

DISTRIBUTION OF FORAMINIFERA OF THE GENUS *BOLIVINA* IN CANADA DE ALISO, VENTURA COUNTY, CALIFORNIA

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ABSTRACT. This report presents a discussion and graphic analysis of the morphology, relative abundance, and ecology of several members of the foraminiferal genus *Bolivina* found in an outcrop section of Tertiary marine strata in southern California. The investigation is a preliminary step in the process of formulating a stratigraphic classification of Upper Cenozoic formations of the California province.

INTRODUCTION.

Canada de Aliso² is a California Coast Range canyon exposing an exceptionally complete section of late Tertiary strata in continuous outcrop. More than 17,000 feet of marine beds are found; no important faults hinder the stratigraphic allocation of samples. Moreover, some zones³ here aggregate several hundred feet or more, whereas elsewhere these same zones total only a few feet in thickness. The section has been reported upon by numerous geologists, among whom is Cartwright,⁴ so there can be little doubt concerning the general accuracy of the sequence.

BASIS OF THE REPORT.

Field methods. A plane-table traverse controlling the section was prepared by H. B. Rathwell and E. R. Baddley. The samples were collected by the geological departments of The Texas Company and Continental Oil Company during April, 1932.

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² Located on the south slope of Sulphur Mountain, Ventura County, California, about 13 miles north of the town of Ventura. On the Ventura quadrangle map, by the U. S. Geological Survey, it extends from a point measuring 47 millimeters east and 26 millimeters north of Lacrosse junction, to a station 75 millimeters east and 62 millimeters south of the same junction.

³ The word "zone" is used in a restricted sense to mean a thickness of strata defined by paleontological evidence.

⁴ Cartwright, Lon D. Jr.: "Sedimentation of the Pico formation in the Ventura quadrangle, California," Bull. Amer. Assoc. Pet. Geol., Vol. 12, no. 3, pp. 235-269, 12 figs. in text, 1928.

Laboratory technique. The samples were prepared in the laboratory of The Texas Company, Los Angeles, California. Due precautions were taken to prevent contamination. The segregated specimens were mounted and carried to the Cushman Laboratory for Foraminiferal Research at Sharon, Massachusetts,⁵ where determinations were made by direct comparison with type material.

EXPLANATION OF CHART.

The accompanying chart shows graphically the ranges and relative abundance of the several bolivines discussed herein. The names of the species are listed across the top. In direct vertical line beneath each species are inserted heavy lines denoting their apparent ranges (dotted if the species are sporadic). The short horizontal lines bisected by the vertical range lines of each species indicate (1) relative abundance⁶ by their width, and (2) stratigraphic placement by their position on the chart. The stratigraphic position of any sample is determined by carrying the line horizontally onto the lithologic column on the left.

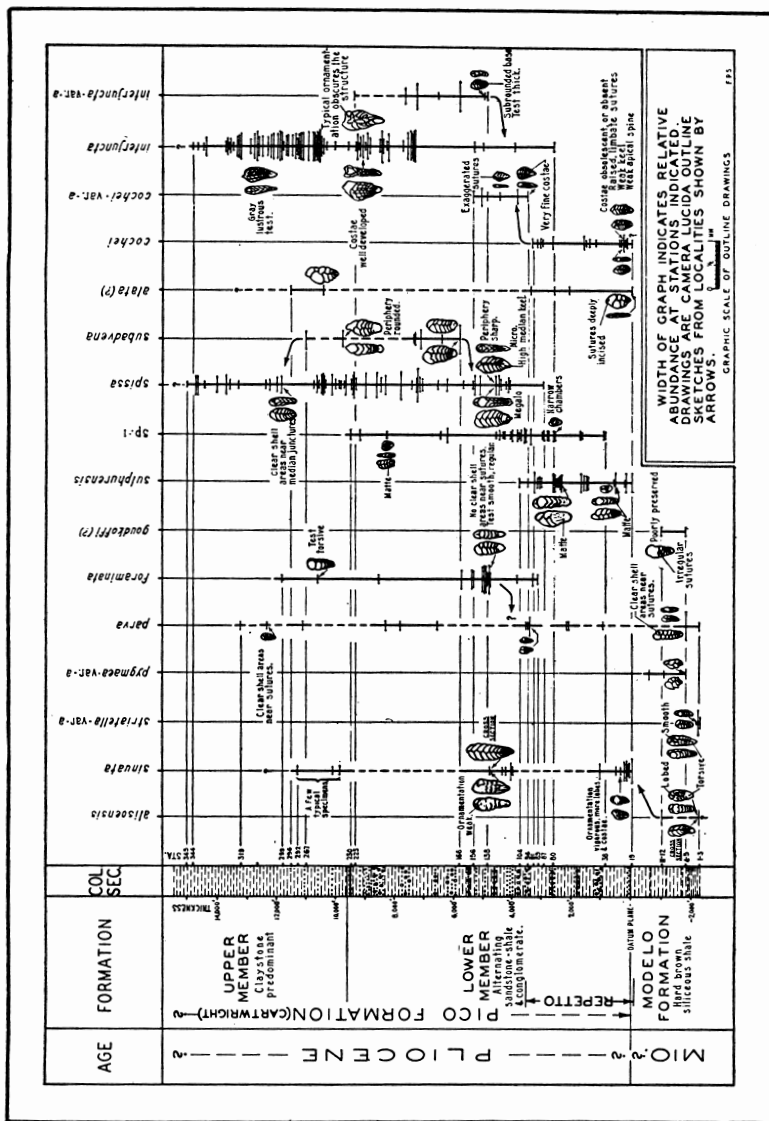
The stratigraphic location of some of the collecting stations is indicated on the right side of the lithologic column; on the left is shown thickness in feet, measured from the datum plane used in this study, namely, the base of the lowest Pico sandstone.⁷

Camera lucida outline sketches of some of the specimens from localities indicated by light arrows are also presented on this chart. All sketches were made to the same scale, indicated graphically on the lower right.

⁵The author acknowledges the assistance of a Grant-in-Aid from the National Research Council during 1934 for this purpose. He is also grateful to Joseph A. Cushman and Hubert G. Schenck for their helpful coöperation.

⁶Roughly determined by examining the concentrate after washing and screening the original rock material. Resultant figures were translated to their logarithms; these logarithms were used to measure the lengths of the horizontal lines.

⁷The lowest 3500 feet of the Pico formation shown on the chart, as well as approximately 25 feet of the subjacent Modelo formation may be correlated with the Repetto formation at the type locality. For a discussion and definition of the Repetto formation, see U. S. Geological Survey, Guidebook 15, Excursion C-1, XVI International Geol. Congress, page 31, footnote 4, 1932.



CATALOG OF SPECIES.

Bolivina alisoensis Cushman and Adams.

Bolivina sinuata Galloway and Wissler, var. *alisoensis* Cushman and Adams; Contr. Cushman Lab. Foram. Res., Vol. 11, pt. 1, pp. 19-20, Pl. 3, Figs. 5a, b, 1935.

Type locality: Canada de Aliso, in brown earthy shale, 31 feet stratigraphically below a conspicuous, finely laminated gray "paper shale" member of the Modelo formation, approximately 2330 feet stratigraphically below the first Pico sandstone.

This bolivina differs from *Bolivina sinuata* in its weaker ornamentation and lack of definite costae. The upper part of the test is covered by weak lobose processes.

Bolivina modeloensis Cushman and Kleinpell⁸ has larger lobes; its surface ornamentation does not obscure the sutures to as great a degree.

Another similar form is *Bolivina floridana* Cushman.⁹ The holotype has a thick, lustrous test, and is more completely lobed than our form.

Bolivina sinuata Galloway and Wissler.

Bolivina sinuata Galloway and Wissler; Jour. Paleo., Vol. 1, no. 1, pp. 71-72, Pl. 11, Fig. 9, 1927.

Type locality: "Middle bed of Decomposed Marine Shell and Bone Quarry, north side of Palos Verdes Hills, 20 miles south of Los Angeles, California, and two miles south of the town of Lomita."

Several variants of this species occur in the section at Canada de Aliso. One of these, *Bolivina alisoensis*, has been graphed separately.

The typical form is found at several stations in the upper part of the section, between 10,075 and 11,280 feet stratigraphically above the base of the lowest Pico sandstone. This typical *sinuata* is distinguished by the four rows of broad indistinct costae grading into lobulate processes.

⁸ *Bolivina modeloensis* Cushman and Kleinpell, Contr. Cushman Lab. Foram. Res., Vol. 10, Pt. 1, pp. 10-11, Pl. 2, Figs. 4a, b, 1934.

Type locality: "Miocene, lowermost Modelo, Dry Canyon road, South of Calabasas, near north line of Sec. 35, T 1 N, R 17 W, California."

⁹ *Bolivina floridana* Cushman, U. S. Geol. Survey, Bull. 676, p. 49, Pl. 10, Fig. 4, 1918.

Type locality: "Choctawhatchee marl, 1 mile south of Red Bay, Florida."

A variant appearing between 4025 and 9880 feet stratigraphically above the datum plane is less ornamented. It is sometimes identified as *Bolivina decussata* H. B. Brady,¹⁰ but the fossils are not as heavily lobed as the Recent species.

Still another variant is present in the lowest one thousand feet of the Pico formation; it is smaller than the typical, has more distinct ornamentation, and more numerous bifurcating costae and lobes.

Thin sections were made of a number of specimens ascribed to this species. Several sketches of these are shown on the chart. The heavy ornamentation makes the sutures appear almost horizontal in external view, actually they are pendant, in outline similar to *Bolivina spissa*.

Bolivina striatella Cushman, var. *a*.

Bolivina advena Cushman, var. *striatella* Cushman; Contr. Cushman Lab. Foram. Res., Vol. I, Pt. 2, p. 30, Pl. 5, Figs. 3a, b, 1925.

Type locality: "Miocene, Monterey shale, Sect. 24 T 28 S, R 14 E, San Luis Obispo County, California."

not *Bolivina jacksonensis* var. *striatella* Cushman and Applin; Bull. Amer. Assoc. Pet. Geol., Vol. 10, no. 2, pp. 167-168, Pl. 7, Figs. 5, 6, 1926.

The variety of the Monterey bolivine here figured was found in brown earthy shale, approximately 31 feet stratigraphically below the base of a prominent, chalky-weathering siliceous "paper shale" member of the Modelo formation (Miocene), approximately 2331 feet stratigraphically below the lowest Pico sandstone.

These differ from typical *striatella* only in the lesser lobation of the chambers and in the lack of distinct striae.

Bolivina pygmaea H. B. Brady, var. *a*.

Bolivina pygmaea H. B. Brady, Rept. Sci. Results Voyage H. M. S. Challenger during years 1873-76, p. 421, Pl. 53, Figs. 5, 6, 1884.

Type locality: "Challenger" station 145, off Prince Edward Island.

The fossil has high, broad, irregularly overlapping chambers,

¹⁰ *Bolivina decussata* H. B. Brady, Rep. Sci. Results Voyage H. M. S. Challenger during years 1873-1876, p. 423, Pl. 53, Figs. 12-13, 1884.

Type locality: "Challenger" station 300, north of Juan Fernandez.

and a thicker test than the Recent species illustrated by Brady. It resembles certain Recent specimens identified as this species by Cushman¹¹ from off the west coast of North America.

The specimens are rare and poorly preserved in some of the Miocene beds at Canada de Aliso. More abundant material may demonstrate that these are worthy of a specific name.

The species has been reported from several stations in Natland's Zones III and IV,¹² from off the Channel Islands of California, at depths between 700 and 2200 feet, in water of temperature 9° C to 5.5° C.

Bolivina parva Cushman and Galliher.

Bolivina hughesi Cushman, var. *parva* Cushman and Galliher, Contr. Cushman Lab. Foram. Res., Vol. 10, Pt. 1, pp. 25-26, Pl. 4, Figs. 10a, b, 1934.

Type locality: "Miocene, Monterey shale, West fork of Canyon Segundo, 108.7 mm. East, 105 mm. (on Map) North of intersection Lat. 36° 30' N, Long. 121° 55' W, Monterey Quadrangle, California."

This species exhibits minute clear shell areas on the upper part of the chambers near the sutures, which are somewhat horizontal, features characteristic of *Bolivina seminuda*. It is distinguished from the latter by the smaller, more torsive test, and narrower chambers.

The range is extensive and sporadic in this section. It is abundant at only one of the stations, i.e., near the top of a prominent siliceous, chalky weathering "paper shale" member of the Modelo formation, (Miocene) and approximately 1900 feet stratigraphically below the base of the lowest Pico sandstone.

Bolivina foraminata R. E. & K. C. Stewart.

Bolivina seminuda Cushman, var. *foraminata* R. E. and K. C. Stewart; Journal of Paleontology, Vol. 4, no. 1, p. 66, Pl. 8, Figs. 5a, b, 1930.

Type locality: "Lower Pico shales exposed along the coast

¹¹ Cushman, J. A.: Bull. Scripps Inst. Oceanography, Tech. Ser., Vol. 1, no. 10, p. 56, Pl. 3, Fig. 9, 1927.

¹² Natland, M. L.: The temperature and depth-distribution of some Recent and fossil Foraminifera in the Southern California region; Bull. Scripps Inst. Oceanography of the University of California, La Jolla, California, Tech. Ser., Vol. 3, no. 10, pp. 225-230, and chart, 1933.

east and north of Pitas Point, SE $\frac{1}{4}$ sec. 22, T 3 n, R 24 W, Ventura County, California."

This bolivine closely resembles the typical *Bolivina seminuda* Cushman¹³ in size, general structural pattern, and nature of wall material. It differs in that typical areas of clear shell are absent near the sutures.

Bolivina foraminata ranges from 3170 feet to 11,780 feet stratigraphically above the base of the lowest Pico sandstone at Canada de Aliso. Its living relative, *Bolivina seminuda*, is found in Zone IV of Natland's chart¹² approximately 1000 to 2200 feet below sea level, in water of temperature 8.5 to 5.04 C.

Bolivina goudkoffi (?) Rankin.

Bolivina goudkoffi Rankin, in Cushman and Kleinpell, Contr. Cushman Lab. Foram. Res., Vol. 10, Pt. 1, p. 22, Pl. 4, Figs. 4, 5, 1934.

Type locality: "Miocene, stratigraphically 2040 feet above base of Modelo formation as exposed along road from Girard to Mohn Spring, Santa Monica Mountains, California."

A few specimens were found in the Miocene strata at Canada de Aliso, too poorly preserved for definite determination. The species to which these are doubtfully referred has a similar structure.

Bolivina sulphurensis Cushman and Adams.

Bolivina subadvena Cushman var. *sulphurensis* Cushman and Adams; Contr. Cushman Lab. Foram. Res., Vol. 11, Part 1, p. 20, Pl. 3, Figs. 8, 9, 1935.

Type locality: Canada de Aliso, 250 feet stratigraphically above base of first Pico sandstone.

In general shape and in the pattern of sutures, this is closely allied to *Bolivina spissa*. It differs in that the lower portion of the test is obscured by filamentous processes. The pointed, or microspheric, specimens lack the raised median line found in corresponding individuals of *Bolivina spissa*. Those with a rounded base, or megalospheric specimens, are less lobed than the corresponding phase of *Bolivina spissa*.

¹³ *Bolivina seminuda* Cushman, U. S. Nat. Museum, Bull. 71, Pt. 2, p. 34, Fig. 55, 1911. (The type figure should be redrawn)

Type locality: Recent, Bering Sea.

Bolivina sp. 1.

This provisional arrangement is used for listing one or more species of small bolivines, in shape elongate to subspatulate, having minute hairy processes across the lower face. The chambers are narrow, flanked by slightly raised, geniculate sutures. It is usually poorly preserved.

Our forms do not appear to have the strongly geniculate sutures typical of *Bolivina vaughani* Natland.¹⁴ Some specimens resemble *Bolivina ornata* Cushman,¹⁵ but are distinguished by the smaller size, narrower periphery, and raised sutures.

This form is rare throughout its range of approximately 7500 feet of strata at Canada de Aliso.

Bolivina spissa Cushman

Bolivina subadvena Cushman, var. *spissa* Cushman, Contr. Cushman Lab. Foram. Res., Vol. 2, Pt. 2, p. 45, Pl. 6, Figs. 8a, b, 1926.

Type locality: "Timms Point, San Pedro, California."

This species maintains a relatively constant character throughout its long stratigraphic extent. The earliest individuals are smaller than the geologically younger and more typical specimens. Slightly more lustrous forms are found near the top of the section.

A few scattered individuals that may be doubtfully referred to *Bolivina serrata* Natland¹⁶ have been listed here. A careful check does not reveal any complete or well defined suite that could be ascribed to these forms.

Bolivina spissa and *Bolivina interjuncta* appear to have the same range, as the chart suggests. *Bolivina spissa*, however, is somewhat more common in the lower part of this range; *Bolivina interjuncta* is notably abundant higher in the section.

The species is abundant in the Pacific Ocean off the Channel

¹⁴ *Bolivina vaughani* Natland, Bull. Scripps Inst. Oceanography Univ. Calif., Technical Ser., Vol. 4, no. 5, p. 146, Pl. 5, Fig. 11, 1938.

Type locality: Natland Locality 137, Lat. 33° 33' 17" N, Long. 118° 15' 40" W. Depth 472 meters. Bottom temp. 6.1° C.

¹⁵ *Bolivina subadvena* Cushman var. *ornata* Cushman, Contr. Cushman Lab. Foram. Res., Vol. 1, Part 1, p. 29, Pl. 5, Figs. 2a, b, 1925.

Type locality: "Miocene Monterey shales, Sec. 24, T 28 S, R 14 E, San Luis Obispo County, California."

¹⁶ *Bolivina subadvena* Cushman var. *serrata* Natland, Bull. Scripps Inst. Oceanography Univ. Calif., Technical Ser., Vol. 4, no. 5, pp. 145-146, Pl. 5, Figs. 8, 9, 1938.

Type locality: Natland locality 134, Lat. 33° 35' 33" N, Long. 118° 15' 26" W. Depth 107 meters. Bottom temp. about 10.4° C.

Islands of Southern California in depths between 900 and 2900 feet in water ranging from 8.75 C to 5.04 C.

Bolivina subadvena Cushman.

Bolivina subadvena Cushman, Contr. Cushman Lab. Foram. Res., Vol. 2, Part 2, p. 44, Pl. 6, Figs. 8a, b, 1926.

Type locality: "Timms Point, San Pedro, California."

This heading embraces certain rounded, well-inflated and lobed megalospheric individuals, provisionally regarded as varieties of *Bolivina spissa*. The same material in which these are found also contains specimens with sharp edges and raised median lines, typical of *Bolivina spissa*.

Holotypes of *Bolivina spissa* and *Bolivina subadvena* were collected from the same locality, thus furthering the suspicion that the relationship between these forms is varietal. The stratigraphic range of *Bolivina subadvena* is not over 5000 feet at Canada de Aliso, whereas the range of *Bolivina spissa* exceeds this in both directions. Again, *Bolivina subadvena* is listed as a species of Zone IV by Natland,¹² living on sea bottom between 1650 and 2300 feet deep and in water temperature of 6.5 to 5 C. *Bolivina spissa*, although likewise more abundant at those depths, extends laterally to both shallower and deeper water. This present day distribution may throw some light on the conditions under which the fossils lived.

The species differs from *Bolivina robusta* Brady¹⁷ in the absence of a basal spine, a lack of denticulate processes along the sutures, and in its broader chambers.

Bolivina alata (?) (Seguenza).

Vulvulina alata Seguenza, Atti. Accad. Gioenia Sci. Nat., Ser. 2, Vol. 18, 1862, p. 115, Pl. 2, Figs. 5, 52.

Type locality: Pleistocene of Catania, Italy.

The test of this doubtfully determined species is highly appressed, well-lobed in outline, and has deep, distinct and wavy sutures, with high rounded chambers.

The form is rare and sporadic at Canada de Aliso. It is similar to a specimen illustrated and identified by H. B. Brady¹⁸

¹⁷ *Bolivina robusta* Brady, H. B., Report Sci. Results Voy. H. M. S. Challenger during years 1873-1876, p. 421, Pl. 53, Figs. 7-9, 1884.

Type locality: "Challenger" stations 191A and 174B, off Ki and Fiji Islands.

¹⁸ Brady, H. B., Rep. Sci. Results Voyage H. M. S. Challenger during years 1873-1876, p. 422, Pl. 55, Figs. 2-4, 1884.

as *Bolivina beyrichi* Reuss, var. *alata* Seguenza, reported off the Arron Islands and Philippines. It does not resemble *Bolivina beyrichi* Reuss,¹⁹ which is a more slender species.

Bolivina cochei Cushman and Adams.

Bolivina cochei Cushman and Adams, Contr. Cushman Lab. Foram. Res., Vol. 11, Part 1, p. 19, Pl. 3, Figs. 6, 7, 1935.

Type locality: Canada de Aliso, 260 feet stratigraphically above base of lowest Pico sandstone.

This is a smooth, lustrous species. Under high power magnification and with well-directed illumination, a few wavy costae may be noted near the proloculum.

The species is similar to *Bolivina pisciformis* Galloway and Morrey,²⁰ but has narrower chambers, less pronounced keel and more appressed test in addition to the filaments referred to.

At Canada de Aliso the range amounts to approximately 3500 feet of strata in the lower part of the Pico formation.

Bolivina cochei, var. *a*.

Differs from the typical series in the heavier sutures, larger size, broader chambers, and more pronounced rudimentary costae. The sutures of some specimens are exaggerated and so opaque as to strongly suggest in outline the skeleton of a fish. Other transparent, less appressed individuals are difficult to distinguish from lower ranging varieties of *Bolivina interjuncta*. The chambers are narrower and the test more appressed than the latter.

Bolivina interjuncta Cushman.

Bolivina costata d'Orbigny, var. *interjuncta* Cushman, Contr. Cushman Lab. Foram. Res., Vol. 2, p. 41, 42, Pl. 6, Fig. 3, 1926.

Type locality: "Lomita Quarry, Palos Verdes Hills, California."

The typical series have a complex, interlacing system of costae across the test, which is appressed, sharply spatulate, somewhat torsive and has wide chambers. Considerable variation is evident both as to ornamentation, the degree in which

¹⁹ *Bolivina beyrichi* Reuss, Zeitschr. Deutsch. Geol. Ges., Vol. 3, 1851, Pl. 6, Fig. 51, 1851.

Type locality: Septarien clay, near Berlin, Germany.

²⁰ *Bolivina pisciformis* Galloway and Morrey, Bulls. of Amer. Paleo., Vol. 15, no. 55, p. 36, Pl. 5, Fig. 10, 1929.

Type locality: Mantua, Ecuador.

the latter obscures the test, the transparency of the wall, and amount of torsion. Of a number of possible varieties, but one has been separated herein, as noted.

The species ranges through the greater part of the section, but is more abundant at younger levels. The living representative is distributed through Natland's Zone IV, ranging in depth from 920 to 2725 feet, in water temperature of 8.52 C to 5.04 C.¹²

Bolivina interjuncta, var. *a*.

This fossil is distinguished by a more transparent, less heavily ornamented test than typical *Bolivina interjuncta*. In outline the two are much alike and may not be sharply divided.

Assemblages of this variant appear lower in the section than the main floods of *Bolivina interjuncta*.

SUMMARY.

The purpose of this report is to outline a technique in handling Foraminifera for stratigraphic research. It is presented as a portion of a general program. This program must be followed on a broad scale before any final conclusions may be set forth concerning the definition of true zones in the Upper Cenozoic of California. Kleinpell²¹ has recently instituted such a scheme for the Miocene of California.

The facts regarding the distribution of the foraminiferal genus *Bolivina* have been arranged here into four groups. First, emphasis has been placed upon the occurrences of the species in the local section. Not only are certain named forms present in the Pico formation, but they are distributed within that formation as indicated on the chart. Second, the various species have been finely discriminated. Third, the ecologic distribution of the living species has been partially examined and an inquiry is begun respecting the bearing of this information on the conditions of sedimentation. Finally, the relative abundance of the specimens is depicted graphically by horizontal lines of fluctuating length.

Were it desirable at this time, the chart could be used to indicate provisional zones for testing "zones" set up by other criteria and for comparison with other geological sections. The following could be deduced from the data at hand:

²¹ Kleinpell, R. M.: Miocene stratigraphy of California; Amer. Assoc. Petroleum Geologists, Special publication. December (Tulsa, Oklahoma), 1938.

(a) The composite ranges of *pygmaea*, var. *a* and *goudkoffi* (?) could be used to identify a group of beds overlying strata carrying *alisoensis* and *striatella*, var. *a*.

(b) A belt of strata marked by the ranges of *sulphurensis* and *cochei* may be distinguished from a higher unit. The dividing line between the two may be placed between stations 80 and 104, which mark the range limits of six bolivines. A subordinate zone might be erected for the strata wherein ranges a distinctive variety of *sinuata*, smaller in size and more strikingly ornamented than the typical form found higher in the section.

(c) A third unit would perhaps be marked by the first appearance of *foraminata*, *spissa* and *interjuncta*. It also includes the local range of *subadvena*.

(d) The highest unit may be separated from the others by the sudden and marked increase in abundance of *interjuncta* above a horizon 7350 feet stratigraphically above the datum plane used on the chart.

The foregoing divisions will have to be tested in several ways before postulating a sequence of zones of regional extent. First, since the completeness of the records and the distribution of any species are always subject to modification, the range data given in the accompanying chart should be verified by independent investigation. Second, other genera must be analyzed in the same manner as *Bolivina*. Third, the ecology of the living species must be fully considered. The latter inquiry will not only enable the investigator to determine the sequence of events at any one section, but will also throw light on the constantly posed question: "Is the stratigraphic restriction of this species real or apparent because of changed environmental conditions?" Fourth, other sections must be studied in the same manner, in order to have lateral as well as vertical control. When such research is completed, a trustworthy zonation of the Upper Tertiary strata of California may be established.

LOS ANGELES, CALIFORNIA.