8</td>
<td>0.26789</td>
<td>0.13945</td>
<td>1.92105</td>
<td></td>
</tr>
<tr>
<td>139</td>
<td>932</td>
<td>14</td>
<td>2</td>
<td>54.5</td>
<td>7.7</td>
<td>4.8</td>
<td>0.28257</td>
<td>0.17615</td>
<td>1.60417</td>
<td></td>
</tr>
<tr>
<td>140</td>
<td>932</td>
<td>15</td>
<td>2</td>
<td>54.5</td>
<td>8.8</td>
<td>2.8</td>
<td>0.32294</td>
<td>0.10275</td>
<td>3.14286</td>
<td></td>
</tr>
<tr>
<td>141</td>
<td>932</td>
<td>16</td>
<td>2</td>
<td>54.5</td>
<td>12.6</td>
<td>4.8</td>
<td>0.46239</td>
<td>0.17615</td>
<td>2.62500</td>
<td></td>
</tr>
<tr>
<td>142</td>
<td>932</td>
<td>17</td>
<td>2</td>
<td>54.5</td>
<td>11.8</td>
<td>4.8</td>
<td>0.43303</td>
<td>0.17615</td>
<td>2.45833</td>
<td></td>
</tr>
<tr>
<td>143</td>
<td>932</td>
<td>18</td>
<td>2</td>
<td>54.5</td>
<td>10.6</td>
<td>4.2</td>
<td>0.38899</td>
<td>0.15413</td>
<td>2.52381</td>
<td></td>
</tr>
<tr>
<td>144</td>
<td>932</td>
<td>19</td>
<td>2</td>
<td>54.5</td>
<td>9.8</td>
<td>4.5</td>
<td>0.35963</td>
<td>0.16514</td>
<td>2.17778</td>
<td></td>
</tr>
<tr>
<td>145</td>
<td>932</td>
<td>20</td>
<td>2</td>
<td>54.5</td>
<td>7.2</td>
<td>3.8</td>
<td>0.26422</td>
<td>0.13945</td>
<td>1.89474</td>
<td></td>
</tr>
<tr>
<td>146</td>
<td>932</td>
<td>21</td>
<td>2</td>
<td>54.5</td>
<td>7.7</td>
<td>4.0</td>
<td>0.28257</td>
<td>0.14679</td>
<td>1.92500</td>
<td></td>
</tr>
<tr>
<td>147</td>
<td>932</td>
<td>22</td>
<td>2</td>
<td>54.5</td>
<td>7.6</td>
<td>4.1</td>
<td>0.27890</td>
<td>0.15046</td>
<td>1.85366</td>
<td></td>
</tr>
<tr>
<td>148</td>
<td>932</td>
<td>23</td>
<td>2</td>
<td>54.5</td>
<td>12.4</td>
<td>4.0</td>
<td>0.45505</td>
<td>0.14679</td>
<td>3.10000</td>
<td></td>
</tr>
<tr>
<td>149</td>
<td>932</td>
<td>24</td>
<td>2</td>
<td>54.5</td>
<td>9.0</td>
<td>4.1</td>
<td>0.33028</td>
<td>0.15046</td>
<td>2.19512</td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>932</td>
<td>25</td>
<td>2</td>
<td>54.5</td>
<td>8.4</td>
<td>3.7</td>
<td>0.30826</td>
<td>0.13578</td>
<td>2.27027</td>
<td></td>
</tr>
<tr>
<td>151</td>
<td>936</td>
<td>1</td>
<td>2</td>
<td>27.4</td>
<td>6.0</td>
<td>2.6</td>
<td>0.43796</td>
<td>0.18978</td>
<td>2.30769</td>
<td></td>
</tr>
<tr>
<td>152</td>
<td>936</td>
<td>2</td>
<td>2</td>
<td>27.4</td>
<td>4.6</td>
<td>2.8</td>
<td>0.33577</td>
<td>0.20438</td>
<td>1.64286</td>
<td></td>
</tr>
<tr>
<td>153</td>
<td>936</td>
<td>3</td>
<td>2</td>
<td>27.4</td>
<td>5.3</td>
<td>2.6</td>
<td>0.38686</td>
<td>0.18978</td>
<td>2.03846</td>
<td></td>
</tr>
<tr>
<td>154</td>
<td>936</td>
<td>4</td>
<td>2</td>
<td>27.4</td>
<td>4.4</td>
<td>2.3</td>
<td>0.32117</td>
<td>0.16788</td>
<td>1.91304</td>
<td></td>
</tr>
<tr>
<td>155</td>
<td>936</td>
<td>5</td>
<td>2</td>
<td>27.4</td>
<td>4.7</td>
<td>2.1</td>
<td>0.34307</td>
<td>0.15328</td>
<td>2.23810</td>
<td></td>
</tr>
<tr>
<td>156</td>
<td>936</td>
<td>6</td>
<td>2</td>
<td>27.4</td>
<td>5.7</td>
<td>2.7</td>
<td>0.41606</td>
<td>0.19708</td>
<td>2.11111</td>
<td></td>
</tr>
<tr>
<td>157</td>
<td>936</td>
<td>7</td>
<td>2</td>
<td>27.4</td>
<td>5.8</td>
<td>3.5</td>
<td>0.42336</td>
<td>0.25547</td>
<td>1.65714</td>
<td></td>
</tr>
<tr>
<td>158</td>
<td>936</td>
<td>8</td>
<td>2</td>
<td>27.4</td>
<td>6.4</td>
<td>3.7</td>
<td>0.46715</td>
<td>0.27007</td>
<td>1.72973</td>
<td></td>
</tr>
<tr>
<td>159</td>
<td>936</td>
<td>9</td>
<td>2</td>
<td>27.4</td>
<td>3.9</td>
<td>1.9</td>
<td>0.28467</td>
<td>0.13869</td>
<td>2.05263</td>
<td></td>
</tr>
<tr>
<td>160</td>
<td>936</td>
<td>10</td>
<td>2</td>
<td>27.4</td>
<td>5.7</td>
<td>2.3</td>
<td>0.41606</td>
<td>0.16788</td>
<td>2.47826</td>
<td></td>
</tr>
<tr>
<td>161</td>
<td>936</td>
<td>11</td>
<td>2</td>
<td>27.4</td>
<td>4.2</td>
<td>2.4</td>
<td>0.30657</td>
<td>0.17518</td>
<td>1.75000</td>
<td></td>
</tr>
<tr>
<td>162</td>
<td>936</td>
<td>12</td>
<td>2</td>
<td>27.4</td>
<td>5.8</td>
<td>2.6</td>
<td>0.42336</td>
<td>0.18978</td>
<td>2.23077</td>
<td></td>
</tr>
<tr>
<td>163</td>
<td>936</td>
<td>13</td>
<td>2</td>
<td>27.4</td>
<td>5.1</td>
<td>2.8</td>
<td>0.37226</td>
<td>0.20438</td>
<td>1.82143</td>
<td></td>
</tr>
<tr>
<td>164</td>
<td>936</td>
<td>14</td>
<td>2</td>
<td>27.4</td>
<td>5.5</td>
<td>2.6</td>
<td>0.40146</td>
<td>0.18978</td>
<td>2.11538</td>
<td></td>
</tr>
<tr>
<td>165</td>
<td>936</td>
<td>15</td>
<td>2</td>
<td>27.4</td>
<td>5.5</td>
<td>2.2</td>
<td>0.40146</td>
<td>0.16058</td>
<td>2.50000</td>
<td></td>
</tr>
<tr>
<td>166</td>
<td>936</td>
<td>16</td>
<td>2</td>
<td>27.4</td>
<td>4.5</td>
<td>2.0</td>
<td>0.32847</td>
<td>0.14599</td>
<td>2.25000</td>
<td></td>
</tr>
<tr>
<td>167</td>
<td>936</td>
<td>17</td>
<td>2</td>
<td>27.4</td>
<td>6.2</td>
<td>2.4</td>
<td>0.45255</td>
<td>0.17518</td>
<td>2.58333</td>
<td></td>
</tr>
<tr>
<td>168</td>
<td>936</td>
<td>18</td>
<td>2</td>
<td>27.4</td>
<td>6.7</td>
<td>2.4</td>
<td>0.48905</td>
<td>0.17518</td>
<td>2.79167</td>
<td></td>
</tr>
<tr>
<td>169</td>
<td>936</td>
<td>19</td>
<td>2</td>
<td>27.4</td>
<td>4.6</td>
<td>2.1</td>
<td>0.33577</td>
<td>0.15328</td>
<td>2.19048</td>
<td></td>
</tr>
<tr>
<td>170</td>
<td>936</td>
<td>20</td>
<td>2</td>
<td>27.4</td>
<td>5.1</td>
<td>2.4</td>
<td>0.37226</td>
<td>0.17518</td>
<td>2.12500</td>
<td></td>
</tr>
<tr>
<td>171</td>
<td>936</td>
<td>21</td>
<td>2</td>
<td>27.4</td>
<td>6.5</td>
<td>2.9</td>
<td>0.47445</td>
<td>0.21168</td>
<td>2.24138</td>
<td></td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Scale true length (pix)</td>
<td>Image scale length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>-------------------</td>
<td>------------------------</td>
<td>------------------------</td>
<td>-----------------------</td>
<td>------------------------</td>
<td>-------------------------</td>
<td>-------------------------</td>
<td>-------------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>172</td>
<td>936</td>
<td>22</td>
<td>2</td>
<td>27.4</td>
<td>5.5</td>
<td>2.3</td>
<td>0.40146</td>
<td>0.16788</td>
<td>2.39130</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>173</td>
<td>936</td>
<td>23</td>
<td>2</td>
<td>27.4</td>
<td>5.9</td>
<td>2.7</td>
<td>0.43066</td>
<td>0.19708</td>
<td>2.18519</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>174</td>
<td>936</td>
<td>24</td>
<td>2</td>
<td>27.4</td>
<td>6.6</td>
<td>2.8</td>
<td>0.48175</td>
<td>0.20438</td>
<td>2.35714</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>175</td>
<td>936</td>
<td>25</td>
<td>2</td>
<td>27.4</td>
<td>6.4</td>
<td>3.2</td>
<td>0.46715</td>
<td>0.23358</td>
<td>2.00000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>176</td>
<td>939</td>
<td>1</td>
<td>2</td>
<td>54.5</td>
<td>7.5</td>
<td>5.2</td>
<td>0.27523</td>
<td>0.19083</td>
<td>1.44231</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>177</td>
<td>939</td>
<td>2</td>
<td>2</td>
<td>54.5</td>
<td>15.1</td>
<td>8.1</td>
<td>0.55413</td>
<td>0.29725</td>
<td>1.86420</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>178</td>
<td>939</td>
<td>3</td>
<td>2</td>
<td>54.5</td>
<td>9.3</td>
<td>4.2</td>
<td>0.34128</td>
<td>0.15413</td>
<td>2.21429</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>179</td>
<td>939</td>
<td>4</td>
<td>2</td>
<td>54.5</td>
<td>8.1</td>
<td>5.9</td>
<td>0.29725</td>
<td>0.21651</td>
<td>1.37288</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>180</td>
<td>939</td>
<td>5</td>
<td>2</td>
<td>54.5</td>
<td>7.1</td>
<td>4.7</td>
<td>0.26055</td>
<td>0.17248</td>
<td>1.51064</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>181</td>
<td>939</td>
<td>6</td>
<td>2</td>
<td>54.5</td>
<td>7.7</td>
<td>4.9</td>
<td>0.28257</td>
<td>0.17982</td>
<td>1.57143</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>182</td>
<td>939</td>
<td>7</td>
<td>2</td>
<td>54.5</td>
<td>11.9</td>
<td>6.7</td>
<td>0.43670</td>
<td>0.24587</td>
<td>1.77612</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>183</td>
<td>939</td>
<td>8</td>
<td>2</td>
<td>54.5</td>
<td>10.5</td>
<td>4.4</td>
<td>0.38532</td>
<td>0.16147</td>
<td>2.38636</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>184</td>
<td>939</td>
<td>9</td>
<td>2</td>
<td>54.5</td>
<td>10.4</td>
<td>4.8</td>
<td>0.38165</td>
<td>0.17615</td>
<td>2.16667</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>185</td>
<td>939</td>
<td>10</td>
<td>2</td>
<td>54.5</td>
<td>8.8</td>
<td>4.6</td>
<td>0.32294</td>
<td>0.16881</td>
<td>1.91304</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>186</td>
<td>939</td>
<td>11</td>
<td>2</td>
<td>54.5</td>
<td>8.9</td>
<td>5.5</td>
<td>0.32661</td>
<td>0.20183</td>
<td>1.61818</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>187</td>
<td>939</td>
<td>12</td>
<td>2</td>
<td>54.5</td>
<td>6.7</td>
<td>3.6</td>
<td>0.24587</td>
<td>0.13211</td>
<td>1.86111</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>188</td>
<td>939</td>
<td>13</td>
<td>2</td>
<td>54.5</td>
<td>7.8</td>
<td>4.4</td>
<td>0.28624</td>
<td>0.16147</td>
<td>1.77273</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>189</td>
<td>939</td>
<td>14</td>
<td>2</td>
<td>54.5</td>
<td>11.0</td>
<td>4.9</td>
<td>0.40367</td>
<td>0.17982</td>
<td>2.24490</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>190</td>
<td>939</td>
<td>15</td>
<td>2</td>
<td>54.5</td>
<td>8.2</td>
<td>5.2</td>
<td>0.30092</td>
<td>0.19083</td>
<td>1.57692</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>191</td>
<td>939</td>
<td>16</td>
<td>2</td>
<td>54.5</td>
<td>6.8</td>
<td>4.4</td>
<td>0.24954</td>
<td>0.16147</td>
<td>1.54545</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>192</td>
<td>939</td>
<td>17</td>
<td>2</td>
<td>54.5</td>
<td>10.8</td>
<td>4.4</td>
<td>0.39633</td>
<td>0.16147</td>
<td>2.45455</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>193</td>
<td>939</td>
<td>18</td>
<td>2</td>
<td>54.5</td>
<td>10.7</td>
<td>5.7</td>
<td>0.39266</td>
<td>0.20917</td>
<td>1.87719</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>194</td>
<td>939</td>
<td>19</td>
<td>2</td>
<td>54.5</td>
<td>8.7</td>
<td>5.4</td>
<td>0.31927</td>
<td>0.19817</td>
<td>1.61111</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>195</td>
<td>939</td>
<td>20</td>
<td>2</td>
<td>54.5</td>
<td>7.4</td>
<td>4.3</td>
<td>0.27156</td>
<td>0.15780</td>
<td>1.72093</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>196</td>
<td>939</td>
<td>21</td>
<td>2</td>
<td>54.5</td>
<td>7.7</td>
<td>3.4</td>
<td>0.28257</td>
<td>0.12477</td>
<td>2.26471</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>197</td>
<td>939</td>
<td>22</td>
<td>2</td>
<td>54.5</td>
<td>7.1</td>
<td>3.8</td>
<td>0.26055</td>
<td>0.13945</td>
<td>1.86842</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>198</td>
<td>939</td>
<td>23</td>
<td>2</td>
<td>54.5</td>
<td>7.8</td>
<td>4.9</td>
<td>0.28624</td>
<td>0.17982</td>
<td>1.59184</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>199</td>
<td>939</td>
<td>24</td>
<td>2</td>
<td>54.5</td>
<td>10.4</td>
<td>5.3</td>
<td>0.38165</td>
<td>0.19450</td>
<td>1.96226</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>200</td>
<td>939</td>
<td>25</td>
<td>2</td>
<td>54.5</td>
<td>8.1</td>
<td>4.4</td>
<td>0.29725</td>
<td>0.16147</td>
<td>1.84091</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>201</td>
<td>947</td>
<td>1</td>
<td>1</td>
<td>41.0</td>
<td>16.4</td>
<td>6.7</td>
<td>0.40000</td>
<td>0.16341</td>
<td>2.44776</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>202</td>
<td>947</td>
<td>2</td>
<td>1</td>
<td>41.0</td>
<td>16.1</td>
<td>6.3</td>
<td>0.39268</td>
<td>0.15366</td>
<td>2.55556</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>203</td>
<td>947</td>
<td>3</td>
<td>1</td>
<td>41.0</td>
<td>13.7</td>
<td>6.4</td>
<td>0.33415</td>
<td>0.15610</td>
<td>2.14063</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>204</td>
<td>947</td>
<td>4</td>
<td>1</td>
<td>41.0</td>
<td>19.8</td>
<td>6.8</td>
<td>0.48293</td>
<td>0.16585</td>
<td>2.91176</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>205</td>
<td>947</td>
<td>5</td>
<td>1</td>
<td>41.0</td>
<td>17.2</td>
<td>7.9</td>
<td>0.41951</td>
<td>0.19268</td>
<td>2.17722</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
<td>L:W ratio</td>
<td>Category</td>
</tr>
<tr>
<td>---------</td>
<td>--------------</td>
<td>-------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>-----------------------------</td>
<td>---------------------------</td>
<td>---------------------------</td>
<td>-------------------------</td>
<td>-----------</td>
<td>--------------------</td>
</tr>
<tr>
<td>206</td>
<td>947</td>
<td>6</td>
<td>1</td>
<td>41.0</td>
<td>18.8</td>
<td>6.8</td>
<td>0.45854</td>
<td>0.16585</td>
<td>2.76471</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>207</td>
<td>947</td>
<td>7</td>
<td>1</td>
<td>41.0</td>
<td>11.3</td>
<td>4.5</td>
<td>0.27561</td>
<td>0.10976</td>
<td>2.51111</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>208</td>
<td>947</td>
<td>8</td>
<td>1</td>
<td>41.0</td>
<td>10.4</td>
<td>6.6</td>
<td>0.25366</td>
<td>0.16098</td>
<td>1.57576</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>209</td>
<td>947</td>
<td>9</td>
<td>1</td>
<td>41.0</td>
<td>9.0</td>
<td>5.0</td>
<td>0.21951</td>
<td>0.12195</td>
<td>1.80000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>210</td>
<td>947</td>
<td>10</td>
<td>1</td>
<td>41.0</td>
<td>11.5</td>
<td>6.8</td>
<td>0.28049</td>
<td>0.16585</td>
<td>1.69118</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>211</td>
<td>947</td>
<td>11</td>
<td>1</td>
<td>41.0</td>
<td>9.0</td>
<td>4.7</td>
<td>0.21951</td>
<td>0.11463</td>
<td>1.91489</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>212</td>
<td>947</td>
<td>12</td>
<td>1</td>
<td>41.0</td>
<td>8.1</td>
<td>4.9</td>
<td>0.19756</td>
<td>0.11951</td>
<td>1.65306</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>213</td>
<td>947</td>
<td>13</td>
<td>1</td>
<td>41.0</td>
<td>8.9</td>
<td>6.4</td>
<td>0.21707</td>
<td>0.15610</td>
<td>1.39063</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>214</td>
<td>947</td>
<td>14</td>
<td>1</td>
<td>41.0</td>
<td>10.7</td>
<td>7.0</td>
<td>0.26098</td>
<td>0.17073</td>
<td>1.52857</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>215</td>
<td>947</td>
<td>15</td>
<td>1</td>
<td>41.0</td>
<td>12.4</td>
<td>6.8</td>
<td>0.30244</td>
<td>0.16585</td>
<td>1.82353</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>216</td>
<td>947</td>
<td>16</td>
<td>1</td>
<td>41.0</td>
<td>10.0</td>
<td>6.2</td>
<td>0.24390</td>
<td>0.15122</td>
<td>1.61290</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>217</td>
<td>947</td>
<td>17</td>
<td>1</td>
<td>41.0</td>
<td>8.9</td>
<td>4.8</td>
<td>0.21707</td>
<td>0.11707</td>
<td>1.85417</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>218</td>
<td>947</td>
<td>18</td>
<td>1</td>
<td>41.0</td>
<td>11.5</td>
<td>7.5</td>
<td>0.28049</td>
<td>0.18293</td>
<td>1.53333</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>219</td>
<td>947</td>
<td>19</td>
<td>1</td>
<td>41.0</td>
<td>11.5</td>
<td>7.0</td>
<td>0.28049</td>
<td>0.17073</td>
<td>1.64286</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>220</td>
<td>947</td>
<td>20</td>
<td>1</td>
<td>41.0</td>
<td>12.5</td>
<td>5.0</td>
<td>0.30488</td>
<td>0.12195</td>
<td>2.50000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>221</td>
<td>947</td>
<td>21</td>
<td>1</td>
<td>41.0</td>
<td>10.7</td>
<td>6.0</td>
<td>0.26098</td>
<td>0.14634</td>
<td>1.78333</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>222</td>
<td>947</td>
<td>22</td>
<td>1</td>
<td>41.0</td>
<td>9.4</td>
<td>5.4</td>
<td>0.22927</td>
<td>0.13171</td>
<td>1.74074</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>223</td>
<td>947</td>
<td>23</td>
<td>1</td>
<td>41.0</td>
<td>16.6</td>
<td>7.4</td>
<td>0.40488</td>
<td>0.18049</td>
<td>2.24324</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>224</td>
<td>947</td>
<td>24</td>
<td>1</td>
<td>41.0</td>
<td>11.6</td>
<td>4.9</td>
<td>0.28293</td>
<td>0.11951</td>
<td>2.36735</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>225</td>
<td>947</td>
<td>25</td>
<td>1</td>
<td>41.0</td>
<td>9.8</td>
<td>4.6</td>
<td>0.23902</td>
<td>0.11220</td>
<td>2.13043</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>226</td>
<td>948</td>
<td>1</td>
<td>2</td>
<td>54.5</td>
<td>8.4</td>
<td>3.4</td>
<td>0.30826</td>
<td>0.12477</td>
<td>2.47059</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>227</td>
<td>948</td>
<td>2</td>
<td>2</td>
<td>54.5</td>
<td>8.3</td>
<td>5.4</td>
<td>0.30459</td>
<td>0.19817</td>
<td>1.53704</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>228</td>
<td>948</td>
<td>3</td>
<td>2</td>
<td>54.5</td>
<td>9.3</td>
<td>4.7</td>
<td>0.34128</td>
<td>0.17248</td>
<td>1.97872</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>229</td>
<td>948</td>
<td>4</td>
<td>2</td>
<td>54.5</td>
<td>11.3</td>
<td>4.8</td>
<td>0.41468</td>
<td>0.17615</td>
<td>2.35417</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>230</td>
<td>948</td>
<td>5</td>
<td>2</td>
<td>54.5</td>
<td>8.4</td>
<td>3.9</td>
<td>0.30826</td>
<td>0.14312</td>
<td>2.15385</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>231</td>
<td>948</td>
<td>6</td>
<td>2</td>
<td>54.5</td>
<td>7.1</td>
<td>4.3</td>
<td>0.26055</td>
<td>0.15780</td>
<td>1.65116</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>232</td>
<td>948</td>
<td>7</td>
<td>2</td>
<td>54.5</td>
<td>10.4</td>
<td>4.4</td>
<td>0.38165</td>
<td>0.16147</td>
<td>2.36364</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>233</td>
<td>948</td>
<td>8</td>
<td>2</td>
<td>54.5</td>
<td>8.6</td>
<td>4.1</td>
<td>0.31560</td>
<td>0.15046</td>
<td>2.09756</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>234</td>
<td>948</td>
<td>9</td>
<td>2</td>
<td>54.5</td>
<td>12.0</td>
<td>5.8</td>
<td>0.44037</td>
<td>0.21284</td>
<td>2.06897</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>235</td>
<td>948</td>
<td>10</td>
<td>2</td>
<td>54.5</td>
<td>9.2</td>
<td>4.7</td>
<td>0.33761</td>
<td>0.17248</td>
<td>1.95745</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>236</td>
<td>948</td>
<td>11</td>
<td>2</td>
<td>54.5</td>
<td>8.0</td>
<td>4.1</td>
<td>0.29358</td>
<td>0.15046</td>
<td>1.95122</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>237</td>
<td>948</td>
<td>12</td>
<td>2</td>
<td>54.5</td>
<td>9.5</td>
<td>6.0</td>
<td>0.34862</td>
<td>0.22018</td>
<td>1.58333</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>238</td>
<td>948</td>
<td>13</td>
<td>2</td>
<td>54.5</td>
<td>9.0</td>
<td>5.4</td>
<td>0.33028</td>
<td>0.19817</td>
<td>1.66667</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>239</td>
<td>948</td>
<td>14</td>
<td>2</td>
<td>54.5</td>
<td>7.7</td>
<td>3.6</td>
<td>0.28257</td>
<td>0.13211</td>
<td>2.13889</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
<td>L:W ratio</td>
<td>Category</td>
</tr>
<tr>
<td>---------</td>
<td>--------------</td>
<td>--------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>----------------------------</td>
<td>----------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>-----------</td>
<td>-------------------</td>
</tr>
<tr>
<td>240</td>
<td>948</td>
<td>15</td>
<td>2</td>
<td>54.5</td>
<td>7.4</td>
<td>4.4</td>
<td>0.27156</td>
<td>0.16147</td>
<td>1.68182</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>241</td>
<td>948</td>
<td>16</td>
<td>2</td>
<td>54.5</td>
<td>7.6</td>
<td>4.6</td>
<td>0.27890</td>
<td>0.16881</td>
<td>1.65217</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>242</td>
<td>948</td>
<td>17</td>
<td>2</td>
<td>54.5</td>
<td>8.9</td>
<td>3.7</td>
<td>0.32661</td>
<td>0.13578</td>
<td>2.40541</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>243</td>
<td>948</td>
<td>18</td>
<td>2</td>
<td>54.5</td>
<td>8.1</td>
<td>4.0</td>
<td>0.29725</td>
<td>0.14679</td>
<td>2.02500</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>244</td>
<td>948</td>
<td>19</td>
<td>2</td>
<td>54.5</td>
<td>9.9</td>
<td>5.5</td>
<td>0.36330</td>
<td>0.20183</td>
<td>1.80000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>245</td>
<td>948</td>
<td>20</td>
<td>2</td>
<td>54.5</td>
<td>6.9</td>
<td>4.0</td>
<td>0.25321</td>
<td>0.14679</td>
<td>1.72500</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>246</td>
<td>948</td>
<td>21</td>
<td>2</td>
<td>54.5</td>
<td>7.4</td>
<td>4.2</td>
<td>0.27156</td>
<td>0.15413</td>
<td>1.76190</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>247</td>
<td>948</td>
<td>22</td>
<td>2</td>
<td>54.5</td>
<td>9.2</td>
<td>4.4</td>
<td>0.33761</td>
<td>0.16147</td>
<td>2.09091</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>248</td>
<td>948</td>
<td>23</td>
<td>2</td>
<td>54.5</td>
<td>9.2</td>
<td>5.2</td>
<td>0.33761</td>
<td>0.19083</td>
<td>1.76923</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>249</td>
<td>948</td>
<td>24</td>
<td>2</td>
<td>54.5</td>
<td>6.3</td>
<td>2.9</td>
<td>0.23119</td>
<td>0.10642</td>
<td>2.17241</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>250</td>
<td>948</td>
<td>25</td>
<td>2</td>
<td>54.5</td>
<td>11.8</td>
<td>5.1</td>
<td>0.43303</td>
<td>0.18716</td>
<td>2.31373</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>251</td>
<td>1034</td>
<td>1</td>
<td>2</td>
<td>54.5</td>
<td>8.2</td>
<td>4.2</td>
<td>0.30092</td>
<td>0.15413</td>
<td>1.95238</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>252</td>
<td>1034</td>
<td>2</td>
<td>2</td>
<td>54.5</td>
<td>6.2</td>
<td>3.5</td>
<td>0.22752</td>
<td>0.12844</td>
<td>1.77143</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>253</td>
<td>1034</td>
<td>3</td>
<td>2</td>
<td>54.5</td>
<td>7.3</td>
<td>3.0</td>
<td>0.26789</td>
<td>0.11009</td>
<td>2.43333</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>254</td>
<td>1034</td>
<td>4</td>
<td>2</td>
<td>54.5</td>
<td>8.2</td>
<td>3.6</td>
<td>0.30092</td>
<td>0.13211</td>
<td>2.27778</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>255</td>
<td>1034</td>
<td>5</td>
<td>2</td>
<td>54.5</td>
<td>13.2</td>
<td>5.1</td>
<td>0.48440</td>
<td>0.18716</td>
<td>2.58824</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>256</td>
<td>1034</td>
<td>6</td>
<td>2</td>
<td>54.5</td>
<td>7.2</td>
<td>3.7</td>
<td>0.26422</td>
<td>0.13578</td>
<td>1.94595</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>257</td>
<td>1034</td>
<td>7</td>
<td>2</td>
<td>54.5</td>
<td>6.7</td>
<td>3.0</td>
<td>0.24587</td>
<td>0.11009</td>
<td>2.23333</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>258</td>
<td>1034</td>
<td>8</td>
<td>2</td>
<td>54.5</td>
<td>5.4</td>
<td>2.8</td>
<td>0.19817</td>
<td>0.10275</td>
<td>1.92857</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>259</td>
<td>1034</td>
<td>9</td>
<td>2</td>
<td>54.5</td>
<td>6.1</td>
<td>3.3</td>
<td>0.22385</td>
<td>0.12110</td>
<td>1.84848</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>260</td>
<td>1034</td>
<td>10</td>
<td>2</td>
<td>54.5</td>
<td>7.2</td>
<td>3.6</td>
<td>0.26422</td>
<td>0.13211</td>
<td>2.00000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>261</td>
<td>1034</td>
<td>11</td>
<td>2</td>
<td>54.5</td>
<td>10.8</td>
<td>4.4</td>
<td>0.39633</td>
<td>0.16147</td>
<td>2.45455</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>262</td>
<td>1034</td>
<td>12</td>
<td>2</td>
<td>54.5</td>
<td>10.2</td>
<td>4.4</td>
<td>0.37431</td>
<td>0.16147</td>
<td>2.31818</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>263</td>
<td>1034</td>
<td>13</td>
<td>2</td>
<td>54.5</td>
<td>8.1</td>
<td>3.7</td>
<td>0.29725</td>
<td>0.13578</td>
<td>2.18919</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>264</td>
<td>1034</td>
<td>14</td>
<td>2</td>
<td>54.5</td>
<td>9.3</td>
<td>4.0</td>
<td>0.34128</td>
<td>0.14679</td>
<td>2.32500</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>265</td>
<td>1034</td>
<td>15</td>
<td>2</td>
<td>54.5</td>
<td>6.7</td>
<td>3.3</td>
<td>0.24587</td>
<td>0.12110</td>
<td>2.03030</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>266</td>
<td>1034</td>
<td>16</td>
<td>2</td>
<td>54.5</td>
<td>9.1</td>
<td>3.8</td>
<td>0.33394</td>
<td>0.13945</td>
<td>2.39474</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>267</td>
<td>1034</td>
<td>17</td>
<td>2</td>
<td>54.5</td>
<td>8.3</td>
<td>4.2</td>
<td>0.30459</td>
<td>0.15413</td>
<td>1.97619</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>268</td>
<td>1034</td>
<td>18</td>
<td>2</td>
<td>54.5</td>
<td>10.9</td>
<td>5.2</td>
<td>0.40000</td>
<td>0.19083</td>
<td>2.09615</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>269</td>
<td>1034</td>
<td>19</td>
<td>2</td>
<td>54.5</td>
<td>8.6</td>
<td>3.5</td>
<td>0.31560</td>
<td>0.12844</td>
<td>2.45714</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>270</td>
<td>1034</td>
<td>20</td>
<td>2</td>
<td>54.5</td>
<td>11.5</td>
<td>4.2</td>
<td>0.42202</td>
<td>0.15413</td>
<td>2.73810</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>271</td>
<td>1034</td>
<td>21</td>
<td>2</td>
<td>54.5</td>
<td>7.5</td>
<td>3.7</td>
<td>0.27523</td>
<td>0.13578</td>
<td>2.02703</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>272</td>
<td>1034</td>
<td>22</td>
<td>2</td>
<td>54.5</td>
<td>11.8</td>
<td>5.0</td>
<td>0.43303</td>
<td>0.18349</td>
<td>2.36000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>273</td>
<td>1034</td>
<td>23</td>
<td>2</td>
<td>54.5</td>
<td>5.7</td>
<td>3.4</td>
<td>0.20917</td>
<td>0.12477</td>
<td>1.67647</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
<td>L:W ratio</td>
<td>Category</td>
</tr>
<tr>
<td>---------</td>
<td>--------------</td>
<td>--------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>------------</td>
<td>----------</td>
</tr>
<tr>
<td>274</td>
<td>1034</td>
<td>24</td>
<td>2</td>
<td>54.5</td>
<td>8.2</td>
<td>3.3</td>
<td>0.30092</td>
<td>0.12110</td>
<td>2.48485</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>275</td>
<td>1034</td>
<td>25</td>
<td>2</td>
<td>54.5</td>
<td>11.1</td>
<td>3.6</td>
<td>0.40734</td>
<td>0.13211</td>
<td>3.08333</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>276</td>
<td>1046</td>
<td>1</td>
<td>2</td>
<td>54.5</td>
<td>17.1</td>
<td>5.1</td>
<td>0.62752</td>
<td>0.18716</td>
<td>3.35294</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>277</td>
<td>1046</td>
<td>2</td>
<td>2</td>
<td>54.5</td>
<td>14.4</td>
<td>3.9</td>
<td>0.52844</td>
<td>0.14312</td>
<td>3.69231</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>278</td>
<td>1046</td>
<td>3</td>
<td>2</td>
<td>54.5</td>
<td>11.7</td>
<td>5.0</td>
<td>0.42936</td>
<td>0.18349</td>
<td>3.34000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>279</td>
<td>1046</td>
<td>4</td>
<td>2</td>
<td>54.5</td>
<td>15.4</td>
<td>5.9</td>
<td>0.56514</td>
<td>0.21561</td>
<td>2.61017</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>280</td>
<td>1046</td>
<td>5</td>
<td>2</td>
<td>54.5</td>
<td>18.3</td>
<td>7.0</td>
<td>0.67156</td>
<td>0.25688</td>
<td>2.61429</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>281</td>
<td>1046</td>
<td>6</td>
<td>2</td>
<td>54.5</td>
<td>17.0</td>
<td>5.0</td>
<td>0.62385</td>
<td>0.18349</td>
<td>3.40000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>282</td>
<td>1046</td>
<td>7</td>
<td>2</td>
<td>54.5</td>
<td>15.4</td>
<td>4.0</td>
<td>0.56514</td>
<td>0.14679</td>
<td>3.85000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>283</td>
<td>1046</td>
<td>8</td>
<td>2</td>
<td>54.5</td>
<td>15.7</td>
<td>3.5</td>
<td>0.57615</td>
<td>0.12844</td>
<td>4.48571</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>284</td>
<td>1046</td>
<td>9</td>
<td>2</td>
<td>54.5</td>
<td>13.0</td>
<td>4.7</td>
<td>0.47706</td>
<td>0.17248</td>
<td>2.76596</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>285</td>
<td>1046</td>
<td>10</td>
<td>2</td>
<td>54.5</td>
<td>13.1</td>
<td>5.0</td>
<td>0.48073</td>
<td>0.18349</td>
<td>2.62000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>286</td>
<td>1046</td>
<td>11</td>
<td>2</td>
<td>54.5</td>
<td>11.9</td>
<td>3.9</td>
<td>0.43670</td>
<td>0.14312</td>
<td>3.05128</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>287</td>
<td>1046</td>
<td>12</td>
<td>2</td>
<td>54.5</td>
<td>9.6</td>
<td>3.9</td>
<td>0.35229</td>
<td>0.14312</td>
<td>2.46154</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>288</td>
<td>1046</td>
<td>13</td>
<td>2</td>
<td>54.5</td>
<td>14.2</td>
<td>5.3</td>
<td>0.52110</td>
<td>0.19450</td>
<td>2.67925</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>289</td>
<td>1046</td>
<td>14</td>
<td>2</td>
<td>54.5</td>
<td>13.4</td>
<td>4.7</td>
<td>0.49174</td>
<td>0.17248</td>
<td>2.85106</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>290</td>
<td>1046</td>
<td>15</td>
<td>2</td>
<td>54.5</td>
<td>10.1</td>
<td>5.0</td>
<td>0.37064</td>
<td>0.18349</td>
<td>2.02000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>291</td>
<td>1046</td>
<td>16</td>
<td>2</td>
<td>54.5</td>
<td>9.8</td>
<td>4.9</td>
<td>0.35963</td>
<td>0.17982</td>
<td>2.00000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>292</td>
<td>1046</td>
<td>17</td>
<td>2</td>
<td>54.5</td>
<td>9.2</td>
<td>4.8</td>
<td>0.33761</td>
<td>0.17615</td>
<td>1.91667</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>293</td>
<td>1046</td>
<td>18</td>
<td>2</td>
<td>54.5</td>
<td>9.7</td>
<td>3.8</td>
<td>0.35596</td>
<td>0.13945</td>
<td>2.55263</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>294</td>
<td>1046</td>
<td>19</td>
<td>2</td>
<td>54.5</td>
<td>8.0</td>
<td>4.3</td>
<td>0.29358</td>
<td>0.15780</td>
<td>1.86047</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>295</td>
<td>1046</td>
<td>20</td>
<td>2</td>
<td>54.5</td>
<td>10.4</td>
<td>3.7</td>
<td>0.38165</td>
<td>0.13578</td>
<td>2.81081</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>296</td>
<td>1046</td>
<td>21</td>
<td>2</td>
<td>54.5</td>
<td>14.9</td>
<td>4.2</td>
<td>0.54679</td>
<td>0.15413</td>
<td>3.54762</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>297</td>
<td>1046</td>
<td>22</td>
<td>2</td>
<td>54.5</td>
<td>10.7</td>
<td>6.1</td>
<td>0.39266</td>
<td>0.22385</td>
<td>1.75410</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>298</td>
<td>1046</td>
<td>23</td>
<td>2</td>
<td>54.5</td>
<td>12.3</td>
<td>6.2</td>
<td>0.45138</td>
<td>0.22752</td>
<td>1.98387</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>299</td>
<td>1046</td>
<td>24</td>
<td>2</td>
<td>54.5</td>
<td>10.1</td>
<td>4.7</td>
<td>0.37064</td>
<td>0.17248</td>
<td>2.14894</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>300</td>
<td>1046</td>
<td>25</td>
<td>2</td>
<td>54.5</td>
<td>16.7</td>
<td>4.0</td>
<td>0.61284</td>
<td>0.14679</td>
<td>4.17500</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>301</td>
<td>1068</td>
<td>1</td>
<td>2</td>
<td>27.4</td>
<td>7.6</td>
<td>3.2</td>
<td>0.55474</td>
<td>0.23538</td>
<td>2.37500</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>302</td>
<td>1068</td>
<td>2</td>
<td>2</td>
<td>27.4</td>
<td>5.3</td>
<td>2.5</td>
<td>0.38686</td>
<td>0.18248</td>
<td>2.12000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>303</td>
<td>1068</td>
<td>3</td>
<td>2</td>
<td>27.4</td>
<td>4.4</td>
<td>2.1</td>
<td>0.32117</td>
<td>0.15328</td>
<td>2.09524</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>304</td>
<td>1068</td>
<td>4</td>
<td>2</td>
<td>27.4</td>
<td>4.8</td>
<td>2.3</td>
<td>0.35036</td>
<td>0.16788</td>
<td>2.08696</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>305</td>
<td>1068</td>
<td>5</td>
<td>2</td>
<td>27.4</td>
<td>6.9</td>
<td>2.5</td>
<td>0.50365</td>
<td>0.18248</td>
<td>2.76000</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>306</td>
<td>1068</td>
<td>6</td>
<td>2</td>
<td>27.4</td>
<td>6.0</td>
<td>2.6</td>
<td>0.43796</td>
<td>0.18978</td>
<td>2.30769</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>307</td>
<td>1068</td>
<td>7</td>
<td>2</td>
<td>27.4</td>
<td>6.3</td>
<td>2.6</td>
<td>0.45985</td>
<td>0.18978</td>
<td>2.42308</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
<td>L:W ratio</td>
<td>Category</td>
</tr>
<tr>
<td>---------</td>
<td>--------------</td>
<td>-------------------</td>
<td>-----------------------</td>
<td>--------------------------</td>
<td>---------------------------</td>
<td>--------------------------</td>
<td>------------------------</td>
<td>------------------------</td>
<td>-------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>308</td>
<td>1068</td>
<td>8</td>
<td>2</td>
<td>27.4</td>
<td>5.1</td>
<td>2.6</td>
<td>0.37226</td>
<td>0.18978</td>
<td>1.96154</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>309</td>
<td>1068</td>
<td>9</td>
<td>2</td>
<td>27.4</td>
<td>5.8</td>
<td>3.5</td>
<td>0.42336</td>
<td>0.25547</td>
<td>1.65714</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>310</td>
<td>1068</td>
<td>10</td>
<td>2</td>
<td>27.4</td>
<td>7.8</td>
<td>3.7</td>
<td>0.56934</td>
<td>0.27007</td>
<td>2.10811</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>311</td>
<td>1068</td>
<td>11</td>
<td>2</td>
<td>27.4</td>
<td>5.8</td>
<td>2.6</td>
<td>0.42336</td>
<td>0.18978</td>
<td>2.23077</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>312</td>
<td>1068</td>
<td>12</td>
<td>2</td>
<td>27.4</td>
<td>8.5</td>
<td>3.2</td>
<td>0.62044</td>
<td>0.23358</td>
<td>2.65625</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>313</td>
<td>1068</td>
<td>13</td>
<td>2</td>
<td>27.4</td>
<td>8.9</td>
<td>2.7</td>
<td>0.64964</td>
<td>0.19708</td>
<td>3.29630</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>314</td>
<td>1068</td>
<td>14</td>
<td>2</td>
<td>27.4</td>
<td>7.7</td>
<td>3.3</td>
<td>0.56204</td>
<td>0.24088</td>
<td>2.33333</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>315</td>
<td>1068</td>
<td>15</td>
<td>2</td>
<td>27.4</td>
<td>7.2</td>
<td>2.1</td>
<td>0.52555</td>
<td>0.15328</td>
<td>3.42857</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>316</td>
<td>1068</td>
<td>16</td>
<td>2</td>
<td>27.4</td>
<td>8.0</td>
<td>2.7</td>
<td>0.58394</td>
<td>0.19708</td>
<td>2.96296</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>317</td>
<td>1068</td>
<td>17</td>
<td>2</td>
<td>27.4</td>
<td>5.5</td>
<td>2.9</td>
<td>0.40146</td>
<td>0.21168</td>
<td>1.89655</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>318</td>
<td>1068</td>
<td>18</td>
<td>2</td>
<td>27.4</td>
<td>7.4</td>
<td>3.1</td>
<td>0.54015</td>
<td>0.22628</td>
<td>2.38710</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>319</td>
<td>1068</td>
<td>19</td>
<td>2</td>
<td>27.4</td>
<td>5.8</td>
<td>2.6</td>
<td>0.42336</td>
<td>0.18978</td>
<td>2.23077</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>320</td>
<td>1068</td>
<td>20</td>
<td>2</td>
<td>27.4</td>
<td>6.0</td>
<td>2.7</td>
<td>0.43796</td>
<td>0.19708</td>
<td>2.22222</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>321</td>
<td>1068</td>
<td>21</td>
<td>2</td>
<td>27.4</td>
<td>6.9</td>
<td>2.4</td>
<td>0.50365</td>
<td>0.17518</td>
<td>2.87500</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>322</td>
<td>1068</td>
<td>22</td>
<td>2</td>
<td>27.4</td>
<td>5.2</td>
<td>2.4</td>
<td>0.37956</td>
<td>0.17518</td>
<td>2.16667</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>323</td>
<td>1068</td>
<td>23</td>
<td>2</td>
<td>27.4</td>
<td>6.2</td>
<td>3.0</td>
<td>0.45255</td>
<td>0.21898</td>
<td>2.06667</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>324</td>
<td>1068</td>
<td>24</td>
<td>2</td>
<td>27.4</td>
<td>7.4</td>
<td>2.6</td>
<td>0.54015</td>
<td>0.18978</td>
<td>2.84615</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>325</td>
<td>1068</td>
<td>25</td>
<td>2</td>
<td>27.4</td>
<td>7.9</td>
<td>2.7</td>
<td>0.57664</td>
<td>0.19708</td>
<td>2.92593</td>
<td>granule aggregate</td>
</tr>
<tr>
<td>1</td>
<td>934</td>
<td>1</td>
<td>0.2</td>
<td>27.4</td>
<td>8.8</td>
<td>4.3</td>
<td>0.06423</td>
<td>0.03139</td>
<td>2.04651</td>
<td>granule</td>
</tr>
<tr>
<td>2</td>
<td>934</td>
<td>2</td>
<td>0.2</td>
<td>27.4</td>
<td>10.1</td>
<td>4.1</td>
<td>0.07372</td>
<td>0.02993</td>
<td>2.46341</td>
<td>granule</td>
</tr>
<tr>
<td>3</td>
<td>934</td>
<td>3</td>
<td>0.2</td>
<td>27.4</td>
<td>8.7</td>
<td>4.4</td>
<td>0.06350</td>
<td>0.03212</td>
<td>1.97727</td>
<td>granule</td>
</tr>
<tr>
<td>4</td>
<td>934</td>
<td>4</td>
<td>0.2</td>
<td>27.4</td>
<td>8.8</td>
<td>4.6</td>
<td>0.06423</td>
<td>0.03358</td>
<td>1.91304</td>
<td>granule</td>
</tr>
<tr>
<td>5</td>
<td>934</td>
<td>5</td>
<td>0.2</td>
<td>27.4</td>
<td>8.1</td>
<td>4.4</td>
<td>0.05912</td>
<td>0.03212</td>
<td>1.84091</td>
<td>granule</td>
</tr>
<tr>
<td>6</td>
<td>935</td>
<td>1</td>
<td>0.5</td>
<td>34.4</td>
<td>5.3</td>
<td>2.8</td>
<td>0.07703</td>
<td>0.04070</td>
<td>1.89286</td>
<td>granule</td>
</tr>
<tr>
<td>7</td>
<td>935</td>
<td>2</td>
<td>0.5</td>
<td>34.4</td>
<td>5.6</td>
<td>3.3</td>
<td>0.08140</td>
<td>0.04797</td>
<td>1.69697</td>
<td>granule</td>
</tr>
<tr>
<td>8</td>
<td>935</td>
<td>3</td>
<td>0.5</td>
<td>34.4</td>
<td>7.7</td>
<td>4.6</td>
<td>0.11192</td>
<td>0.06686</td>
<td>1.67391</td>
<td>granule</td>
</tr>
<tr>
<td>9</td>
<td>935</td>
<td>4</td>
<td>0.5</td>
<td>34.4</td>
<td>4.9</td>
<td>2.8</td>
<td>0.07122</td>
<td>0.04070</td>
<td>1.75000</td>
<td>granule</td>
</tr>
<tr>
<td>10</td>
<td>935</td>
<td>5</td>
<td>0.5</td>
<td>34.4</td>
<td>5.8</td>
<td>2.6</td>
<td>0.08430</td>
<td>0.03779</td>
<td>2.23077</td>
<td>granule</td>
</tr>
<tr>
<td>11</td>
<td>935</td>
<td>6</td>
<td>0.5</td>
<td>34.4</td>
<td>8.5</td>
<td>4.2</td>
<td>0.12355</td>
<td>0.06105</td>
<td>2.02381</td>
<td>granule</td>
</tr>
<tr>
<td>12</td>
<td>935</td>
<td>7</td>
<td>0.5</td>
<td>34.4</td>
<td>5.4</td>
<td>2.3</td>
<td>0.07849</td>
<td>0.03343</td>
<td>2.34783</td>
<td>granule</td>
</tr>
<tr>
<td>13</td>
<td>935</td>
<td>8</td>
<td>0.5</td>
<td>34.4</td>
<td>5.9</td>
<td>2.9</td>
<td>0.08576</td>
<td>0.04215</td>
<td>2.03448</td>
<td>granule</td>
</tr>
<tr>
<td>14</td>
<td>935</td>
<td>9</td>
<td>0.5</td>
<td>34.4</td>
<td>5.1</td>
<td>2.9</td>
<td>0.07413</td>
<td>0.04215</td>
<td>1.75862</td>
<td>granule</td>
</tr>
<tr>
<td>15</td>
<td>935</td>
<td>10</td>
<td>0.5</td>
<td>34.4</td>
<td>4.6</td>
<td>2.2</td>
<td>0.06686</td>
<td>0.03198</td>
<td>2.09091</td>
<td>granule</td>
</tr>
<tr>
<td>16</td>
<td>938</td>
<td>1</td>
<td>1</td>
<td>41.0</td>
<td>3.8</td>
<td>2.1</td>
<td>0.09268</td>
<td>0.05122</td>
<td>1.80952</td>
<td>granule</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Crystal # on image</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image crystal length (pix)</td>
<td>Image crystal width (pix)</td>
<td>Crystal true length (µm)</td>
<td>Crystal true width (µm)</td>
<td>L:W ratio</td>
<td>Category</td>
</tr>
<tr>
<td>---------</td>
<td>--------------</td>
<td>--------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>---------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>-----------</td>
<td>----------</td>
</tr>
<tr>
<td>17</td>
<td>938</td>
<td>2</td>
<td>41.0</td>
<td>3.1</td>
<td>1.8</td>
<td>0.07561</td>
<td>0.04390</td>
<td>1.72222</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>938</td>
<td>3</td>
<td>41.0</td>
<td>2.9</td>
<td>1.6</td>
<td>0.07073</td>
<td>0.03902</td>
<td>1.81250</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>938</td>
<td>4</td>
<td>41.0</td>
<td>2.8</td>
<td>1.6</td>
<td>0.06829</td>
<td>0.03902</td>
<td>1.75000</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>938</td>
<td>5</td>
<td>41.0</td>
<td>3.4</td>
<td>1.7</td>
<td>0.08293</td>
<td>0.04146</td>
<td>2.00000</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>938</td>
<td>6</td>
<td>41.0</td>
<td>3.1</td>
<td>1.6</td>
<td>0.07561</td>
<td>0.03902</td>
<td>1.93750</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>938</td>
<td>7</td>
<td>41.0</td>
<td>3.6</td>
<td>1.7</td>
<td>0.08780</td>
<td>0.04146</td>
<td>2.11765</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>938</td>
<td>8</td>
<td>41.0</td>
<td>3.4</td>
<td>2.0</td>
<td>0.08293</td>
<td>0.04878</td>
<td>1.70000</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>938</td>
<td>9</td>
<td>41.0</td>
<td>2.7</td>
<td>1.8</td>
<td>0.06585</td>
<td>0.04390</td>
<td>1.50000</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>938</td>
<td>10</td>
<td>41.0</td>
<td>2.7</td>
<td>1.3</td>
<td>0.06585</td>
<td>0.03171</td>
<td>2.07692</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>946</td>
<td>1</td>
<td>41.0</td>
<td>3.8</td>
<td>1.8</td>
<td>0.09268</td>
<td>0.04390</td>
<td>2.11111</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>946</td>
<td>2</td>
<td>41.0</td>
<td>3.7</td>
<td>1.9</td>
<td>0.09024</td>
<td>0.04634</td>
<td>1.94737</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>946</td>
<td>3</td>
<td>41.0</td>
<td>3.4</td>
<td>1.7</td>
<td>0.08293</td>
<td>0.04146</td>
<td>2.00000</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>946</td>
<td>4</td>
<td>41.0</td>
<td>6.1</td>
<td>2.3</td>
<td>0.14878</td>
<td>0.05610</td>
<td>2.65217</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>946</td>
<td>5</td>
<td>41.0</td>
<td>3.7</td>
<td>1.5</td>
<td>0.09024</td>
<td>0.03659</td>
<td>2.46667</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>946</td>
<td>6</td>
<td>41.0</td>
<td>4.9</td>
<td>2.5</td>
<td>0.11951</td>
<td>0.06098</td>
<td>1.96000</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>946</td>
<td>7</td>
<td>41.0</td>
<td>4.0</td>
<td>1.9</td>
<td>0.09756</td>
<td>0.04634</td>
<td>2.10526</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>946</td>
<td>8</td>
<td>41.0</td>
<td>3.5</td>
<td>1.8</td>
<td>0.08537</td>
<td>0.04390</td>
<td>1.94444</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>946</td>
<td>9</td>
<td>41.0</td>
<td>4.5</td>
<td>2.4</td>
<td>0.10976</td>
<td>0.05854</td>
<td>1.87500</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>946</td>
<td>10</td>
<td>41.0</td>
<td>4.2</td>
<td>2.0</td>
<td>0.10244</td>
<td>0.04878</td>
<td>2.10000</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>946</td>
<td>11</td>
<td>41.0</td>
<td>4.2</td>
<td>2.3</td>
<td>0.10244</td>
<td>0.05610</td>
<td>1.82609</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>946</td>
<td>12</td>
<td>41.0</td>
<td>4.7</td>
<td>2.9</td>
<td>0.11463</td>
<td>0.07073</td>
<td>1.62069</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>946</td>
<td>13</td>
<td>41.0</td>
<td>4.0</td>
<td>2.3</td>
<td>0.09756</td>
<td>0.05610</td>
<td>1.73913</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>946</td>
<td>14</td>
<td>41.0</td>
<td>3.4</td>
<td>2.1</td>
<td>0.08293</td>
<td>0.05122</td>
<td>1.61905</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>946</td>
<td>15</td>
<td>41.0</td>
<td>4.9</td>
<td>2.7</td>
<td>0.11951</td>
<td>0.06585</td>
<td>1.81481</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>946</td>
<td>16</td>
<td>41.0</td>
<td>4.6</td>
<td>3.3</td>
<td>0.11220</td>
<td>0.08049</td>
<td>1.39394</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>946</td>
<td>17</td>
<td>41.0</td>
<td>4.4</td>
<td>2.1</td>
<td>0.10732</td>
<td>0.05122</td>
<td>2.09524</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>946</td>
<td>18</td>
<td>41.0</td>
<td>4.8</td>
<td>3.9</td>
<td>0.11707</td>
<td>0.09512</td>
<td>1.23077</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>946</td>
<td>19</td>
<td>41.0</td>
<td>3.3</td>
<td>1.8</td>
<td>0.08049</td>
<td>0.04390</td>
<td>1.83333</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>946</td>
<td>20</td>
<td>41.0</td>
<td>2.9</td>
<td>2.1</td>
<td>0.07073</td>
<td>0.05122</td>
<td>1.38095</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>46</td>
<td>946</td>
<td>21</td>
<td>41.0</td>
<td>3.2</td>
<td>1.7</td>
<td>0.07805</td>
<td>0.04146</td>
<td>1.88235</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>47</td>
<td>946</td>
<td>22</td>
<td>41.0</td>
<td>3.7</td>
<td>2.0</td>
<td>0.09024</td>
<td>0.04878</td>
<td>1.85000</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>48</td>
<td>946</td>
<td>23</td>
<td>41.0</td>
<td>2.7</td>
<td>1.4</td>
<td>0.06585</td>
<td>0.03415</td>
<td>1.92857</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>49</td>
<td>946</td>
<td>24</td>
<td>41.0</td>
<td>3.4</td>
<td>1.6</td>
<td>0.08293</td>
<td>0.03902</td>
<td>2.12500</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>946</td>
<td>25</td>
<td>41.0</td>
<td>3.3</td>
<td>2.0</td>
<td>0.08049</td>
<td>0.04878</td>
<td>1.65000</td>
<td>granule</td>
<td></td>
</tr>
<tr>
<td>51</td>
<td>947.1</td>
<td>1</td>
<td>1</td>
<td>41.0</td>
<td>3.3</td>
<td>2.0</td>
<td>0.08049</td>
<td>0.04878</td>
<td>1.65000</td>
<td>granule</td>
</tr>
<tr>
<td>52</td>
<td>947.1</td>
<td>2</td>
<td>1</td>
<td>41.0</td>
<td>5.1</td>
<td>2.4</td>
<td>0.12439</td>
<td>0.05854</td>
<td>2.12500</td>
<td>granule</td>
</tr>
<tr>
<td>53</td>
<td>947.1</td>
<td>3</td>
<td>1</td>
<td>41.0</td>
<td>3.7</td>
<td>2.1</td>
<td>0.09024</td>
<td>0.05122</td>
<td>1.76190</td>
<td>granule</td>
</tr>
<tr>
<td>54</td>
<td>947.1</td>
<td>4</td>
<td>1</td>
<td>41.0</td>
<td>3.4</td>
<td>2.0</td>
<td>0.08293</td>
<td>0.04878</td>
<td>1.70000</td>
<td>granule</td>
</tr>
<tr>
<td>55</td>
<td>947.1</td>
<td>5</td>
<td>1</td>
<td>41.0</td>
<td>2.7</td>
<td>1.9</td>
<td>0.06585</td>
<td>0.04634</td>
<td>1.42105</td>
<td>granule</td>
</tr>
<tr>
<td>56</td>
<td>947.1</td>
<td>6</td>
<td>1</td>
<td>41.0</td>
<td>3.4</td>
<td>1.7</td>
<td>0.08293</td>
<td>0.04146</td>
<td>2.00000</td>
<td>granule</td>
</tr>
<tr>
<td>57</td>
<td>947.1</td>
<td>7</td>
<td>1</td>
<td>41.0</td>
<td>3.7</td>
<td>1.8</td>
<td>0.09024</td>
<td>0.04390</td>
<td>2.05556</td>
<td>granule</td>
</tr>
<tr>
<td>58</td>
<td>947.1</td>
<td>8</td>
<td>1</td>
<td>41.0</td>
<td>3.1</td>
<td>2.2</td>
<td>0.07561</td>
<td>0.05366</td>
<td>1.40909</td>
<td>granule</td>
</tr>
<tr>
<td>59</td>
<td>947.1</td>
<td>9</td>
<td>1</td>
<td>41.0</td>
<td>3.9</td>
<td>2.0</td>
<td>0.09512</td>
<td>0.04878</td>
<td>1.95000</td>
<td>granule</td>
</tr>
<tr>
<td>60</td>
<td>947.1</td>
<td>10</td>
<td>1</td>
<td>41.0</td>
<td>2.6</td>
<td>1.5</td>
<td>0.06341</td>
<td>0.03659</td>
<td>1.73333</td>
<td>granule</td>
</tr>
<tr>
<td>61</td>
<td>948.1</td>
<td>1</td>
<td>2</td>
<td>54.5</td>
<td>2.9</td>
<td>2.0</td>
<td>0.10642</td>
<td>0.07339</td>
<td>1.45000</td>
<td>granule</td>
</tr>
<tr>
<td>62</td>
<td>948.1</td>
<td>2</td>
<td>2</td>
<td>54.5</td>
<td>2.9</td>
<td>1.6</td>
<td>0.10642</td>
<td>0.05872</td>
<td>1.81250</td>
<td>granule</td>
</tr>
<tr>
<td>63</td>
<td>948.1</td>
<td>3</td>
<td>2</td>
<td>54.5</td>
<td>3.5</td>
<td>2.3</td>
<td>0.12844</td>
<td>0.08440</td>
<td>1.52174</td>
<td>granule</td>
</tr>
<tr>
<td>64</td>
<td>948.1</td>
<td>4</td>
<td>2</td>
<td>54.5</td>
<td>3.3</td>
<td>1.8</td>
<td>0.12110</td>
<td>0.06606</td>
<td>1.83333</td>
<td>granule</td>
</tr>
<tr>
<td>65</td>
<td>948.1</td>
<td>5</td>
<td>2</td>
<td>54.5</td>
<td>3.5</td>
<td>2.2</td>
<td>0.12844</td>
<td>0.08073</td>
<td>1.59091</td>
<td>granule</td>
</tr>
<tr>
<td>66</td>
<td>948.1</td>
<td>6</td>
<td>2</td>
<td>54.5</td>
<td>3.2</td>
<td>1.7</td>
<td>0.11743</td>
<td>0.06239</td>
<td>1.88235</td>
<td>granule</td>
</tr>
<tr>
<td>67</td>
<td>948.1</td>
<td>7</td>
<td>2</td>
<td>54.5</td>
<td>3.3</td>
<td>1.7</td>
<td>0.12110</td>
<td>0.06239</td>
<td>1.94118</td>
<td>granule</td>
</tr>
<tr>
<td>68</td>
<td>948.1</td>
<td>8</td>
<td>2</td>
<td>54.5</td>
<td>2.7</td>
<td>1.5</td>
<td>0.09908</td>
<td>0.05505</td>
<td>1.80000</td>
<td>granule</td>
</tr>
<tr>
<td>69</td>
<td>948.1</td>
<td>9</td>
<td>2</td>
<td>54.5</td>
<td>2.9</td>
<td>1.4</td>
<td>0.10642</td>
<td>0.05138</td>
<td>2.07143</td>
<td>granule</td>
</tr>
<tr>
<td>70</td>
<td>948.1</td>
<td>10</td>
<td>2</td>
<td>54.5</td>
<td>3.1</td>
<td>1.6</td>
<td>0.11376</td>
<td>0.05872</td>
<td>1.93750</td>
<td>granule</td>
</tr>
<tr>
<td>71</td>
<td>948.1</td>
<td>11</td>
<td>2</td>
<td>54.5</td>
<td>3.2</td>
<td>1.8</td>
<td>0.11743</td>
<td>0.06606</td>
<td>1.77778</td>
<td>granule</td>
</tr>
<tr>
<td>72</td>
<td>948.1</td>
<td>12</td>
<td>2</td>
<td>54.5</td>
<td>3.8</td>
<td>2.2</td>
<td>0.13945</td>
<td>0.08073</td>
<td>1.72727</td>
<td>granule</td>
</tr>
<tr>
<td>73</td>
<td>948.1</td>
<td>13</td>
<td>2</td>
<td>54.5</td>
<td>3.2</td>
<td>1.9</td>
<td>0.11743</td>
<td>0.06972</td>
<td>1.68421</td>
<td>granule</td>
</tr>
<tr>
<td>74</td>
<td>948.1</td>
<td>14</td>
<td>2</td>
<td>54.5</td>
<td>3.0</td>
<td>1.4</td>
<td>0.11009</td>
<td>0.05138</td>
<td>2.14286</td>
<td>granule</td>
</tr>
<tr>
<td>75</td>
<td>948.1</td>
<td>15</td>
<td>2</td>
<td>54.5</td>
<td>3.1</td>
<td>1.5</td>
<td>0.11376</td>
<td>0.05505</td>
<td>2.06667</td>
<td>granule</td>
</tr>
</tbody>
</table>
Table C2. Bootstrapped crystal aspect variation. Category colors correspond to Fig. 4.12.

<table>
<thead>
<tr>
<th>Category</th>
<th>Measurement</th>
<th>Mean</th>
<th>Lower 95% C.I. (2.5%)</th>
<th>Upper 95% C.I. (97.5%)</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perpendicularly oriented</td>
<td>Length (µm)</td>
<td>1.08744</td>
<td>1.04196</td>
<td>1.13164</td>
<td>350</td>
</tr>
<tr>
<td>prismatic apatite</td>
<td>Width (µm)</td>
<td>0.34622</td>
<td>0.32944</td>
<td>0.36186</td>
<td>350</td>
</tr>
<tr>
<td>Perpendicularly oriented</td>
<td>L:W ratio</td>
<td>3.26374</td>
<td>3.19498</td>
<td>3.33334</td>
<td>350</td>
</tr>
<tr>
<td>prismatic apatite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tangentially oriented</td>
<td>Length (µm)</td>
<td>0.30487</td>
<td>0.29455</td>
<td>0.31388</td>
<td>200</td>
</tr>
<tr>
<td>bladed apatite</td>
<td>Width (µm)</td>
<td>0.10487</td>
<td>0.10254</td>
<td>0.10731</td>
<td>200</td>
</tr>
<tr>
<td>Tangentially oriented</td>
<td>L:W ratio</td>
<td>3.05554</td>
<td>2.99579</td>
<td>3.11809</td>
<td>200</td>
</tr>
<tr>
<td>bladed apatite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Randomly oriented equant</td>
<td>Length (µm)</td>
<td>0.18260</td>
<td>0.17378</td>
<td>0.19246</td>
<td>125</td>
</tr>
<tr>
<td>apatite</td>
<td>Width (µm)</td>
<td>0.15003</td>
<td>0.14310</td>
<td>0.15686</td>
<td>125</td>
</tr>
<tr>
<td>Randomly oriented equant</td>
<td>L:W ratio</td>
<td>1.21828</td>
<td>1.19671</td>
<td>1.24116</td>
<td>125</td>
</tr>
<tr>
<td>apatite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Granule aggregates</td>
<td>Length (µm)</td>
<td>0.34554</td>
<td>0.33489</td>
<td>0.35683</td>
<td>325</td>
</tr>
<tr>
<td></td>
<td>Width (µm)</td>
<td>0.16392</td>
<td>0.15991</td>
<td>0.16795</td>
<td>325</td>
</tr>
<tr>
<td>Granule aggregates</td>
<td>L:W ratio</td>
<td>2.11305</td>
<td>2.06349</td>
<td>2.16613</td>
<td>325</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Granules</td>
<td>Length (µm)</td>
<td>0.09290</td>
<td>0.08809</td>
<td>0.09780</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>Width (µm)</td>
<td>0.05060</td>
<td>0.04769</td>
<td>0.05370</td>
<td>75</td>
</tr>
<tr>
<td>Granules</td>
<td>L:W ratio</td>
<td>1.87154</td>
<td>1.82051</td>
<td>1.92958</td>
<td>75</td>
</tr>
</tbody>
</table>
Figure repository C1. SEM micrographs of perpendicularly oriented, micrometric, prismatic apatite.

Figure C1.1-1

Figure C1.1-2
Figure C1.3-2

Figure C1.3-3
Figure C1.4-3

Figure C1.5-1
Figure C1.6-3

Figure C1.6-4
Figure C1.10-1 (see also C3.2 for randomly oriented equant apatite from this specimen)

Figure C1.10-2
Figure C1.11-1 (see also C3.3 for randomly oriented equant apatite from this specimen)

Figure C1.11-2
Figure C1.13-3

Figure C1.14-1 (see also C3.4 for randomly oriented equant apatite from this specimen)
Figure repository C2. SEM micrographs of tangentially oriented, sub-micrometric, bladed apatite.

Figure C2.1-1

Figure C2.1-2
Figure repository C3. SEM micrographs of randomly oriented, sub-micrometric, equant apatite.
Figure C3.2 (specimen overview shown in Figure C1.10-1)

Figure C3.3 (specimen overview shown in Figure C1.11-1)
Figure C3.4 (specimen overview shown in Figure C1.14-1)

Figure C3.5 (specimen overview shown in Figure C4.7-1)
Figure repository C4. SEM micrographs of phosphatic filaments, rods, and granules (with substructures).

Figure C4.1-1

Figure C4.1-2
Figure C4.5-12

Figure C4.5-13
Figure C4.6-1

Figure C4.6-2
Figure C4.7-1 (see also C3.5 for randomly oriented equant apatite from this specimen)

Figure C4.7-2
Figure repository C5. Measured SEM micrographs of perpendicularly oriented, micrometric, prismatic apatite. Table C1 image file # in lower right corner.

Figure C5.1 (specimen overview shown in Figure C1.13-1)
Figure C5.2 (specimen overview shown in Figure C1.12-1)
Figure C5.3 (specimen overview shown in Figure C1.1-1)
Figure C5.4 (specimen overview shown in Figure C1.1-1)
Figure C5.5 (specimen overview shown in Figure C1.1-1)
Figure C5.6 (specimen overview shown in Figure C1.1-1)
Figure C5.7 (specimen overview shown in Figure C1.1-1)
Figure C5.9 (specimen overview shown in Figure C1.5-1)
Figure C5.10 (specimen overview shown in Figure C1.3-1)
Figure C5.11 (specimen overview shown in Figure C1.6-1)
Figure C5.12 (specimen overview shown in Figure C1.9-1)
Figure C5.14 (specimen overview shown in Figure C1.10-1)
Figure repository C6. Measured SEM micrographs of tangentially oriented, sub-micrometric, bladed apatite. Table C1 image file # in lower right corner.

Figure C6.1 (specimen overview shown in Figure C.4-1)
Figure C6.2 (specimen overview shown in Figure C2.3-1)
Figure C6.3 (specimen overview shown in Figure C2.3-1)
Figure C6.4 (specimen overview shown in Figure C2.2-1)
Figure C6.5 (specimen overview shown in Figure C2.5-1)
Figure C6.6 (specimen overview shown in Figure C2.6-1)
Figure C6.7 (specimen overview shown in Figure C2.1-1)
Figure C6.8 (specimen overview shown in Figure C.7-1)
Figure repository C7. Measured SEM micrographs of randomly oriented, sub-micrometric, equant apatite. Table C1 image file # in lower right corner.
Figure C7.2 (specimen overview shown in Figure C1.11-1)
Figure C7.4 (specimen overview shown in Figure C1.10-1)
Figure C7.5 (specimen overview shown in Figure C4.7-1)
Figure repository C8. Measured SEM micrographs of phosphatic granule aggregates (C8a) and granules (C8b). Table C1 image file # in lower right corner.

Figure C8a.1 (specimen overview shown in Figure C4.2-1)
Figure C8a.2 (specimen overview shown in Figure C4.2-1)
Figure C8a.3 (specimen overview shown in Figure C4.3-1)
Figure C8a.4 (specimen overview shown in Figure C4.3-1)
Figure C8a.5 (specimen overview shown in Figure C4.5-1)
Figure C8a.6 (specimen overview shown in Figure C4.5-1)
Figure C8a.7 (specimen overview shown in Figure C4.5-1)
Figure C8a.8 (specimen overview shown in Figure C4.5-1)
Figure C8a.9 (specimen overview shown in Figure C4.5-1)
Figure C8a.10 (specimen overview shown in Figure C4.5-1)
Figure C8a.12 (specimen overview shown in Figure C4.6-1)
Figure C8a.13 (specimen overview shown in Figure C4.4-1)
Figure C8b.1 (specimen overview shown in Figure C4.5-1)
Figure C8b.2 (specimen overview shown in Figure C4.5-1)
Figure C8b.3 (specimen overview shown in Figure C4.5-1)
Figure C8b.4 (specimen overview shown in Figure C4.5-1)
Figure C8b.5 (specimen overview shown in Figure C4.5-1)
Figure C8b.6 (specimen overview shown in Figure C4.5-1)
CHAPTER 5

The microstructural record of predation: A new approach for identifying predatory drill holes

JAMES D. SCHIFFBAUER\textsuperscript{1}, YURENA YANES\textsuperscript{2}, CARRIE L. TYLER\textsuperscript{1}, MICHAŁ KOWALEWSKI\textsuperscript{1}, & LINDSEY R. LEIGHTON\textsuperscript{3}

\textsuperscript{1}Department of Geosciences, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061, USA

\textsuperscript{2}Savannah River Ecology Laboratory, University of Georgia, Drawer E, Aiken, South Carolina 29802, USA

\textsuperscript{3}Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta, Canada, T6G 2E3
5.1 Abstract
Drill holes in prey skeletons are the most common source of data for quantifying predator-prey interactions in the fossil record. To be useful, however, such drill holes need to be identified correctly. Field emission scanning electron microscopy (FE-SEM) and environmental scanning electron microscopy (ESEM) were applied to describe and quantify microstructural characteristics of drill holes. Various specimens, including modern limpets and mussels drilled by muricid snails in laboratory experiments, subfossil limpets collected from a tidal flat (San Juan Island, Washington state, USA), and various Miocene bivalves collected from multiple European sites, were examined for microstructural features. The microstructures observed are interpreted here as *Radulichnus*-like micro-rasping marks, or predatory microtraces, made by the radula of drilling gastropod predators. The mean adjacent spacing of these microtraces is notably denser than the spacing of muricid radular teeth determined by measurements taken from the literature. Because the radular marks typically overlie or crosscut each other, the denser spacing of predatory microtraces likely reflects superimposition of scratches from repeated passes of the radula. One incomplete drill hole showed a clear, chemically aided drilling dissolution signature around its outer margin, while a number of other specimens showed similar, but ambiguous, traces of dissolution. The range of organisms examined illustrates the utility of scanning electron microscopy (SEM) imaging for identifying micro-rasping marks associated with predatory drill holes in both modern and fossil specimens. These distinct microtraces offer promise for augmenting our ability to identify drill holes in the fossil record and to distinguish them from holes produced by non-predatory means.

5.2 Introduction
Drill holes bored by predators in prey shells provide direct data on predator-prey interactions and have been widely used by paleontologists to quantify predation patterns in the fossil record (e.g., Hoffmeister et al., 2003; Hoffmeister et al., 2004; Huntley and Kowalewski, 2007; Kelley and Hansen, 2006; Kelley and Hansen, 1993; Kelley and Hansen, 1996; Kowalewski et al., 1998; Kowalewski et al., 2005; Leighton, 2003; Leighton, 2001; Vermeij, 1987 and numerous references therein). Many qualitative and quantitative assumptions, however, are involved in applying drill holes to study the fossil record of predation (see Kowalewski, 2002; Walker, 2007 for detailed reviews), including the fundamental issue of correctly distinguishing traces produced
by drilling predators from those produced by other biotic and abiotic agents (e.g., Kaplan and Baumiller, 2001; Wilson and Palmer, 2001). Specifically, two main types of diagnostic errors can be anticipated: (1) traces other than predatory drill holes (i.e., substrate borings, non-predatory dissolution or bioerosion, punctures, fixichnia, etc.) are misidentified as drillings of predatory origin (Lescinsky and Benninger, 1994); and (2) true drill holes are not identified as predatory in origin. Both of these errors may be particularly frequent when the examined fossils have been significantly degraded. In such cases, “false” drill holes may form by taphonomic processes and “true” drill holes may remain unidentified due to their poor preservation.

Efforts to mitigate identification errors have focused so far on two independent strategies: (1) the use of non-morphological criteria, such as evaluating holes for non-random (site-specific, size-selective, or taxon-restricted) distribution of traces (e.g., Hoffmeister et al., 2003; Kelley, 1988; Kitchell et al., 1981; Leighton, 2002; Sheehan and Lesperance, 1978) and (2) morphometric strategies focused on quantifying drill-hole shapes (e.g., Dietl and Kelley, 2006; Grey et al., 2005; Kowalewski, 1993; Urrutia and Navarro, 2001). Here, we explore a third approach based on physical and chemical microstructural criteria: micron-scale predatory signatures (predatory microtraces) of drill holes that can be recognized and examined through high-magnification, high-resolution imaging under field emission and environmental scanning electron microscopy (FE-SEM and ESEM, respectively).

The microstructural approach builds directly on the pioneering work of Carriker (1969; 1978) and Carriker and Van Zandt (1972), who used scanning electron microscopy (SEM) micrographs to study microstructural details of drill holes bored by modern snails in oysters and mussels. Substantial advances in nano-imaging technology, taphonomy, and paleoecology make this approach a particularly promising strategy for augmenting our ability to identify drill holes found in fossil prey correctly.

This study represents a first step towards establishing and using microstructural criteria to identify predatory drillings. We focus on comparing microstructural details of drillings in a range of taxa from laboratory feeding experiments and field collections of both subfossil and fossil shells. Specifically, we have evaluated micron-scale features of drill holes made by muricid gastropod predators in both limpets and mussels from laboratory settings at Friday Harbor Laboratories (FHL), San Juan Island (University of Washington). In addition, we have examined subfossil limpet specimens collected from a modern tidal-flat setting (San Juan Island,
Washington state, USA) and various bivalve fossil samples collected from marine Miocene bioprovinces of Europe, including the Boreal province, Paratethys, and southeast North Atlantic (Kowalewski et al., 2002). This range of organisms illustrates the utility of SEM image analysis to identify radular microtraces of predatory drill holes. Moreover, the integration of observations from feeding experiments with analyses of subfossil and fossil material makes it possible to assess the detrimental effects of taphonomic processes on microtraces of predatory drill holes and evaluate the preservation potential of these microtraces in the fossil record. The initial data reported here suggest that microstructural criteria may indeed facilitate the identification of drill holes in the fossil record.

5.3 Materials and Methods

5.3.1 Laboratory-observed limpets: Sample collection and feeding experiment protocol

All studied lottiid prey and muricid predators were collected from rocky intertidal habitats of False Bay, located on the southwest coast of San Juan Island. Collection for the feeding experiments focused on two limpet species, coarsely ribbed *Lottia digitalis* (Rathke) and smooth-shelled *Tectura scutum* (Rathke), both of which are known to be prey species. One species of drilling predator, the muricid gastropod *Nucella ostrina* (Gould) (common name, northern striped dogwinkle) was also collected. These three species are highly abundant, readily accessible for collecting, and overlap spatially in their distribution in the study area.

To examine examples of drilling known to be made by the muricid *Nucella*, 100 specimens of *N. ostrina* and 120 limpets (60 of *L. digitalis* and 60 of *T. scutum*) were housed in an open-circulation sea table at FHL. The prey had freedom of movement and were readily accessible to each predator individual. Salinity and temperature, which were monitored daily in the open-circulation system, were relatively stable during the month-long laboratory observation period (30.5‰ ± 0.8‰ and 13.5° ± 0.9 °C, respectively). Only two drilled limpets (*L. digitalis* and *T. scutum*) were obtained in the laboratory, as the muricid gastropods in the laboratory setting were not as active as anticipated.

The two drilled limpets were collected after being abandoned by their predator (no predation attempts were manually interrupted), and any remaining limpet soft tissue was removed from the shell. The predator responsible for the kill was photographed and its shell maximum length and width were measured with digital calipers to the nearest 0.1 mm. In order
to protect local dogwinkle and limpet populations, all individuals still alive at the end of the experiment were returned to the original sampling locale.

5.3.2 Laboratory-observed mussels: Sample collection and feeding experiment protocol

The mussel samples examined came from a previously published experimental study (Kowalewski, 2004). Mytilid prey and their muricid predators were originally collected from Argyle Creek, a narrow channel connecting Argyle Lagoon and North Bay, San Juan Island. Kowalewski (2004) used the mussel *Mytilus trossulus* (Gould) and the gastropod predator *Nucella lamellosa* (Gmelin) (common name, frilled dogwinkle) in laboratory-feeding experiments. It was also noted by Kowalewski (2004) that empty *Mytilus* shells with predatory drill holes were abundant at the sample site, and that snails were commonly observed actively feeding on mussels. These two organisms not only co-occur naturally, but also represent an important predator-prey interaction within the creek habitat (Kowalewski, 2004).

The current study examined six mussels drilled by two predator individuals; the six were selected from the Virginia Tech repository of 76 drilled mussels from the feeding experiment reported by Kowalewski (2004). Using the same FHL facilities as employed for the limpet feeding experiment, Kowalewski (2004) placed ~100 specimens of *N. lamellosa* and several hundred *M. trossulus* specimens into two open-circulation sea tables. The gastropod predators were permitted to hunt freely until observed attacking prey. During the attack, the snail and mussel were caged in a meshed container and allowed to finish their attack unobstructed and uncontested. Abandoned prey shells were collected, predators were recorded, and all individuals, predator and prey, were measured. All individuals alive at the end of the experiment were returned to the original sampling locale, with the exception of two predatory dogwinkles that drilled the shells examined for this study; these were stored in ethyl alcohol.

5.3.3 Subfossil limpets: Sample collection

Three bulk samples of subfossil shell remains (including complete and fragmented shells) were randomly collected from a single surficial shell assemblage from the same intertidal region of False Bay as the live specimens. Each bulk sample, which consisted of ~1 kg of shell remains of multiple organisms, was first cleaned, sorted for limpet shells, and then examined for the presence of possible drill holes. Drill holes of probable or possible predatory origin were
identified by measuring the circular regularity of the outline under reflected light microscopy. In
total, ten limpets with putative drill holes were selected for SEM analysis. Drilled *T. scutum*
individuals were exceedingly rare in the subfossil bulk samples, and consequently only *L. digitalis* specimens are included in the FE-SEM examination of subfossil material.

5.3.4 Miocene bivalves: Sample collection
The examined Miocene samples came from a previously published study (Kowalewski et al.,
2002; see also Hoffmeister and Kowalewski, 2001), in which a total of 24 bulk samples were
collected from 13 Miocene localities spanning central and western Europe. Specimens were
selected from the Virginia Tech repository on the basis of range of sampling locales, in an effort
to examine material from each of the sampled bioprovinces and ages. Drill holes of probable
predatory origin were first examined under reflected light, and a total of twelve specimens were
chosen for SEM analysis. These included eight specimens of *Astarte radiata* (Nyst and
Westendorp) from Burdigalian deposits (early Miocene, sample age of 16.5 Ma) of the Boreal
province, from the Winterswijk-Miste area (Netherlands); one *Clausinella basteroti* (Deshayes)
from Langhian deposits (middle Miocene, sample age of 15.5 Ma) of the Paratethys, Szabó
Quarry (Várpalota Basin, Hungary), and three specimens (*Callista* sp. [Lamarck], *Anadara
diluvii* [Lamarck], and *Callucina dujardini* [Dall]) from Serravallian deposits (middle Miocene,
sample age of ~14 Ma) of the southeastern North Atlantic province, from Ferrière Larçon (Loire
River, France) (Kowalewski et al., 2002).

The sampled material was reposited in the Department of Geosciences at Virginia Polytechnic Institute and State University (Virginia Tech). Specimen identification numbers are
provided in Table 5.1 and throughout the text where applicable.

5.3.5 Scanning electron microscopy
Randomly located drill holes bored by muricid gastropods in limpets and mussels in the
laboratory setting and putative, randomly located drill holes identified in field-collected subfossil
limpets and fossil bivalves were analyzed using field-emission scanning electron microscopy
(LEO 1550 FE-SEM) or environmental scanning electron microscopy (FEI Quanta 600 FEG).
All limpet specimens were sputter-coated with a gold-palladium mixture (20 nm thickness in a
Cressington 208HR high resolution sputter coater) and analyzed via FE-SEM. The laboratory-
drilled mussels and Miocene bivalves were imaged via ESEM in low-vacuum mode without gold-palladium coating, in order to avoid possibly obscuring submicron-scale features of interest (e.g., shell crystalline microarchitectures). The brightness (or shadowing) effects observed for various features of the drill holes, when utilizing secondary electron detection in either FE-SEM or ESEM, indicate areas receiving more (or less) electron beam interaction, thus demonstrating simulated three-dimensional surface relief that represents topographic sculpture of the external drill-hole surfaces. Each electron micrograph was examined with ImageJ® or Adobe Photoshop® CS2 software, both of which permitted the collection of precise numerical measurements of the drill holes, including (1) spacing between the microrasping marks produced by the teeth of the radula; (2) distance between microrasping marks and the inner-hole margin; and (3) overall diameter of the drill-hole opening. These numerical measures were taken in order to quantitatively describe the preserved microstructures in and around the observed drill holes. The ESEM micrographs of uncoated mussels presented an opportunity to collect data on the crystalline microarchitecture of the shells possibly related to the radular rasping microtraces. These features were also imaged and analyzed via Photoshop® CS2 as were two published scanning electron micrographs of the radula of the dogwhelk, *Nucella lapillus* (Linnaeus) (Rolán et al., 2004) for comparative purposes. This specific publication was chosen because the illustrated radulae were from drilling predators congeneric to those used in the two laboratory feeding experiments (*N. ostrina* in the limpet-feeding experiment and *N. lamellosa* in the mussel-feeding experiment). The measurements assessed from these micrographs consisted of basal widths of the cusps from each rachidian tooth. PAST software (Hammer et al., 2001) was used for univariate statistical analyses.

### 5.4 Results

#### 5.4.1 Overview of microtrace morphology

A number of randomly located drill holes examined under high-resolution FE-SEM or ESEM displayed physical scratch marks consisting of parallel to subparallel, straight to slightly curvilinear, distinctly corrugated lines. These *Radulichmus*-like lines are oriented in laterally sweeping patterns, ranging from subparallel to perpendicular to the drill-hole outline (Fig. 5.1). This corrugated pattern consists of indentations (or troughs) separated by raised ridges, which are interpreted as radular teeth marks (radular cusp width) and areas between the radular teeth (or
intercusp spacing), respectively. As a proxy of radular cusp width, quantifications of microtrace spacing consisted of measuring from ridge to ridge. These measurements were evaluated for individual shells and also pooled by group (as defined in Table 1; Fig. 5.2). The spacing of adjacent microtraces, pooled for all measured individuals, ranges from 1.84 to 21.67 μm with a mean spacing of 7.60 μm, and standard deviation of 3.13 μm (n = 624; pooled data histogram Fig. 5.3A). Spacings of the interpreted predatory microtraces, pooled by grouping and type (multiple-pass and single-pass radular microtraces), were additionally compared to crystalline shell microfabrics (Fig. 5.3B–D) and to radular tooth widths from the literature (Figs. 5.3E–F, 5.4A–C).

5.4.2 Drill holes in laboratory-observed limpets
The two limpets (L. digitalis and T. scutum) that were drilled in the laboratory setting had N. ostrina predators of similar size: 21.1 mm and 24.1 mm long, by 14.6 mm and 15.7 mm wide. Lottia digitalis displayed a complete drill hole, with a maximum inner diameter of ~770 μm (Fig. 5.1A), while T. scutum showed a non-functional (incomplete) hole, with a maximum inner diameter of ~260 μm (Fig. 5.1B–C). Both specimens displayed quantifiable microrasping marks. The mean distance between adjacent microtraces of L. digitalis was more than two times greater (11.18 μm; n = 42) than that assessed for T. scutum (5.38 μm; n = 88), a difference that is statistically significant (Mann Whitney U test, p < 0.001). The pooled, laboratory observed limpet microtraces ranged in size from 2.94 to 20.04 μm, with a mean spacing of 7.25 μm (n = 130; Table 5.1, Fig. 5.2A). In addition to physical rasping microtraces, chemical dissolution signatures can be recognized toward the outer margin of the incomplete drill hole found on the T. scutum shell (Fig. 5.1B). In contrast, physical microrasping marks occupy the inner, depressed region of the incomplete drill hole (Fig. 5.1C).

5.4.3 Drill holes in laboratory-observed mussels
The six individuals selected had been drilled by one of two N. lamellosa predators (specimen ID# VT-NL-34 drilled two shells and VT-NL-16 drilled four shells). These specific predators were significantly larger than the N. ostrina specimens used in the limpet-feeding experiment, with lengths of 33.5 mm and 36.1 mm and widths of 20.8 mm and 21.1 mm for VT-NL-34 and VT-NL-16, respectively. The drill holes exhibited maximum inner diameters ranging from ~900
to ~1500 μm, and quantifiable micro-rasping marks were present on all six specimens. The mean distance between adjacent microtraces (Table 5.1) of *M. trossulus* pooled by predator differs significantly between the two predators (Mann Whitney U test, p = 0.026), with micro-rasping marks produced by the smaller snail (VT-NL-34) averaging 7.64 μm (n = 89) and those produced by the larger snail (VT-NL-16) averaging 8.55 μm (n = 189). In total, the pooled laboratory-observed mussel microtraces ranged in size from 1.84 to 21.67 μm, with a mean spacing of 8.26 μm (n = 278; Table 5.1, Fig. 5.2F). Two specimens illustrated possible chemical dissolution signatures in addition to physical predatory microtraces. In contrast to the dissolution signatures observed on the laboratory-drilled *T. scutum* specimen, the putative chemical signatures were located towards the inner drill-hole margin, with radular microtraces occupying the outer drill-hole margin. Additionally, the chemical dissolution features noted here appear comparatively rough and give the impression of erosional or bioerosional surfaces commonly observed in the subfossil and fossil specimens.

### 5.4.4 Published Nucella radula micrographs

Two published scanning electron micrographs (Rolán et al., 2004, fig. 2E–F from original publication; see Fig. 5.3F here for modified version) of the radula of the dogwhelk *N. lapillus* were analyzed for comparative purposes. Because these radulae came from drilling predators congeneric to those used in the two laboratory feeding experiments, they should display similar radular morphologies. Moreover, the two radula illustrated in Rolán et al. (2004) came from muricids of similar sizes to those used in the feeding experiments (lengths of 26.2 mm and 25.9 mm, respectively). Individual cusp widths ranged from 11.53 to 21.36 μm, with a mean cusp width of 15.26 μm (n = 45; Table 5.1, Fig. 5.3E).

### 5.4.5 Drill holes in subfossil limpets

Ten drilled subfossil shells of *L. digitalis* were examined for microstructural features under FE-SEM. The majority of the individuals recovered showed signs of substantial taphonomic degradation, including fragmentation, loss of color, corrosion (deterioration and abrasion), bioerosion (microperforations not caused by predation or parasitism), and encrustation. Nevertheless, four of the ten shells preserve distinct micro-rasping marks around the drill-hole margins (Fig. 5.1G–I), one of which contains radular microtraces oriented in a sweeping, fan-like
pattern (Fig. 5.1H). These four drill holes exhibited maximum inner diameters of ~360 to ~670 μm. The distance between micro-rasping marks illustrated a mean of 8.44 μm and ranged from 3.58 to 17.31 μm (n = 53; Table 5.1, Fig. 5.2J). One specimen contained a tenuous chemical dissolution signature in addition to physical rasping microtraces (Fig. 5.1I). Much like those of the laboratory-drilled mussels, the possible chemical dissolution signature appeared rutted and was located towards the inner drill-hole margin, with radular microtraces and indications of bioerosion occupying the outer drill-hole margin.

5.4.6 Drill holes in Miocene bivalves

The majority of the twelve Miocene bivalves examined displayed signs of substantial taphonomic degradation. A total of three shells illustrated easily identifiable micro-rasping marks around the drill-hole margins, including two *A. radiata* shells (Burdigalian) and the *C. basteroti* specimen (Langhian) (Fig. 5.1J–L). The maximum inner diameters of these three drill holes ranged from ~650 to ~1070 μm, and the micro-rasping marks ranged from 2.51 to 13.58 μm with a mean of 6.50 μm (n = 163; Table 5.1, Fig. 5.2M).

The observed subfossil and fossil predatory microtraces are located in direct proximity to the drill-hole margins and bear close resemblance to microtraces observed around the laboratory-observed drill holes for both limpets and mussels. The spacing of individual micro-rasping marks is comparable (overlapping) to those observed in the laboratory data. Distinct chemical dissolution signatures observed for the incomplete drill hole obtained in the laboratory could not be confidently identified for any of the field-collected subfossil and fossil specimens.

5.4.7 Multiple-pass and single-pass micro-rasping marks

In order to further categorize the rasping microtraces, the measured images from all four groupings were selected, pooled, and comparatively evaluated in two categories: (1) clearly overlain micro-rasping marks—i.e., multiple, superimposed radular-pass microtraces (Fig. 5.4D–G), which ranged in size from 1.84 to 11.21 μm (mean = 5.75 μm, n = 149); and (2) micro-rasping marks that show no evidence of superimposition—i.e., single radular-pass microtraces (Fig. 5.4H–K), which ranged in size from 4.18 to 21.67 μm (mean = 10.31 μm, n = 108) (Table 5.1, Fig. 5.4A–B). These two distributions are significantly different from each other, as well as
from the literature-assessed radular tooth widths (Mann Whitney U test, in all three cases p < 0.001).

5.4.8 Shell crystalline microarchitecture

Two of the six laboratory-drilled mussels analyzed illustrated quantifiable crystalline microfabrics oriented subparallel to the radular microtraces (Fig. 5.1F, 3C), which ranged in size from 0.53 to 2.57 μm (mean = 1.48 μm, n = 102). The laboratory-drilled *L. digitalis* limpet specimen showed hints of crystalline microfabrics oriented subparallel to the radular microtraces (Fig. 5.4H), which are similar, although less continuous and pronounced, to crystalline microfabrics observed in the laboratory-drilled mussels. These structures were not quantified, as their interpretation remains tenuous. In addition to the quantified mussel microfabrics, one of the Miocene bivalve specimens, *A. radiata* from the Winterswijk-Miste area, showed a crossed-lamellar microfabric on a fracture surface (Fig. 5.3D). These lamellae illustrated a similar, but narrower, range to those ascertained from the two mussel specimens, extending from 0.66 to 1.75 μm, with a mean of 1.17 μm, (n = 50). The pooled crystalline microfabrics ranged from 0.53 to 2.57 μm (mean = 1.37 μm, n = 152; Table 5.1, Fig. 5.3B).

5.5 Discussion

The predatory drilling process involves intermittent use of the accessory boring organ, located in the foot of muricids, and the radula. The accessory boring organ reduces the structural integrity of the prey’s calcium carbonate shell and proteinaceous matrix via secretion of ion chelating agents (acids and enzymes), and the radula physically rasps the weakened shell material away (Carriker, 1981). We infer that the microtraces observed in high-resolution FE-SEM and ESEM micrographs represent this rasping motion and consequent removal of shell material, as has been suggested in earlier studies on modern prey shells such as oysters and mussels (Carriker, 1969; Carriker, 1978; Carriker and Van Zandt, 1972). Two hypotheses can be proposed to explain the microtrace spacing variation among these groups: (1) predator taxonomy and size may induce variations in radular cusp size or radular intercusp spacing, thus affecting the spacing of the micro-rasping marks observed on the prey shells; and (2) observed microtrace spacing may result from overprinting of multiple radular passes.
5.5.1 Primary hypotheses to explain predatory microtrace variations: Predator taxonomy and size-age class

Differences in radular size and cusp spacing may be related to intergeneric distinctions in radular morphology as well as variations in predator size or age class. The two muricid predators (*N. ostrina*) responsible for drilling in the limpet-feeding experiment differed by only a few millimeters in size (3.0 mm in length); the predator that drilled *L. digitalis* was slightly smaller than the one that drilled *T. scutum*. The primary assumption was that larger predators would produce more widely spaced micro-rasping marks. Accordingly, due to the roughly similar sizes of these two predator individuals, the spacings of the microtraces generated were expected, *a priori*, to differ proportionally with predator size, but not dramatically. The difference in microtrace spacing means between these two predators, 5.80 \(\mu\)m (11.18 \(\mu\)m mean for *L. digitalis*, 5.38 \(\mu\)m mean for *T. scutum*; Mann Whitney U test, \(p < 0.001\)), however, was much larger than anticipated. In fact, the two species of limpets showed an appreciably wide variation of microtrace spacing, nearly reaching the range endpoints of all examined shells, including both subfossil and fossil shells. Moreover, the larger dogwinkle predator that drilled *T. scutum* produced more tightly spaced micro-rasping marks.

In the mussel-feeding experiments, the two *N. lamellosa* predators again varied in size by only a few millimeters (a difference of 2.6 mm in length). Based on size differences in the predators, the distances between radular microtraces on the mussel prey shells were anticipated to differ respectively—if much at all. Although the microtrace spacing variation between predators observed in the mussels was much less than that of the limpets, the difference was again statistically significant. The predators used in the mussel-feeding experiments were nearly 10 mm larger than those used in the limpet-feeding experiments, so a larger relative difference between pooled means would be expected. Because the microtrace spacing means for laboratory-drilled limpets illustrated a difference of nearly 6 \(\mu\)m between prey drilled by the two different predators, a difference in mean rasp-mark spacing between pooled laboratory experiments of only 1.01 \(\mu\)m was unexpected (8.26 \(\mu\)m mean for pooled mussels, 7.25 \(\mu\)m mean for pooled limpets; Mann Whitney U test, \(p < 0.001\)). Unfortunately, even with statistically significant results, no quantitatively prognostic statements can be made relating predator size to radular microtrace-spacing distances due to the irregular and unpredictable magnitudes by which the spacings differ from case to case.
Despite substantial taphonomic alterations, multiple subfossil and fossil specimens preserve a distinct predatory microstructural signature associated with the drilling process or predatory microtraces. The notable differences in rasp-mark spacing are difficult to evaluate given that the size and specific taxonomic identity of predators that drilled the field-collected shells are unknown. Indeed, in regard to the subfossil-collected assemblage, not only do False Bay muricids vary notably in size as observed in the field, but field studies also (e.g., Palmer, 1988) indicate that there are at least two more Nucella species that may drill limpets in the study area, N. lima (Gmelin) and N. canaliculata (Duclos). Certainly, multiple species of drilling gastropods (from varying size or age classes) were present throughout the sampled European Miocene deposits (Hoffmeister and Kowalewski, 2001; Kowalewski et al., 2002). The distances between rasping microtraces around the drill holes of subfossil limpet shells (ranging from 3.58 to 17.31 μm) and Miocene bivalve shells (2.51–13.58 μm) overlap with the range of values reported above for laboratory-observed drill holes (Table 5.1, Fig. 5.2A, F, J, M).

A pertinent test for effects of predator size on radular microtrace spacing undoubtedly exists, although we could not evaluate this issue more rigorously in the current experimental design, as the animals used in the limpet experiment were released unharmed after the study to protect local snail populations, and the specimens in the mussel-feeding experiment were too highly degraded after four years in alcohol to remove the radula intact. It is noteworthy that the minimum radular tooth widths (11.53 μm) measured from similar-sized congeneric dogwhelks (Rolán et al., 2004) overlap with the predatory microtrace spacings measured in all laboratory specimens. Nearly 15% (60 of 408) of the measured micro-rasping marks have spacings ≥11.53 μm, although comparisons of the overall measurement distributions are significantly different (Mann Whitney U test, p < 0.001). Because the drilling muricids examined by Rolán et al. (2004) are closely related, and morphologically similar, to those used in the feeding experiments here, they should display relatively similar radular morphologies and drilling methodologies versus, for example, a comparison with the radular morphologies and drilling methodologies of naticid or cassid gastropods. The difference between maximum values for radular cusp width (21.36 μm) and microtrace spacings among all laboratory-observed drill holes (21.67 μm) is only 0.31 μm, which is certainly reasonable given that radular size and morphology may vary considerably across predator size and age classes. The maximum value for the pooled subfossil and fossil microtrace spacings (17.31 μm) is 4.05 μm smaller than the upper limit of the radular cusp width.
range, and ~9% (20 of 216) of the measured subfossil-fossil microtrace spacings are ≥11.53 μm. Again, the distributions remain statistically different (Mann Whitney U test, p < 0.001). The proximity of rasp-mark spacings between the subfossil-fossil drill holes and the radular cusp widths assessed from Rolán et al. (2004), however, is obviously less meaningful than that calculated for the laboratory-observed micro-rasping marks, but this is to be expected with the lack of information on predator taxonomy, size, and age class.

Although the radulae used for comparative analyses were preserved in alcohol (Rolán et al., 2004), which may cause radular shrinkage, it was still possible to assess the basal cusp widths. As the drill-hole microtrace widths should correlate closely to depth of radular cusp penetration, using the basal cusp widths approximates a maximum value for predatory microtrace-spacing. That is, radular passes with less pressure should produce more narrowly spaced rasping microtraces, as only the tip of the radular cusps would penetrate the shell material; conversely, deeply penetrating radular passes should be nearer to the basal width of the radular cusps. Varying widths of the predatory microtraces should be expected, however, as the scenarios described above simply represent end members of the range.

5.5.2 Primary hypotheses to explain predatory microtrace variations: Superimposition of radular passes

The differences in microtrace spacing may be induced by the superimposition of multiple radular passes (visible in Figs. 5.1C, 5.4D–G), which is perhaps more likely than differences resulting from predator size variation. In this scenario, the differences in microtrace spacing represent a composite of sequential overlying raspings on the drilled region of the prey shell. It has been proposed that mechanical radular rasping plays a relatively minor role in the drilling process, functioning to remove chelated prey shell material (Carriker, 1981). A study on drilling predation by modern *N. lapillus* on *Mytilus edulis* (Linnaeus) prey, however, proposes a more extensive role for the radula, in which the first quarter of the drilling process consists of “frequent and intense mechanical scraping” by the radula, broken by periods of inactivity, inferred as shell chelation (Rovero et al., 1999). The case for superimposition of radular rasping, or multiple radular passes, is supported by the rachidian cusp widths measured from published *N. lapillus* SEM micrographs (Rolán et al., 2004), where the mean cusp width (15.26 μm) was approximately double the mean of the pooled rasping microtraces (7.60 μm) and, more
specifically, the feeding experiment micro-rasping marks (7.94 μm). Detailed information about radular teeth spacing from drill-hole microtrace spacing could be disputable, however, because it may not be feasible to distinguish an earlier radular pass from any later passes. It may be worthwhile to examine variation among the inner drill-hole-region microtrace spacing, particularly in incomplete drill holes, versus that of the outer drill-hole margin. Presumably, the outer margin of drill holes should not receive as many radular passes as the central region of the bored area because less prey shell material is removed along the outer margin. Thus, the lower number of overlapping radular rasp marks along the outer margin may have more diagnostic value in relation to radular cusp width of the predator. Ultimately, the best-case scenario would be the identification of pristine, single radular passes. In more heavily rasped regions of the drill hole, it is challenging to discern (1) the number of overlapping radular passes and (2) the amount or spacing of overlap. Therefore, extracting any meaningful data on radular cusp width in such areas is unlikely, and such data would also be contentious.

It is most likely that, as the drilling process proceeds, the fluids released by the accessory boring organ reduce or obscure earlier micro-rasping marks and create a smoothed dissolution halo around the outer rim of the drill-hole cavity. During the final stages of penetration, rasping may overprint and obscure evidence for dissolution around the inner opening. While no definitive chemical dissolution features were observed in any subfossil or fossil shells, one unambiguous dissolution feature was observed in the incomplete drill hole produced in the limpet laboratory experiment. Chemical dissolution signatures in previous laboratory experiments were observed when the drilling process was interrupted (Carriker, 1969; Carriker and Van Zandt, 1972), and distinct chemical dissolution halos were observed in complete drill holes (interpreted as cassid gastropod drillings) found in echinoid tests (Nebelsick and Kowalewski, 1999). Although not always present or discernible, the predatory microstructural gradient documented in the laboratory-observed incomplete drill hole—with physical micro-rasping marks located proximally and a chemical dissolution halo more distally—represents a distinct signature of chemically aided radular drilling. The equivocal chemical dissolution signatures toward the inner drill-hole margins from two of the laboratory-observed mussels and one of the subfossil limpets may represent variations in shell structure toward the inner surface of the shell or a period of chemically aided dissolution just prior to the final puncturing of the prey shell.
If an accurate depth-profile of radular marks could be attained, presumably the most recent pass would generate the deepest and most pristine microtraces, while microtraces generated in earlier passes would be less pronounced or more eroded. Although obtaining precise three-dimensional measurements is difficult, a distinction can be made between more pristine, single radular passes and overlying, multiple passes by searching for signs of crosscutting within the predatory microtraces, and this characteristic may provide a means to further resolve microtrace spacing. To test this idea, representative multiple-pass and single-pass micro-rasping marks from all four primary groupings of shells were comparatively evaluated. The range of multiple-pass predatory microtrace widths does not intersect the distribution of radular tooth widths (Fig. 5.4A, C), while the distribution of single-pass predatory microtrace widths is closer to, and overlaps the distribution of radular tooth widths, with slightly more than 35% (38 of 108) overlap (Fig. 5.4B, C).

5.5.3 Primary hypotheses to explain predatory microtrace variations: microtraces and shell crystalline microarchitecture

An alternative interpretation of the predatory microtraces is that their morphology reflects the crystal fabric of the shells. In the laboratory-drilled mussels, two of the six mussels illustrated crystalline fabrics that are unambiguously oriented subparallel to the radular rasping marks (Figs. 5.1F, 5.3C). Additionally, one of the Miocene bivalves illustrated typical crossed-lamellar growth fabrics (Fig. 5.3D) (for SEM of shell microarchitectures, see Carter, 1990; Carter, 1990; Herbert, 2005). When the pooled crystalline microfabric measurements, ranging from 0.53 to 2.57 μm wide (mean = 1.37 μm, n = 152, Table 5.1), are compared to the overall range of predatory microtrace sizes, the larger end of the crystalline microfabric range only slightly overlaps the smallest radular microtraces (8.6% overlap; 13 of 152 microfabric elements are larger than the smallest rasp mark (1.84 μm). This difference is statistically significant (Mann Whitney U test, p < 0.001). Conversely, the smallest observed predatory microtraces overlap the crystalline microfabric range by a mere 0.48%. Only three of 624 predatory microtraces were ≤2.57 μm, the maximum size of the crystalline elements. In the mussels, the crystalline microstructures are organized predominantly into fibrous prismatic bundles, which group together into higher-order structural growth packages. At first inspection, the radular marks reported here may be mistakenly identified as either individual bundles or larger structural
packages of bundles. The size and arrangement of these bundles and higher-order packages, however, is consistent from individual to individual, due to the regularity of shell growth patterns within species. On the other hand, the rasp marks vary in spacing, direction relative to drill-hole margin, and orientation relative to the crystalline bundles, all of which distinguish them from features of the shell microstructure. In addition, no combination of the shell-growth microfabrics has been observed to produce the larger, corrugated pattern of ridges and troughs formed by the rasp marks, a pattern which varies in direction from shell to shell. Many of the rasping marks not only change direction within single drill holes, but also cut across one another, which would not be expected if they were merely expressions of the underlying growth layers. Perhaps most convincing is the incomplete drill hole observed in one of the laboratory-drilled limpets showing distal chemical-dissolution features, with superimposed micro-rasping marks in the central drill-hole depression. Because chemical dissolution serves to reduce or smooth the topographical expression of the crystalline shell microarchitecture, the superposition of parallel rasping microtraces on top of this smoothed area provides further evidence to separate the rasping marks from any shell-growth microfabrics. Lastly, radular rasp marks have a similar morphology, regardless of species of prey, while shell structure varies from prismatic, crossed-lamellar, and fibrillar in limpets (Lindberg, 1988) to irregular, complex crossed-lamellar and fibrous prismatic bundles in mussels (Carter and Lutz, 1990), to crossed-lamellar in Miocene bivalves (Carter and Lutz, 1990). This consistency of predatory-microtrace morphology despite differences in the prey-shell crystalline microfabrics suggests that shell microarchitecture plays a negligible role in predatory interpretations. Furthermore, due to differences in scale, orientation, and arrangement between the predatory microtraces and the prey-shell crystalline microarchitectures, we suggest that the microtraces reported here are distinctly not expressions of underlying shell microarchitectures.

5.6 Conclusions
The numerical evaluation and diagnostic value of predatory microtrace spacing deserves attention and provides intriguing avenues for future research. In particular, experimental studies that would jointly consider SEM micrographs of rasping microtraces and radular morphology and cusp width of their producers could help to evaluate the anatomical fidelity of these microtraces. Moreover, as these radular corrugations seem randomly oriented, future
examinations may focus on more stringently assessing rasp-mark orientation with regard to location of the drill hole on the prey shell and variation of prey-shell crystalline microarchitectures.

The presence of such predatory microtraces, especially in true fossil specimens, may provide a viable tool for identifying taphonomically degraded or irregularly shaped drill holes that would otherwise be dismissed by researchers. Likewise, dissolution signatures, which can be preserved around drill-hole margins in well-preserved fossils, may help us to evaluate whether the drilling process was chemically aided—an important criterion for identifying the presence of accessory boring organs or similar structures in ancient predators. Although chemical dissolution signatures have been observed in numerous modern drill holes, the quantification of predatory microtrace spacing may have more diagnostic value in evaluating predator-prey interactions. Finally, distinct microtraces of radular rasping that can be readily identified and numerically evaluated using SEM techniques offer promise for augmenting our ability to identify drill holes from fossil specimens, especially when fossils are degraded or when drilling organisms are difficult to infer independently.

5.7 Acknowledgments
The experimental portions of this study were conducted at the Friday Harbor Laboratories during a Predator-Prey Interactions summer course. We would like to thank the FHL faculty and staff for providing funding, facilities, and logistic and intellectual support. All EM analyses were conducted at the Virginia Tech Institute for Critical Technology and Applied Science Nanoscale Characterization and Fabrication Laboratory (ICTAS-NCFL). The final stages of the study were partly supported by National Science Foundation grant (OCE-0602375). We thank J.W. Huntley (University of Kentucky) for his generous help during the FHL summer course and for insights on the manuscript; S.R.F. McCartney and J. McIntosh (ICTAS-NCFL) for FE-SEM and ESEM technical assistance; and T.A. Dexter, P.J. Voice, A.F. Wallace, and S. Xiao (Virginia Tech) for constructive comments on earlier drafts of this report. We also thank G.S. Herbert (University of South Florida) for valuable discussions, as well as K. Parsons-Hubbard (Oberlin College), E.M. Harper (Cambridge University), two anonymous reviewers, and an anonymous associate editor for constructive reviews, suggestions, and comments that greatly improved the quality of this manuscript.
### Table 5.1. Descriptive statistics for the quantified predatory microtraces, shell-growth microfabrics, and radular cusp measurements from Rolán et al. (2004).

<table>
<thead>
<tr>
<th>Specimen ID#</th>
<th>Species</th>
<th>Sample origin</th>
<th>N</th>
<th>Mean (μm)</th>
<th>SD (μm)</th>
<th>Max (μm)</th>
<th>Min (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VT-P-001</td>
<td><em>L. digitalis</em></td>
<td>Laboratory-observed limpets</td>
<td>42</td>
<td>11.18</td>
<td>3.16</td>
<td>20.04</td>
<td>6.88</td>
</tr>
<tr>
<td>VT-P-002</td>
<td><em>T. scutum</em></td>
<td>Laboratory-observed limpets</td>
<td>88</td>
<td>5.38</td>
<td>1.45</td>
<td>10.28</td>
<td>2.94</td>
</tr>
<tr>
<td><strong>Pooled laboratory-observed limpets</strong></td>
<td></td>
<td></td>
<td>130</td>
<td>7.25</td>
<td>3.47</td>
<td>20.04</td>
<td>2.94</td>
</tr>
<tr>
<td>VT-MT-17 (predator NL-16)</td>
<td><em>M. trossulus</em></td>
<td>Laboratory-observed mussels</td>
<td>13</td>
<td>8.67</td>
<td>3.37</td>
<td>17.67</td>
<td>4.17</td>
</tr>
<tr>
<td>VT-MT-52 (predator NL-16)</td>
<td><em>M. trossulus</em></td>
<td>Laboratory-observed mussels</td>
<td>132</td>
<td>8.61</td>
<td>3.58</td>
<td>21.67</td>
<td>1.84</td>
</tr>
<tr>
<td>VT-MT-53 (predator NL-16)</td>
<td><em>M. trossulus</em></td>
<td>Laboratory-observed mussels</td>
<td>26</td>
<td>8.44</td>
<td>2.21</td>
<td>13.25</td>
<td>5.21</td>
</tr>
<tr>
<td>VT-MT-72 (predator NL-16)</td>
<td><em>M. trossulus</em></td>
<td>Laboratory-observed mussels</td>
<td>18</td>
<td>8.14</td>
<td>1.68</td>
<td>11.76</td>
<td>5.56</td>
</tr>
<tr>
<td>VT-MT-48 (predator NL-34)</td>
<td><em>M. trossulus</em></td>
<td>Laboratory-observed mussels</td>
<td>42</td>
<td>6.47</td>
<td>2.02</td>
<td>10.86</td>
<td>3.49</td>
</tr>
<tr>
<td>VT-MT-68 (predator NL-34)</td>
<td><em>M. trossulus</em></td>
<td>Laboratory-observed mussels</td>
<td>47</td>
<td>8.69</td>
<td>2.29</td>
<td>16.13</td>
<td>5.07</td>
</tr>
<tr>
<td><strong>Pooled laboratory-observed mussels</strong></td>
<td></td>
<td></td>
<td>278</td>
<td>8.26</td>
<td>3.04</td>
<td>21.67</td>
<td>1.84</td>
</tr>
<tr>
<td>VT-2-3 C-3</td>
<td><em>L. digitalis</em></td>
<td>Subfossil limpet assemblage</td>
<td>16</td>
<td>8.24</td>
<td>1.81</td>
<td>10.69</td>
<td>4.35</td>
</tr>
<tr>
<td>VT-1-4 B-3</td>
<td><em>L. digitalis</em></td>
<td>Subfossil limpet assemblage</td>
<td>12</td>
<td>4.72</td>
<td>0.89</td>
<td>6.09</td>
<td>3.58</td>
</tr>
<tr>
<td>VT-2-3 B-10</td>
<td><em>L. digitalis</em></td>
<td>Subfossil limpet assemblage</td>
<td>10</td>
<td>6.37</td>
<td>1.49</td>
<td>9.85</td>
<td>4.51</td>
</tr>
<tr>
<td>VT-1-6 B-1</td>
<td><em>L. digitalis</em></td>
<td>Subfossil limpet assemblage</td>
<td>15</td>
<td>13.03</td>
<td>2.47</td>
<td>17.31</td>
<td>9.68</td>
</tr>
<tr>
<td><strong>Pooled subfossil limpets</strong></td>
<td></td>
<td></td>
<td>53</td>
<td>8.44</td>
<td>3.64</td>
<td>17.31</td>
<td>3.58</td>
</tr>
<tr>
<td>VT-B5-3-1</td>
<td><em>A. radiata</em></td>
<td>Winterswijk-Miste, Burdigalian Stage</td>
<td>50</td>
<td>6.92</td>
<td>1.71</td>
<td>10.68</td>
<td>3.86</td>
</tr>
<tr>
<td>VT-B5-3-4</td>
<td><em>A. radiata</em></td>
<td>Winterswijk-Miste, Burdigalian Stage</td>
<td>25</td>
<td>10.47</td>
<td>1.66</td>
<td>13.58</td>
<td>7.25</td>
</tr>
<tr>
<td>VT-S14-11</td>
<td><em>C. basteroti</em></td>
<td>Szabó Quarry, Langhian Stage</td>
<td>88</td>
<td>5.13</td>
<td>1.34</td>
<td>8.83</td>
<td>2.51</td>
</tr>
<tr>
<td><strong>Pooled Miocene bivalves</strong></td>
<td></td>
<td></td>
<td>163</td>
<td>6.50</td>
<td>2.40</td>
<td>13.58</td>
<td>2.51</td>
</tr>
<tr>
<td><strong>Total pooled predatory microtraces</strong></td>
<td></td>
<td></td>
<td>624</td>
<td>7.60</td>
<td>3.13</td>
<td>21.67</td>
<td>1.84</td>
</tr>
<tr>
<td><strong>Additional structures of note</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pooled crystalline shell microfabrics</td>
<td></td>
<td></td>
<td>152</td>
<td>1.37</td>
<td>0.39</td>
<td>2.57</td>
<td>0.53</td>
</tr>
<tr>
<td>Radular cusp width</td>
<td><em>N. lapillus</em></td>
<td>Rolán et al., 2004</td>
<td>45</td>
<td>15.26</td>
<td>2.18</td>
<td>21.36</td>
<td>11.53</td>
</tr>
<tr>
<td><strong>Multiple-pass versus single-pass radular microtraces</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multiple-pass microtraces</td>
<td></td>
<td></td>
<td>149</td>
<td>5.75</td>
<td>1.79</td>
<td>11.21</td>
<td>1.84</td>
</tr>
<tr>
<td>Single-pass microtraces</td>
<td></td>
<td></td>
<td>108</td>
<td>10.31</td>
<td>3.25</td>
<td>21.67</td>
<td>4.18</td>
</tr>
</tbody>
</table>

Symbols: Specimen ID = Virginia Tech repository number; n = number of measured rasp marks; SD = standard deviation; Max = maximum size measured; Min = minimum size measured.
5.9 Figures and Figure Captions

Figure 5.1. Caption on following page.
**Figure 5.1.** Representative micro-rasping marks. (A–C) FE-SEM micrographs of drill holes from limpets killed by the muricid gastropod *Nucella ostrina* in the laboratory. (A) *Lottia digitalis* drill hole with perpendicular to subparallel, sweeping microtraces on margin (specimen VT-P-001). (B) *Tectura scutum* outer margin of non-functional or incomplete drill hole; arrow = chemical dissolution signature (VT-P-002). (C) Inner surface of *T. scutum* non-functional drill hole showing rasping microtraces perpendicular to drill-hole margin; arrows = superimposition of radular passes. (D–F) ESEM micrographs of drill holes from mussel specimens killed by *Nucella lamellosa* in the laboratory. (D) *Mytilus trossulus* (VT-MT-68, killed by VT-NL-34); outer drill-hole margin with parallel to slightly subparallel micro-rasping marks oriented subparallel to drill hole. (E–F) *M. trossulus* (VT-MT-52, killed by VT-NL-16) showing (E) outer drill-hole margin with parallel micro-rasping marks oriented parallel to drill hole and (F) inner drill-hole margin with crystalline microstructures (arrow) oriented obliquely to the parallel micro-rasping marks; note variable spacing of rasp marks (F) compared to microtraces (E). (G–I) FE-SEM micrographs of predatory drill holes from field-collected *L. digitalis* specimens. G) Parallel micro-rasping marks in *L. digitalis* (VT-2-3 C-3), oriented perpendicular to drill-hole margin. (H–I) Inner drill-hole margin of *L. digitalis* (VT-1-4 B-3) showing a sweeping, fan-like pattern of micro-rasping marks (H) (arrows = outer fan edge) and possible chemical dissolution signature on inner drill-hole margin (arrow, I). J–L) ESEM micrographs of drill holes on Miocene bivalves. (J) *Astarte radiata* (VT-B5-3-1) outer drill-hole margin with parallel micro-rasping marks oriented nearly perpendicular to margin (left arrow) and parallel to drill-hole margin (lower right). (K) *A. radiata* (VT-B5-3-4) with perpendicularly oriented micro-rasping marks on outer drill-hole margin. (L) *Clausinella basteroti* (VT-S14-11); outer drill-hole margin with possible eroded micro-rasping marks (upper arrow) and minor perforations likely associated with bioerosion (lower arrow).
Figure 5.2. Caption on following page.
Figure 5.2. Predatory microtrace size-frequency distributions and images of corresponding shells. Spacing between micro-rasping marks measured to the nearest 0.01 μm. (A, F, J, M) Microtrace spacing distribution of laboratory-drilled shells; for histogram shading, see Figure 5.3. (B–E) Shells of *Tectura scutum* (B–C, specimen VT-P-002) and *Lottia digitalis* (D–E, VT-P-001) with corresponding electron micrographs illustrating measured predatory microtraces (lighter strip on shells in B and D represents area covered by conductive copper tape where specimen was not sputter coated). (G–I) *Mytilus trossulus* showing representative specimen (G) and electron micrographs of predatory microtraces drilled by *Nucella lamellosa* (H–I, VT-NL-16 and VT-NL-34, respectively). (K–L) Representative subfossil *L. digitalis* and electron micrograph of predatory microtraces. (N–Q) Miocene bivalves *Clausinella basteroti* (N–O, VT-S14-11) and *Astarte radiata* (P–Q, VT-B5-3-1) with corresponding electron micrographs illustrating predatory microtraces. Photographic scale bars = 0.5 cm; EM scale bars = 50 μm.
Figure 5.3. Predatory microtrace, shell microstructure, and radular cusp data. (A) Size-frequency distribution of spacing between rasping marks for all analyzed drill holes. (B) Size-frequency distribution of crystalline mussel-shell microstructures. (C) Electron micrograph of mussel-shell fibrous prismatic microfabric. (D) Electron micrograph of Miocene *Astarte radiata* shell crossed-lamellar microfabric. (E) Radular cusp widths measured from (Rolán et al., 2004). (F) Radular cusps of *N. lapillus*, upper arrow indicates rachidian tooth containing three radular cusps; line = tooth width. Lower arrow indicates single radular cusp; line = cusp width (modified from figure 2E of Rolán et al., 2004). Scale bars in (C, D, and F) = 50 μm.
Figure 5.4. Size differentiation of multiple-pass (overlain) and single-pass predatory microtraces (A–B) versus distribution of radular cusp widths in *N. lapillus* (C), as measured from Rolán et al., 2004. (D–G) Representative multiple-pass predatory microtraces from: (D) a laboratory-observed limpet (specimen VT-P-002), (E) a laboratory-observed mussel (VT-MT-52, left margin), (F) a subfossil limpet (VT-1-4 B-3), and (G) Miocene *Astarte radiata* (VT-B5-3-1). Arrows indicate points of crosscutting radular marks. (H–K) Representative single-pass predatory microtraces from: (H) a laboratory-observed limpet (VT-P-001), (I) a laboratory-observed mussel (VT-MT-52, bottom margin), (J) a subfossil limpet (VT-2-3 C-3), and (K) *A. radiata* (specimen VT-B5-3-4). All scale bars = 50 μm unless otherwise labeled.
5.10 References


LEIGHTON, L.R., 2003, Morphological response of prey to drilling predation in the Middle Devonian *Palaeogeography Palaeoclimatology Palaeoecology*, v. 201, p. 221-234.


5.11 Appendix D

**Table D1.** Predatory microtrace spacing measurements. (Note: image file #s and corresponding image information were unavailable for measurements conducted by Dr. Y. Yanes)

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Image file #</th>
<th>Specimen ID#</th>
<th>Species</th>
<th>Scale true length (µm)</th>
<th>Image scale length (pix)</th>
<th>Image rasp spacing (pix)</th>
<th>True rasp spacing (µm)</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>8.348</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>2</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>8.693</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>3</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>8.348</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>4</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>8.348</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>5</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>13.335</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>6</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>15.474</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>7</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>11.522</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>8</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>15.101</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>9</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>13.873</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>10</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>10.341</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>11</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>12.498</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>12</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>8.837</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>13</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>10.058</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>14</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>11.092</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>15</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>8.672</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>16</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>9.932</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>17</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>20.035</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>18</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>13.943</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>19</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>11.354</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>20</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>9.810</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>21</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>8.348</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>22</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>7.499</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>23</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>7.696</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>24</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>7.213</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>25</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>11.317</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>26</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>17.404</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>27</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>12.012</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>28</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>13.536</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Specimen ID#</td>
<td>Species</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>True rasp spacing (µm)</td>
<td>Category</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>--------------</td>
<td>--------------</td>
<td>------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>------------------------</td>
<td>-----------------------</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitalis</td>
<td>.</td>
<td>.</td>
<td>10.565</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitalis</td>
<td>.</td>
<td>.</td>
<td>13.272</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitalis</td>
<td>.</td>
<td>.</td>
<td>9.562</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitalis</td>
<td>.</td>
<td>.</td>
<td>10.076</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitalis</td>
<td>.</td>
<td>.</td>
<td>8.348</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitalis</td>
<td>.</td>
<td>.</td>
<td>8.824</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitalis</td>
<td>.</td>
<td>.</td>
<td>8.181</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitalis</td>
<td>.</td>
<td>.</td>
<td>8.122</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitalis</td>
<td>.</td>
<td>.</td>
<td>6.880</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitalis</td>
<td>.</td>
<td>.</td>
<td>17.708</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitalis</td>
<td>.</td>
<td>.</td>
<td>15.96</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitalis</td>
<td>.</td>
<td>.</td>
<td>13.518</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitalis</td>
<td>.</td>
<td>.</td>
<td>11.113</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>.</td>
<td>VT-P-001</td>
<td>Lottia digitalis</td>
<td>.</td>
<td>.</td>
<td>12.867</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>4.754</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>4.255</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>5.124</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>46</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>4.997</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>47</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>4.874</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>48</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>6.123</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>49</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>7.372</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>4.497</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>51</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>4.125</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>52</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>4.417</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>53</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>4.389</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>54</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>6.751</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>55</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>8.871</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>56</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>5.136</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>57</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>5.160</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>58</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>6.382</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>59</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>8.621</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>4.874</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>61</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>5.253</td>
<td>Laboratory-observed limpets</td>
<td></td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Specimen ID#</td>
<td>Species</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image rasp spacing (pix)</td>
<td>True rasp spacing (µm)</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>--------------</td>
<td>---------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>------------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>62</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>3.748 Laboratory-observed limpets</td>
</tr>
<tr>
<td>63</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>4.255 Laboratory-observed limpets</td>
</tr>
<tr>
<td>64</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>3.756 Laboratory-observed limpets</td>
</tr>
<tr>
<td>65</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>5.497 Laboratory-observed limpets</td>
</tr>
<tr>
<td>66</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>4.874 Laboratory-observed limpets</td>
</tr>
<tr>
<td>67</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>5.52 Laboratory-observed limpets</td>
</tr>
<tr>
<td>68</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>6.501 Laboratory-observed limpets</td>
</tr>
<tr>
<td>69</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>8.245 Laboratory-observed limpets</td>
</tr>
<tr>
<td>70</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>8.995 Laboratory-observed limpets</td>
</tr>
<tr>
<td>71</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>5.873 Laboratory-observed limpets</td>
</tr>
<tr>
<td>72</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>4.874 Laboratory-observed limpets</td>
</tr>
<tr>
<td>73</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>5.503 Laboratory-observed limpets</td>
</tr>
<tr>
<td>74</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>7.512 Laboratory-observed limpets</td>
</tr>
<tr>
<td>75</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>5.768 Laboratory-observed limpets</td>
</tr>
<tr>
<td>76</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>5.997 Laboratory-observed limpets</td>
</tr>
<tr>
<td>77</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>5.373 Laboratory-observed limpets</td>
</tr>
<tr>
<td>78</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>5.136 Laboratory-observed limpets</td>
</tr>
<tr>
<td>79</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>4.874 Laboratory-observed limpets</td>
</tr>
<tr>
<td>80</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>5.160 Laboratory-observed limpets</td>
</tr>
<tr>
<td>81</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>4.912 Laboratory-observed limpets</td>
</tr>
<tr>
<td>82</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>4.874 Laboratory-observed limpets</td>
</tr>
<tr>
<td>83</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>6.373 Laboratory-observed limpets</td>
</tr>
<tr>
<td>84</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>6.252 Laboratory-observed limpets</td>
</tr>
<tr>
<td>85</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>5.300 Laboratory-observed limpets</td>
</tr>
<tr>
<td>86</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>6.133 Laboratory-observed limpets</td>
</tr>
<tr>
<td>87</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>8.121 Laboratory-observed limpets</td>
</tr>
<tr>
<td>88</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>10.281 Laboratory-observed limpets</td>
</tr>
<tr>
<td>89</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>7.999 Laboratory-observed limpets</td>
</tr>
<tr>
<td>90</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>7.131 Laboratory-observed limpets</td>
</tr>
<tr>
<td>91</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>7.622 Laboratory-observed limpets</td>
</tr>
<tr>
<td>92</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>3.806 Laboratory-observed limpets</td>
</tr>
<tr>
<td>93</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>3.375 Laboratory-observed limpets</td>
</tr>
<tr>
<td>94</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>4.248 Laboratory-observed limpets</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Specimen ID#</td>
<td>Species</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image rasp spacing (pix)</td>
<td>True rasp spacing (µm)</td>
<td>Category</td>
</tr>
<tr>
<td>---------</td>
<td>--------------</td>
<td>--------------</td>
<td>-------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>------------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>95</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>4.255</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>96</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>4.255</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>97</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>4.638</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>98</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>4.747</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>99</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>7.880</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>100</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>5.053</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>101</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>5.733</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>102</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>5.795</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>103</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>6.181</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>104</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>5.253</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>105</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>4.774</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>106</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>4.887</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>107</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>4.374</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>108</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>3.923</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>109</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>3.998</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>110</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>4.389</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>111</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>5.124</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>112</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>5.385</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>113</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>5.905</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>114</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>4.170</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>115</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>2.941</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>116</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>4.029</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>117</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>4.624</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>118</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>3.286</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>119</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>3.875</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>120</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>3.923</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>121</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>4.029</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>122</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>3.970</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>123</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>3.507</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>124</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>4.255</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>125</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>5.997</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>126</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>4.417</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>127</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>5.548</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Specimen ID#</td>
<td>Species</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image rasp spacing (pix)</td>
<td>True rasp spacing (µm)</td>
<td>Category</td>
</tr>
<tr>
<td>---------</td>
<td>--------------</td>
<td>--------------</td>
<td>---------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>------------------------</td>
<td>------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>128</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>8.093</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>129</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>5.022</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>130</td>
<td>.</td>
<td>VT-P-002</td>
<td>Tectura scutum</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>5.160</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>1</td>
<td>17 right 003</td>
<td>VT-MT-17</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>43</td>
<td>7.6</td>
<td>17.674</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>2</td>
<td>17 right 003</td>
<td>VT-MT-17</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>43</td>
<td>2.8</td>
<td>6.512</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>3</td>
<td>17 right 003</td>
<td>VT-MT-17</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>43</td>
<td>4.0</td>
<td>9.302</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>4</td>
<td>17 top right 002</td>
<td>VT-MT-17</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>26.4</td>
<td>3.4</td>
<td>6.439</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>5</td>
<td>17 top right 002</td>
<td>VT-MT-17</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>26.4</td>
<td>6.4</td>
<td>12.121</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>6</td>
<td>17 top right 002</td>
<td>VT-MT-17</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>26.4</td>
<td>4.0</td>
<td>7.576</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>7</td>
<td>17 top right 002</td>
<td>VT-MT-17</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>26.4</td>
<td>5.6</td>
<td>10.606</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>8</td>
<td>17 top right 002</td>
<td>VT-MT-17</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>26.4</td>
<td>4.0</td>
<td>7.576</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>9</td>
<td>17 top right 002</td>
<td>VT-MT-17</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>26.4</td>
<td>4.5</td>
<td>8.523</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>10</td>
<td>17 top right 002</td>
<td>VT-MT-17</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>26.4</td>
<td>3.6</td>
<td>6.818</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>11</td>
<td>17 top right 002</td>
<td>VT-MT-17</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>26.4</td>
<td>3.6</td>
<td>6.818</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>12</td>
<td>17 top right 002</td>
<td>VT-MT-17</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>26.4</td>
<td>3.6</td>
<td>6.818</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>13</td>
<td>17 top right 002</td>
<td>VT-MT-17</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>26.4</td>
<td>4.5</td>
<td>8.523</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>14</td>
<td>52 bottom 003</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.3</td>
<td>2.3</td>
<td>6.005</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>15</td>
<td>52 bottom 003</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.3</td>
<td>2.3</td>
<td>6.005</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>16</td>
<td>52 bottom 003</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.3</td>
<td>2.0</td>
<td>5.222</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>17</td>
<td>52 bottom 003</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.3</td>
<td>2.2</td>
<td>5.744</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>18</td>
<td>52 bottom 003</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.3</td>
<td>1.6</td>
<td>4.178</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>19</td>
<td>52 bottom 003</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.3</td>
<td>3.8</td>
<td>9.922</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>20</td>
<td>52 bottom 003</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.3</td>
<td>3.0</td>
<td>7.833</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>21</td>
<td>52 bottom 003</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.3</td>
<td>2.3</td>
<td>6.005</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>22</td>
<td>52 bottom 003</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.3</td>
<td>1.9</td>
<td>4.961</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>23</td>
<td>52 bottom 003</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.3</td>
<td>1.7</td>
<td>4.439</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>24</td>
<td>52 bottom 003</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.3</td>
<td>3.2</td>
<td>8.355</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>25</td>
<td>52 bottom 003</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.3</td>
<td>3.7</td>
<td>9.661</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>26</td>
<td>52 bottom 003</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.3</td>
<td>4.1</td>
<td>10.705</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>27</td>
<td>52 bottom 003</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.3</td>
<td>4.4</td>
<td>11.488</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>28</td>
<td>52 bottom 003</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.3</td>
<td>3.5</td>
<td>9.138</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>29</td>
<td>52 bottom 003</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.3</td>
<td>5.9</td>
<td>15.405</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>30</td>
<td>52 bottom 003</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.3</td>
<td>6.1</td>
<td>15.927</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Specimen ID#</td>
<td>Species</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image rasp spacing (pix)</td>
<td>True rasp spacing (µm)</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>--------------</td>
<td>---------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>------------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>31</td>
<td>52 bottom 003</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>100</td>
<td>38.3</td>
<td>3.1</td>
<td>8.094</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>32</td>
<td>52 bottom 003</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>100</td>
<td>38.3</td>
<td>4.1</td>
<td>10.705</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>33</td>
<td>52 bottom 003</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>100</td>
<td>38.3</td>
<td>6.1</td>
<td>15.927</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>34</td>
<td>52 bottom 003</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>100</td>
<td>38.3</td>
<td>6.8</td>
<td>17.755</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>35</td>
<td>52 bottom 003</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>100</td>
<td>38.3</td>
<td>8.3</td>
<td>21.671</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>36</td>
<td>52 bottom 003</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>100</td>
<td>38.3</td>
<td>4.8</td>
<td>12.533</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>37</td>
<td>52 bottom 003</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>100</td>
<td>38.3</td>
<td>5.0</td>
<td>13.055</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>38</td>
<td>52 bottom 003</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>100</td>
<td>38.3</td>
<td>3.8</td>
<td>9.922</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>39</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>50</td>
<td>26.6</td>
<td>3.6</td>
<td>6.767</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>40</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>50</td>
<td>26.6</td>
<td>5.8</td>
<td>10.902</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>41</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>50</td>
<td>26.6</td>
<td>4.9</td>
<td>9.211</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>42</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>50</td>
<td>26.6</td>
<td>6.1</td>
<td>11.466</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>43</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>50</td>
<td>26.6</td>
<td>6.3</td>
<td>11.842</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>44</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>50</td>
<td>26.6</td>
<td>6.4</td>
<td>12.030</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>45</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>50</td>
<td>26.6</td>
<td>8.5</td>
<td>15.977</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>46</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>50</td>
<td>26.6</td>
<td>5.8</td>
<td>10.902</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>47</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>50</td>
<td>26.6</td>
<td>5.4</td>
<td>10.150</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>48</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>50</td>
<td>26.6</td>
<td>4.2</td>
<td>7.895</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>49</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>50</td>
<td>26.6</td>
<td>3.6</td>
<td>6.767</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>50</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>50</td>
<td>26.6</td>
<td>5.9</td>
<td>11.090</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>51</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>50</td>
<td>26.6</td>
<td>4.5</td>
<td>8.459</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>52</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>50</td>
<td>26.6</td>
<td>5.9</td>
<td>11.090</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>53</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>50</td>
<td>26.6</td>
<td>4.8</td>
<td>9.023</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>54</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>50</td>
<td>26.6</td>
<td>2.7</td>
<td>5.075</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>55</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>50</td>
<td>26.6</td>
<td>4.6</td>
<td>8.647</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>56</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>50</td>
<td>26.6</td>
<td>5.1</td>
<td>9.586</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>57</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>50</td>
<td>26.6</td>
<td>2.6</td>
<td>4.887</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>58</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>50</td>
<td>26.6</td>
<td>2.0</td>
<td>3.759</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>59</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>50</td>
<td>26.6</td>
<td>4.6</td>
<td>8.647</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>60</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>50</td>
<td>26.6</td>
<td>4.5</td>
<td>8.459</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>61</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>50</td>
<td>26.6</td>
<td>1.6</td>
<td>3.008</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>62</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>50</td>
<td>26.6</td>
<td>6.6</td>
<td>12.406</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>63</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td><em>Mytilus trossulus</em></td>
<td>50</td>
<td>26.6</td>
<td>4.4</td>
<td>8.271</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Specimen ID#</td>
<td>Species</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image rasp spacing (pix)</td>
<td>True rasp spacing (µm)</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>-------------</td>
<td>--------------</td>
<td>---------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>------------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>64</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>26.6</td>
<td>1.8</td>
<td>3.383</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>65</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>26.6</td>
<td>5.3</td>
<td>9.962</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>66</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>26.6</td>
<td>2.1</td>
<td>3.947</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>67</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>26.6</td>
<td>3.6</td>
<td>6.767</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>68</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>26.6</td>
<td>3.1</td>
<td>5.827</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>69</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>26.6</td>
<td>5.3</td>
<td>9.962</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>70</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>26.6</td>
<td>4.9</td>
<td>9.211</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>71</td>
<td>52 left 002</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>26.6</td>
<td>2.6</td>
<td>4.887</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>72</td>
<td>52 left 010</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>27.2</td>
<td>2.0</td>
<td>3.676</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>73</td>
<td>52 left 010</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>27.2</td>
<td>3.7</td>
<td>6.801</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>74</td>
<td>52 left 010</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>27.2</td>
<td>3.6</td>
<td>6.618</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>75</td>
<td>52 left 010</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>27.2</td>
<td>1.5</td>
<td>2.757</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>76</td>
<td>52 left 010</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>27.2</td>
<td>3.8</td>
<td>6.985</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>77</td>
<td>52 left 010</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>27.2</td>
<td>4.9</td>
<td>9.007</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>78</td>
<td>52 left 010</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>27.2</td>
<td>5.0</td>
<td>9.191</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>79</td>
<td>52 left 010</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>27.2</td>
<td>4.5</td>
<td>8.272</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>80</td>
<td>52 left 010</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>27.2</td>
<td>4.2</td>
<td>7.721</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>81</td>
<td>52 left 010</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>27.2</td>
<td>1.8</td>
<td>3.309</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>82</td>
<td>52 left 010</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>27.2</td>
<td>2.7</td>
<td>4.963</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>83</td>
<td>52 left 010</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>27.2</td>
<td>1.3</td>
<td>2.390</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>84</td>
<td>52 left 010</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>27.2</td>
<td>6.1</td>
<td>11.213</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>85</td>
<td>52 left 010</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>27.2</td>
<td>4.8</td>
<td>8.824</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>86</td>
<td>52 left 010</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>27.2</td>
<td>1.0</td>
<td>1.838</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>87</td>
<td>52 left 010</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>27.2</td>
<td>4.7</td>
<td>8.640</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>88</td>
<td>52 left 010</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>27.2</td>
<td>4.5</td>
<td>8.272</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>89</td>
<td>52 top left 008</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>25</td>
<td>2.2</td>
<td>8.800</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>90</td>
<td>52 top left 008</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>25</td>
<td>2.1</td>
<td>8.400</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>91</td>
<td>52 top left 008</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>25</td>
<td>3.3</td>
<td>13.200</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>92</td>
<td>52 top left 008</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>25</td>
<td>3.7</td>
<td>14.800</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>93</td>
<td>52 top left 008</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>25</td>
<td>3.3</td>
<td>13.200</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>94</td>
<td>52 top left 008</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>25</td>
<td>3.7</td>
<td>14.800</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>95</td>
<td>52 top left 008</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>25</td>
<td>1.4</td>
<td>5.600</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>96</td>
<td>52 top left 008</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>25</td>
<td>1.9</td>
<td>7.600</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Specimen ID#</td>
<td>Species</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image rasp spacing (pix)</td>
<td>True rasp spacing (µm)</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>--------------</td>
<td>---------</td>
<td>-----------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>------------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>97</td>
<td>52 top left 008 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>25</td>
<td>2.5</td>
<td>10.000</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>98</td>
<td>52 top left 008 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>25</td>
<td>1.5</td>
<td>6.000</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>99</td>
<td>52 top left 008 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>25</td>
<td>2.3</td>
<td>9.200</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>52 top left 008 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>25</td>
<td>1.8</td>
<td>7.200</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>101</td>
<td>52 top left 008 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>25</td>
<td>2.1</td>
<td>8.400</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>102</td>
<td>52 top left 008 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>25</td>
<td>2.0</td>
<td>8.000</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>103</td>
<td>52 top left 008 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>25</td>
<td>2.4</td>
<td>9.600</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>104</td>
<td>52 top left 008 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>25</td>
<td>1.8</td>
<td>7.200</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>105</td>
<td>52 top left 008 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>25</td>
<td>1.1</td>
<td>4.400</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>106</td>
<td>52 top left 008 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>25</td>
<td>2.5</td>
<td>10.000</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>107</td>
<td>52 top left 008 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>25</td>
<td>2.0</td>
<td>8.000</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>108</td>
<td>52 top left 008 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>25</td>
<td>3.1</td>
<td>12.400</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>109</td>
<td>52 top left 008 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>25</td>
<td>4.8</td>
<td>19.200</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>110</td>
<td>52 top left 008 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>25</td>
<td>2.2</td>
<td>8.800</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>111</td>
<td>52 top left 008 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>25</td>
<td>3.2</td>
<td>12.800</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>112</td>
<td>52 top left 008 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>25</td>
<td>1.8</td>
<td>7.200</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>113</td>
<td>52 top left 008 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>25</td>
<td>1.5</td>
<td>6.000</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>114</td>
<td>52 top left 008 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>25</td>
<td>1.9</td>
<td>7.600</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>115</td>
<td>52 top left 008 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>25</td>
<td>2.4</td>
<td>9.600</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>116</td>
<td>52 top left 008 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>25</td>
<td>4.4</td>
<td>17.600</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>117</td>
<td>52 top 009 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>45.5</td>
<td>3.2</td>
<td>7.033</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>118</td>
<td>52 top 009 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>45.5</td>
<td>4.5</td>
<td>9.890</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>119</td>
<td>52 top 009 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>45.5</td>
<td>4.5</td>
<td>9.890</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>52 top 009 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>45.5</td>
<td>5.4</td>
<td>11.868</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>121</td>
<td>52 top 009 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>45.5</td>
<td>4.9</td>
<td>10.769</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>122</td>
<td>52 top 009 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>45.5</td>
<td>2.4</td>
<td>5.275</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>123</td>
<td>52 top 009 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>45.5</td>
<td>2.3</td>
<td>5.055</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>124</td>
<td>52 top 009 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>45.5</td>
<td>2.1</td>
<td>4.615</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>125</td>
<td>52 top 009 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>45.5</td>
<td>1.6</td>
<td>3.516</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>126</td>
<td>52 top 009 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>45.5</td>
<td>1.9</td>
<td>4.176</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>127</td>
<td>52 top 009 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>45.5</td>
<td>3.2</td>
<td>7.033</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>128</td>
<td>52 top 009 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>45.5</td>
<td>2.8</td>
<td>6.154</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>129</td>
<td>52 top 009 VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>45.5</td>
<td>3.3</td>
<td>7.253</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Specimen ID#</td>
<td>Species</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image rasp spacing (pix)</td>
<td>True rasp spacing (µm)</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>--------------</td>
<td>--------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>-------------------------</td>
<td>------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>130</td>
<td>52 top 009</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>45.5</td>
<td>2.8</td>
<td>6.154</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>131</td>
<td>52 top 009</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>45.5</td>
<td>4.0</td>
<td>8.791</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>132</td>
<td>52 top 009</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>45.5</td>
<td>2.3</td>
<td>5.055</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>133</td>
<td>52 top 009</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>45.5</td>
<td>1.5</td>
<td>3.297</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>134</td>
<td>52 top 009</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>45.5</td>
<td>3.4</td>
<td>7.473</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>135</td>
<td>52 top 009</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>45.5</td>
<td>5.5</td>
<td>12.088</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>136</td>
<td>52 top 009</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>45.5</td>
<td>1.9</td>
<td>4.176</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>137</td>
<td>52 top 009</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>45.5</td>
<td>3.6</td>
<td>7.912</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>138</td>
<td>52 top 009</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>45.5</td>
<td>4.2</td>
<td>9.231</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>139</td>
<td>52 top 009</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>45.5</td>
<td>5.6</td>
<td>12.308</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>140</td>
<td>52 top 009</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>45.5</td>
<td>2.7</td>
<td>5.934</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>141</td>
<td>52 b.hmag 004</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>10</td>
<td>25.5</td>
<td>22.6</td>
<td>8.863</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>142</td>
<td>52 b.hmag 004</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>10</td>
<td>25.5</td>
<td>24.7</td>
<td>9.686</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>143</td>
<td>52 b.hmag 004</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>10</td>
<td>25.5</td>
<td>21.3</td>
<td>8.353</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>144</td>
<td>52 b.hmag 004</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>10</td>
<td>25.5</td>
<td>27.4</td>
<td>10.745</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>145</td>
<td>52 b.hmag 004</td>
<td>VT-MT-52</td>
<td>Mytilus trossulus</td>
<td>10</td>
<td>25.5</td>
<td>18.2</td>
<td>7.137</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>146</td>
<td>53 bottom</td>
<td>VT-MT-53</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>34.0</td>
<td>2.0</td>
<td>5.882</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>147</td>
<td>53 bottom</td>
<td>VT-MT-53</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>34.0</td>
<td>2.4</td>
<td>7.059</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>148</td>
<td>53 bottom</td>
<td>VT-MT-53</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>34.0</td>
<td>3.6</td>
<td>10.588</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>149</td>
<td>53 bottom</td>
<td>VT-MT-53</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>34.0</td>
<td>2.8</td>
<td>8.235</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>150</td>
<td>53 left edge</td>
<td>VT-MT-53</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>40.3</td>
<td>2.2</td>
<td>5.459</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>151</td>
<td>53 left edge</td>
<td>VT-MT-53</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>40.3</td>
<td>2.1</td>
<td>5.211</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>152</td>
<td>53 left edge</td>
<td>VT-MT-53</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>40.3</td>
<td>4.6</td>
<td>11.414</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>153</td>
<td>53 left edge</td>
<td>VT-MT-53</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>40.3</td>
<td>4.1</td>
<td>10.174</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>154</td>
<td>53 left edge</td>
<td>VT-MT-53</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>40.3</td>
<td>3.3</td>
<td>8.189</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>155</td>
<td>53 left edge</td>
<td>VT-MT-53</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>40.3</td>
<td>2.5</td>
<td>6.203</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>156</td>
<td>53 left edge</td>
<td>VT-MT-53</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>40.3</td>
<td>3.5</td>
<td>8.685</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>157</td>
<td>53 left edge</td>
<td>VT-MT-53</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>40.3</td>
<td>2.6</td>
<td>6.452</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>158</td>
<td>53 left edge</td>
<td>VT-MT-53</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>40.3</td>
<td>3.3</td>
<td>8.189</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>159</td>
<td>53 left edge</td>
<td>VT-MT-53</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>40.3</td>
<td>3.2</td>
<td>7.940</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>160</td>
<td>53 left edge</td>
<td>VT-MT-53</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>40.3</td>
<td>3.7</td>
<td>9.181</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>161</td>
<td>53 right edge</td>
<td>VT-MT-53</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>33.2</td>
<td>3.4</td>
<td>10.241</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>162</td>
<td>53 right edge</td>
<td>VT-MT-53</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>33.2</td>
<td>3.6</td>
<td>10.843</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Specimen ID#</td>
<td>Species</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image rasp spacing (pix)</td>
<td>True rasp spacing (µm)</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>--------------</td>
<td>----------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>------------------------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>163</td>
<td>53 right edge</td>
<td>VT-MT-53</td>
<td><em>Mytilus trossulus</em></td>
<td>100</td>
<td>33.2</td>
<td>2.1</td>
<td>6.325</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>164</td>
<td>53 right edge</td>
<td>VT-MT-53</td>
<td><em>Mytilus trossulus</em></td>
<td>100</td>
<td>33.2</td>
<td>2.5</td>
<td>7.530</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>165</td>
<td>53 right edge</td>
<td>VT-MT-53</td>
<td><em>Mytilus trossulus</em></td>
<td>100</td>
<td>33.2</td>
<td>2.3</td>
<td>6.928</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>166</td>
<td>53 right edge</td>
<td>VT-MT-53</td>
<td><em>Mytilus trossulus</em></td>
<td>100</td>
<td>33.2</td>
<td>4.2</td>
<td>12.651</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>167</td>
<td>53 right edge</td>
<td>VT-MT-53</td>
<td><em>Mytilus trossulus</em></td>
<td>100</td>
<td>33.2</td>
<td>2.1</td>
<td>6.325</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>168</td>
<td>53 right edge</td>
<td>VT-MT-53</td>
<td><em>Mytilus trossulus</em></td>
<td>100</td>
<td>33.2</td>
<td>4.4</td>
<td>13.253</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>169</td>
<td>53 right edge</td>
<td>VT-MT-53</td>
<td><em>Mytilus trossulus</em></td>
<td>100</td>
<td>33.2</td>
<td>2.3</td>
<td>6.928</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>170</td>
<td>53 right edge</td>
<td>VT-MT-53</td>
<td><em>Mytilus trossulus</em></td>
<td>100</td>
<td>33.2</td>
<td>3.1</td>
<td>9.337</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>171</td>
<td>53 right edge</td>
<td>VT-MT-53</td>
<td><em>Mytilus trossulus</em></td>
<td>100</td>
<td>33.2</td>
<td>3.4</td>
<td>10.241</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>172</td>
<td>72 bottom right 001</td>
<td>VT-MT-72</td>
<td><em>Mytilus trossulus</em></td>
<td>100</td>
<td>30.6</td>
<td>3.0</td>
<td>9.804</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>173</td>
<td>72 bottom right 001</td>
<td>VT-MT-72</td>
<td><em>Mytilus trossulus</em></td>
<td>100</td>
<td>30.6</td>
<td>1.7</td>
<td>5.556</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>174</td>
<td>72 bottom right 001</td>
<td>VT-MT-72</td>
<td><em>Mytilus trossulus</em></td>
<td>100</td>
<td>30.6</td>
<td>2.4</td>
<td>7.843</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>175</td>
<td>72 bottom right 001</td>
<td>VT-MT-72</td>
<td><em>Mytilus trossulus</em></td>
<td>100</td>
<td>30.6</td>
<td>2.3</td>
<td>7.516</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>176</td>
<td>72 bottom right 001</td>
<td>VT-MT-72</td>
<td><em>Mytilus trossulus</em></td>
<td>100</td>
<td>30.6</td>
<td>2.3</td>
<td>7.516</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>177</td>
<td>72 bottom right 001</td>
<td>VT-MT-72</td>
<td><em>Mytilus trossulus</em></td>
<td>100</td>
<td>30.6</td>
<td>3.6</td>
<td>11.765</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>178</td>
<td>72 bottom right 001</td>
<td>VT-MT-72</td>
<td><em>Mytilus trossulus</em></td>
<td>100</td>
<td>30.6</td>
<td>2.5</td>
<td>8.170</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>179</td>
<td>72 bottom right 001</td>
<td>VT-MT-72</td>
<td><em>Mytilus trossulus</em></td>
<td>100</td>
<td>30.6</td>
<td>2.7</td>
<td>8.824</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>180</td>
<td>72 bottom</td>
<td>VT-MT-72</td>
<td><em>Mytilus trossulus</em></td>
<td>200</td>
<td>46.8</td>
<td>2.3</td>
<td>9.829</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>181</td>
<td>72 bottom</td>
<td>VT-MT-72</td>
<td><em>Mytilus trossulus</em></td>
<td>200</td>
<td>46.8</td>
<td>2.0</td>
<td>8.547</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>182</td>
<td>72 bottom</td>
<td>VT-MT-72</td>
<td><em>Mytilus trossulus</em></td>
<td>200</td>
<td>46.8</td>
<td>2.5</td>
<td>10.684</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>183</td>
<td>72 bottom</td>
<td>VT-MT-72</td>
<td><em>Mytilus trossulus</em></td>
<td>200</td>
<td>46.8</td>
<td>1.7</td>
<td>7.265</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>184</td>
<td>72 bottom</td>
<td>VT-MT-72</td>
<td><em>Mytilus trossulus</em></td>
<td>200</td>
<td>46.8</td>
<td>1.3</td>
<td>5.556</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>185</td>
<td>72 bottom</td>
<td>VT-MT-72</td>
<td><em>Mytilus trossulus</em></td>
<td>200</td>
<td>46.8</td>
<td>2.2</td>
<td>9.402</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>186</td>
<td>72 bottom</td>
<td>VT-MT-72</td>
<td><em>Mytilus trossulus</em></td>
<td>200</td>
<td>46.8</td>
<td>1.8</td>
<td>7.692</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>187</td>
<td>72 bottom</td>
<td>VT-MT-72</td>
<td><em>Mytilus trossulus</em></td>
<td>200</td>
<td>46.8</td>
<td>1.6</td>
<td>6.838</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>188</td>
<td>72 bottom</td>
<td>VT-MT-72</td>
<td><em>Mytilus trossulus</em></td>
<td>200</td>
<td>46.8</td>
<td>1.6</td>
<td>6.838</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>189</td>
<td>72 bottom</td>
<td>VT-MT-72</td>
<td><em>Mytilus trossulus</em></td>
<td>200</td>
<td>46.8</td>
<td>1.6</td>
<td>6.838</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>190</td>
<td>48 bottom right 001</td>
<td>VT-MT-48</td>
<td><em>Mytilus trossulus</em></td>
<td>200</td>
<td>35.0</td>
<td>1.8</td>
<td>10.286</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>191</td>
<td>48 bottom right 001</td>
<td>VT-MT-48</td>
<td><em>Mytilus trossulus</em></td>
<td>200</td>
<td>35.0</td>
<td>1.3</td>
<td>7.429</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>192</td>
<td>48 bottom right 001</td>
<td>VT-MT-48</td>
<td><em>Mytilus trossulus</em></td>
<td>200</td>
<td>35.0</td>
<td>1.8</td>
<td>10.286</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>193</td>
<td>48 bottom right 001</td>
<td>VT-MT-48</td>
<td><em>Mytilus trossulus</em></td>
<td>200</td>
<td>35.0</td>
<td>1.5</td>
<td>8.571</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>194</td>
<td>48 bottom right 001</td>
<td>VT-MT-48</td>
<td><em>Mytilus trossulus</em></td>
<td>200</td>
<td>35.0</td>
<td>1.9</td>
<td>10.857</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>195</td>
<td>48 bottom</td>
<td>VT-MT-48</td>
<td><em>Mytilus trossulus</em></td>
<td>100</td>
<td>29.5</td>
<td>3.1</td>
<td>10.508</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Specimen ID#</td>
<td>Species</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image rasp spacing (pix)</td>
<td>True rasp spacing (µm)</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>---------------------</td>
<td>--------------</td>
<td>---------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>-------------------------</td>
<td>--------------------------------</td>
</tr>
<tr>
<td>196</td>
<td>48 bottom VT-MT-48</td>
<td></td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>29.5</td>
<td>2.0</td>
<td>6.780</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>197</td>
<td>48 bottom VT-MT-48</td>
<td></td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>29.5</td>
<td>2.0</td>
<td>6.780</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>198</td>
<td>48 bottom VT-MT-48</td>
<td></td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>29.5</td>
<td>1.5</td>
<td>5.085</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>199</td>
<td>48 bottom VT-MT-48</td>
<td></td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>29.5</td>
<td>2.0</td>
<td>6.780</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>200</td>
<td>48 bottom VT-MT-48</td>
<td></td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>29.5</td>
<td>1.9</td>
<td>6.441</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>201</td>
<td>48 bottom VT-MT-48</td>
<td></td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>29.5</td>
<td>1.4</td>
<td>4.746</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>202</td>
<td>48 bottom VT-MT-48</td>
<td></td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>29.5</td>
<td>1.5</td>
<td>5.085</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>203</td>
<td>48 bottom VT-MT-48</td>
<td></td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>29.5</td>
<td>2.5</td>
<td>8.475</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>204</td>
<td>48 bottom VT-MT-48</td>
<td></td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>29.5</td>
<td>2.4</td>
<td>8.136</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>205</td>
<td>48 bottom VT-MT-48</td>
<td></td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>29.5</td>
<td>2.2</td>
<td>7.458</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>206</td>
<td>48 left VT-MT-48</td>
<td></td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.1</td>
<td>3.2</td>
<td>8.399</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>207</td>
<td>48 left VT-MT-48</td>
<td></td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.1</td>
<td>1.8</td>
<td>4.724</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>208</td>
<td>48 left VT-MT-48</td>
<td></td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.1</td>
<td>1.9</td>
<td>4.987</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>209</td>
<td>48 left VT-MT-48</td>
<td></td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.1</td>
<td>1.9</td>
<td>4.987</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>210</td>
<td>48 left VT-MT-48</td>
<td></td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.1</td>
<td>2.5</td>
<td>6.562</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>211</td>
<td>48 left VT-MT-48</td>
<td></td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.1</td>
<td>2.9</td>
<td>7.612</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>212</td>
<td>48 left VT-MT-48</td>
<td></td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.1</td>
<td>2.5</td>
<td>6.562</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>213</td>
<td>48 left VT-MT-48</td>
<td></td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.1</td>
<td>3.2</td>
<td>8.399</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>214</td>
<td>48 left VT-MT-48</td>
<td></td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.1</td>
<td>2.2</td>
<td>5.774</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>215</td>
<td>48 left VT-MT-48</td>
<td></td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.1</td>
<td>1.7</td>
<td>4.462</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>216</td>
<td>48 left VT-MT-48</td>
<td></td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.1</td>
<td>1.6</td>
<td>4.199</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>217</td>
<td>48 left VT-MT-48</td>
<td></td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>38.1</td>
<td>2.1</td>
<td>5.512</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>218</td>
<td>48 top right 002</td>
<td>VT-MT-48</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>37.3</td>
<td>1.9</td>
<td>5.094</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>219</td>
<td>48 top right 002</td>
<td>VT-MT-48</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>37.3</td>
<td>1.3</td>
<td>3.485</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>220</td>
<td>48 top right 002</td>
<td>VT-MT-48</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>37.3</td>
<td>1.5</td>
<td>4.021</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>221</td>
<td>48 top right 002</td>
<td>VT-MT-48</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>37.3</td>
<td>2.6</td>
<td>6.971</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>222</td>
<td>48 top right 002</td>
<td>VT-MT-48</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>37.3</td>
<td>1.9</td>
<td>5.094</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>223</td>
<td>48 top right 002</td>
<td>VT-MT-48</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>37.3</td>
<td>1.9</td>
<td>5.094</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>224</td>
<td>48 top right 003</td>
<td>VT-MT-48</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>32.9</td>
<td>6.9</td>
<td>10.486</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>225</td>
<td>48 top right 003</td>
<td>VT-MT-48</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>32.9</td>
<td>2.9</td>
<td>4.407</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>226</td>
<td>48 top right 003</td>
<td>VT-MT-48</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>32.9</td>
<td>2.3</td>
<td>3.495</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>227</td>
<td>48 top right 003</td>
<td>VT-MT-48</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>32.9</td>
<td>3.2</td>
<td>4.863</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>228</td>
<td>48 top right 003</td>
<td>VT-MT-48</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>32.9</td>
<td>3.8</td>
<td>5.775</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Specimen ID#</td>
<td>Species</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image rasp spacing (pix)</td>
<td>True rasp spacing (µm)</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>--------------</td>
<td>---------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>-------------------------</td>
<td>------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>229</td>
<td>48 top right 003 VT-MT-48</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>32.9</td>
<td>4.0</td>
<td>6.079</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>230</td>
<td>48 top right 003 VT-MT-48</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>32.9</td>
<td>3.7</td>
<td>5.623</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>231</td>
<td>48 top right 003 VT-MT-48</td>
<td>Mytilus trossulus</td>
<td>50</td>
<td>32.9</td>
<td>3.4</td>
<td>5.167</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>232</td>
<td>68 bottom 003 VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>32.6</td>
<td>2.7</td>
<td>8.282</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>233</td>
<td>68 bottom 003 VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>32.6</td>
<td>2.1</td>
<td>6.442</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>234</td>
<td>68 bottom 003 VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>32.6</td>
<td>1.7</td>
<td>5.215</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>235</td>
<td>68 bottom 003 VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>32.6</td>
<td>2.1</td>
<td>6.442</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>236</td>
<td>68 bottom 003 VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>32.6</td>
<td>2.3</td>
<td>7.055</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>237</td>
<td>68 bottom 003 VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>32.6</td>
<td>2.5</td>
<td>7.669</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>238</td>
<td>68 bottom 003 VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>32.6</td>
<td>2.1</td>
<td>6.442</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>239</td>
<td>68 bottom 003 VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>32.6</td>
<td>2.8</td>
<td>8.589</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>240</td>
<td>68 bottom 003 VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>32.6</td>
<td>3.2</td>
<td>9.816</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>241</td>
<td>68 bottom 003 VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>32.6</td>
<td>3.5</td>
<td>10.736</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>242</td>
<td>68 bottom 003 VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>32.6</td>
<td>2.2</td>
<td>6.748</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>243</td>
<td>68 bottom 003 VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>32.6</td>
<td>3.2</td>
<td>9.816</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>244</td>
<td>68 bottom 003 VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>32.6</td>
<td>3.5</td>
<td>10.736</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>245</td>
<td>68 bottom 003 VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>32.6</td>
<td>2.0</td>
<td>6.135</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>246</td>
<td>68 bottom 003 VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>32.6</td>
<td>2.8</td>
<td>8.589</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>247</td>
<td>68 bottom 003 VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>32.6</td>
<td>3.7</td>
<td>11.350</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>248</td>
<td>68 bottom 003 VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>32.6</td>
<td>3.8</td>
<td>11.656</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>249</td>
<td>68 bottom 003 VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>32.6</td>
<td>4.0</td>
<td>12.270</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>250</td>
<td>68 bottom 003 VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>32.6</td>
<td>3.0</td>
<td>9.202</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>251</td>
<td>68 bottom 003 VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>32.6</td>
<td>2.6</td>
<td>7.975</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>252</td>
<td>68 bottom 003 VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>100</td>
<td>32.6</td>
<td>2.8</td>
<td>8.589</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>253</td>
<td>68 left edge VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>200</td>
<td>43.4</td>
<td>2.1</td>
<td>9.677</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>254</td>
<td>68 left edge VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>200</td>
<td>43.4</td>
<td>1.7</td>
<td>7.834</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>255</td>
<td>68 left edge VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>200</td>
<td>43.4</td>
<td>1.8</td>
<td>8.295</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>256</td>
<td>68 left edge VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>200</td>
<td>43.4</td>
<td>2.2</td>
<td>10.138</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>257</td>
<td>68 left edge VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>200</td>
<td>43.4</td>
<td>3.5</td>
<td>16.129</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>258</td>
<td>68 left edge VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>200</td>
<td>43.4</td>
<td>2.9</td>
<td>13.364</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>259</td>
<td>68 left edge VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>200</td>
<td>43.4</td>
<td>2.2</td>
<td>10.138</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>260</td>
<td>68 left edge VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>200</td>
<td>43.4</td>
<td>2.6</td>
<td>11.982</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>261</td>
<td>68 left edge VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>200</td>
<td>43.4</td>
<td>1.9</td>
<td>8.756</td>
<td>Laboratory-observed mussels</td>
<td></td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Specimen ID#</td>
<td>Species</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image rasp spacing (pix)</td>
<td>True rasp spacing (µm)</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>--------------</td>
<td>-----------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>-----------------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>262</td>
<td>68 left edge</td>
<td>VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>200</td>
<td>43.4</td>
<td>1.7</td>
<td>7.834</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>263</td>
<td>68 left edge</td>
<td>VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>200</td>
<td>43.4</td>
<td>1.7</td>
<td>7.834</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>264</td>
<td>68 left edge</td>
<td>VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>200</td>
<td>43.4</td>
<td>1.9</td>
<td>8.756</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>265</td>
<td>68 left edge</td>
<td>VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>200</td>
<td>43.4</td>
<td>1.2</td>
<td>5.530</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>266</td>
<td>68 left edge</td>
<td>VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>200</td>
<td>43.4</td>
<td>1.1</td>
<td>5.069</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>267</td>
<td>68 left edge</td>
<td>VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>200</td>
<td>43.4</td>
<td>1.2</td>
<td>5.530</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>268</td>
<td>68 left edge</td>
<td>VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>200</td>
<td>43.4</td>
<td>1.9</td>
<td>8.756</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>269</td>
<td>68 left edge</td>
<td>VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>200</td>
<td>43.4</td>
<td>1.2</td>
<td>5.530</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>270</td>
<td>68 left edge</td>
<td>VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>200</td>
<td>43.4</td>
<td>1.3</td>
<td>5.991</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>271</td>
<td>68 left edge</td>
<td>VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>200</td>
<td>43.4</td>
<td>1.8</td>
<td>8.295</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>272</td>
<td>68 left edge</td>
<td>VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>200</td>
<td>43.4</td>
<td>1.6</td>
<td>7.373</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>273</td>
<td>68 left edge</td>
<td>VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>200</td>
<td>43.4</td>
<td>2.4</td>
<td>11.060</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>274</td>
<td>68 left edge</td>
<td>VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>200</td>
<td>43.4</td>
<td>1.9</td>
<td>8.756</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>275</td>
<td>68 left edge</td>
<td>VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>200</td>
<td>43.4</td>
<td>1.8</td>
<td>8.295</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>276</td>
<td>68 left edge</td>
<td>VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>200</td>
<td>43.4</td>
<td>2.3</td>
<td>10.599</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>277</td>
<td>68 left edge</td>
<td>VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>200</td>
<td>43.4</td>
<td>2.1</td>
<td>9.677</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>278</td>
<td>68 left edge</td>
<td>VT-MT-68</td>
<td>Mytilus trossulus</td>
<td>200</td>
<td>43.4</td>
<td>1.6</td>
<td>7.373</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>1</td>
<td>.</td>
<td>VT-2-3 C-3</td>
<td>Lottia digitallis</td>
<td>200</td>
<td>43.4</td>
<td>.</td>
<td>10.392</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>2</td>
<td>.</td>
<td>VT-2-3 C-3</td>
<td>Lottia digitallis</td>
<td>200</td>
<td>43.4</td>
<td>.</td>
<td>10.170</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>3</td>
<td>.</td>
<td>VT-2-3 C-3</td>
<td>Lottia digitallis</td>
<td>200</td>
<td>43.4</td>
<td>.</td>
<td>10.690</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>4</td>
<td>.</td>
<td>VT-2-3 C-3</td>
<td>Lottia digitallis</td>
<td>200</td>
<td>43.4</td>
<td>.</td>
<td>8.509</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>5</td>
<td>.</td>
<td>VT-2-3 C-3</td>
<td>Lottia digitallis</td>
<td>200</td>
<td>43.4</td>
<td>.</td>
<td>6.648</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>6</td>
<td>.</td>
<td>VT-2-3 C-3</td>
<td>Lottia digitallis</td>
<td>200</td>
<td>43.4</td>
<td>.</td>
<td>7.139</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>7</td>
<td>.</td>
<td>VT-2-3 C-3</td>
<td>Lottia digitallis</td>
<td>200</td>
<td>43.4</td>
<td>.</td>
<td>7.303</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>8</td>
<td>.</td>
<td>VT-2-3 C-3</td>
<td>Lottia digitallis</td>
<td>200</td>
<td>43.4</td>
<td>.</td>
<td>9.349</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>9</td>
<td>.</td>
<td>VT-2-3 C-3</td>
<td>Lottia digitallis</td>
<td>200</td>
<td>43.4</td>
<td>.</td>
<td>10.377</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>10</td>
<td>.</td>
<td>VT-2-3 C-3</td>
<td>Lottia digitallis</td>
<td>200</td>
<td>43.4</td>
<td>.</td>
<td>8.415</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>11</td>
<td>.</td>
<td>VT-2-3 C-3</td>
<td>Lottia digitallis</td>
<td>200</td>
<td>43.4</td>
<td>.</td>
<td>4.353</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>12</td>
<td>.</td>
<td>VT-2-3 C-3</td>
<td>Lottia digitallis</td>
<td>200</td>
<td>43.4</td>
<td>.</td>
<td>8.733</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>13</td>
<td>.</td>
<td>VT-2-3 C-3</td>
<td>Lottia digitallis</td>
<td>200</td>
<td>43.4</td>
<td>.</td>
<td>9.390</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>14</td>
<td>.</td>
<td>VT-2-3 C-3</td>
<td>Lottia digitallis</td>
<td>200</td>
<td>43.4</td>
<td>.</td>
<td>7.046</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>15</td>
<td>.</td>
<td>VT-2-3 C-3</td>
<td>Lottia digitallis</td>
<td>200</td>
<td>43.4</td>
<td>.</td>
<td>7.486</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>16</td>
<td>.</td>
<td>VT-2-3 C-3</td>
<td>Lottia digitallis</td>
<td>200</td>
<td>43.4</td>
<td>.</td>
<td>5.869</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Specimen ID#</td>
<td>Species</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image rasp spacing (pix)</td>
<td>True rasp spacing (µm)</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>--------------</td>
<td>--------------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>------------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>17</td>
<td>.</td>
<td>VT-1-4 B-3</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>4.325</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>18</td>
<td>.</td>
<td>VT-1-4 B-3</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>4.548</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>19</td>
<td>.</td>
<td>VT-1-4 B-3</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>5.879</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>20</td>
<td>.</td>
<td>VT-1-4 B-3</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>3.772</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>21</td>
<td>.</td>
<td>VT-1-4 B-3</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>6.091</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>22</td>
<td>.</td>
<td>VT-1-4 B-3</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>3.938</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>23</td>
<td>.</td>
<td>VT-1-4 B-3</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>3.577</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>24</td>
<td>.</td>
<td>VT-1-4 B-3</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>5.058</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>25</td>
<td>.</td>
<td>VT-1-4 B-3</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>5.439</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>26</td>
<td>.</td>
<td>VT-1-4 B-3</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>5.755</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>27</td>
<td>.</td>
<td>VT-1-4 B-3</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>3.874</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>28</td>
<td>.</td>
<td>VT-1-4 B-3</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>4.325</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>29</td>
<td>.</td>
<td>VT-2-3 B-10</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>5.452</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>30</td>
<td>.</td>
<td>VT-2-3 B-10</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>7.646</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>31</td>
<td>.</td>
<td>VT-2-3 B-10</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>6.591</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>32</td>
<td>.</td>
<td>VT-2-3 B-10</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>6.201</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>33</td>
<td>.</td>
<td>VT-2-3 B-10</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>6.278</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>34</td>
<td>.</td>
<td>VT-2-3 B-10</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>9.846</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>35</td>
<td>.</td>
<td>VT-2-3 B-10</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>5.266</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>36</td>
<td>.</td>
<td>VT-2-3 B-10</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>5.488</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>37</td>
<td>.</td>
<td>VT-2-3 B-10</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>4.511</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>38</td>
<td>.</td>
<td>VT-2-3 B-10</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>6.418</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>39</td>
<td>.</td>
<td>VT-1-6 B-1</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>13.142</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>40</td>
<td>.</td>
<td>VT-1-6 B-1</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>16.056</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>41</td>
<td>.</td>
<td>VT-1-6 B-1</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>15.370</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>42</td>
<td>.</td>
<td>VT-1-6 B-1</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>15.992</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>43</td>
<td>.</td>
<td>VT-1-6 B-1</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>13.204</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>44</td>
<td>.</td>
<td>VT-1-6 B-1</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>12.660</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>45</td>
<td>.</td>
<td>VT-1-6 B-1</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>13.046</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>46</td>
<td>.</td>
<td>VT-1-6 B-1</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>17.313</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>47</td>
<td>.</td>
<td>VT-1-6 B-1</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>14.715</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>48</td>
<td>.</td>
<td>VT-1-6 B-1</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>10.246</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>49</td>
<td>.</td>
<td>VT-1-6 B-1</td>
<td><em>Lottia digitallis</em></td>
<td></td>
<td></td>
<td></td>
<td>10.731</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Specimen ID#</td>
<td>Species</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image rasp spacing (pix)</td>
<td>True rasp spacing (µm)</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>--------------</td>
<td>------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>------------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>50</td>
<td>.</td>
<td>VT-1-6 B-1</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>10.484</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>51</td>
<td>.</td>
<td>VT-1-6 B-1</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>9.677</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>52</td>
<td>.</td>
<td>VT-1-6 B-1</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>12.865</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>53</td>
<td>.</td>
<td>VT-1-6 B-1</td>
<td>Lottia digitallis</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>9.905</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>1</td>
<td>5-3-1 b.hmag 002</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>63.7</td>
<td>4.0</td>
<td>6.279</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>2</td>
<td>5-3-1 b.hmag 002</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>63.7</td>
<td>6.8</td>
<td>10.675</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>3</td>
<td>5-3-1 b.hmag 002</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>63.7</td>
<td>4.4</td>
<td>6.907</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>4</td>
<td>5-3-1 b.hmag 002</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>63.7</td>
<td>3.5</td>
<td>5.495</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>5</td>
<td>5-3-1 b.hmag 002</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>63.7</td>
<td>2.6</td>
<td>4.082</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>6</td>
<td>5-3-1 b.hmag 002</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>63.7</td>
<td>5.1</td>
<td>8.006</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>7</td>
<td>5-3-1 b.hmag 002</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>63.7</td>
<td>3.7</td>
<td>5.808</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>8</td>
<td>5-3-1 b.hmag 002</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>63.7</td>
<td>5.2</td>
<td>8.163</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>9</td>
<td>5-3-1 b.hmag 002</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>63.7</td>
<td>5.1</td>
<td>8.006</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>10</td>
<td>5-3-1 b.hmag 002</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>63.7</td>
<td>3.5</td>
<td>5.495</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>11</td>
<td>5-3-1 b.hmag 002</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>63.7</td>
<td>4.6</td>
<td>7.221</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>12</td>
<td>5-3-1 b.hmag 002</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>63.7</td>
<td>2.8</td>
<td>4.396</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>13</td>
<td>5-3-1 b.hmag 002</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>63.7</td>
<td>4.2</td>
<td>6.593</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>14</td>
<td>5-3-1 b.hmag 002</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>63.7</td>
<td>6.5</td>
<td>10.204</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>15</td>
<td>5-3-1 b.hmag 002</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>63.7</td>
<td>5.1</td>
<td>8.006</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>16</td>
<td>5-3-1 b.hmag 002</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>63.7</td>
<td>6.2</td>
<td>9.733</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>17</td>
<td>5-3-1 b.hmag 002</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>63.7</td>
<td>4.2</td>
<td>6.593</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>18</td>
<td>5-3-1 b.hmag 002</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>59.6</td>
<td>5.4</td>
<td>9.060</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>19</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>59.6</td>
<td>4.7</td>
<td>7.886</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>20</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>59.6</td>
<td>4.1</td>
<td>6.879</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>21</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>59.6</td>
<td>3.7</td>
<td>6.208</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>22</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>59.6</td>
<td>4.7</td>
<td>7.886</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>23</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>59.6</td>
<td>5.1</td>
<td>8.557</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>24</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>59.6</td>
<td>2.6</td>
<td>4.362</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>25</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>59.6</td>
<td>5.9</td>
<td>9.899</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>26</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>59.6</td>
<td>4.3</td>
<td>7.215</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>27</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>59.6</td>
<td>3.8</td>
<td>6.376</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>28</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>59.6</td>
<td>2.8</td>
<td>4.698</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>29</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td>Astarte radiata</td>
<td>100</td>
<td>59.6</td>
<td>2.8</td>
<td>4.698</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Specimen ID#</td>
<td>Species</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image rasp spacing (pix)</td>
<td>True rasp spacing (µm)</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>--------------</td>
<td>---------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>------------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>30</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>59.6</td>
<td>4.3</td>
<td>7.215</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>31</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>59.6</td>
<td>4.1</td>
<td>6.879</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>32</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>59.6</td>
<td>4.4</td>
<td>7.383</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>33</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>59.6</td>
<td>3.6</td>
<td>6.040</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>34</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>59.6</td>
<td>4.0</td>
<td>6.711</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>35</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>59.6</td>
<td>5.7</td>
<td>9.564</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>36</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>59.6</td>
<td>4.0</td>
<td>6.711</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>37</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>59.6</td>
<td>2.8</td>
<td>4.698</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>38</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>59.6</td>
<td>4.5</td>
<td>7.550</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>39</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>59.6</td>
<td>2.8</td>
<td>4.698</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>40</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>59.6</td>
<td>3.6</td>
<td>6.040</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>41</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>59.6</td>
<td>3.9</td>
<td>6.544</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>42</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>59.6</td>
<td>4.0</td>
<td>6.711</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>43</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>59.6</td>
<td>6.3</td>
<td>10.570</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>44</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>59.6</td>
<td>3.0</td>
<td>5.034</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>45</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>59.6</td>
<td>5.0</td>
<td>8.389</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>46</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>59.6</td>
<td>2.7</td>
<td>4.530</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>47</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>59.6</td>
<td>2.3</td>
<td>3.859</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>48</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>59.6</td>
<td>4.0</td>
<td>6.711</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>49</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>59.6</td>
<td>3.6</td>
<td>6.040</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>50</td>
<td>5-3-1 b-l.hmag 003</td>
<td>VT-B5-3-1</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>59.6</td>
<td>3.7</td>
<td>6.208</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>51</td>
<td>5-3-4 left hmag 010</td>
<td>VT-B5-3-4</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>64.8</td>
<td>7.0</td>
<td>10.802</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>52</td>
<td>5-3-4 left hmag 010</td>
<td>VT-B5-3-4</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>64.8</td>
<td>5.9</td>
<td>9.105</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>53</td>
<td>5-3-4 left hmag 010</td>
<td>VT-B5-3-4</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>64.8</td>
<td>7.2</td>
<td>11.111</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>54</td>
<td>5-3-4 left hmag 010</td>
<td>VT-B5-3-4</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>64.8</td>
<td>7.7</td>
<td>11.883</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>55</td>
<td>5-3-4 left hmag 010</td>
<td>VT-B5-3-4</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>64.8</td>
<td>6.1</td>
<td>9.414</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>56</td>
<td>5-3-4 left hmag 010</td>
<td>VT-B5-3-4</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>64.8</td>
<td>5.3</td>
<td>8.179</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>57</td>
<td>5-3-4 left hmag 010</td>
<td>VT-B5-3-4</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>64.8</td>
<td>5.8</td>
<td>8.951</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>58</td>
<td>5-3-4 left hmag 010</td>
<td>VT-B5-3-4</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>64.8</td>
<td>8.8</td>
<td>13.580</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>59</td>
<td>5-3-4 left hmag 010</td>
<td>VT-B5-3-4</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>64.8</td>
<td>7.2</td>
<td>11.111</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>60</td>
<td>5-3-4 left hmag 010</td>
<td>VT-B5-3-4</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>64.8</td>
<td>6.8</td>
<td>10.494</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>61</td>
<td>5-3-4 left hmag 010</td>
<td>VT-B5-3-4</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>64.8</td>
<td>5.8</td>
<td>8.951</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>62</td>
<td>5-3-4 left hmag 010</td>
<td>VT-B5-3-4</td>
<td><em>Astarte radiata</em></td>
<td>100</td>
<td>64.8</td>
<td>8.6</td>
<td>13.272</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Specimen ID#</td>
<td>Species</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image rasp spacing (pix)</td>
<td>True rasp spacing (µm)</td>
<td>Category</td>
</tr>
<tr>
<td>---------</td>
<td>--------------</td>
<td>--------------</td>
<td>---------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>63</td>
<td>5-3-4 left hmag 010</td>
<td>VT-B5-3-4</td>
<td>Astarte radiata</td>
<td>100</td>
<td>64.8</td>
<td>6.8</td>
<td>10.494</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>64</td>
<td>5-3-4 left hmag 010</td>
<td>VT-B5-3-4</td>
<td>Astarte radiata</td>
<td>100</td>
<td>64.8</td>
<td>6.2</td>
<td>9.568</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>65</td>
<td>5-3-4 left hmag 010</td>
<td>VT-B5-3-4</td>
<td>Astarte radiata</td>
<td>100</td>
<td>64.8</td>
<td>6.0</td>
<td>9.259</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>66</td>
<td>5-3-4 left hmag 010</td>
<td>VT-B5-3-4</td>
<td>Astarte radiata</td>
<td>100</td>
<td>64.8</td>
<td>4.7</td>
<td>7.253</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>67</td>
<td>5-3-4 left hmag 010</td>
<td>VT-B5-3-4</td>
<td>Astarte radiata</td>
<td>100</td>
<td>64.8</td>
<td>5.6</td>
<td>8.642</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>68</td>
<td>5-3-4 left hmag 010</td>
<td>VT-B5-3-4</td>
<td>Astarte radiata</td>
<td>100</td>
<td>64.8</td>
<td>6.6</td>
<td>10.185</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>69</td>
<td>5-3-4 left hmag 010</td>
<td>VT-B5-3-4</td>
<td>Astarte radiata</td>
<td>100</td>
<td>64.8</td>
<td>8.8</td>
<td>13.580</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>70</td>
<td>5-3-4 left hmag 010</td>
<td>VT-B5-3-4</td>
<td>Astarte radiata</td>
<td>100</td>
<td>64.8</td>
<td>7.5</td>
<td>11.574</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>71</td>
<td>5-3-4 left hmag 010</td>
<td>VT-B5-3-4</td>
<td>Astarte radiata</td>
<td>100</td>
<td>64.8</td>
<td>7.8</td>
<td>12.037</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>72</td>
<td>5-3-4 left 009</td>
<td>VT-B5-3-4</td>
<td>Astarte radiata</td>
<td>100</td>
<td>42.2</td>
<td>3.8</td>
<td>9.005</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>73</td>
<td>5-3-4 left 009</td>
<td>VT-B5-3-4</td>
<td>Astarte radiata</td>
<td>100</td>
<td>42.2</td>
<td>4.7</td>
<td>11.137</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>74</td>
<td>5-3-4 left 009</td>
<td>VT-B5-3-4</td>
<td>Astarte radiata</td>
<td>100</td>
<td>42.2</td>
<td>4.8</td>
<td>11.374</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>75</td>
<td>5-3-4 left 009</td>
<td>VT-B5-3-4</td>
<td>Astarte radiata</td>
<td>100</td>
<td>42.2</td>
<td>4.6</td>
<td>10.900</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>76</td>
<td>14-11 b-left 025</td>
<td>VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.0</td>
<td>2.8</td>
<td>5.385</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>77</td>
<td>14-11 b-left 025</td>
<td>VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.0</td>
<td>3.1</td>
<td>5.962</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>78</td>
<td>14-11 b-left 025</td>
<td>VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.0</td>
<td>3.2</td>
<td>6.154</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>79</td>
<td>14-11 b-left 025</td>
<td>VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.0</td>
<td>2.4</td>
<td>4.615</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>80</td>
<td>14-11 b-left 025</td>
<td>VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.0</td>
<td>2.9</td>
<td>5.577</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>81</td>
<td>14-11 b-left 025</td>
<td>VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.0</td>
<td>2.6</td>
<td>5.000</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>82</td>
<td>14-11 b-left 025</td>
<td>VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.0</td>
<td>2.1</td>
<td>4.038</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>83</td>
<td>14-11 b-left 025</td>
<td>VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.0</td>
<td>1.8</td>
<td>3.462</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>84</td>
<td>14-11 b-left 025</td>
<td>VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.0</td>
<td>2.8</td>
<td>5.385</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>85</td>
<td>14-11 b-left 025</td>
<td>VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.0</td>
<td>3.2</td>
<td>6.154</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>86</td>
<td>14-11 b-left 025</td>
<td>VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.0</td>
<td>2.5</td>
<td>4.808</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>87</td>
<td>14-11 b-left 025</td>
<td>VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.0</td>
<td>2.6</td>
<td>5.000</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>88</td>
<td>14-11 b-left 025</td>
<td>VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.0</td>
<td>2.2</td>
<td>4.231</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>89</td>
<td>14-11 b-left 025</td>
<td>VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.0</td>
<td>2.6</td>
<td>5.000</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>90</td>
<td>14-11 b-left 025</td>
<td>VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.0</td>
<td>1.8</td>
<td>3.462</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>91</td>
<td>14-11 b-left 025</td>
<td>VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.0</td>
<td>2.1</td>
<td>4.038</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>92</td>
<td>14-11 b-left 025</td>
<td>VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.0</td>
<td>2.3</td>
<td>4.423</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>93</td>
<td>14-11 b-left 025</td>
<td>VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.0</td>
<td>2.1</td>
<td>4.038</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>94</td>
<td>14-11 bottom 024</td>
<td>VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.1</td>
<td>3.4</td>
<td>6.526</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>95</td>
<td>14-11 bottom 024</td>
<td>VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.1</td>
<td>2.9</td>
<td>5.566</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Specimen ID#</td>
<td>Species</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image rasp spacing (pix)</td>
<td>True rasp spacing (µm)</td>
<td>Category</td>
</tr>
<tr>
<td>---------</td>
<td>--------------</td>
<td>--------------</td>
<td>---------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>-------------------------</td>
<td>----------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>96</td>
<td>14-11 bottom 024 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.1</td>
<td>2.7</td>
<td></td>
<td>5.182</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>97</td>
<td>14-11 bottom 024 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.1</td>
<td>2.8</td>
<td></td>
<td>5.374</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>98</td>
<td>14-11 bottom 024 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.1</td>
<td>4.6</td>
<td></td>
<td>8.829</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>99</td>
<td>14-11 bottom 024 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.1</td>
<td>2.4</td>
<td></td>
<td>4.607</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>100</td>
<td>14-11 bottom 024 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.1</td>
<td>3.4</td>
<td></td>
<td>6.526</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>101</td>
<td>14-11 bottom 024 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.1</td>
<td>3.7</td>
<td></td>
<td>7.102</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>102</td>
<td>14-11 bottom 024 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.1</td>
<td>3.1</td>
<td></td>
<td>5.950</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>103</td>
<td>14-11 bottom 024 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.1</td>
<td>3.4</td>
<td></td>
<td>6.526</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>104</td>
<td>14-11 bottom 024 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.1</td>
<td>2.4</td>
<td></td>
<td>4.607</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>105</td>
<td>14-11 bottom 024 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.1</td>
<td>2.9</td>
<td></td>
<td>5.566</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>106</td>
<td>14-11 bottom 024 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.1</td>
<td>1.9</td>
<td></td>
<td>3.647</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>107</td>
<td>14-11 bottom 024 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>52.1</td>
<td>1.9</td>
<td></td>
<td>3.647</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>108</td>
<td>14-11 left 027 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>50</td>
<td>47.8</td>
<td>4.3</td>
<td></td>
<td>4.498</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>109</td>
<td>14-11 left 027 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>50</td>
<td>47.8</td>
<td>2.4</td>
<td></td>
<td>2.510</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>110</td>
<td>14-11 left 027 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>50</td>
<td>47.8</td>
<td>3.9</td>
<td></td>
<td>4.079</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>111</td>
<td>14-11 left 027 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>50</td>
<td>47.8</td>
<td>3.4</td>
<td></td>
<td>3.556</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>112</td>
<td>14-11 left 027 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>50</td>
<td>47.8</td>
<td>3.7</td>
<td></td>
<td>3.870</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>113</td>
<td>14-11 left 027 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>50</td>
<td>47.8</td>
<td>4.6</td>
<td></td>
<td>4.812</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>114</td>
<td>14-11 left 027 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>50</td>
<td>47.8</td>
<td>3.7</td>
<td></td>
<td>3.870</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>115</td>
<td>14-11 left 027 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>50</td>
<td>47.8</td>
<td>5.1</td>
<td></td>
<td>5.335</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>116</td>
<td>14-11 left 027 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>50</td>
<td>47.8</td>
<td>5.2</td>
<td></td>
<td>5.439</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>117</td>
<td>14-11 left 027 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>50</td>
<td>47.8</td>
<td>7.0</td>
<td></td>
<td>7.322</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>118</td>
<td>14-11 left 027 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>50</td>
<td>47.8</td>
<td>4.9</td>
<td></td>
<td>5.126</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>119</td>
<td>14-11 left 027 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>50</td>
<td>47.8</td>
<td>5.2</td>
<td></td>
<td>5.439</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>120</td>
<td>14-11 left 027 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>50</td>
<td>47.8</td>
<td>5.2</td>
<td></td>
<td>5.439</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>121</td>
<td>14-11 left 027 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>50</td>
<td>47.8</td>
<td>3.4</td>
<td></td>
<td>3.556</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>122</td>
<td>14-11 left 027 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>50</td>
<td>47.8</td>
<td>3.4</td>
<td></td>
<td>3.556</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>123</td>
<td>14-11 left 027 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>50</td>
<td>47.8</td>
<td>3.9</td>
<td></td>
<td>4.079</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>124</td>
<td>14-11 left 027 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>50</td>
<td>47.8</td>
<td>3.7</td>
<td></td>
<td>3.870</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>125</td>
<td>14-11 left 027 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>50</td>
<td>47.8</td>
<td>7.7</td>
<td></td>
<td>8.054</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>126</td>
<td>14-11 low right 034 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>61.9</td>
<td>4.5</td>
<td></td>
<td>7.270</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>127</td>
<td>14-11 low right 034 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>61.9</td>
<td>3.6</td>
<td></td>
<td>5.816</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>128</td>
<td>14-11 low right 034 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>61.9</td>
<td>3.8</td>
<td></td>
<td>6.139</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Specimen ID#</td>
<td>Species</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image rasp spacing (pix)</td>
<td>True rasp spacing (µm)</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>--------------</td>
<td>---------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>-------------------------</td>
<td>------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>129</td>
<td>14-11 low right 034 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>61.9</td>
<td>3.5</td>
<td>5.654</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>130</td>
<td>14-11 low right 034 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>61.9</td>
<td>3.8</td>
<td>6.139</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>131</td>
<td>14-11 low right 034 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>61.9</td>
<td>2.5</td>
<td>4.039</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>132</td>
<td>14-11 low right 034 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>61.9</td>
<td>3.7</td>
<td>5.977</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>133</td>
<td>14-11 low right 034 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>61.9</td>
<td>4.4</td>
<td>7.108</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>134</td>
<td>14-11 right 033 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>62.0</td>
<td>4.4</td>
<td>7.097</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>135</td>
<td>14-11 right 033 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>62.0</td>
<td>2.2</td>
<td>3.548</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>136</td>
<td>14-11 right 033 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>62.0</td>
<td>2.8</td>
<td>4.516</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>137</td>
<td>14-11 right 033 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>62.0</td>
<td>3.7</td>
<td>5.968</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>138</td>
<td>14-11 right 033 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>62.0</td>
<td>4.0</td>
<td>6.452</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>139</td>
<td>14-11 right 033 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>62.0</td>
<td>4.9</td>
<td>7.903</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>140</td>
<td>14-11 right 033 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>62.0</td>
<td>4.4</td>
<td>7.097</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>141</td>
<td>14-11 upper left 029 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>61.9</td>
<td>2.5</td>
<td>4.039</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>142</td>
<td>14-11 upper left 029 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>61.9</td>
<td>2.4</td>
<td>3.877</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>143</td>
<td>14-11 upper left 029 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>61.9</td>
<td>3.2</td>
<td>5.170</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>144</td>
<td>14-11 upper left 029 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>61.9</td>
<td>3.0</td>
<td>4.847</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>145</td>
<td>14-11 upper left 029 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>61.9</td>
<td>2.8</td>
<td>4.523</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>146</td>
<td>14-11 upper left 029 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>61.9</td>
<td>3.3</td>
<td>5.331</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>147</td>
<td>14-11 upper left 029 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>61.9</td>
<td>5.4</td>
<td>8.724</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>148</td>
<td>14-11 upper left 029 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>61.9</td>
<td>2.0</td>
<td>3.231</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>149</td>
<td>14-11 upper left 029 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>61.9</td>
<td>2.2</td>
<td>3.554</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>14-11 upper left 029 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>61.9</td>
<td>3.1</td>
<td>5.008</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>151</td>
<td>14-11 upper left 029 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>61.9</td>
<td>2.7</td>
<td>4.362</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>152</td>
<td>14-11 upper left 029 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>100</td>
<td>61.9</td>
<td>5.1</td>
<td>8.239</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>153</td>
<td>14-11 up. right 031 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>50</td>
<td>47.9</td>
<td>4.4</td>
<td>4.593</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>154</td>
<td>14-11 up. right 031 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>50</td>
<td>47.9</td>
<td>5.8</td>
<td>6.054</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>155</td>
<td>14-11 up. right 031 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>50</td>
<td>47.9</td>
<td>3.1</td>
<td>3.236</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>156</td>
<td>14-11 up. right 031 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>50</td>
<td>47.9</td>
<td>3.7</td>
<td>3.862</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>157</td>
<td>14-11 up. right 031 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>50</td>
<td>47.9</td>
<td>3.9</td>
<td>4.071</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>158</td>
<td>14-11 up. right 031 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>50</td>
<td>47.9</td>
<td>4.1</td>
<td>4.280</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>159</td>
<td>14-11 up. right 031 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>50</td>
<td>47.9</td>
<td>5.1</td>
<td>5.324</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>160</td>
<td>14-11 up. right 031 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>50</td>
<td>47.9</td>
<td>4.1</td>
<td>4.280</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>161</td>
<td>14-11 up. right 031 VT-S14-11</td>
<td>Clausinella basteroti</td>
<td>50</td>
<td>47.9</td>
<td>3.7</td>
<td>3.862</td>
<td>Miocene bivalves</td>
<td></td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Specimen ID#</td>
<td>Species</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image rasp spacing (pix)</td>
<td>True rasp spacing (µm)</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>--------------</td>
<td>--------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>------------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>162</td>
<td>14-11 up. right 031</td>
<td>VT-S14-11</td>
<td><em>Clausinella basteroti</em></td>
<td>50</td>
<td>47.9</td>
<td>4.7</td>
<td>4.906</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>163</td>
<td>14-11 up. right 031</td>
<td>VT-S14-11</td>
<td><em>Clausinella basteroti</em></td>
<td>50</td>
<td>47.9</td>
<td>4.0</td>
<td>4.175</td>
<td>Miocene bivalves</td>
</tr>
</tbody>
</table>
Table D2. Crystalline shell microfabric measurements.

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Image file #</th>
<th>Scale true length (µm)</th>
<th>Image scale length (pix)</th>
<th>Image microstructure spacing (pix)</th>
<th>True microstructure spacing (µm)</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.8</td>
<td>1.374</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>2</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.4</td>
<td>1.069</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>3</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>2.3</td>
<td>1.756</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>4</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.5</td>
<td>1.145</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>5</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.2</td>
<td>0.916</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>6</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.1</td>
<td>0.840</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>7</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>0.7</td>
<td>0.534</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>8</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>2.0</td>
<td>1.527</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>9</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.4</td>
<td>1.069</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>10</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.4</td>
<td>1.069</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>11</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.6</td>
<td>1.221</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>12</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>0.9</td>
<td>0.687</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>13</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>0.9</td>
<td>0.687</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>14</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.1</td>
<td>0.840</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>15</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.5</td>
<td>1.145</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>16</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.2</td>
<td>0.916</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>17</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.1</td>
<td>0.840</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>18</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.4</td>
<td>1.069</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>19</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.4</td>
<td>1.069</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>20</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.4</td>
<td>1.069</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>21</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.6</td>
<td>1.221</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>22</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.5</td>
<td>1.145</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>23</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.8</td>
<td>1.374</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>24</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.5</td>
<td>1.145</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>25</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.9</td>
<td>1.450</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>26</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>2.0</td>
<td>1.527</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>27</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>2.0</td>
<td>1.527</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>28</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.5</td>
<td>1.145</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>29</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>2.0</td>
<td>1.527</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>30</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>2.0</td>
<td>1.527</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>31</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.9</td>
<td>1.450</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image microstructure spacing (pix)</td>
<td>True microstructure spacing (µm)</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>-----------------------------------</td>
<td>---------------------------------</td>
<td>----------------------------</td>
</tr>
<tr>
<td>32</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.5</td>
<td>1.145</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>33</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.5</td>
<td>1.145</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>34</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>2.0</td>
<td>1.527</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>35</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.6</td>
<td>1.221</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>36</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.8</td>
<td>1.374</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>37</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.6</td>
<td>1.221</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>38</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.9</td>
<td>1.450</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>39</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.4</td>
<td>1.069</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>40</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>2.2</td>
<td>1.679</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>41</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.6</td>
<td>1.221</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>42</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.5</td>
<td>1.145</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>43</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>2.5</td>
<td>1.908</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>44</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.8</td>
<td>1.374</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>45</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.4</td>
<td>1.069</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>46</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.8</td>
<td>1.374</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>47</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>2.0</td>
<td>1.527</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>48</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.4</td>
<td>1.069</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>49</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>2.3</td>
<td>1.756</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>50</td>
<td>48 right fine subp microst005</td>
<td>30</td>
<td>39.3</td>
<td>1.4</td>
<td>1.069</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>51</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.7</td>
<td>1.287</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>52</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.7</td>
<td>1.287</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>53</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>1.0</td>
<td>1.838</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>54</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.7</td>
<td>1.287</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>55</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.9</td>
<td>1.654</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>56</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>1.1</td>
<td>2.022</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>57</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>1.0</td>
<td>1.838</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>58</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>1.1</td>
<td>2.022</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>59</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.9</td>
<td>1.654</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>60</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.8</td>
<td>1.471</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>61</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.8</td>
<td>1.471</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>62</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.7</td>
<td>1.287</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>63</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.9</td>
<td>1.654</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>64</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>1.0</td>
<td>1.838</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image microstructure spacing (pix)</td>
<td>True microstructure spacing (µm)</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>-----------------------------------</td>
<td>----------------------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>65</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>1.0</td>
<td>1.838</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>66</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>1.0</td>
<td>1.838</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>67</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.8</td>
<td>1.471</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>68</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.6</td>
<td>1.103</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>69</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.8</td>
<td>1.471</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>70</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>1.0</td>
<td>1.838</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>71</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.9</td>
<td>1.654</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>72</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>1.2</td>
<td>2.206</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>73</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>1.2</td>
<td>2.206</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>74</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.9</td>
<td>1.654</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>75</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>1.0</td>
<td>1.838</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>76</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>1.1</td>
<td>2.022</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>77</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.9</td>
<td>1.654</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>78</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.9</td>
<td>1.654</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>79</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>1.4</td>
<td>2.574</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>80</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>1.0</td>
<td>1.838</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>81</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>1.0</td>
<td>1.838</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>82</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.9</td>
<td>1.654</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>83</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>1.1</td>
<td>2.022</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>84</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>1.1</td>
<td>2.022</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>85</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>1.0</td>
<td>1.838</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>86</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.9</td>
<td>1.654</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>87</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>1.2</td>
<td>2.206</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>88</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>1.3</td>
<td>2.390</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>89</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.9</td>
<td>1.654</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>90</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.9</td>
<td>1.654</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>91</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>1.2</td>
<td>2.206</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>92</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.9</td>
<td>1.654</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>93</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.9</td>
<td>1.654</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>94</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>1.1</td>
<td>2.022</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>95</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.7</td>
<td>1.287</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>96</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.7</td>
<td>1.287</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>97</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.9</td>
<td>1.654</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image microstructure spacing (pix)</td>
<td>True microstructure spacing (µm)</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>-----------------------------------</td>
<td>---------------------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>98</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.7</td>
<td>1.287</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>99</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.6</td>
<td>1.103</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>100</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.9</td>
<td>1.654</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>101</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.9</td>
<td>1.654</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>102</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>0.8</td>
<td>1.471</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>103</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.7</td>
<td>1.528</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>104</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.4</td>
<td>0.873</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>105</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.6</td>
<td>1.310</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>106</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.5</td>
<td>1.092</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>107</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.5</td>
<td>1.092</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>108</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.4</td>
<td>0.873</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>109</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.6</td>
<td>1.310</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>110</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.7</td>
<td>1.528</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>111</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.7</td>
<td>1.528</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>112</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.5</td>
<td>1.092</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>113</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.5</td>
<td>1.092</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>114</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.5</td>
<td>1.092</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>115</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.4</td>
<td>0.873</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>116</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.5</td>
<td>1.092</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>117</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.5</td>
<td>1.092</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>118</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.7</td>
<td>1.528</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>119</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.7</td>
<td>1.528</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>120</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.7</td>
<td>1.528</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>121</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.6</td>
<td>1.310</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>122</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.6</td>
<td>1.310</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>123</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.7</td>
<td>1.528</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>124</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.4</td>
<td>0.873</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>125</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.6</td>
<td>1.310</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>126</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.3</td>
<td>0.655</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>127</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.3</td>
<td>0.655</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>128</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.6</td>
<td>1.310</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>129</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.6</td>
<td>1.310</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>130</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.4</td>
<td>0.873</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image microstructure spacing (pix)</td>
<td>True microstructure spacing (µm)</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>----------------------------------</td>
<td>---------------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>131</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.5</td>
<td>1.092</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>132</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.7</td>
<td>1.528</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>133</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.5</td>
<td>1.092</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>134</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.4</td>
<td>0.873</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>135</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.5</td>
<td>1.092</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>136</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.4</td>
<td>0.873</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>137</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.4</td>
<td>0.873</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>138</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.6</td>
<td>1.310</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>139</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.4</td>
<td>0.873</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>140</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.5</td>
<td>1.092</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>141</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.5</td>
<td>1.092</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>142</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.5</td>
<td>1.092</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>143</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.6</td>
<td>1.310</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>144</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.7</td>
<td>1.528</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>145</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.5</td>
<td>1.092</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>146</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.5</td>
<td>1.092</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>147</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.8</td>
<td>1.747</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>148</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.4</td>
<td>0.873</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>149</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.7</td>
<td>1.528</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>150</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.7</td>
<td>1.528</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>151</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.4</td>
<td>0.873</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>152</td>
<td>5-3-5 left 14</td>
<td>100</td>
<td>45.8</td>
<td>0.3</td>
<td>0.655</td>
<td>Miocene bivalves</td>
</tr>
</tbody>
</table>
Table D3. Radular cusp width measurements (Rolán et al., 2004).

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Image file #</th>
<th>Tooth #</th>
<th>Species</th>
<th>Scale true length (µm)</th>
<th>Image scale length (pix)</th>
<th>Image cusp width (pix)</th>
<th>True cusp width (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2E</td>
<td>1L</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>6.0</td>
<td>20.339</td>
</tr>
<tr>
<td>2</td>
<td>2E</td>
<td>1M</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.7</td>
<td>15.932</td>
</tr>
<tr>
<td>3</td>
<td>2E</td>
<td>1R</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>3.8</td>
<td>12.881</td>
</tr>
<tr>
<td>4</td>
<td>2E</td>
<td>2L</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>6.3</td>
<td>21.356</td>
</tr>
<tr>
<td>5</td>
<td>2E</td>
<td>2M</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>5.3</td>
<td>17.966</td>
</tr>
<tr>
<td>6</td>
<td>2E</td>
<td>2R</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.9</td>
<td>16.610</td>
</tr>
<tr>
<td>7</td>
<td>2E</td>
<td>3L</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>5.7</td>
<td>19.322</td>
</tr>
<tr>
<td>8</td>
<td>2E</td>
<td>3M</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.7</td>
<td>15.932</td>
</tr>
<tr>
<td>9</td>
<td>2E</td>
<td>3R</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.5</td>
<td>15.254</td>
</tr>
<tr>
<td>10</td>
<td>2E</td>
<td>4L</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>5.8</td>
<td>19.661</td>
</tr>
<tr>
<td>11</td>
<td>2E</td>
<td>4M</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.7</td>
<td>15.932</td>
</tr>
<tr>
<td>12</td>
<td>2E</td>
<td>4R</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.1</td>
<td>13.898</td>
</tr>
<tr>
<td>13</td>
<td>2E</td>
<td>5L</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>5.4</td>
<td>18.305</td>
</tr>
<tr>
<td>14</td>
<td>2E</td>
<td>5M</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.6</td>
<td>15.593</td>
</tr>
<tr>
<td>15</td>
<td>2E</td>
<td>5R</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.5</td>
<td>15.254</td>
</tr>
<tr>
<td>16</td>
<td>2E</td>
<td>6L</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>5.0</td>
<td>16.949</td>
</tr>
<tr>
<td>17</td>
<td>2E</td>
<td>6M</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.2</td>
<td>14.237</td>
</tr>
<tr>
<td>18</td>
<td>2E</td>
<td>6R</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.7</td>
<td>15.932</td>
</tr>
<tr>
<td>19</td>
<td>2E</td>
<td>7L</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>5.4</td>
<td>18.305</td>
</tr>
<tr>
<td>20</td>
<td>2E</td>
<td>7M</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>3.6</td>
<td>12.203</td>
</tr>
<tr>
<td>21</td>
<td>2E</td>
<td>7R</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.5</td>
<td>15.254</td>
</tr>
<tr>
<td>22</td>
<td>2F</td>
<td>1L</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.6</td>
<td>15.593</td>
</tr>
<tr>
<td>23</td>
<td>2F</td>
<td>1M</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.7</td>
<td>15.932</td>
</tr>
<tr>
<td>24</td>
<td>2F</td>
<td>1R</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.1</td>
<td>13.898</td>
</tr>
<tr>
<td>25</td>
<td>2F</td>
<td>2L</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.2</td>
<td>14.237</td>
</tr>
<tr>
<td>26</td>
<td>2F</td>
<td>2M</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.4</td>
<td>14.915</td>
</tr>
<tr>
<td>27</td>
<td>2F</td>
<td>2R</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>3.8</td>
<td>12.881</td>
</tr>
<tr>
<td>28</td>
<td>2F</td>
<td>3L</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.2</td>
<td>14.237</td>
</tr>
<tr>
<td>29</td>
<td>2F</td>
<td>3M</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.2</td>
<td>14.237</td>
</tr>
<tr>
<td>30</td>
<td>2F</td>
<td>3R</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>3.6</td>
<td>12.203</td>
</tr>
<tr>
<td>31</td>
<td>2F</td>
<td>4L</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.6</td>
<td>15.593</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Tooth #</td>
<td>Species</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image cusp width (pix)</td>
<td>True cusp width (µm)</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>---------</td>
<td>-----------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>------------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>32</td>
<td>2F</td>
<td>4M</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.5</td>
<td>15.254</td>
</tr>
<tr>
<td>33</td>
<td>2F</td>
<td>4R</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.0</td>
<td>13.559</td>
</tr>
<tr>
<td>34</td>
<td>2F</td>
<td>5L</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.1</td>
<td>13.898</td>
</tr>
<tr>
<td>35</td>
<td>2F</td>
<td>5M</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.1</td>
<td>13.898</td>
</tr>
<tr>
<td>36</td>
<td>2F</td>
<td>5R</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.1</td>
<td>13.898</td>
</tr>
<tr>
<td>37</td>
<td>2F</td>
<td>6L</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>3.8</td>
<td>12.881</td>
</tr>
<tr>
<td>38</td>
<td>2F</td>
<td>6M</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.5</td>
<td>15.254</td>
</tr>
<tr>
<td>39</td>
<td>2F</td>
<td>6R</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>3.9</td>
<td>13.220</td>
</tr>
<tr>
<td>40</td>
<td>2F</td>
<td>7L</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.1</td>
<td>13.898</td>
</tr>
<tr>
<td>41</td>
<td>2F</td>
<td>7M</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.7</td>
<td>15.932</td>
</tr>
<tr>
<td>42</td>
<td>2F</td>
<td>7R</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.1</td>
<td>13.898</td>
</tr>
<tr>
<td>43</td>
<td>2F</td>
<td>8L</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.0</td>
<td>13.559</td>
</tr>
<tr>
<td>44</td>
<td>2F</td>
<td>8M</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>4.5</td>
<td>15.254</td>
</tr>
<tr>
<td>45</td>
<td>2F</td>
<td>8R</td>
<td>Nucella lapillus</td>
<td>100</td>
<td>29.5</td>
<td>3.4</td>
<td>11.525</td>
</tr>
</tbody>
</table>
Table D4. Multiple-pass microtrace vs. single-pass microtrace spacing measurements.

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Image file #</th>
<th>Scale true length (µm)</th>
<th>Image scale length (pix)</th>
<th>Image rasp spacing (pix)</th>
<th>True rasp spacing (µm)</th>
<th>Pass</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.754</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.255</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.124</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.997</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.874</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.123</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.372</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.497</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.125</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.417</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.389</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.751</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8.871</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.136</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.16</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.382</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8.621</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.874</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.253</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.748</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>21</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.255</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.756</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.497</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>24</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.874</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.52</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>26</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.501</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>27</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8.245</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>28</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8.995</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>29</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.873</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.874</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>31</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.503</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image rasp spacing (pix)</td>
<td>True rasp spacing (µm)</td>
<td>Pass</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>------------------------</td>
<td>------</td>
<td>----------</td>
</tr>
<tr>
<td>32</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.512</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>33</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.768</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>34</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.997</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.373</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>36</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.136</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>37</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.874</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>38</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.16</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>39</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.912</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.874</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>41</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.373</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>42</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.252</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>43</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.3</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>44</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.133</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>45</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8.121</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>46</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10.281</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>47</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.999</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>48</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.131</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>49</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.622</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.806</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>51</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.375</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>52</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.248</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>53</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.255</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>54</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.255</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>55</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.638</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>56</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.747</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>57</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.88</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>58</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.053</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.733</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.795</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>61</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.181</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>62</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.253</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>63</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.774</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>64</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.887</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image rasp spacing (pix)</td>
<td>True rasp spacing (µm)</td>
<td>Pass</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>----------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>------------------------</td>
<td>--------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>65</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.374</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>66</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.923</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>67</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.998</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>68</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.389</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>69</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.124</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>70</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.385</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>71</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.905</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>72</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.17</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>73</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.941</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>74</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.029</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>75</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.624</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>76</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.286</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>77</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.875</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>78</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.923</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>79</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.029</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>80</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.97</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>81</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.507</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>82</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.255</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>83</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.997</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>84</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.417</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>85</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.548</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>86</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8.093</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>87</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.022</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>88</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.16</td>
<td>Multiple</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>89</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>2.0</td>
<td>3.676</td>
<td>Multiple</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>90</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>3.7</td>
<td>6.801</td>
<td>Multiple</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>91</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>3.6</td>
<td>6.618</td>
<td>Multiple</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>92</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>1.5</td>
<td>2.757</td>
<td>Multiple</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>93</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>3.8</td>
<td>6.985</td>
<td>Multiple</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>94</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>4.9</td>
<td>9.007</td>
<td>Multiple</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>95</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>5.0</td>
<td>9.191</td>
<td>Multiple</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>96</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>4.5</td>
<td>8.272</td>
<td>Multiple</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>97</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>4.2</td>
<td>7.721</td>
<td>Multiple</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Scale true length (μm)</td>
<td>Image scale length (pix)</td>
<td>Image rasp spacing (pix)</td>
<td>True rasp spacing (μm)</td>
<td>Pass</td>
<td>Category</td>
</tr>
<tr>
<td>---------</td>
<td>---------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>-------------------------</td>
<td>------------------------</td>
<td>------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>98</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>1.8</td>
<td>3.309</td>
<td>Multiple</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>99</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>2.7</td>
<td>4.963</td>
<td>Multiple</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>100</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>1.3</td>
<td>2.390</td>
<td>Multiple</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>101</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>6.1</td>
<td>11.213</td>
<td>Multiple</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>102</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>4.8</td>
<td>8.824</td>
<td>Multiple</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>103</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>1.0</td>
<td>1.838</td>
<td>Multiple</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>104</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>4.7</td>
<td>8.640</td>
<td>Multiple</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>105</td>
<td>52 left 010</td>
<td>50</td>
<td>27.2</td>
<td>4.5</td>
<td>8.272</td>
<td>Multiple</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>106</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>4.325</td>
<td>Multiple</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>107</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>4.548</td>
<td>Multiple</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>108</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>5.879</td>
<td>Multiple</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>109</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>3.772</td>
<td>Multiple</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>110</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>6.091</td>
<td>Multiple</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>111</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>3.938</td>
<td>Multiple</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>112</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>3.577</td>
<td>Multiple</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>113</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>5.058</td>
<td>Multiple</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>114</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>5.439</td>
<td>Multiple</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>115</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>5.755</td>
<td>Multiple</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>116</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>3.874</td>
<td>Multiple</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>117</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>4.325</td>
<td>Multiple</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>118</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>5.4</td>
<td>9.060</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>119</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>4.7</td>
<td>7.886</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>120</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>4.1</td>
<td>6.879</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>121</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>3.7</td>
<td>6.208</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>122</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>4.7</td>
<td>7.886</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>123</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>5.1</td>
<td>8.557</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>124</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>2.6</td>
<td>4.362</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>125</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>5.9</td>
<td>9.899</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>126</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>4.3</td>
<td>7.215</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>127</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>3.8</td>
<td>6.376</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>128</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>2.8</td>
<td>4.698</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>129</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>4.3</td>
<td>7.215</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>130</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>4.1</td>
<td>6.879</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image rasp spacing (pix)</td>
<td>True rasp spacing (µm)</td>
<td>Pass</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>-------------------------</td>
<td>------------------------</td>
<td>------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>131</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>4.4</td>
<td>7.383</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>132</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>3.6</td>
<td>6.040</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>133</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>4.0</td>
<td>6.711</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>134</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>5.7</td>
<td>9.564</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>135</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>4.0</td>
<td>6.711</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>136</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>2.8</td>
<td>4.698</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>137</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>4.5</td>
<td>7.550</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>138</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>2.8</td>
<td>4.698</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>139</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>3.6</td>
<td>6.040</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>140</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>3.9</td>
<td>6.544</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>141</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>4.0</td>
<td>6.711</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>142</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>6.3</td>
<td>10.570</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>143</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>3.0</td>
<td>5.034</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>144</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>5.0</td>
<td>8.389</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>145</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>2.7</td>
<td>4.530</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>146</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>2.3</td>
<td>3.859</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>147</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>4.0</td>
<td>6.711</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>148</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>3.6</td>
<td>6.040</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>149</td>
<td>5-3-1 b-l.hmag 003</td>
<td>100</td>
<td>59.6</td>
<td>3.7</td>
<td>6.208</td>
<td>Multiple</td>
<td>Miocene bivalves</td>
</tr>
</tbody>
</table>

<p>| 1 | . | . | . | 8.348 | Single | Laboratory-observed limpets      |
| 2 | . | . | . | 8.693 | Single | Laboratory-observed limpets      |
| 3 | . | . | . | 8.348 | Single | Laboratory-observed limpets      |
| 4 | . | . | . | 8.348 | Single | Laboratory-observed limpets      |
| 5 | . | . | . | 13.335 | Single | Laboratory-observed limpets      |
| 6 | . | . | . | 15.474 | Single | Laboratory-observed limpets      |
| 7 | . | . | . | 11.522 | Single | Laboratory-observed limpets      |
| 8 | . | . | . | 15.101 | Single | Laboratory-observed limpets      |
| 9 | . | . | . | 13.873 | Single | Laboratory-observed limpets      |
| 10 | . | . | . | 10.341 | Single | Laboratory-observed limpets      |
| 11 | . | . | . | 12.498 | Single | Laboratory-observed limpets      |
| 12 | . | . | . | 8.837 | Single | Laboratory-observed limpets      |
| 13 | . | . | . | 10.058 | Single | Laboratory-observed limpets      |
| 14 | . | . | . | 11.092 | Single | Laboratory-observed limpets      |</p>
<table>
<thead>
<tr>
<th>Sample #</th>
<th>Image file #</th>
<th>Scale true length (µm)</th>
<th>Image scale length (pix)</th>
<th>Image rasp spacing (pix)</th>
<th>True rasp spacing (µm)</th>
<th>Pass</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8.672</td>
<td>Single</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9.932</td>
<td>Single</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20.035</td>
<td>Single</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13.943</td>
<td>Single</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11.354</td>
<td>Single</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9.81</td>
<td>Single</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>21</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8.348</td>
<td>Single</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.499</td>
<td>Single</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.696</td>
<td>Single</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>24</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.213</td>
<td>Single</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11.317</td>
<td>Single</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>26</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>17.404</td>
<td>Single</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>27</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12.012</td>
<td>Single</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>28</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13.536</td>
<td>Single</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>29</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10.565</td>
<td>Single</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13.272</td>
<td>Single</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>31</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9.562</td>
<td>Single</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>32</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10.076</td>
<td>Single</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>33</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8.348</td>
<td>Single</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>34</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8.824</td>
<td>Single</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8.181</td>
<td>Single</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>36</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8.122</td>
<td>Single</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>37</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.88</td>
<td>Single</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>38</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>17.708</td>
<td>Single</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>39</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15.96</td>
<td>Single</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13.518</td>
<td>Single</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>41</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11.113</td>
<td>Single</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>42</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12.867</td>
<td>Single</td>
<td>Laboratory-observed limpets</td>
</tr>
<tr>
<td>43</td>
<td>52 bottom 003</td>
<td>100</td>
<td>38.3</td>
<td>2.3</td>
<td>6.005</td>
<td>Single</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>44</td>
<td>52 bottom 003</td>
<td>100</td>
<td>38.3</td>
<td>2.3</td>
<td>6.005</td>
<td>Single</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>45</td>
<td>52 bottom 003</td>
<td>100</td>
<td>38.3</td>
<td>2.0</td>
<td>5.222</td>
<td>Single</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>46</td>
<td>52 bottom 003</td>
<td>100</td>
<td>38.3</td>
<td>2.2</td>
<td>5.744</td>
<td>Single</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>47</td>
<td>52 bottom 003</td>
<td>100</td>
<td>38.3</td>
<td>1.6</td>
<td>4.178</td>
<td>Single</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image rasp spacing (pix)</td>
<td>True rasp spacing (µm)</td>
<td>Pass</td>
<td>Category</td>
</tr>
<tr>
<td>---------</td>
<td>--------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>-------------------------</td>
<td>------------------------</td>
<td>------</td>
<td>------------------------</td>
</tr>
<tr>
<td>48</td>
<td>52 bottom 003</td>
<td>100</td>
<td>38.3</td>
<td>3.8</td>
<td>9.922</td>
<td>Single</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>49</td>
<td>52 bottom 003</td>
<td>100</td>
<td>38.3</td>
<td>3.0</td>
<td>7.833</td>
<td>Single</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>50</td>
<td>52 bottom 003</td>
<td>100</td>
<td>38.3</td>
<td>2.3</td>
<td>6.005</td>
<td>Single</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>51</td>
<td>52 bottom 003</td>
<td>100</td>
<td>38.3</td>
<td>1.9</td>
<td>4.961</td>
<td>Single</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>52</td>
<td>52 bottom 003</td>
<td>100</td>
<td>38.3</td>
<td>1.7</td>
<td>4.439</td>
<td>Single</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>53</td>
<td>52 bottom 003</td>
<td>100</td>
<td>38.3</td>
<td>3.2</td>
<td>8.355</td>
<td>Single</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>54</td>
<td>52 bottom 003</td>
<td>100</td>
<td>38.3</td>
<td>3.7</td>
<td>9.661</td>
<td>Single</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>55</td>
<td>52 bottom 003</td>
<td>100</td>
<td>38.3</td>
<td>4.1</td>
<td>10.705</td>
<td>Single</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>56</td>
<td>52 bottom 003</td>
<td>100</td>
<td>38.3</td>
<td>4.4</td>
<td>11.488</td>
<td>Single</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>57</td>
<td>52 bottom 003</td>
<td>100</td>
<td>38.3</td>
<td>3.5</td>
<td>9.138</td>
<td>Single</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>58</td>
<td>52 bottom 003</td>
<td>100</td>
<td>38.3</td>
<td>5.9</td>
<td>15.405</td>
<td>Single</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>59</td>
<td>52 bottom 003</td>
<td>100</td>
<td>38.3</td>
<td>6.1</td>
<td>15.927</td>
<td>Single</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>60</td>
<td>52 bottom 003</td>
<td>100</td>
<td>38.3</td>
<td>3.1</td>
<td>8.094</td>
<td>Single</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>61</td>
<td>52 bottom 003</td>
<td>100</td>
<td>38.3</td>
<td>4.1</td>
<td>10.705</td>
<td>Single</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>62</td>
<td>52 bottom 003</td>
<td>100</td>
<td>38.3</td>
<td>6.1</td>
<td>15.927</td>
<td>Single</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>63</td>
<td>52 bottom 003</td>
<td>100</td>
<td>38.3</td>
<td>6.8</td>
<td>17.755</td>
<td>Single</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>64</td>
<td>52 bottom 003</td>
<td>100</td>
<td>38.3</td>
<td>8.3</td>
<td>21.671</td>
<td>Single</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>65</td>
<td>52 bottom 003</td>
<td>100</td>
<td>38.3</td>
<td>4.8</td>
<td>12.533</td>
<td>Single</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>66</td>
<td>52 bottom 003</td>
<td>100</td>
<td>38.3</td>
<td>5.0</td>
<td>13.055</td>
<td>Single</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>67</td>
<td>52 bottom 003</td>
<td>100</td>
<td>38.3</td>
<td>3.8</td>
<td>9.922</td>
<td>Single</td>
<td>Laboratory-observed mussels</td>
</tr>
<tr>
<td>68</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>10.392</td>
<td>Single</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>69</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>10.17</td>
<td>Single</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>70</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>10.69</td>
<td>Single</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>71</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>8.509</td>
<td>Single</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>72</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>6.648</td>
<td>Single</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>73</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>7.139</td>
<td>Single</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>74</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>7.303</td>
<td>Single</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>75</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>9.349</td>
<td>Single</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>76</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>10.377</td>
<td>Single</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>77</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>8.415</td>
<td>Single</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>78</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>4.353</td>
<td>Single</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>79</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>8.733</td>
<td>Single</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>80</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>9.39</td>
<td>Single</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>Sample #</td>
<td>Image file #</td>
<td>Scale true length (µm)</td>
<td>Image scale length (pix)</td>
<td>Image rasp spacing (pix)</td>
<td>True rasp spacing (µm)</td>
<td>Pass</td>
<td>Category</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>------------------------</td>
<td>------</td>
<td>----------------</td>
</tr>
<tr>
<td>81</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.046</td>
<td>Single</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>82</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.486</td>
<td>Single</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>83</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.869</td>
<td>Single</td>
<td>Subfossil limpets</td>
</tr>
<tr>
<td>84</td>
<td>5-3-4 left hmag 010</td>
<td>100</td>
<td>64.8</td>
<td>7.0</td>
<td>10.802</td>
<td>Single</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>85</td>
<td>5-3-4 left hmag 010</td>
<td>100</td>
<td>64.8</td>
<td>5.9</td>
<td>9.105</td>
<td>Single</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>86</td>
<td>5-3-4 left hmag 010</td>
<td>100</td>
<td>64.8</td>
<td>7.2</td>
<td>11.111</td>
<td>Single</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>87</td>
<td>5-3-4 left hmag 010</td>
<td>100</td>
<td>64.8</td>
<td>7.7</td>
<td>11.883</td>
<td>Single</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>88</td>
<td>5-3-4 left hmag 010</td>
<td>100</td>
<td>64.8</td>
<td>6.1</td>
<td>9.414</td>
<td>Single</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>89</td>
<td>5-3-4 left hmag 010</td>
<td>100</td>
<td>64.8</td>
<td>5.3</td>
<td>8.179</td>
<td>Single</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>90</td>
<td>5-3-4 left hmag 010</td>
<td>100</td>
<td>64.8</td>
<td>5.8</td>
<td>8.951</td>
<td>Single</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>91</td>
<td>5-3-4 left hmag 010</td>
<td>100</td>
<td>64.8</td>
<td>8.8</td>
<td>13.580</td>
<td>Single</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>92</td>
<td>5-3-4 left hmag 010</td>
<td>100</td>
<td>64.8</td>
<td>7.2</td>
<td>11.111</td>
<td>Single</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>93</td>
<td>5-3-4 left hmag 010</td>
<td>100</td>
<td>64.8</td>
<td>6.8</td>
<td>10.494</td>
<td>Single</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>94</td>
<td>5-3-4 left hmag 010</td>
<td>100</td>
<td>64.8</td>
<td>5.8</td>
<td>8.951</td>
<td>Single</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>95</td>
<td>5-3-4 left hmag 010</td>
<td>100</td>
<td>64.8</td>
<td>8.6</td>
<td>13.272</td>
<td>Single</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>96</td>
<td>5-3-4 left hmag 010</td>
<td>100</td>
<td>64.8</td>
<td>6.8</td>
<td>10.494</td>
<td>Single</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>97</td>
<td>5-3-4 left hmag 010</td>
<td>100</td>
<td>64.8</td>
<td>6.2</td>
<td>9.568</td>
<td>Single</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>98</td>
<td>5-3-4 left hmag 010</td>
<td>100</td>
<td>64.8</td>
<td>6.0</td>
<td>9.259</td>
<td>Single</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>99</td>
<td>5-3-4 left hmag 010</td>
<td>100</td>
<td>64.8</td>
<td>4.7</td>
<td>7.253</td>
<td>Single</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>100</td>
<td>5-3-4 left hmag 010</td>
<td>100</td>
<td>64.8</td>
<td>5.6</td>
<td>8.642</td>
<td>Single</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>101</td>
<td>5-3-4 left hmag 010</td>
<td>100</td>
<td>64.8</td>
<td>6.6</td>
<td>10.185</td>
<td>Single</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>102</td>
<td>5-3-4 left hmag 010</td>
<td>100</td>
<td>64.8</td>
<td>8.8</td>
<td>13.580</td>
<td>Single</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>103</td>
<td>5-3-4 left hmag 010</td>
<td>100</td>
<td>64.8</td>
<td>7.5</td>
<td>11.574</td>
<td>Single</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>104</td>
<td>5-3-4 left hmag 010</td>
<td>100</td>
<td>64.8</td>
<td>7.8</td>
<td>12.037</td>
<td>Single</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>105</td>
<td>5-3-4 left 009</td>
<td>100</td>
<td>42.2</td>
<td>3.8</td>
<td>9.005</td>
<td>Single</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>106</td>
<td>5-3-4 left 009</td>
<td>100</td>
<td>42.2</td>
<td>4.7</td>
<td>11.137</td>
<td>Single</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>107</td>
<td>5-3-4 left 009</td>
<td>100</td>
<td>42.2</td>
<td>4.8</td>
<td>11.374</td>
<td>Single</td>
<td>Miocene bivalves</td>
</tr>
<tr>
<td>108</td>
<td>5-3-4 left 009</td>
<td>100</td>
<td>42.2</td>
<td>4.6</td>
<td>10.900</td>
<td>Single</td>
<td>Miocene bivalves</td>
</tr>
</tbody>
</table>
Figure repository D1. SEM micrographs of laboratory-observed limpets.

Figure D1.1-1 (Specimen ID# VT-P-001)

Figure D1.1-2
Figure D1.2-1 (Specimen ID# VT-P-002)

Figure D1.2-2
Figure repository D2. SEM micrographs of laboratory-observed mussels.
Figure D2.2-2

Figure D2.2-3
Figure D2.3-1 (Specimen ID# VT-MT-53)

Figure D2.3-2
Figure D2.4-1 (Specimen ID# VT-MT-72)

Figure D2.4-2
Figure D2.4-3

Figure D2.5-1 (Specimen ID# VT-MT-48)

Byssal thread
Figure D2.5-2

Figure D2.5-3
Figure D2.5-6

Figure D2.6-1 (Specimen ID# VT-MT-68)
Figure repository D3. SEM micrographs of subfossil limpets.

Figure D3.1-1 (Specimen ID# VT-2-3 C-3)

Figure D3.1-2
Figure D3.2-1 (Specimen ID# VT-1-4 B-3)

Figure D3.2-2
Figure D3.3-1 (Specimen ID# VT-2-3 B-10)

Figure D3.3-2
Figure D3.4-1 (Specimen ID# VT-1-6 B-1)

Figure D3.4-2
Figure repository D4. SEM micrographs of Miocene bivalves.

Figure D4.1-1 (Specimen ID# VT-B5-3-1)

Figure D4.1-2
Figure repository D5. SEM micrographs of crystalline shell microfabrics and published *Nucella lapillus* radulae.

![Figure D5.1 (Specimen ID# VT-B5-3-5)]()

![Figure D5.2 (Specimen ID# VT-MT-48)]()
Figure D5.3 (Specimen ID# VT-MT-52)

Figure D5.4 (*Nucella lapillus* radulae modified from Rolán et al., 2004; image# 2E left, image# 2F right)
CHAPTER 6

Closing thoughts

JAMES D. SCHIFFBAUER

Department of Geosciences, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061, USA
The study of paleobiology has been typically divided into various camps. Three of the most central themes are as follows: organismal or systematic paleobiology, which is comprised of specimen-based research in an effort to understand biological/taxonomic affinities of fossil organisms; paleoecology, which explores ecological interactions at the individual level, population level, or community level through time; and synthesis paleobiology, which focuses on the compilation of datasets in order to observe and decode large-scale ecological or evolutionary trends through time. I have chosen to mention these three themes of paleobiological exploration specifically because the budding field of digital paleobiology has the potential to significantly impact each of them. Having already unlocked an incredible amount of detail contributing to our understanding of fossil organisms, their modes of life, and their biological affinities, digital paleobiological methodologies and techniques are certain to significantly progress our understanding of biological/taxonomic affinities of individual fossil taxa, the modes in which we examine ecological interactions in the fossil record, and our comprehension and knowledge of the evolution of life through time – among many, many other exciting possibilities.

To summarize the points of interest in a digital paleobiology context from the primary research chapters presented here:

Chapter two details a method for examining the biogenicity of potential microfossils using a suite of advanced instrumentation, including scanning and transmission electron microscopy, laser Raman spectroscopy, electron microprobe, and secondary ion mass spectroscopy. From the compilation of evidence derived from these analytical instruments, we were able to demonstrate that the graphitized discs recovered from the late Archean-early Paleoproterozoic Wutai Metamorphic Complex are potentially metamorphic products of acritarchs, which would represent some of the earliest acritarchs known. Scanning electron microscopy illustrated surficial morphologies, such as compression folds, fine surface wrinkles and naonridges, and possible nanopores, of the discs that are highly comparable to younger acritarchs of undisputed biological origin and unknown in metamorphically-produced graphites. Transmission electron microscopy illustrated further morphological and ultrastructural evidence consistent with a biological interpretation, that is, these graphite discs were comprised of two distinct outer layers analogous to the vesicle walls of younger acritarchs. Laser Raman spectroscopy and electron microprobe analyses showed that these discs were in fact completely graphitized, and also provided a means for locating the distinct populations of graphite within
thin section. Finally, results from SIMS analysis, although inconclusive on their own, supported a biological interpretation of the discs.

Chapter three describes a novel application of focused ion beam electron microscopy for the three-dimensional examination of microfossil ultrastructures. While this paper is centered on the capabilities of the instrumentation, the methodology described here, known as FIB-EM nanotomography, with coupled dual-beam systems allows for real-time, 3-D ultrastructural analysis and compositional mapping with precise site selectivity, and may provide new insights in ultrastructural examination of numerous fossil organisms. Moreover, it is applicable across numerous disciplines both within the geosciences and beyond. Using the FIB-EM nanotomography method, we investigated sphaeromorphic and acanthomorphic acritarchs extracted from the ≥1000 Ma Mesoproterozoic Ruyang Group of North China. The structures that we observed here in individual two-dimensional slices show similarities to structures illustrated in previously published TEM ultrastructural analyses, but more so, we illustrated three-dimensional ultrastructural complexities, such as multiple chambers in acanthomorphic processes and nanometer-scale pores or tubes in acritarch central bodies, that would have been impossible to observe using simply SEM and TEM studies. The study of fossil ultrastructure stands much to gain by popularizing the use of FIB nanotomography; in addition, studies that would jointly consider possible modern analogs of acritarchs, such as dinoflagellate cysts and diapause animal eggs, would undoubtedly aid in unlocking some of the taxonomic conundrums surrounding acritarch interpretations.

In chapter four, we utilized high-resolution, high-magnification field emission scanning electron micrographs of exceptionally-well preserved fossil organisms from the Doushantuo phosphorites for quantitative evaluation of the phosphatization taphonomic process. We recognized and characterized several different phosphatic textures, which potentially indicate different phosphatization processes responsible for the preservation of the Doushantuo microfossils. The first texture, encrustation by micrometric, perpendicularly oriented, prismatic apatite crystals, is the most pervasive in the Doushantuo Formation, and it occurs as botryoidal and isopachous cements on a variety of substrates, including animal egg/embryo cell surfaces, egg/embryonic envelopes, algal cell walls, organic filaments, as well as secondary coatings on pre-existing phosphatic surfaces. The second texture, infilling of intracellular space by sub-micrometric, tangentially oriented, bladed apatite crystals, was likely driven by random
nucleation sites within algal cells or acritarch vesicle walls. The tangential orientation is probably a result of the crystals growing or pushing against the recalcitrant cell walls of the preserved organism. We did not observe these tangentially aligned crystals in animal cells, perhaps because their cell membranes are more labile and would be deflated and degraded before cell lumens were completely phosphatized. The third texture, impregnation by sub-micrometric, randomly oriented, equant apatite crystals, occurred when nucleation was initiated within organic substrates after only minimal degradation. Lastly, the fourth texture, phosphatic filaments, rods, and granules, supplies tentative evidence for bacterial (or nano-/ultramicro-bacterial) activities preserved in the Doushantuo microfossils, although the exact taphonomic roles of these bacterial activities are still uncertain. Our analysis shows that the preservational quality and taphonomic resolution of phosphatic impregnation and intracellular infilling is much better than phosphatic encrustation, most likely because the former processes tend to preserve the more recalcitrant structures after less degradation, and by smaller crystals. Therefore, from our analysis of Doushantuo microfossils, we conclude that the recalcitrance, degree of degradation, and crystal size all play significant, controlling roles in phosphatization of soft-bodied microorganisms. Furthermore, in terms of searching for signs of extraterrestrial life in potential fossil records beyond our planet, Bitter Spring-type and Doushantuo/Orsten-type preservational pathways hold the greatest potential. Detailed investigation of silicified and phosphatized microbiotas preserved in Precambrian rocks on the Earth, in conjunction with experimental approaches to better understand of the molecular and geochemical processes of silicification and phosphatization, will undoubtedly facilitate progress with current astrobiological research, and in the future may help us effectively choose astrobiological landing/sampling sites.

Finally, chapter five describes a new approach for identifying drill holes of predatory origin in the fossil record. This study utilized FE-SEM and ESEM for the examination and identification of predatory drill holes, first in modern organisms that were drilled by predatory whelks in monitored feeding experiments and then also in fossil organisms. The FE-SEM and ESEM examination of micrometer-scale traces left by the predators during the construction of the drill holes represents a more explicit approach than what has been commonly utilized for recognizing predatory drill holes in fossil organisms, and moreover brings advanced microbeam equipment into a field of paleobiology (specifically paleoecology) not commonly known for using such technologies. We specifically state that our numerical evaluation and diagnostic value
of predatory microtrace spacing deserves attention and provides intriguing avenues for future research, e.g., experimental studies that would jointly consider SEM micrographs of rasping microtraces in addition to the radular morphology and cusp width of their producers could help to evaluate the anatomical reliability of these microtraces (which is a project currently underway by C.L. Tyler and J.D. Schiffbauer). Nonetheless, the presence of distinct microtraces of predatory radular rasping that can be readily identified and numerically evaluated using SEM techniques offer promise for augmenting our ability to correctly identify drill holes from fossil specimens, especially when fossils are degraded or when drilling organisms are difficult to infer independently.