| 1 2 3 4 | Supplementary Information and Methods for: |
|--|---|
| 5 | Two pulses of origination in Pacific pelagic fish following the Cretaceous-Paleogene Mass |
| 6 | Extinction |
| 7 | Elizabeth Sibert ^{1,2,3*} , Matt Friedman ⁴ , Pincelli Hull ⁵ , Gene Hunt ⁶ , Richard Norris ³ |
| 8 | |
| 9 | ¹ Society of Fellows, Harvard University, Cambridge, MA 02138 |
| 10 | ² Department of Earth and Planetary Sciences, Harvard University, Cambridge, MA 02138 |
| 11 | ³ Scripps Institution of Oceanography, University of California, San Diego, La Jolla, CA 92037 |
| 12 | ⁴ Museum of Paleontology, University of Michigan, Ann Arbor, MI 48109 |
| 13 | ⁵ Department of Geology and Geophysics, Yale University, New Haven, CT 06511 |
| 14 | ⁶ Department of Paleobiology, National Museum of Natural History, Smithsonian Institution, |
| 15 | Washington, D.C. 20013 |
| 16 | *please address correspondence to esibert@fas.harvard.edu |
| 17 | |
| 18 | Earth, Atmospheric, and Planetary Sciences/Evolution |
| 19 20 21 22 23 24 25 26 | This document includes: 1. Information on DSDP Site 596 2. Ichthyolith Morphological Character Coding System (includes Figure S1) 3. Sampling, Binning, and Reworking (includes Figures S2-3, Tables S1-2) 4. Evolutionary Rates: Capture-Mark-Recapture analyses (includes Figure S4, Table S3) 5. Table S4: morphotype range-chart number key 6. Appendix 1: An image index of all fish tooth morphotypes described in this study |
| 27 28 | Relevant CSV files and R code are available at http://github.com/esibert/toothmorph |

30 **1. DSDP SITE 596**

31 Ichthyoliths were isolated from discrete sediment samples from Deep Sea Drilling Program

32 (DSDP) Site 596. DSDP Site 596 is located in the South Pacific Gyre, at 23°51.20'S,

33 165°39.27'W, in approximately 5710 meters water depth [1]. DSDP Site 596 is almost

34 completely pure pelagic red clay, and has remained within the South Pacific Gyre for its >85

35 million year history [2]. A sedimentation history for DSDP Site 596 using a constant cobalt-flux

36 model reveals a relatively low and constant sedimentation rate of approximately 0.2 to 0.27

37 m/myr throughout the study interval from 73 to 42 Ma. A prominent iridium anomaly at the site

38 at the K/Pg boundary [3], and several biostratigraphic tie points provide additional stratigraphic

39 context [4]. DSDP Site 596 was sampled every 5 cm down-core (~200kyr temporal resolution),

40 from 15 meters below seafloor (mbsf) to 22 mbsf. The 5 to 10-gram samples of red clay were

41 dried to a constant weight in a 50°C oven, disaggregated in de-ionized water, and washed over a

42 38µm sieve to concentrate and retain the ichthyoliths [5]. The majority of the sediment is red

43 clay, the coarse fraction >38µm is composed nearly exclusively of ichthyoliths, with occasional

44 manganese nodules and other sediment grains. The residues were inspected under a high-power

dissection microscope, and a fine paintbrush was used to transfer the ichthyoliths to cardboard
microfossil slides for storage and further analysis. Ichthyolith accumulation rate was calculated

47 using the cobalt-accumulation sediment age-depth model by Zhou and Kyte [2].

48

50 2. ICHTHYOLITH MORPHOLOGICAL CHARACTER CODING SYSTEM

51 Defining Tooth Morphological Disparity

Fish teeth have distinct morphological shapes that are likely a combination of taxonomic history and ecological role. While taxonomic identification of Cretaceous and Paleogene fish teeth is not possible at present, a character-based coded system which quantifies morphological traits can be used to quantify the morphological variation in these microfossils and create a non-hierarchical, "taxon-free" morphological classification [6-13]. Here we employ a new ichthyolith morphological coding system that is loosely modeled after the system developed by Doyle, Kennedy, and Riedel (1974).

59

Our system differs from prior ichthyolith classification schemes in several important ways. First, 60 61 it differentiates between teeth and denticles: while these ichthyolith subgroups have similar 62 mineral composition, they are produced by different clades of organisms (fish versus 63 elasmobranchs) and have entirely different functional purposes (teeth versus scales), so we 64 consider them completely independently. Second, while prior ichthyolith studies relied on 65 transmitted light microscopy, our system uses reflected light microscopy. This allows for 66 observation of 3D tooth structure, facilitates identification from different angles, reduces the 67 complexity of mounting and analysis of teeth in transmitted-light slides, and leaves the teeth free to be used in future analyses, such as advanced imaging (eg. microCT or Scanning Electron 68 69 Microscopy) and geochemical analyses. Third, our coding system considers the same set of 70 characters as potential descriptors for all teeth, removing the need for nested, hybrid character 71 states, or complicated nomenclature syntax, as was used in prior ichthyolith morphological 72 coding schemes. Our system retains the flexibility built into prior ichthyolith classification

73 schemes: it is straightforward to include additional characters or character-states to the system as 74 novel tooth morphotypes are found and classified [6, 10]. While our system is still a work in 75 progress, and currently only includes traits for the teeth included in this study (South Pacific 76 Gyre, Cretaceous to Eocene), it represents a considerable step forward in the field of ichthyolith 77 paleontology. Details of the characters, character states, and identified morphotypes are included 78 in Appendix I, and summarized in Figure 1. To facilitate ichthyolith description, ichthyolith 79 assemblages were imaged at high resolution (1µm/pixel), and measured using the Hull Lab 80 Imaging System and AutoMorph software at Yale University [14]. Images of individual teeth 81 were then classified within the morphotype description system, described in detail below, and 82 summarized in Figure S1.

83

84 We used this system to code each whole or otherwise identifiable tooth from the sample set, 85 from 74 discrete sediment samples, for a total of 1897 identified teeth, ranging in age from 42 to 86 73 Ma. For this study, we defined any tooth that has a unique set of character-states as a distinct 87 morphotype: 136 unique tooth morphotypes were identified in the set, and given descriptive in-88 house names to facilitate processing. As this character-coding system is, by definition, nonhierarchical, we felt this "splitting", rather than "clumping" of morphotypes was the most 89 90 reasonable way to consider tooth types without introducing a potentially false hierarchy into the 91 system.

92

93 Description of the Ichthyolith Coding System

94 We define 23 traits for tooth morphology, within 6 trait groups: general shape/structure, blades

95 (if any), flange (if any), tip shape, base shape, and pulp cavity. While general shape is important

96 for differentiating broad groups of teeth, the majority of variation is within the shape of the pulp 97 cavity, the size and structure of the blades, and composition of the tip, all traits that are 98 distinguishable with reflected light microscopy and high resolution imaging. Using this system, 99 we identified 136 ichthyolith morphotypes in our dataset, where each individual ichthyolith 100 morphotype is defined as a unique combination of character-states within the system. Similar to 101 prior ichthyolith coding schemes, we define a set of characters, each with a series of character-102 states. While this system is currently designed for handling ichthyoliths from the South Pacific 103 Cretaceous to Eocene, it is straightforward to add novel character states or even whole characters 104 into the analysis. Our ichthyolith coding scheme, with illustrations, follows. Throughout, tooth 105 character-groups are denoted in **bold**, individual characters are denoted as underline, and any 106 specific notes clarifying identification or differentiation of a particular character state are noted 107 in *italics*. Pictoral representations of these traits are shown in Figure S1.

108

109 Section 1: General Ichthyolith Classification and identifiers:

Note that while these two traits (A and B) are part of the classification scheme, they are simply
quality control and data management flags, and are not used directly in the disparity calculations.
<u>Trait A</u>: Ichthyolith type. *While our system currently only has coded traits for teeth, denticles are present and common in our ichthyolith assemblages, and are quantified here.*

- 114 1 = Tooth
- 115 2 = Denticle
- 116 3 =Other

117 <u>Trait B</u>: Degree of Fragmentation. *Level of fragmentation determines whether the outline-based*

118 morphometrics (length/width/aspect ratio; traits LEN, WID, AR) are included in the

| 119 | morphospace analysis, while outline data is not. However, in future studies, tooth outlines may |
|-----|--|
| 120 | be used, and as such, the teeth are classified to include a differentiation here. |
| 121 | 1 = No fragmentation; entire ichthyolith is preserved. <i>Outline and LEN/WID/AR</i> |
| 122 | appropriate for analysis |
| 123 | 2 = Small amounts of fragmentation, whole ichthyolith is identifiable. <i>LEN/WID/AR</i> |
| 124 | appropriate for analysis |
| 125 | 3 = Fragmentation is considerable, but most traits are discernable; ichthyolith is |
| 126 | identifiable to morphotype. Only qualitative descriptors, no measurement data used in |
| 127 | final analysis |
| 128 | 4 = Fragmentation is too great to identify morphological characters, but the ichthyolith is |
| 129 | identifiable to tooth or denticle |
| 130 | |
| 131 | Section 2: Tooth Morphological Characters |
| 132 | Notes: Throughout, the "base" and "bottom" of the tooth refers to the part of the tooth which |
| 133 | connects to the jawbone, and the "tip" and "top" refers to the part of the tooth opposite the |
| 134 | base, most often a pointed end. |
| 135 | |
| 136 | 2.1. General ichthyolith shape |
| 137 | Trait C: Overall shape of ichthyolith: There are many additional potential generic ichthyolith |
| 138 | shapes, however none of these were present in this sample set. As such, we include the note that |
| 139 | for very different shapes, character-states can be added to this system. |
| 140 | 1 = Cone (tooth starts wide, goes to a small tip, eg. triangular in shape; has round base in |
| | |

141 cross-section)

- 2 = Triangle (tooth starts wide, goes to small tip, eg. triangular in shape; has flattened
- 143 base cross-section)
- 3 = Asymmetrical triangle with flared base (approximately triangular in shape, has base
- 145 which flares out from tooth and is not symmetrical)
- 4 =Flat, cusped
- 147 <u>Trait E:</u> Degree of curvature
- 1 = Straight; Tip centered above base
- 2 = Small curve: tip does not pass edge of tooth base
- 3 = Large curve: tip extends past base edge
- 151 <u>Trait F:</u> Shape of triangle
- 1 =Straight (tip centered above base)
- 2 =Concave edges (tip centered above base)
- 3 =Convex edges (tip centered above base)
- 155 4 = Curved (concavo-convex; tip not centered)
- 5 = plano-convex (right angle from base to tip, convex hypotenuse; tip not centered)
- 157 6 = Right Triangle (right angle from base to tip; hypotenuse straight)
- 158 <u>Trait G:</u> Shape of edges
- 1 =No obvious edge (eg. tooth is cone-shaped [Trait C1])
- 2 = Defined edge, no extended edge/blade
- 3 = Has a blade or extended edge
- 163 Edge Details: Blades (H1-H5) and Flanges (K1-K2)

| 164 | Notes: "blades" are defined as edge-details which extend from the side of a tooth, lengthwise, |
|-----|---|
| 165 | and do not have abrupt beginnings or endings. They can reach the top or bottom of the tooth, but |
| 166 | it is not necessary. "Flanges" are edge details which extend from the side of a tooth, and begin |
| 167 | at the tip, and which have an abrupt ending partway down the tooth. If the tooth has no blade or |
| 168 | no flange, this is encoded with values of 1 in Trait H1 and Trait K1 respectively. All other traits |
| 169 | are coded as 0, and not considered in the morphological analysis for those teeth. |
| 170 | Trait H1: Number of blades: note that the numeric coding does not correspond directly with the |
| 171 | absolute number of blades for this trait. |
| 172 | 1 = no blades |
| 173 | 2 = both sides have blades (2 blades) |
| 174 | 3 = One side has a blade only |
| 175 | Trait H2: Blade symmetry: |
| 176 | 0 = no blades |
| 177 | 1 = Blades are symmetrical |
| 178 | 2 = Blades are asymmetrical (but two are present) |
| 179 | 3 = One blade only |
| 180 | Trait H3: Blade width along edge: while some blades are approximately the same size along the |
| 181 | tooth, others flare at the top or bottom. |
| 182 | 0 = no blades |
| 183 | 1 = equal sized along length |
| 184 | 2 = wider at the top |
| 185 | 3 = wider at the bottom |
| 186 | 4 = widest in the middle |

| 187 | 5 = different each blade; Note that asymmetrical blades may fall into any H3 character |
|-----|---|
| 188 | state, as it simply describes the overall shape of the blades. |
| 189 | Trait H4: Blade size: describes the relative size of blades present, compared to the tooth proper |
| 190 | 0 = no blades |
| 191 | 1 = small blades, both sides (blades combined <1/4 of width of tooth) |
| 192 | 2 = large blades, both sides (blades combined > 1/4 of width of tooth) |
| 193 | 3 = One small, one large |
| 194 | 4 = Concave large, convex/straight small (for non-straight teeth) |
| 195 | 5 = convex large, concave/straight small (for non-straight teeth) |
| 196 | Trait H5: Blade length: note: additional character states are possible for novel tooth |
| 197 | morphotypes |
| 198 | 0 = no blades |
| 199 | 1 = Blade runs length of tooth, from tip to base |
| 200 | 2 = Top 1/3 of tooth only |
| 201 | 3 = Top 2/3 of tooth only |
| 202 | 4 = Bottom 1/3 of tooth only |
| 203 | 5 = bottom 2/3 of tooth only |
| 204 | 6 = concave whole length; convex upper part only |
| 205 | 7 = large blade runs whole length; small blade runs upper part only |
| 206 | Trait K1: Flange presence/absence |
| 207 | 1 = flange absent |
| 208 | 2 = flange present |
| | |

209 <u>Trait K2:</u> Flange length: *relative to the total tooth size*

| 210 | 0 = no flange |
|--|--|
| 211 | 1 = small (<1/4 of tooth length) |
| 212 | 2 = medium (1/4-1/2 of tooth length) |
| 213 | 3 = long (>1/2 of tooth length) |
| 214 | 4 = very long (>80% length) |
| 215 | Trait K3: Flange location: |
| 216 | 0 = no flange |
| 217 | 1 = concave only |
| 218 | 2 = convex or straight side |
| 219 | 3 = one side (for an otherwise symmetrical tooth) |
| 220 | |
| 221 | Tip (L, M) and base (N1, N2) characters |
| | |
| 222 | <u>Trait L:</u> Tip shape |
| 222 223 | <u>Trait L:</u> Tip shape 0 = tip not preserved |
| | |
| 223 | 0 = tip not preserved |
| 223 224 | 0 = tip not preserved 1 = Pointed tip |
| 223 224 225 | 0 = tip not preserved 1 = Pointed tip 2 = smoothed point |
| 223224225226 | 0 = tip not preserved 1 = Pointed tip 2 = smoothed point 3 = rounded |
| 223 224 225 226 227 | 0 = tip not preserved 1 = Pointed tip 2 = smoothed point 3 = rounded <u>Trait M:</u> Tip material: <i>note that many actinopterygian teeth have a small layer of acrodin, a</i> |
| 223 224 225 226 227 228 | 0 = tip not preserved 1 = Pointed tip 2 = smoothed point 3 = rounded Trait M: Tip material: note that many actinopterygian teeth have a small layer of acrodin, a modified bone material, as a slight cap on their teeth. Here we assess whether teeth have tips |
| 223 224 225 226 227 228 229 | 0 = tip not preserved 1 = Pointed tip 2 = smoothed point 3 = rounded Trait M: Tip material: note that many actinopterygian teeth have a small layer of acrodin, a modified bone material, as a slight cap on their teeth. Here we assess whether teeth have tips made of different material than the rest of the tooth. |
| 223 224 225 226 227 228 229 230 | 0 = tip not preserved 1 = Pointed tip 2 = smoothed point 3 = rounded Trait M: Tip material: note that many actinopterygian teeth have a small layer of acrodin, a modified bone material, as a slight cap on their teeth. Here we assess whether teeth have tips made of different material than the rest of the tooth. 0 = tip not preserved |

| 233 | 3 = Whole tip, with flat bottom |
|------------|--|
| 234 | 4 = Tip and blades |
| 235 | 5 = More than tip/blades |
| 236 | Trait N1: Base shape |
| 237 | 0 = base not preserved |
| 238 | 1 = flat base |
| 239 | 2 = concave base (often has 'base tips', trait N2) |
| 240 | 3 = convex base |
| 241 | 4 = asymmetrical base with base tip(s) |
| 242 | 5 = flared base (often correlates with Trait C-3) |
| 243 | Trait N2: Base tip shape: if only one tip, assess the single one |
| 244 | 0 = no base preserved |
| 245 | 1 = no tips |
| 246 | 2 = curved tip(s) |
| 247 | 3 = pointed tip(s) (straight) |
| 248 | 4 = flat/square tip(s) |
| 249 | 5 = asymmetrical tips (two, different) |
| | |
| 250 | |
| 250 251 | Pulp cavity size (O-Q) and morphology (R1-R4): nearly all teeth have some sort of pulp |

- 253 often best viewed using transmitted light microscopy, but is visible in high-magnitude reflected
- 254 light microscopoy as well. As pulp cavity morphology is highly variable, we have defined four
- 255 characters which, when considered together, describe an overall structure for the pulp cavity.

| 256 | While there are some characters that often link together, there are many which can be combined |
|-----|--|
| 257 | in different permutations to create unique pulp cavity shapes. If there is no pulp cavity, Trait O |
| 258 | the only one which counts in the morphospace analysis. The rest are considered a value of 0, |
| 259 | which discounts them from the analysis. |
| 260 | Trait O: Is there a pulp cavity? |
| 261 | 1 = no pulp cavity present |
| 262 | 2 = pulp cavity present |
| 263 | Trait P: Pulp cavity base size: this is measured relative to the base of the whole tooth |
| 264 | 0 = no pulp cavity |
| 265 | 1 = small (<1/3 of base width) |
| 266 | 2 = medium (1/3 – 2/3 of base width) |
| 267 | 3 = large (>2/3 of base width) |
| 268 | 4 = whole base (base of pulp cavity extends to both edges of the tooth) |
| 269 | Trait Q: Pulp cavity length: measured relative to the whole tooth |
| 270 | 0 = no pulp cavity |
| 271 | 1 = short (<1/3 of tooth length) |
| 272 | 2 = medium (1/3 – 2/3 of tooth length) |
| 273 | 3 = large (>2/3 of tooth length) |
| 274 | 4 = full length (pulp cavity stretches to the tip of the tooth) |
| 275 | Trait R1: Pulp cavity approximate shape, in relation to tooth shape: if tooth is curved, a curved |
| 276 | pulp cavity which mirrors the curve of the tooth is considered 'straight', etc. |
| 277 | 0 = no pulp cavity |
| 278 | 1 = straight |

278 1 = straight

| 279 | 2 = concave (curves in from the tooth edges) |
|-----|---|
| 280 | 3 = convex (curves out from the tooth edges) |
| 281 | 4 = funnel (convex at the bottom, concave at the top) |
| 282 | 5 = parallel (pulp cavity edges are parallel to each other, not to the tooth edges) |
| 283 | 6 = asymmetrical (pulp cavity combines any two other pulp cavity shape descriptors) |
| 284 | 7 = vase-shaped (concave at base, rounded at top) |
| 285 | Trait R2: Pulp cavity center width, in relation to the tooth edges: here "center" is defined as the |
| 286 | middle, length-wise, of the pulp cavity, not the tooth. |
| 287 | 0 = no pulp cavity |
| 288 | 1 = small, pulp cavity center width is $<1/3$ of tooth width |
| 289 | 2 = medium, pulp cavity center width is $1/3$ to $3/4$ of tooth width |
| 290 | 3 = large, pulp cavity center width is $>3/4$ of tooth width |
| 291 | Trait R3: Pulp cavity base shape |
| 292 | 0 = no pulp cavity |
| 293 | 1 = curve out towards edges of tooth |
| 294 | 2 = flat (no change from the rest of the pulp cavity shape) |
| 295 | 3 = curve in, away from edges of tooth |
| 296 | Trait R4: Pulp cavity tip shape |
| 297 | 0 = no pulp cavity |
| 298 | 1 = pointed goes to obvious angular point |
| 299 | 2 = rounded point <i>pointed</i> , <i>but no angular tip</i> |
| 300 | 3 = very rounded <i>nearly semi-circular in many cases</i> |
| 301 | 4 = pinched tip (rounded, wide) <i>can see area in the tip</i> |
| | |

5 = pinched tip (extended, thin) often appears to be single line at the top

303

6 = rounded with tip similar to state #3, but with an angular tip

304

The final traits included in our morphospace analysis are LEN, WID, and AR. These traits are measured as the "length", "width", and "aspect ratio" of the minimum bounding box that surrounds a tooth, when the tooth is placed flat so its widest surface is facing up. These traits are only included in the analysis if the image and tooth are of sufficient quality to obtain appropriate measurements.

310

311 Morphotype Designation

312 Morphotypes were defined as teeth with unique combinations of traits. As our ichthyolith 313 morphological scheme is currently in development, and there is no taxonomic identification for 314 these teeth, we believe that it would be premature to develop and apply a formal naming scheme 315 to the different tooth morphotypes. However, as strings of alpha-numeric codes are cumbersome 316 and do not easily convey information, we have developed a series of working names for the tooth 317 morphotypes identified in this study. These names are a combination of character-trait keywords 318 which capture the essence of the tooth, and facilitated repeated visual identification of 319 morphotypes. We fully expect that these names will change as the morphological scheme 320 continues to expand and develop to include other morphotypes. A morphotype was considered 321 "distinct" when it had a unique set of coded characters, regardless of how large or small the 322 differences were. A key to morphotype names used in the range chart figures (Figure 1, main 323 text, Figure S3 in this supplement) is given in Table S4. Appendix I (at the end of this document) 324 includes pictures of a representative of each tooth morphotype determined in this study. While

the assignment of teeth to morphotypes is somewhat subjective, the details included in the coding scheme make it possible to replicate and articulate the characters necessary for a fossil to be grouped with a particular morphotype. For consistency, all of the coding and morphotype designation in this study was done by E. Sibert, however morphotypes were discussed among coauthors. While there is some inter-person variability in the assignment of morphotypes, as there is amongst most taxonomists working to classify organisms, consistent use of the characters and codes allowed for consistent description and tooth morphotype designation.

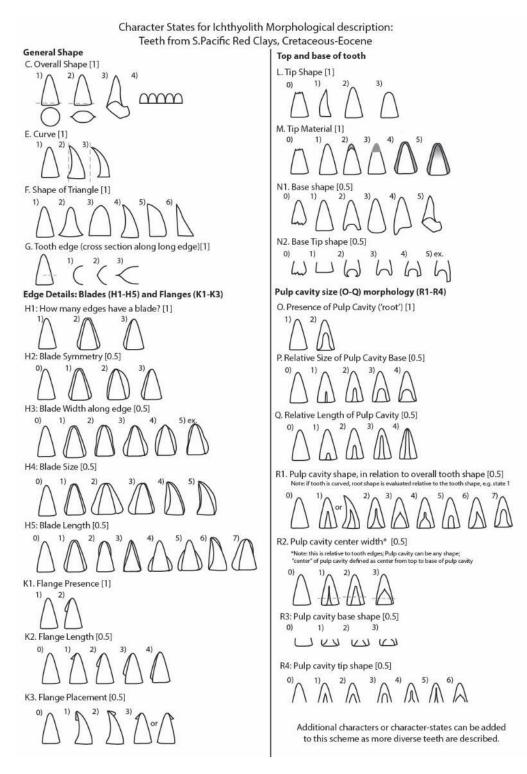


Figure S1. A schematic representation of the different character-states described in our tooth morphology system. We use a generic triangular tooth for simplicity in this figure, however note that because our traits are described relative to overall tooth shape, this schematic can be

- expanded and applied to a variety of tooth shapes beyond the scope of this study.
- 337

339 *Calculating morphological disparity*

340 To assess changes in tooth morphology through time, we evaluated morphological disparity of 341 the tooth morphotypes present in our samples. We calculated distances between tooth types by 342 assigning distances and weights to all characters considered (see Figure S1) and evaluating a 343 weighted distance between each pair of teeth based on the character-states they displayed. Traits 344 within a character were considered to be equally distant unless there was an obvious hierarchy, in 345 which case we created distance matrices for the character states. The characters were weighted 346 either equally, or paired to combine several traits to have the same weight (e.g. the 4 pulp cavity 347 morphology traits were reduced to ¹/₂ weight each, so that they did not overpower other 348 characters which were more succinctly described).

349

Our tooth coding scheme, like many other schemes developed to describe complex biological systems, has several sets of characters which, when not present, may confound disparity analyses – for example, a tooth with no blades (H1) cannot have their blades described (characters H2-H5). These inapplicable characters (H2-H5, K2-K3, R2-R4) are designated in our coding scheme with a value of 0, and where they are not present, this designates the maximum distance (usually 1.0) from teeth with the character present for that particular character in the calculations. These inapplicable characters have no impact on morphotype designations.

357

358 For unbroken teeth which had good length, width, and aspect ratio measurements from

359 *AutoMorph*, we combined these discrete character states with the continuous measurements by

360 discretizing the continuous measurements into normalized bins and treating each bin as a discrete

361 state. Distances for all traits available to compare for each pair of teeth were then averaged, to

| 362 | get an average distance value for each pair of teeth. Since the traits are discrete, rather than |
|-----|---|
| 363 | continuous, the resulting distance matrix was reduced using nonmetric multidimensional scaling |
| 364 | (NMDS) to create an ichthyolith morphospace for visualization. We present a 3-dimension |
| 365 | NMDS, which has a stress of 0.110, because the visual representation of the teeth did not change |
| 366 | considerably by adding more dimensions, and the stress was a reasonable value that was not |
| 367 | much improved by adding additional dimensions to the ordination. This was done simply to |
| 368 | visualize the major axes of variation. We used NMDS rather than PCA, as it does not use |
| 369 | eigenvectors, so that any triangle inequalities caused by missing or inapplicable characters do not |
| 370 | have the potential warp the eigenvector space and thus confound the interpretation. All data were |
| 371 | analyzed in R using in-house functions and the R package 'vegan' [15]. All data, distance |
| 372 | matrices, and code are available at www.github.com/esibert/toothmorph. |
| 373 | |
| | |

375 3. SAMPLING, BINNING, AND REWORKING

376 Binning and potential sample bias

377 Each ichthyolith morphotype has a distinct stratigraphic range within our sample interval, 378 however, not all morphotypes which span the range are present in each sample (Figure 1). The 379 average length of time that a tooth morphotype existed throughout the interval sampled was 12.6 380 million years (all teeth). If teeth which are likely reworked are excluded, this reduces to 12.0 381 million years (low levels of reworking, see discussion below) or 11.1 million years (high levels 382 of reworking). As there are a considerable number of morphotypes in our record which extend in 383 range beyond the observed interval (out of 136 described morphotypes, ~24 likely extend deeper 384 in the Cretaceous, ~34 into the Eocene, with at least 5 morphotypes spanning the entire interval), 385 it is likely that this is an underestimate of average morphotype duration. This interval is 386 considerably longer than the estimated species duration for freshwater fish, approximately 3 387 million years [16], or the duration of marine invertebrate species, which range from 5 to 12 388 million years [17]. However, it is not surprising that tooth morphotypes, which may represent 389 relatively high level taxonomic groups of fish (e.g. genera or families), or taxonomic-free 390 ecotypes, would have longer persistence through time than is seen in species-level taxonomies. 391 Further, the wide variation in morphotype duration may be due to different morphotypes 392 representing different taxonomic specificity: it is probable that certain families of fish have 393 identical teeth across all individuals, while others have considerable differences within the 394 genera, species, individual, or ontogenetic stage [18].

395

396 To address the issue of small sample size, particularly in the Cretaceous and early Paleocene 397 samples, which often had fewer than 20 teeth in a discrete sediment sample, we grouped the 398 samples into ~1 myr time bins, so that each time bin included sufficient teeth for analysis (34-399 241 teeth per time bin, average = 90.3 teeth). The time bins with the largest numbers of teeth 400 described in this study (sampling intensity) occur after peaks in novel morphotypes suggesting 401 that observed morphotype origination is not simply due to an increase in sampling intensity 402 (Figure S2). It is therefore likely that the peaks in morphotype origination rate reported in this 403 manuscript are underestimates of the true magnitude of origination in fish tooth morphology. 404

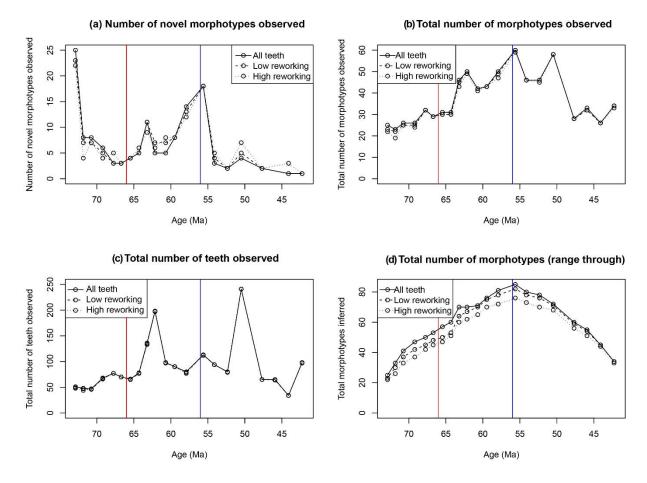




Figure S2: Plots comparing sampling intensity to morphotype observation. Plots showing the
absolute abundance of a) novel morphotypes observed in each sample; b) number of total
morphotypes observed in each sample; c) the total number of teeth counted in each sample; and
d) the total number of morphotypes inferred for each sample counting range-through taxa not
present in the sample. Note that the peaks in tooth observed fall after the peaks in novel

411 morphotypes. Red line is the K/Pg mass extinction; Blue line is the Paleocene/Eocene boundary.

413 Reworking

414 In some cases, a single occurrence of a tooth morphotype was found well outside its more 415 common stratigraphic range, suggesting that there was some amount of reworking or 416 bioturbation within the sediment core. To assess the impact of reworked teeth artificially 417 extending the range of any given morphotype, we selectively removed individual occurrences of 418 particular teeth from the analysis following a specific set of rules, described in full below, to 419 generate three datasets: (1) original, with no teeth removed, (2) low reworking, and (3), high 420 reworking. Using our conservative set of rules ("low reworking"), we removed 9 occurrences 421 (0.5% of total teeth described, Table S1) from the analysis due to suspected reworking (1887 422 teeth total, ranging from 34-241 teeth per time bin, average = 89.9). Following a more liberal set 423 of rules ("high reworking"), we removed an additional 14 occurrences (1% of total teeth 424 described, Table S2) from the analysis (1873 total teeth, 34-241 teeth per time bin, average = 425 89.2). We conducted all successive analyses on all three of these datasets, and note that while the 426 high reworking dataset consistently yields slightly higher estimates for speciation and extinction 427 rates, as it has the shortest ranges, overall, the patterns reported here are robust regardless of 428 dataset analyzed, suggesting that the effect of reworking on the overall tooth record is minimal. 429 When only one dataset is represented in the figures, we use the "low reworking" dataset 430 throughout the main text. A comparison of the range charts for all three datasets is shown in 431 Figure S3.

432

433 <u>Rules used for removing potentially reworked teeth from analysis.</u>

434 A. Low reworking

- 435 Remove a data point if:
- 436 1. Suspected reworking of previously abundant taxa that has likely gone extinct: if
- 437 abundance decreases from >3 per time bin to 1 per time bin and lasts <1 million years
- 438 across a known geologic boundary (either the K/Pg or the P/E)
- 439 2. Suspected reworking: if there is an interval of >5 myr between a singleton occurrence of
- 440 a morphotype, before or after an interval where the morphotype is not rare (eg. present in
- 441 at least 2 time bins in a row)
- 442 3. Suspected reworking: if there is an interval of >8 myr, only single occurrence, assume
- 443 reworking of the morphotype away from most common time intervals which it is present
- 444 (not necessary to be present in two consecutive time bins, as in rule 2)
- 445 Table S1: Teeth removed from analysis under the low reworking dataset rules (10 total)

| Tooth Morphotype Name | Tooth Object ID | Action | Rule |
|--|--|------------------------|------|
| Straight, half-length flange | P136.084.1.obj00024 P137.085.1.obj00022 | remove upper 2 samples | 1 |
| Clear, convex tooth, dome root, small blades | P127.075.1.obj00076 | remove upper 1 sample | 1 |
| Clear, full straight root | P175.123.1.obj00031 | remove lower 1 sample | 2/3 |
| Clear, flared blades, 3/4 root | P173.121.1.obj00002 | remove lower 1 sample | 2/3 |
| Acrodin Tip, 1/2 length funnel root | P169.117.1.obj00011 | remove lower 1 sample | 3 |
| Acrodin Tip, 1/2 length convex root | P163.111.1.obj00004 | remove lower 1 sample | 2/3 |
| Acrodin Tip, no obvious root | P158.106.1.obj00012 | remove lower 1 sample | 2/3 |
| cone short dome root | P065.013.1.obj00019 | remove upper 1 sample | 2 |
| Clear, 3/4 Dome root | P109.057.1.obj00033 | remove lower 1 sample | 2 |

447 B. High reworking

- 448 Remove teeth from the dataset if they meet the criteria for low reworking cuts OR any of the
- 449 following:
- 450 4. If common during range (>2 per time bin, no long intervals), singleton present >3 myr
- 451 before common range (mixed down)

452 5. If common during range (>2 per time bin, no long intervals), any individuals >5 myr

453 above common range (mixed up)

454 6. If the morphotype is rare (eg. present as a singleton occurrence throughout range, with

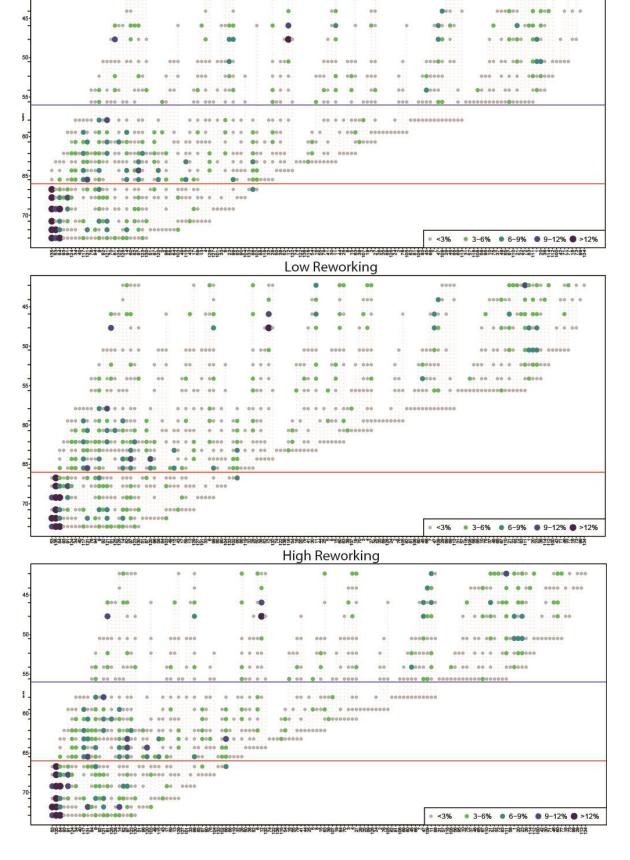
455 intervals of non-presence <5myr), any gaps >12 million years, remove singleton at end of

456 gap.

457

458 Table S2: Teeth removed from analysis under the high reworking dataset rules (14 total)

| Tooth Morphotype Name | Tooth Object ID | Action | Rule |
|---|---|------------------------|------|
| Clear, pointed tip, 1/2 dome root | P175.123.1.obj00008 | remove lower 1 sample | 4 |
| Clear, flared blades, 3/4 root | P116.064.1.obj00037; P124.072.1.obj00090 | remove next lowest 2 | 4 |
| Cloudy, extended triangle | P168.116.1.obj00022 | remove lower 1 sample | 4 |
| Cloudy, Triangle, full root | P085.033.1.obj00031; P098.046.1.obj00102 | remove upper 2 samples | 5 |
| Clear, flared blades (small), cocnave root*** | P168.116.1.obj00019 | remove 1 lower sample | 6 |
| Clear, Flat, Curved, 3/4 dome root | P170.118.1.obj00006 | remove 1 lower sample | 6 |
| Acrodin Tip, 1/2 length straight root | P156.104.1.obj00012 | remove 1 lower sample | 4 |
| Bladed cone (acrodin tip)** | P129.077.1.obj00023 | remove lower 1 sample | 6 |
| Acrodin Tip, 3/4 length convex root | P131.079.1.obj00076 | remove 1 lower sample | 4 |
| Bladed cone | P105.053.1.obj00019 | Remove 1 lower sample | 6 |
| Clear, Flat, thin root | P053.001.1.obj00070 | remove 1 upper sample | 5 |
| Curved, large concave root | P105.053.1.obj00057 | remove 1 lower sample | 6 |



Original Dataset

.

. ...

....

.....

.

.

.....

461 Figure S3: Stratigraphic range charts of all ichthyolith morphotypes for each of the three levels 462 of reworking considered. Size and color of dot is the absolute number of each morphotype observed in a time bin, from small and gray representing a single occurrence, to large and purple 463 464 representing up to 18 teeth of a particular morphotype). Red horizontal line is the K/Pg extinction; Blue line is the Paleocene-Eocene boundary. The x-axis morphotype, ordered by first 465 466 occurrence then last occurrence age. Note that the abundance values reported in the figure are 467 absolute abundance, not relative abundance, so the absolute number of ichthyoliths in a time bin 468 can vary considerably – the time bins with the most teeth (62.1 and 50.5 Ma) contain nearly 2xthe number of teeth for each other time bin considered. 469

470

471 **4. EVOLUTIONARY RATES: CAPTURE-MARK-RECAPTURE ANALYSIS**

472 To assess the turnover of tooth morphotypes, we estimated origination and extinction rates.

473 While we recognize that these fish teeth are not identifiable as individual taxa, and indeed, likely

474 represent a combination of ecological groups, taxonomic clades, and ontogenetic stages.

475 However their distinct stratigraphic ranges can be used for crude biostratigraphy [7, 12, 19],

476 suggesting that they represent a clade undergoing evolutionary change through time. Therefore

477 our calculations cannot be compared in absolute terms to taxonomic-unit based evolutionary

478 rates (e.g. genus-specific origination rates). However, as these teeth do represent lineages or

479 ecotypes which originate and go extinct, these rate estimations can highlight times of significant

480 change in open ocean fishes and their roles in the open ocean ecosystem. Our approach is similar

481 to other 'taxon-free' morphological approaches that have been used to describe evolution in

482 many now-extinct groups, including trilobites and blastoids [20]. Here we use two different

483 metrics to calculate per-capita origination and extinction rates for fish tooth morphotypes:

484 Boundary Crossers (BC) [21] and maximum likelihood-based capture-mark-recapture (CMR)

485 [22, 23].

486

487 CMR models use a time-series-based set of presence/absence observations for individuals in a
488 population and a maximum-likelihood approach to estimate detection probability (p) and

489 probability of survival (φ) of individuals in a population from one observation point in a time 490 series to the next. In macroevolutionary terms, this means that one can estimate the probability 491 that one individual (or morphotype, in the case of our data) present in time bin (t), has survived 492 to the next time bin (t+1). The complement of this is the probability that this individual 493 (morphotype) has gone extinct, yielding an estimation of extinction probability. Run in reverse, 494 this can be used to estimate "recruitment", or the probability that an individual that was present 495 in time point (t) was not around in the prior time point (t-1) – in macroevolutionary terms, this 496 provides an estimate of origination [23]. For our analyses, we used the Pradel-recruitment model 497 in MARK, a parameterization of Pradel's 1996 model [24] suitable for use with fossil datasets, 498 which provide estimates of recruitment (f), in addition to the survival and detection probability 499 parameters. These CMR models best fit the assumptions of the fossil record, and incorporate 500 incomplete sampling into the estimates [22]. The estimated parameters can be transformed to 501 extinction rate (1-survival) and origination rate (recruitment). Models were fit allowing for the 502 parameters to vary within each time bin, to be fixed over the whole interval, or to vary with 503 sampling intensity, which was higher in the Cretaceous and Paleocene than in the Eocene, to 504 make up for the lower abundances of teeth in individual samples in the Cretaceous and 505 Paleocene. As the time bins were not evenly spaced (though we aimed for approximately 1 myr 506 resolution), we incorporated these unequal time bins into the design matrices of the CMR 507 models, such that the probabilities estimated for each time interval were normalized to 508 "probability per 1 million years". The models were evaluated using AICc, and the figures are 509 made with a weighted average of each model parameter, using the AICc weight (function 510 model.average() in the RMark package [25]) – however, it is worthwhile noting that the two

- 511 best-fit models are nearly identical in their parameter estimation, and this model-averaging had
- 512 no significant impact on the outcome (Table S3).

| Model | # of Parameters | AICc | A AICc from best fit model | weight | Deviance |
|-----------------------------|--------------------|---------|-------------------------------|----------|----------|
| φ(~1)p(~1)f(~time) | 22 | 2697.77 | 0.00 | 0.63 | 1354.32 |
| φ (~1)p(~sample)f(~time) | 23 | 2699.18 | 1.41 | 0.31 | 1353.60 |
| φ (~time)p(~1)f(~time) | 41 | 2703.29 | 5.52 | 0.04 | 1318.48 |
| φ (~time)p(~sample)f(~time) | 42 | 2705.21 | 7.44 | 0.02 | 1318.17 |
| φ (~time)p(~time)f(~time) | 61 | 2710.58 | 12.82 | 1.04E-03 | 1279.87 |
| φ (~time)p(~1)f(~1) | 22 | 2725.78 | 28.01 | 5.23E-07 | 1382.33 |
| φ (~time)p(~sample)f(~1) | 23 | 2727.89 | 30.12 | 1.82E-07 | 1382.32 |
| φ (~time)p(~time)f(~1) | 42 | 2730.94 | 33.17 | 3.96E-08 | 1343.90 |
| φ (~1)p(~time)f(~time) | 42 | 2740.83 | 43.06 | 2.82E-10 | 1353.79 |
| φ (~1)p(~1)f(~1) | 3 | 2745.29 | 47.53 | 3.02E-11 | 1441.16 |
| φ (~1)p(~sample)f(~1) | 4 | 2747.06 | 49.30 | 1.25E-11 | 1440.91 |
| φ (~1)p(~time)f(~1) | 23 | 2785.90 | 88.14 | 0.00E+00 | 1440.33 |

514 *Table S3: model variations and output summary from MARK analysis for Pradel-Recruitment*

515 analysis on the "low reworking reworking" dataset. (~1) corresponds to "hold parameter value

516 constant through time". (~time) corresponds to allowing a different parameter value for each

517 time interval. (~sample) allowed the parameter to differ between the Cretaceous/Paleocene, and

518 *Eocene, where different sampling intensities were used. Weighted averages were calculated for*

519 *each parameter. Note that p(~sample) and p(~1) carried 94% of the weight, and the probability*

520 of detection (p) values were very similar for p(~sample) [0.58 pre-Eocene and 0.56 Eocene] and

521 $p(\sim 1)$ [0.57 throughout the interval]. Other model-estimated parameters for every model

522 considered here are available in the MARK output files included with the extended code and

- 523 *data package*.
- 524

525 CMR has a distinct advantage over other traditional rate metrics: it inherently assumes that the

526 observed first and last occurrences of a taxon may not be the precise origination or extinction

527 dates. The likelihood model that is fit assumes that the observation of an individual is a function

528 of the probability that the individual was alive (survival) and the probability that it was detected

529 (p). Thus, the parameters estimated by CMR include detection probability for all observed

530 stratigraphic ranges, negating the need for additional confidence interval calculations (e.g.

531 Marshall [26]), and allowing for the inclusion of single occurrences in the dataset. In contrast, we

532 discarded the oldest 2 origination rate estimates and the youngest 2 extinction rate estimates

within the time-series because they algebraically yield highly inflated estimates, effectively edge
effects [21], and all morphotypes which occurred only once were not considered in the BC
calculations. The CMR analysis was carried out using the MARK software [27, 28] through the

536 RMark package [25]. All evolutionary rate calculations were carried out in R [29].

537

538 It is unlikely that sampling biases are driving the evolutionary rate signals, as BC and CMR yield 539 similar patterns in evolutionary rate estimates, despite being significantly different in their 540 approach: BC calculates origination and extinction for each interval independently and is unable 541 to estimate confidence intervals, while CMR assumes a null model of constant origination and 542 extinction rates throughout all intervals, and uses Akaike Information Criterion (AIC) to evaluate 543 time-variant models, penalizing for higher numbers of parameters, and estimating confidence 544 intervals for each parameter estimated. Further, where the BC method is designed to minimize 545 the impact of incomplete sampling, CMR explicitly accounts for error due to sampling biases. 546 The broad congruence between these two incredibly different methodological approaches 547 provides evidence that our results are likely real, and not just due to random sampling errors. The 548 absolute value of origination and extinction rate differs somewhat between CMR and BC. During 549 certain intervals, CMR yields values for origination approximately twice the BC estimates. The 550 BC method ignores single occurrences of taxa, and as such may underestimate the true extinction 551 and origination rates for our dataset, as there are considerable morphotypes which occur only 552 once, particularly during the early Paleocene (Figure 1), when abundance is low but novelty is 553 high. Further, the three datasets with varying levels of reworking yield strikingly similar patterns 554 using both BC and CMR, suggesting that reworking of teeth through bioturbation is not a

- significant factor in the estimates of tooth morphotype origination and extinction rates in our
- 556 dataset.
- 557

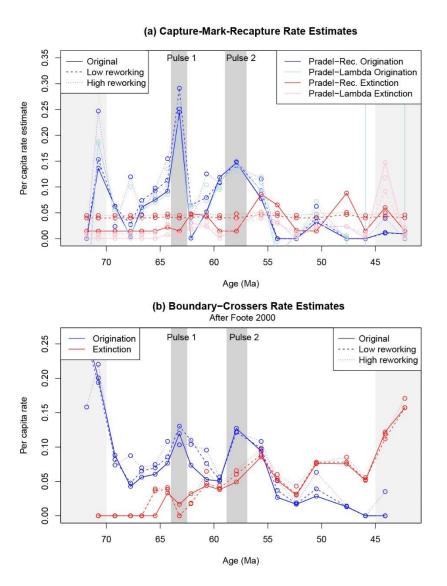
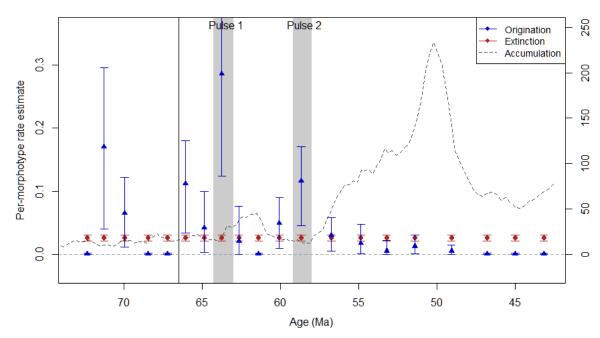


Figure S4. Origination and extinction rate estimates using (a) the Pradel-Recruitment and Pradel-Lambda formulations of the Pradel capture-mark-recapture models in MARK [24, 27] (top) and comparing to the Boundary Crosser calculations (bottom; Foote 2000). Dark gray shaded regions represent the two non-zero pulses of origination observed. Light-gray shaded areas represent regions of possible edge effects in our sampling. Red is extinction, while blue is origination. The

different shades represent different configurations of the CMR models, while the different linedashes represent the three levels of reworking assumed in the data.

566

567 While our results are robust to variations in tooth morphotype designations. While we erred on 568 the side of caution and were morphological "splitters" throughout this process, some tooth types 569 are invariably much more similar than others, which could have an impact on the outcome of the 570 study. To test whether our split morphotypes were biasing our results, we used k-means cluster 571 analysis (a non-hierarchical clustering method) to group the 136 morphotypes into half that 572 number (68 morphotypes), allowing the most similar morphotypes to be grouped into a single 573 category. We then repeated the CMR on the revised morphotype capture histories. Overall, the 574 results were nearly identical to the original dataset analyses (Figure S5), with the two pulses 575 occurring at the same time intervals. The main difference is that the extinction estimate 576 decreased from ~4% to ~2.9%, which is to be expected when there are fewer morphotypes which 577 persist longer and are more commonly found throughout their ranges. Further, the error bars on 578 the origination estimations on this clumped morphotype analysis were slightly smaller than the 579 original analyses. This suggests that our conclusions are robust to morphotype similarity metrics, 580 and that, if anything, we erred on the side of "splitting" too much, though this did not have a 581 significant impact on our conclusions, and if anything, our conclusions are more conservative 582 than they would have been with less distinct morphotypes.



CMR Evolutionary Rate Estimates, clustered morphotypes

Figure S5. Capture-Mark-Recapture evolutionary rate analyses using revised capture-histories of
68 clustered morphotype groups. Note that this is highly similar to the results generated by the
full 136-morphotype dataset considered in our manuscript, and suggests that our results are
generally robust to morphotype "splitting".

- Table S4. An alphabetical list of tooth morphotype names used in this study, and the corresponding axis labels used on the range chart figures (Figure 1 of the main text and Figure
- S3).

| Range Chart IDMorphotype Name1Acrodin Tip, 1/2 length Concave Root2Acrodin Tip, 1/2 length Concave root, flared blades3Acrodin Tip, 1/2 length Concave Root, no tips4Acrodin Tip, 1/2 length Concave Root, no tips5Acrodin Tip, 1/2 length convex root6Acrodin Tip, 1/2 length straight root7Acrodin Tip, 1/2 length straight root, flare blades8Acrodin Tip, 1/2 length straight root9Acrodin Tip, 1/4 length concave root10Acrodin Tip, 3/4 length concave root11Acrodin Tip, 3/4 length straight root12Acrodin Tip, 3/4 length straight root13Acrodin Tip, Cone-like, Big blades14Acrodin Tip, Cone, small dome root | |
|---|--|
| 1Acrodin Tip, 1/2 length Concave Root2Acrodin Tip, 1/2 length Concave root, flared blades3Acrodin Tip, 1/2 length Concave Root, no tips4Acrodin Tip, 1/2 length convex root5Acrodin Tip, 1/2 length funnel root6Acrodin Tip, 1/2 length straight root, flare blades7Acrodin Tip, 1/2 length straight root, flare blades8Acrodin Tip, 1/2 length dome root9Acrodin Tip, 1/4 length dome root10Acrodin Tip, 3/4 length concave root11Acrodin Tip, 3/4 length straight root12Acrodin Tip, 3/4 length straight root13Acrodin Tip, Cone-like, Big blades | |
| Acrodin Tip, 1/2 length Concave root, flared blades Acrodin Tip, 1/2 length Concave Root, no tips Acrodin Tip, 1/2 length Concave Root, no tips Acrodin Tip, 1/2 length convex root Acrodin Tip, 1/2 length funnel root Acrodin Tip, 1/2 length straight root Acrodin Tip, 1/2 length straight root, flare blades Acrodin Tip, 1/2 length straight root, flare blades Acrodin Tip, 1/4 length concave root Acrodin Tip, 3/4 length concave root Acrodin Tip, 3/4 length straight root | |
| Acrodin Tip, 1/2 length Concave Root, no tips Acrodin Tip, 1/2 length Concave Root, no tips Acrodin Tip, 1/2 length convex root Acrodin Tip, 1/2 length funnel root Acrodin Tip, 1/2 length straight root, flare blades Acrodin Tip, 1/2 length straight root, flare blades Acrodin Tip, 1/4 length concave root Acrodin Tip, 3/4 length concave root Acrodin Tip, 3/4 length straight root | |
| Acrodin Tip, 1/2 length convex root Acrodin Tip, 1/2 length funnel root Acrodin Tip, 1/2 length funnel root Acrodin Tip, 1/2 length straight root, flare blades Acrodin Tip, 1/2 length straight root, flare blades Acrodin Tip, 1/4 length concave root Acrodin Tip, 3/4 length concave root Acrodin Tip, 3/4 length convex root Acrodin Tip, 3/4 length straight root Acrodin Tip, Cone-like, Big blades | |
| 5 Acrodin Tip, 1/2 length funnel root 6 Acrodin Tip, 1/2 length straight root 7 Acrodin Tip, 1/2 length straight root, flare blades 8 Acrodin Tip, 1/4 length concave root 9 Acrodin Tip, 1/4 length dome root 10 Acrodin Tip, 3/4 length concave root 11 Acrodin Tip, 3/4 length convex root 12 Acrodin Tip, 3/4 length straight root 13 Acrodin Tip, Cone-like, Big blades | |
| 6 Acrodin Tip, 1/2 length straight root 7 Acrodin Tip, 1/2 length straight root, flare blades 8 Acrodin Tip, 1/4 length concave root 9 Acrodin Tip, 1/4 length dome root 10 Acrodin Tip, 3/4 length concave root 11 Acrodin Tip, 3/4 length convex root 12 Acrodin Tip, 3/4 length straight root 13 Acrodin Tip, Cone-like, Big blades | |
| 7 Acrodin Tip, 1/2 length straight root, flare blades 8 Acrodin Tip, 1/4 length concave root 9 Acrodin Tip, 1/4 length dome root 10 Acrodin Tip, 3/4 length concave root 11 Acrodin Tip, 3/4 length convex root 12 Acrodin Tip, 3/4 length straight root 13 Acrodin Tip, Cone-like, Big blades | |
| 8 Acrodin Tip, 1/4 length concave root 9 Acrodin Tip, 1/4 length dome root 10 Acrodin Tip, 3/4 length concave root 11 Acrodin Tip, 3/4 length convex root 12 Acrodin Tip, 3/4 length straight root 13 Acrodin Tip, Cone-like, Big blades | |
| 9 Acrodin Tip, 1/4 length dome root 10 Acrodin Tip, 3/4 length concave root 11 Acrodin Tip, 3/4 length convex root 12 Acrodin Tip, 3/4 length straight root 13 Acrodin Tip, Cone-like, Big blades | |
| 10 Acrodin Tip, 3/4 length concave root 11 Acrodin Tip, 3/4 length convex root 12 Acrodin Tip, 3/4 length straight root 13 Acrodin Tip, Cone-like, Big blades | |
| 11Acrodin Tip, 3/4 length convex root12Acrodin Tip, 3/4 length straight root13Acrodin Tip, Cone-like, Big blades | |
| 12Acrodin Tip, 3/4 length straight root13Acrodin Tip, Cone-like, Big blades | |
| 13 Acrodin Tip, Cone-like, Big blades | |
| · · · · · · · · · · · · · · · · · · · | |
| Acrouit Tip, Cone, small dome root | |
| 15 Acrodin Tip, convex tooth, straight 1/2 root | |
| 1, , 5 | |
| 16 Acrodin Tip, convex tooth, straight 3/4 root17 Acrodin Tip, Convex, Curved | |
| | |
| 18 Acrodin Tip, Curve, 1/2 concave root | |
| 19 Acrodin Tip, curve, full root | |
| 20 Acrodin Tip, Dome Root | |
| 21 Acrodin Tip, extended long root | |
| 22 Acrodin Tip, Flared Blades | |
| 23 Acrodin Tip, no obvious root | |
| 24 Acrodin Tip, pointy convex, 1/2 root | |
| 25 Acrodin Tip, right, convex | |
| 26 Acrodin Tip, small blades | |
| 27 Acrodin Tip, Thick Blades, Big root | |
| 28 Acrodin Tip, Thick Blades, Small root | |
| 29 Bladed cone | |
| 30 Bladed cone (acrodin tip) | |
| 31 Bladed cone (acrodin tip), curved | |
| 32 Bladed cone single blade | |
| 33 Bladed cone small root acrodin tip | |
| 34 Bladed cone straight no flare | |
| 35 Bladed cone, curved | |
| 36 Blades on top | |
| 37 Blades on top (cone) | |
| 38 Clear, 1/2 convex root | |
| 39 Clear, 1/2 dome root | |
| 40 Clear, 1/2 straight dome root | |
| 41 Clear, 1/2 straight root | |
| 42 Clear, 1/3 dome root | |

| 43 | Clear, 1/4 straight root |
|----------|---|
| 44 | Clear, 1/4 straight root, convex tooth |
| 45 | Clear, 3/4 concave root |
| 46 | Clear, 3/4 Dome root |
| 47 | Clear, 3/4 straight root |
| 48 | - |
| | Clear, 3/4 thin root |
| 49 | Clear, concave tooth, 1/4 root |
| 50 | Clear, concave tooth, full root |
| 51 | Clear, convex tooth, 1/4 dome root |
| 52 | Clear, convex tooth, dome root |
| 53 | Clear, convex tooth, dome root, small blades |
| 54 | Clear, curved, 1/2 root |
| 55 | Clear, curved, concave root |
| 56 | Clear, curved, full root |
| 57 | Clear, flange, straight |
| 58 | Clear, flared blades (small), cocnave root |
| 59 | Clear, flared blades, 1/2 root |
| 60 | Clear, flared blades, 3/4 root |
| 61 | Clear, flared blades, concave root |
| 62 | Clear, Flat, Curved, 1/2 concave root |
| 63 | Clear, Flat, Curved, 3/4 concave root |
| 64 | Clear, Flat, Curved, 3/4 concave root Clear, Flat, Curved, 3/4 dome root |
| | |
| 65 65 | Clear, Flat, curved, extended root |
| 66 | Clear, flat, curved, full root |
| 67 | Clear, flat, small root |
| 68 | Clear, flat, straight, tall |
| 69 | Clear, Flat, thin root |
| 70 | Clear, full straight root |
| 71 | Clear, Funnel root |
| 72 | Clear, large root |
| 73 | Clear, long flange |
| 74 | Clear, long flange pointed tip |
| 75 | Clear, long S-shape root |
| 76 | Clear, long straight root |
| 77 | Clear, Long, skinny root |
| 78 | Clear, pointed tip, 1/2 dome root |
| 79 | Clear, right, concave extended root |
| 80 | Clear, right, concave root, flange |
| 81 | Clear, right, concave root, small flange |
| 82 | Clear, thick, concave |
| 83 | Clear, vase-root |
| 84 | Cloudy, 1/2 root, flare blades |
| 85 | Cloudy, 1/2 100t, hare blades Cloudy, convex, flared bottom |
| 86 | Cloudy, curve bladed |
| 87 | |
| | Cloudy, extended triangle |
| 88 | Cloudy, flare blades |
| 89 | Cloudy, hooked |
| | |

| 00 | Olaudu riaht aanvar |
|-----|--|
| 90 | Cloudy, right convex |
| 91 | Cloudy, small thin root |
| 92 | Cloudy, Triangle, 3/4 root |
| 93 | Cloudy, Triangle, 3/4 root thin blades |
| 94 | Cloudy, Triangle, dome root |
| 95 | Cloudy, Triangle, extended root |
| 96 | Cloudy, Triangle, full root |
| 97 | Cone Elongated (no acrodin tip) |
| 98 | Cone Elongated (with acrodin tip) |
| 99 | Cone long thin root |
| 100 | Cone long thin root (acrodin tip) |
| 101 | Cone pointed tip |
| 102 | cone short dome root |
| 103 | Cone small curved |
| 104 | Cone small curved acrodin tip |
| 105 | Cone triangle root acrodin tip |
| 106 | Curved (minor), large concave root |
| 107 | Curved triangle dome root |
| 108 | Curved, Flange (fat) |
| 109 | Curved, Flange (large) |
| 110 | Curved, Flange (large) small root |
| 111 | Curved, Flange (small) |
| 112 | Curved, flat, 1/2-3/4 root, convex sides |
| 113 | Curved, large concave root |
| 114 | Curved, large concave root, asym bottom |
| 115 | Flared base, big curve |
| 116 | Flared base, cloudy bladed |
| 117 | Flared base, cusps |
| 118 | Flared base, flange |
| 119 | Flared base, short cloudy cone |
| 120 | Flared base, straight bladed cone |
| 121 | Flared blades, dome root |
| 122 | Hooked, flat head |
| 123 | Large long cone |
| 124 | Large long curved bladed cone |
| 125 | Large long curved cone |
| 126 | Large long straight bladed cone |
| 127 | Mostly Blade |
| 128 | Pointy, Flare bottom, curve |
| 129 | Pointy, flare bottom, tall |
| 130 | Pointy, flare bottom, wide |
| 131 | Pointy, flare, convex |
| 132 | Right Triangle, flat |
| 133 | Right Triangle, one blade |
| 134 | Short triange flared blades |
| 135 | Straight, half-length flange |
| 136 | Straight, many cusps |
| | |

593 **REFERENCES**

- 594
- 595 1. Menard H.W., Natland J.H., Jordan T.H., Orcutt J.A., Adair R.G., Burnett M.S., Kim I.I.,

596 Lerner-Lam A., Mills W., Prevot R., et al. 1987 Site 596; hydraulic piston coring in an area of

low surface productivity in the Southwest Pacific. *Initial Reports of the Deep Sea Drilling Project* 91, 245-267. (doi:http://dx.doi.org/10.2973/dsdp.proc.91.103.1987).

- Zhou L., Kyte F.T. 1992 Sedimentation history of the South Pacific pelagic clay province
 over the last 85 million years inferred from the geochemistry of Deep Sea Drilling Project Hole
 596. *Paleoceanography* 7(4), 441-465.
- 3. Zhou L., Kyte F.T., Bohor B.F. 1991 Cretaceous/Tertiary boundary of DSDP Site 596,
 South Pacific. *Geology* 19(7), 694-697. (doi:10.1130/0091-
- 604 7613(1991)019<0694:ctbods>2.3.co;2).
- 605 4. Winfrey E.C., Doyle P.S. 1984 Preliminary ichthyolith biostratigraphy, Southwest
- Pacific, DSDP sites 595 and 596. In *Eos, Transactions, American Geophysical Union* (p. 949.
- 607 Washington, American Geophysical Union.
- 5. Sibert E.C., Cramer K.L., Hastings P.A., Norris R.D. 2017 Methods for isolation and
 quantification of microfossil fish teeth and elasmobranch dermal denticles (ichthyoliths) from
 marine sediments. *Palaeontologia Electronica* 20(1), 1-14.
- 6. Doyle P., Kennedy G.G., Riedel W.R. 1974 Stratigraphy. *Initial Reports of the Deep Sea*
- 612 Drilling Project 26, Durban, South Africa to Fremantle, Australia; Sept.-Oct. 1972, 825-905.
 613 (doi:10.2973/dsdp.proc.26.135.1974).
- 7. Doyle P.S., Riedel W.R. 1979 *Ichthyoliths: present status of taxonomy and stratigraphy of microscopic fish skeletal debris*. La Jolla, CA, Scripps Institution of Oceanography, University
 of California, San Diego.
- 617 8. Doyle P.S., Riedel W.R. 1985 *Cenozoic and Late Cretaceous ichthyoliths*. Cambridge, 618 United Kingdom (GBR), Cambridge Univ. Press, Cambridge.
- 619 9. Tway L.E. 1977 Pennsylvanian ichthyoliths from the Shawnee Group of eastern Kansas
 620 [Master's]. Norman, University of Oklahoma.
- 621 10. Tway L.E. 1979 A coded system for utilizing ichthyoliths of any age. *Micropaleontology*622 25(2), 151-159.
- 623 11. Tway L.E., Riedel W.R. 1991 Prototype expert system to assist in ichthyolith
- 624 identifications. In *J Vertebr Paleontol* (eds. Emry R.J., Sues H.-D.), pp. 58-59. Norman,
 625 University of Oklahoma.
- 626 12. Johns M.J., Barnes C.R., Narayan Y.R. 2006 Cenozoic ichthyolith biostratigraphy;
- 627 Tofino Basin, British Columbia. *Canadian Journal of Earth Sciences/ Revue Canadienne des* 628 Sciences de la Terre **43**(2), 177-204 (doi:10.1120/c05.102)
- 628 *Sciences de la Terre* **43**(2), 177-204. (doi:10.1139/e05-102).
- Riedel W.R. 1978 Systems of morphologic descriptors in paleontology. *Journal of Paleontology* 52(1), 1-7.
- 631 14. Hsiang A.Y., Nelson K., Elder L.E., Sibert E.C., Kahanamoku S.S., Burke J.E., Kelly A.,
- Liu Y., Hull P.M. 2017 AutoMorph: Accelerating morphometrics with automated 2D and 3D
- 633 image processing and shape extraction. *Methods Ecol Evol*, n/a-n/a. (doi:10.1111/2041-
- 634 210X.12915).
- 635 15. Oksanen J., Blanchet F.G., Friendly M., Kindt R., Legendre P., McGlinn D., Minchin
- 636 P.R., O'Hara R.B., Simpson G.L., Solymos P., et al. 2017 vegan: Community Ecology Package.
- 637 R package version 2.4-4. (

- 638 16. McKinney M.L. 1997 Extinction Vulnerability and Selectivity: Combining Ecological
 639 and Paleontological Views. *Annu Rev Ecol Syst* 28, 495-516.
- Raup D.M. 1981 Extintion: bad genes or bad luck? *Acta geológica hispánica* 16(1), 2533.
- 642 18. Streelman J., Webb J., Albertson R., Kocher T. 2003 The cusp of evolution and
- 643 development: a model of cichlid tooth shape diversity. *Evol Dev* **5**(6), 600-608.
- 644 19. Edgerton C.C., Doyle P.S., Riedel W.R. 1977 Ichthyolith age determinations of otherwise
- 645 unfossiliferous Deep Sea Drilling Project cores. *Micropaleontology* **23**(2), 194-205.
- Foote M. 1993 Discordance and concordance between morphological and taxonomic
 diversity. *Paleobiology* 19(02), 185-204.
- Foote M. 2000 Origination and extinction components of taxonomic diversity: general
 problems. *Paleobiology* 26(sp4), 74-102.
- 650 22. Liow L.H., Nichols J.D. 2010 Estimating rates and probabilities of origination and
- 651 extinctionusing taxonomic occurrence data: capture-mark-recapture (CMR) approaches. *Alroy* 652 *and Hunt*, 81-94.
- 653 23. Nichols J.D., Pollock K.H. 1983 Estimating taxonomic diversity, extinction rates, and
- 654 speciation rates from fossil data using capture-recapture models. *Paleobiology* **9**(2), 150-163.
- Pradel R. 1996 Utilization of capture-mark-recapture for the study of recruitment andpopulation growth rate. *Biometrics*, 703-709.
- 657 25. Laake J.L. 2013 RMark: an R interface for analysis of capture-recapture data with
- 658 *MARK*, US Department of Commerce, National Oceanic and Atmospheric Administration,
- 659 National Marine Fisheries Service, Alaska Fisheries Science Center.
- 660 26. Marshall C.R. 1997 Confidence intervals on stratigraphic ranges with nonrandom
- distributions of fossil horizons. *Paleobiology*, 165-173.
- 662 27. White G.C., Burnham K.P. 1999 Program MARK: survival estimation from populations
 663 of marked animals. *Bird study* 46(S1), S120-S139.
- 664 28. Cooch E., White G. 2006 Program MARK: a gentle introduction. Available in pdf format
 665 for free download at http://wwwphidotorg/software/mark/docs/book.
- 666 29. R Core Team. 2017 R: A language and environment for statistical computing. Vienna,
- 667 Austria: R Foundation for Statistical Computing; . (
- 668 669

| 670 | |
|-----|---|
| 671 | |
| 672 | |
| 673 | |
| 674 | |
| 675 | |
| 676 | |
| 677 | |
| 678 | |
| 679 | |
| 680 | Appendix 1. An image index of all fish tooth morphotypes described in this study. |
| 681 | |
| 682 | |

Acrodin Tip, 1/2 length Concave Root



Object #00001 of 00157 (489 x 605 pixels at sile position 06.47% x 78.92%) L00 microm per pixel 1 Age and Source. Locener from USDP-396-001-Exceed Processed at X1% Peabody Massessing by the Null LBC Stationg Number: None) continuous an analysis, microsource and analysis at a sile memory Differentiation and the Sile and Sile at a sile at a sile memory Differentiation and the Sile and Sile at a sile at a

Acrodin Tip, ¹/₂ length concave root, flared blades



Object 400025 of 00214 (323 x 455 pixels at skie portion 14 0005 x 64 625 x) LOO motions per pixel (Age and Source: Locent from DSDP-596-033-6octer Processed at 1% and Pachado Massemb by the Hull Lab. (Catalog Number Rene) constrained as inde-day. Recession 2016-66 at 24 61 is mean 2016-1676-161-31-36-4 (Recession 2016-66 at 24 61 is

Acrodin Tip, 1/2 length Concave Root, no tips



Diject 400004 of 00072 (326 x 440 pixels at side position 08.71% x 7.4.99%) 1.0 microns per pixel | Age and Source: Econer from DSDP-586-007-Econer Processed at Yale Paabod Waxeum by the Hull Lab Catalog Number. None) 0.0000 (2000) (2000

Acrodin Tip, 1/2 length convex root



Transition Object #00060 of 00157 (364 x 66) points at side position 42.11% x 74.06%) 1.00 micros per pracel Age and Source: Escene from DSDP-596-001-Escene Processed at Yale Peabody Museum by the Hull Lab (Catalog Number: None) Converses of a Yale Peabody Museum Dy the Hull Lab (Catalog Number: None) Security 2014 (2014) (2014) (2014) (2014) (2014) Neuron 2014 (2014) (2014) (2014) (2014) (2014) (2014) Neuron 2014 (2014) (2014) (2014) (2014) (2014) (2014)

Acrodin Tip, ½ length funnel root



Object #00035 of 00253 (155 x 367 pixels at sile position 24.0658 x 51.538)) LO0 microso per puxel | Age and Source. Excent from DSDP-364-64-focer Protessia at 14 and 14

Acrodin Tip, ½ length straight root, flare blades

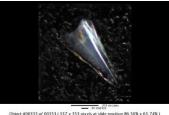


25 morts 26 morts 26 morts 26 morts 26 morts 26 morts 26 morts 27 morts 20 mor

Acrodin Tip, 1/2 length straight root



Acrodin Tip, ¹/₄ concave root



In the second sec

Acrodin Tip, ¼ dome root



Acrodin Tip, ³/₄ length concave root



Timuin
 Timuin

Acrodin Tip, 3/4 length convex root



2 3600¹¹ erosis Object #00016 of 00157 (49 3 x 21 picks at sidle goostion 17.438 x 72.938) 1.00 microson per pickel Age and Source. Excern from DSDP-596-001-Eocene Processed at Yale Peabody Museum by the Hull Lab (Catalog Number: None) OCCURRENT, 210-06-168, ACCOSTOR 2017-01-213 at 213.01 Instantion (2017-01-01-01-2017-01-00) microson Ensource (2017-01-01-01-01-01-01-01) microson Ensource (2017-01-01-01-01-01-01-01-01)

Acrodin Tip, 3/4 length straight root



 Of microns per pixel | Age and Source: Eocene from DSDP-596-001-Eocen Processed at Yale Peabody Museum by the Hull Lab. (Catalog Number: None) conversion and the second processing of the second pixel and the second pixel and

Acrodin Tip, cone-like, big blades



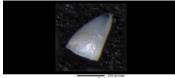
Processed at Yale Peabody Museum by the Hull Lab. (Catalog Number: Nonconversion iou-aw-ois, reconstruction iou-aware and ioumessed of Jana Vale for each 2010 microso Descary, BD-501–018–013–01–0140–0150, Hull, Narvare, Olici, U, Juliz-0, XS

Acrodin Tip, Cone, small dome root



.00 microms per pixel | Age and Source: focene from DSDP-S98-001-focene Processed at Yale Peabody Museum by the Hull Lab (Catalog Number: None) Oct Vietnes: b31-0-0-30, NoCEED 06, 203-0-1 at 213:519 Instant (DS-1653-00-51-16-32-203-e163) MultiAst (Sumano, Gui(1), LEF-0,33

Acrodin Tip, convex, curved



- 27 minimums - 27 minimums - 28 minimums - 29 minimums - 20 m

Acrodin Tip, convex tooth, straight ¹/₂ root



Acrodin Tip, convex tooth, straight ³/₄ root



— 2 min 10²⁰ minute — 2 min 10²⁰ minute Disject 400016 of 00214 (504 × 47 picel at slike position 09.3118 × 59.30%) 1.00 micrors per pixel | Age and Source: Eocene from DSDP-596-033-Eocene Processed at Talle Peabody Massam by the Hull Lab. (Catalog Number: None) CONTENTS piase-biol. Research 2013 - 2014 or 10 minute Network DSP-03-03-21-36-37-46-46-300 minute Source DSP-03-03-21-36-37-46-46-300 minute. (Sec). (JUIT-0.31

Acrodin Tip, Curve, 1/2 concave root



Clopert 900011 of 00072 (/ 59 x 113) period at Med postion (88,65 x 42,94 x) 1.00 microsis per pixel | App and Source: Encore from DSDP-996-807-Sectors Protected at 2 vise | App and Source: Encore from DSDP-996-807-Sectors Protected at 2 vise | App and Source: Encore from DSDP-996-807-Sectors Discource at 2 vise | App and Source: Encore from DSDP-996-807-800 Discource at 2 vise | App and Source: Encore from DSDP-996-807-800 Discource at 2 vise | App and Source: Encore from DSDP-996-800 Discource at 2 vise | App and DSDP-906-800 micros

Acrodin Tip, curve full root



25 minutes 25 minutes 26 minutes 26 minutes 26 minutes 27 minutes 27 minutes 28 minutes 29 minutes 20 min

Acrodin Tip, Dome Root



Object #00046 of 00157 (458 x 555 picks at side position 37.01X x 77.87X) 1.00 microne per givel | Age and Source: Eccenter from DSDP-66-001-Eccent Processed at Vise Pachody Missieum by the Initial Lab. (Statiog Numier: None) 0.00 microse (Station 1976-01, NCORECO x 2076-01, at 21.85 Newsy IEE-MicroSolita File Eccine (Station 2076-01, at 21.85 Newsy IEE-MicroSolita File Eccine) (Station 2076-01, at 21.85 Newsy IEE-MicroSolita Fil

Acrodin Tip, extended long root



Transmission Transmission Diget \$90023 of 00157 (235 x 518 j) relief at tides position 22.738 x 74.548 j) L00 microns per pacel Age and Source. Excene from DSIP-596-001-5eccee Processed at Yale Peakody Massum by the Hull Lab (Catalog Number: None) Constructions patient-line (neutron patient) at L181 Thermore REI-Final Patient and Patient and Patients (Lab Patient) Thermore REI-Final Patient and Patient and Patients (Lab Patient) Thermore REI-Final Patients (Lab Patient) Thermore REI-Final Patients (Lab Patient) Patients (Lab Patient) Thermore REI-Final Patients (Lab Patient) Patients (Lab Patient) Patients (Lab Patient) Thermore REI-Final Patients Patients (Lab Patient) Patients (Lab Patient) Patients Patients (Lab Patient) Patients Pat

Acrodin Tip, Flared Blades



Tension T

Acrodin Tip, no obvious root



Transition
 T

Acrodin Tip, pointy convex, ½ root



Object 400017 of 00047 (267 x 40) packed as position 40.89% x 81.69%)
L00 microns per pixel 1 Age and Source. Pixeocene from DSIP-349-043-Pialocene
Processed at 1% Peakody Maxwamb the Mail L1a bit Labadi gambariti Automation
 Constraints and the Pixeo framework and the Pixeo framework

Acrodin Tip, right convex



Object #00083 of ODE51 (201) x 447 pixels at state position 41.208 x 57.003) 100 microse pay pay lide janut discusse. Palatocene from DoBS-596-747-42-betecence Processed at Vale Pashody Marseum by the Hull Lab. (Catalog Rumber-None) Constructions and the state of the State o

Acrodin tip, small blades



Object #00004 of 00055 (5.7.2.3.29) (above at side position 11.7.29 & 47.7.28) L00 microsing per pixel | Age and Source: Palecener (bit | Catalog | Number Read) Processed at 7.2.29 (above catalog | Number Read) Processed at 7.2.29 (above catalog | Number Read) Catal

Acrodin Tip, Thick Blades, Big root



Object PO0119 of 00157 (G72 x G12 pieces at sales poston 66,765 x 84,508) 1.00 micross per piece [A gar and Source: Econer (From DD67-565-00)-Econe Processed at Yale Peakody Moseum by the Hull Lab. (Catalog Number: None] Conesses (Catalog Number) (Catalog Number) (Catalog Number: None] Conesses (Catalog Number) (Catalog Number) (Catalog Number) Number (Catalog Number) (Catalog Number) (Catalog Number) (Catalog Number) Number (Catalog Number) (Catalog Number) (Catalog Number) (Catalog Number) Number (Catalog Number) (Catalog Number

Acrodin Tip, Thick Blades, Small root



Diject #00125 of 00157 (241 x 295 picks at al6e position 70.88% x 71.14%) Loo microm per pixel Age and Source: Econer from DSDP-596-001-Econer Processed at Yale Peabody Museum by the Hill Lab (Catalog Number: None) Control (2014)

Bladed cone



Digiet #00011 of 00157 (32.6 x 42.4 jerk at sile position 15.16% x 77.30%) 1.00 micrors per pixel [Age and Source: Excent from DSDP-359-601-Excent Processel at 73.4 Readow Maxemb pixel holi Lab Catadog Numier: None) com strates and an analysis and an analysis of the sile of the sile of the communication of the sile of the sile of the sile of the sile of the neurost end-sile of the sile o

Bladed cone (Acrodin tip)



2 minute received and a second a seco

Bladed cone (Acrodin tip) curved



Timina management of the second second

Bladed cone, curved



Object #00032 of 00049 (284 x 834 pixels at side position 46 95% x 63 .45%) 1.00 microns per pixel | Age and Source: Paleocene from DSDP-596-061-Paleocene Processed at 244 Peabody Maxemb by the Hull Lab (Schalsh Numher Kone) Conversion pass-exist, incorrection 201-07-16 at 1846 Theorem 244 Phalshoph Maxemb for data (Scharberg Numher Kone) Denversion Part Paleocene (Scharberg Van Borner) Denversion Pale

Bladed cone, single blade



The provide sector of the sect

Bladed cone small root acrodin tip



CCD1 VEISION 1014-19-016, PEC INSELION 1015-04-01 at 17.04-15 Threshold of 0.18 and size filter of 325 - 1010 micross Directory, ISER-596-F015-031-3R-104-10-15cm-g106_Hmail, Nicol, Microsom, Olat, 12, TaER-0, XS

Bladed cone, straight, no flare



Object #00022 of 00071 (239 x 572 jnsek as slide position 31.178 x 75.308) 1.00 microsys per joel / Age and Source: Relocenter from DSDP-566-Delocence Processed at Yale Peabody Museum by the Hull Lab. (Catalog Number: None) 0.001 Microsoft (State 46.4, MICSURG 10.11-41.4, MICSURG 10.11, USE 51. Denses BOrder-State 46.4, State 51.4, State 51.4, State 51.5, Stat

Blades on top



2 Issue 2000 and 2

Blades on top (cone)



Diget #00056 of 00072 (214 x 343 pixels at tide position 59.36% x 86.47%) 1.0 microm per pixel | Age and Source. Eccene from DSDP-596-007-Eccene Processed at Yale Pabbog Masseum by the Holl Lab (Catalog Number: None) Exercised at Yale Pabbog Masseum by the Holl Lab (Catalog Number: None) Exercised 2014 (2014) (2014) (2014) (2014) (2014) (2014) (2014) Internet of 2014) (2014) (2014) (2014) (2014) (2014) (2014) (2014) Internet of 2014) (2014)

Clear, ¹/₂ convex root



Characteristic formation of the second second

Clear, 1/2 dome root



Clear, ¹/₂ straight dome root



Clear, 1/2 straight root



Object #00094 of 00102 (252 x 466 pixels at sile position 84.42% x 72.73%)
 1.00 micrors per pixel Age and Source. Excent from DSDP-396-019-Eccent
 Processed at 24% be Packby Macanin by the Hull Lab Catalog Number None)
 Controller Pixel-Dab. NONEDECK at 21%-01% of 02% of 02%
 Pixel Pixel

Clear, 1/3 dome root



Disject #00008 of 00102 (104 x 510 picek at sile portion 12.70% x 71.00%)
 1.00 micrors per pavel | Age and Source: Execute from DSDP-556-019-Execute
 Processed at 74% Pashood Massemb by the Init Like Exclusion Numeric None)
 certainers insteadows, restrictions and a class
 mean 2004 (104-28)
 means 2004 (104-28)
 means 2004 (104-28)

Clear, ¹/₄ straight root



Object 600085 of 00119 (223 54 (j=6) host at tilde position 48.30% x 59.54%) 1.00 micrors per pare] Age and Source: Paleocene from DSDP-596-077-Paleocene Processed at 21a/e Paalod Museum by the Huil Lai Scatalog Number (Source Source 2014) (2014) (2014) (2014) (2014) (2014) (2014) (2014) (2014) (2014) (2014) (2014) (2014) (2014) International (2014) (2014) (2014) (2014) (2014) International (2014) (2014) (2014) (2014) (2014) (2014) (2014) International (2014) (2014) (2014) (2014) (2014) (2014) (2014) International (2014) (2014) (2014) (2014) (2014) (2014) (2014) (2014) International (2014) (2014) (2014) (2014) (2014) (2014) (2014) (2014) International (2014) (201

Clear, ¼ straight root, convex tooth



THE UNCLASSING AND A STATEMENT OF A STATEMA STATEMA STATEMA STATEMA STATEMA STATEMA STATEMA STAT

Clear, ³/₄ concave root

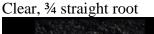


Ubject 400037 of 00150 (343 x 634 pixels at slide position 24.805 x 43.805 x 10.0 microm per pixel | Age and Suize: Econer from DSDP-596-026-Econer Processed at Yale Pashody Museum by the Hull Lab (Catalog Humber None) 027 microm per pixel | Age and Suize: Both Pashody Lab (Catalog Humber None) 028 microm per pixel | Age and Pashody Data (2010) 108 microm per pixel | Age and Pashody P

Clear, ³⁄₄ dome-root



21 mm²¹ mm²¹
 21 mm²¹ mm²²
 Object #00062 of 00157 (433 x 680 pm²² set 3 tide position 42.415 x 753.774) |
100 mmcroms per pixel A Apa and Source. Excerne (rom DSDP-598-001-forcene
Processed at Yale Pabadoy Museum by the Hull Lab (Catalog Number None)
 converses: Pixel-Ada, Michael Marka, Michael Ada, Michael Marka, Michael Marka, Michael Micha





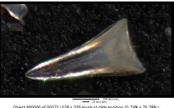
Deject #00001 of 00114 (399 x 1053 poets at 146 poets on 04.51% x 59 02%) 1.00 mcrons per jose (Age and Source Lectere (rom 15007-556-012-foceme Processes at 13a Pabody Maxeum by the Huil Lab. (2atalog Number Hone) 0.00 etension 210-054 (2014) (2014) (2014) 1.00 mercine 210-014 (2014) (2014) (2014) (2014) 1.00 mercine 210-014 (2014) (2014) (2014) (2014) (2014) 1.00 mercine 2014) (2014) (2014) (2014) (2014) (2014) 1.00 mercine 2014) (2014) (2014) (2014) (2014) (2014) (2014) 1.00 mercine 2014) (2014) (2014) (2014) (2014) (2014) (2014) (2014) 1.00 mercine 2014) (

Clear, ³/₄ thin root



Diget #00067 of 00072 (265 x 683 picels at 164 position 76.44% x 78.01%) LO microm per pixel [Age and Source: Econer from DSDP-596-007-Econer Processed at Yale Peabody Museum by the Hull Lab [Catalog Number: None) Source: Sourc

Clear, concave tooth, ¹/₄ root



Deject #00006 of 00071 (638 x 339 provide at side position 10.74% x 79.78%) 1.00 microms per pixel | Age and Source Palacener from DSIP-566-268-24locene Processed at 748 reakody Mixempi to the fault Lab Catalog Numeric Polacener (Catalog Numeric Source), macano contraction at at at Catalog Numeric Palacener (Source), and the source of the Site Catalog Numeric Palacener (Source), and the Site of the Site Catalog Numeric Palacener (Source), and the Site of the Site Numeric Palacener (Source), and the Site of the Site Numeric Palacener (Source), and the Site of the Site Numeric Palacener (Source), and the Site of the Site Numeric Palacener (Source), and the Site of the Site Numeric Palacener (Source), and the Site of the Site Numeric Palacener (Source), and the Site of the Site Numeric Palacener (Source), and the Site of the Site Numeric Palacener (Source), and the Site of the Site Numeric Palacener (Source), and the Site of the Site Numeric Palacener (Source), and the Site of the Site of the Site Numeric Palacener (Source), and the Site of the

Clear, concave tooth, full root



Separation 1, Sec. 2015 (2015). Sec. 2016; Sec. 2016 Sec. 2016 (2016). Sec. 2016 (2016). Sec. 2016 Sec. 2017 Sec. 2016 Sec. 2016 (2016). Sec. 2017 (2016). Sec. 2017 Sec. 2016 Sec. 2016 (2016). Sec. 2017 (2016). Sec. 2017 Sec. 2016 Sec. 2016 Sec. 2017 (2016). Sec. 2017 (2016). Clear, convex tooth, dome root



1 Howard Object #00078 of 00102 (405 x 610 pixels at sile position 62.59% x 77.12%) 1.00 microns per pixel 1 Age and Source. Eocene from DSDP-596-019-Eocene Processed at 12% are backed Macazine by the Huil Lab Catalog Number None) constance (15.64-64, Incotance on 15.64-64, et 23.35 Data (15.674-67.16-67-64)). Incotance of 23.35 Data (15.674-67.16-67-64). Incotance on 15.64-64, et 23.35

Clear, convex tooth, dome root, small blades



Object 100003 of 00024 Y782 x 984 packs active position 15 259 x e7 3 4%). 100 mirrors per period (Ag and Stocker Centencous from DDDF 556-100-102-reteneous Processed at Yale Polaboly Maarum by the Hull Lib (Catalog Kumber Hoste) the set of the Stocker Stocker Stocker Stocker Stocker Stocker Stocker Stocker The set of Stocker Stocker Stocker Stocker Stocker Stocker Stocker The set of Stocker Stocker Stocker Stocker Stocker Stocker Stocker The set of Stocker Stocker Stocker Stocker Stocker Stocker Stocker Stocker The set of Stocker Stocke

Clear, convex tooth, ¹/₄ dome root



The use of the second s

Clear, curved, concave root



Emission
 Disject #00057 of 00214 (529 x 559 pice) at slide points
 Disject #00057 of 00214 (529 x 559 pice) at slide points
 1x0 microms per pace| Ape and Source: Excene from DSDP-56-0357 Secore
 Processed at Yale Poakody Massum by the Hull Lab (Catalog Munder: None)
 Constants: 3144 e-04, Incentions: 3151 d-04 at at
 Tenakod 21 at a at at at at 3157 200 mism
 Tenakody 314 at at at at at 3157 200 mism
 Tenakody 314 at at at at at 3157 200 mism
 Tenakody 314 at at at at at 3157 200 mism

Clear, curved, full root



Diject #00188 of 00214 (330 x 023 pick at tild position 69,55% x 54.86%) 100 micrors per pixel j Age and Source. Excent from DSDP :596-033-Excent Processed at 74% Peabody Misseum by the Holl Like Zicataby Ruminer. Romp Committee Transmission, microarce processes at the time Instance DSMP-133-233-574-56 (2000-050) and the time Transmission (2000-1107).

Clear, curved 1/2 root



The second second

Clear, flange, straight



21 minutes 200 most 2

Clear, flared blades, 1/2 root



 2 Numini music 2

Clear, flared blades, 3/4 root



Diget #00088 of 00157 (253 x 465 pixels at siller position 46.145 x 74.80%) Loo microm per pixel Age and Source. Eccent from USDP-596-001-Eccent Proceeded at Yala Peabody Maximum by the Hill Lab (Catalog Humber None) Convergence Raise Age Add Source Raise Add Source Raise Beaker Bart (183) 416 310 - 3

Clear, flared blades concave root



Clear, flared blade (small),

concave root



<u>1 21 mol 20 errors</u> Object 400.138 of 00351 (433 x 656 picks at slide position 43.445 x 75.538) LO0 microm per partiel (Age and Source: Eocene from DSDP-596-026-focene Processed at Yale Peabody Museum by the Hull Lab (Eatalog Number: None) occurrence, 314-04-38, Annother 1015: 100 min Finanzy EEE/Hord 2013 218 with 24 house at 1015 100 min Finanzy EEE/Hord 2013 2

Clear, Flat, Curved, 3/4 concave root (or ½ root)



Object #00137 of 00157 (535 x 1055 pixels at 1616 position 74.113 x 46.91%) 10.0 micromy per pixel | Age and Source: Eccenter from DSDP-559-001-Eocene Processed at Yala Paabody Museum by the Hull Lab. (Stableg Number: None) (Conversion: Read-body, Museum By the Hull Lab. (Stableg Number: None) (Conversion: Read-body, Museum By the Hull Lab. (Stableg Number: None) (Conversion: Read-body, Museum By the Hull Lab. (Stableg Number: None) (Conversion: Read-body, Museum By the Hull Lab. (Stableg Number: None) (Conversion: Read-body, Number: Read-By the Hull Lab. (Stableg Number: None) (Conversion: Read-By the Hull Lab. (Stableg Number: Read-By

Clear, Flat, Curved, ³/₄ dome root



20 access 21 movements 21 movements 20 access 21 movements 20 access 21 movements 21 movement

Clear, flat curved full root



Digiet #00090 of 00100 (417 x 1161 pixels at site position 47.60% x 15.29%) 1.00 microm per pixel / Age and Source. Econer from DSDP-596-026-Econer Processed at Yale Peabody Museum by the Hull Lab (Catalog Humber: None) 0000 (2000) (2000

Clear, Flat, Curved, extended root



The most of the second second

Clear, flat, small root



Object #00041 of 00072 (476 x 729 pixels at slide pocktion 48.00% x 73.92%) L00 microms per pixel | Age and Source: Excern from 05297-359-007-Excern Processed at 734 Pablody Misseum by the Hull Lab. Zitadia (Kumiter: None) Conversion 214-364, microsoft or 014-361 at 10117 Process Public Pablody Misseum (2014) at 10117 Processed Pablody Misseum (2014) at 10117

Clear, flat, straight, tall



Clear, Flat, Thin root <u>*should be "c</u>loudy"*



Object #00070 of 00157 (224 x 344 priekt as tilde position 47.37% x 7.1.93%) 1.00 micrors per pixel [Age and Source: Goene from DSDP-359-601-Socre Processed at 724 headopt Macamb pite Intil Lids (Zatalog Number: None) Construction 304-646, international of the Lids (Zatalog Number: None) Construction 304-646, international of the Lids (Zatalog Number: None) Construction 304-646, international of the Lids (Zatalog Number: None) Construction 304-646, international of the Lids (Zatalog Number: None) Construction 304-646, international of the Lids (Zatalog Number) Construction 304-646, international of the Lids (

Clear, full straight root



21 model 21 model 21 model 21 model 22 model 23 model 24 model 24 model 25 model 20 mod

Clear, funnel root



25 Section 2007 Section 20

Clear, large root



 Object 190014 of 2003 / (88 x 89 posts at side postsion (8, 288 x 37, 628) 100 micros per speel (Agrin of Source: Locente from DUD-596-001-Locente Processed at Side Pedocy Maximum the Hall Lab. Xalabog Namber, Bose) Construction and the Advances and the Hall Lab. Xalabog Namber, Bose) Constructions and the Advances and the Advances and the Advances from y Maximum terms in the Advances and the Advances year, Letter 1, M

Clear, long flange



Third Technology (1997)
 The second second

Clear, long flange, pointed tip



Clear, long S-shape root



Object #00014 of 00114 (469 x 1282 picks at side position if 7.45% x 41.25%) LOO microm per pixel | Age and Source: Loocene from DSDP-596-013-6ocene Processed at 7.45% Pachado Misseum by the Huil Lab Catalog Number Nene) convertience at 1.45% And Advances at 2.45% (Advances) Convertience at 1.45% (Advances) Completed at 2.45% (Advances) (Advances) Completed at 2.45% (Advances) Completed at 2.45% (Advances) (Completed at 2.45\% (Adv

Clear, Long, skinny root



20 Accoss 11 Moreira 15 Moreira 10 Moreira 10 Moreira 10 Moreira 10 Moreira per pixel Age and Source Locener from DSDP-596-001-Cocene Processed at Yale Peabody Museum by the Hull Lab (Catalog Humber None) Cocener Processed at Yale Peabody Museum Moreira 10 Moreira Peabody Museum Moreira Peabody and Source 10 Moreira Peabody Museum Moreira Peabody and Source 10 Moreira Peabody Museum Moreira (Stational Peabody Hold Actional Pe

Clear, long straight root



Delet #00033 of 00353 (220 x 468 pixels at slide position 17.86% x 68.52%) 1.00 microns per pixel | Age and Source: Eccent from DSCP-396-026-Eoccene Processed at Yale Peabody Museum by the Hull Lab (Catalog Number: None) CODE VEISION: 2014-184-014, PROCESSED ON: 2011-04-18 at 87-15-25 Theshold of 0.14 and size lifter of 125 - 1000 micros Develop: 0509-1976-1078-026-31-229-01-258-0156, Microsport, Olia, 12, TEDF-0, X5

Clear, pointed tip, ¹/₂ dome root



23 more - 23 mor

Clear, right, concave extended root



Clear, right, concave root, flange



T THE MERICAL STATES AND A STAT

Clear, right, concave root, small flange



 Object #00055 of 00063 (442 x 715 pixels at slide position 74.77% x 49.65%)
 1.00 microns per pixel | Age and Source: Paleocene from DSDP-596-053-Paleocene
 Processed at Yale Peabody Museum by the Hull Lab. (Catalog Number: None) CDELVENDER 2014-01-014, PECEBEDOR 2015-01-15 et 10-4448 Threshold OL 16 and size filter of 225 - 1040 micros Erectory EDP-510-715-051-347-29-146-14/Cm-q166_head_R1ad1_Microport_Ola; II_TzIDI-0, X5

Clear, thick, concave



the second second

Clear, vase-root



29 moles Object #00010 of 00157 (279 x 554 pixels at slide position 14.43% x 72.66%) 1.00 microms per pixel | Age and Source: Eccent From DSDP-596-001-Eccene Processed at Yale Peabody Museum by the Hull Lab (Catalog Number: None)

Cloudy, 1/2 root flare blades



Object #00037 of 00050 (328 x 336 pixels at slide position 63.07% x 71.84%) 1.00 microns per pixel | Age and Source: Cretacous from DSDP-596-094-Cretacous Processed at Yale Peabody Museum by the Hull Lab (Catalog Number: None) CORE VIENEN 2014-01-014, MOCENEDON 2015-03-26 al 87-13-38 Threshold of 0.16 and size filter of 128 - 2500 micros Brischer, ESP-598-7146-648-14-67-07-28m-2005, Medit, Nati, Neoropart, Okai, 11, 7a:19-0, X5

Cloudy, convex, flare bottom



Object #8007 of 00112 (531) x 470 peeks at side position 58 673 x 632 00%) LO microsor pay read (Age and Source, Falocone from Om 2007-596-072-Palencere Processed at Yale Pathody Maxaum by the Hull Lab. (Catalog Kumber: None) Construction 210-2004 (Catalog Kumber) Design 2004 (Catalog Kumber) Design

Cloudy, hooked



Discussion of the second secon

Cloudy, right convex



 Object M00015 of 00119 (400 × 160²) reset as size poston 15.34% x 23.05%) 20 micross per pixel / Ape and Source. Falencem From DSDP-266-077-Alexcene Processed at Yale Peakody Moseum by the Hull Lab (Catalog Humer: Kone) 001475 in Sec.416.56, Moseum 12.34-56 are 10.444 Moseum 21.25 (2004) microssed at 23.455 (2004) 001475 in Sec.416.56, Moseum 21.25 (2004) microssed at 24.05 Data (2004) microssed at 23.455 (2004) microssed at 23.455 (2004) Data (2004) microssed at 23.455 (2004) microssed a

Cloudy curve bladed



Processes at Vial Polyton Massam by Her Hall Call Catalog Bondle. New York A state And Annual March 1997 (Sector 1997) March 1997 (Sector 1997) Sector 1

Cloudy extended triangle



Object 900004 of 00119 (413 + 822 pixels at site position 03.695 + 55 168) 1.00 micros per pixel (Age and Source: Alaboratin from DSDP-566-077-Alaccem Processed at 1/4 Pedady Marriam by the Mill Lab (Lab (Marther Hone) COLVIDER 1944-03A, Protection 1944-014, at 244 December 2415 - 6124 - 6124 December 2415 - 6124 December 2415

Cloudy flare blades



The second secon

Cloudy, small thin root



Object 90007 of 00050 (216 5/5) priek at tilde position 22.71% x 71.52%) L00 microm per parel / Age and Source: Cretaceous from DSDP-596-048-cretaceous Processed at 744 Packdoy Maximum by the Mild Lab Cratadia fundament. Nano) Construction of the Packdoy Maximum by the Mild Lab Cratadia fundament. Nano) Construction of the Packdoy Maximum Construc

Cloudy triangle ³/₄ root



The second secon

Cloudy triangle, ³/₄ root thin blades



Diget #00114 of 00119 (550 v 11) prices at side position 69,72% v 47.61%)
 L00 microms per posel | Age and Source. Paloecener from DSDP-596-077-Paloecene
 Processed 174 be Palodo Massem by the Init List D-List By Mumerir Knore
 Concerning the Palodo Massem by the Init List D-List By Mumerir Knore
 Concerning the Palodo Massem by the Init List D-List By Mumerir Knore
 Concerning the Palodo Massem by the Init List D-List By Mumerir Knore
 Concerning the Palodo Massem By Mumerir Massem By Mumirir Massem By M

Cloudy triangle, dome root



25 mccm²⁰ micros Object #00377 of 00431 (386 x 442 pixels at slide position 71.231 x 50.67%) 1.00 microns per pixel | Age and Source. Econer from DSDP-596-040-Ecorne Processed at Yale Peabody Museum by the Hull Lab (Catalog Number None) CORE VIRISH: 2014-01-01a, FROCESSION: 2015-01-01 ar 01 57 20 Threshold 0: 13 and size filter of 106 - 3060 micros Directory: DSP-596-1992-040-318-248-06 (http://ki.uku.org.on/j.ltg/1_1_EEF-0_X3

Cloudy triangle extended root



T multiple object #00017 of 00214 (403 x88 (picel at slide position 10 38% x 61.61%) 1.00 micromy per pacel | Age and Source. Excent from DSDP-596-035-facetree Processed at Yale Peakody Maxeum by the Huil Lab (Catalog Number: None) COLEMENT 2014-01-2014 (2014) (2014) (2014) (2014) (2014) COLEMENT 2014-01-2014) (2014)

Cloudy triangle full root



et 400031 of 00214 (669 x 1.418 pixels at site position 16.8778 x 2.8.858.) of micronic per panel (Age and Source: Scient from DSDP-596-033-Socree occessed at yield (Age and Source: Scient from DSDP-596-033-Socree occessed at yield (Age and Source: Scient from DSDP-596-033-Socree occessed at yield (Age and Source: Scient from DSDP-596-033-Socree occessed at yield (Age and Source: Scient from DSDP-596-033-Socree at yield (Age and Source: Scient from Socree at yield (Age and Source: Scient from Socree at yield (Age and Source: Scient for Age at yield (Age Object i 1.00 m

Cone elongated (w/ or w/o Acrodin tip)



Diject #00052 of 00157 (262 x 505 pixels at silde position 38.17% x 86.34%) 1.00 micrors per pixel | Age and Source: Eocene from DSDP-596-001-Eocene Processed at Yale Peabody Museum by the Hull Lab. (Catalog Number: None) CORE VERSION 1014-89-016, PROCEEDEDRE 2015-03-11 at 12.15.58 Thesion of 0.14 one size filter of 135 - 1000 micross Binetary, BDF-595-1013-101-101-2016, Physill (Nationgoort, Olina, 11, TaEP-0, X5

Cone long thin root (w/ or w/o acrodin tip)



CODE VERSION. 2014-00-014, PROCESSED DN: 2015-01-01 at 39.01.17 Threshold of 0.17 and size Titer of 125 -1000 microns Einectory. ISDP-596-PE59-607-39-10-59-580n-g106, Peetl, N.Dri, Microsom, Oliat 11, TaEEF-0, X5

Cone pointed tip



3 (1) 20 more 3 (1) 20 more 3 (1) 20 more 3 (1) 20 more per pixel Age and Source Econem From BDP-596-026-Econem Processed at Yale Peakody Museum by the Hull Lab (Catalog Humber None) COX version: Reviewed And Catalog Humber 20 More The State (1) 20 More (1) 20 More The State (1) 20 More (1) 20 More The State (1) 20 More (1) 20 More (1) 20 More The State (1) 20 More (1) 20 More (1) 20 More (1) 20 More More (1) 20 Mo

Cone small curved



2 minute results of 00114 (445 x 47 picks at sidle possion 18.125 x 59.37%)
1.00 microms per picel (Age and Source: Eorene from DSDP-596-013-Eorene
Processed at Yale Peabody Museum by the Hull Lab (Eatalog Number: None)
0.02 veters: y14-0-6.36, MC0002109: y14-0-6.47 y14-0
0.02 veters: y14-0-6.37 y14-0-6.47 y14-0-6.37 y14-0

Cone small curved acrodin tip



Object #00026 of 00214 (316 x 518 pixels at slide position 14.01% x 52.58%) 1.00 mixtons per pixel | Age and Source: Eocene from DSDP-596-033-Eocene Processed at Yale Peabody Museum by the Hull Lab (Catalog Number: None) CCRE VESSION 2014-69-014, PEXCERTEON 2011-04-01 at 67-46-18 Threshold of 0.14 and size Mater of 115 - 3000 microso Eventary: EXP-596-P385-333-34-29-46-48cm-ç105, Hwell, N.2x2, Macegount, Olar, J.L, TaEEF-0, X5

Cone Triangle root acrodin tip



Chiper #00087 of 00114 (174 x 245 pixels at slide position 63 20% x 67.49%) L00 microns per pixel | Age and Source: Eocene from DSDP-596-013-Eocene Processed at Yale Peabody Museum by the Hull Lab (Catalog Number: None) CON VINUENI 2014-09-014, PECCEREDOR 2011-04-01 at 82.94.15 Thresholf of 0.18 and size fiber at 23 - 1000 micross Birectary, EDF-505-62-13-13-18-10-51-50, rest), Microsover, Olla, 13, TaEF-0, X5

Curved flange (fat)



Object 20006 of 00411 (374 c 1050 etc.) and 00 etc.) and 00 etc. (b) and 20006 of 00411 (374 c 1050 etc.) and 004 etc.) and 004 etc.) and 004 etc. (b) and 004 etc.) and 004 etc. (b) and 004 etc.) and 004 etc.) and 004 etc. (b) and 004 etc.) and 004 etc.) and 004 etc.) and 004 etc.) and 004 etc. (004) (b) and 004 etc.) and 004 etc.) and 004 etc.) (b) and 004 etc.) (b) and 004 etc.) and 004 etc.) and 004 etc.) and 004 etc.) (b) and 004 etc.) and 004 etc.) and 004 etc.) and 004 etc.) (b) and 004 etc.) and 004 etc.) and 004 etc.) and 004 etc.) (b) and 004 etc.) and 004 etc.) and 004 etc.) and 004 etc.) (b) and 004 etc.) and 004 etc.) and 004 etc.) and 004 etc.) (b) and 004 etc.) and 004 etc.) and 004 etc.) and 004 etc.) (b) and 004 etc.) and 004 etc.) and 004 etc.) and 004 etc.) (b) and 004 etc.) and 004 etc.) and 004 etc.) and 004 etc.) (b) and 004 etc.) and 004 etc.) and 004 etc.) and 004 etc.) (b) and 004 etc.) (b) and 004 etc.) and 004 e

Curved Flange (large)



Curved Flange (large) small root



The sector of the sector

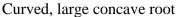
Curved, Flange (small)



Curved, flat, 1/2-3/4 root, convex sides



The matter sector of the secto





Object #00032 of 00157 (259 x 682 pixels at site opsision 29 0005 x 79.55%) 1.00 microris per pixel | Age and Source: Escent Form (SDP-596-001-Course Processes at Val Pabado) Museum by the Hull Lab (Catalog Humber None) Octoverse in the site of the site o

Curved, large concave root, asym bottom



Deject #00015 of 00072 (424 x 669 pixels at clife postion 25.64% x 70.03%) LOO microme per pixel | Age and Source: Eccenter from DSDP-596-007-Eccente Processed at Yale Peabody Massumi by the Hull Lab. (Catalog Number: None) Comparison of the Source Pixel (Alexandro) (Alexandro) (Alexandro) memory at 804-660 (2014) (Alexandro) (2014) (Alexandro) (2014) Memory Microl (Alexandro) (2014) (Alexandro) (2014) (2014) Memory Microl (Alexandro) (2014) (2014) (2014) (2014) Memory Microl (2014) (2014) (2014) (2014) (2014) (2014) (2014) Memory Microl (2014) (201

Curved (minor), large concave root



Object r00014 of 00253 (326 xr 222 pixels at tidle position 16.42% x 54.78%) LO microros per pixel | Age and Source Eccenter from DSDP-596-046-Eccente Processed at Yale Paabody Museum by the Hull Lab Catalog Number None) USE (1996) (1996) (1996) (1996) (1996) (1996) (1996) (1996) (1996) (1996) (1997) (1996) (199

Curved triangle, dome root



T maximum Object #00038 of 00253 (354 x 64 [bites at tilde position 24.88% x 7.137%) 1.00 micros per parel (Age and Source: Excene from DSID=596-044-Escene Processed at Yale Peabody Maxeum by the Hull Lab (Catalog Number: None) convinces and a Yale Peabody Maxeum by the Hull Lab (Catalog Number: None) convinces and a Paral and Age and the Alter and Age and Age and hence and SH-041-04-04-05-10-11-10-10-05 Maxeum (Star) (1489-03)

Flared base, big curve



Flared base, flange



Object #00106 of 0023511545 x 1446 peeds as takes position 38.455 x 39.0335 1.00 micross per peiel 1 Age and Source: Econem From SDP-595-046-Foccene Processed at Vale Peabody Museum by the Hull Lab (Catalog Number: None) Control Biology 2014 (Satalog Number) at 10.100 micross Dates (BS-794-974-69-75-28): 10.100 micross

Flared base, cusps



Object 64002.1 of 60022.7 (7.9 p. co. p. p. et al. 436 per points (7.6 6484 5.2 p. 08)) 12.0 Indexes per part of Lyst and Score points (7.6 6484 5.2 p. 08)) 12.0 Indexes per part of Lyst and Score points (7.6 6485 5.6 6.6 6.6 F. 6 6.6

Flared base, cloudy bladed



Flared base, short cloudy cone



Object 400030 of 00067 (417 x 440 pixels at sile position 43.078 x 50.238) L00 micross per pixel [Age and Source: Relocence from USUP-356-066-Felacence Processed at Vise Peakof Maximum by the Intil List (Schlass [Number Hone) concentration statestical pixelines in processing at 21144 Intel (DST-1112) 066-1786-064 and (Schlass 2016) 064 (2116-0,31 Intel (DST-1112) 066-1786-064 (Schlass 2016) 064 (2116-0,31 Intel (DST-1112) 064-1786-064 (Schlass 2016) 064 (Schlass 2016)

Flared base, straight bladed cone



ната с славни на селото с славни с славни на селото на селото на селото на селото на селото на селото на селот Историја на селото с славита на Историја на ССС-ОбСС-Стана на постата на селото с славата на селото с слава с слава на селото с селото с слава на селото с слава на селото на с

Flared blades, dome root



Hooked, flat head



The union The union Digiter #00022 of 00106 (453 x 1007 picels at xilds postion 24.50% x 55.66%) 1.00 microns per pixel | Age and Source: Pakeceren form SDSP-596-073-Pielocome Processed at Yale Pababay Maxium by the Hull Lab (Katalog Number Inon) Strategies (2014) (201



The second secon

Large, long, curved bladed cone



Large, long, straight

bladed cone



The assist The assist Digitet #00001 of 00052 (252 x 453 pixels at still position 12.09K x 68.11K) 1.00 microis per pixel | Age and Source: Flackcene from DSDF-598-018-Pikeocene Processes at TAIP Position Maximum by the Hill Link Catalog Number: Tomol Concerning: Anis-Net Annual Statistical Position and Statistical Position Maximum Anisotrophysical Position and Statistical Position Maximum Anisotrophysical Position and Statistical Position Statistical Position and Statistical Position Anisotrophysical Position Position Position Position Anisotrophysical Position Pos

Large, long curved cone



Mostly Blade



Pointy, flare bottom, "Tall" (can also be "wide" or "curved")



Object #00135 of 00157 (780 x 911 jones in a table position 72,688 x 54,158)
1.00 microms per pixel | Age and State: Externel from DSIP-556,601-Excere
Processed at Ville Phalodo Materianty for Healt Lide (Xatalia Swatter Katalia)
 Other States and States a

Pointy flare, convex



Dijset #00051 of 00119 (139 x 552 pries at side position 35.13% x 60.75%) 1.00 microms per posel (Age and Source: Felociene from DSDP-596-077-Felociene Processed at 7 x 48 Felocidy Museum by the Will Lab Estable Number Hencene Constructions and the source of the so

Right Triangle, flat



Object 400133 of 00157 (240 x 405 pixels at silder position 72,025 x 76,389). 100 mm cross per speciel (Ape and Source: Econem from (SDP-584-00-16-secrete Processed at Yale Peabody Museum by the Hull Lab (Catalog Number: Nons) convertion: at selection, microsoftware (March 101 at 1818) (Instity BP-614-614-614-3-814-614).

Right Triangle, one blade



Object 20005 of 00015 (21 × SB) priek at tills position 12.75% x 65.09%) 1.00 microms per parel / Age and Source: Cretaceous from DDP-596-022-Cretaceous Processed at 71% Packbog Maximum by the Mill Lab Crashs Junnier House Creation and The Packbog Maximum by the Mill Lab Crashs Junnier House Creation and The Packbog Maximum Creation (2014) (2014) The Packbog Maximum Creation and The Packbog Maximum Creation (2014) (2014) (2014) The Packbog Maximum Creation (2014) (20

Short triangle flared blades



Straight, half-length flange



Thuman
 Dispect #00010 of 00050 (588 x 1239 picek at tille position 33.138 x 70.728)
 L00 microms per pixel | Ape and Source: Cretaceous from DSUP-596-047-Cretaceous
 Processed at 148 Packbog Maaching the Hold Like LikeLang Kumber Nonel
 Constraints at interaction, incompose at 11.6 None 20.118
 Constraints at interaction, incompose at 11.6 None 20.118
 Disputs BDO-914-914-914-916-914, pixel, Maannee, Kolt, L1(10-4), IS

Straight many cusps



2 Sumplements and the second secon