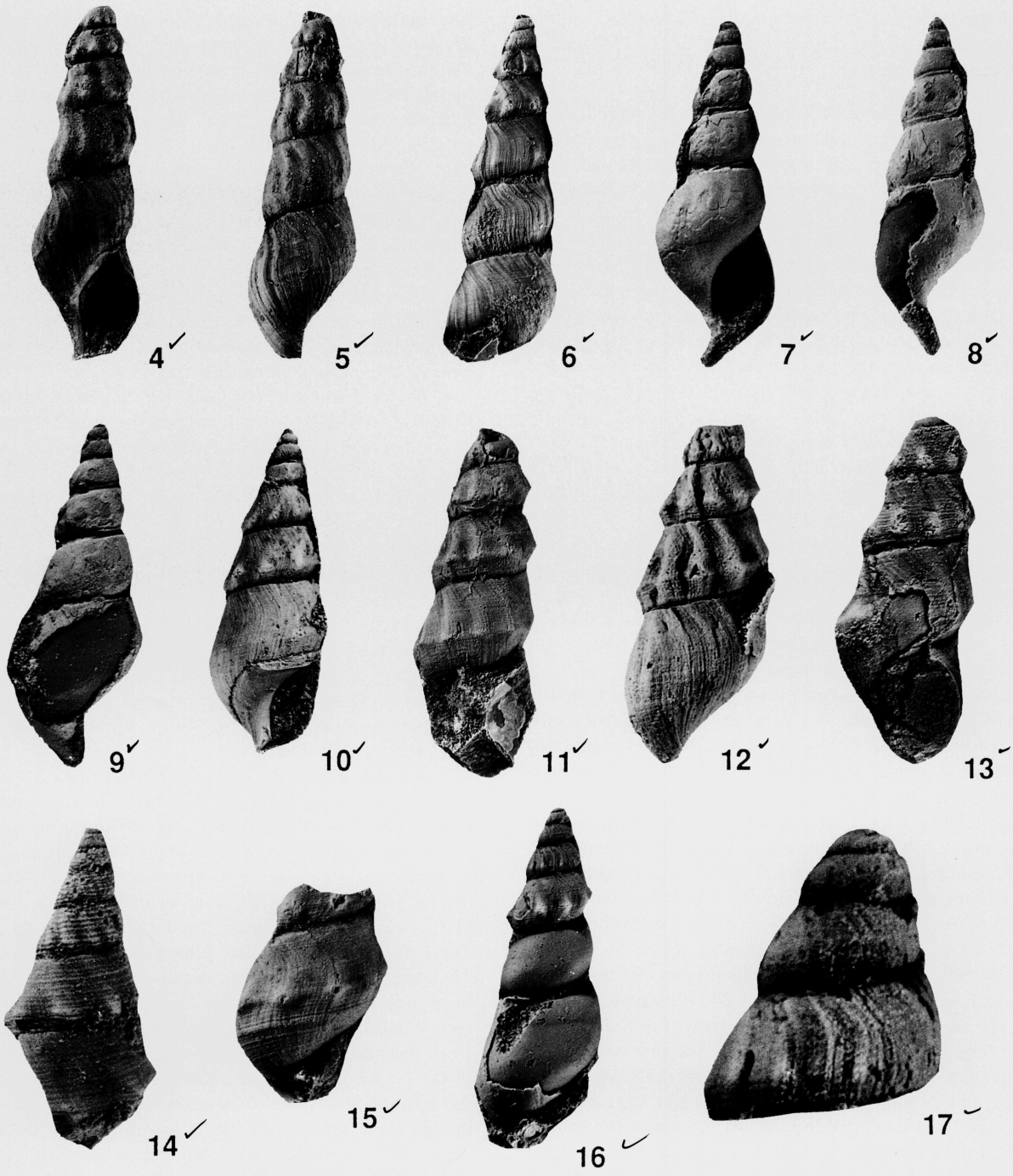

Explanation of Figures 4 to 17

Specimens coated with ammonium chloride.

Figures 4 to 17. *Boggsia tenuis* (Gabb, 1864). Figures 4-5. Hypotype LACMIP 7898, LACMIP loc. 24340, height 22.7 mm, ×2.4. Figure 4. Apertural view. Figure 5. Abapertural view. Figure 6. Hypotype LACMIP 7899, LACMIP loc. 24081, abapertural view, height 19.7 mm, ×2.7. Figures 7-9. Hypotype LACMIP 7900, LACMIP loc. 24340, shell material partially decorticated, height 15.2 mm, ×3.5. Figure 7. Apertural view. Figure 8. Left-lateral view. Figure 9. Abapertural view. Figure 10. Hypotype LACMIP 7901, LACMIP loc. 24081, apertural view, height 13.5 mm, ×3.7. Figure 11. Hypotype LACMIP 7902, LACMIP loc. 24340, apertural view, height 18.7 mm, ×2.9. Figure 12. Hypotype LACMIP 7903, LACMIP loc. 22406, abapertural view, height 13.4 mm, ×3.9. Figure 13. Hypotype LACMIP 7904, LACMIP loc. 23637, apertural view, height 16.6 mm, ×3.2. Figure 14. Hypotype LACMIP 7905, LACMIP loc. 23637, right-lateral view, height 8.3 mm, ×6. Figure 15. Hypotype LACMIP 7906, LACMIP loc. 24081, left-lateral view, height 7.4 mm, ×4.7. Figures 16-17. Hypotype LACMIP 7907, LACMIP loc. 10832. Figure 16. Abapertural view, height 13.5 mm, ×3.9. Figure 17. Abapertural view of protoconch and uppermost spire, height 2.5 mm, ×17.

Geologic age: Early Campanian in California, middle Campanian in Washington, and middle to late Campanian in British Columbia.

Discussion: A total of 683 specimens were studied. Preservation is poor to excellent, and there is no obvious evidence of abrasion. Specimens that have retained their protoconchs, however, are very rare. Nearly all the specimens are juveniles (less than about 15 mm high).

Specimens of *B. tenuis* in northern California are known from 17 localities: 10 from the Chico Creek area, one from the Butte Creek area, and six from the Pentz area (Figure 1). Specimens from Chico Creek range from the lowermost part of the Ten Mile Member of the Chico Formation to near the top, but are more common in the lowermost part. Their range extends throughout Chron 33R and into Chron 33N (= early Campanian). A single specimen from Butte Creek was collected from the lowermost part of the Ten Mile Member and is also early Campanian in age, utilizing the detailed molluscan biostratigraphic work by Saul (1959). Russell et al. (1986) and Baum et al. (1987) inferred that this member at Chico Creek consists of inner shelf sediments deposited by storm-surge events and that the fossils accumulated in lensoidal shell lags. Russell et al. (1986) inferred that the basal part of the Ten Mile Member at Butte Creek represents a shoreface environment.

Specimens from the Pentz area were collected from the lower Chico Formation in the informal Pentz Road member of Russell et al. (1986), who reported the member to be early Campanian in age, based on the ammonites *Submortoniceras chicoense* (Trask) and *Baculites chicoensis* (Trask). The presence of the gastropod *Anchura callosa* Whiteaves, 1903, in these rocks suggests, utilizing the work of Elder & Saul (1996), that the Pentz Road member is similar in age to the lower Ten Mile Member of Chico Creek. The depositional environment of these particular rocks will be discussed below.

Specimens are present in great numbers in the Pentz area at LACMIP locs. 10832 and 24340, where 370 and 118 specimens were found, respectively. Fifty specimens were found at LACMIP loc. 24081. The few adult specimens that have been found are from LACMIP locs. 24081 and 24340. The best preserved and largest specimens are from LACMIP loc. 24340. Specimens of *B. tenuis* that have retained their anterior canal are rare and are also from this locality. One of these specimens (hypotype LACMIP 7900) that best shows the anterior canal is illustrated in Figures 7 to 9. The smooth-looking shell of this specimen is only an apparent feature because much of the shell material has been removed by weathering. The second best locality for preservation is LACMIP loc. 24081.

Whiteaves (1879) reported two specimens of "*Potamides*" *tenuis* from Upper Cretaceous strata on the northwest side of Denman Island, British Columbia, and other specimens from Upper Cretaceous strata on Sucia Island, Washington. In 1903, he corrected himself and reported that the Denman Island specimens were actually from the northwest side of nearby Hornby Island and that the Sucia Island specimens are not "*P.*" *tenuis*. We obtained Whiteaves' (1879:pl. 15, fig. 8a–c) hypotype GSC 5762 of "*P.*" *tenuis* that was collected from the northwest side of Hornby Island (latitude 49°35″, longitude 124°43″), which is just offshore of the east-central part of Vancouver Island, British Columbia. The specimen belongs to *B. tenuis*. The exact locality where it was collected is indefinite but is most likely from within the Spray Formation, to which Elder & Saul (1996) assigned a middle to late Campanian age. The Hornby Island occurrence is the youngest, as well as the northernmost, record of *B. tenuis*.

A few specimens of *B. tenuis* from Sucia Island (LACMIP loc. 10442) were detected in the LACMIP collection. They are from the Cedar District Formation, which Muller & Jeletzky (1970) assigned a Campanian age. Elder & Saul (1996) refined the age of this formation as middle Campanian.

Whiteaves (1879) also named and described *Potamides tenuis*, variety *nanaimoensis* Whiteaves (1879:121–122, pl. 15, figs. 9, 9a) from the northwest side of Hornby Island in strata that Elder & Saul (1996) tentatively assigned to the Spray Formation of late middle to late Campanian age. Elder & Saul (1996) reported also that Whiteaves (1879) based his description of this "variety" on juvenile specimens belonging to the apporhaiid *Anchura nanaimoensis* (Whiteaves).

The specimens of *Boggsia* from the United States and Canada extend the geologic range of this genus into the Late Cretaceous (Campanian) and extend the geographic range into western North America. Previously, the genus was only known as two Eocene species from the extreme northernwestern part of Peru, South America. Woods (1922) originally assigned these two species to genus *Turritella*, although he was somewhat reluctant to do so. They are *Turritella anceps* Woods (1922:81, text fig. 8, pl. 8, figs. 12, 13; pl. 9, figs. 1, 2) and *Turritella annectens* Woods (1922:81–82, pl. 9, figs. 3, 4). The former is from nearshore sandy deposits containing beach pebbles in the Negritos Formation, and the latter is mainly from the Parinas Sandstone. Marsaglia & Carozzi (1991) correlated these formations to the lower Eocene. Both species are represented by plentiful specimens. Olsson (1929:12–13, unfigured) assigned these two species to his genus *Boggsia*. He noted that the genus had a marine rather than a freshwater habit.

Russell et al. (1986:191–192, fig. 12) reported that the Upper Cretaceous strata in the Pentz area comprise the estuarine facies of their Pentz Road member (informal). They described this member as containing faunal assemblages that represent shallow-marine to brackish conditions. They referred to the faunal assemblage containing the specimens of *Potamides tenuis* as the "*Potamides ten-*

uis assemblage" and reported it to contain a mixture of soft-bottom bivalves and transported rocky shoreline gastropods that were deposited under estuarine conditions. Our findings dispute this paleoenvironmental interpretation. *Boggsia tenuis* (Gabb) was not a rocky shoreline dweller. Rather, it was a soft-bottom dweller and probably a shallow burrower, as indicated by its short anterior canal. In the Pentz area, specimens of *B. tenuis* are associated with a moderately diverse assemblage of subtidal, shelf-dwelling mollusks, such as ammonites. We see no indication that the specimens of *B. tenuis* were deposited under estuarine conditions.

Most melanopsids have a body whorl with a robust cylindrical shape and an aperture with an anterior notch, but lacking an anterior canal. Some melanopsids, however, have a short but distinct anterior canal. Those that are similar to *Boggsia* in that they have a turriculate shape, as well as a distinct anterior canal, are certain fossil forms of "*Faunus*." The aperture of *Boggsia tenuis* is very similar to "*Faunus*" *cerithiformis* (Watelet, 1851: 121, pl. 1, figs. 1, 2) from uppermost Paleocene (Sparnacian) strata in the Paris Basin, France. A well-preserved LACMIP collection specimen of this species from Pourcy, France, has a curved, spoutlike anterior canal just like *Boggsia*. *Boggsia tenuis* differs from "*F.*" *cerithiformis* by being smaller, narrower, and having axial ribbing.

The spoutlike anterior canal of *Boggsia tenuis* is also very similar to that of "*Faunus*" *dufresnei* (Deshayes, 1825:120, pl. 12, figs. 3, 4; Cossmann & Pissarro, 1910–1913:pl. 19, fig. 117–7; Farchard, 1936:pl. 23, fig. 11) from upper Paleocene (Thanetian Stage) and lower Eocene (Ypresian Stage) strata in Paris Basin, France. *Boggsia tenuis* differs from "*F.*" *dufresnei* in the following features: smaller, narrower, and angulate whorls with axial ribs becoming obsolete on adult whorls rather than more pronounced. Unlike *Boggsia tenuis*, as "*F.*" *dufresnei* becomes more mature, the outer lip thickens considerably, the sculpture on the body whorl becomes very prominent, and the anterior canal becomes much less apparent. "*Faunus*" *dufresnei* is now assigned to genus *Pseudobellardia* Cox, 1931. Wenz (1939:fig. 2003 a–d) figured the growth stages of a species of *Pseudobellardia*, and he placed *Pseudobellardia* in the melanopsids.

In 1991, Houbrick discussed *Faunus sensu stricto* and put the single living species, *Faunus ater* (Linnaeus, 1758) in subfamily Melanopsinae of family Thiaridae. It is important to mention, however, that on *Faunus ater* the anterior canal has been replaced by a wide, deep sinus. *Faunus ater* does not have an anterior canal, and in this respect is unlike "*F.*" *cerithiformis* and "*F.*" *dufresnei*.

Tracey et al. (1993) reported the geologic range of melanopsids to be Late Cretaceous (Turonian) to Recent, but this range can be emended based on a report by Kollman (1984) of a melanopsid species from Baja California, Mexico. Allison (1955) used the name *Microschiza* (*Cloughtonia*) *scalaris* (Conrad, 1852) for this earliest species and assigned it to family Pseudomelaniidae. Kollman (1984) placed the species in the melanopsid genus *Megalonoda* Kollmann, 1984. *Megalonoda scalaris* is the earliest member of the family and is of Early Cretaceous (Albian) age. It is from the Alisitos Formation, Baja California, Mexico (Allison, 1955). Kollman (1984) reported that this genus is also known from Upper Cretaceous strata in Austria, Greece, and North Africa. Although Kollman (1984) reported that *Megalonoda* is restricted to deposits of brackish water, the deposits in the Alisitos Formation, Baja California, are tropical shallow-marine in origin and are associated with reef corals, nerineid gastropods, caprinid rudistid bivalves, and numerous other shallow-marine invertebrates.

The Cretaceous New and Old World genus *Megalonoda* has a distinctive robust cylindrical shape that closely resembles the late Miocene *Melanopsis handmanniana* Fischer, 1996 [= *Melanopsis fossilis* Wenz, 1929, *fide* Fischer, 1996] from Austria and the Recent *Melanopsis* (*Canthidomus*) *costata* Férussac, 1828, from Syria and Jordan. It could be that during the Late Cretaceous, the marine *Megalonoda* migrated from Baja California, Mexico, to Europe, where the genus adapted to brackish and freshwater environments and has endured in those environments ever since.

Melanopsids live today in a variety of freshwater to brackish-water habitats, including saline lakes, freshwater lakes, rivers, streams, and springs in the areas surrounding the Mediterranean Sea, the Black and Caspian seas, and in New Zealand and New Caledonia (Tchernov, 1975; Geary, 1990). Transition of marine forms to freshwater forms might have occurred in Late Cretaceous times, according to Bandel (1993). Bandel & Riedel (1994) reported several smooth-shelled genera of melanopsids from Upper Cretaceous (upper Santonian-?lower Campanian) freshwater deposits in the Ajka region, Bakony Mountains, Hungary. From Paleocene to late Eocene time, many Paris Basin species (Cossmann & Pissarro, 1910–1913) seem to have inhabited brackish and shallow-marine environments (Tracey et al., 1993). At least one late Oligocene subspecies is known from Hungary (Báldi, 1973), and several late Miocene and Recent species are known from central and eastern Europe (Geary, 1990; Fischer, 1996).

None of the ancient or Recent Old World melanopsids resembles the shape of *Boggsia*, possibly because the shell of *Boggsia* was adapted for living in a shallow-marine environment. This habitat also allowed for a much wider paleogeographic distribution than if *Boggsia* had been restricted to brackish or freshwater habitats.

A review of the scant literature revealed that fossil melanopsids are not likely to be part of an admixed molluscan fauna consisting of freshwater species and shallow-marine species. For example, Bandel & Riedel (1994) reported that although the melanopsid-bearing Upper Cretaceous (upper Santonian/?lower Campanian) freshwater

deposits in the Bakony Mountains of Hungary were part of a river-mouth coastal swamp near a sea, the molluscan fauna consists only of typical freshwater forms containing fully grown unionid bivalve shells. Similarly, Geary (1990) reported that late Miocene melanopsids in scattered freshwater deposits from the margins of the Pannonian basin of eastern and central Europe never co-occur with marine organisms.

Boggsia tenuis closely resembles *Brotiopsis wakinoensis* (Kobayashi & Suzuki, 1936) from Lower Cretaceous (Barremian) brackish-water deposits of Japan and Lower Cretaceous freshwater deposits of South Korea. Kase (1984:127–128, pl. 20, figs. 1–6) illustrated this species, and the specimen in his figure 4 especially resembles *B. tenuis* in terms of the slender turriculate shell with opisthocline and spinose axial ribs. *Brotiopsis wakinoensis*, which shows considerable variability, is imperfectly known and is represented by incomplete external molds of juvenile to early adult? specimens. The anterior part of the aperture and the protoconch are unknown. It is possible that with better preserved material, *Brotiopsis wakinoensis* might prove to be a melanopsid. If so, it would be the earliest one.

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LITERATURE CITED

ABBASS, H. L. 1973. Some British Cretaceous gastropods belonging to the families Procerithiidae, Cerithiidae and Cerithiopsidae (Cerithiacea). Bulletin of the British Museum (Natural History) Geology 23(2):105–175, pls. 1–8.

ALLISON, E. C. 1955. Middle Cretaceous Gastropoda from Punta China, Baja California, Mexico. Journal of Paleontology 29(3):400–432, pls. 40–44.

ANDERSON, F. M. 1958. Upper Cretaceous of the Pacific coast. The Geological Society of America Memoir 71:1–378, pls. 1–75.

BÁLDI, T. 1973. Mollusc Fauna of the Hungarian Upper Oligocene/Egerian. Akadémiai Kiadó: Budapest. 511 pp., 51 pls.

BANDEL, K. 1993. Caenogastropoda during Mesozoic times. Scripta Geologica, Special Issue 2:7–56, pls. 1–15.

BANDEL, K. & F. RIEDEL. 1994. The Late Cretaceous gastropod fauna from Ajka (Bakony Mountains, Hungary): a revision. Annalen des Naturhistorischen Museums in Wien 96A:1–65, pls. 1–16.

BAUM, S. L., R. WATKINS & J. S. RUSSELL. 1987. Inner shelf storm-surge deposits of Late Cretaceous Chico Formation, northeastern Sacramento Valley, California [Asbtract]. American Association of Petroleum Geologists Bulletin 71(5):528.

CONRAD, T. A. 1852. Description of the fossils of Syria collected in the Palestine expedition. Pp. 211–235, pls. 1–8 in Official Report of the U. S. Expedition to the Dead Sea. Baltimore.

COSSMANN, M. & G. PISSARRO. 1910–1913. Iconographie complète des coquilles fossiles de l'Éocène des environs de Paris. Tome 2. Scaphopodes, Gastropodes, Brachiopodes, Céphalopodes & Supplement. Paris. 65 pls.

COX, L. R. 1931. A contribution to the molluscan fauna of the Laki and basal Khirthar groups of the Indian Eocene. Transactions of the Royal Society of Edinburgh 57:25–92, pls. 1–4.

DAVIES, A. M. & F. E. EAMES. 1971. Tertiary Faunas, a Text-Book for Oilfield Palaeontologists and Students of Geology. Vol. 1. The Composition of Tertiary Faunas. Revised by F. E. Eames. George Allen and Unwin: London. 571 pp.

DESHAYES, G. P. 1824–1837. Description des coquilles fossiles des environs de Paris. Vol. 2, 4 parts. Paris. 814 pp.

ELDER, W. P. & L. R. SAUL. 1996. Taxonomy and biostratigraphy of Coniacian through Maastrichtian *Anchura* (Gastropod: Aporrhaidae) of the North American Pacific slope. Journal of Paleontology 70(3):381–399, figs. 1–6.

FARCHAD, H. 1936. Étude du Thanétian (landénien marin) du Bassin de Paris. Mémoires de la Société Géologique de France, nouvelle série, Mémoire 30, 103 pp., 6 pls.

FÉRUSSAC, A. E. J. P. J. F. 1828. Monographie des espèces vivantes et fossiles du genre *Melanopsis* et observations géologiques à leur sujet. Mémoires de la Société d'Histoire Naturelles de Paris 1:132–164.

FISCHER, W. 1996. Beiträge zur Kenntnis der rezenten und fossilen Melanopsidae V. (*Melanopsis handmanniana nov. nomen* und *Melanoposis fossils* (Gmelin 1790), Gastropoda, Prosobranchia). Club Conchylia Informationen 28(1–2):25–38, figs. 1–18.

GABB, W. M. 1864. Description of the Cretaceous fossils. California Geological Survey, Palaeontology 1:57–243, pls. 9–32.

GABB, W. M. 1869. Cretaceous and Tertiary fossils. California Geological Survey, Palaeontology 2:1–299, pls. 1–36.

GEARY, D. H. 1990. Patterns of evolutionary tempo and mode in the radiation of *Melanopsis* (Gastropoda; Melanopsidae). Paleobiology 16(4):492–511.

HOUBRICK, R. S. 1988. Cerithioidean phylogeny. Pp. 88–128 in W. F. Ponder (ed.), Prososbranch Phylogeny. Malacological Review, Supplement 4.

HOUBRICK, R. S. 1991. Anatomy and systematic placement of *Faunus* Montfort 1810 (Prosobranchia: Melanopsinae). Malacological Review 24:35–54.

KASE, T. 1984. Early Cretaceous Marine and Brackish-Water Gastropoda from Japan. National Science Museum: Tokyo. 263 pp., 31 pls.

KOBAYASHI, T. & K. SUZUKI. 1936. Non-marine shells of the Naktong-Wakino Series. Japanese Journal of Geology and Geography 13(3–4):243–257, pls. 27–29.

KOLLMANN, H. A. 1984. *Megalonoda* n. gen. (Melanopsidae, Gastropoda) aus de Oberkreide der Nördlichen Kalkalpen (Österreich). Annalen des Naturhistorischen Museums in Wien 86A:55–62, pls. 1–2.

LINNAEUS, C. 1758. Systema Naturae, per Regna Tria Naturae, Secundum Classes, Ordines, Genera, Species, cum Characteribus, Differentiis, Synonymis, Locis. Tomus 1. Editio 10, Reformata. Laurentii Salvii: Holmiae. 824 pp.

MARSAGLIA, K. M. & A. V. CAROZZI. 1991. Depositional environments, sand provenance, and diagensis of the basal Salina Formation (lower Eocene), northwestern Peru. Journal of South American Earth Sciences 3(4):253–267.

MULLER, J. E. & J. A. JELETZKY. 1970. Geology of the Upper