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Upper Cretaceous Planktonic Foraminifera from the Putah Creek Subsurface Section along the Yolo-Solano County Line, California

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ABSTRACT

The Upper Cretaceous planktonic Foraminifera from the Putah Creek subsurface section are described, and six local concurrent-range zones are proposed on the basis of their stratigraphic distributions.

The subsurface section of the Upper Cretaceous along the Putah Creek on the Yolo-Solano County line, in the southwestern part of the Sacramento Valley, comprises seven formations, the Forbes, Guinda, Funks, Sites, Yolo, Venado and one unnamed one in descending order. From these formations 36 planktonic species are discriminated, including one new to science. The species belonging to *Heterohelix, Gublerina, Globigerinelloides, Schackoina, Hedbergella, Praeglobotruncana, Globotruncana* and *Rugoglobigerina* are described, illustrated and their stratigraphic ranges are ascertained. As the result six foraminiferal zones are defined by the overlapping ranges of the planktonic forms, and they are correlated with the stages of the European standard as follows: *Globotruncana imbricata* zone with the lower Turonian, *Globotruncana fornicata/Globotruncana coronata* zone with the upper Turonian, *Hedbergella loetterli* zone with the lower Coniacian, *Globotruncana schneegansi* zone with the upper Coniacian, *Globotruncana arca* zone with the Santonian, and the *Globotruncana subcircumnodifer* zone with the Campanian.

A marked change in the planktonic foraminiferal components is recognized before and after the upper *Globotruncana schneegansi* zone. In this respect, some paleoecological considerations are given based upon the sedimentary environment and climate as related with the change in planktonic species stock. Consequently a change of the sedimentary environment was accompanied with a reduction of the marine area during the later phase of that zone and local prevalence of colder water since the post-*Globotruncana schneegansi* zone.

CONTENTS

INTRODUCTION

In California the first literature on the Cretaceous Foraminifera seems to go back to the nineties. Since then numerous papers were published by the collective effort of workers in stratigraphy and paleontology. Despite the important geographical and economical position of California studies on the geology and paleontology of its Cretaceous System have not progressed so much as compared with those of the Gulf Coast region. However, researches on the Foraminifera advanced steadily with the progress in exploration of the gas and oil fields in California. Among the many contributions on the paleontology of the Foraminifera the works of Goudkoff (1945), Cushman and Todd (1948), Küpper (1955, 1956), Trujillo (1960) and Graham and Church (1963)* are outstanding.

From the view of historical development of the Pacific basin during the Cretaceous Period, investigation of the marine Cretaceous deposits of the Pacific coast of North America and Japan by marine organisms is one of the most outstanding subjects. Matsumoto's recent studies on the ammonites of California and Alaska (1959a, 1959b, 1959c, 1960) are important contributions to this problem. His proposed Cretaceous correlation between both America and Japan stimulated the views on classification and chronology of the Upper Cretaceous deposits of the circum-Pacific region.

Among Foraminifera the planktonic forms can be considered as valuable as the ammonites so far as interregional or intercontinental correlation is concerned. Since Thalmann (1932) first emphasized the significance of the planktonic Foraminifera for widespread correlation, the biostratigraphy of that group progressed rapidly in various countries. This has resulted in the establishment of zones and correlation for which reason it has become necessary to make taxonomical reexaminations and revisions of the group, and this was undertaken by many authors (Bermudez, 1952; Subbotina, 1953; Bolli, Loeblich and Tappan, 1957; Reiss, 1957; Banner and Blow, 1959; Loeblich and Tappan, 1964). The value of the planktonic Foraminifera for stratigraphic correlation, especially for world-wide zonation of the marine Tertiary is upheld also by the increased knowledge on their ecology, morphology and evolutionary trends.

The significance of the genus *Globotruncana* for regional correlation was stressed by Thalmann (1934), and many important contributions to the globotruncanids were given by Gandolfi (1955) and Brönnimann and Brown (1956) in addition to the works mentioned above. The tropical marine fauna of the Late Cretaceous extended far beyond the limits of the modern tropical faunas. In the northern hemisphere the *Globotruncana* fauna extended into about 60°N. latitude during the late Turonian to early Campanian interval (Bandy, 1960). It is shown by Durham (1950) that a warm climate prevailed during the Late Cretaceous to the polar regions farther north than at present and also during the Tertiary. Therefore it is difficult to suppose that there was a differentiation and migration of the *Globotruncana* fauna into various latitudes during the Late Cretaceous. Although no Cretaceous planktonic foraminiferal zones have been established on a world-wide scale, to undertake such a project it is necessary to make an examination of the Cretaceous planktonic species previously proposed, and to accumulate the data on the distribution and paleoecology of the Cretaceous planktonic Foraminifera.

To date there are many important contributions on the planktonic Foraminifera among which the following should be mentioned. The recent revision of the Cenomanian planktonic species by Loeblich and Tappan (1961) is a valuable and very important work. The recent monographic works by Trujillo for the Redding area, California (1960), Tappan for Alaska (1962), and the study by Graham and Church on the Campanian Foraminifera from the Stanford University Campus (1963) have increased our knowledge of the group. Also to be mentioned is the valuable contribution made by Hamilton (1953) on the Upper Cretaceous planktonic Foramininfera from the Mid-Pacific seamount west of Hawaii. This work has given us important information on the Cretaceous history of the Pacific basin.

Since the study on the Cretaceous Foraminifera from Hokkaido (Takayanagi, 1960; Takayanagi and Iwamoto, 1962), the present writer became interested in and desired to know the foraminiferal fauna of California because of its geographic position being on the opposite side of the Pacific Ocean. Very fortunately, Professor Joseph Graham of Stanford

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* For further references, see Graham (1961).

University offered the writer the opportunity to study the Californian material at Stanford University. The present study was done during the one-year stay at Stanford from 1961 to 1962, and the work was continued thereafter at the Tohoku University after the writer's return to Japan.

In the Great Valley of California, Goudkoff's zones which were based upon the Foraminifera (1945) have been generally adopted for correlation of the Cretaceous subsurface geology. Among the 67 diagnostic species listed by him for zonal designation, only three planktonic species, namely, *Globotruncana arca* (Cushman), *G. canaliculata* (Reuss) and *Guembelina globulosa* (Ehrenberg), are mentioned. Thus, it is difficult to evaluate his zones in the light of universal Cretaceous chronology based upon planktonic Foraminifera. Consequently it becomes necessary to investigate the succession of the planktonic Foraminifera in the type sections in order to evaluate his biostratigraphic classification.

In 1951 the Shell Oil Company drilled wells to obtain a complete subsurface standard section of the Upper Cretaceous along the Putah Creek between Yolo and Solano Counties. As mentioned later, a nearly 15,000 feet thick section is exposed along the Putah Creek, where Kirby (1943) divided the Cretaceous into six formations and Goudkoff selected one of his type sections for biostratigraphic division. Fortunately the writer was able to study the Foraminifera from the core samples of the section through the kindness of the Shell Oil Company.

This paper describes the planktonic foraminiferal species from the Upper Cretaceous formations in the Putah Creek area, interprets the foraminiferal assemblages in terms of vertical distribution in the subsurface section to establish planktonic foraminiferal zones, discusses the age of the foraminiferal zones, and also some paleoecological considerations are given on these zones.

Through this study the biostratigraphic relation between Goudkoff's zones and the planktonic foraminiferal zones are examined. However, with regard to their relation with the other type sections of Goudkoff, further study will be required. Because his zones are essentially defined by means of benthonic Foraminifera, which are susceptible to local bottom control. As already proved by his study, the paleogeography of California changed considerably throughout the Late Cretaceous. To analyze the development of the Californian sedimentary basin both benthonic and planktonic Foraminifera together are believed to play an important role. The result of the writer's studies on the benthonic Foraminifera from the Putah Creek subsurface section will be published at another occasion.

ACKNOWLEDGEMENTS

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The writer also thanks the Shell Oil Company for the loan of all Foraminifera slides from the Putah Creek and for the permission to take the material to Japan for continued study. The type specimens dealt with in the study are deposited in the Stanford University Collection. Particular thanks are due to Mr. Edwin H. Stinemeyer of the Bakersfield Office, Shell Oil Company, for making all arrangements with the Shell Management for the loan.

Appreciation and thanks are also extended to the following persons: Mr. Max B. Payne of the Norris Oil Company for his valuable information and advice on the Cretaceous stratigraphy of California; Dr. Alfred R. Loeblich, Jr. of the California Research Corporation and Dr. Helen Tappan Loeblich of the University of California, Los Angeles for their suggestions concerning the Californian micropaleontology; Professor Orville L. Bandy of the University of Southern California for his kind permission to study his type specimens from the Carlsbad area, California; Mr. Cliford C. Church for supplying many foraminiferal specimens for the study; Dr. Andrew W. Marianos of the Humble Oil and Refining Company for his suggestions on some systematic problems; Mr. Alvin A. Almgren of the Union Oil Company for his valuable information on the Cretaceous biostratigraphy of California; Dr. Edwin L. Hamilton of the U.S. Navy Electronic Laboratory for the foraminiferal samples from the Mid-Pacific seamounts; Mr. Arthur Grantz of the U.S. Geological Survey, Menlo Park for the opportunity to study samples from the Alaskan Cretaceous.

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STRATIGRAPHY OF THE PUTAH CREEK AREA

In California the Coast Ranges extends along the Pacific Coast on the west whereas the Sierra Nevada runs parallel with it on the eastern inland side. They are united by the Klamath Mountains in the north and the Tehachapi Mountains in the south. An elongate central alluvial plain of NNE-SSW direction, the Great Valley of California is situated among the mentioned mountain systems. This valley is divided into the Sacramento Valley in the northern part and the San Joaquin Valley in the south. Along the west side of the Sacramento Valley which is the eastern border of the Coast Ranges, there is developed a thick series of marine sedimentary rocks dipping generally eastwards. This series, ranging from Cretaceous to Pliocene in age, is underlain by the Jurassic to Cretaceous Franciscan and Knoxville Groups which comprise the basement along the western side (Fig. 1).

Concerning the geology and paleontology of the Franciscan and Knoxville Groups, there have been many discussions. According to Lachenbruch (1962) who reviewed the geology of the west side of the Sacramento Valley, the results of current studies on both groups can be summarized as follows (p. 55):

> "The Franciscan group, named by Andrew C. Lawson (1895) for typical exposures on San Francisco Peninsula, underlies a major portion of the Coast Ranges from Santa Barbara on the south into southwestern Oregon. It consists of a heterogeneous assemblage of marine clastics, basic volcanics, basic and ultrabasic intrusives (many metamorphosed) with smaller proportions of radiolarian chert and limestone. These are characteristic eugeosynclinal deposits and represent deposition in a tectonically active and rapid subsiding trough. Glaucophane schists and other

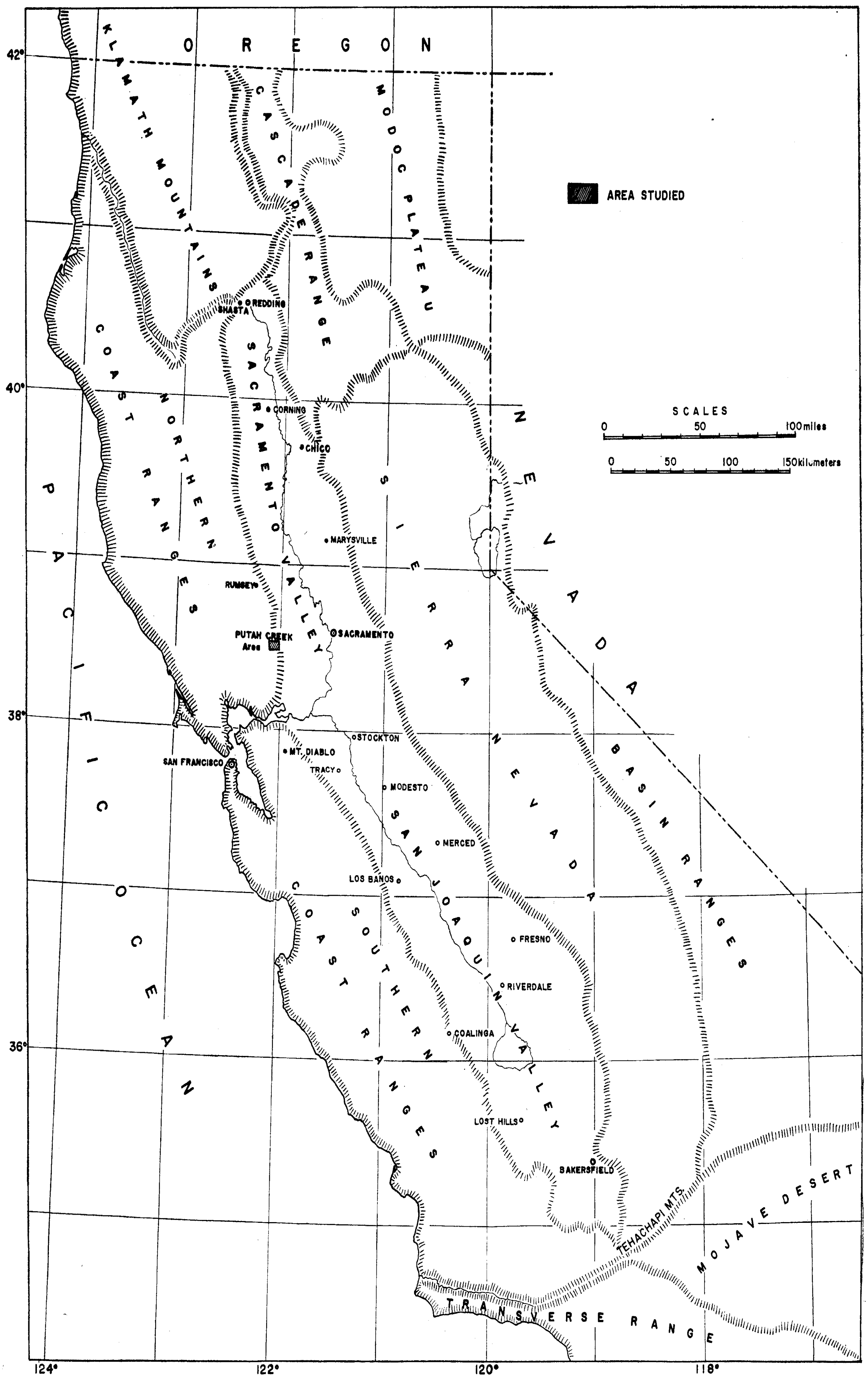

Fig. 1. Map showing the geomorphic provinces of California and the location of the area studied.

> metamorphic rocks are found in the Franciscan in many areas, but slightly metamorphosed phyllites and semi-schists questionably assigned to the Franciscan group are the most common products of metamorphism in the ranges adjacent to the Sacramento Valley. Serpentine or serpentinized igneous rocks are almost universal at or near the contact between the Franciscan and the Knoxville group."
>
> "The term "Knoxville series" was applied by G.F. Becker in 1888 to the deposits that characterize the district about Knoxville, Napa County. Although the term was at times used to include Lower Cretaceous strata, F.M. Anderson (1933 and 1945).... clearly distinguished it from the overlying Lower Cretaceous beds. The Knoxville group includes all the Upper Jurassic rocks exposed on the west side of the Sacramento Valley....The Knoxville is characterized by a predominance of clay shales with subordinate sandstone and conglomerate. The shale is generally interbedded with thin, hard, calcareous, sandstone beds and thin beds and lenses of calcilutite."

As to the relationship between the Franciscan and Knoxville Groups he also stated (p. 58):

> "The Franciscan and Knoxville groups are in fault contact almost the entire length of the Sacramento Valley. In northern Tehama and Shasta Counties, however, the Knoxville(?) rest unconformably upon metamorphosed Paleozoic and Mesozoic rocks of the Klamath Mountains complex. At one locality, ... the strata unconformably underlying the Knoxville (?) may possibly be Franciscan. Franciscan-like debris consisting of basalt, red and green chert, and serpentine, in some of the basal and lower Knoxville conglomerate in different parts of the outcrop area, suggest that the part of the Franciscan formation may predate the Knoxville and may have been locally exposed to erosion prior to and during early Knoxville deposition. However, one formation of the Klamath Mountains complex resembles lithologically the Franciscan — and many of the pebbles mentioned above could be derived therefrom."

Thus their relation as well as the age of the Franciscan Group are still open to question, at least in part.

Another question yet in debate is the relation between the Franciscan Group and the marine Cretaceous rocks. From the fossil evidence hitherto known, Durham (1962, p. 35) pointed out that: "(1) widely distributed rocks in the Coast Ranges which have been assigned to the Franciscan (formation or group) range in age from Late Jurassic to Late Cretaceous and are contemporaneous with "more normal" rocks along the west side of the Sacramento-San Joaquin Valley; (2) part, at least, of the type section of the Franciscan is of Albian and Cenomanian age; (3) throughout the region where there are rocks of "Franciscan facies", some of them are of Late Jurassic age."

The Cretaceous marine strata of "more normal" type developing along the west side of the Great Valley are estimated to attain about 25,000 to 40,000 feet in thickness. For a long time, they were represented by the "Shasta series" and "Chico series". Although these terms are almost abandoned at present (*fide* Popenoe, Imlay and Murphy, 1960), they had been loosely treated as if the Shasta was synonymous with the Lower Cretaceous and the Chico with the Upper Cretaceous. The progress of the stratigraphic nomenclature of the Californian Cretaceous was concisely reviewed by Chuber (1963).

In 1934 Kirby made a stratigraphic classification of the "Chico series" on the west side of the Sacramento Valley from Putah Creek, Yolo County in the south to Logan Creek, Glenn County in the north. He selected five surface sections and divided the Chico into six formations, namely, the Forbes, Guinda, Funks, Sites, Yolo and Venado in descending order. Among his five sections the Putah Creek one is most important, because the thickest strata of these formations are exposed there.

In 1945 Goudkoff presented the results of his biostratigraphic subdivision of the Upper Cretaceous Series distributed in the Great Valley based upon the Foraminifera from numerous surface sections and well cores. He established 12 zones, four of which each was assumed to be represented by two different ecologic facies, and grouped them into seven stages as follows:

A–1 zone	Upper Cheneyan stage
A–2 (A'–2) zone	Lower Cheneyan stage
B zone	Upper Ciervian stage
C (C') zone	Lower Ciervian stage
D–1 zone	Upper Ingramian stage
D–2 zone	Lower Ingramian stage
E (E') zone	Tracian stage
F–1 (F'–1) zone	Upper Weldonian stage
F–2 zone	Lower Weldonian stage
G–1 zone	Upper Cachenian stage
G–2 zone	Lower Cachenian stage
H zone	Delevanian stage

Among these stages, the Cheneyan was believed to be Paleocene by Goudkoff (1945), whereas Loeblich (1958) stated it to be a correlative of the Danian of the European standard. A systematic micropaleontological work and a clean-cut biostratigraphic zonation was rendered impossible by the unfortunate death of Goudkoff. Although there were some confusions in the application of Goudkoff's zones due to the incompleteness of his definitions, his classification has been widely used for subsurface correlation in California. The Putah Creek section is the most important reference section which Goudkoff selected for his zoning.

Furthermore, when Matsumoto (1959a, 1959c, 1960) reexamined the Late Cretaceous ammonites from California, he also referred to the fossils found in and around the Putah Creek area and correlated the Upper Cretaceous section with the European standard.

As previously mentioned, Kirby (*op. cit.*) divided the Upper Cretaceous strata in the Putah Creek area into six formations, which have an average dip of 60 degrees eastward. His classification is also applied to the subsurface section in this study. Therefore the outline of these formations will be described in upward succession, with reference to Goudkoff's biostratigraphic subdivisions.

The Venado Formation consists mainly of sandstone with subordinate siltstone and shale, intercalated with conglomerate layers at various horizons but particularly at or near the base of the formation. As cited by Lachenbruch (1962, p. 61), submarine slump deposits as much as one mile long and 100 feet thick were lately found at or near the base of this formation along the west side of the Sacramento Valley in the Lodoga quadrangle. These deposits may possibly be related genetically with the basal conglomerate in the Putah Creek area. Lachenbruch regarded these deposits as an evidence for a local disturbance in the Nevadan basement rocks, just prior to the deposition of the Venado. At first Kirby (*op. cit.*) believed the Venado to be the basal unit of the Upper Cretaceous, and considered that it was underlain with unconformity by the "Shasta series (=Horsetown Formation)". The Upper Cretaceous rock unit below the Venado was, however, recognized in Colusa and Glenn Counties by subsequent workers. Even in the Putah Creek area the strata below the Venado is thought to be correlative with the strata subjacent to it in the Colusa and Glenn Counties, and the nature of the actual contact between them is not known (*fide* Popenoe, Imlay and Murphy, *op. cit.*, Lachenbruch, *op. cit.*).

The Yolo Formation, overlying the Venado with conformity, comprises chiefly siltstone with thin layers of fine grained sandstone; the sandstone increases in relative abundance down to the base. The thickness of the formation ranges from about 500 to 1000 feet in various measured sections and tends to become thin northwards. Goudkoff assigned the whole Venado and the lower part of the Yolo to his H zone.

The Sites Formation overlies the Yolo with conformity and consists mainly of massive to well bedded or rhythmically banded, concretionary sandstone, with thin carbonaceous siltstone commonly intercalated in the bedded parts. On the Putah Creek the formation attains about 4,000 feet in thickness, but northwards it thins to only 125 to 150 feet on Logan Creek, Glenn County. Goudkoff's G–2 zone includes the upper part of the Yolo and the whole of the Sites Formations.

The Funks Formation is conformable with the underlying Sites Formation and comprises shale and siltstone, interbedded with some sandstone beds in the southern outcrop area. Kirby noticed a remarkable lateral change of thickness of the Funks, which however, Lachenbruch (*op. cit.*, p. 61) pointed out, that only the lowest about 600 feet thick part underlying the sandstone unit with calcareous concretions of the Funks on the Putah Creek was correlative with the Funks Formation distributed in the north. According to the latter author's view, the Funks Formation thickens southwards. Goudkoff's G–1 zone corresponds to the lower half of the Funks Formation in the Putah Creek area.

The Guinda Formation, which rests on the Funks Formation with conformity, comprises chiefly massive to well bedded sandstone with many calcareous concretions interbedded with shale. It attains about 3,000 feet in thickness in the Putah Creek area.

The Forbes Formation overlies with conformity on the Guinda and consists of well bedded to massive siltstone and shale intercalated with thin sandstones. In the lower part about 250 to 300 feet thick shale with fossiliferous calcareous concretions is developed, and locally thin limestone layers are seen immediately above the Guinda Formation. In the Putah Creek area Goudkoff's F–2 zone comprises the upper part of the Funks, the entire Guinda and the basal part of the Forbes Formations, while the rest of the Forbes belongs to Goudkoff's F'–1 zone. The Forbes is the youngest formation of the Upper Cretaceous Series recognized on the west side of Sacramento Valley, but undescribed still younger Upper Cretaceous strata are said to crop out in some surface sections in the south of the Putah Creek area, in Solano County (Lachenbruch, *ibid.*, p. 61).

MATERIALS

The materials treated in the present study are all from the cores of 30 wells drilled along the Putah Creek on the Yolo-Solano County line by the Shell Oil Company in 1951. These cores represent an almost complete subsurface section extending from the contact with the Eocene Capay Formation down to an unnamed Upper Cretaceous formation*) just below the Venado Formation. The lithostratigraphic correlation of this section with Kirby's division of the surface section was carried out by the geologists of the Shell Oil Company. The total thickness of the section is approximately 15,500 feet.

The samples are all composite ones, each weighing 90 g, and were collected from an average of five feet thick stratum with intervals of about five feet. After washing, the foraminiferal specimens were picked up and mounted on slides by some micropaleontologists of the Shell Oil Company. Some slides contain all specimens from each samples, but other ones only a part of the specimens especially when they were abundant. All of these slides were loaned to the writer through the kindness of the same company for the present study. Owing to the various procedures involved during the course of treatment, precise quantitative analysis could not be carried out, but the comparative abundancies of the species were exmained. Accordingly the main analysis is concentrated to the vertical distribution of the species.

The location of the wells and the formational boundaries drawn by Kirby on the Putah Creek are shown in Fig. 2.

All of the type specimens studied in the present study will be deposited in the

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*) According to Lachenbruch, Taliaferro applied the term "Antelope shale" to this unit in the southern part of the outcrop area. This term was, however, preoccupied by a subsurface Miocene unit in Kern County (*ibid.*, p. 59).

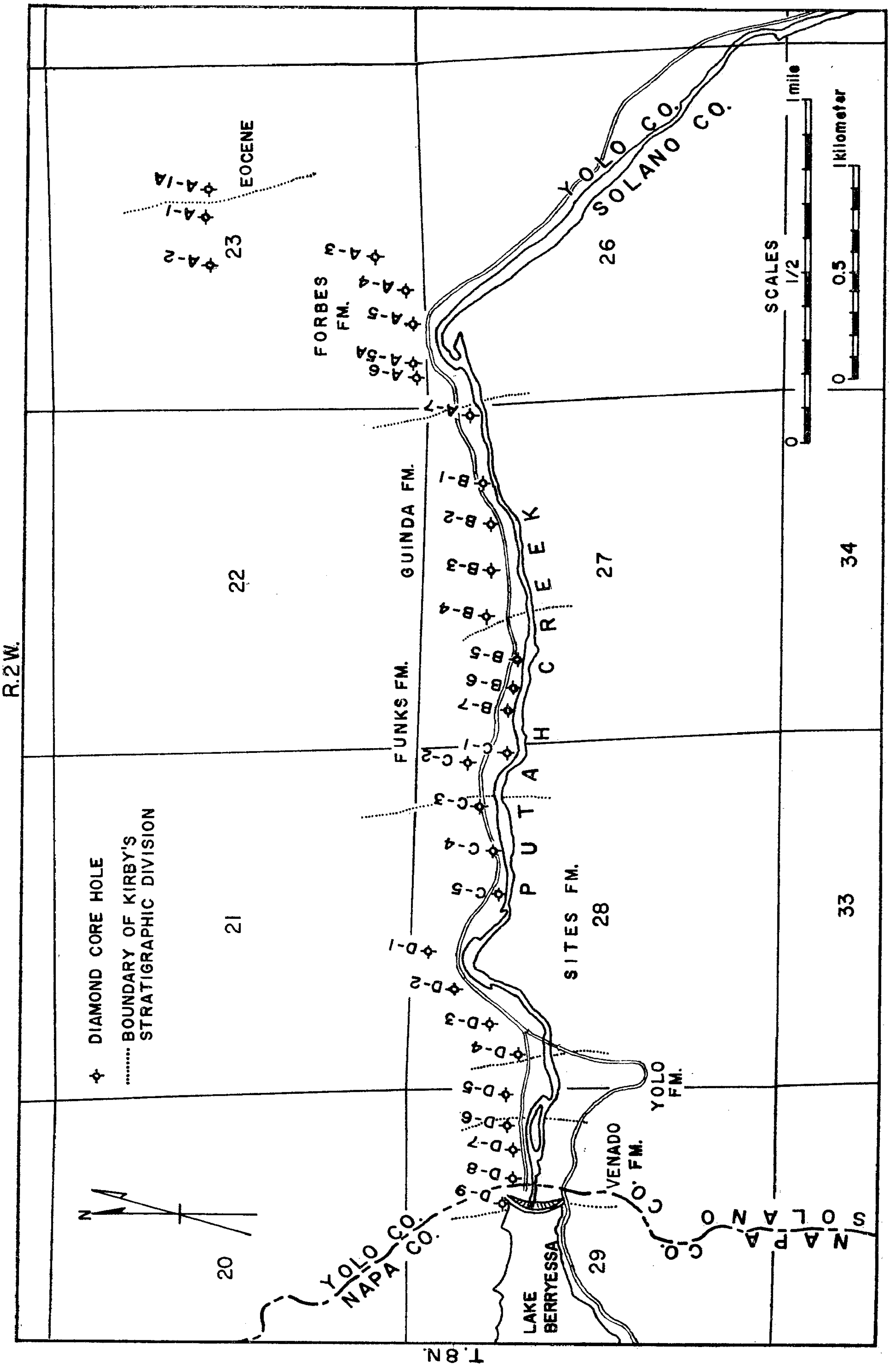


Fig. 2. Map showing the geographic position of the wells and formational boundaries according to Kirby.

Stanford University Paleontology Type Collection.

PLANKTONIC FORAMINIFERA AND THEIR SUCCESSION

Throughout the Putah Creek subsurface section, planktonic Foraminifera show a considerable fluctuation in quantity as well as in species. Except for the Forbes Formation, the planktonic foraminiferal succession is often interrupted by strata devoid of the planktonic forms in the section. Furthermore, the planktonic Foraminifera are quite rare in the major part of the Venado Formation and the underlying unnamed formation. Nevertheless, 36 species and subspecies have been determined from the Upper Cretaceous section, and they are recorded on the distribution chart (Fig. 3).

On the basis of stratigraphic ranges of these Foraminifera, the Upper Cretaceous formations are tentatively subdivided into six zones. Although the "zone" was used as a comprehensive term even in biostratigraphy, recently it has been clearly defined in the Code of Stratigraphic Nomenclature (1961, p. 655–657). In conformity with this code the present zones are classified into the category of the concurrent-range zone, which is defined by the overlapping ranges of one or more specified taxa from which it takes its name. The lateral extent of these zones could not be determined, because the present study is confined to the Putah Creek area. Therefore, it might be adequate to define the zones as local concurrent-range zones in a rigid sense.

During the course of defining the limits of the planktonic foraminiferal zones, the first appearance of species is used as a criterion of most importance, and the last appearance of species and the appearance of short-ranging species are used as supplementary data. The ranges of the respective species and subspecies and the result of zoning with reference to the lithostratigraphic units are shown in Fig. 4 in concise manner. The established six foraminiferal zones are described below in ascending order.

Globotruncana imbricata zone: — The base of this zone, the lowest unit in the Putah Creek area, is indeterminable in the investigated section, though it is defined by the first appearance of *G. imbricata* Mornod. So far as its occurrence in the present section is concerned, it appears to be adequate to place the base at the depth of 402 feet in the unnamed formation, in Diamond Core Hole No. 9, Section D. Actually *G. imbricata* is first recognized in the core at 392–402 feet in the said core hole. In this case the deepest level is selected for the lower boundary of the zone. The same procedure is followed for the other zones unless otherwise stated.

This zone is situated in the uppermost part of the unnamed formation, and includes the whole Venado, and the lower half of the Yolo Formations (about 1,780 feet in stratigraphic thickness). It is generally poor in yield of Foraminifera, and the lower to middle parts are almost barren of planktonic forms, but is characterized by *Praeglobotruncana stephani* (Gandolfi), which is confined within it, and the first appearances of *Globotruncana marginata* (Reuss) *G. imbricata*, *Rugoglobigerina bulbosa* Belford, *R. rugosa* (Plummer), *Hedbergella crassa* (Bolli), *H. delrioensis* (Carsey) and *H. planispira* (Tappan), which range upward into the younger zones.

As to the range of the genus *Rugoglobigerina* there are some discrepancies among authors; some considers it as Campanian to Maastrichtian (e.g., Brönnimann and Brown, 1956, p. 554; Berggren, 1962b, p. 120), while others take it as Turonian to Maastrichtian (e.g., Bolli, Loeblich and Tappan, 1957, p. 44). The latter view seems to be upheld as discussed in the systematic part. The genus *Globotruncana* is generally accepted as ranging from Turonian to Maastrichtian, and *G. imbricata* is inferred to make its first appearance in the lower Turonian (see "previous record of occurrence" under *G. imbricata* in the systematic part). *Praeglobotruncana stephani* is known from the Cenomanian and lower Turonian in

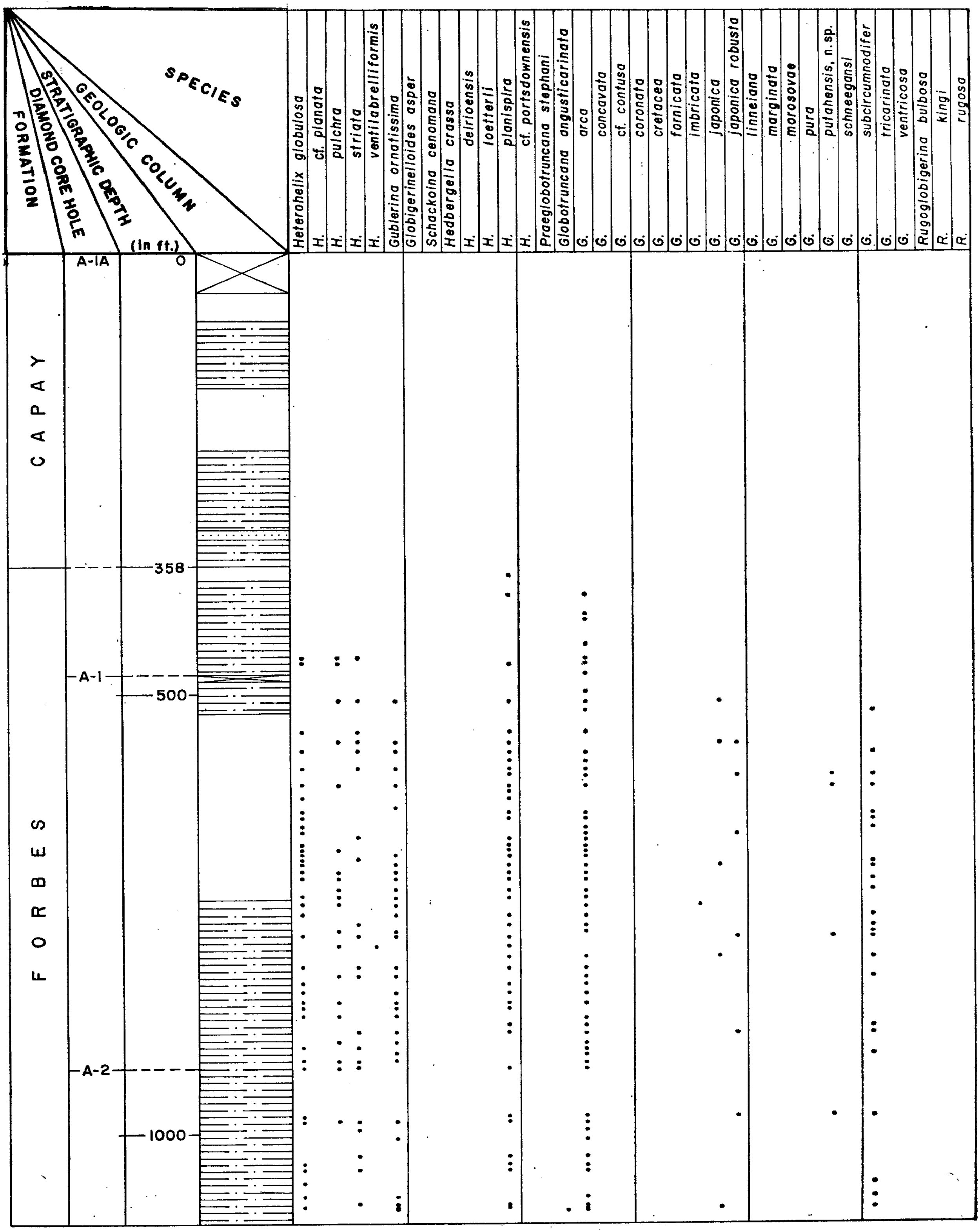
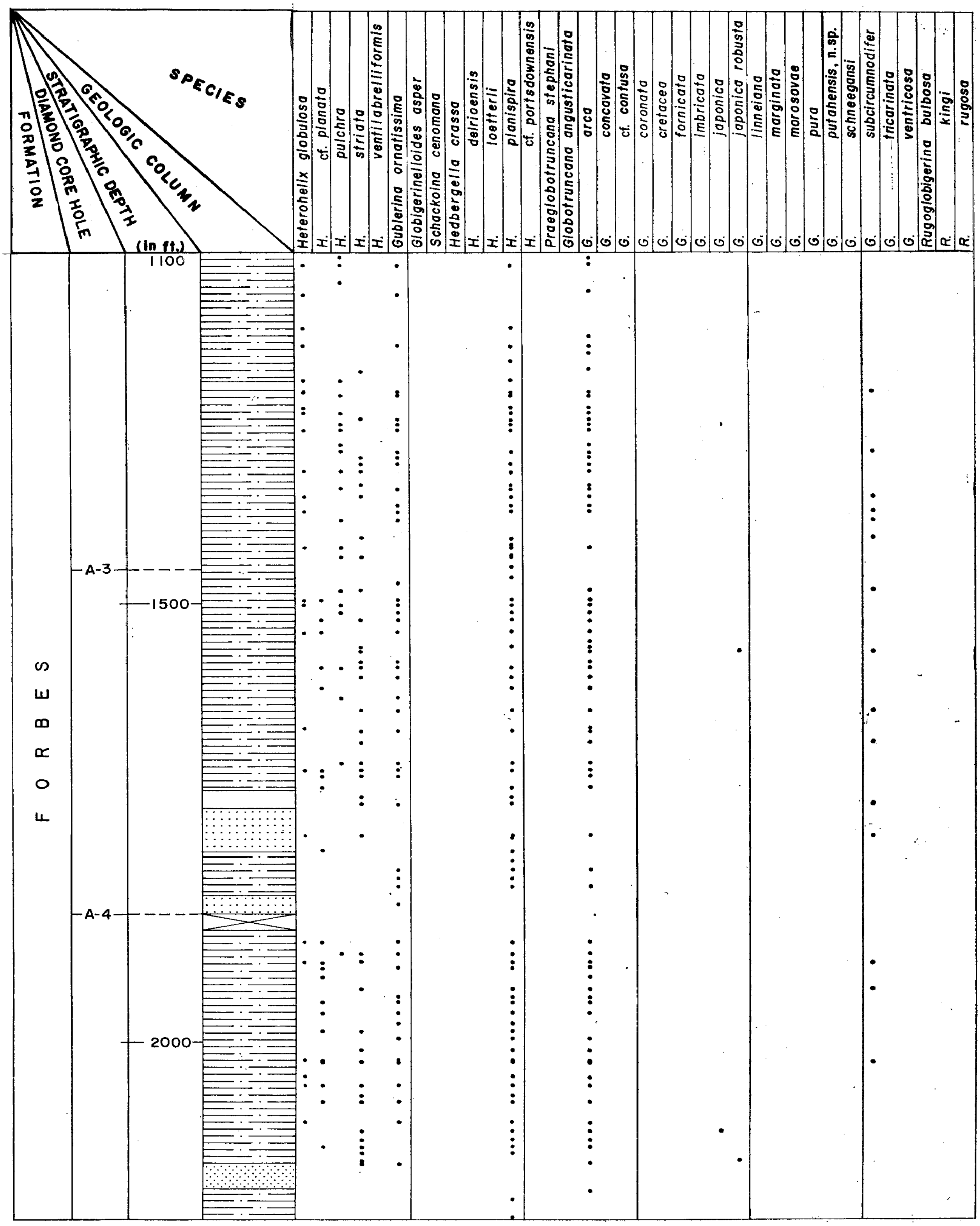


Fig. 3. Distribution of planktonic Foraminifera.



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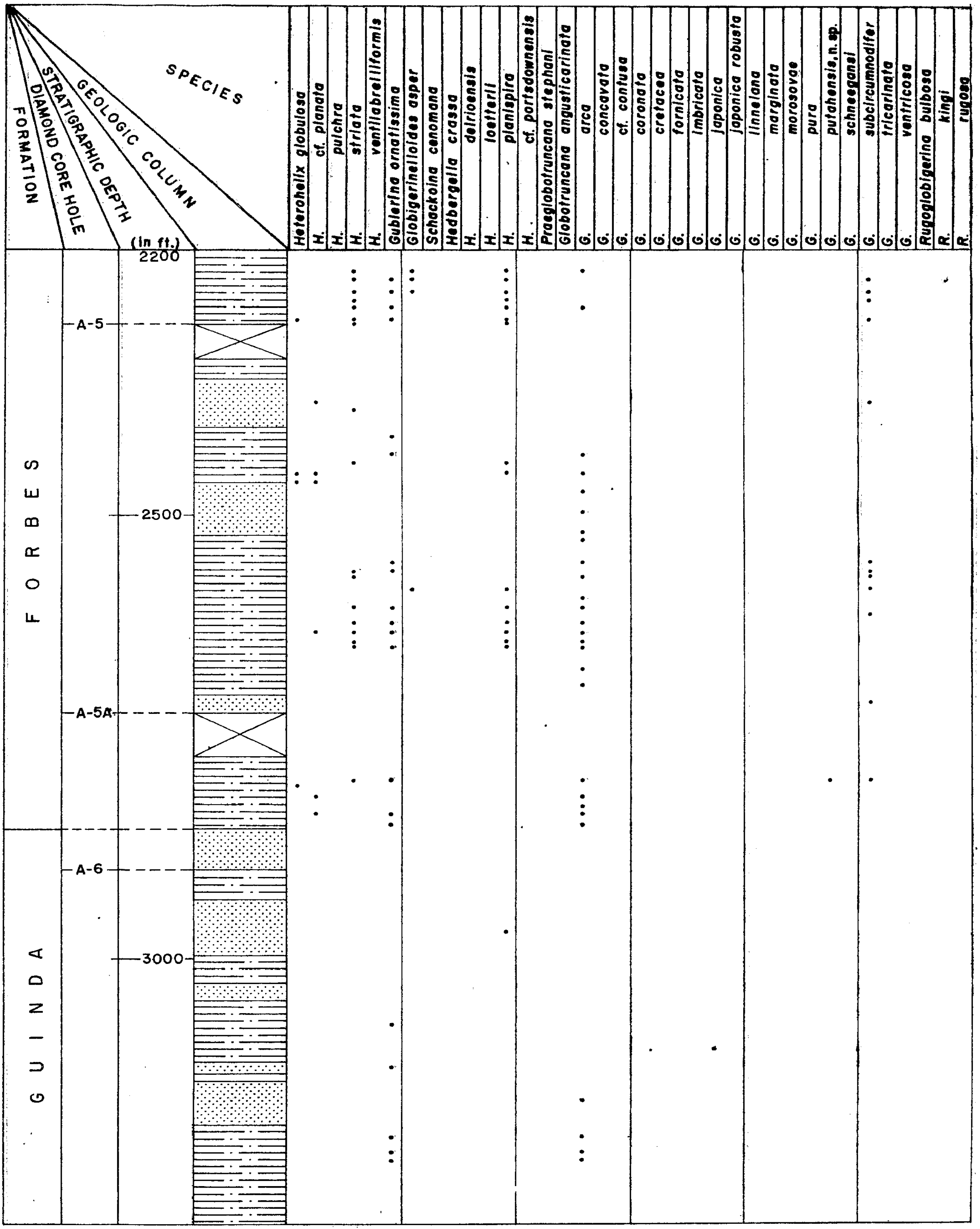

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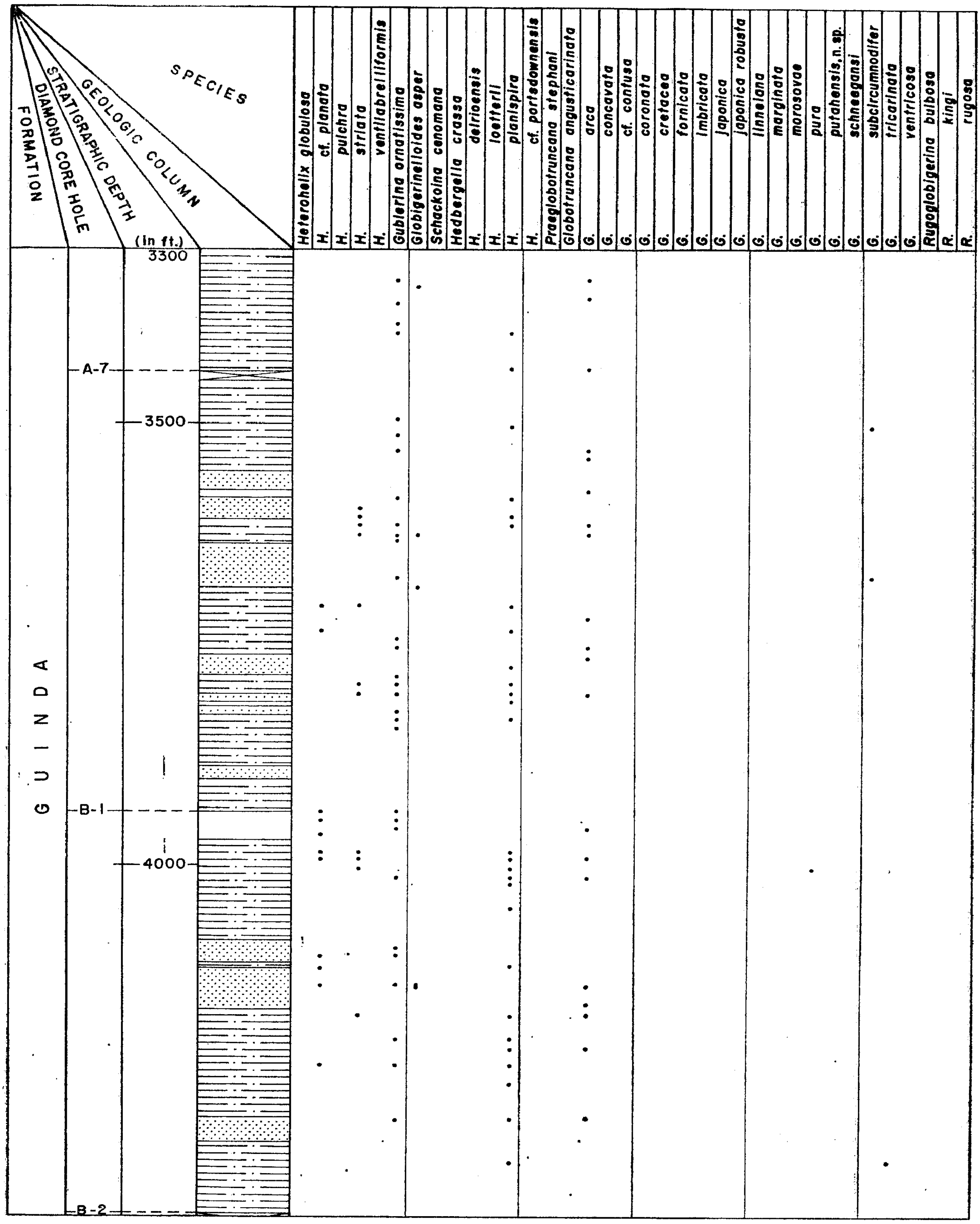

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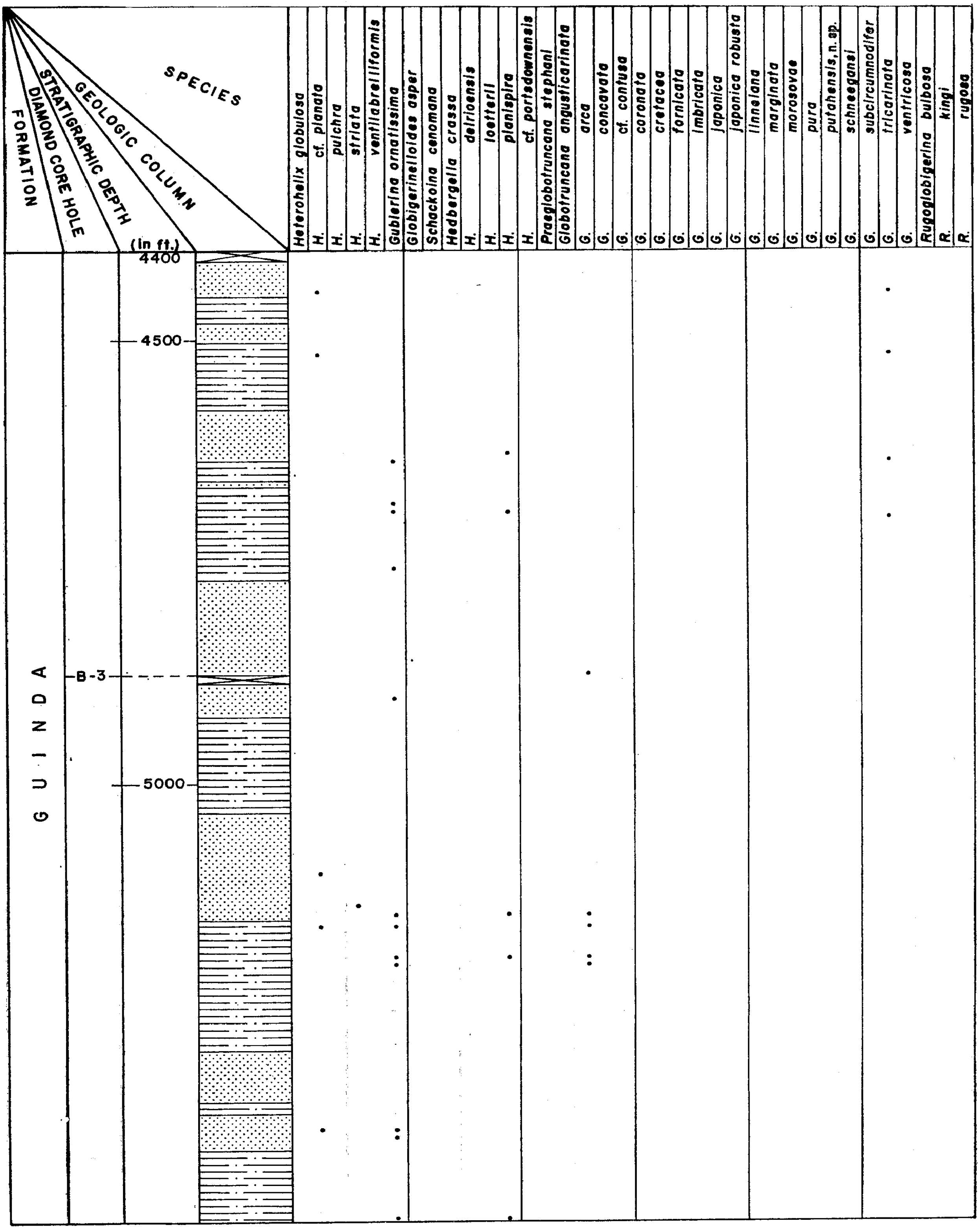

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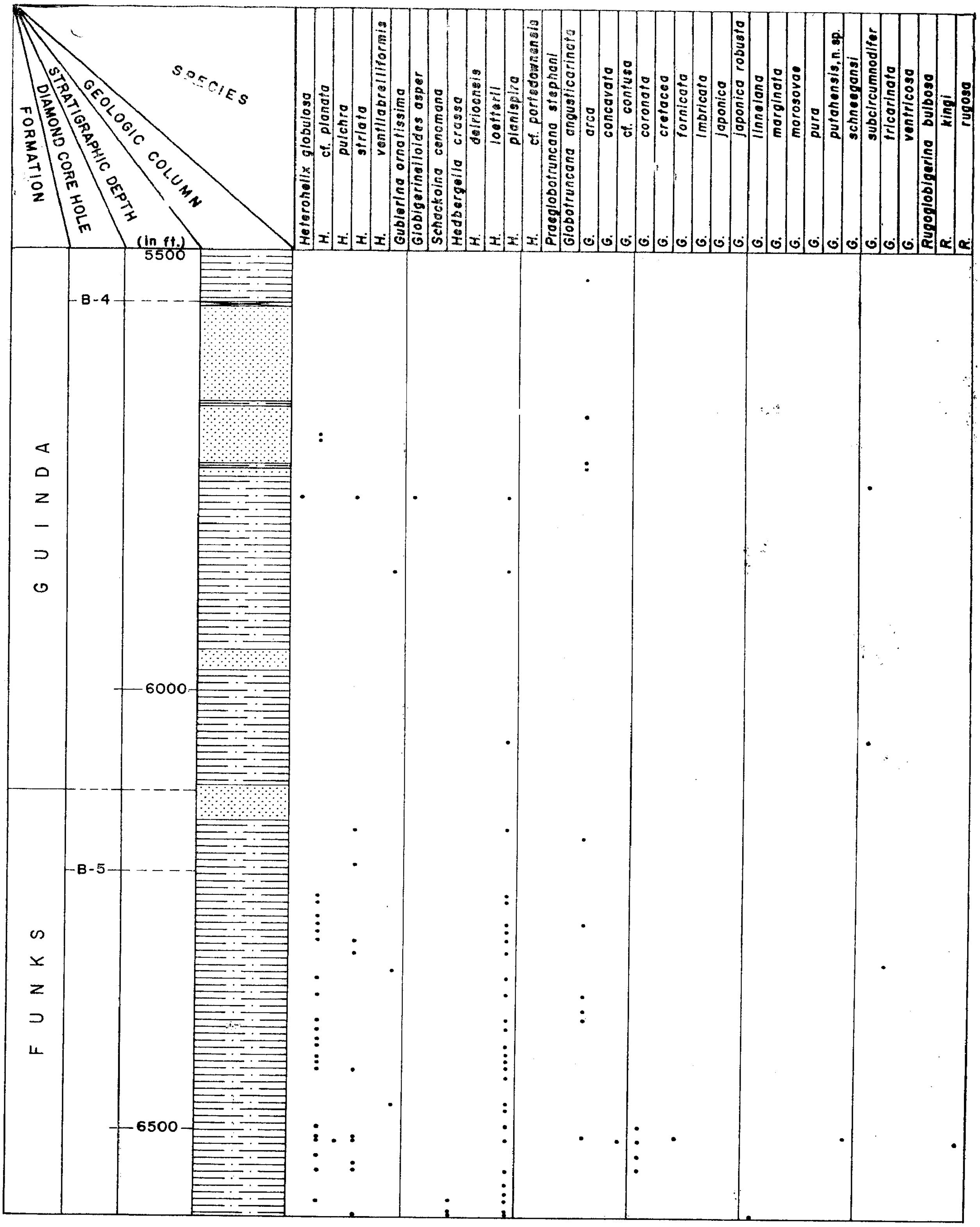

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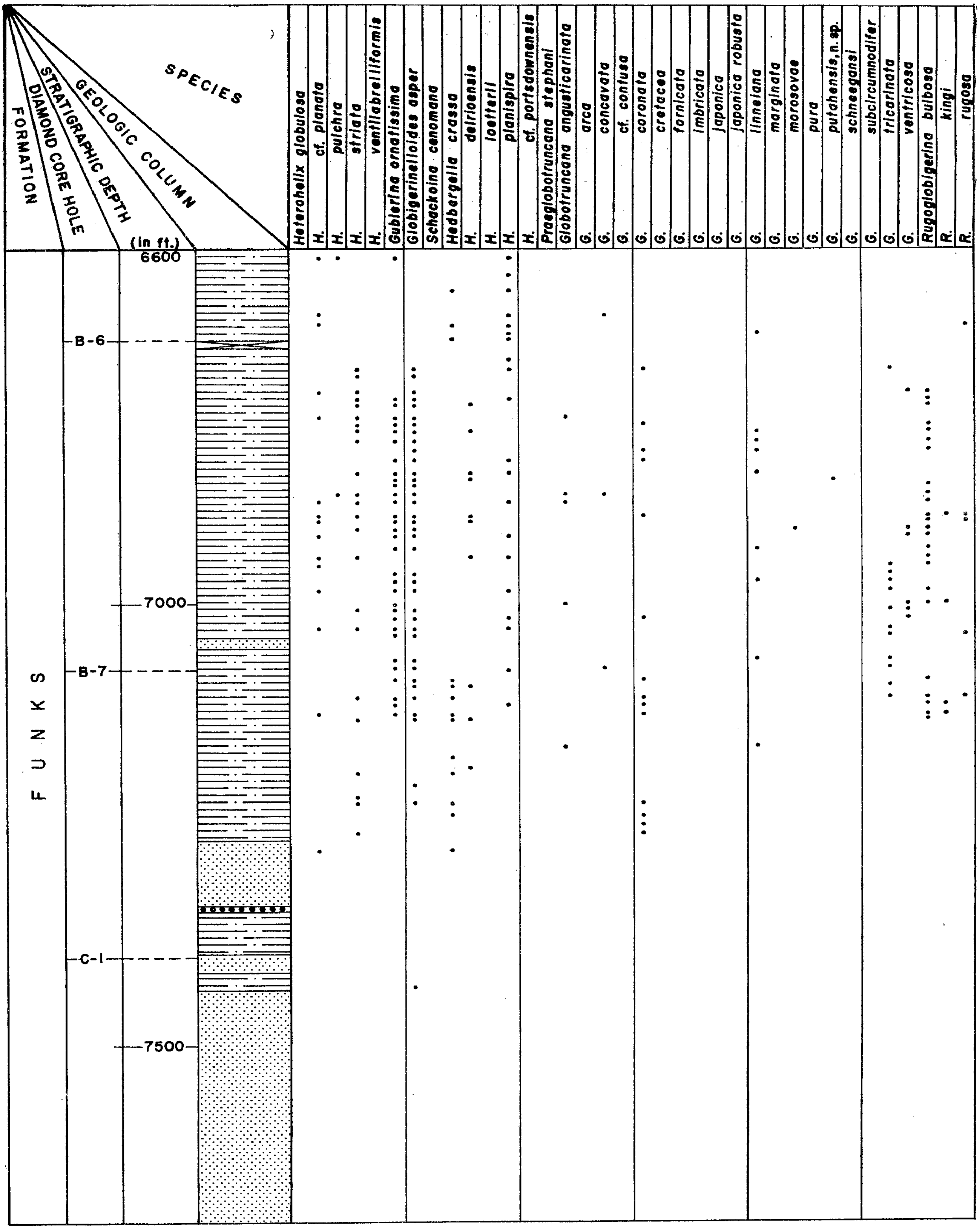

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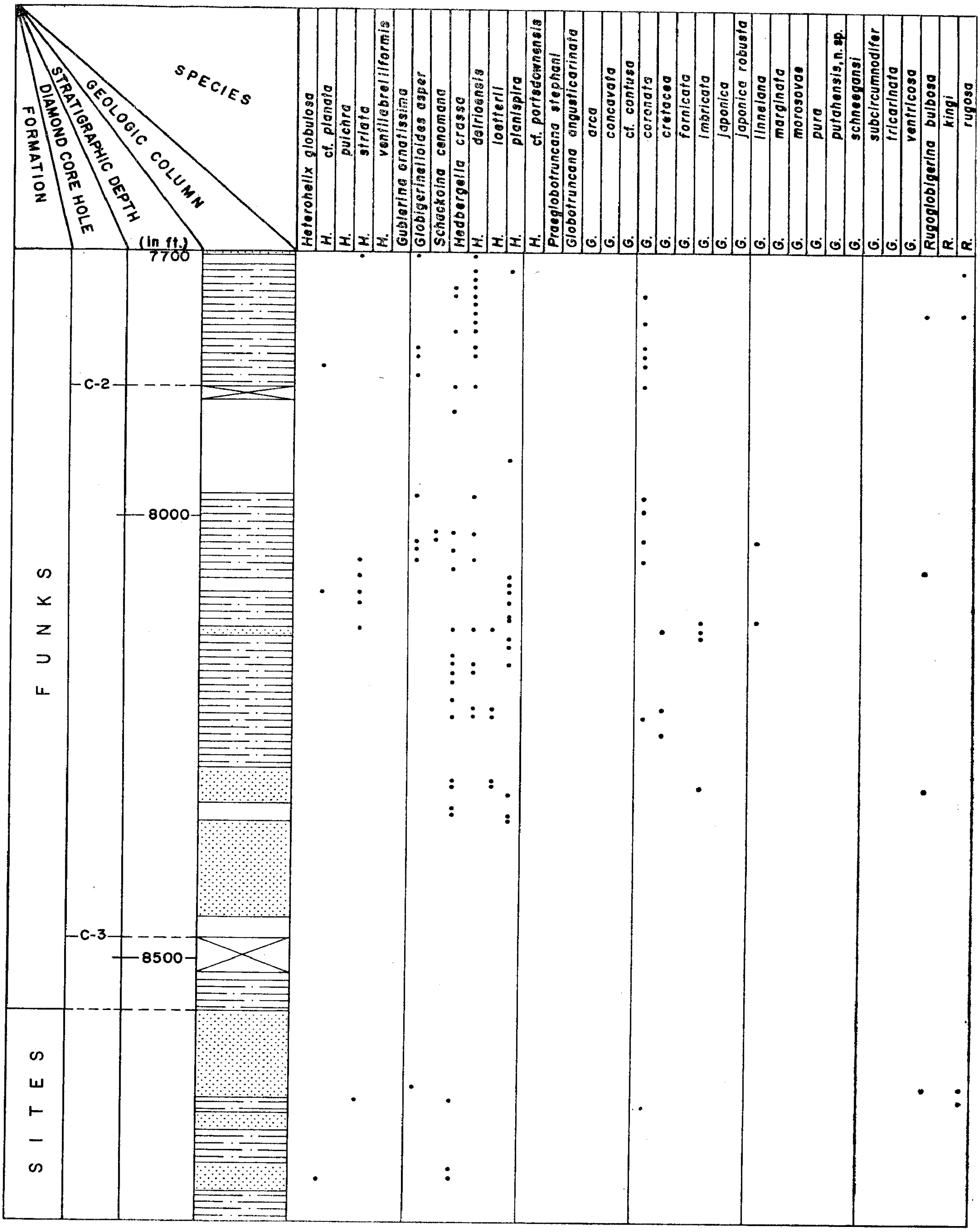

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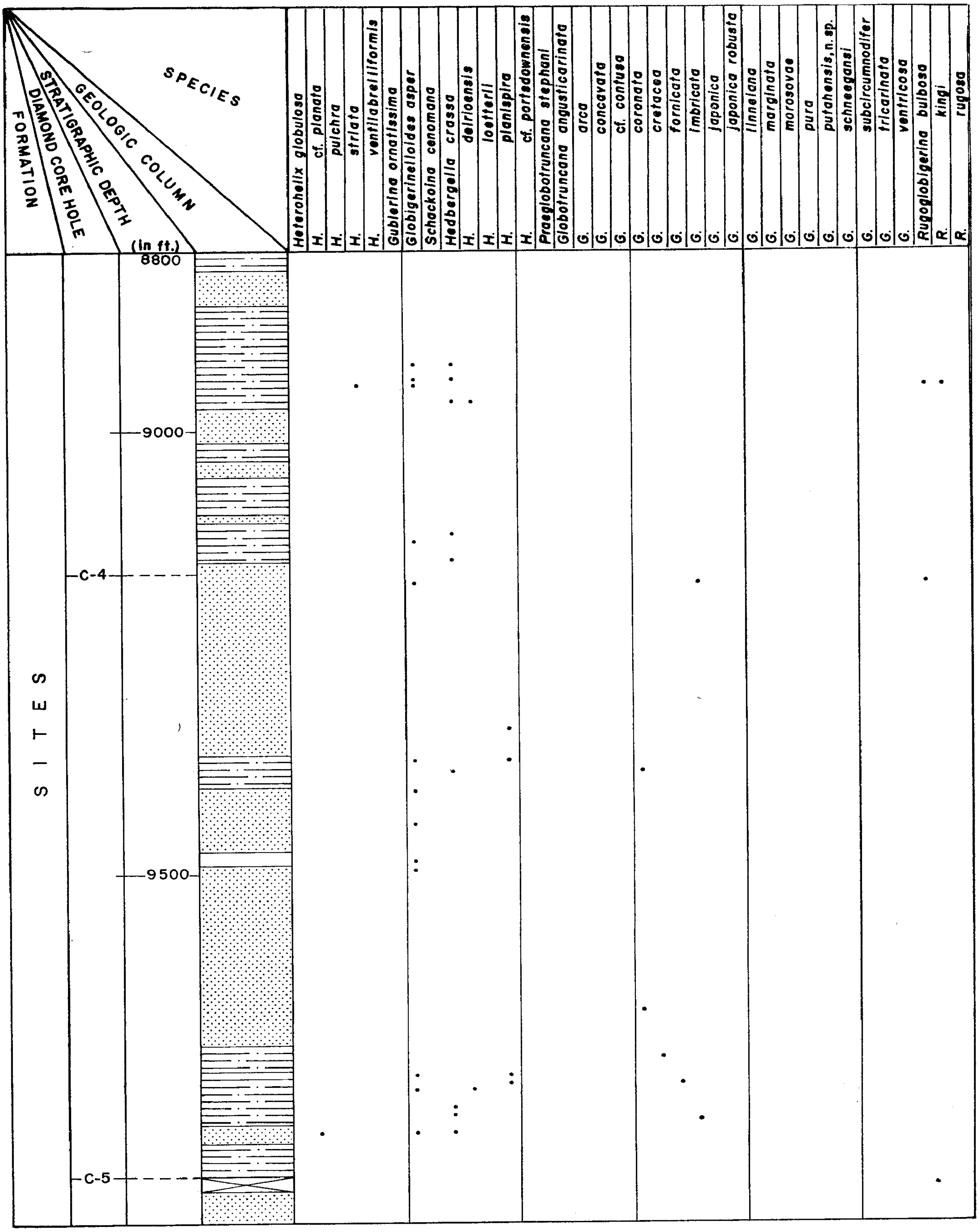

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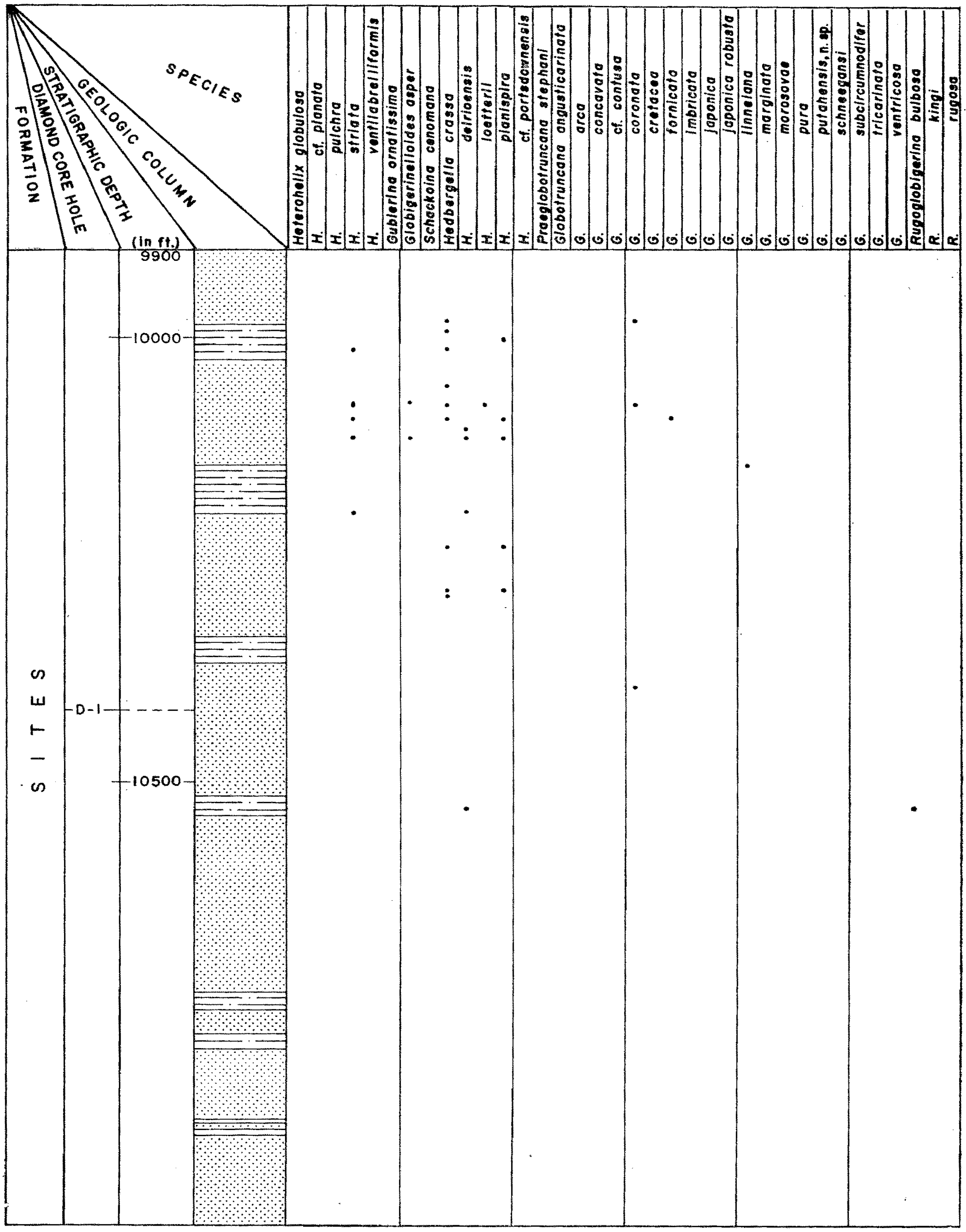

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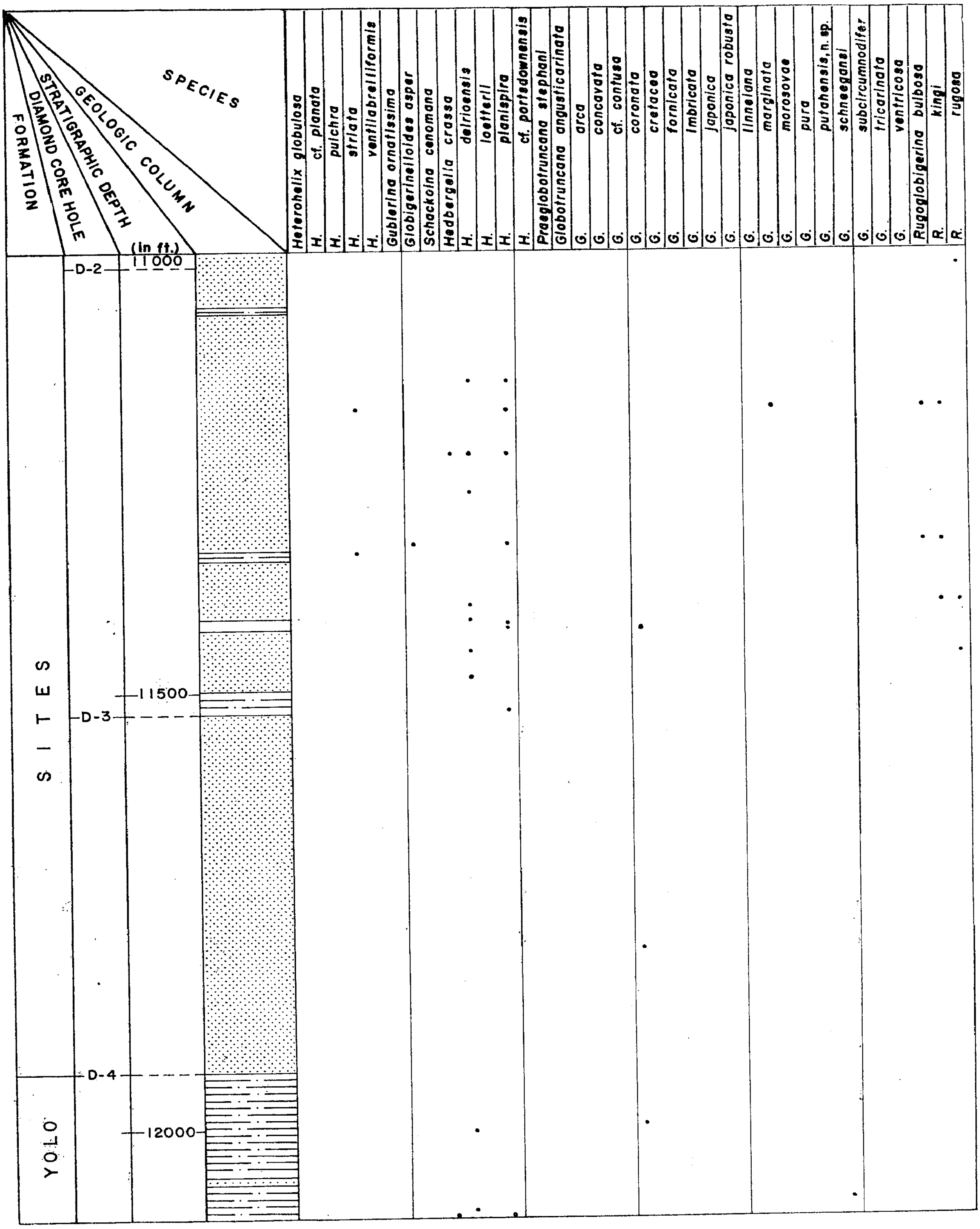

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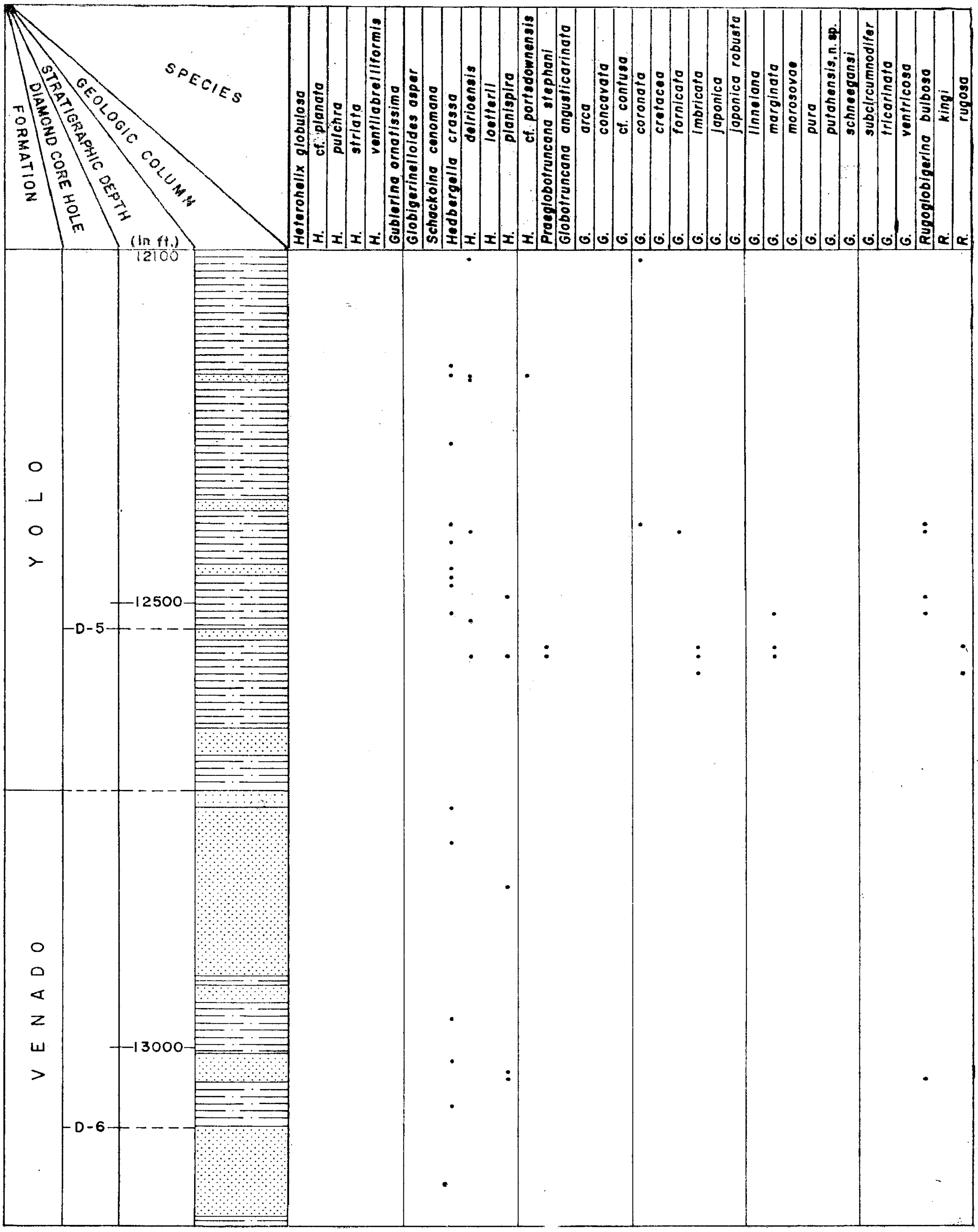

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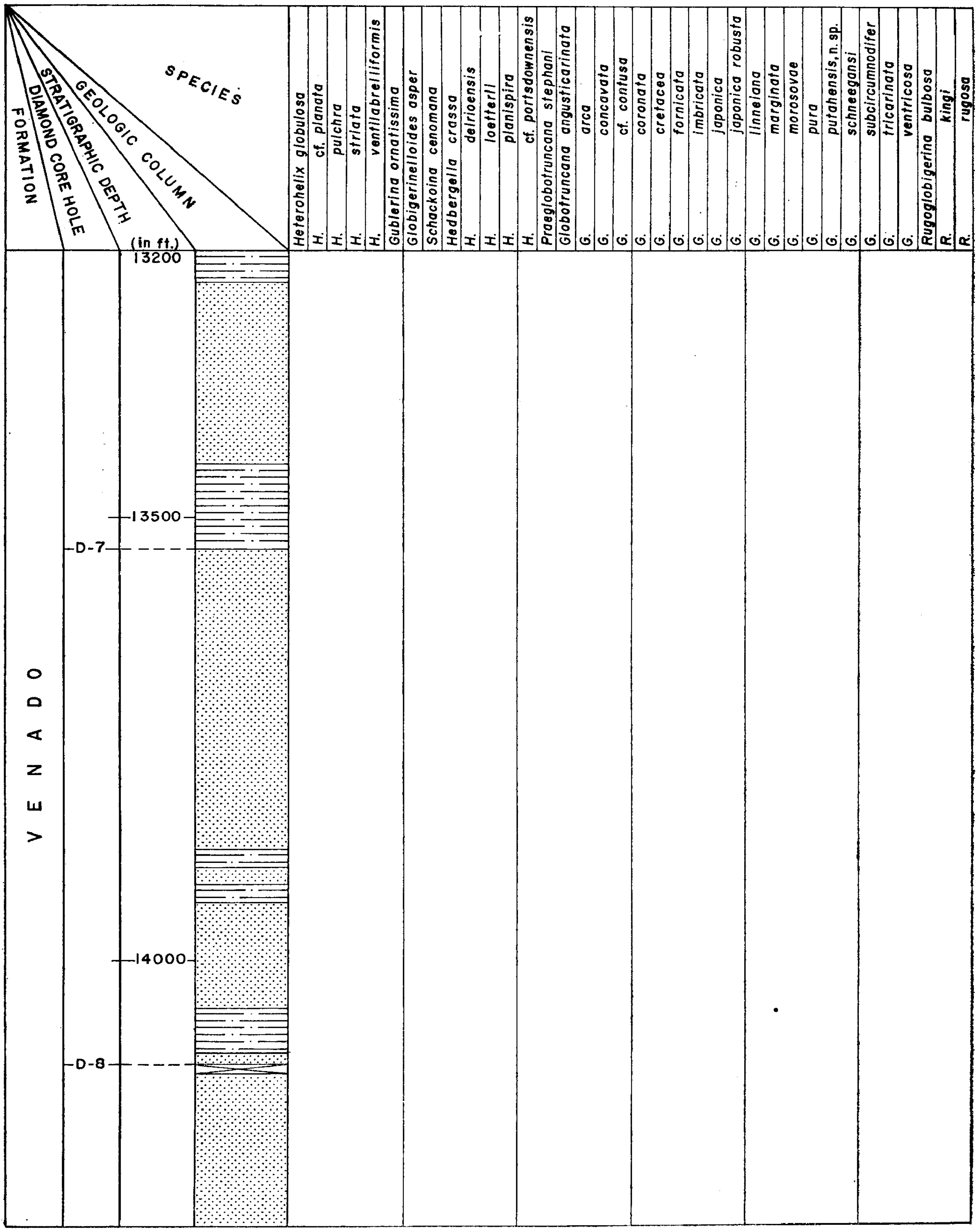

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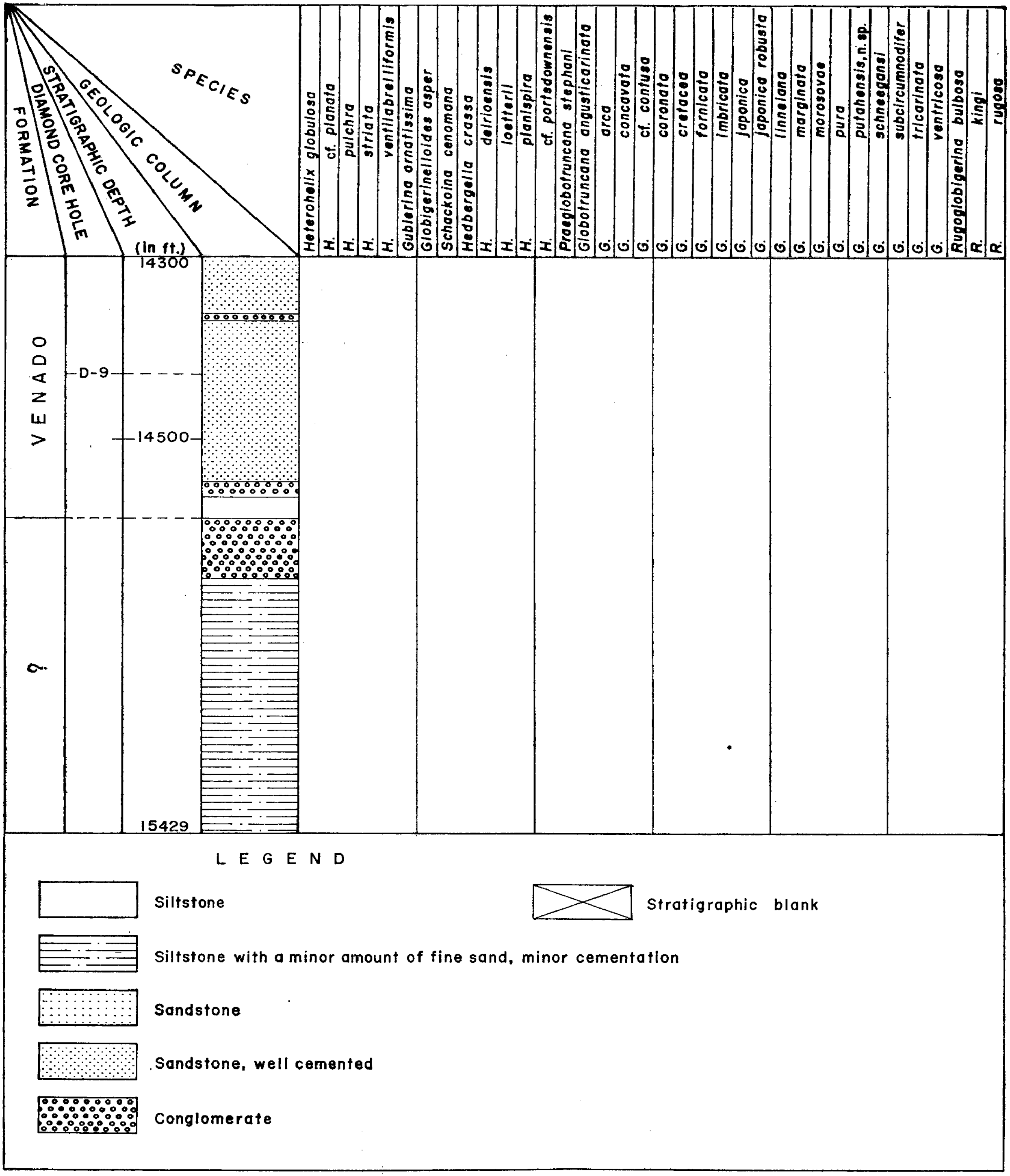

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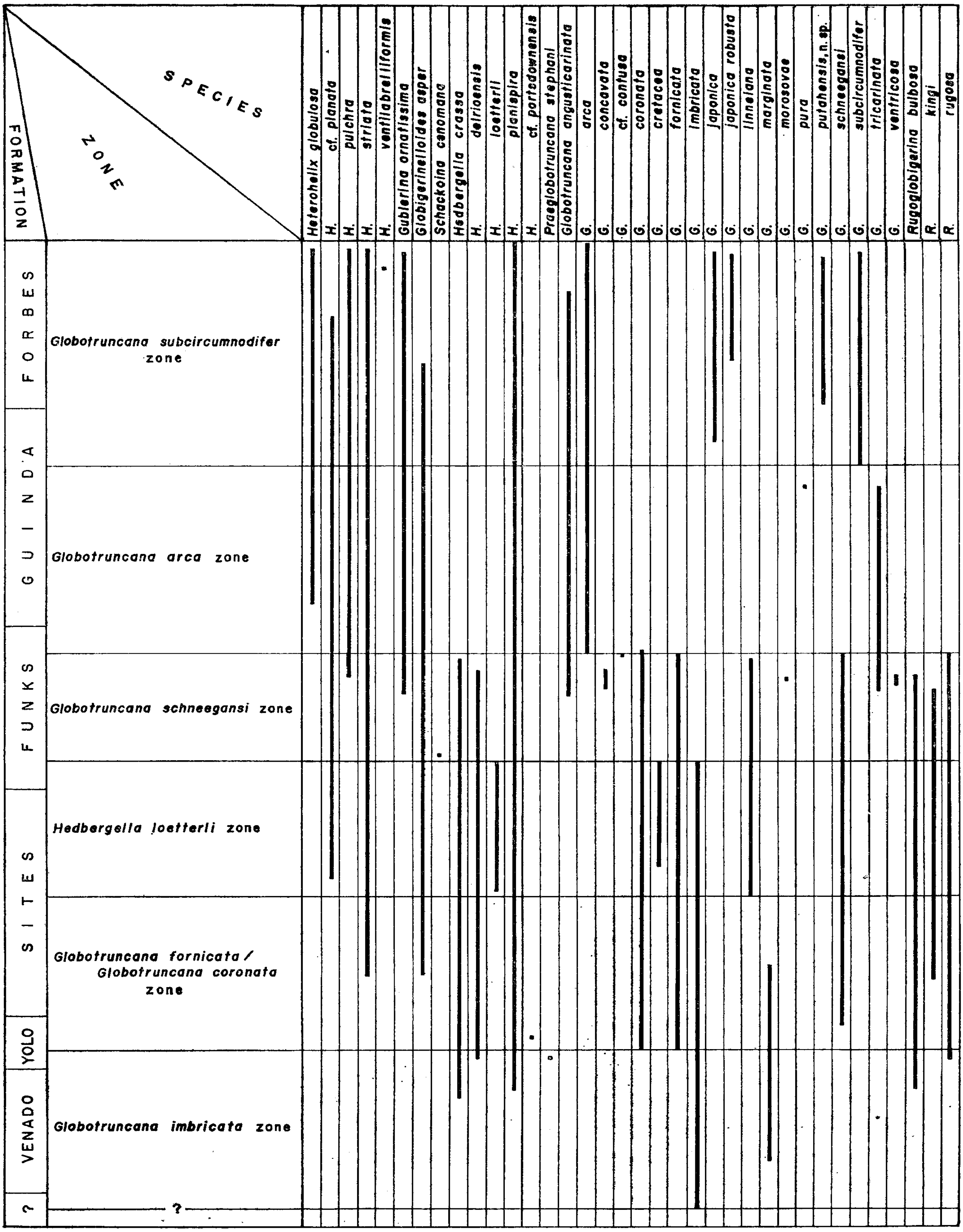

Fig. 4. Range chart of the planktonic Foraminifera.

the northern hemisphere. Thus the co-existence of both species just mentioned above suggests that the zone is equivalent to the lower Turonian of the European standard.

Globotruncana fornicata/Globotruncana coronata zone: – The boundary between this and the subjacent zone is drawn at the depth of 519 feet in the Yolo Formation, in Diamond Core Hole No. 4, Section D. It is marked by the first appearance of *G. fornicata* Plummer. In about 10 feet above the base *G. coronata* Bolli also appears for the first time. This zone includes the upper half of the Yolo and the lower half of the Sites Formations (approximately 1,950 feet in stratigraphic thickness). As compared with the subjacent *Globotruncana imbricata* zone, the planktonic Foraminifera become rather common in this zone, though there are still numerous layers barren of fossils in the sequence. In addition to the afore-mentioned two species, the zone is characterized by the first appearance of *Globotruncana schneegansi* Sigal in the lower part and of *Rugoglobigerina kingi* Trujillo, *Heterohelix striata* (Ehrenberg) and *Globigerinelloides asper* (Ehrenberg) in the middle, all of which range into the younger zones. A single specimen of *Hedbergella* cf. *potsdownensis* (Williams-Mitchell) was found in the lowermost part. The zone contains 13 planktonic species.

Although there are many records about the stratigraphic distribution of *G. fornicata*, it most probably ranges from late Turonian to early Maastrichtian, so far as concerns the reliable records. *G. coronata* and *G. schneegansi* are also known to make their first appearance in the Turonian. Accordingly, the *Globotruncana fornicata/Globotruncana coronata* zone is assumed to be of late Turonian age. Hitherto *Hedbergella portsdownensis* has been known only from the Cenomanian, but the occurrence of a comparable form within this zone might suggest that its range should be extended upward to the middle Turonian.

Hedbergella loetterli zone: – The base of this zone is defined by the first appearance of *Globotruncana linneiana* (d'Orbigny), and its top by the last appearance of *G. imbricata.* The stratigraphic thickness of the zone is approximately 2,045 feet. It includes the upper half of the Sites and the lowermost part of the Funks Formations. The base, the boundary between this and the subjacent zone, is at the depth of 337 feet in the Sites Formation, in Diamond Core Hole No. 5, Section C. The planktonic Foraminifera are fairly common in the zone, but the faunal sequence is still interrupted by several layers devoid of planktonic forms. Beside *G. linneiana*, the forms newly added in this zone are *Heterohelix planata*, *Hedbergella loetterli* and *Globotruncana cretacea* (d'Orbigny), the last two of which are restricted to it. In the Putah Creek section *H. loetterli* and *G. cretacea* disappear nearly contemporaneously with *G. imbricata.* This evidence defines the top of this zone by which it is clearly recognized. Within the present zone 16 planktonic species are encountered.

Among the species encountered in this zone none serve to determine the age of this zone definitely. In the light of present knowledge, however, *G. imbricata* is thought to disappear at about the middle of the Coniacian. Therefore the *Hedbergella imbricata* zone may be correlated with the lower Coniacian of the European standard.

Globotruncana schneegansi zone: – The present zone is distinguished from the underlying *Hedbergella loetterli* zone by the absence of *G. imbricata*, and from the overlying zone by the presence of *G. schneegansi* and *G. fornicata.* In the Putah Creek section the zone has a stratigraphic thickness of about 1,610 feet, which is the main part of the Funks Formation. The base of the zone lies at the depth of 290 feet in the Funks Formation, in Diamond Core Hole No. 2, Section C. It is rather rich in planktonic Foraminifera, especially in its upper part, and layers barren of fossils are much less in the sequence as compared with the underlying and overlying zones.

In the upper part of this zone many species show their last appearance, whereas a number of species are newly added and nearly half of them range into the superjacent zone.

In addition to *G. schneegansi* and *G. fornicata*, the species disappearing within the zone are *Hedbergella crassa* , *H. delrioensis*, *Rugoglobigerina kingi*, *R. bulbosa* and *R. rugosa*. On the other hand, the species that newly appeared are *Globotruncana angusticarinata* Gandolfi, *G. tricarinata* (Quereau), *Gublerina ornatissima* (Cushman and Church) and *Heterohelix pulchra* (Brotzen), which range upward into the superjacent zone, and *Schackoina cenomana* (Schacko), *Globotruncana concavata* (Brotzen), *G. morosovae* Vassilenko, *G. ventricosa* White, and *G.* cf. *contusa* (Cushman), which are limited to this zone. Twenty-two planktonic species are recognized in the zone.

The *Globotruncana schneegansi* zone can be correlated with the upper Coniacian from the joint occurrence of *R. kingi*, *G. schneegansi* and *G. ventricosa*. The former two forms are known to range upward into the upper Coniacian, whereas the last one makes its first appearance in the Coniacian (probably upper).

Globotruncana arca zone: – The base of the present zone is characterized by the first appearance of *Globotruncana arca* (Cushman), which is recognized at a depth of 315–324 feet in the Funks Formation, in Diamond Core Hole No. 5, Section B. In the same sample the last appearance of *G. schneegansi* and *G. fornicata* are noted. The boundary between this and the subjacent zones is considered to be within a stratigraphic thickness of 10 feet. However, it is defined at the depth of 324 feet for convenience. The total stratigraphic thickness of the strata making up the zone in the Putah Creek section is about 2,840 feet; this includes the top part of the Funks and the main part of the Guinda Formations.

Generally planktonic Foraminifera are less common in the present zone in contrast to the under- and overlying zones, and the sequence is frequently intercalated with layers barren of fossils. Among the 13 planktonic species appearing in this zone, *Globotruncana coronata* and *G. linneiana* disappear at a short distance from the base, whereas *G. tricarinata* is no longer found in the upper part. Only *G. pura* Hofker is restricted to the zone. Although there can be found no species useful for age assignment, the *Globotruncana arca* zone may be correlated with the Santonian from the stratigraphic and faunal relations with the sub- and superjacent zones.

Globotruncana subcircumnodifer zone: – This is the highest biostratigraphic unit recognized in the Putah Creek section. The lower boundary of this zone is defined by the first appearance of *Globotruncana subcircumnodifer* (Gandolfi), and the top coincides with the unconformity between the Forbes and the overlying Eocene Capay Formation. The zone has a stratigraphic thickness of approximately 3,300 feet, and includes the upper part of the Guinda and the whole of the Forbes Formations. Its base is at the depth of 240 feet in the Guinda Formation, in Diamond Core Hole No. 7, Section A, and the top is at the depth of 358 feet which is the contact between the Forbes and Capay Formations, in Diamond Core Hole No. 1A, Section A. It is rich in planktonic Foraminifera and the sequence is nearly complete except for the lower part.

This zone is characterized by 14 planktonic species, among which *G. subcircumnodifer*, *G. japonica* Takayanagi, *G. japonica robusta* Takayanagi, *G. putahensis* Takayanagi, n. sp., and *Heterohelix ventilabrelliformis* (van der Sluis) are the forms that newly appeared. The others all range up from the subjacent zones: they are *Hedbergella planispira*, *Heterohelix globulosa*, *H.* cf. *planata*, *H. pulchra*, *H. striata*, *Gublerina ornatissima*, *Globigerinelloides asper*, *Globotruncana angusticarinata*, and *G. arca*. From the joint occurrence of *G. subcircumnodifer* making its first appearance in the Campanian and *H. planispira* expiring in the Campanian, the present zone can be correlated with the Campanian of the European standard.

From the known stratigraphic ranges of the widely distributed planktonic species, the age of the six foraminiferal zones can be determined approximately according to the European standard. The result attained therefrom is consistent with the age and correlation based on ammonites and inocerami (Matsumoto, 1960, pl. 2). However, it is rather difficult to correlate these zones with those of Goudkoff which were based upon the surface section of the Putah Creek area. Since Goudkoff's Zones are essentially defined by 67 diagnostic species, among which three are planktonic forms, it may be most reasonable to correlate the subsurface section with surface one on the basis of these forms. However, zonal distinction could not be made clear in the subsurface section by the diagnostic forms selected by Goudkoff. Fortunately Goudkoff (*op. cit.*, Fig. 5 on p. 966) illustrated the relation of his zones (F'–1 to G–2) with respect to the lithostratigraphic divisions of Kirby in the Putah Creek area. This has proved to be important for accomplishing the present correlation. As shown in Table 1, we may reach the following result. The *Globotruncana imbricata* zone is almost equivalent to Goudkoff's H zone; the *Globotruncana fornicata/Globotruncana coronata* zone and the main part of the *Hedbergella loetterli* zone to G–2 zone; the topmost part of the *Hedbergella loetterli* zone and the main part of the *Globotruncana schneegansi* zone to G–1 zone; the upper part of the *Globotruncana schneegansi* zone, the entire *Globotruncana arca* zone and the lower part of the *Globotruncana subcircumnodifer* zone to F–2 zone; and the larger part of the *Globotruncana subcircumnodifer* zone to F'–1 zone.

Table 1. Correlation of the planktonic foraminiferal zones.

European Stage	Formation	Planktonic Foraminiferal Zone	Goudkoff's	
			Zone	Stage
Campanian	Forbes	*Globotruncana subcircumnodifer*	F'–1	Upper Weldonian
	Guinda			
Santonian		*Globotruncana arca*	F–2	Lower Weldonian
			?	?
Upper Coniacian	Funks	*Globotruncana schneegansi*	G–1	Upper Cachenian
Lower Coniacian		*Hedbergella loetterli*	G–2	Lower Cachenian
	Sites			
Upper Turonian		*Globotruncana fornicata/ Globotruncana coronata*		
	Yolo		?	?
Lower Turonian	Venado	*Globotruncana imbricata*	H	Delevanian
?	?	?		

PALEOECOLOGICAL ASPECTS OF SOME PLANKTONIC FORAMINIFERAL ZONES

As already stated, the six zones proposed for the Putah Creek subsurface section are principally defined by the overlapping ranges of the planktonic species. There have been published many papers (e. g., Bolli , 1957, 1959) stating that the zones of this nature of the planktonic Foraminifera, when confirmed in a number of sections, serve as good time-markers not only for regional but also for world-wide correlation of the Cretaceous strata. The planktonic foraminiferal zones established locally as in the present case of the Putah Creek section, however, should be subjected to further examination of their characters from a paleoecological point of view.

Taking a general view of the stratigraphic distribution of the planktonic forms in the Putah Creek section, remarkable features are noticed in the vertical change of species, such as, species having the same vertical distribution, those appearing at the same time but terminating in succession, showing succession in time of appearance but not in extermination, the ones occupying the same geological age but without overlapping in vertical range, species occupying one geological age with marked overlapping in vertical range, and, different combinations of the aforementioned can also be recognized. The recognized features in the vertical ranges of the planktonic Foraminifera, for the sake of convenience will be called, in this article, chronological alternative species.

Such features are marked at about the upper part of the *Globotruncana schneegansi* zone, which is characterized by yielding the largest planktonic fauna of the six zones. The forms encountered in that zone are the species restricted to and dying out in it, those making their first appearance, and the ones having a rather short range, besides some with long-range.

The total number of species in a zone and the total number in a zone of the number of newly appearing species, of the ones becoming extinct and of the ones confined to a zone in the respective zones are plotted in Fig. 5. It is clearly shown that the total number of species increases progressively from the *Globotruncana imbricata* zone up to the *Globotruncana schneegansi* zone but suddenly decreases toward the *Globotruncana arca* zone. On the other hand, the number of alternating species are extremely abundant in the *Globotruncana schneegansi* zone as compared with the other zones. Apparent ranges of the alternating species involved in about the upper part of this zone are delineated in contrast to their total ranges as inferred from the records available to the present study (Fig. 6). The difference of the two kinds of ranges may suggest that remarkable truncation and/or shortening of the ranges of the species happened at about the late *Globotruncana schneegansi* zone time.

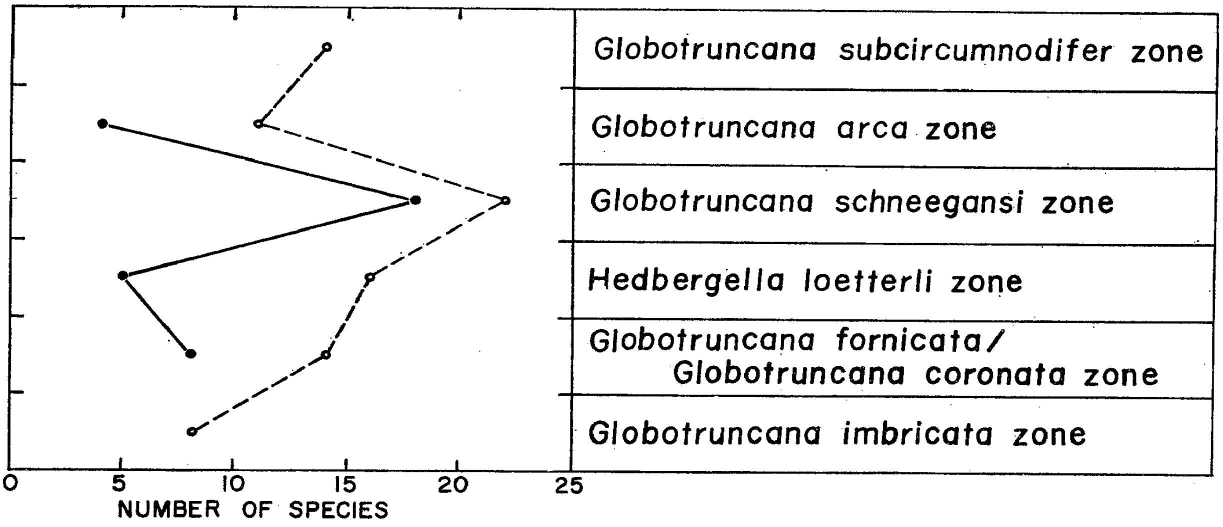

Fig. 5. Showing the total number of species in the respective zones (○), and the total number of newly appearing species, of last appearing and the ones confined to the respectives zones (•).

The cause or causes for the peculiar ranges of the species mentioned above in the present zone seems to be in need of explanation.

Similar phenomena have sometimes been observed and reported in interrupted stratigraphic sequences. In such case, however, the phenomena in range of species as mentioned may not occur in a continuous set of strata as in the present case but, in general, prior to and immediately after the stratigraphic break. For the present case we may enumerate the following possibilities as the cause or causes; that is, (1) the change of the

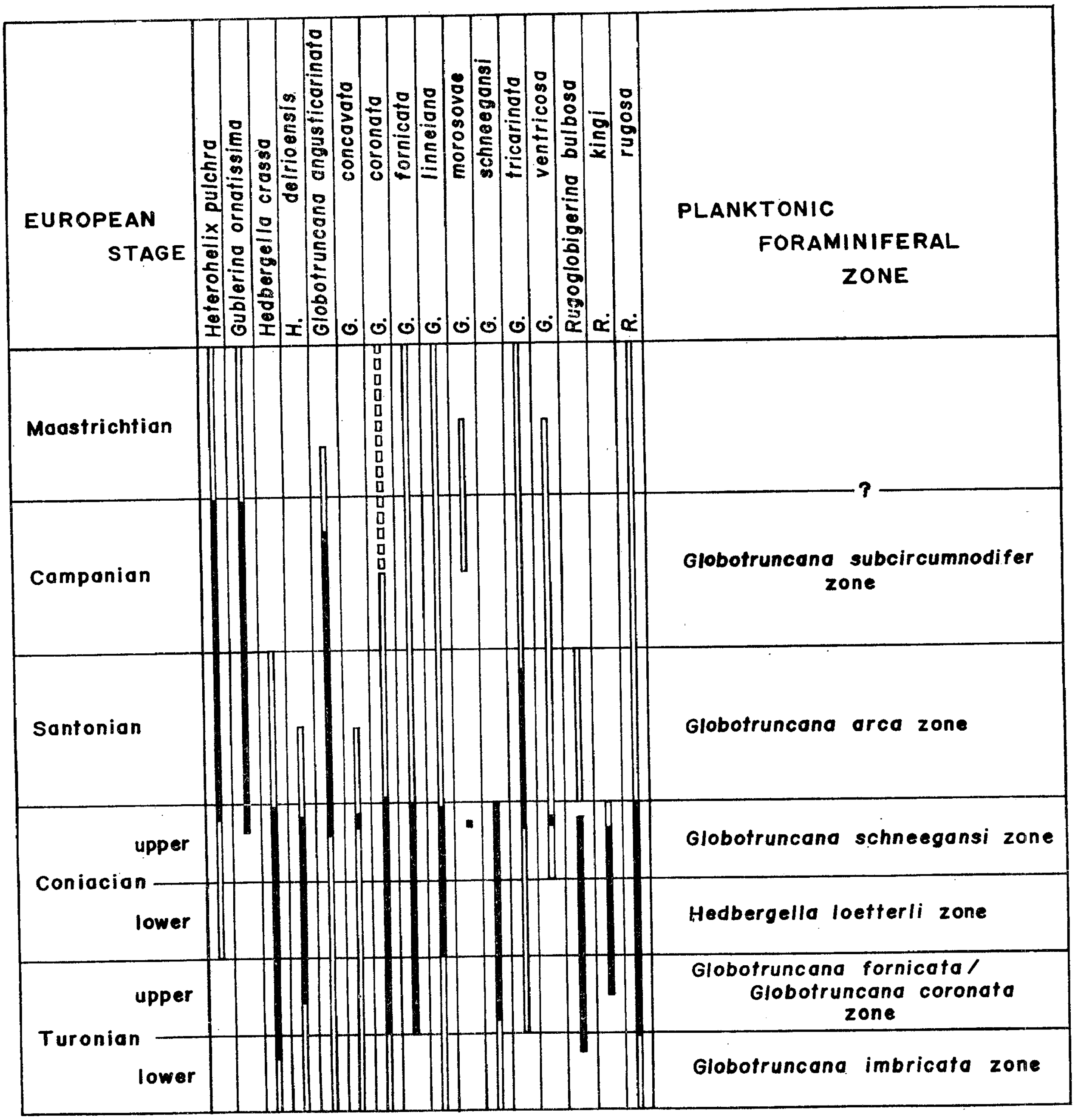

Fig. 6. Known range (black and white bars) and determined range (black bar) in the Putah Creek area with special reference to the planktonic foraminiferal zones.

planktonic species groups — alternation of one species group with another group of a similar or of a different stock, (2) change of or in the sedimentary environment, and (3) climatic change.

First, it may be assumed that the old group as represented by *Globotruncana fornicata* retreated from the Putah Creek area at the close of the present zone time in consequence to a new group represented by *Globotruncana arca* which invaded the area and took place of the former. Formerly Gandolfi (1955) attempted to classify the Globotruncanidae into groups and branches based upon their morphogenetical relationship. Concerning such phylogenetic relationship of the globotruncanid Foraminifera, however, opinions still diverge among authors (Brönnimann and Brown, 1956; Banner and Blow, 1959; Pessagno, 1960; Berggren, 1962b, van Hinte, 1963). In other words, such genetical grouping of the Upper Cretaceous planktonic species is not based upon a secure foundation. Actually there is no distinct difference between the old and new groups in the scheme of the globotruncanid branches proposed by Gandolfi. Although there are many species which records are hitherto restricted to the European and North American regions, these do not support the present assumption, because the available micropaleontological records are rather limited outside the regions mentioned above.

Next, we should examine the sedimentary environment to interpret the faunal facies and related features during the time of deposition of the zones. As one means to approach to this problem, the following procedures are taken: (1) the foraminiferal assemblages from about the upper part of the *Globotruncana schneegansi* zone can be classified into three groups of the agglutinated (inclusive of siliceous), calcareous benthonic, and planktonic species; an analysis of them becomes important for interpretation from the faunal side, (2) the total number of species, and relative frequencies of the specimens and species of the respective groups in each core sample are calculated; this may aid in understanding the environmental conditions, (3) the frequency-curves of the Foraminifera are compared with the variation in lithology and the vertical ranges of the planktonic species (Fig. 7) as a means for studying the stability and conditions of the sedimentary environment.

At the basal silty facies of the upper part of the Funks Formation the foraminiferal assemblage appears to be nearly stable as indicated by the lack of marked oscillations in the frequency curves. And then the agglutinated forms gradually increase their number toward the lower part of the Guinda Formation, where sandy facies predominates. Although they occupy at first only about 30 percent of the species in the assemblage, they become more numerous and attain nearly 100 percent in the basal part of the Guinda, showing considerable fluctuations in individual and species number from basal upper Funks to lower Guinda time. On the other hand, the chronological alternative species of planktonic forms begin to occur near the end of the stable phase, and reach their maximum at the horizon where the agglutinated group exceeds more than 50 percent of the total number of species. This particular horizon marks the boundary between the *Globotruncana schneegansi* and the *Globotruncana arca* zones. As a general rule, the changes in the frequencies of the planktonic species and calcareous benthonic forms parallel one another, but the planktonic ones disappear when the agglutinated species exceed 70 percent of the total number of species.

Of the three groups already mentioned, in general the agglutinated group is represented in the Funks Formation by such genera as *Ammodiscus, Bathysiphon, Dorothia, Eggerella, Gaudryinella, Glomospira, Haplophragmoides, Plectina, Reophax, Rzehakina, Silicosigmoilina, Spiroplectammina, Tritaxia* and *Trochammina*, whereas the basal part of the Guinda Formation yields only *Bathysiphon, Haplophragmoides, Trochammina* and a form closely related to the Recent *Sphaerammina.* On the other hand, the calcareous benthonic group consists mainly of the Nodosariidae and other genera: namely, *Astacolus, Dentalina, Fissurina, Frondicularia, Lenticulina, Lingulina, Marginulina, Nodosaria, Pseudonodosaria, Saracenaria, Allomorphina, Bandyella, Colomia, Conorotalites, Globorotalites, Gyroidinoides, Hoeglundina, Loxostomum, Oolina, Osangularia, Planulina, Pleurostomella, Praebulimina, Stensioina* and *Stilostomella.*

The above generic composition is rather uniform in the part of the section under discussion, except for the top part which is characterized by a few agglutinated genera. These benthonic assemblages are associated with a number of planktonic species and all of them together may indicate fairly deep open-sea conditions. However, such genera as *Trochammina* and *Haplophragmoides,* well known euryhaline forms, occur commonly in brackish waters which are often stagnant and rich in suspending materials. *Bathysiphon*

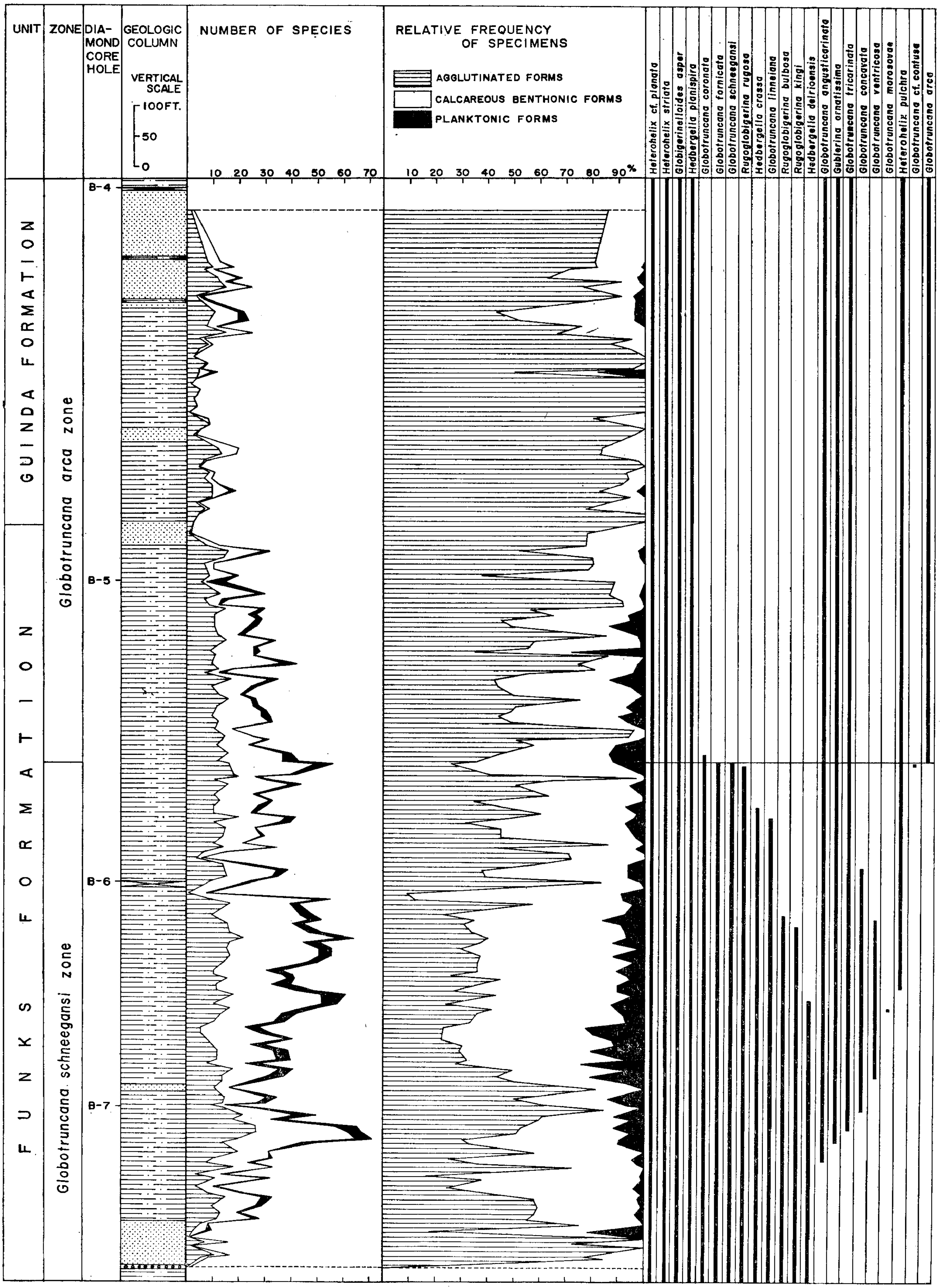

Fig. 7. Late Funks and early Guinda planktonic Foraminifera.

is also considered to be a very tolerant form which can live in adverse environments as recorded from the Alaskan Cretaceous (Tappan, 1962, p. 128). In addition, Stainforth (1952, p. 43) stressed that neither depth, temperature nor salinity could be a major factor but turbidity principally controls the development of the agglutinated forms.

In a discussion on the Recent planktonic foraminiferal distributions on continental shelves, Phleger (1960, p. 239) remarked that:

> "Planktonic Foraminifera seem to be adjusted to the environments characteristic of offshore, oceanic water. They generally do not thrive in nearshore shelf waters off high runoff areas. In such areas the sediments on the outer part of the continental shelf may contain a planktonic foraminiferal fauna characteristic of offshore areas. This fauna is characterized by smaller total planktonic populations and fewer species as the shore is approached, and no planktonic forms may occur in sediments nearest shore."

This statement seems quite suggestive for interpretation of the reducing tendency of the planktonic group of the upper Funks towards from the basal Guinda Formation. This tendency in association with the flourishing of tolerant agglutinated Foraminifera may indicate a remarkable change in the environment during the time of the late *Globotruncana schneegansi* to the early *Globotruncana arca* zones. From the available data it is inferred that the sedimentary basin was originally a fairly deep open-sea environment favorable to the flourishing of Foraminifera but was already influenced by turbidity. Later the basin gradually shifted to a nearshore shallow-water environment characterized by high turbidity and probably by turbulence, too, as is indicated by the frequent intercalation of sandstone layers in the basal part of the Guinda Formation. Furthermore, it may be possible that some causes either preventing or hindering the circulation of oceanic water or facilitating the influx of terrestrial water from the adjacent land compelled the planktonic Foraminifera to retreat from this area at that time.

In this respect, it is desirable to take into account the paleogeographic conditions thought to have prevailed throughout the Great Valley area. Fortunately, Goudkoff (*op. cit.*, Figs. 16 and 17) presented a series of paleogeographic maps for each of his zones. According to these maps, the Cretaceous sea during the F–2 zone time was narrowed into an elongate one of trough shape as compared with the previous ones of the H to G–1 zone times (Fig. 8). And Goudkoff added (*ibid.*, p. 900) that the foraminiferal assemblages of F–2 zone are usually very poor throughout the Great Valley area. A similar but more detailed paleogeographic map showing the distribution of the Venado up to and including the Forbes Formations in the Sacramento Valley was recently published by Safonov (1962, Fig. 11). Basing upon the results of previous subsurface geologic investigations, he gave a comprehensive discussion on the tectonism and geology of Sacramento Valley, and the main events enumerated by him are: southerly tilt of the valley; progressive uplift of the west side and the Diablo uplift in the south; and, the oscillatory and differential movements within the valley.

Taking all those events into consideration, we may assume the following processes during deposition of the upper Funks to lower Guinda Formations, namely, reduction of the marine area due to uplift of the western hinterland and/or development of barriers, increase in influx of terrigenous materials and fresh water, and deterioration of circulation of oceanic water. At first the most sensitive and intolerant planktonic group might react on a chain of these environmental changes. Further it is possible that they were gradually excluded from the area by both the offshore current and rapid sedimentation analogous to the case described by Tappan (1962, p. 127). Tracing all of the foraminiferal assemblages from below upwards, it is readily noticed that the balance between the respective groups was gradually subjected to change by the increase of the agglutinated species group, and decrease of the planktonic forms, owing to the breaking of the balance between the

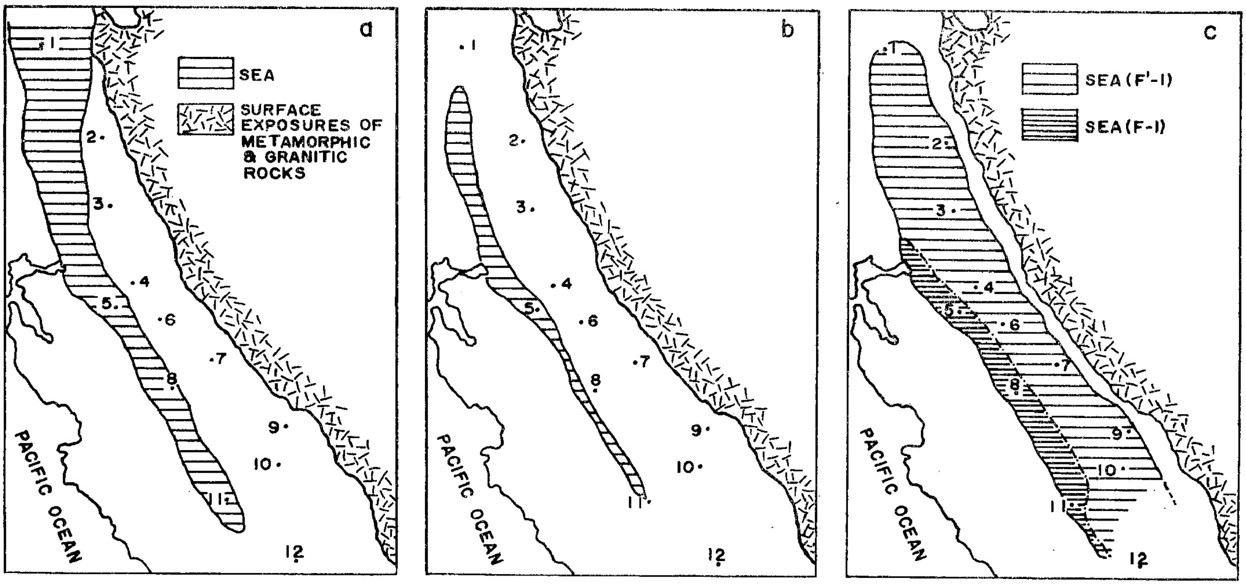

Fig. 8. Map showing the paleogeography of California from H to F-1 zone time (simplified after Goudkoff, 1945).
a, H, G-2 and G-1 zone time; b, F-2 zone time; c, F-1 (F′-1) zone time.
1, Corning; 2, Marysville; 3, Sacramento; 4, Stockton; 5, Tracy; 6, Modesto; 7, Merced; 8, Los Banos; 9, Fresno; 10, Riverdale; 11, Coalinga; 12, Lost Hills.

agglutinated and calcareous benthonic groups. Finally the agglutinated group dominates over the calcareous benthonic and planktonic groups, and contemporaneously the sediments themselves indicate a physical change in the environmental conditions.

To check the environmental changes, the same procedure is followed for the boundary between the *Hedbergella loetterli* and the *Globotruncana schneegansi* zones (Fig. 9). In this part of the section, those tendencies as cited above are not so distinct, because the frequency curves often assume extremely digitated forms owing to the rich sandy facies and meager number of species. Even under these circumstances, the ranges of the planktonic species appear to terminate in advance of the predominance of the agglutinated species associated with a shift from silty to sandy facies.

Thus the disappearance or termination of the species ranging from the older zones may be explained at least in part by the change of the sedimentary environment. However, there still remain some problems which are not explicable by such temporary environmental change. The species change remarkably before and after the late *Globotruncana schneegansi* zone, and *Rugoglobigerina* is not found among the later assemblages. In addition, some of the species which newly appeared at about this time are restricted in their apparent ranges to very short intervals.

With regard to the above, it may be certainly possible that climatic change also influenced the sequence of the chronological alternative species. Once Durham (1950) made a comparison of the fossil and Recent molluscs and corals, and interpreted the evolution of temperature in the shallow seas of the Pacific coast during the Mesozoic and Tertiary. According to him (*ibid.*, p. 1252), the 18.5°C isotherm based upon reef corals was estimated to be in the vicinity of 53°N. Latitude, or even farther north during the Cretaceous time. Urey *et al.* (1951, p. 140) discussed on the Late Cretaceous paleotemperature based upon the results of oxygen isotopic analysis of the belemnites from the Upper Cretaceous chalk in England. Successively, Bandy (1960, p. 3) showed the positions of the general northern limits of the *Globotruncana* fauna during the Late Cretaceous, and his review well accords with the results of the above mentioned authors. They inferred that there was a

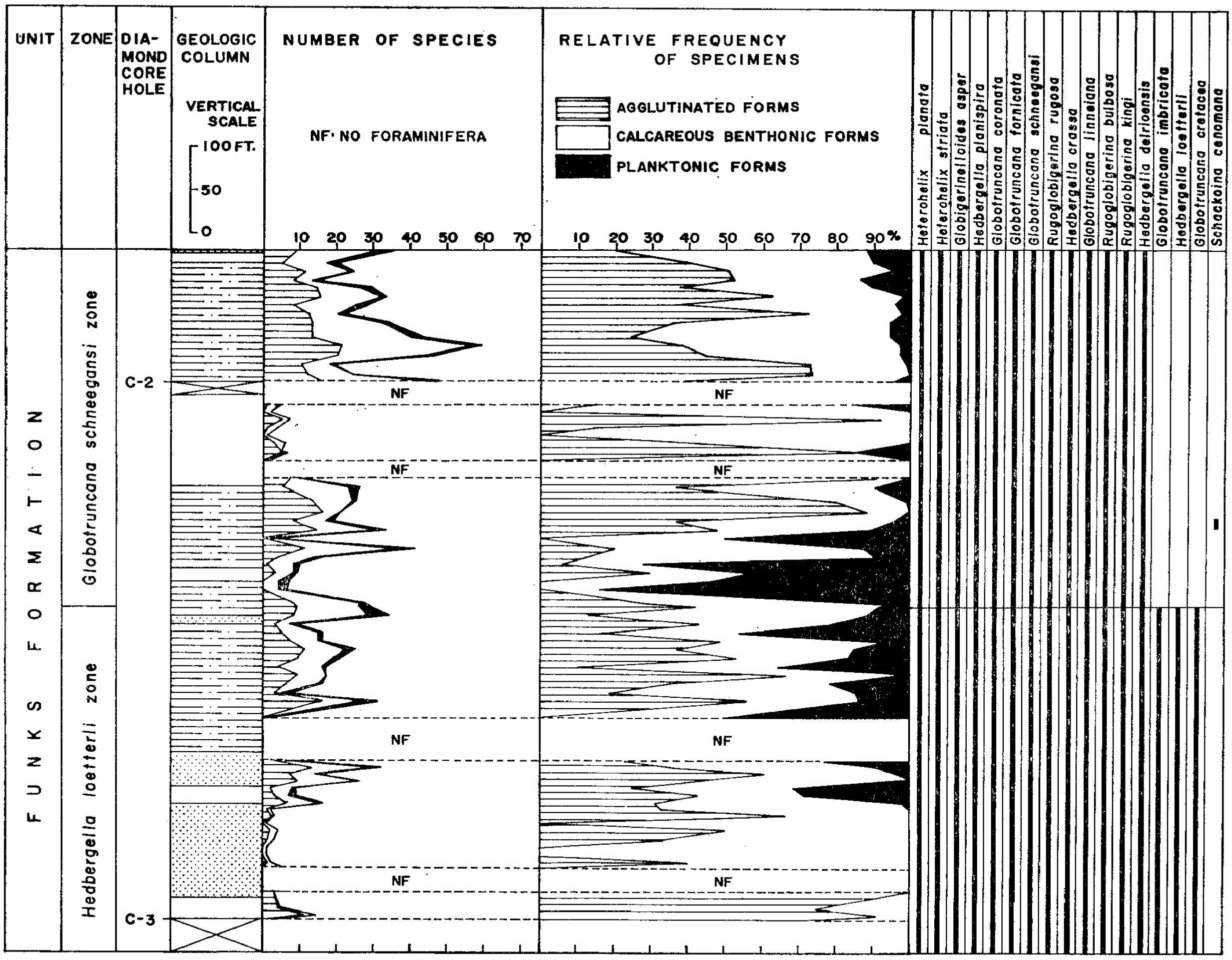

Fig. 9. Early Funks planktonic Foraminifera.

progressive increase of temperature from the Cenomanian to Senonian and then a decrease toward the Maastrichtian on a world wide scale. Therefore it seems quite difficult to assume a pronounced climatic change to explain in full the chronological alternative planktonic species during the great expansion of marine faunas toward the polar regions.

On the basis of the Cretaceous foraminferal faunas, Bettenstaedt and Wicher (1955) recognized two different facies, and pointed out that "worldwide species often show a longer stratigraphic range (duration of life) in the Tethys than in Boreal (duration of existence)" (p. 497). And they attributed the short duration of existence in the 'Boreal" Province to immigration. They wrote: "Gradual lowering of the temperatures through Upper Cretaceous time toward the Maestrichtian are indicated in England and agree with the establishing of climatic zones noted by Dacqué". However, whether the Late Cretaceous planktonic foraminiferal assemblages were differentiated in the same manner as their modern counterparts in low-, mid-, and high-latitudes of the oceans, remains to be settled by an investigation of more planktonic assemblages of the tethysian and boreal facies. Even if there were a shift from one facies to another at about the late Coniacian time, we would not expect a drastic change of the planktonic faunal elements on a world-wide scale under the circumstances mentioned above.

Another view to the above problem may be the possibility of local paleoclimatic change and its effect on the planktonic species. In reference to the geographic distribution of *Globotruncana contusa*, Troelsen (1955, p. 78) noted that all strongly convex species of

Globotruncana were restricted in their known distribution to rather low latitudes. Taking *G. contusa* in the Maastrichtian of Europe as an example, it has been recorded from Austria, Belgium, Denmark and Italy, while there are no records of it in Sweden (*vide* Berggren, 1962a, p. 54). This restricted distribution of that species seems to suggest its preference to the warmer waters of the Cretaceous seas. It is noteworthy that such strongly convex forms as *G.* cf. *contusa* and *G. concavata* appeared in the Putah Creek area for a while during the time in question. It is probably an ecological convergence that *G. morosovae* and *G. ventricosa* develop a tendency in distribution similar to those forms. On the other hand, newly appearing forms in the post-*Globotruncana schneegansi* zone time are: *Globotruncana pura* recorded only from the Netherlands and northwestern Germany ("Boreal" facies of Bettenstaedt and Wicher), *G. japonica* and *G. japonica robusta* previously known only from Hokkaido, Japan, besides one new species and two widely distributed species, *G. arca* and *G. subcircumnodifer*. According to Campbell and Clark (1944, p. 4) who described the radiolarian fossils from the Campanian shale near Tesla, east of San Francisco, the presence of the ciliate genus *Parafavella* which flourishes at freezing temperatures in modern seas would be indicative of cool-water. On the basis of this data, Bandy (1960, p. 6) inferred the upwelling of deeper colder waters, a feature that is common in the coastal waters of southern California and in the Gulf of California. Although it may be a bold attempt to assume the local change of temperature in the light of present knowledge, tendency toward local prevalence of colder water in the post-*Globotruncana schneegansi* zone time appears to be most likely a hypothesis for explanation of alternation of species components and shortening of their ranges.

The present result of the investigation on the planktonic Foraminifera does not coincide well with that of the Redding area, northeastern part of Sacramento Valley, carried out by Trujillo (1960). Even in presumably the same geosynclinal basin such as the Sacramento Valley, local differentiation of foraminiferal assemblages may be caused by complex environmental processes. In short, the results of the present study suggest us that the local zones established by means of the vertical ranges of planktonic Foraminifera are more or less modified by the environment of the individual areas. Accordingly, before standard zones for correlation are established, it is necessary to incorporate all available data.

SYSTEMATIC DESCRIPTION

Family Heterohelicidae Cushman, 1927

Subfamily Heterohelicinae Cushman, 1927

Genus *Heterohelix* Ehrenberg, 1841

Heterohelix globulosa (Ehrenberg), 1840

Pl. 20 figs. 1a, b

Textularia globulosa Ehrenberg, 1840, p. 135, pl. 4, figs. 2, 4, 5, 7, 8 (*fide* Ellis and Messina, 1940 *et seq.*); Franke, 1928, p. 134, pl. 12, fig. 11.

Textilaria globulosa Ehrenberg. Ehrenberg, 1854, p. 24, pl. 21, fig. 87, pl. 24, figs. 13, 14, pl. 27, fig. 6, pl. 28, figs. 9, 10, pl. 29, figs. 17a, b, pl. 30, figs. 3a, b, pl. 32 (1), fig. 8, pl. 32 (2), fig. 12, pl. 37 (6), fig. 6 (*fide* Ellis and Messina, 1940 *et seq.*); Cushman, 1928, p. 215, pl. 34, fig. 8, pl. 35, fig. 12.

Textularia globifera Reuss (part), 1860, p. 232, pl. 13, figs. 7, 8 (exclusive of synonymy) (*fide* Ellis and Messina, 1940 *et seq.*).

Textularia decurrens Chapman, 1892, p. 515, pl. 15, fig. 6.

Gümbelina globulosa (Ehrenberg). Egger, 1900, p. 32, pl. 14, fig. 43; White, 1929, p. 36, pl. 6, figs. 10a, b; Cushman, 1946, p. 105, pl. 45, figs. 9–15 (with synonymy additional to 1946); Kikoïne, 1948, p. 17, pl. 1, figs. 3a-c; Cushman, 1949, p. 7, pl. 3, fig. 23; Loeblich, 1951, p. 108, pl. 12, figs. 4, 5; Noth, 1951, p. 60, pl. 7, figs. 3, 4; Visser, 1951, p. 254, pl. 8, fig. 8; Young, 1951, p. 63, pl. 14, figs. 12, 23-26; Civrieux, 1952, p. 270, pl. 6, figs. 13a-14;

Hamilton, 1953, p. 234, pl. 30, fig. 15, pl. 31, fig. 9; Frizzell, 1954, p. 109, pl. 15, figs. 24-27b; Hagn, 1954, p. 73, pl. 6, figs. 16, 17; Stelck and Wall, 1954, p. 22, pl. 2, fig. 20; Weiss, 1955, p. 307, pl. 1, fig. 8; Bolin, 1956, p. 289, pl. 38, figs. 10–11b, 14a-16; Said and Kenawy, 1956, p. 139, pl. 3, figs. 29a, b; McGugan, 1957, p. 339, pl. 32, figs. 18a-19b; Belford, 1960, p. 59, pl. 15, figs. 10, 11; Scheibnerová, 1961, p. 77, pl. 14, figs. 4a, b.

Guembelina globulosa (Ehrenberg). Cushman, 1931, p. 43, pl. 7, figs. 3a-5; Nagappa, 1959, pl. 7, figs. 11a-12b.

Heterohelix globulosa (Ehrenberg). Montanaro Gallitelli, 1957, p. 137, pl. 31, figs. 12–15; Montanaro Gallitelli, 1958, p. 19, pl. 2, figs. 4, 8; Takayanagi, 1960, p. 119, pl. 7, figs. 20a, b; Tappan, 1962, p. 196, pl. 55, figs. 1, 2; Graham and Church, 1963, p. 61, pl. 7, figs. 11a, b; Barr and Cordey, 1964, p. 306, pl. 49, fig. 4 (lectotype of *Textularia decurrens* Chapman).

Remarks: – The very minute *Heterohelix* with globular chambers found in the Putah Creek material is referred to *H. globulosa.* It is distinguished by its small tapering test, broadly rounded periphery, globular chambers, distinctly depressed, straight sutures, thin wall with fine perforation, and the high arched aperture with a distinct rim at the inner margin of the last chamber.

Compared with the specimens illustrated by Loeblich (*op. cit.*) and Montanaro Gallitelli (*op. cit.*), the Putah Creek material has generally smaller test with less number of chambers. No microspheric forms with an initial coil were observed among them.

Length of hypotype 0.19 mm, breadth 0.13 mm.

Type and occurrence: – Hypotype (fig. 1a, b), Stanford Univ. Paleo. Type Coll. No. 9756, from the core at 190–200 feet in the Forbes Formation, in Diamond Core Hole No. 1, Section A.

Occurrence in the studied area: – This species is almost confined to the Forbes Formation, though it is exceptionally found in the lower part of the Guinda Formation. *Range-Globotruncana arca* zone to *Globotruncana subcircumnodifer* zone.

Previous record of occurrence: – The Upper Cretaceous of various parts of the world, such as Europe, Africa, North and South Americas, Japan, Australia and Middle Pacific seamount (*vide* Takayanagi, *loc. cit.*). From the available records *H. globulosa* makes its first appearance in the Turonian, but there is no sufficient evidence to determine the top of its stratigraphic range. It is also known from the base of the Velasco Formation (White, *loc. cit.*) and the Danian of Assam (Nagappa, *loc. cit.*). In California it occurs in the Campanian of the Stanford University Campus and the Maastrichtian of Fresno County (Graham and Church, 1963, *op. cit.*).

Heterohelix cf. *planata* (Cushman), 1938

Pl. 20, figs. 2a, b

Compared with:

Gümbelina planata Cushman, 1938, p. 12, pl. 2, figs. 13a-14; Cushman, 1944, p. 10, pl. 2, fig. 20; Cushman, 1946, p. 105, pl. 45, figs. 6a-7.

Heterohelix planata (Cushman). Montanaro Gallitelli, 1958, p. 20, pl. 2, figs. 9, 10.

Remarks: *Heterohelix planta* was originally described by Cushman from the Taylor Marl of Texas, as follows (1938, *op. cit.*):

> "Test compressed, about 1 ½ times as long as broad, rapidly tapering with the greatest breadth formed by the last pair of chambers, periphery slightly keeled in the early portion, in the remainder deeply indentate; chambers broader than high throughout, somewhat compressed, in the adult portion separated by depressed triangular areas; sutures distinctly depressed, somewhat curved; wall smooth, finely perforate, the perforations tending to be in longitudinal lines; aperture high, arched, with distinct, lateral flanges running out onto the preceding chamber. Length 0.35–0.45 mm.; breadth 0.25–0.30 mm; thickness 0.12–0.14 mm".

This species is more related to *Heterohelix pulchra* (Brotzen) than to *H. striata*

(Ehrenberg) with which Cushman made comparison. It differs from *H. pulchra* in having coarser perforations in longitudinal lines.

The forms referred to *H.* cf. *planata* in the present material show no trace of a slight keel in the early portion and have smaller test (even in the case of specimens with the same number of chambers as the typical one). Except for such differences, however, these forms appear quite similar to Cushman's species. The microspheric forms, though they are very rare compared with the megalospheric ones, are found to possess about five chambers in the very tiny initial coiled portion. The former forms also show a tendency to become shorter and broadly flaring test in contrast to the latter. Actually the ratio of breadth to length is approximately 4: 5 in the microspheric form and 2: 3 in the megalospheric ones.

Length of hypotype (megalospheric) 0.25 mm, breadth 0.15 mm.

Type and occurrence: – Hypotype (figs. 2a, b), Stanford Univ. Paleo. Type Coll. No. 9757, from the core at 71–78 feet in the Forbes Formation, in Diamond Core Hole No. 3, Section A.

Occurrence in the studied area: – Common in the lower part of the Forbes, the middle part of the Guinda, and the upper part of the Funks Formations; it also occurs sporadically in the upper part of the Sites and the other parts of the aforementioned formations. *Range-Hedbergella loetterli* zone to *Globotruncana subcircumnodifer* zone.

Previous record of occurrence: – The Taylor Marl (Campanian) of Texas, U.S.A., and the Upper Cretaceous (Campanian-Maastrichtian) of Italy.

Heterohelix pulchra (Brotzen), 1936

Pl. 20 figs. 3a, b

Gümbelina tessera (Ehrenberg). Cushman, 1932, p. 338, pl. 51, figs. 4-5b (non *Grammostomum tessera* Ehrenberg, 1854); Loetterle, 1937, p. 34, pl. 5, fig. 4 (non Ehrenberg); Jennings, 1936, p. 27, pl. 3, figs. 10a, b (non Ehrenberg).

Gümbelina pulchra Brotzen, 1936, p. 121, pl. 9, figs. 2a-3b; Cushman, 1938, p. 12, pl. 2, figs. 12a, b.

Gümbelina pseudotessera Cushman, 1938, p. 14, pl. 2, figs. 19–21; Cushman, 1944, p. 91, pl. 14, figs. 5a, b; Cushman, 1946, p. 106, pl. 45, figs. 16–20; Schijfsma, 1946, p. 76, pl. 4, fig. 7; Hamilton, 1953, p. 234, pl. 30, fig. 14; Frizzell, 1954, p. 109, pl. 15, figs. 33–34b; Bolin, 1956, p. 290, pl. 38, fig. 13.

Heterohelix pulchra (Brotzen). Montanaro Gallitelli, 1957, p. 137, pl. 31, fig. 20; Montanaro Gallitelli, 1958, p. 20, pl. 2, figs. 11, 12; Pessagno, 1962, p. 358, pl. 1, fig. 3.

Gümbelina aff. *pseudotessera* Cushman. Sacal and Debourle, 1957, p. 12, pl. 3, fig. 5.

Non *Heterohelix pulchra* (Brotzen). Olsson, 1960, p. 27, pl. 4, fig. 6 (non Brotzen).

Remarks: – This species is characteristic in having compressed test, rather inflated chambers tending to become rapidly much broader than high toward the middle stage then less rapidly in the later stage, and depressed, slightly curved sutures.

At the time of proposal of this species, Brotzen (*op. cit.*) illustrated a microspheric form with *Planoglobulina*-like (or possibly *Gublerina*-like) appearance. In the Putah Creek material such form is not observed even among the microspheric forms. However it is noticeable that many specimens possess depressed triangular areas among the later chambers though in transmitted light they prove to be lateral parts of reniform chambers. As to the variability of the genus *Gublerina*, Montanaro Gallitelli (1957, p. 141) stated:

> "Specimens where the reniform chambers are arranged in two diverging series, separated by a non-septate central area but without proliferation at the top of the test, are representatives of aberrant forms (although still of *Gublerina*) which tend toward the extreme limits of variability of the genus *Heterohelix* (*H. tessera, H. pulchra, H. lata*)".

Thus this species appears to be close to *Gublerina* in morphological character. So far no subsequent authors have recorded such *Planoglobulina*-like form as shown by Brotzen. But further research on its variation may furnish a key to the genetical interrelationship between *Heterohelix* and *Gublerina*.

Adopting the results of the comparative study by Montanaro Gallitelli, *H. pseudotessera* is included in the synonymy of the present species.

Length of hypotype 0.24 mm, breadth 0.16 mm.

Type and occurrence: – Hypotype (figs. 3a, b), Stanford Univ. Paleo. Type Coll. No. 9758, from the core at 80–90 feet in the Forbes Formation, in Diamond Core Hole No. 1, Section A.

Occurrence in the studied area: – The upper part of the Funks and Forbes Formations, being most common in the upper part of the latter. *Range*-Top of the *Globotruncana schneegansi* zone to the *Globotruncana subcircumnodifer* zone.

Previous record of occurrence: – Mainly from the Coniacian to Maastrichtian of Europe and North America. These records are the Coniacian to Santonian of Sweden; Campanian of the Netherlands; Maastrichtian of France; Campanian to Maastrichtian of Italy, upper Santonian to lower Maastrichtian of Puerto Rico; and Coniacian to Masstrichtian of the Gulf Coast and Western Interior regions, U.S.A.

Heterohelix striata (Ehrenberg), 1840

Pl. 20, figs. 4a, b

Textularia striata Ehrenberg, 1840, p. 135, pl. 4, figs. 1*a*, 1*a*, 2*a*, 3*a*, 9*a*.

Textilaria striata Ehrenberg. Ehrenberg, 1854, pl. 27, fig. 3, pl. 28, fig. 6, pl. 31, fig. 9, pl. 32 (1), fig. 4b, pl. 32 (2), figs. 11, 14; Cushman, 1928, p. 215, pl. 34, fig. 4b, pl. 35, figs. 11, 14.

Gümbelina striata (Ehrenberg). Egger, 1900, p. 33, pl. 14, figs. 5–7, 10, 11, 37–39; Brotzen, 1936, p. 118, pl. 9, figs. 1a, b, text-figs. 1 (4, 5), 2 (A-E), 39 (1—10), 40 (1–3); Cushman, 1938, p. 8, pl. 1, figs. 34–40b; Cushman and Deaderick, 1942, p. 63, pl. 15, figs. 8–10; Cushman and Todd, 1943, p. 64, pl. 11, fig. 11; Cushman, 1944a, p. 10, pl. 2, fig. 19; Cushman, 1944b, p. 91, pl. 14, fig. 4; Cushman, 1946, p. 104, pl. 45, figs. 4, 5; Schijfsma, 1946, p. 74, pl. 4, fig. 6; Kikoïne, 1948, p. 19, pl. 1, figs. 7a-c; Cushman, 1949, p. 258, pl. 24, fig. 3; Cushman, 1949, p. 7, pl. 3, fig. 24; Bandy, 1951, p. 510, pl. 75, figs. 8a–9b (including additional synonymy up to 1951); Hagn, 1953, p. 73, pl. 6, figs. 16, 17; Hamilton, 1953, p. 235, pl. 30, fig. 13; Frizzell, 1954, p. 110, pl. 15, figs. 39, 40; LeRoy, 1953, p. 34, pl. 5, figs. 13, 14, pl. 6, figs. 6, 7.

Textularia globulosa f. *striata* (Ehrenberg). Franke, 1928, p. 134.

Guembelina striata (Ehrenberg). Cushman, 1931, p. 43, pl. 7, figs. 6, 7; Nagappa, 1959, pl. 7, fig. 4.

Gümbelina globulosa (Ehrenberg) var. *striatula* Marie, 1941, p. 182, pl. 28, figs. 273a–275b.

Pseudogümbelina striata (Ehrenberg). Brönnimann and Brown, 1953, p. 154, text-fig. 6; Said and Kenawy, 1956, p. 139, pl. 3, fig. 37; Belford, 1960, p. 60, pl. 15, figs. 12, 13.

Gümbelina cf. *G. striata* (Ehrenberg). Bolin, 1956, p. 291, pl. 38, figs. 12a, b, 17a, b.

Gümbelina striata f. *turonica* Hofker, 1957, p. 419, text-fig. 477, row 1, figs. a-e.

Gümbelina striata f. *emscheriana-quadrata* Hofker, 1957, p. 420, text-fig. 477, row 2, figs. a, b, row 3, figs. a-e.

Gümbelina striata f. *supracretacea* Hofker, 1957, p. 420, text-fig. 477, row 4, figs. a-f.

Gümbelina striata f. *infraquadrata* Hofker, 1957, p. 420, text-fig. 477, row 2, figs. c-f.

Heterohelix striata (Ehrenberg). Montanaro Gallitelli, 1957, p. 137; Graham and Clark, 1961, p. 107, pl. 5, figs. 4a, b; Berggren, 1962a, p. 21, pl. 6, figs. 1a-5b; Pessagno, 1962, p. 358, pl. 1, fig. 5; Graham and Church, 1963, p. 62, pl. 7, figs. 12a, b; Kavary and Frizzell, 1964, p. 62, pl. 13, figs. 1, 2.

Heterohelix globulosa (Ehrenberg). Trujillo, 1960, p. 344, pl. 50, figs. 10a, b (non Ehrenberg).

Remarks: – This is the most characteristic and common species among the Putah Creek heterohelicids. It is characterized by its elongate, tapering test, globular chambers increasing gradually in size as added, constricted sutures, and surface ornamented with fine longitudinal striae.

As precisely reviewed by Berggren (*loc. cit.*), a dispute arose as to whether this species should be included in *Heterohelix* as done by Montanaro Gallitelli (1957, *loc. cit.*) or be placed in *Pseudogümbelina* as upheld by Brönnimann and Brown (1953, *loc. cit.*). The opinions fundamentally concern the genetical evaluation of the accessory apertures at the base of the ultimate chamber. In the Putah Creek material, however, these accessory apertures are not always present, a feature which Montanaro Gallitelli observed and which was substantiated by Berggren on the Scandinavian material. Consequently, it is regarded to be most reasonable from the morphology and grade of development of the accessory apertures to place the present species in the Genus *Heterohelix,* as done by the above authors.

Microspheric forms with a tiny initial coil, though quite rare, show a tendency to expand the chamber size rather rapidly from the initial part toward the last pair of the chambers, and thus they have relatively broader test than the megalospheric form.

A close examination of Trujillo's hypotype of *H. globulosa* shows it to be *H. striata,* because of the very fine striae on the wall surface.

Length of hypotype 0.37 mm, breadth 0.23 mm.

Type and occurrence: – Hoypotype (figs. 4a, b), Stanford Univ. Paleo. Type Coll. No. 9759, from the core at 269–278 feet in the Forbes Formation, in Diamond Core Hole No. 5, Section A.

Occurrence in the studied area: – The Sites, Funks, Guinda, and Forbes Formations, but is most common in the upper part of the Guinda and Forbes Formations. *Range*-Upper part of the *Globotruncana fornicata/Globotruncana coronata* zone to the *Globotruncana subcircumnodifer* zone.

Previous record of occurrence: – Various parts of Europe, north Africa, Near and Far Easts, North America, Caribbean region, West Indies, Middle Pacific seamount, and western Australia. Most of the records are from the Campanian and Maastrichtian, though it is considered to range from Turonian to Maastrichtian. In California this species has been found in the Coniacian of Shasta County, the Campanian of San Diego and Merced Counties and the Stanford University Campus, and the Maastrichtian of Fresno County (Graham and Church, *op. cit.*).

Heterohelix ventilabrelliformis (van der Sluis), 1950

Pl, 20, figs. 5a, b

Gümbelina ventilabrelliformis van der Sluis, 1950, p. 21, pl. 1, figs. 2a-c (*fide* Ellis and Messina, 1940 *et seq.*).

Remarks: – In the Putah Creek material a few specimens of *H. ventilabrelliformis* have been found. This species was originally described from the Maastrichtian marl of the Island of Ceram, Indonesia. It is characterized by its elongate tapering test, broadly rounded periphery, globular, biserial chambers which tend to become triserial in the last portion, depressed, nearly straight sutures, and finely perforate wall with inconspicuous fine costae.

The most notable feature of this species is the appearance of an aberrant chamber at the final stage. The last chamber is deflected from the normal biserial alignment to become nearly central in position as often seen in specimens of *Pseudotextularia.* Although van der Sluis did not mention the presence of a supplementary aperture, a tiny aperture is recognized at the opposite side of the main one which is situated at the base of the last chamber in the present material. A similar feature was once observed in the specimens of *H. moremani* Cushman (Cushman, 1938, p. 10). Such a tendency in the final developmental stage may suggest a transition from the biserial *Heterohelix* to *Planog lobulina* with proliferation of the chambers in its later stage. It seems, however, appropriate to retain this species in the genus *Heterohelix,* because such variability is restricted only to the last chamber so far as the Putah Creek specimens are concerned. In the present study the deficiency of specimens does not allow an examination of the variation despite the importance.

Compared with the holotype, the Putah Creek specimens are much smaller in size.

Length of hypotype 0.20 mm, breadth 0.14 mm.

Type and occurrence: – Hypotype (figs. 5a, b), Stanford Univ. Paleo. Type Coll. No. 9760, from the core at 360–366 feet in the Forbes Formation, in Diamond Core Hole No. 1, Section A.

Occurrence in the studied area: — Very rare, only found near the top of the Forbes Formation, *Globotruncana subcircumnodifer* zone.

Previous record of occurrence: — None outside of the type locality, Maastrichtian marl of the Island of Ceram.

Genus *Gublerina* Kikoïne, 1948

Gublerina ornatissima (Cushman and Church), 1929

Pl. 20, figs. 6a–8b

Ventilabrella ornatissima Cushman and Church, 1929, p. 512, pl. 39, figs. 12–15; Cushman, 1938, p. 27, pl. 4, figs. 11a, b; Kikoïne, 1948, p. 25, pl. 2, figs. 8a-c.

Gublerina ornatissima (Cushman and Church). 1929, Montanaro Gallitelli, 1957, p. 140, pl. 32, figs. 1–6b; Graham and Church, 1963, p. 61, pl. 7, figs. 10a, b; Brönnimann and Rigassi, 1963, pl. 17, fig. 4.

Gublerina cuvillieri Kikoïne, 1948, p. 26, pl. 2, figs. 10a–c; de Klasz, 1953b, p. 246, pl. 8, figs. 1a, b.

Güblerina cuvillieri Kikoïne. Bettenstaedt and Wicher, 1955, p. 502, pl. 2, fig. 15.

Remarks: – As already discussed in detail by Montanaro Gallitelli (*op. cit.*), this species is marked by its compressed, triangular test in broad outline, chambers often coiled in the early stage, which is followed by a biserial stage, then progressed divergence by leaving a central cavity between the chambers, proliferation of chambers at the top of the test, limbate and granular sutures, thick wall finely perforate, radial in structure, usually with longitudinal and beaded costae.

In the Putah Creek material examined, the characteristic development of the central cavity which was pointed out by Montanaro Gallitelli is well substantiated. This characteristic development is the sequence from a flat, depressed, and unornamented central area to a subcostate to a bubbled one and finally to polycamerate ones. The inner structure of the central cavity was studied on immersed specimens by transmitted light as well as on dissected specimens. All of them show a broad internal communication between the chambers and an undivided central cavity. The surface ornamentation is variable, and irregularly beaded costae are less distinct or obscure on the later part compared with the early one. Apertures are not visible on the majority of the specimens at hand, but one shows an aperture at the inner margin of the last chamber.

Accepting Montanaro Gallitelli's study, *G. cuvillieri* is included in the synonymy of this species. At the same time she identified *G.* aff. *cuvillieri* Kikoïne described by de Klasz (*op. cit.*, p. 248, footnote 1, pl. 8, figs. 2a, b) with *G. glaessneri* Brönnimann and Brown, and re-illustrated the holotype of the latter species. According to de Klasz, this form is distinguished from *G. cuvillieri* (=*G. ornatissima* in this paper) by the lack of coarse rugosity on the early portion of the test, while Brönnimann and Brown distinguished them by the subangular chambers exhibited late in the early stage of the former form. Although two criteria have been used for the discrimination, it is evident that the surface ornaments are individually variable in *Gublerina* and the subangular chambers are scarcely displayed on the holotype of *G. glaessneri* re-figured by Montanaro Gallitelli (*op. cit.*, pl. 32, fig. 7). Therefore, such criteria do not seem to be convincing for discrimination of the species. Accordingly it is necessary to reexamine both *G. ornatissima* and *G. glaessneri* to confirm their validity.

Length of hypotype (figs. 6a, b) 0.38 mm, breadth 0.34 mm; length of hypotype (figs. 7a, b) 0.45 mm, breadth 0.36 mm; length of hypotype (figs. 8a, b) 0.62 mm. breadth

0.43 mm.

Type and occurrence: – Hypotype (figs. 6a, b), Stanford Univ. Paleo. Type Coll. No. 9761, from the core at 450–459 feet in the Forbes Formation, in Diamond Core Hole No. 1A, Section A. Hypotype (figs. 7a, b) and hypotype (figs. 8a, b), Stanford Univ. Paleo. Type Coll. Nos. 9762, and 9763, both from the core at 138–143 feet in the Funks Formation, in Diamond Core Hole No. 6, Section B.

Occurrence in the studied area: – Common in the upper part of the Funks, Guinda, and Forbes Formations, except for the top of the Funks and the basal part of the Guinda Formations. *Range*–Upper part of the *Globotruncana schneegansi* zone to the *Globotruncana subcircumnodifer* zone.

Previous record of occurrence: – Originally described from the Chico Series in a well, west of Coalinga, Fresno County, California. The age of the horizon was later assigned to Campanian by Graham (1962). Subsequently it has been recorded in California from the Santonian to Campanian of the Panoche Hills area of the same county and the Campanian of the Stanford University Campus (Graham and Church, *op. cit.*). Outside of California the records are almost restricted to the Maastrichtian of France, Austria, Germany and Cuba.

Family Planomalinidae Bolli, Loeblich and Tappan, 1957

Genus *Globigerinelloides* Cushman and ten Dam, 1948

Globigerinelloides asper (Ehrenberg), 1854

Pl. 20, figs. 9a–c

Rotalia aspera Ehrenberg, 1854, p. 24, pl. 23, fig. 28, pl. 27, figs. 57, 58, pl. 28, fig. 42, pl. 31, fig. 44; Beissel, 1891, p. 73, pl. 14, figs. 1–6.

Phanerostomum asperum Ehrenberg, 1854, p. 23, pl. 30, figs. 26a, b, pl. 32 (group 1), fig. 24, pl. 32 (group 2), fig. 42.

Globigerina aspera (Ehrenberg). Egger, 1900, p. 170, pl. 21, figs. 18–21;

Globigerinella aspera (Ehrenberg). Carman, 1929, p. 315, pl. 34, fig. 6; Cushman 1931a, p. 59, pl. 11, figs, 5a, b; Brotzen, 1936, p. 170, pl. 13, figs. 2a-c, text-fig. 62; Bandy, 1951, p. 508, pl. 75, figs. 3a-c (with additional synonymy up to 1951); Hamilton, 1953, p. 226, pl. 30, fig. 5; Belford, 1960, p. 91, pl. 25, figs. 4–6.

Globigerinella voluta (White). Sandidge, 1932, p. 284, pl. 44, figs. 1, 2 (non White).

Planomalina yacuoensis Pessagno, 1960, p. 98, pl. 2, figs. 14, 15, pl. 5, fig. 4; Pessagno, 1962, p. 358, pl. 1, figs. 1, 2.

"*Globigerinella*" *aspera* (Ehrenberg). Graham and Clark, 1961, p. 113, pl. 5, figs. 6a-c; Graham and Church, 1963, p. 64, pl. 7, figs. 17a-c.

Planomalina aspera (Ehrenberg). Barr, 1962, p. 561, pl. 69, figs. 4a, b.

Planomalina ehrenbergi Barr, 1962, p. 563, pl. 69, figs. 1a, b.

Planomalina (*Globigerinelloides*) *aspera aspera* (Ehrenberg). van Hinte, 1963, p. 97, pl. 12, figs. 2a-3, 5, text-figs. 15 (a-f) (with additional synonymy up to 1963).

Globigerinella (?) sp. cf. *G. aspera* (Ehrenberg). Kavary and Frizzell, 1964, p. 48, pl. 9, figs. 6–9.

Remarks: – This species is characterized by its biumbilicate, planispiral test, inflated globular chambers (six to seven in final whorl), nearly radially straight constricted sutures, hispid surface especially of the earlier chambers in the final whorl, the interiomarginal, equatorial arched aperture with bordering lip, and the lateral portion of previous apertures and lips exposing in the umbilical region as relict supplementary apertures.

In the description of this species from Austria van Hinte (*loc. cit.*) stated that its test is planisprial throughout or sometimes trochospiral in the initial part. In the same way some specimens from the Putah Creek material suggest the presence of a trochospiral stage in the intial part by the asymmetrical development of their test and the relict apertures. The presence or absence of the initial trochospiral stage would depend on trimorphism as previously recognized in *Biticinell ? breggiensis* (Gandolfi) (Takayanagi and Iwamoto, 1962, p. 188). In this sense Hofker's assumption on the evolutionary trend in this group seems acceptable as a rule (Hofker, 1957, p. 414; 1959, p. 4). He stated that the "*Globigerina aspera* group" were derived from trochospiral forms in the lower Upper Cretaceous. However, it is difficult to accept that the three genera, *Globigerina*, *Globigerinella* and *Biglobigerinella*, merely represent stages in the morphological cycle of the *Globigerina* group, and further, that their distinctions from one another is of value merely equal to subspecific ranking, as already stated elsewhere (cf. Takayanagi, 1960, p. 132; Berggren, 1962, p. 44).

Van Hinte (*loc. cit.*) gave a full account of the present species and placed in its synonymy some species lately proposed (inclusive of "*Globigerinella*" *japonica* Takayanagi). However there are still some doubts as to regarding "*G.*" *japonica* as a junior synonym of this species. After examination of the additional collection, the present writer agrees with van Hinte on the point that "*G.*" *japonica* is to be referred to the genus *Globigerinelloides*, in the emended definition of Loeblich and Tappan (1961, p. 267). Nevertheless, this species has much smaller test (about 0.15 mm in mean diameter) and thinner wall with smoother surface even in the full adult stage as compared with the typical *Globigerinelloides asper*. At the present state of knowledge on the present species it is evident that size differentiation may not be attributed simply to ecologic control. For such reason the inclusion of "*G.*" *japonica* into the synonymy of *Globigerinelloides asper* should be reserved.

Maximum diameter of hypoptye 0.37 mm, thickness through the last chamber 0.15 mm.

Type and occurrence: – Hypotype (figs. 9a–c), Stanford Univ. Paleo. Type Coll. No. 9764, from the core at 437–445 feet in the Guinda Formation, in Diamond Core Hole No. 6, Section A.

Occurrence in the studied area: – The Sites, Funks, Guinda and Forbes Formations, but is most common in the Funks Formation. *Range*-Upper part of the *Globotruncana fornicata*/*Globotruncana coronata* zone to the lower part of the *Globotruncana subcircumnodifer* zone.

Previous record of occurrence: – Recorded commonly from the Cretaceous of Europe, Africa, North America and Australia. Although further research is required to ascertain its stratigraphic range, *G. asper* appears to be limited to the Turonian to lower Maastrichtian, so far as reliable records are concerned.

Family Schackoinidae Pokorný, 1958

Genus *Schackoina* Thalmann, 1932

Schackoina cenomana (Schacko), 1897

Pl. 21, figs. 1a–c

Siderolina cenomana Schacko, 1897, p. 166, pl. 4, figs. 3–5; Egger, 1900, p. 174, pl. 21, fig. 42; Franke, 1928, p. 193, pl. 18, figs. 11a-c (reproduction of holotype).

Hantkenina cenomana (Schacko). Cushman and Wickenden, 1930, p. 40, pl. 6, figs. 1–3 (reproduction of holotype).

Hantkenina (*Schackoina*) *cenomana* (Schacko). Thalmann, 1932, p. 288.

Hantkenina (*Schackoina*) *senoniensis* Thalmann, 1932, p. 289 (Egger's *Siderolina cenomana* is designated as holotype).

Schackoina gandolfii Reichel, 1948, p. 397, pl. 8, fig. 1, text-figs. 3a-g, 6 (3), 7(3), 8a, 10 (1, 3, 4); Aurouze and de Klasz, 1954, p. 99, text-fig. 1C; Bolli, 1959, p. 263, pl. 20, figs. 12–18.

Hastigerinoides rohri Brönnimann, 1952, p. 55, pl. 1, figs. 8, 9, text-fig. 29 (a-f).

Schackoina cenomana (Schacko). Noth, 1951, p. 74, pl. 5, figs. 9, 10; Subbotina, 1953, p. 128, pl. 1, figs. 1–3; Montanaro Gallitelli, 1955, pp. 143, 144; Bolli, Loeblich and Tappan, 1957, p. 26, pl. 2, figs. 1a-2; Bykova, Vassilenko, Voloshinova, Miatliuk and Subbotina, 1959, p. 300, text-fig. 676a, b; Loeblich and Tappan, 1961, p. 270, pl. 1, figs. 2–7; Ayala-Castanares, 1962, p. 20, pl. 2, figs. 2a-3c, pl. 7, figs. 3a, b, pl. 8, figs. 1a-c.

Schackoina sp. du groupe *cenomana* (Schacko). Aurouze and de Klasz, 1954, pl. 6a.

Schackoina tappanae Montanaro Gallitelli, 1955, p. 142, pl. 1, figs. 1–10; Montanaro Gallitelli, 1958, p. 25, pl. 4, figs. 5a–c.

Remarks: – A minute, water-chestnut-shaped form is referred to *Schackoina cenomana.* This species is characterized by its low trochospiral test in the early portion followed by nearly planispiral later one, the final whorl consists commonly of four flask-shaped chambers with a peripheral tubulospine respectively, and the interiomarginal equatorial arched aperture with a broad lip. In the Putah Creek specimens the tubulospines are broken off at their bases. But it is quite evident that they were arranged radially in a coiling plane.

Montanaro Gallitelli (1955, p. 143) discussed the taxonomic problem of *Schackoina,* and discriminated *S. tappanae* from the present species by the number of chambers in the final whorl. She stressed that *S. tappanae* has three chambers whereas *S. cenomana* has four or five. But at that time she failed to clarify the character of *Hantkenina* (*Schackoina*) *senoniensis* (=*Siderolina cenomana* of Egger, 1900). The present author is, however, in agreement with Loeblich and Tappan (*loc. cit.*) that Egger's form should be included in the synonymy of *S. cenomana.* Therefore it is a matter of time for general acceptance that *H.* (*S.*) *senoniensis* will be considered as conspecific with *S. cenomana.* Moreover Loeblich and Tappan recognized three-chambered forms among the specimens which they identified as *S. cenomana.* Thus there seems to be no solid foundation for separating *S. tappanae* from *S. cenomana.* Herein those two species are regarded as conspecific.

Maximum diameter of hypotype 0.23 mm, maximum thickness 0.07 mm.

Type and occurrence: – Hypotype (figs. 1a–c), Stanford Univ. Paleo. Type Coll. No. 9765, from the core at 180–190 feet in the Funks Formation, in Diamond Core Hole No. 2, Section C.

Occurrence in the studied area: – Very rare, only found in the lower part of the Funks Formation, lower part of the *Globotruncana schneegansi* zone.

Previous record of occurrence: – This species, originally described from the Cenomanian of Germany, has been recorded under various names from widely separated regions. The records available in the present study are: Germany, Cenomanian and Campanian; France, Cenomanian to Turonian; Switzerland, Cenomanian; Italy, upper Senonian (probably Santonian); Crimea and Caucasus, U.S.S.R., Cenomanian; Cuba, Cenomanian; Trinidad, Cenomanian to Coniacian; Texas and Kansas, U.S.A., Cenomanian. In California it has been recorded from the Franciscan Calera Limestone (Cenomanian) at San Mateo County, and Cenomanian outcrop at Gleen County. It thus leaves little doubt with regard to its first appearance in the Cenomanian. But further evidence will be needed to settle the upper limit of the range of *S. cenomana.*

Family Rotaliporidae Sigal, 1958

Subfamily Hedbergellinae Loeblich and Tappan, 1961

Genus *Hedbergella* Brönnimann and Brown, 1958

Hedbergella crassa (Bolli), 1959

Pl. 21, figs. 2a-3c

Praeglobotruncana crassa Bolli, 1959, p. 265, pl. 21, figs. 1a-2; Pessagno, 1962, p. 358, pl. 6, figs. 5, 6.

Remarks: – A minute, low-trochospiral form is referred to *Hedbergella crassa.* This species is characterized by its nearly flat spiral side, about five chambers of the last whorl increasing moderately in size, and the radial sutures on umbilical side and radial to slightly oblique on spiral side.

Although originally placed by Bolli in *Praeglobotruncana*, this species is considered to be referable to *Hedbergella* because of the lack of any trace of a keel or poreless margin. As stated by Banner and Blow (1959, p. 18) and by Loeblich and Tappan (1961, p. 273), the distinction between *Praeglobotruncana* and *Hedbergella* is clear in the recent emendations of planktonic genera. There is, however, a discrepancy in their opinions whether the taxa are of subgeneric or generic ranking. In the present study both taxa are regarded as distinct genera, following the opinion expressed by Loeblich and Tappan.

The Putah Creek form has a smaller test with a narrower umbilicus compared with the typical specimens figured by Bolli (*loc. cit.*), and show a narrow but distinct lip bordering a low arched aperture.

Maximum diameter of hypotype (figs. 2a-c) 0.17 mm, maximum thickness 0.09 mm; maximum diameter of hypotype (figs. 3a-c) 0.16 mm, maximum thickness 0.08 mm.

Type and occurrence: – Hypotype (figs. 2a-c), Stanford Univ. Paleo. Type Coll. No. 9766, from the core at 410–416 feet in the Funks Formation, in Diamond Core Hole No. 5, Section B. Hypotype (figs. 3a-c), Stanford Univ. Paleo.Type Coll. No. 9767, from the core at 460–465 feet in the Funks Formation, in Diamond Core Hole No. 5, Section B.

Occurrence in the studied area: – *H. crassa* occurs commonly from the upper part of the Venado, Yolo, Sites and Funks Formations. *Range*-Upper part of the *Globotruncana imbricata* zone to *Globotruncana schneegansi* zone.

Previous record of occurrence: – Known from the Turonian to lower Santonian (*Globotruncana inornata* zone to *Globotruncana concavata* zone) of Trinidad, and from the late Stantonian Cariblanco Formation of Puerto Rico.

Hedbergella delrioensis (Carsey), 1926

Pl. 21, figs. 4a-c

Globigerina cretacea d'Orbigny var. *del rioensis* [sic!] Carsey, 1926, p. 43.

Globigerina cretacea d'Orbigny. Tappan, 1940, p. 121, pl. 19, figs. 11a-c (non d'Orbigny); Tappan, 1943, p. 512, pl. 82, figs. 16a-17 (non d'Orbigny); Takayanagi, 1960, p. 137, pl. 10, figs. 8a-c (non d'Orbigny).

Globigerina gautierensis Brönnimann, 1952, p. 11, pl. 1, figs. 1–3, text-fig. 2 (a-m); Montanaro Gallitelli, 1958, p. 23, pl. 3, fig. 15.

Globigerina delrioensis Carsey. Frizzell, 1954, p. 127, pl. 20, figs. 1a-c.

Praeglobotruncana gautierensis (Brönnimann). Bolli, 1959, p. 265, pl. 21, figs. 3a-6; Jones, 1960, p. 102, pl. 15, figs. 1a-9c.

Praeglobotruncana cf. *gautierensis* (Brönnimann). Bolli, 1959, p. 266, pl. 21, figs. 7a-8.

Praeglobotruncana (*Hedbergella*) *delrioensis* (Carsey). Banner and Blow, 1959, p. 8.

Globigerina cf. *delrioensis* Carsey. Takayanagi, 1960, p. 138, pl. 10, figs. 9a–c.

Hedbergella delrioensis (Carsey). Loeblich and Tappan, 1961, p. 275, pl. 2, figs. 11a–13c; Takayanagi and Iwamoto, 1962, p. 190, pl. 28, figs. 10a–12c; Renz, Luterbacher and Schneider, 1963, p. 1083, pl. 9, figs. 5a–c.

Remarks: – *Hedbergella delrioensis* was originally described by Carsey from the upper part of the Washita Group of Texas, U.S.A., as a variety of "*Globigerina cretacea* d'Orbigny". This species is marked by its low trochospiral test with lobulate periphery, the final whorl consisting very commonly of five subglobular chambers, nearly radial and deeply constricted sutures, and relatively large apertural flap. As a rule the chambers increase rapidly in size as added, while the spiral side is nearly flat or slightly depressed centrally. Accordingly the last chamber often assumes a somewhat protruded appearance on the umbilical side. Owing to its extraumbilical aperture and the lack of peripheral keel or poreless margin, the present species is placed in *Hedbergella.*

This species is similar to *Hedbergella crassa* in commonly having five chambers in the final whorl, but is distinguished by its larger test, wider umbilicus and well developed apertural flap.

Comparing with the Texan hypotypes illustrated by Loeblich and Tappan (*loc. cit.*), the Putah Creek specimens possess smoother surface, though the wall perforation is distinct.

Maximum diameter of hypotype 0.34 mm, maximum thickness 0.15 mm.

Type and occurrence: – Hypotype (figs. 4a-c), Stanford Univ. Paleo. Type Coll. No. 9768, from the core at 448–450 feet in the Funks Formation, in Diamond Core Hole No. 1, Section C.

Occurrence in the studied area: – Rather common in the Yolo, Sites, and Funks Formations. *Range*-Top of the *Globotruncana imbricata* zone to the *Globotruncana schneegansi* zone.

Previous record of occurrence: — This species is considered to have a fairly long range (*vide* Takayangai and Iwamoto, 1962, p. 186) from the upper Aptian (?) to lower Campanian or higher so far as the literatures are concerned; very common in the Cenomanian to Coniacian. It has been recorded from the Gulf Coastal region, U.S.A., Trinidad, Italy, Switzerland, Hokkaido, etc.

Hedbergella loetterli (Nauss), 1947

Pl. 21, figs. 5a-c

Globigerina loetterli Nauss, 1947, p. 336, pl. 49, figs. 11a–c.
Globigerina loetterlei Nauss. Tappan, 1951, p. 4, pl. 1, figs. 19a–c.
Hedbergella loetterlei (Nauss). Tappan, 1962, p. 196, p. 55, figs. 3–5.
Non *Globotruncana* (*Rugoglobigerina*) *loetterli loetterli* (Nauss). Gandolfi, 1955, p. 35, pl. 1, figs. 15a–c.

Remarks: – The specimens referred to this species are characterized by their low trochospiral test with moderately lobulate periphery, the last whorl consisting usually of six chambers, which rapidly increase in size in the earlier whorls but very slowly in the final one, and the interiomarginal, extraumbilical-umbilical aperture. As pointed out by Nauss (*loc. cit.*), the ultimate and penultimate chambers are sometimes smaller than the antepenultimate one, and also so in the present specimens examined.

Although Nauss could not clarify the apertural character of this species at the time of the original description, Tappan (1962, *loc. cit.*) recognized its extraumbilical aperture and placed the species in the genus *Hedbergella*.

Maximum diameter of hypotype 0.39 mm, maximum thickness 0.12 mm.

Type and occurrence: – Hypotype (figs. 5a–c), Stanford Univ. Paleo. Type Coll. No. 9769, from the core at 291–300 feet in the Funks Formation, in Diamond Core Hole No. 2, Section C.

Occurrence in the studied area: – Funks and Sites Formations, but is rather common in the lower part of the former. *Range*– *Globotruncana loetterli* zone.

Previous record of occurrence: – The middle part of the Lloydminister Shale in the Vermililion area, Alberta, Canada, and from the Seabee Formation and the Rogers Creek Member of the Schrader Bluff Formation in northern Alaska. According to Tappan (1962), the middle part of the Lloydminister Shale is approximately correlated with the upper Cenomanian and lower Turonian, the Seabee Formation with the Turonian and lower Coniacian, and the Rogers Creek member with the upper Coniacian and lower Santonian of the European standard. Thus it is restricted in range from the upper Cenomanian to lower Santonian.

Hedbergella planispria (Tappan), 1940

Pl. 21, figs. 6a-7c; Pl. 33, figs. 1a-c

Globigerina planispira Tappan, 1940, p. 122, pl. 19, figs. 12a–c; Tappan, 1943, p. 513, pl. 83, fig. 3;

Frizzell, 1954, p. 127, pl. 20, figs. 2a–c.

Globigerina globigerinelloides Subbotina, 1949, p. 32, pl. 2, figs. 11–16; Subbotina, 1953, p. 51, pl. 1, figs. 11a–12v; Kaptarenko-Chernousova, et al., 1963, p. 103, pl. 13, figs. 8a, b.

Globorotalia ? youngi Fox, 1954, p. 119, pl. 26, figs. 15–18.

Praeglobotruncana planipsira (Tappan). Bolli, Loeblich and Tappan, 1957, p. 40, pl. 9, figs. 3a–c; Bolli, 1959, p. 267, pl. 22, figs. 3a–4.

Praeglobotruncana modesta Bolli, 1959, p. 267, pl. 22, figs. 2a–c.

Globigerina cretacea d'Orbigny. Belford, 1960, p. 90, pl. 25, figs. 1–3 (non d'Orbigny).

Hedbergella planispira (Tappan). Loeblich and Tappan, 1961, p. 276, pl. 5, figs. 4–11c.

Remarks: – Although the present species has been placed in various genera, Loeblich and Tappan (1961, *op. cit.*) included it in the genus *Hedbergella*. They wrote:

> "Test free, tiny spiral side with a low trochospiral coil of two to two and one-half whorls, opposite side deeply umbilicate; five to seven chambers (commonly six or seven) in the final whorl, chambers globular, increasing regularly in size as added; sutures distinct, slightly depressed, radial to gently curved; wall calcareous, finely perforate, surface finely hispid, but some specimens apparently worn smooth before preservation; aperture interiomarginal, extraumbilical-umbilical, with a narrow bordering lip which expands as a subtriangular flap near the umbilicus, the flaps of preceding chambers remaining visible around the umbilical depression."

These diagnostic features are well displayed in the Putah Creek specimens. It may be pointed out that *H. planispira* has wider open umbilicus compared with any known species of *Hedbergella*.

The western Australian specimen illustrated by Belford (1960, *loc. cit.*) as "*Globigerina cretacea*" is quite similar to those referred to *H. planispira*, and is considered to be identical therewith on the basis of the apertural character.

Maximum diameter of hypotype (figs. 6a–c) 0.21 mm, thickness through the last chamber 0.09 mm. Maximum diameter of hypotype (figs. 7a–c) 0.02 mm, thickness through the last chamber 0.10 mm. Hypotype (figs. 1a–c) 0.21 mm, thickness through the last chamber 0.09 mm.

Type and occurrence: – Hypotype (figs. 6a–c), Stanford Univ. Paleo. Type Coll. No. 9770, from the core at 250–260 feet in the Funks Formation, in Diamond Core Hole No. 2, Section C. Hypotype (figs. 7a–c), Stanford Univ. Paleo. Type Coll. No. 9771, from the core at 460–466 feet in the Forbes Formation, in Diamond Core Hole No. 1, Section A. Hypotype (figs. 1a–c), Stanford Univ. Paleo. Type Coll. No. 9772, from the core at 194–204 feet in the Forbes Formation, in Diamond Core Hole No. 3, Section A.

Occurrence in the studied area: – Common in the uppermost parts of the Venado, Yolo, Sites, Funks, Guinda and Forbes Formations. *Range*-Upper part of the *Globotruncana imbricata* zone to the *Globotruncana subcircumnodifer* zone.

Previous record of occurrence: – The upper Albian, Cenomanian and Turonian formations of Texas, South Dakota, Wyoming and Kansas, U.S.A. In Europe it is known from the Cenomanian of Germany and Albian of England. In the Soviet Union, Subbotian (1953, p. 53) remarked that it occurs occurs rarely in the lower Aptian but commonly in the upper Aptian and very commonly in the upper Albian of southern Caucasus though it is also found in the lower Cenomanian. Later Kaptarenko-Chernousova *et al.* (1963, p. 104) added the record of its occurrence as follows: the Albian of the Dnieper-Donets basin and the Aptian to Cenomanian of Crimea and Caucasus. In the Caribbean region it was recorded from a submarine core of Cenomnaian age (Loeblich and Tappan, 1961, p. 277); upper Aptian to lower Campanian of Trinidad (Bolli, 1959, p. 267; the specimens from the post-Turonian probably belong to this species). It is occurs also in the Santonian and Campanian of western Australia. It thus has long range from Aptian to Campanian.

Hedbergella cf. *portsdownensis* (Williams-Mitchell), 1948

Pl. 22, figs. 2a–c

Compared with:

Globigerina portsdownensis Williams-Mitchell, 1948, p. 96, pl. 8, figs. 4a–c.

Hedbergella portsdownensis (Williams-Mitchell). Loeblich and Tappan, 1961, p. 277, Pl. 5 figs. 3a-c; Maslakova, 1963, p. 139 (table), pl. 1, fig. 1, pl. 3, fig. 6.

Remarks: – The single specimen from Putah Creek material is compared with *Hedbergella portsdownensis*. Described originally as *Globigerina*, this species is now placed in *Hedbergella* because of the lack of a keel or poreless margin. The present specimen is characterized by its low-trochosprial test, broadly rounded axial periphery, five chambers in the last whorl, inflated globular chambers, constricted sutures, and interiomarginal, extraumbilical-umbilical aperture bordered by a narrow lip. As compared with the typical specimen illsutrated by Loeblich and Tappan (*loc. cit.*), the present one displays less lobulate periphery and less strongly constricted sutures. But such differences seem to be largely due to the state of preservation. The characteristic feature of the last chamber that tends toward the umbilicus in position, as marked by Williams-Mitchell, is well observed in the Putah Creek specimen.

Maximum diameter of hypotype 0.33 mm, thickness through center 0.15 mm.

Type and occurrence: – Hypotype (figs. 2a-c), Stanford Univ. Paleo. Type Coll. No. 9773, from the core at 335–341 feet in the Yolo Formation, in Diamond Core Hole No. 4, Section D.

Occurrence in the studied area: – The middle part of the Yolo Formation, the basal part of the *Globotruncana fornicata/Globotruncana coronata* zone.

Previous record of occurrence: – Known only from the Cenomanian of England, Germany and Crimea along the Alma River, U.S.S.R.

Genus *Praeglobotruncana* Bermudez, 1952

Praeglobotruncana stephani (Gandolfi), 1942

Pl. 22, figs. 3a–c

Globotruncana stephani Gandolfi, 1942, p. 130, pl. 3, figs. 4a–5c, pl. 4, figs. 36, 37, 41–45, pl. 6, figs. 4, 6, pl. 9, figs. 5, 8, pl. 13, fig. 5, pl. 14, fig. 2; Nagappa, 1959, pl. 6, figs. 5a–c.

Globotruncana apenninica Renz var. *β* Gandolfi, 1942, p. 119, text-fig. 41 (2a, b).

Globorotalia californica Cushman and Todd, 1948, p. 96, pl. 16, figs. 22, 23.

Globotruncana (*Globotruncana*) *stephani* Gandolfi. Reichel, 1950, p. 608, pl. 16, fig. 6, pl. 7, fig. 6.

Globotruncana stephani Gandolfi var. *turbinata* Reichel, 1950, p. 609; Mornod, 1950, p. 589, text-fig. 11 (no. 1a–3c).

Globotruncana stephani Gandolfi *turbinata* Reichel. Hagn and Zeil, 1954, p. 34, pl. 2, figs. 2a–c, pl. 5, figs. 3, 4.

Globigerina aumalensis Sigal, 1952, p. 28, text-fig. 29.

Globotruncana (*Globotruncana*) *stephani* Gandolfi var. *turbinata* Reichel. Bolli *in* Church, 1952, p. 70, text-fig. 1 (bottom).

Rotundina stephani (Gandolfi). Subbotina, 1953, p. 165, pl. 2, figs. 5a–7v, pl. 3, figs. 1a–2v; Salaj and Samuel, 1963, p. 103, pl. 6, figs. 2a–3c.

Globotruncana (*Rotundina*) *aumalensis* (Sigal). Küpper, 1955, p. 116, pl. 18, figs. 5a–c (non *Globigerina aumalensis* Sigal).

Globotruncana (*Rotundina*) *stephani stephani* (Gandolfi). Küpper, 1955, p. 116, pl. 18, figs. 6a–c.

Globotruncana (*Praeglobotruncana*) *stephani* (Gandolfi) *turbinata* Reichel. Küpper, 1956, p. 43, pl. 8, figs. 1a–c.

Globotruncana (*Praeglobotruncana*) *renzi* (Thalmann and Gandolfi) ssp. *primitiva* Küpper. 1956, p. 43, pl. 8, figs. 2a–c.

Praeglobotruncana delrioensis (Plummer). Brönnimann and Brown, 1956 (part), p. 531 (not pl. 21, figs. 8–10, pl. 24, figs. 16, 17, text-figs. 9, 11, 13a, b, d, 15c–f, 16b); Sheibnerová, 1961, p. 59, pl. 9, figs. 2a–c (non *Globorotalia delrioensis* Plummer).

Praeglobotruncana delrioensis (Plummer) var. *turbinata* (Reichel). Brönnimann and Brown, 1956,

p. 532, text-figs. 16c–e.

Globotruncana (*Globotruncana*?) *stephani stephani* Gandolfi. Gandolfi, 1957, p. 62, pl. 9, figs. 3a–c.

Globotruncana (*Globotruncana*?) *stephani turbinata* Reichel. Gandolfi, 1957, p. 62, pl. 9, figs. 4a, b.

Praeglobotruncana stephani (Gandolfi). Bolli, Loeblich and Tappan, 1957, p. 39, pl. 9, figs. 2a–c; Klaus, 1960b, p. 302, text-fig. 1-e; Takayanagi, 1960, p. 132, pl. 9, figs. 13a–c. Loeblich and Tappan, 1961, p. 284, pl. 6, figs. 1a–8c (with additional synonymy up to 1961): Maslakova, 1963, p. 139 (table), pl. 3, fig. 4; Renz, Luterbacher and Schneider, 1963, p. 1086, pl. 9, figs. 1a–c, 3a–c.

Praeglobotruncana (*Praeglobotruncana*) *stephani* (Gandolfi). Banner and Blow, 1959, p. 3, text-fig. 1a.

Globotruncana kuepperi Thalmann, 1959, p. 130.

Praeglobotruncana stephani stephani (Gandolfi). Klaus, 1960a, p. 794, pl. 6, figs. 2a–c.

Praeglobotruncana stephani turbinata (Reichel). Klaus, 1960a, p. 795, pl. 6, figs. 3a–c.

Praeglobotruncana stephani (Gandolfi), premièr variété. Malapris and Rat, 1961, p. 89, text-fig. 4a, pl. 2, figs. 1a–c.

Praeglobotruncana stephani (Gandolfi), deuxième variété. Malapris and Rat, 1961, p. 89, text-fig. 4b, pl. 2, figs. 2a–c.

Praeglobotruncana stephani (Gandolfi), troisième variété. Malapris and Rat, 1961, p. 89, pl. 2, figs. 3a–c.

Praeglobotruncana delrioensis turbinata (Reichel). Scheibnerová, 1961, p. 60, pl. 9, figs. 3a–c.

Remarks: – The specimens found in the Putah Creek material are characterized by their low trochospiral shape, moderately to strongly convex spiral side and nearly flat to slightly convex umbilical side, subacute axial periphery, five to six chambers in the last whorl, depressed sutures which are curved on the spiral side and nearly radial on the umbilical side, single beaded keel bordering the whorls which becomes less distinct on the periphery of the last one or two chambers. These features coincide well with those of the hypotypes of *P. stephani* illustrated by Loeblich and Tappan (*loc. cit.*). As to the variability of this species, they mentioned that the number of chambers in the final whorl and the height of spire are a function of the age of the specimen. In the present material this species shows usually five chambers in the final whorl and relatively low spire even in the specimen larger than their hypotypes.

Loeblich and Tappan (*op. cit.*, p. 286, 288) studied many types described under various names, and many of them were included in the synonymy of this species.

Maximum diameter of hypotype 0.54 mm, maximum thickness 0.26 mm.

Type and occurrence: – Hypotype (figs. 3a–c) Stanford Univ. Paleo. Type Coll. No. 9774, from the core at 41–50 feet in the Yolo Formation, in Diamond Core Hole No. 5, Section D.

Occurrence in the studied area: – Very rare, found only in the lower part of the Yolo Formation, upper part of the *Globotruncana imbricata* zone.

Previous record of occurrence: – The Cenomanian and lower Turonian strata of Switzerland, Germany, Italy, France, Czechoslovakia, Caucasus and Tunisia, and from the Cenomanian of Crimea, U.S.S.R., Japan, Texas and Kansas, U.S.A. The Turonian Pabuni Group of Pakistan. It occurs also in the Cenomanian strata of several districts in California (*fide* Graham, 1962). The range of this species is generally accepted as Cenomanian to lower Turonian, but it appears to be most common in the middle to upper Cenomanian.

Family Globotruncanidae Brotzen, 1942

Genus *Globotruncana* Cushman, 1927

Globotruncana angusticarinata Gandolfi, 1942

Pl. 22, figs. 4a–c, 5

Globotruncana linnei (d'Orbigny) var. *angusticarinata* Gandolfi, 1942, p. 127, pl. 4, figs. 17, 30, text-fig. 46 (3a–c).

Globotruncana angusticarinata Gandolfi. Sigal, 1952, p. 34, text-fig. 37; Sacal and Debourle, 1957, p.

60, pl. 27, figs. 2, 4, 23, 24; Klaus, 1960, p. 821, pl. 7, figs. 3a–c.

Globotruncana lapparenti Brotzen *angusticarinata* Gandolfi. Hagn and Zeil, 1954, p. 44, pl. 7, figs. 9, 10.

Globotruncana lapparenti angusticarinata Gandolfi. Ziegler, 1957, p. 78, pl. 1, figs. 11a-c; Tollmann, 1960, p. 192, pl. 20, figs. 8, 9.

Globotruncana (*Globotruncana*) *renzi angusticarinata* Gandolfi. van Hinte, 1963, p. 67, pl. 2, figs. 3a–c.

Remarks: – This species was originally described as a variety of *G. linnei*, and has been raised to the rank of subspecies of *G. lapparenti* by many authors. This is distinguished by having biconvex test with closely spaced double keel. Based upon the characteristic single keel of *G. sigali* Reichel showing a tendency of becoming double in the earlier chambers of the last whorl, Sigal (1952, *op. cit.*) supposed a proterogenetic evolutionary trend from *G. sigali* to *G. angusticarinata*. Among the Putah Creek specimens, forms with a single keel instead of double one in the last-formed chamber are sometimes found (e.g., fig. 4c in Plate 1). The presence of these forms appears to favour Sigal's supposition. In general appearance, however, the present species seems to be more closely related with *G. renzi* Gandolfi, as pointed out by van Hinte (*loc. cit.*).

The relationship among three species morphologically as well as stratigraphically should be studied.

The present specimens have strongly curved sigmoidal sutures on the umbilical side with a fairly large umbilicus, and are generally more convex on the spiral side than the other side. In these features the species differs from *G. arca*.

Maximum diameter of hypotype (figs. 4a–c) 0.34 mm., maximum thickness 0.17 mm; maximum diameter of hypotype (fig. 5) 0.29 mm, maximum thickness 0.12 mm.

Type and occurrence: – Hypotype (figs. 4a–c), Stanford Univ. Paleo. Type Coll. No. 9775, hypotype (fig. 5), Stanford Univ. Paleo. Type Coll. No. 9776, both from the core at 160–162 feet, in the Forbes Formation, in Diamond Core Hole No. 2, Section A.

Occurrence in the studied area: – Rare in the Forbes and Funks Formations. *Range-Globotruncana schneegansi* zone to *Globotruncana subcircumnodifer* zone.

Previous record of occurrence: – Switzerland, lower Turonian; Germany, lower Turonian to lower Campanian; France, Senonian; Algeria, middle Turonian to upper Coniacian, and rare in Santonian to lowest Maastrichtian.

Globotruncana arca (Cushman), 1926

Pl. 22, figs. 6a–c; Pl. 23, figs. 1a-2c

Pulvinulina arca Cushman, 1926, p. 23, pl. 3, figs. 1a-c.

Globotruncana arca (Cushman). Cushman, 1927, p. 91, pl. 19, figs. 11a–c; Cushman, 1927b, p. 169, pl. 28, figs. 15a–c; Sandidge, 1932, p. 285, pl. 44, figs. 6–8; Glaessner, 1937, p. 36, pl. 1, figs. 10a-c (with additional synonymy); Cushman and Church, 1929, p. 518, pl. 41, figs. 1–3; Cushman, 1946 (part), p. 150, pl. 62, figs. 4a–c (not 5a–c) (with additional synonymy); Bandy, 1951, p. 509, pl. 75, figs. 1a–c; Subbotina, 1953 (part), p. 185, pl. 9, figs. 2a–5v, pl. 10, figs. 1a–5v (not pl. 9, figs. 1a–v); Hagn, 1953, p. 97, pl. 8, figs. 11a–c, text-figs. 20, 21; Brönnimann and Brown, 1956, p. 539, pl. 23, figs. 10–12 (with additional synonymy); Ganss and Knipscheer, 1956, p. 624, text-fig. 2 (1a-c); Bolli, Loeblich and Tappan, 1957, p. 44, pl. 11, figs. 6–11c; McGugan, 1957, pl. 34, figs. 15a–c; Sacal and Debourle, 1957, p. 59, pl. 27, figs. 6–8, 10–12; Klaus, 1960a, p. 824, pl. 7, figs. 5a–c; Scheibnerová, 1961, p. 71, pl. 13, figs. 2a–c; Barr, 1962, p. 567, pl. 69, figs. 8a–c; Maslakova, 1963, p. 139 (table), pl. 1, fig. 3, pl. 6, fig. 3; Kavary and Frizzell, 1964, p. 51, pl. 10, figs. 5–9.

Globotruncana sp. (ex. gr. *ventricosa* Brotzen). Hiltermann and Koch, 1955, pl. 27, figs. 1a–c.

Globotruncana (*Globotruncana*) *arca* (Cushman). Dalbiez, 1955, p. 164, figs. 5a–c; Edgell, 1957 (part), p. 110, pl. 3, figs. 4–6 (not pl. 1, figs. 10–12, pl. 3, figs. 13–15); Berggren, 1962, p. 49, pl. 9, figs. 1a–2c (with additional synonymy); van Hinte, 1963, p. 80, pl. 6, figs. 2a–c, 4a–c.

Globotruncana arca arca (Cushman). Gandolfi, 1955, p. 63, pl. 5, figs. 2a–c (numeral for 2b is omitted

on pl. 5), 3a–c (not figs. 4a–c).
Globotruncana leupoldi Bolli. Olsson, 1960, p. 50, pl. 11, figs. 1–3 (not of Bolli).

Remarks: – Until the holotype was redrawn by Bolli, Loeblich and Tappan (1957), this species had created much discussion among authors, because Cushman (1946) figured two different species under the name of *Globotruncana arca* (cf. Berggren, 1962, p. 50). The present species is characterized by its stout form with distinctly double and fairly thick keel, spiral side more convex than the umbilical, sutures curved radially on spiral side and radially straight on umbilical side, and oblique peripheral band.

G. arca is the most dominant species among the Putah Creek globotruncanids. It shows fairly wide variation in general shape of the test. Usually the test is moderately biconvex in side view, but some show strong convexity on the spiral side, where the later whorl departs progressively from the coiling plane of the former one (figs. 6a-c). The surface is beaded especially on the earlier chambers of the spiral side. The umbilical tegilla are not recognizable except on unusually well preserved specimens (figs. 1a-c). In the last chamber of this specimen the double peripheral keel transforms into a single keel. Such a feature is identical with the hypotype from the Redbank Formation which was referred to *G. leupoldi* Bolli by Olsson (1960, *op. cit.*). Except for this feature, these specimens appear to fall within the range of variation of *G. arca*. Nevertheless, this tendency suggests a potential evolutionary trend of this species toward such species as *G. rosetta* (Carsey), as already discussed by Berggren (1962, *op. cit.*). Leaving aside *G. leupoldi* which was defined solely by thin-sections, the Redbank form is herein included into the synonymy of *G. arca*.

Berggren (1962) considered the derivation of *G. arca* from *G. tricarinata* through modification of the sutures and umbilical apertural features. Although they have many features in common with each other, *G. arca* may be distinguished from the latter by possessing thick and beaded keels and distinctly convex spiral side.

Maximum diameter of hypotype (figs. 6a–c) 0.44 mm, maximum thickness 0.21 mm; maximum diameter of hypotype (figs. 1a–c) 0.37 mm, maximum thickness 0.18 mm; maximum diameter of hypotype (figs. 2a-c) 0.48 mm, maximum thickness 0.21 mm.

Types and occurrence: – Hypotype (figs. 6a–c), Stanford Univ. Palaeo. Type Coll. No. 9777, hypotype (figs. 1a-c), Stanford Univ. Paleo. Type Coll. No. 9778, both from the core at 120–125 feet in the Forbes Formation, in Diamond Core Hole No. 2, Section A. Hypotype (figs. 2a-c), Stanford Univ. Paleo. Type Coll. No. 9779, from the core at 80–90 feet in the Forbes Formation, in Diamond Core Hole No. 1, Section A.

Occurrence in the studied area: – Generally common in the Forbes, Guinda and the top of the Funks Formations, and especially rich in the first said formation. *Range-Globotruncana arca* zone to *Globotruncana subcircumnodifer* zone.

Previous record of occurrence: – Concerning the range of this species opinions diverge among authors. It was originally described from the Mendez Shale, near Huiches, Hacienda El Limon, San Luis Potosi, Mexico. According to Imlay (1944), this formation is correlated with the Campanian to Maastrichtian of the European standard. Glaessner (1937, *loc. cit.*) emphasized the limited stratigraphic occurrence of the present species within the Campanian and Maastrichtian of the European region. His opinion was supported by authors as Brönnimann and Brown (1956, *op. cit.*) and Berggren (1962, *op. cit.*). They insisted that the records from the pre-Maastrichtian are probably erroneous or that its transitional forms may be found in the upper Campanian but that it is restricted to the Maastrichtian Stage. Against this, Sigal (1952) recorded the species as ranging from the lower Turonian to upper Maastrichtian of Algeria, though without description or illustration. Similarly, it is reported from the upper Turonian to Campanian of south-central Alaska (Bergquist, 1961). Furthermore *G. arca* was described from the upper Turonian (the upper one-third) to Santonian or higher horizon of the Préalpes médianes, Swtizerland (Klaus, 1960a, 1961a) and from the upper Coniacian to lower Maastrichtian of Austria (van Hinte, 1963, *op. cit.*). At least as Barr stated (1962, *op. cit.*), it can hardly be doubted that this species occurs from the Campanian of various parts of the world. However, the lower limit of its vertical range has not been settled.

Globotruncana concavata (Brotzen), 1934

Pl. 23, figs. 3a-c

Rotalia concavata Brotzen, 1934, p. 66, pl. 3, fig. b.
Globotruncana asymetrica Sigal, 1952, p. 35, fig. 35.
Globotruncana (*Globotruncana*) *ventricosa ventricosa* White. Dalbiez, 1955, p. 168, text-figs. 7a–d (non White).
Globotruncana concavata (Brotzen). Bolli, 1957, p. 57, pl. 13, figs. 3a-c; Scheibnerová, 1961, p. 67, pl. 12, figs. 1a–c; Barr, 1962, p. 569, pl. 71, figs. 4a–c; Kavary and Frizzell, 1964, p. 52, pl. 10, figs. 12–14.
Non *Praeglobotruncana concavata* (Brotzen). Klaus, 1960a, p. 797, pl. 7, figs. 2a–c.
Globotruncana concavata concavata (Brotzen). Herb, 1963, p. 905, pl. 1, figs. 4a–c.

Remarks: – The specimens referred to this species are characterized by their low trochospiral form, slightly concave sprial side and distinctly convex umbilical side, closely spaced double keel, strongly curved sprial sutures, and wide and deep umbilicus. The aforementioned features are well in accord with the description of the Trinidad specimens given by Bolli (*op. cit.*), when he made a sharp distinction between the topotype specimens of *G. concavata* and *G. ventricosa* White. Comparing with the typical specimens, the Putah Creek forms have six to six and one half chambers in the last whorl instead the usual five to six, and show rough appearance on surface of the umbilical side.

Maximum diameter of hypotype 0.70 mm, maximum thickness 0.20 mm.

Type and occurrence: – Hypotype (figs. 3a-c), Stanford Univ. Paleo. Type Coll. No. 9780, from the core at 218–222 feet in the Funks Formation, in Diamond Core Hole No. 6, Section B.

Occurrence in the studied area: – Very rare, only found in the middle part of the Funks Formation, *Globotruncana schneegansi* zone.

Previous record of occurrence: – Iran, Senonian; Czechoslovakia, Turonian; Algeria, upper Turonian to Coniacian; Tunisia, lower Santonian; Isle of Wight, England, Coniacian; Säntisgebirge, Switzerland, Senonian?; Trinidad, lower Santonian. Bolli (*op. cit.*) stated, however, that this species appears to be restricted to the upper Coniacian to lower Santonian.

Globotruncana cf. *contusa* (Cushman), 1926

Pl. 23, figs. 4a-c

Compared with:
Pulvinulina arca Cushman var. *contusa* Cushman, 1926, p. 23,
Globotruncana conica White, var. *plicata* White, 1928, p. 285, pl. 38, figs. 8a–c.
Globotruncana contusa (Cushman). Glaessner, 1937, p. 37; Bolli, 1951, p. 196, pl. 34, figs. 7–9; Subbotina, 1953, p. 192, pl. 11, figs. 3a–v, pl. 12, figs. 1a–2v; Troelsen, 1955, p. 80, text-figs. 2a–g; Wicher, 1956, p. 136, pl. 12', figs. 5, 6; Sacal and Debourle, 1957, p. 59, pl. 28, figs. 11–13; Olsson, 1960, p. 50, pl. 10, figs. 25, 26; Vinogradov, 1960, p. 311, pl. 4, figs. 24a–c, pl. 5, figs. 25a–c; Scheinebrová, 1961, p. 73, pl. 14, figs. 1a–c; Brönnimann and Rigassi, 1963, pl. 16, figs. 2a–c.
Globotruncana arca (Cushman) Cushman var. *contusa* (Cushman) Cushman. Cushman, 1946, p. 150, pl. 62, figs. 6a, b.
Globotruncana contusa contusa (Cushman). Gandolfi, 1955, p. 53, pl. 4, figs. 3a–c.
Globotruncana contusa scutilla Gandolfi, 1955, p. 54, pl. 4, figs. 1a–c.

Globotruncana contusa patelliformis Gandolfi, 1955, p. 54, pl. 4, figs. 2a–c.
Marginotruncana contusa (Cushman). Hofker, 1956, p. 53, text-fig. 9.
Globotruncana (*Globotruncana*) *contusa* (Cushman). Noth, 1951, p. 79, pl. 8, figs. 17a–c; Edgell, 1957, p. 111, pl. 2, figs. 10–12, pl. 4, figs. 1–3; Berggern, 1962, p. 51, pl. 9, figs. 3a–4c.
Globotruncana (*Globotruncana*) cf. *contusa* (Cushman). Edgell, 1957, p. 122, pl. 3, figs. 7–9.
Globotruncana (*Marginotruncana*) *contusa* (Cushman). Hofker, 1960, p. 225, text-figs. 22a–c.
Globotruncana sp. cf. *G. contusa* (Cushman). Kavary and Frizzell, 1964, p. 53, pl. 10, figs. 15–16.

Remarks: — A single specimen with a conical test is compared with *Globotruncana contusa* described originally from the Mendez Shale of Mexico. Although the present specimen is not well preserved, it is characterized by its spiro-convex test, subacute periphery and narrow double keel.

Berggren (1962, *op. cit.*) assumed the evolutional development of *G. contusa* from *G. fornicata* through some modifications of the test, such as increase in convexity of the sprial side, increase in size and number of chambers, increased development of undulating surface in adult stage, and so on. Because of the lack of characteristic undulations of the chambers, the present specimen is not strictly identifiable with *G. contusa*. As shown in a later paragraph, however, its stratigraphic horizon in the Putah Creek is lower than the supposed lower limit of the range of *G. contusa*. In this respect, the present specimen may be an incipient form of *G. contusa*.

Maximum diameter of hypotype 0.31 mm, maximum thickness 0.16 mm.

Type and occurrence: - Hypotype (figs. 4a–c), Stanford Univ. Paleo. Type Coll. No. 9781, from the core at 325–328 feet in the Funks Formation, in Diamond Core Hole No. 5, Section B.

Occurrence in the studied area: - The Funks Formation, *Globotruncana schneegansi* zone.

Previous record of occurrence: - As already cited by Berggren (1962, *op. cit.*), *G. contusa* is known from the Campanian and Maastrichtian of the various parts of the world, inclusive of Europe, the Middle East, Africa, North and South America, and Australia. However there are no reliable records from older strata.

Globotruncana coronata Bolli, 1945

Pl. 24, figs. 1a-2c

Rosalina linnei d'Orbigny, type 4, de Lapparent, 1918, p. 7; p, 4, figs. 1g (non *Rosalina linnei* d'Orbigny).
Globotruncana linnei (d'Orbigny) tipica. Gandolfi, 1942, p. 127; p. 126, fig. 46 (2a–c).
Globotruncana lapparenti coronata Bolli, 1945, p. 233, fig. 1 (21, 22); pl. 9, figs. 14, 15; Mornod, 1949, p. 591, figs. 13a–d; Ziegler, 1957, p. 77, pl. 1, fig. 12; Tollmann, 1960, p. 194, pl. 21, fig. 2.
Globotruncana (*Globotruncana*) *lapparenti coronata* Bolli. Noth, 1951, p. 76, pl. 5, figs. 8a–c.
Globotruncana coronata Bolli. Sigal, 1952, p. 34, fig. 36; Subbotina, 1953, p. 180, pl. 8, figs. 1a–c; Vassilenko, 1961, p. 154, pl. 33, figs. 2a–d; Herb, 1963, p. 905, pl. 1, figs. 1a–c.
Globotruncana lapparenti Brotzen *coronata* Bolli. Hagan and Zeil, 1954, p. 43, pl. 3, figs. 4a, b; pl. 7, figs. 1–3.
Globotruncana lapparenti Brotzen. Nagappa, 1959, pl. 6, figs. 7–10.
Globotruncana linneiana (d'Orbigny). Graham and Clark, 1961, p. 113, pl. 5, figs. 11a–c (non *Rosalina linneiana* d'Orbigny).
Globotruncana linneiana coronata Bolli. Barr, 1962, p. 572, pl. 70, figs. 1a–c; pl. 72, figs. 3, 4.
Globotruncana (*Globotruncana*) sp. "*coronata*" Bolli. van Hinte, 1963, p. 81, pl. 7, figs. 1a–c.

Remarks: - Recognizing the present form as one of the types belonging to *G. linneiana* (d'Orbigny), de Lapparent (1918, *op. cit.*) gave the following description:

> "Un type à côté spiral plat ou subconique et à bandeau carénal réduit, représenté par des individus qui peuvent atteindre une grande taille. L'apparence de la coquille vue du côté de

l'ombilic est celle d'une couronne de feuilles imbriquées (fig. 1g). Dans certains très grands individus, le plafond des dernières loges est fortement relevé".

Among the Putah Creek globotruncanids, the present form is characterized by its low biconvex and large test, narrow double keel, large number of chambers, and wide umbilicus. These features serve to easily distinguish it from such allied forms as *G. linneiana* or *G. tricarinata*. For such reason this form is herein treated as a distinct species, following Subbotina (1953, *op. cit.*) and others.

Maximum diameter of hypotype (figs. 1a–c), 0.45 mm, maximum thickness 0.21 mm; maximum diameter of hypotpye (figs. 2a–c) 0.58 mm, maximum thickness 0.28 mm.

Type and occurrence: – Hypotype (figs. 1a–c), Stanford Univ. Paleo. Type Coll. No. 9782, from the core at 340–349 feet in the Funks Formation, in Diamond Core Hole No. 1, Section C. Hypotype (figs. 2a–c), Stanford Univ. Paleo. Type Coll. No. 9783, from the core at 305–311 feet in the Funks Formation, in Diamond Core Hole No. 5, Section B.

Occurrence in the studied area: – Fairly common in the Funks Formation, but rare in the Sites and upper part of the Yolo Formations. *Range-Globotruncana fornicata/Globotruncana coronata* zone to the basal *Globotruncana arca* zone.

Previous record of occurrence: – Turonian to middle Campanian of Europe and North Africa; Senonian of Pakistan; Campanian of California. A single record of occurrence in the Maastrichtian is from Klein St. Paul, Kärnten, Austria (Tollmann, 1950, *op. cit.*). But most of the records are restricted to the Turonian, Coniacian and Santonian.

Globotruncana cretacea (d'Orbigny), 1840

Pl. 24, figs. 3a–c

Globigerina cretacea d'Orbigny, 1840, p. 34, pl. 3, figs. 12–14; Banner and Blow, 1960, p. 8, pl. 7, fig. 1a–c (lectotype designated).

Globigerina cretacea d'Orbigny var. *saratogaensis* Applin, *in* Applin, Ellisor and Kniker, 1925, p. 98, pl. 3, fig. 8.

Globigerina voluta var. White, 1928, p. 284, pl. 38, fig. 4.

Globotruncana globigerinoides Brotzen, 1936, p. 177, pl. 12, figs. 3a–c, pl. 13, fig. 3; Bolli, 1945, p. 233, pl. 9, fig. 16, text-fig. 1 (23, 24); Noth, 1951, p. 76, pl. 5, figs. 4a, b; Hagn, 1954, p. 94, pl. 8, figs. 9a–c, text-figs. 12, 13; Sacal and Debourle, 1957, p. 59, pl. 26, figs. 1, 11; Belford, 1960, p 99, pl. 29, figs. 12–14; Tollmann, 1960, p. 195, pl. 21, figs. 4, 5.

Rosalinella globigerinoides (Brotzen). Schijfsma, 1946, p. 96, pl. 7, figs. 9a–c.

Globigerina saratogaensis Applin. Frizzell, 1954, p. 127, pl. 20, figs. 7a–c.

Globotruncana bulloides globigerinoides (Brotzen). Gandolfi, 1955, p. 33, pl. 1, figs. 10a–c.

Globotruncana saratogaensis (Applin). Brönnimann and Brown, 1956, p. 544, pl. 21, figs. 1–3.

Marginotruncana globigerinoides (Brotzen). Hofker, 1956, p. 329, text-figs. 19, 20.

Globotruncana (*Globotruncana*) *globigerinoides* Brotzen, Edgell, 1957, p. 112, pl. 2, figs. 13–15.

Globotruncana cretacea (d'Orbigny). Barr, 1962, p. 567, pl. 69, figs. 9a–c, pl. 72, fig. 6.

Globotruncana (*Globotruncana*) *cretacea* (d'Orbigny). van Hinte, 1963, p. 85, pl, 6, figs. 3a–c.

Remarks: – As already discussed in detail by Banner and Blow (1960, *op. cit.*), considerable confusion existed in the taxonomy of "*Globigerina cretacea*" since d'Orbigny described it. And various forms have been included in this species by many authors. Through a re-examination of d'Orbigny's material from the lower Campanian White Chalk of St. Germain, near Paris, Banner and Blow found one specimen which corresponded with d'Orbigny's original illustration in a syntypic series and designated it as the lectotype. According to them, the lectotype possesses depressed and slightly curved sutures on the spiral side and depressed and nearly radial ones on the umbilical side; wide but weakly developed double keel; broad and deep umbilicus; and hispid surface of wall. In addition, a fragile tegillum was observed in d'Orbigny's collection, though it is missing on the lectotype. Thus the present species is not a *Globigerina* but a *Globotruncana* in present-day taxonomy. Comparing with the typical specimens, the Putah Creek ones have rather narrow umbilicus and the hispidity of surface is not distinct, probably due to difference in fossilization. However, the other features coincide with the typical ones.

Following the opinions expressed by Brönnimann and Brown (*loc. cit.*), Banner and Blow (*loc. cit.*) and Barr (*loc. cit.*), such species as *Globotruncana saratogaensis*, and *G. globigerinoides* are herein treated as junior synonyms of the present species.

Maximum diameter of hypotype 0.28 mm, maximum thickness 0.13 mm.

Type and occurrence: – Hypotype (figs. 3a–c), Stanford Univ. Paleo. Type Coll. No. 9784, from the core at 291–300 feet in the Funks Formation, in Diamond Core Hole No. 2, Section C.

Occurrence in the studied area: – Rare, only found in the lower part of the Funks Formation and the upper part of the Sites Formation. *Range-Hedbergella loetterli* zone.

Previous record of occurrence: – Owing to the state of confusion aforementioned, it is difficult to ascertain the exact stratigraphic range of this species. Brönnimann and Brown (*op. cit.*, p. 545) stated that the species ("*Globotruncana saratogaensis*") ranges from Turonian to Campanian. Banner and Blow (*op. cit.*, p. 10) consider it to be limited in range from Coniacian to Campanian, with the possibility of its occurrence in the highest Turonian. Later Barr (*op. cit.*) confirms its occurrence in the upper Campanian, though Banner and Blow doubted it. So far as the records of the species which are included into the synonymy are concerned, *G. cretacea* occurs in the upper Turonian to Campanian (or lower Maastrichtian) of Europe, North America and Australia.

Globotruncana fornicata Plummer, 1931

Pl. 24, figs. 4a–c

Globotruncana fornicata Plummer, 1931, p. 198, pl. 13, figs. 4a–6; Sandidge, 1932, p. 285, pl. 44, figs. 12, 13; Cushman and Hedberg, p. 99, pl. 23, figs. 18a–c; Cushman and Deaderick, 1944, p. 340, pl. 53, figs. 28a, b; Cushman, 1946, p. 149, pl. 61, figs. 19a–c; Cushman, 1948, p. 265, pl. 26, figs. 1a, b; Tilev, 1951, p. 75, pl. 3, figs. 7a–d, text-figs. 23a–d: Bermudez, 1952, pl. 7, figs. 4a–c; Sigal, 1952, p. 35, text-fig. 39; de Civrieux, 1952, p. 281, pl. 9, fig. 4; Hamilton, 1953, p. 232, pl. 29, fig. 21; Hagn, 1953, p. 98, pl. 8, figs. 8a–c; text-figs. 22, 23; Subbotina, 1953, p. 184, pl. 8, figs. 3a–5c; Frizzell, 1954, p. 129, pl. 20, figs. 26a–c; Brönnimann and Brown, 1956, p. 542, pl. 21, figs. 7, 14, 15; Sacal and Debourle, 1957, p. 61, pl. 28, figs. 6, 7 (non 8), 14, 15; Klaus, 1959, p. 825, pl. 8, figs. 4a–c; Takayanagi, 1960, p. 135, pl. 10, figs. 3a–c; Graham and Clark, 1961, p. 112, pl. 5, figs. 10a–c; Vassilenko, 1961, p. 154, pl. 33, figs. 3a–c; Scheibnerová, 1961, p. 69, pl. 12, figs. 4a–c; Barr, 1962, p. 570, pl. 69, figs. 6a–c, pl. 72, figs. 1, 2; Kaptarenko Chernousova, *et al.*, 1963, p. 105, pl. 21, figs. 2a–v; Graham and Church, 1963, p. 63, pl. 7, figs. 14a–c; Kavary and Frizzell, 1964, p. 54, pl. 10, figs. 22, 23.

Globotruncana canaliculata (Reuss), Cushman and Deaderick, 1942, p. 65, pl. 15, figs. 23–27 (non *Rosalina canaliculata* Reuss).

Globotruncana fornicata fornicata (Plummer). Gandolfi, 1955, p, 40, pl. 2, figs. 2a–c (author's name was erroneously parenthesized).

Globotruncana fornicata plummerae Gandolfi, 1955, p.42, pl. 2, figs. 3a–4c.

Globotruncana (*Globotruncana*) *fornicata* Plummer. Edgell, 1957, p. 112, pl. 3, figs. 10–12; Pessagno, 1960, p. 101, pl. 4, fig. 7; Pessagno, 1962, p. 362, pl. 4, figs. 4, 5, 11.

Globotruncana (*Globotruncana*) *fornicata fornicata* Plummer. van Hinte, 1963, p. 61, pl. 1, figs. 1a–2c, pl. 20, fig. 3.

Remarks: – This species is easily distinguished from most of the other double keeled globotruncanids by its broadly curved, narrow and long chambers in the last whorl. Barr (*op. cit.*, p. 571) pointed out that "cone in cone" arrangement of the peripheral double keel will serve as another criterion to distinguish *G. fornicata* from related species. Although such a feature does not seem to be a satisfactory one, the coexistence of both characters will be diagnostic for this and its allied forms (see also the remarks under *Globotruncana morozovae*).

Brönnimann and Brown (*op. cit.*, p. 524, 543) suggested that this species descended from *Globotruncana imbricata* through the elongation of its later chambers in the direction of growth. At that time, however, they also referred to a short axial bar or ridge connecting the two keels at the posterior edge of the later chambers. Occasional specimens of *G. fornicata* possess such bars, and these are well exhibited in the type specimens of *G. imbricata* shown by Mornod (1950, p. 581). They laid stress on the above observation, and considered these bars as showing close relationship in an evolutionary lineage. Nevertheless, such bars are not always observable on specimens of *G. imbricata*, and moreover, they are sometimes seen on specimens of some species of different lineage.

Maximum diameter of hypotype 0.38 mm, maximum thickness 0.21 mm.

Type and occurrence: – Hypotype (figs. 4a–c), Stanford Univ. Paleo. Type Coll. No. 9785, from the core at 616–624 feet in the Sites Formation, in Diamond Core Hole No. 4, Section C.

Occurrence in the studied area: – Rare, but found in the upper part of the Yolo, Sites and main part of Funks Formations. *Range-Globotruncana fornicata/Globotruncana coronata* zone to *Globotruncana schneegansi* zone.

Previous record of occurrence: – Originally from the upper Taylor Marl (Campanian) of Texas, it was subsequently recorded mainly from the Santonian to Maastrichtian of various parts of the world by many authors. The records from the Turonian and Coniacian are as follows: Turonian of the Malaya Laba River area in the Soviet Union (Subbotina, 1953, p. 185); upper Coniacian of Austria (van Hinte, *loc. cit.*) upper Turonian and Coniacian of Switzerland (Klaus, 1961a, p. 699); upper Turonian and Coniacian of Algeria (Sigal, 1952); Turonian and Coniacian of Hokkaido, Japan (Takayanagi, 1960, *op. cit.*); Coniacian of Mangyshlaka area of the Soviet Union (Vassilenko, 1961, *op. cit.*); Emscher (Coniacian) of Caucasus (Glaessner, 1937, p. 44); Coniacian of Haiti (Ayala-Castanares, 1959). Hence it appears to range from the Turonian (upper?) to Maastrichtian, though it did not become common before the Santonian.

Globotruncana imbricata Mornod, 1950

Pl. 24, figs. 5a–c; Pl. 25, figs. 1a–2c

Globotruncana imbricata Mornod, 1950, p. 589, text-fig. 5 (2a–3d), pl. 15, figs. 21–34; Hagn and Zeil, 1954, p. 34, pl. 2, figs. 6a–c, pl. 5, figs. 9, 10;

Praeglobotruncana imbricata (Mornod). Scheibnerová, 1961, p. 62, pl. 10, figs. 3a–c.

Remarks: – In the original description, Mornod (*op. cit.*, p. 590) stated:

> "Petite coquille à enroulement trochospiral dextrogyre, à face spirale convexe, face ombilicale concave, contour périphérique peu lobé, sauf à la hauteur des deux dernières loges—la dernière seulement chez le cotype — grandes, globuleuses, dépourvues des bourrelets carénaux qui ornent les loges précédentes. Face spriale: 2½ tour, 5 loges au dernier tour, surface des loges plane ou faiblement bombée par rapport aux bourrelets suturaux qui disparaissent dans les deux dernières loges ou leslignes de suture occupent une dépression. Bourrelets suturaux granuleux dans les premiers tours, saillants, arqués dans le sens de l'enroulement, ... La face ombilcale montre des loges trapézoïdes peu renflées, àlignes suturales droites, radiales, dans des dépressions peu profondes, dépourvues de bourrelets. .... L'ombilic type possède un étroit replat formé par les prolongements adombilicaux de chaque loge et porte une lèvre ou un liséré continu qui surmonte les ouvertures. Vue de profil, la position oblique des bourrelets carénaux donne l'aspect de loges imbriquées. ...."

These features are clearly observed on the Putah Creek specimens. A well-preserved specimen (figs. 5a-c) shows a typical oblique arrangement of truncate margins of the chambers, especially of later ones, in profile. In the adult specimens the sutures are curved, raised and thickened on the spiral side, and nearly radial and depressed on the umbilical side. The surface of the chambers are often finely beaded on the umbilical side and have truncate margins except on the last formed chamber. The present materials show considerable variation in general appearance, but they all fall within the range of variation which Mornod (*op. cit.*, pl. 15, figs. 21–34) showed by sections. As already discussed by Mornod, *G. lapparenti inflata* Bolli appears to be conspecific with the present species, inasmuch as they are compared with one another by sections. But since that subspecies was designated only in thin sections, it is difficult at present either to treat it as a senior synonym, or to distinguish it as a distinct species. Further comparative study on thin sections of the topotypic specimens of both species should be undertaken.

Maximum diameter of hypotype (figs. 5a–c) 0.45 mm., maximum thickness 0.20 mm. Maximum diameter of hypotype (figs. 1a–c) 0.29 mm., maximum thickness 0.14 mm. Maximum diameter of hypotype (figs. 2a–c) 0.31 mm., maximum thickness 0.15 mm.

Type and occurrence: – Hypotype (figs. 5a–c), Stanford Univ. Paleo. Type Coll. No. 9786, from the core at 291–300 feet in the Funks Formation, in Diamond Core Hole No. 2, Section C. Hypotype (figs. 1a–c), Stanford Univ. Paleo. Type Coll. No. 9787, from the core at 41–50 feet in the Yolo Formation, in Diamond Core Hole No. 5, Section D. Hypotype (figs. 2a–c), Stanford Univ. Paleo. Type Coll. No. 9788, from the core at 71–81 feet in the Yolo Formation, in Diamond Core Hole No. 5, Section D.

Occurrence in the studied area: – Rarely found in the unnamed formation below the Venado, Yolo, Sites and the basal part of the Funks Formations. *Range-Globotruncana imbricata* zone to *Hedbergella loetterli* zone.

Previous record of occurrence: – Mornod (*op. cit.*, p. 590) stated that *G. imbricata* appears rarely in the Cenomanian with *Praeglobotruncana stephani* and is abundant at the base of Turonian but does not extend to the strata containing *Globotruncana ventricosa* (Santonian age) in the upper Cretaceous of Montsalvens. According to the current view on the stratigraphic range of the genus *Globotruncana*, however, the true *Globotruncana* does not occur in the Cenomanian (Bolli, Loeblich and Tappan, 1957, p. 46). Further, *G. imbricata* and *P. stephani* coexist often in the lower Turonian. Therefore it is appropriate to assume the horizon in which *G. imbricata* first appears as the lowest Turonian. Subsequently this species was recorded from the lower Turonian of Czechoslovakia (Scheibnerová, *op. cit.*), the upper Turonian of Spain and the lower Turonian of the Bavarian Alps (Hagn and Zeil, *op. cit.*, p. 35). Although its upper range limit has not been settled, basing upon Mornod's record, it is estimated to be Coniacian (probably earlier half).

Globotruncana japonica Takayanagi, 1960

Pl. 25, figs. 3a–c

Globotruncana japonica Takayanagi, 1960, p. 135, pl. 10, figs. 4a–c.

Remarks: – In the Putah Creek material several specimens were found to be referable to *G. japonica* described originally from Hokkaido. They are characterized by their small and low trochospiral test, with four and a half chambers in the last whorl, depressed sutures on both sides, and distinct double keel at the margins of the chambers. Fine beads are visible on the surface of the chambers, especially in the young specimens. In the case of young specimens, the earlier chambers assume a subglobular appearance lacking the characteristic keel (See: the earliest chamber of the last whorl in figs. 3a-c). This obviously suggests direct derivation of this species from a *Hedbergella* ancestor.

Maximum diameter of hypotype 0.22 mm., maximum thickness 0.11 mm.

Type and occurrence: – Hypotype (figs. 14a–c), Stanford Univ. Paleo. Type Coll. No. 9789, from the core at 130–136 feet in the Forbes Formation, in Diamond Core Hole No. 2, Section A.

Occurrence in the studied area: – Rare, found only in the uppermost part of the Guinda and Forbes Formations. *Range-Globotruncana subcircumnodifer* zone.

Previous record of occurrence: – Known only from the Lower Urakawan to Lower Hetonaian (=Coniacian to Campanian) of Hokkaido, Japan.

Globotruncana japonica robusta Takayanagi, 1960

Pl. 25, figs. 4a-5c

Globotruncana japonica robusta Takayanagi, 1960, p. 136, pl. 10, figs. 5a–c.

Remarks: – This form is distinguished from *G. japonica* (*s. s.*) in having comparatively larger test with robust double keel throughout all chambers, and sutures which are raised, thickened and beaded, especially on the spiral side. In the earlier portion of a young specimen (figs. 4a-c), the chambers are subglobular and the sutures are depressed on both sides, though a distinct keel develops at the margin of each chamber. The beads covering the surface of the chambers are more distinct on the earlier chambers.

Judging from its profile, the present form resembles *Globotruncana linnei bulloides* described by Vogler from the Upper Cretaceous of Indonesia. The characters of the latter form has not been fully described yet, because it was originally defined on thin sections and the hypotypes previously referred to it by various authors are mostly determined by thin sections. Neverthless, *G. japonica robusta* differs from *G. linnei bulloides* in possessing smaller test with fewer chambers in a whorl and narrower umbilicus.

Maximum diameter of hypotype (figs. 4a–c) 0.28 mm, maximum thickness 0.18 mm. Maximum diameter of hypotype (figs. 5a–c) 0.32 mm., maximum thickness 0.18 mm.

Types and occurrence: – Hypotype (figs. 4a–c), Stanford Univ. Paleo. Type Coll. No. 9790, from the core at 169–173 feet in the Forbes Formation, in Diamond Core Hole No. 1, Section A. Hypotype (figs. 5a–c), Stanford Univ. Paleo. Type Coll. No. 9791, from the core at 132–134 feet in the Forbes Formation, in Diamond Core Hole No. 3, Section A.

Occurrence in the studied area: – Rarely found in the Forbes Formation. *Range-Globotruncana subcircumnodifer* zone.

Previous record of occurrence: – In Hokkaido the range of *G. japonica robusta* is Lower Urakawan to Lower Hetonaian (=Coniacian to Campanian).

Globotruncana linneiana (d'Orbigny), 1839

Pl. 25, figs. 6a-c; Pl. 26, figs. 1a-2c

Rosalina linneiana d'Orbigny, *in* Ramon de la Sagra, 1839, p. 101, vol. 8, pl. 5, figs. 10–12 (plate published separately). (*fide* Ellis and Messina, 1940 *et seq.*)

Globotruncana canaliculata (Reuss). Cushman, 1932, p. 343, pl. 51, figs. 14a–c (non Reuss); Bandy, 1951, p. 509, pl. 75, figs. 2a–c (non Reuss).

Globotruncana canaliculata (Reuss). Cushman and Goudkoff, 1944, p. 62, pl. 10, figs. 10a, b.

Globotruncana linneiana (d'Orbigny). Subbotina, 1953, p. 176, pl. 5, figs. 7a–9v, pl. 6, figs. 1a–4v; Brönnimann and Brown, 1956, p. 540, pl. 20, figs. 13–17, pl. 21, figs. 16–18; Nagappa, 1959, pl. pl. 6, fig. 6; Brönnimann and Rigassi, 1963, pl. 17, figs. 5a–c; Kaptarenko-Chernousova, *et al.*, 1963, p. 105, pl. 17, figs. 3a–v.

Globotruncana linneiana linneiana (d'Orbigny). Barr, 1962, p. 571, pl. 69, figs. 7a–c, pl. 72, fig. 5 (synonymy in part).

Globotruncana lapparenti linneiana (d'Orbigny). Pessagno, 1962, p. 360, pl. 3, figs. 7–9.

Remarks: – Owing to the close resemblance between *G. linneiana* and *G. lapparenti* Brotzen, many discussions have been given by authors. Selecting among the topotypic specimens from the beach sand of Habana Bay, Brönnimann and Brown (1956, *op. cit.*) designated the neotype of *G. linneiana*. And they tentatively treated *G. lapparenti* as a species distinct and valid from *G. linneiana*, because it appears to differ from the latter in being less compressed on the umbilical side. Lately some authors, as Trujillo (1960), Graham and Clark (1961), Barr (1962) and van Hinte (1963), stated that both species are conspecific. Pessagno (*loc. cit.*) considers *G. linneiana* to be a subspecies of *G. lapparenti* though it should be named *G. linneiana lapparenti* by the law of priority. However, at the time of proposal of *G. lapparenti,* Brotzen (1936, p. 176) made the following distinction between them. *G. linneiana* possesses flat to lightly convex spiral side, round chambers on the umbilical side, and slightly convex chambers; while *G. lapparenti* shows convex spiral side, narrowly elongated chambers on the umbilical side, and strongly convex chambers. Subbotina (*op. cit.*, p. 177) remarked that *G. lapparenti* is a species closest to *G. linneiana,* but the chambers always possess characteristic reniform shape and the sutures are sigmoidal on the umbilical side. Applying these criteria, the species may be distinguished from each other, and the Putah Creek specimens are identified with *G. linneiana.* They show some variations in shape of profile, but all fall within the range of variation illustrated by Subbotina (*loc. cit.*). As to *G. canaliculata* (Reuss), some authors considered it as a junior synonym of *G. linneiana,* without reference to the type itself (Subbotina, *loc. cit.*; Brönnimann and Brown, *loc. cit.*). However they appear to be fairly different from each other, inasmuch as Reuss' insufficient illustrations of the holotype are concerned.

Maximum diameter of hypotype (figs. 6a–c) 0.38 mm., maximum thickness 0.18 mm. Maximum diameter of hypotype (figs. 1a–c) 0.41 mm., maximum thickness 0.20 mm. Maximum diameter of hypotype (figs. 2a–c) 0.31 mm., maximum thickness 0.15 mm.

Types and occurrence: – Hypotype (figs. 6a–c), Stanford Univ. Paleo. Type Coll. No. 9792, from the core at 305–311 feet in the Funks Formation, in Diamond Core Hole No. 5, Section B. Hypotype (figs. 1a–c), Stanford Univ. Paleo. Type Coll. No. 9793, from the core at 410–416 feet in the Funks Formation, in Diamond Core Hole No. 5, Section B. Hypotype (figs. 2a–c), Stanford Univ. Paleo. Type Coll. No. 9794, from the core at 190–200 feet in the Funks Formation, in Diamond Core Hole No. 2, Section C.

Occurrence in the studied area: – Fairly common in the Funks Formation, but rare in the upper part of the Sites Formation. *Range-Hedbergella loetterli* zone to the basal *Globotruncana arca* zone.

Previous record of occurrence: – The Turonian to Maastrichtian of the Soviet Union (Subbotina, *op. cit.*), whereas Brönnimann and Brown (*op. cit.*, p. 542) gave its range as Turonian to Campanian. According to most records from Europe, North America, Caribbean region, etc., however, the present species appears to be almost limited in range from Coniacian to Campanian. It might be that the species appearing in the Turonian became common during Coniacian to Campanian and extinction was in the middle of the Maastrichtian.

Globotruncana marginata (Reuss), 1845

Pl. 26, figs. 3a-4c

Rosalina marginata Reuss, 1845 (part), p. 36, pl. 13, figs. 68a, b, (not pl. 8, figs. 54a, b, 74a, b). (*fide* Ellis and Messina, 1940 *et seq.*) (lectotype designated by Bolli, Leoblich and Tappan, 1957, p. 46).

Globigerina marginata (Reuss). Loetterle, 1937, p. 44, pl. 7, fig. 3.

Rosalinella marginata (Reuss). Schijfsma, 1946, p. 97, pl. 7, figs. 10a–c.

Globotruncana marginata (Reuss). Cushman, 1946, p. 150, pl. 62, figs. 1a–2c; Hagn, 1953, p. 93, pl. 8, figs. 10a–c, tect-figs. 10, 11; Hagn and Zeil, 1954, p. 46, pl. 2, figs. 4a–c, pl. 7, figs. 5, 6; Frizzell, 1954, p. 129, pl. 20, figs. 24a–c; Sacal and Debourle, 1957, p. 59, pl. 26, figs. 3, 5, 12, 13; Barr, 1962, p. 574, pl. 70, figs. 3a–c, pl. 72, figs. 7, 8a–c.

Globotruncana (*Globotruncana*) *marginata* (Reuss). Edgell, 1957, p. 114, pl. 2, figs. 4–6; van Hinte, 1963, p. 33, pl. 7, figs. 2a–c, pl. 8, figs. 3a–4c.

Globotruncana sp. aff. *G. marginata* (Reuss). Graham and Church, 1963, p. 64, pl. 7, figs. 15a-16c.

Globotruncana marginata (Reuss). Belford, 1960, p. 100, pl. 30, figs. 1-7.

Remarks: – As stated by Barr (*op. cit.*, p. 575), the confusions about the nature of *G.*

marginata caused by the inadequacy of Reuss's original designation appear to be clarified through the designation of the lectotype by Bolli *et al.* (*loc. cit.*). The present material is characterized by possessing relatively small and biconvex test; spiral side with two and a half to three whorls, and more strongly convex than umbilical side; lobate periphery with a distinct double keel; chambers inflated but with angular truncate margins, five to six in the last whorl; sutures raised, gently curved, usually thickened and beaded, on the umbilical side nearly straight, radial, on the spiral side slightly raised to flush or depressed, and finely beaded when raised; umbilicus comparatively narrow, and fragmentary tegilla rarely preserved. These features coincide well with the diagnosis of *G. marginata* given by Hagn and Zeil (*loc. cit.*) or Barr (*loc. cit.*). Comparing with the typical specimens, those from Putah Creek have slightly less inflated chambers on the spiral side, and slightly more raised sutures on the umbilical side in general.

Barr (*op. cit.*) considered *G. lapparenti bulloides* Vogler as a junior synonym of the present species, after examination of Bolli's hypotype (1945, pl. 9, fig. 12). However, both species can be separated from one another by the form of the sutures as pointed out by Hagn and Zeil (*op. cit.*, p. 45), whom stated:

> "Tatsächlich unterscheidet sich *G. lapparenti bulloides* Vogl. von *G. marginata* (Rss.) wohl kaum in einer anderen Eigenschaft als darin, das bei ersterer Form die Nahtleisten nach Art der *G. lapparenti* auf der Ventralseite stark nach vorwärts geschwungen sind und auf die nächstjüngeren Kammern übergreifen, während die Nähte bei *G. marginata* nahezu radial stehen."

This species is also closely related with *G. japonica robusta* in general appearance. But it is distinguishable from the latter form in having the chambers with keeled margins even in the younger whorl, and the chamber surface covered with weak hispidity instead of beads.

Maximum diameter of hypotype (figs. 3a-c) 0.36 mm., maximum thickness 0.16 mm. Maximum diameter of hypotype (figs. 4a–c) 0.39 mm., maximum thickness 0.18 mm.

Types and occurrence: – Hypotype (figs. 3a–c), Stanford Univ. Paleo. Type Coll. No. 9795, and hypotype (figs. 4a–c), Stanford Univ. Paleo. Type Coll. No. 9796, both from the core at 41–50 feet in the Yolo Formation, in Diamond Core Hole No. 5, Section D.

Occurrence in the studied area: – Very rare, only found in the Venado, Yolo and Sites Formations. *Range-Globotruncana imbricata* zone to *Globotruncana fornicata / Globotruncana coronata* zone.

Previous record of occurrence: – The Turonian to Campanian of various parts of Europe and North America. It was also reported from the Santonian and Campanian of Australia (Edgell, 1957; Belford, 1957, *op. cit.*).

Globotruncana morozovae Vassilenko, 1961

Pl. 26, figs. 5a-d

Globotruncana arca (Cushman). Subbotina, 1953 (part), p. 185, pl. 9, figs. 1a-v.
Globotruncana morozovae Vassilenko, 1963, p. 161, p. 36, figs. 2-4g.

Remarks: – Among the Putah Creek globotruncanids there is a specimen referable to *G. morozovae* Vassilenko. Concerning this species Vassilenko (*op. cit.*) described as follows (literally translated from the Russian text):

"Test strongly convex, with scalary outline in side view, peripheral margin weakly lobulate. At dorsal side first and second whorls trochoid, last whorl flat and strongly inclined to ventral side; chambers of first whorl globular, very small, without septal rim, smooth; chambers of second whorl semicircular, flattened, parts of septal sutures with tubercles, rarely spinose at narrow rim; chambers of last whorl six to seven in number, arched, flat, strongly inclined to direction, opposite of spiral coiling; last chamber often smaller than two proceedings; septal suture arched, with broad tubercles or very finely spinose rim, continuously changing into such tubercular and broad dorsal keels; in last whorl sutures and keels become less tubercular, but no change in width. On ventral side chambers convex, with flattened surface and strongly inclined to umbilicus, their arrangement is very close to each other, almost no increase in size in last whorl; septal sutures depressed, weakly curved, partially covered by rims, which result from combination of umbilical rim and ventral keel of each chamber; all chambers of ventral side, circular to weakly elongated oval, form in regular rosette through thickening. Peripheral margin broad, with two keels; ventral keel continuous, while dorsal – disconnected; on ventral side well visible is dorsal keel in cornice appearance coiling on peripheral margin and its being parallel with ventral keel; midway area broadly concave; in each chamber it increases on side of spiral coiling."

Thus *G. morosovae* assumes a feature very similar to *G. fornicata*, so far as the chamber arrangement of the last whorl on the spiral side is concerned. But in general appearance this species is closely related with *G. arca*, as already discussed by Vassilenko. *G. morosovae* differs principally from the latter species in possessing globular chambers in the primary whorl and elongate arched ones in the succeeding whorls on the spiral side. Its chamber height in the last whorl is about three times smaller than the length, whereas *G. arca* has semicircular chambers in the last whorl. Brönnimann and Brown (1956, pp. 523–524) constructed several evolutional lineages in the globotruncanid Foraminifera. Among their "*Globigerina*"–*Globotruncana* series, "*Globigerina*" cf. *G. cretacea–Globotruncana saratogaensis* (=*Globotruncana cretacea*)–*Glt. marginata–Glt. lapparenti–Glt. lapparenti tricarinata–Glt. arca* lineage and "*Globigerina*" cf. *G. cretacea–Globotruncana saratogaensis* (=*Globotruncana cretacea*)–*Glt. marginata–Glt. imbricata–Glt. fornicata–Glt. contusa* lineage are presented. Setting aside the question whether the view is right or wrong, *Globotruncana morosovae* will furnish an important key to clarify the relation between the *G. tricarinata–G. arca* group and the *G. fornicata–G. contusa* group. It seems to be suggested from their morphology that there is much closer genetic relationship between both groups than previously thought (Brönnimann and Brown, *loc. cit.*; Berggren, 1962b). Brönnimann and Brown pointed out that during the course of evolution *G. tricarinata* attained to *G. arca* by developing two stronger and heavier keels while the distance between them remained nearly constant. In addition to the trend noted by them, there seems to be a further trend wherein the test becomes thicker and the spiral side becomes more convex than the dorsal. On the other hand, in the lineage from *G. imbricata* to *G. contusa*, they mentioned that *G. fornicata* descended from *G. imbricata* by the elongation of its later chambers in the direction of growth. Such tendency is more emphasized in *G. morozovae*. It appears to be a distinct morphologic character suggesting a close phylogenetic relationship between *G. fornicata* and *G. morosovae*. If *G. morosovae* is assumed to be a descendant of *G. fornicata*, it is noteworthy that the test becomes thicker and the spiral side more convex than the dorsal in this lineage, too. Thus the characteristic modification in this lineage is just a type intermediate between Brönnimann and Brown's two lineages. Although it is difficult to recognize the present species as a product of closely interwoven evolving plexus of the two lineages, the *G. fornicata–G. morosovae* lineage as a branch of the *G. imbricata–G. contusa* lineage might suggest a homeomorphic pattern of evolution for the *G. lapparenti–G. arca* lineage.

Maximum diameter of hypotype 0.45 mm., maximum thickness 0.21 mm.

Type and occurrence: – Hypotype (figs. 5a–d), Stanford Univ. Paleo. Type Coll. No. 9797, from the core at 256–261 feet in the Funks Formation, in Diamond Core Hole No. 6. Section B.

Occurrence in the studied area: – The upper part of the Funks Formation, upper part of the *Globotruncana schneegansi* zone.

Previous record of occurrence: – The upper Campanian and lower Maastrichtian of

Mangyshlaka, along the Caspian Sea and northern Caucasus of the Soviet Union (Vassilenko, *op. cit.*). The range is extended to include the upper part of the *Globotruncana schneegansi* zone.

Globotruncana pura Hofker, 1956

Pl. 27, figs. 1a-c

Globotruncana pura Hofker, 1956, p. 327. text-figs. 16a-d.

Remarks: – A very minute form with globular chambers is found in the Putah Creek material. It is characterized by its low trochospiral and biconvex test with lobate periphery, five subglobular chambers in the last whorl, slightly truncate with poreless marginal band on the later chambers, and nearly radial and depressed sutures. These features coincide quite well with those of *G. pura* Hofker, with which the present form is identified. Although Hofker (*loc. cit.*) illustrated poreless marginal bands on the whole chambers of the type specimen, such a band is only visible on the last and occasionally penultimate chambers of the present material. This is probably due to their juvenility. Reyment (1960, p. 76) recorded *Globotruncana* cf. *pura* from Logbaba, near Duala, French Cameroons. However, owing to the presence of a faint double keel on his specimen, it may be distinguished from *G. pura*

At the time of description of the present species, Hofker did not refer to the character of the aperture except for the saying that "Auf der Ventralseite ein weit geöffneter Nabel" (*op. cit.*, p. 327). And only a small apertural lip is shown in his illustrations. Apart from the question about the existence of a tegilla which may be easily broken, the present species may be suspected of belonging to *Praeglobotruncana.* Because such apertural character coupled with the broad poreless marginal band on the whole chambers appears to be not diagnostic of *Globotruncana* but of *Praeglobotruncana.* Unfortunately the umbilical part of the Putah Creek material is obscured by cementing material. The present species is tentatively placed under the genus *Globotruncana.*

Maximum diameter of hypotype 0.21 mm., maximum thickness 0.12 mm.

Type and occurrence: – Hypotype (figs. 1a–c), Stanford Univ. Paleo. Type Coll. No. 9798, from the core at 129–135 feet in the Guinda Formation, in Diamond Core Hole No. 1, Section B.

Occurrence in the studied area: – A few specimens from the upper middle part of the Guinda Formation, upper part of the *Globotruncana arca* zone.

Previous record of occurrence: – There has been no reliable record outside northwestern Germany and the Netherlands. They are all from the upper lower Campanian according to Hofker (*op. cit.*). The stratigraphic range is here extended downward to include the upper part of the *Globotruncana arca* zone.

Globotruncana putahensis Takayanagi, n. sp.

Pl. 27, figs. 2a-c

Globotruncana (*Globotruncana*) *elevata elevata* (Brotzen). Edgell, 1957, p. 112, pl. 4, figs. 4–6 (non Brotzen).

Globotruncana elevata elevata (Brotzen). Graham and Church, 1963, p. 63, pl. 7, figs. 13a–c (non Brotzen).

Description: – Test medium in size, low trochospiral, spiral side nearly flat or slightly convex, umbilical side strongly convex; peripheral outline subcircular, peripheral margin moderately lobate, axial periphery subacute, with a double keel, often weakened and transformed into a faint narrow peripheral band in later chambers of last whorl; chambers hemispherical, elevated towards umbilical region, lunate in spiral view, strongly inflated on umbilical side, about 16 to 18 chambers arranged in three whorls on spiral side, early ones globular, inflated, later flattened, increasing gradually in size, usually six in last whorl, commonly obliquely overlapping earlier chambers; sutures on umbilical side slightly curved, generally depressed, somewhat incised about umbilicus between adumbilical extension of peripheral keels on earlier chambers of last whorl; sutures on spiral side curved, obliquely directed backwards, strongly raised, beaded; early chambers with two closely spaced beaded keels, one of which is located on umbilical side and becoming feeble on later chambers, transformed into faint narrow peripheral band on last and penultimate chambers; wall finely perforate, coarsely hispid to beaded on umbilical side, and especially in earlier chambers, spiral side smooth; primary aperture interiomarginal, umbilical; tegilla with accessory apertures not preserved in examined specimens; coiling of test predominantly dextral.

Maximum diameter of holotype 0.46 mm., maximum thickness 0.25 mm.

Type and occurrence: – Holotype (figs. 2a–c), Stanford Univ. Paleo. Type Coll. No. 9799, from the core at 70–76 feet in the Forbes Formation, in Diamond Core Hole No. 5A, Section A.

Remarks: – The new species is very similar to *Globotruncana wiedenmayeri wiedenmayeri* Gandolfi (1955, p. 71, pl. 7, figs. 4a–c) in general appearance, but it differs in lacking rugose ridges on the umbilical side and "arched lips (*rosetta* type) covering the umbilical apertures". Furthermore *G. wiedenmayeri wiedenmayeri* has finely raised double keel throughout the whole chamber margins. In this respect the present form is more similar to *G. wiedenmayeri magdalenaensis* Gandolfi (1955, p. 72, pl. 7, figs. 3a–c), but it is also distinguished from the latter form in having generally six chambers in the last whorl, in contrast to four to five of the latter subspecies, distinctly beaded sutures on the spiral side, and relatively sharp angle at axial periphery. Nevertheless, some morphological characters as shape of chamber, nature of double keel, and roughness of chamber surface on the umbilical side suggests a close relationship among these three forms. However, according to Berggren (1962, p. 70, 71) who examined the holotypes of Gandolfi's two subspecies, these are considered to be synonymous with *Globotruncana fundiconulosa* Subbotina (1953, p. 200, pl. 14, figs. 1a–3c (not 4a–c)). And he emphasized "the acute circum-umbilical rim (and the broad slope of the chambers towards the umbilical region) and scalloped chambers (and raised sutures) on the spiral side" as diagnostic to this form. Further, *Globotruncana* (*Globotruncana*) *ventricosa carinata* Dalbiez (1955, p. 168, text-figs. 8a–d) seems to be synoymous with *G. fundiconulosa,* so far as their illustrations and descriptions are concerned. Employing these criteria, *G. putahensis* can be distinguished from *G. fundiconulosa.*

An Australian form referred to *Globotruncana* (*Globotruncana*) *elevata elevata* (Brotzen) by Edgell* (*op. cit.*) and the Californian form illustrated by Graham and Church (*op. cit.*) under the name of *G. elevata elevata* (Brotzen) appear to be identical with *G. putahensis.* Concerning the Australian specimens, Edgell noted that in the earlier chambers of some specimens there is a tendency toward a doubtful second keel. On the illustrations by Edgell and/or Graham and Church, such kind of second beaded keels are clearly shown on the earlier chambers on the umbilical side. These features are believed to suggest the presence of definite double keels on the chambers of the earlier whorls just as in *G. putahensis.* Such characteristic feature as a double keel was, however, not noticed by Brotzen (1934), Dalbiez (1955) and Knipscheer (1956). In addition, Pessagno (1960, pl. 5, figs. 1, 8) showed excellent thin sections of *G.* (*G.*) *stuarti elevata* (=*G. elevata elevata* of authors), in which a single-keeled nature of the peripheral margin is clearly visible throughout its ontogenetic

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* Van Hinte (1963, p. 70) regarded this form as *G.* (*G.*) *rosetta rosetta* Carsey. But the present writer disagrees with this opinion for the reason stated later.

development. Taking these features into consideration, the present writer agrees with Pessagno's determination, and thus regards both Australian and Californian forms as distinct from *G. elevata elevata* (Brotzen).

In the feature of the characteristic tendency of two closely spaced keels which fuse into a single keel, *G. putahensis* resembles *Globotruncana rosetta* (Carsey). But *G. putahensis* differs from the latter species and its allied forms in lacking a distinct peri-umbilical collar-like rise formed by the adumbilical extension of the peripheral keels and in having beaded umbilical surface. It is also similar to *Globotruncana gansseri* Bolli in general outline of test, shape of chamber, and roughened umbilical surface. But the latter exhibits a single-keeled imperforate, peripheral margin on all chambers of the last whorl, though it possesses double keels on the chambers of the penultimate whorl (Brönnimann and Brown, 1956, p. 550, text-fig. 23). *G. putahensis* appears to be taxonomically intermidiate between *G. rosetta* and *G. gansseri*, in position.

Occurrence in the studied area: – Rare, restricted to the Forbes Formation, middle to upper part of the *Globotruncana subcircumnodifer* zone.

Globotruncana schneegansi Sigal, 1952

Pl. 27, figs. 3a–c

Globotruncana schneegansi Sigal, 1952, p. 33, text-fig. 34; Hagn and Zeil, 1954, p. 37, pl. 5, fig. 12; Bolli, 1957, p. 58, pl. 14, figs. 1a–c; Trujillo, 1960, p. 343, pl. 49, figs. 9a–c.
?*Praeglobotruncana schneegansi* (Sigal). Klaus, 1960a, p. 796, pl. 6, figs. 5a–c.
?*Globotruncana schneegansi* Sigal. Tollmann, 1960, p. 192, pl. 20, fig. 7.

Remarks: – This species is characterized by its biconvex and low trochospiral test with acute axial periphery, and distinct single keel on all chambers of the last whorl. The sutures on the spiral side are curved but later become nearly straight and tangential, raised and beaded; while on the umbilical side they are curved but nearly radial, and depressed. Its umbilicus is generally wide and shallow. The surface on both side is somewhat beaded on the earlier chambers, but becomes smooth later.

Hagn and Zeil (*loc. cit.*) demonstrated the nature of the chambers of the penultimate whorl of the present species in thin section. In their illustration, it is clearly seen that the early chambers are globular and then become furnished with closely spaced double keels at the margin, and that the double keels fuse into a single keel on almost all chambers of the last whorl. This feature may be assumed as an indication suggesting the derivation of *G. schneegansi* from *Globotruncana renzi* Gandolfi.

The umbilical feature on well preserved specimens have not been observed in detail by previous authors, and the taxonomic position of the present species has been in rather confused state. Although this species was originally placed in *Globotruncana* by Sigal (*op. cit.*), Klaus (*op. cit.*) later placed it under *Praeglobotruncana*. Because he regarded the little apertural lip of his material from the "Complexe schisteux intermédiaire" as characteristic of the latter genus. In the Putah Creek material the umbilical tegilla structure is not observed, because of the unfavorable preservation. According to Berggren (1962a, p. 29, 34), who separated *Globotruncana* from *Praeglobotruncana*, in *Globotruncana* the primary aperture is not umbilical-extraumbilical but intraumbilical, and the bifurcation and adumbilical extension of the ventral keel is a distinct feature of *Globotruncana*. Although the apertural character is obscured by the cementing material in the present specimens, the presence of raised and beaded sutures is ascertained especially on the peri-umbilical sides of the later chambers. In the original description Sigal (*loc. cit.*) did not refer to its sutural character, however, the type figure seems to present the same feature as the Putah Creek material. Accordingly this species is herein included in *Globotruncana*, and

Klaus' form is retained in the synonymy with some doubt. In the same way, the form described by Tollmann (*op. cit.*) from the upper Coniacian of the Gosau Basin is questionably included into the synonymy. For its sutures assume a sigmoidal shape on the umbilical side like the *Globotruncana lapparenti* group.

Maximum diameter of hypotype 0.26 mm., maximum thickness 0.13 mm.

Type and occurrence: – Hypotype (figs. 3a–c), Stanford Univ. Paleo. Type Coll. No. 9800, from the core at 315–324 feet in the Funks Formation, in Diamond Core Hole No. 5, Section B.

Occurrence in the studied area: – Very rare, only found in the Funks and Yolo Formations. *Range-Globotruncana fornicata/Globotruncana coronata* zone to *Globotruncana schneegansi* zone.

Previous record of occurrence: – The Turonian and Coniacian of Europe (Germany, Switzerland), Africa (Algeria and Tunisia) and Trinidad. In California it was reported from a middle Turonian shale, near Redding, Shasta County (Trujillo, *op. cit.*).

Globotruncana subcircumnodifer (Gandolfi)

Pl. 28, figs. 1a–4c

Globotruncana cf. *globigerinoides* Brotzen. Bolli, 1951, p. 198, pl. 35, figs. 16–18 (non Brotzen).
Globotruncana (*Rugoglobigerina*) *circumnodifer subcircumnodifer* Gandolfi, p. 44, pl. 2, figs. 8a–c.
Globotruncana (*Rugoglobigerina*) *pennyi subpennyi* Gandolfi, p. 73, pl. 7, figs. 7a–c (written erroneously as *pennyi pennyi* in the explanation of plate 7 on p. 118).
Rugotruncana ellisi Brönnimann and Brown, 1956, p. 547, pl. 22, figs. 7–9.
Rugotruncana tilevi Brönnimann and Brown, 1956, p. 547, pl. 22, figs. 1–3.
Globotruncana (*Rugotruncana*) *tilevi* (Brönnimann and Brown). Pessagno, 1960, p. 102, pl. 5, fig. 10.
Globotruncana (*Rugotruncana*) *subcircumnodifer* (Gandolfi). Berggren, 1962a, p. 67, pl. 10, figs. 4a–c.

Remarks: – In the Putah Creek material there is a small double-keeled form with its surface covered with small pustules or rarely with rugosity, this is referred to *Globotruncana subcircumnodifer*. The main characteristic of this species are the inflated, globular chambers, beaded double keel and rough ornamentation. As shown in the illustration, however, the specimens from the Putah Creek area show considerable variation in surface ornamentation, and grade of development of the keel. The chamber surface is usually covered with dense and fine pustules which are comparatively better developed on the umbilical side than the spiral one. In some specimens such pustules closely line up in meridional trend, or discontinuous fine costellae develop especially on the earlier chambers of the umbilical side. But in general, distinct rugose costellae such as shown by Brönnimann and Brown (*op. cit.*) and Berggren (*op. cit.*) are not well developed in the present material. Furthermore the double keel on the peripheral margin is usually faint and often missing on the earlier chambers of the last whorl. Besides, most of the present specimens commonly possess 11 to 14 chambers arranged in about two whorls and with five to six in the last whorl. On the other hand typical specimens as those from Scandinavia with well marked rugose ornamentation have larger tests and 15 to 20 chambers in three whorls (Berggren, *op. cit.*, p. 67). Taking these differences into consideration, the Putah Creek specimens are not regarded as full adults. In the present state of knowledge it is very difficult to give a full explanation for their stage, but it may be possibly caused by some ecological condition.

Following Berggren (*op. cit.*) who examined the holotypes, *Globotruncana* (*Rugoglobigerina*) *pennyi subpennyi*, *Rugotruncana ellisi*, and *Rugotruncana tilevi* are included into the synonymy in the present study.

Maximum diameter of hypotype (figs. 1a–c) 0.23 mm., maximum thickness 0.10 mm. Maximum diameter of hypotype (figs. 2a–c) 0.23 mm., maximum thickness 0.11 mm.

Maximum diameter of hypotype (figs. 3a–c) 0.23 mm., maximum thickness 0.11 mm. Maximum diameter of hypotype (figs. 4a–c) 0.18 mm., maximum thickness 0.11 mm.

Type and occurrence: – Hypotype (figs. 1a–c), Stanford Univ. Paleo. Type Coll. No. 9801, from the core at 90–100 feet; hypotype (figs. 2a–c), Stanford Univ. Paleo. Type Coll. No. 9802, from the core at 185–190 feet; hypotype (figs. 3a–c), Stanford Univ. Paleo. Type Coll. No. 9803, from the core at 271–274 feet; hypotype (figs. 4a–c), Stanford Univ. Paleo. Type Coll. No. 9804, from the core at 320–330 feet; all in the Forbes Formation, in Diamond Core Hole No. 1, Section A.

Occurrence in the studied area: – Rather rare in the upper part of the Guinda Formation, but common in the Forbes Formation. *Range*: – *Globotruncana subcircumnodifer* zone.

Previous record of occurrence: – The Campanian of Colombia, the Campanian to Maastrichtian of North America, and the Maastrichtian of Scandinavia. The reworked specimens are also recorded from the Eocene of Trinidad (Bolli, *op. cit.*).

Globotruncana tricarinata (Quereau), 1893
Pl. 27, figs. 4a–c

Pulvinulina tricarinata Quereau, 1893, p. 89, pl. 5, fig. 3a,

Rosalina linnei d'Orbigny, type 2, de Lapparent, p. 7; p. 4, figs. 1b, d-f; p. 5, figs. 2d, n; pl. 1, fig. 1. (non *Rosalina linneiana* d'Orbigny)

Globotruncana linnei (d'Orbigny). Renz, 1936 (part), p. 19, pl. 6, figs. 28–30, pl. 8, fig. 7 (non pl. 6, figs. 32–34); Gandolfi, 1942, pl. 10, fig. 7.

Globotruncana linnei tricarinata (Quereau). Vogler, 1941, p, 287, pl. 33, figs. 22–31.

Globotruncana lapparenti tricarinata (Quereau). Bolli, 1945, p. 232, text-figs. 1 (19, 20), pl. 9, fig. 13; Tilev, 1951, p. 79, text-figs. 24a–d; Said and Kenawy, 1956, p. 150, pl. 5, figs. 20a—c; Klaus, 1959, p. 823, pl. 8, figs. 3a–c; Tollmann, 1960, p. 193, pl. 21, fig. 1.

Globotruncana canaliculata (Reuss). Cushman, 1946 (part), p. 149, pl. 61, figs. 18a–c (non pl. 61, figs. 17a–c) (non *Rosalina canaliculata* Reuss).

Globotruncana lapparenti Brotzen. Subbotina, 1953, p. 178, pl. 6, figs. 5a–6v, pl. 7, figs. 1a–5v.

Globotruncana lapparenti Brozten *tricarinata* (Quereau). Hagn and Zeil, 1954, p. 42, pl. 6, figs. 6, 7; Klaus, 1959, p. 823, pl. 8, figs. 3a–c; Belford, 1960, p. 97, pl. 28, figs. 1–6.

Globotruncana sp. (ex. gr. *arca* Cushman). Hiltermann and Koch, 1955, pl. 27, figs. 2a–c.

Globotruncana (*Globotruncana*) *lapparenti* Brotzen cf. subsp. *tricarinata* (Quereau). Edgell, 1957, p. 113, pl. 3, fig. 1–3.

Globotruncana linneiana (d' Orbigny). Trujillo, 1960, p. 342, pl. 49, figs. 8a–c (non *Rosalina linneiana* d'Orbigny).

Globotruncana linneiana tricarinata (Quereau). Graham and Clark, 1961, p. 112, pl. 5, figs. 8a–c; Barr, 1962, p. 573, pl. 70, figs. 2a–c.

Globotruncana (*Globotruncana*) *tricarinata* (Quereau). Berggren, 1962, p. 64, pl. 10, figs. 3a–c.

Globotruncana (*Globotruncana*) *linneiana tricarinata* (Quereau). van Hinte, 1963, p. 79, pl. 6, figs. 1a–c.

Globotruncana tricarinata (Quereau). Herb, 1963, p. 905, pl. 1, figs. 2a–c.

Globotruncana lapparenti Brotzen subsp. *tricarinata* (Quereau). Kavary and Frizzell, 1964, p. 55, pl. 11, figs. 4–6.

Remarks: – This species is distinguished by its low trochospiral test with nearly flat spiral side and rather inflated umbilical side, the two distinct broadly spaced keels, the "third keel" formed by peri-umbilical extension of the umbilical keel, the raised sutures which are arcuate on the spiral side and sigmoidal on the umbilical, and the broad and deep umbilicus. *G. tricarinata* is similar to *G. linneiana*, but differs in being more convex on the spiral side and having the "third keel" and sigmoidal sutures on the spiral side. It also resembles *G. arca*, but the latter species possesses more convex spiral side and less protrusive periumbilical extension of the umbilical keel. In this sense the present writer approves of Berggren's assumption concerning their relationship. He stated (Berggren, 1962a, p. 50):

"...... *G. arca* has developed from *G. lapparenti* stock (and more directly from *G. lapparenti tricarinata*) by progressive modification of the raised sigmoidal sutures and suppression of the periumbilical extension of the ventral (umbilical) carina and increased complexity of the umbilical apparatus."

Maximum diameter of hypotype 0.46 mm., maximum thickness 0.23 mm.

Type and occurrence: – Hypotype (figs. 4a–c), Stanford Univ. Paleo. Type Coll. No. 9805, from the core at 329–337 feet in the Forbes Formation, in Diamond Core Hole NO. 5, Section A.

Occurrence in the studied area: – Common in the upper part of the Funks, Guinda and the lower part of the Forbes Formation. *Range*-The upper part of the *Globotruncana schneegansi* zone to the lower part of the *Globotruncana subcircumnodifer* zone.

Previous record of occurrence: – The Coniacian to Maastrichtian of Europe, Middle East, Africa, North America and Australia. Its records from the Turonian strata are rather limited to Switzerland (Gandolfi; Klaus; *op. cit.*), Germany (Hagn and Zeil, *op. cit.*) and California (Trujillo, *op. cit.*).

Globotruncana ventricosa White, 1928

Pl. 29, figs. 1a–d

Globotruncana canaliculata var. *ventricosa* White, 1928, p. 284, pl. 38, figs. 5a–c.

Globotruncana ventricosa White. Cushman, 1946, p. 150, pl. 62, figs. 3a–c (reproduction of holotype); Bolli, 1951, p. 194, text-fig. 1e; Mornod, 1950; p. 590, text-fig. 12 (no. 1a–2c); Hamilton, 1953, p. 233, pl. 29, figs. 29–31; Hagn, 1954, p. 99, pl. 8, figs. 15a–c, text-figs. 26, 27; Bolli, 1957, p. 57, pl. 13, figs. 4a–c; Belford, 1960, p. 98, pl. 29, figs. 5–11; Graham and Clark, 1961, p. 112, pl. 5, figs. 9a–c; Scheibnerová, 1961, p. 68, pl. 12, figs. 2a–c; Kavary and Frizzell, 1964, p. 56, pl. 11, figs. 14–16.

Globotruncana ventricosa ventricosa White. Gandolfi, 1955, p. 22, pl. 1, figs. 5a–c; Tollmann, 1960, p. 195, pl. 21, figs. 6, 7.

Globotruncana (*Globotruncana*) *paraventricosa* (Hofker). Edgell, 1957, p. 114, pl. 1, figs. 1–3 (non *Marginotruncana paraventricosa* Hofker).

Globotruncana cf. *ventricosa* White. Barr, 1962, p. 577, pl. 71, figs. 2a–c.

Globotruncana (*Globotruncana*) *ventricosa* White, van Hinte, 1963, p. 86, pl. 7, figs. 3a–c.

Non *Globotruncana canaliculata* (Reuss) var. *ventricosa* White. Plummer, 1931, pl. 13, figs. 10a-c (=*Globotruncana cretacea* Cushman=*Globotruncana mariei* Banner and Blow).

Non *Globotruncana ventricosa* White. Brotzen, 1936, p. 171, pl. 13, figs. 4a–c, text-fig. 63 (1–3); Subbotina, 1953, p. 194, pl. 13, figs. 1a–4v [=*Globotruncana paraventricosa* (Hofker)].

Non *Globotruncana* (*Globotruncana*) *ventricosa ventricosa* White. Dalbiez, 1955, p. 168, text-figs. 7a-d; Ashworth, 1959, p. 498, text-figs. 2a–c [=*Globotruncana concavata* (Brotzen)].

Remarks: – This species was originally described as a variety of *G. canaliculata* from the Papagallos Formation (Campanian) of the Tampico region, Mexico. It may be characterized by its very low trochospiral test, flat to slightly convex spiral side and strongly convex umbilical side, the well developed double keel, and the sutures which are raised and curved on the spiral side and slightly curved and depressed on the umbilical side. In these features the present species is very similar to *G. concavata*. As already cited in the remarks under *G. concavata*, however, Bolli (1957, *op. cit.*, p. 57) clearly distinguished between them in the following respects; namely, number of chambers in the last whorl, shape of sutures on the spiral side, shape of the spiral side, character of two keels and stratigraphic range. Among the criteria just mentioned, the shape of the spiral side and the character of the two keels seem to be most useful for distinction so far as Putah Creek material is concerned. *G. concavata* is usually slightly concave on the spiral side while *G. ventricosa* is nearly flat to slightly convex on the same side. In addition *G. concavata* has more closely spaced, and two relatively weakly developed keels. Furthermore as pointed out by Barr (*op. cit.*, p. 569), the spiral sutures of *G. ventricosa* are much more strongly raised and thicker than those of *G. concavata.* The Putah Creek specimens show less developed periumbilical extension of umbilical carina as compared with the typical specimen figured by Bolli (1957, *loc. cit.*).

Maximum diameter of hypotype 0.56 mm., maximum thickness 0.22 mm.

Type and occurrence: – Hypotype (figs. 1a–d), Stanford Univ. Paleo. Type Coll. No. 9806, from the core at 341–345 feet in the Funks Formation, in Diamond Core Hole No. 6, Section B.

Occurrence in the studied area: – Rare, limited only within the lower part of the upper trisection of the Funks Formation, *Globotruncana schneegansi* zone.

Previous record of occurrence: – The upper (?) Coniacian to lower Maastrichtian, though Bolli (1957, *op. cit.*) regarded its range as upper Santonian to Campanian. The present species is known from the Campanian to lower Maastrichtian of Austria; the Campanian of Germany, Czechoslovakia, England, Iran, Colombia, Trinidad, Mexico, Gulf Coast region, California and Australia; the Santonian of Switzerland, Gulf Coastregion and Australia; and the upper Coniacian of Austria and the Austin Group of Texas. Besides it is reported from the seamount in the Pacific.

Genus *Rugoglobigerina* Brönnimann, 1952

Rugoglobigerina bulbosa Belford, 1960

Pl. 29, figs. 2a–3c

Rugoglobigerina (*Rugoglobigerina*) *bulbosa* Belford, 1960, p. 94, pl. 26, figs. 1–10, text-fig. 7 (1–8).

Remarks: – Among the Putah Creek material three forms of *Rugoglobigerina* were recognized, and one of them is referred to *Rugoglobigerina bulbosa* described originally from the Toolonga Calcilutite of Western Australia. The present specimens are characterized by their low-trochospiral test, nearly flat to slightly convex spiral side, inflated, globular chambers, which are usually four in the last whorl, radiate, depressed sutures, and rugose ornament in a meridional pattern. Their umbilical tegilla are partially preserved in relatively well preserved specimens.

This species is similar to *Rugoglobigerina rugosa* (Plummer), especially the four-chambered specimens of the latter. Compared with *R. rugosa,* it has fewer chambers in the last whorl and smaller umbilical aperture. Moreover, in the mature specimens of *R. rugosa* the chambers in the last whorl are truncate toward the umbilicus and the last chamber is commonly displaced toward the umbilical side, as pointed out by previous authors (Brönnimann, 1952, p. 29; Berggren, 1962, p. 72). These features are scarcely seen among the specimens of *R. bulbosa.*

It is also similar to the *Rugoglobigerina macrocephala* Brönnimann group in possessing four to five chambers in the last whorl. But as stated by Belford (*op. cit.*), distinction between them appears to be clear, in that the chambers of *R. bulbosa* do not increase in size so rapidly as in *R. macrocephala* group, and it lacks hispid ornament on the surface.

Maximum diameter of hypotype (figs. 2a–c) 0.30 mm., thickness 0.16 mm. Maximum diameter of hypotype (figs. 3a–c) 0.26 mm., thickness 0.13 mm.

Type and occurrence: – Hypotype (figs. 2a–c), and hypotype (figs. 3a–c), Stanford Univ. Paleo. Type Coll. Nos. 9807 and 9808, both form the core at 98–106 feet in the Funks Formation, in Diamond Core Hole No. 6, Section B.

Occurrence in the studied area: – Sporadically in the top of the Venado, Yolo, Sites, and Funks Formations, but is common in the upper part of the Funks Formation. *Range*- Upper part of the *Globotruncana imbricata* zone to the *Globotruncana schneegansi* zone.

Previous record of occurrence: – The Santonian beds of the Toolonga Calcilutite in the

Murchison River area of the Carnarvron Basin and the Gingin Chalk in the Perth Basin, Western Australia.

Rugoglobigerina kingi Trujillo, 1960

Pl. 29, figs. 4a-c

Rugoglobigerina kingi Trujillo, 1960, p. 339, pl. 49, figs. 5a–c.

Remarks: – The species is characterized by its low-trochospiral test, moderately lobulate periphery, inflated globular chambers, which increase gradually in size as added and commonly have six in the final whorl, the radial, depressed sutures, coarse hispid ornament with feeble rugosity on the chambers, deep umbilicus, primary umbilical aperture, and the accessory apertures when the umbilical tegilla are preserved.

The Putah Creek material coincides well with the holotype (UCLA no. 26678) of *R. kingi* with which it was compared. At the time of proposal of this species Trujillo did not compare it with *R. rugosa pennyi* Brönnimann, to which it appears very similar in general features. Although the writer had no opportunity of examining *R. rugosa pennyi*, comparative morphology of them would probably reveal their relationship. Because *R. kingi* is described from the Coniacian of California, while *R. rugosa pennyi* occurs in the Campanian and Maastrichtian of various regions.

Maximum diameter of hypotype 0.34 mm., thickness 0.18 mm.

Type and occurrence: – Hypotype (figs. 4a–c), Stanford Univ. Paleo. Type Coll. No. 9809, from the core at 235–247 feet in the Funks Formation, in Diamond Core Hole No. 6, Section B.

Occurrence in the studied area: – Sporadically found in the Sites and Funks Formations. *Range-Globotruncana fornicata/Globotruncana coronata* zone to *Globotruncana schneegansi* zone.

Previous record of occurrence: – Known only from the upper Coniacian strata (upper part of the Member IV) of Shasta County, California.

Rugoglobigerina rugosa (Plummer), 1927

Pl. 29, ffgs. 5a-c

Globigerina cretacea d'Orbigny. Carsey, 1926, p. 43, pl. 5, figs. 5a, b (non d'Orbigny); White, 1928, p. 193, pl. 27, figs. 15a, b (non d'Orbigny).

Globigerina rugosa Plummer, 1927, p. 38, pl. 2, figs. 10a–d; Plummer, 1931, p. 194; Frizzell, 1954, p. 127, pl. 20, figs. 3–6; Hofker, 1956, p. 53, text-fig. 1.

Rugoglobigerina rugosa rugosa (Plummer). Brönnimann, 1952, p. 28, text-figs. 11a–13i; Hamilton, 1953, p. 227, pl. 30, figs. 1–3; Olsson, 1960, p. 50, pl. 10, figs. 16–18; Corminboeuf, 1961, p. 119, pl. 2, figs. 5a–c; Brönnimann and Rigassi, 1963, pl. 18, figs. 1a–c.

Rotundina ordinaria Subbotina, 1953, p. 166, pl. 3, figs. 3a–9v, pl. 4, figs. 1a–9v.

Globotruncana (*Rugoglobigerina*) *rugosa rugosa* (Plummer). Gandolfi, 1955, p. 72, pl. 7, figs. 6a–c, text-fig. 11c.

Rugoglobigerina rugosa (Plummer). Weiss, 1955, p. 307, pl. 1, fig. 9; Bolli, Loeblich and Tappan, 1957, p. 43, pl. 11, figs. 2a–c; Reyment, 1960, p. 75, pl. 15, figs. 13, pl. 16, figs. 5a–f; Graham and Clark, 1961, p. 111, pl. 5, figs. 1a–c; Berggren, 1962, p. 71, pl. 11, figs. 1a–5b, text-fig. 8 (1a–5b) (with additional synonymy); Kavary and Frizzell, 1964, p. 49, pl. 9, figs. 14, 15.

Rugoglobigerina ordinaria (Subbotina). Bykova, Vassilenko, Voloshinova, Miatliuk, and Subbotina, 1959, text-figs. 693a–v.

Rugoglobigerina cf. *rugosa* (Plummer). Takayanagi, 1960, p. 134, pl. 10, figs. 2a–c.

Rugoglobigerina (*Rugoglobigerina*) *rugosa* (Plummer). van Hinte, 1963, p. 92, pl. 11, figs. 1a–3c.

Remarks: – The Putah Creek specimens referred to this species are generally small in size as compared with the typical specimens. It is characterized by the low-trochospiral test, inflated, globular chambers, which number four to six (most commonly five) in the last whorl, distinctly meridional rugosity, relatively large umbilicus, and tegilla partially retained in well preserved specimens.

Although the present specimens exhibit considerable variation in shape and surface ornamentation, all of them fall within the range of variation as already described by Subbotina (*loc. cit.*). The present specimens do not seem to be full adult forms. They have relatively small test with less lobulate peripheral outline, small umbilical cavity, and are generally lakcing in the aforementioned characteristic features shown in mature specimens (see remarks under *R. bulbosa* Belford). These features may originate from either ecological control or genetical incipiency, though the writer is inclined to consider that they are due to the former cause. As discussed in a later section, this species appears to reach its maximum development in the Maastrichtian, but fully developed forms also occur in the Turonian (cf. Subbotina, *loc. cit.*). Therefore it is difficult to regard all of the Putah Creek specimens as ancestral ones just because they are from strata older than the Santonian.

Maximum diameter of hypotype 0.23 mm., thickness 0.12 mm.

Type and occurrence: – Hypotype (figs. 5a–c), Stanford Univ. Paleo. Type Coll. No. 9810, from the core at 325–328 feet in the Funks Formation, in Diamond Core Hole No. 5, Section B.

Occurrence in the studied area: – Rarely found in the Yolo, Sites and Funks Formations. *Range*-Uppermost part of the *Globotruncana imbricata* zone to the *Globotruncana schneegansi* zone.

Previous record of occurrence: – Some authors consider the range of this species to be from the Campanian to Maastrichtian. It has been recorded commonly from the Maastrichtian of various areas. Besides such records, however, it is also known from older strata as: Maastrichtian of Scandinavia, Netherlands, France, Switzerland, Caucasus and Emba regions, U.S.S.R., Iran, Nigeria and Peru; Campanian to Maastrichtian of Texas, U.S.A., Colombia and a seamount in the Middle Pacific; upper Santonian to lower Maastrichtian of Austria; Coniacian? to Maastrichtian of Mexico; Turonian to Maastrichtian of Trinidad; Turonian of the central Volga Valley area, Shilovka, U.S.S.R.: Turonian to Campanian of Hokkaido, Japan. In California it was recorded from the Panoche Formation of Merced County (Graham and Clark, *op. cit.*).

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Plate 20

Figs. 1a, b. *Heterohelix globulosa* (Ehrenberg) .... p. 195
Hypotype, Stanford Univ. Paleo. Type Coll. No. 9756, from the core at 190–200 feet in the Forbes Formation, in Diamond Core Hole No. 1, Section A. 1a, side view; 1b, top view. × 150.

Figs. 2a, b. *Heterohelix* cf. *planata* (Cushman) .... p. 196
Hypotype, Stanford Univ. Paleo. Type Coll. No. 9757, from the core at 71–78 feet in the Forbes Formation, in Diamond Core Hole No. 3, Section A. 2a, side view; 2b, top view. × 150.

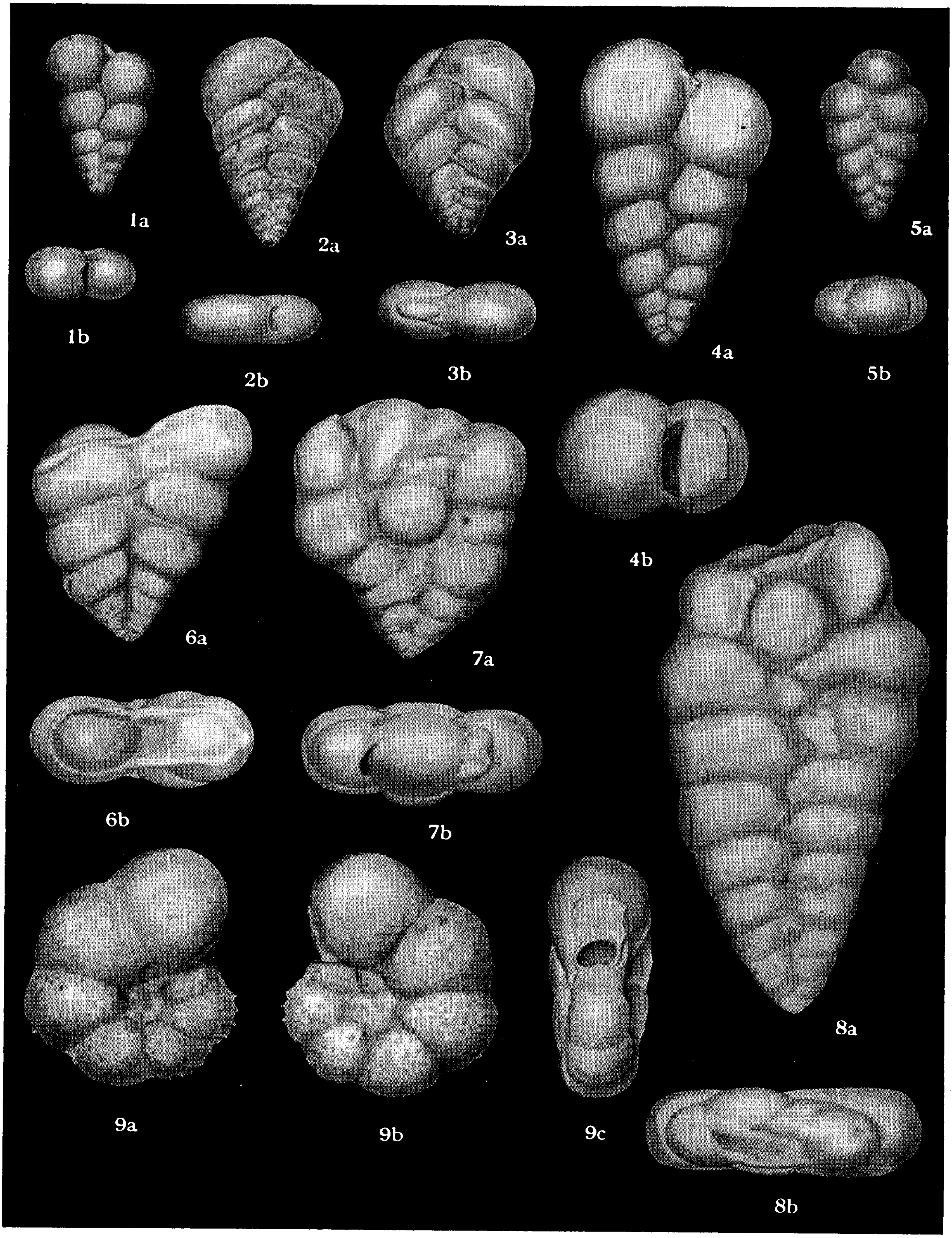
Figs. 3a, b. *Heterohelix pulchra* (Brotzen) .... p. 197
Hypotype, Stanford Univ. Paleo. Type Coll. No. 9758, from the core at 80–90 feet in the Forbes Foramtion, in Diamond Core Hole No. 1, Section A. 3a, side view of microspheric specimen, 3b, edge view. × 150.

Figs. 4a, b. *Heterohelix striata* (Ehrenberg) .... p. 198
Hypotype, Stanford Univ. Paleo. Type Coll. No. 9759, from the core at 269–278 feet in the Forbes Foramation, in Diamond Core Hole No. 5, Section A. 4a, side view; 4b, top view. × 150.

Figs. 5a, b. *Heterohelix ventilabrelliformis* (van der Sluis) .... p. 199
Hypotype, Stanford Univ. Paleo. Type Coll. No. 9760, from the core at 360–366 feet in the Forbes Formation, in Diamond Core Hole No. 1, Section A. 5a, side veiw; 5b, top view. × 150

Figs. 6a–8b. *Gublerina ornatissima* (Cushman and Church) .... p. 200
6a, b, hypotype,Stanford Univ. Paleo. Type Coll. No. 9761, from the core at 450–459 feet in the Forbes Formation, in Diamond Core Hole No. 1A, Section A. 6a, side view of megalospheric specimen, showing development of the central cavity late in the biserial stage; 6b, top view showing the central cavity between the biserial chambers. × 110. 7a, b, hypotype, Stanford Univ. Paleo. Type Coll. No. 9762, from the core at 138–143 feet in the Funks Formation, in Diamond Core Hole No. 6, Section B. 7a, side view of megalospheric specimen, showing the bubbled chambers in the central area; 7b, top view, showing an aperture at the inner margin of the last chamber . × 100. 8a, b, hypotype, Stanford Univ. Paleo. Type Coll. No. 9763, from the core at 138–143, feet in the Funks Formation, in Diamond Core Hole No. 6, Section B. 8a, side view of microspheric specimen, showing sequence of development of the central cavity; 8b, top view. × 140.

Figs. 9a–c. *Globigerinelloides asper* (Ehrenberg) .... p. 201
Hypotype, Stanford Univ. Paleo. Type Coll. No. 9764, from the core at 437–445 feet in the Guinda Formation, in Diamond Core Hole No. 6, Section A. 9a, side view showing the relict apertures in the umbilical region; 9b, another side view, notice slight asymmetry of both sides; 9c, edge view showing equatorial primary aperture. × 115.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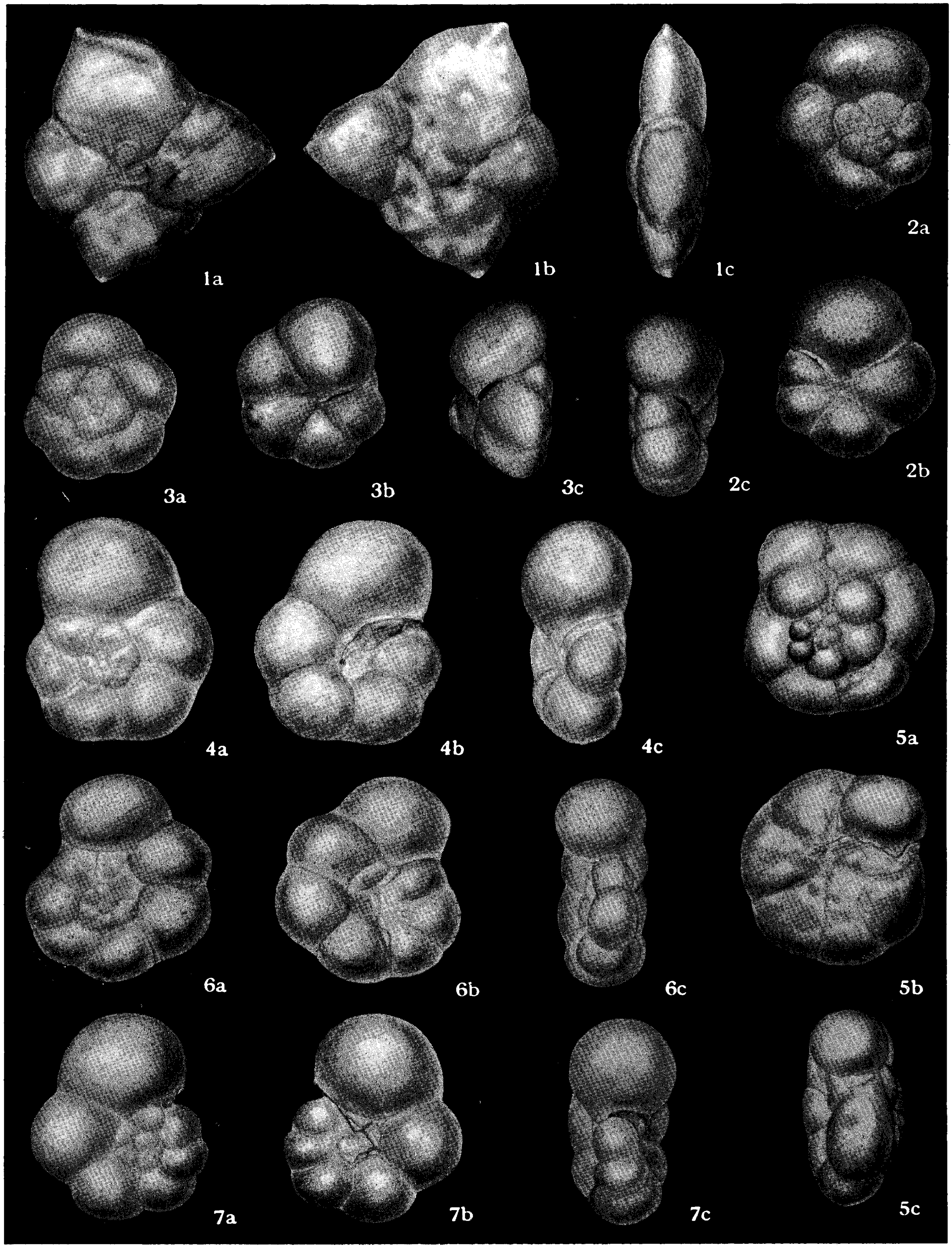
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Plate 21

Figs. 1a–c. *Schackoina cenomana* (Schacko) .... p. 202
Hypotype, Stanford Univ. Paleo. Type Coll. No. 9765, from the core at 180–190 feet in the Funks Formation, in Diamond Core Hole No. 2, Section C. 1a, b, opposite side views; 1c, edge view. × 195.

Figs. 2a–3c. *Hedbergella crassa* (Bolli) .... p. 203
2a–c, hypotype, Stanford Univ. Paleo. Type Coll. No. 9766, from the core at 410–416 feet in the Funks Formation, in Diamond Core Hole No. 5, Section B. 2a, spiral view; 2b, umbilical view; 2c, edge view. × 190. 3a-c, hypotype, Stanford Univ. Paleo. Type Coll. No. 9767, from the core at 460–465 feet in the Funks Formation, in Diamond Core Hole No. 5, Section B. 3a, spiral view; 3b, umbilical view; 3c, edge view showing somewhat appressed specimen. × 200.

Figs. 4a–c. *Hedbergella delrioensis* (Carsey) .... p. 204
Hypotype, Stanford Univ. Paleo. Type Coll. No. 9768, from the core at 448–450 feet in the Funks Formation, in Diamond Core Hole No. 1, Section C. 4a, spiral view; 4b, umbilical view; 4c, edge view. × 114.

Figs. 5a–c. *Hedbergella loetterli* (Nauss) .... p. 205
Hypotype, Stanford Univ. Paleo. Type Coll. No. 9769, from the core at 291–300 feet in the Funks Formation, in Diamond Core Hole No. 2, Section C. 5a, spiral view; 5b, umbilical view, 5c, edge view. × 100.

Figs. 6a–7c. *Hedbergella planispira* (Tappan) .... p. 205
a, spiral view; b, umbilical view; c, edge view. 6a–c, hypotype, Stanford Univ. Paleo. Type Coll. No. 9770, from the core at 250–260 feet in the Funks Formation, in Diamond Core Hole No. 2, Section C. × 170. 7a-c, hypotype, Stanford Univ. Paleo. Type Coll. No. 9771, from the core at 460–466 feet in the Forbes Formation, in Diamond Core Hole No. 1, Section A. × 180.

Plate 22

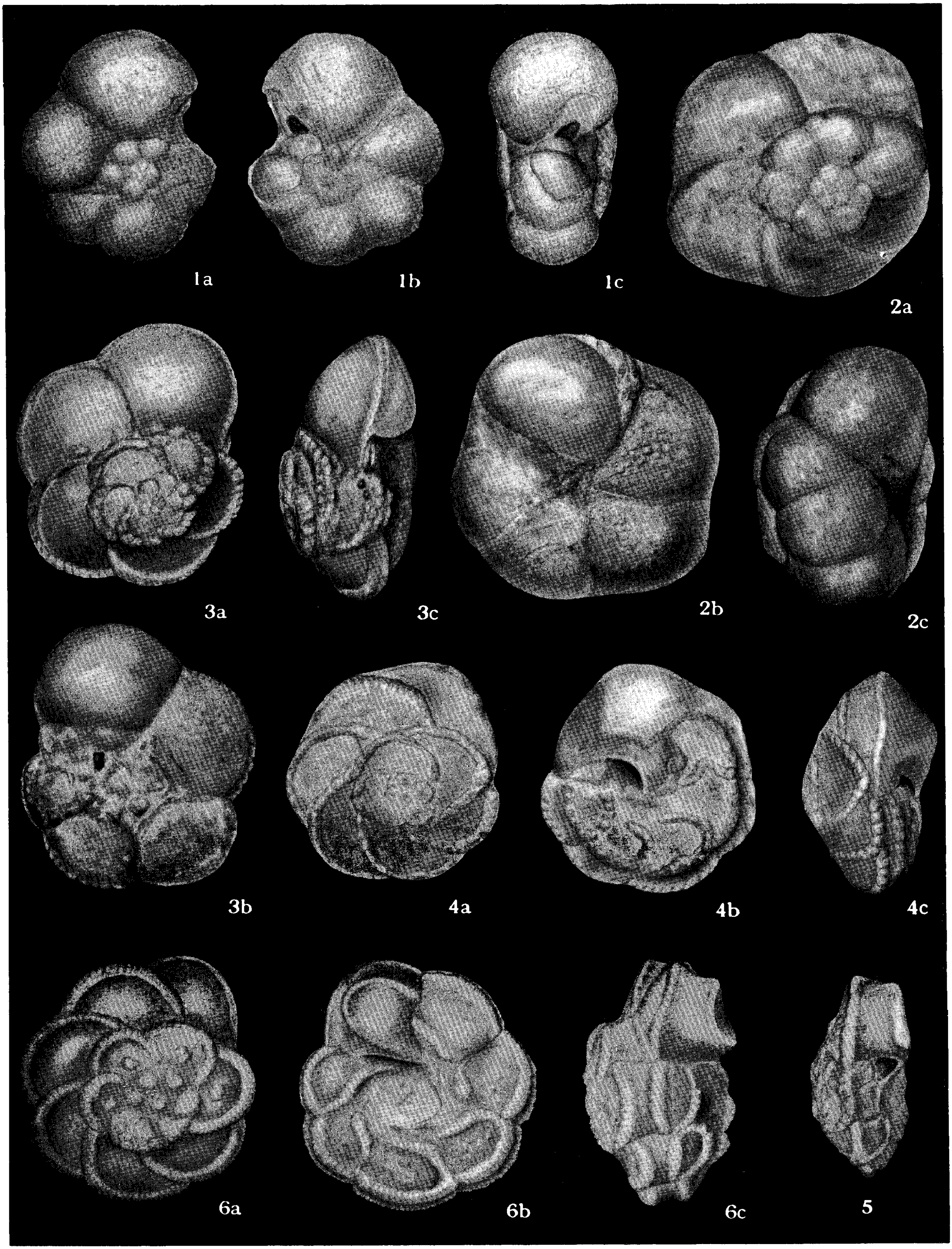
Figs. 1a–c. *Hedbergella planispira* (Tappan) .... p. 205
Hypotype, Stanford Univ. Paleo. Type Coll. No. 9772, from the core at 194–204 feet in the Forbes Formation, in Diamond Core Hole No. 3, Section A. 1a, spiral view; 1b, umbilical view; 1c, edge view: all showing finely hispid surface, though the final chamber was broken during preservation. × 190.

Figs. 2a–c. *Hedbergella* cf. *portsdownensis* (Williams-Mitchell) .... p. 207
Hypotype, Stanford Univ. Paleo. Type Coll. No. 9773, from the core at 335–341 feet in the Yolo Formation, in Diamond Core Hole No. 4, Section D. 2a, spiral view; 2b, umbilical view, 2c, edge view, showing the robust test with elevated spire and the last chamber tending toward the umbilicus. × 140.

Figs. 3a–c. *Praeglobotruncana stephani* (Gandolfi) .... p. 207
Hypotype, Stanford Univ. Paleo. Type Coll. No. 9774, from the core at 41–50 feet in the Yolo Formation, in Diamond Core Hole No. 5, Section D. 3a, spiral view; 3b, umbilical view; 3c, edge view. × 85.

Figs. 4a–c, 5. *Globotruncana angusticarinata* Gandolfi .... p. 208
4a–c, hypotype, Stanford Univ. Paleo. Type Coll. No. 9775, from the core at 160–162 feet, in the Forbes Formation, in Diamond Core Hole No. 2, Section A. 4a, spiral view; 4b, umbilical view; 4c, edge view, showing the single keeled last chamber. × 115. 5, edge view of hypotype, Stanford Univ. Paleo. Type Coll. No. 9776, from the core at 160–162 feet, in the Forbes Formation, in Diamond Core Hole No. 2, Section A. × 125.

Figs. 6a–c. *Globotruncana arca* (Cushman) .... p. 209
Hypotype, Stanford Univ. Paleo. Type Coll. No. 9777, from the core at 120–125 feet in the Forbes Formation, in Diamond Core Hole No. 2, Section A. 6a, spiral view; 6b, umbilical view; 6c, edge view. × 100.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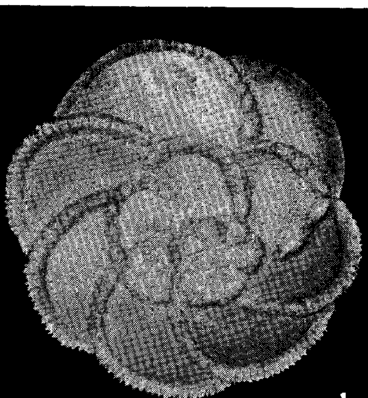
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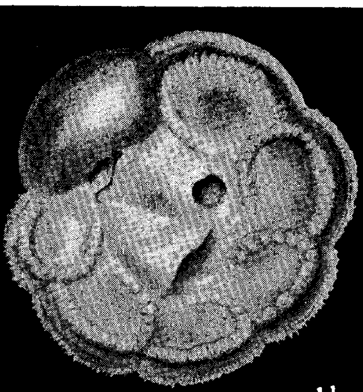
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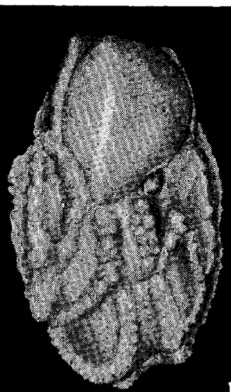
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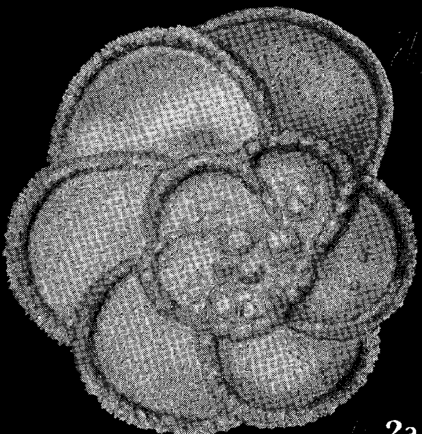
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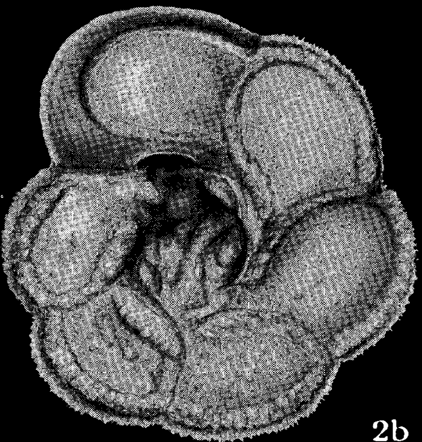
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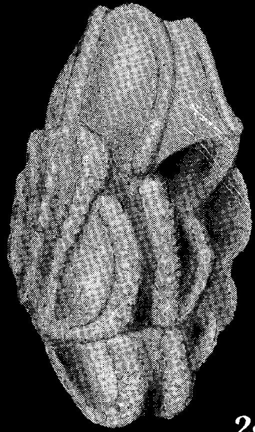
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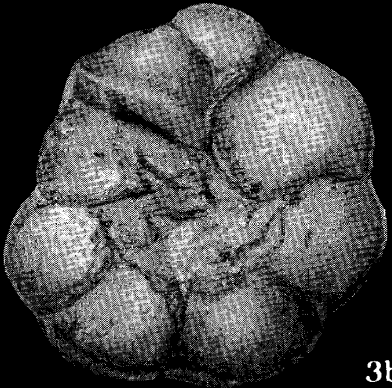
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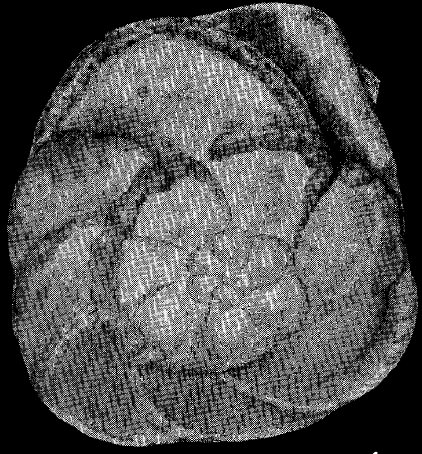
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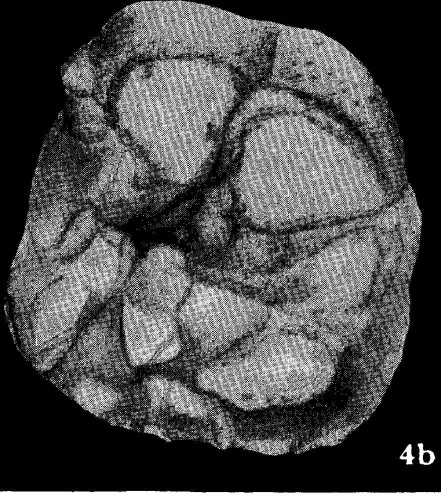
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Plate 23

Figs. 1a–2c. *Globotruncana arca* (Cushman) .... p. 209
1a–c, hypotype, Stanford Univ. Paleo. Type Coll. No. 9778, from the core at 120–125 feet in the Forbes Formation, in Diamond Core Hole No. 2, Section A. 1a, spiral view; 1b, umbilical view showing nearly completely preserved umbilical tegilla; 1c, edge view showing variation of the last chamber which does not show characteristic double keel but a single keel at its margin. × 105. 2a-c, hypotype, Stanford Univ. Paleo. Type Coll. No. 9779, from the core at 80–90 feet in the Forbes Formation, in Diamond Core Hole No. 1, Section A. 2a, spiral view; 2b, umbilical view, showing traces of umbilical tegilla mostly broken at center and the primary umbilical aperture of the last chamber; 2c, edge view. × 100.

Figs. 3a–c. *Globotruncana concavata* (Brotzen) .... p. 211
Hypotype, Stanford Univ. Paleo. Type Coll. No. 9780, from the core at 218–222 feet in the Funks Formation, in Diamond core Hole No. 6, Section B. 3a, spiral view showing slightly concave spiral side, though most of septal sutures of the last whorl are obscured owing to bad preservation; 3b, umbilical view showing wide umbilicus; 3c, edge view showing closely spaced double keel and deep umbilicus. × 63.

Figs. 4a–c. *Globotruncana* cf. *contusa* (Cushman) .... p. 211
Hypotype, Stanford Univ. Paleo. Type Coll. No. 9781, from the core at 325–328 feet in the Funks Formation, in Diamond Core Hole No. 5, Section B. 4a, spiral view; 4b, umbilical view; 4c, edge view showing spiroconvex test. × 170.

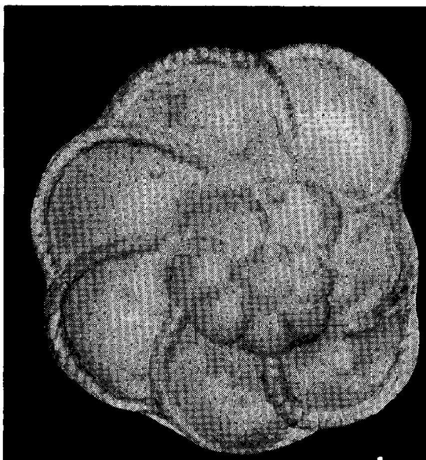
Plate 24

Figs. 1a–2c. *Globotruncana coronata* Bolli .... p. 212
a, spiral view; b, umbilical view; c, edge view. 1a–c, hypotype, Stanford Univ. Paleo. Type Coll. No. 9782, from the core at 340–349 feet in the Funks Formation, in Diamond Core Hole No. 1, Section C. × 104. 2a-c, hypotype, Stanford Univ. Paleo. Type Coll. No. 9783, from the core at 305–311 feet in the Funks Formation, in Diamond Core Hole No. 5, Section B. × 86.

Figs. 3a–c. *Globotruncana cretacea* (d'Orbigny) .... p. 213
Hypotype, Stanford Univ. Paleo. Type Coll. No. 9784, from the core at 291–300 feet in the Funks Formation, in Diamond Core Hole No. 2, Section C. 3a, spiral view; 3b, umbilical view, showing broken tegilla covering the primary umbilical aperture; 3c, edge view, showing weak but widely spaced double keel. × 157.

Figs. 4a–c. *Globotruncana fornicata* Plummer .... p. 214
Hypotype, Stanford Univ. Paleo. Type Coll. No. 9785, from the core at 616–624 feet in the Sites Formation, in Diamond Core Hole No. 4, Section C. 4a, spiral view showing broadly curved, narrow and long chambers in the last whorl, though the surface is partially covered with clayey material; 4b, umbilical view; 4c, edge view. × 110.

Figs. 5a–c. *Globotruncana imbricata* Mornod .... p. 215
Hypotype, Stanford Univ. Paleo. Type Coll. No. 9786, from the core at 291–300 feet in the Funks Formation, in Diamond Core Hole No. 2, Section C. 5a, spiral view; 5b, umbilical view showing the primary umbilical aperture; 5c, edge view. × 115.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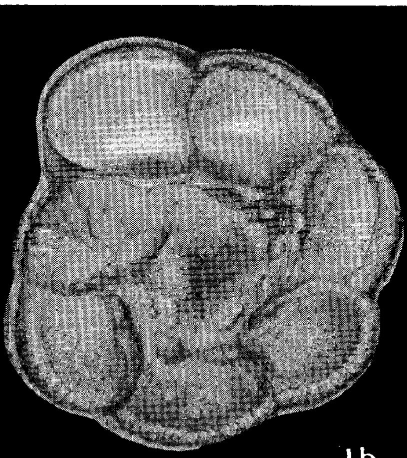
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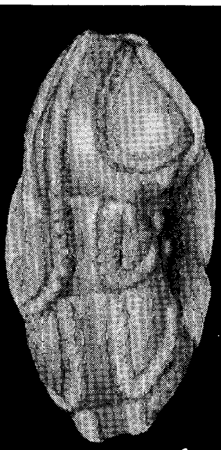
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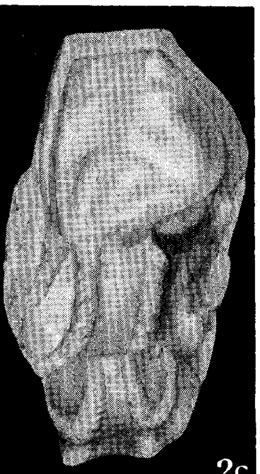
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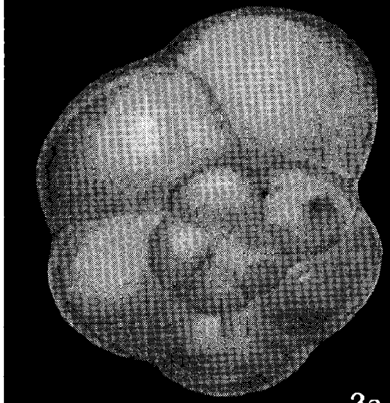
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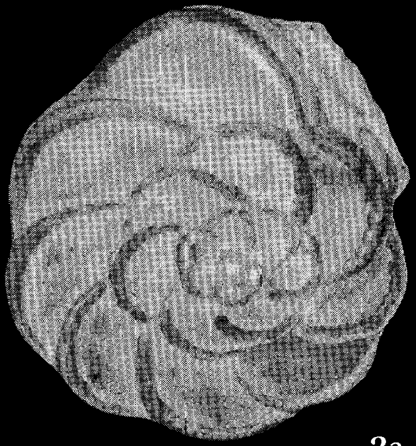
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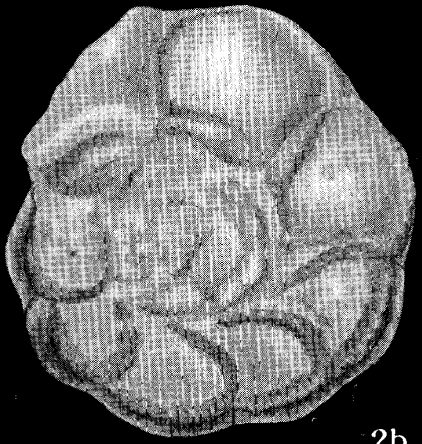
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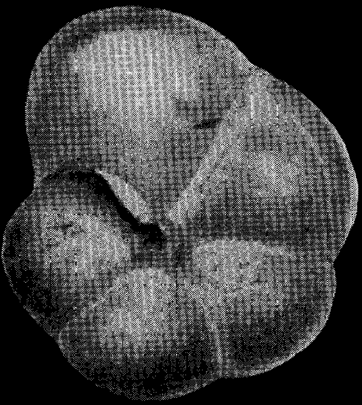
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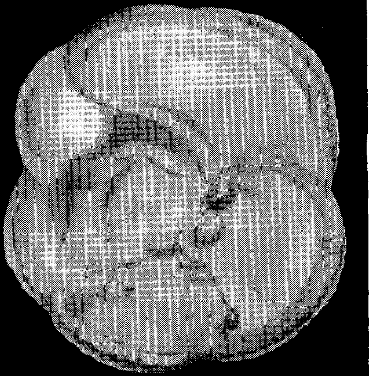
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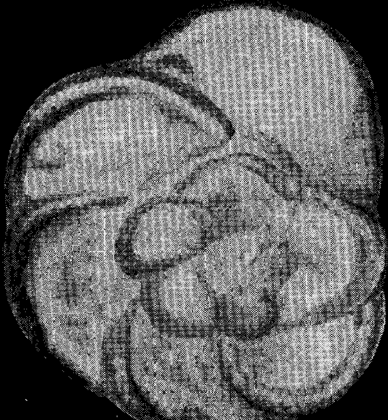
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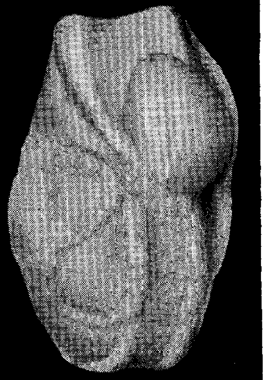
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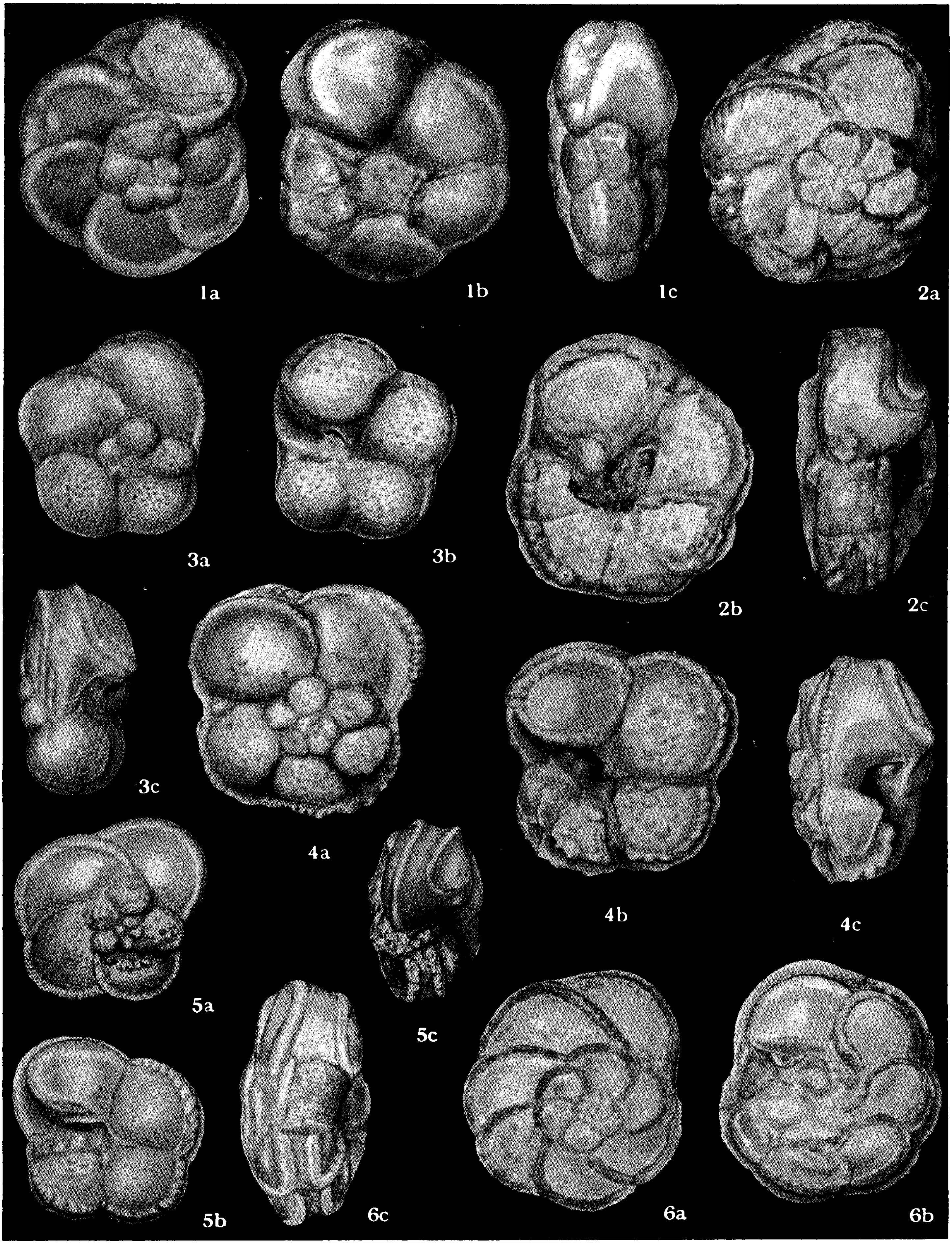
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Plate 25

Figs. 1a–2c. *Globotruncana imbricata* Mornod .... p. 215
a, spiral view; b, umbilical view; c, edge view. 1a-c, hypotype, Stanford Univ. Paleo. Type Coll. No. 9787, from the core at 41–50 feet in the Yolo Formation, in Diamond Core Hole No. 5, Section D. × 157. 2a–c, hypotype, Stanford Univ. Paleo. Type Coll. No. 9788, from the core at 71–81 feet in the Yolo Formation, in Diamond Core Hole No. 5, Section D. × 148. All hypotypes (including the one on Pl. 24, figs. 5a–c) show the variation of this species.

Figs. 3a–c. *Globotruncna japonica* Takayanagi .... p. 216
Hypotype, Stanford Univ. Paleo. Type Coll. No. 9789, from the core at 130–136 feet in the Forbes Formation, in Diamond Core Hole No. 2, Section A. 3a, spiral view; 3b, umbilcial view; 3c, edge view, showing the earlier subglobular chambers of the juvenile specimen. × 160.

Figs. 4a–5c. *Globotruncana japonica robusta* Takayanagi .... p. 217
a, spiral view; b, umbilical view; c, edge view. 4a–c, hypotype, Stanford Univ. Paleo. Type Coll. No. 9790, from the core at 169–173 feet in the Forbes Formation, in Diamond Core Hole No. 1, Section A. × 144. 5a–c, hypotype, Stanford Univ. Paleo. Type Coll. No. 9791, from the core at 132–134 feet in the Forbes Formation, in Diamond Core Hole No. 3, Section A. × 100.

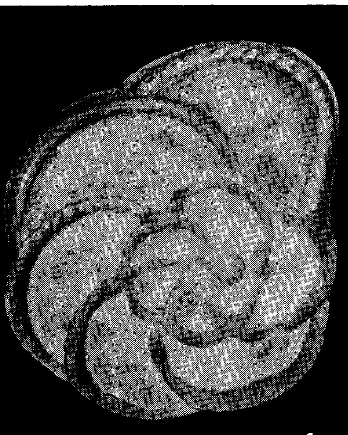
Figs. 6a–c. *Globotruncana linneiana* (d'Orbigny) .... p. 217
Hypotype, Stanford Univ. Paleo. Type Coll. No. 9792, from the core at 305–311 feet in the Funks Formation, in Diamond Core Hole No. 5, Section B. 6a, spiral view; 6b, umbilical view; 6c, edge view. × 115.

Plate 26

Figs. 1a–2c. *Globotruncana linneiana* (d'Orbigny) .... p. 217
a, spiral view; b, umbilical view; c, edge view. 1a–c, hypotype, Stanford Univ. Paleo. Type Coll. No. 9793, from the core at 410–416 feet in the Funks Formation , in Diamond Core Hole No. 5, Section B. × 105. 2a–c, hypotype, Stanford Univ. Paleo. Type Coll. No. 9794, from the core at 190–200 feet in the Funks Formation, in Diamond Core Hole No. 2, Section C. × 148.

Figs. 3a–4c. *Globotruncana marginata* (Reuss) .... p. 218
a, spiral view; b, umbilical view; c, edge view. 3a-c, hypotype, Stanford Univ. Paleo. Type Coll. No. 9795, from the core at 41–50 feet in the Yolo Formation, in Diamond Core Hole No. 5, Section D. × 110. 4a–c, hypotype, Stanford Univ. Paleo. Type Coll. No. 9796, from the core at 41–50 feet in the Yolo Formation, in Diamond Core Hole No. 5, Section D. × 104.

Figs. 5a–d. *Globotruncana morozovae* Vassilenko .... p. 219
Hypotype, Stanford Univ. Paleo. Type Coll. No. 9797, from the core at 256–261 feet in the Funks Formation, in Diamond Core Hole No. 6, Section B. a, spiral view showing broadly curved, narrow and long chambers in the last whorl; 5b, umbilical view showing flattened surface; 5c, d, opposite edge views, showing scalary outline. × 110.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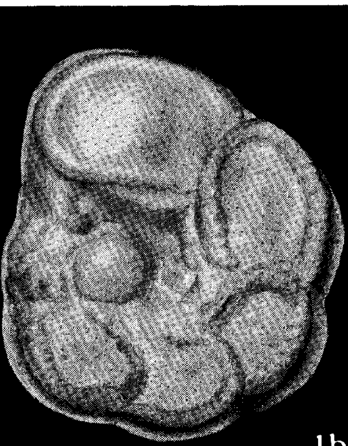
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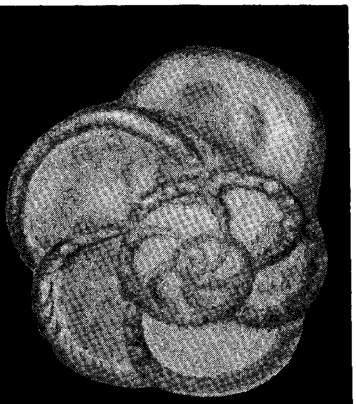
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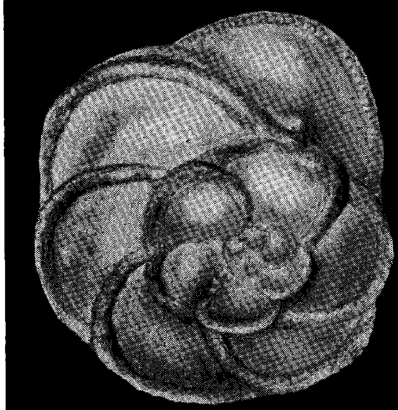
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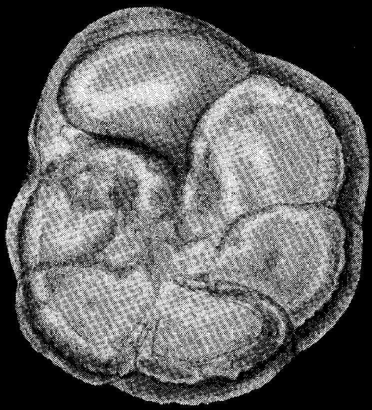
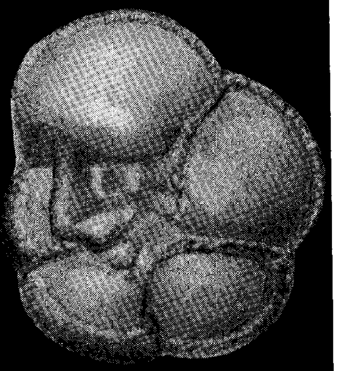

2b


2c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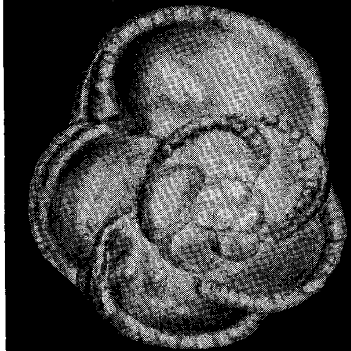
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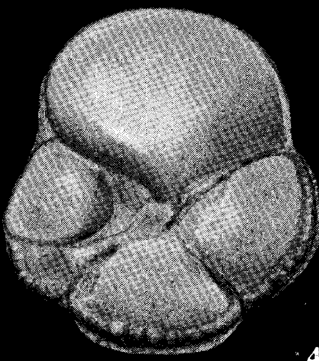
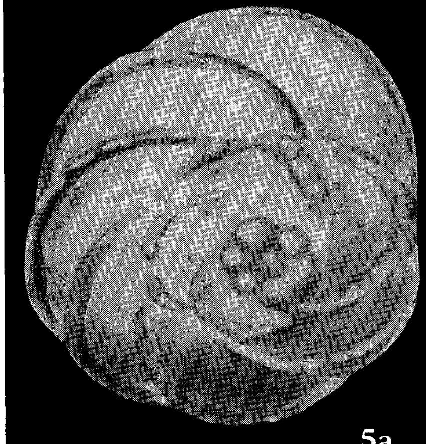

4b


4c


3c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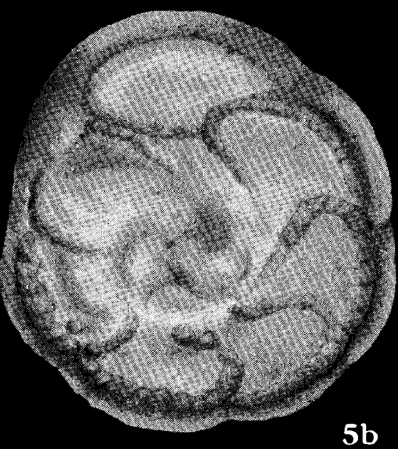
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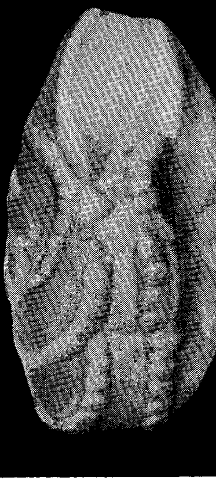
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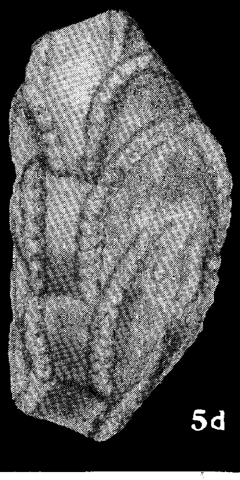
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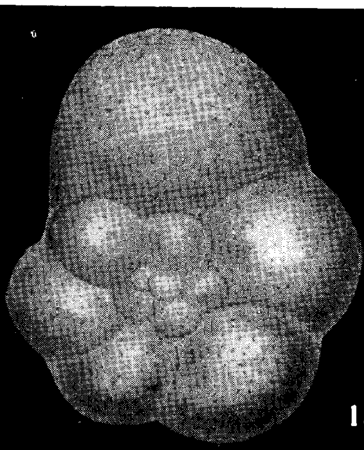
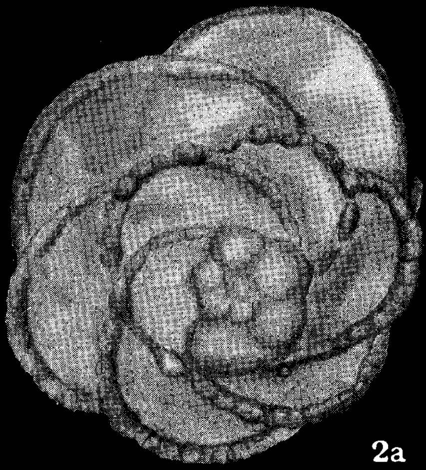

1a


1b


1c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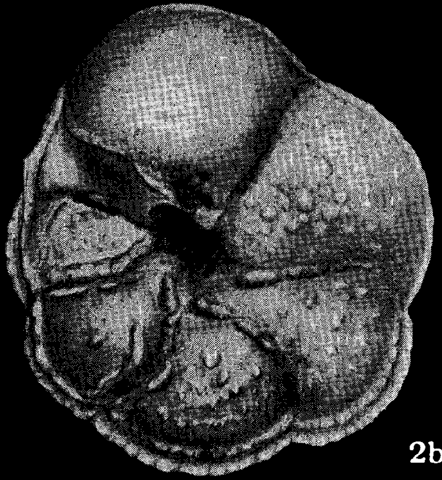
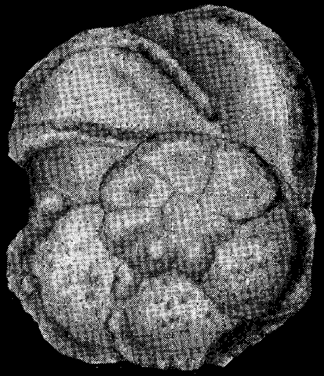

2b


2c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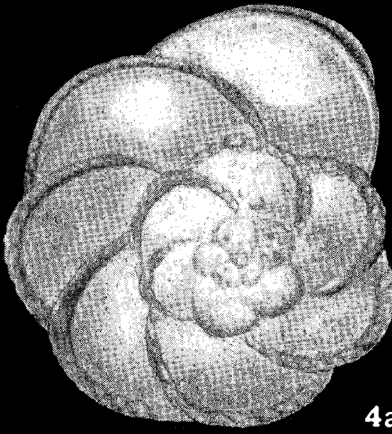
3b


3c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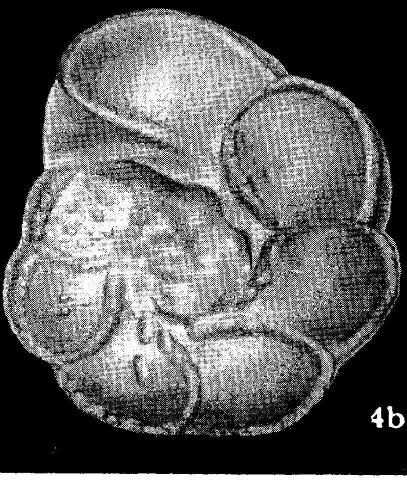
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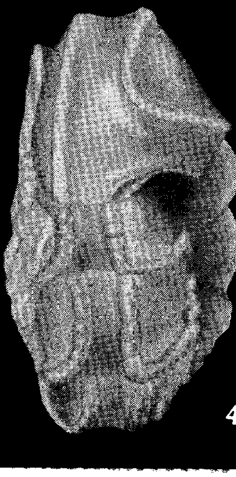

4c

Plate 27

Figs. 1a–c. *Globotruncana pura* Hofker .... p. 221
Hypotype, Stanford Univ. Paleo. Type Coll. No. 9798, from the core at 129–135 feet in the Guinda Formation, in Diamond Core Hole No. 1, Section B. 1a, spiral view; 1b, umbilical view; 1c, edge view showing poreless marginal band of the last chamber. × 216.

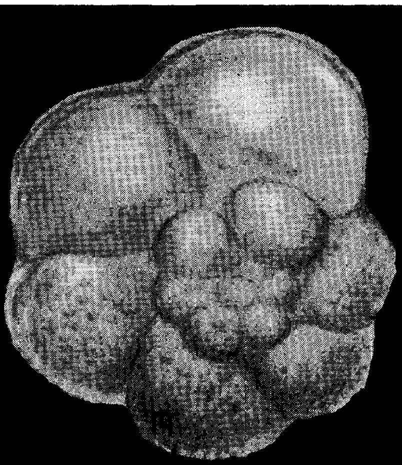
Figs. 2a–c. *Globotruncana putahensis* Takayanagi, n. sp. .... p. 221
Holotype, Stanford Univ. Paleo. Type Coll. No. 9799, from the core at 70–76 feet in the Forbes Formation, in Diamond Core Hole No. 5A, Section A. 2a, spiral view showing lunate appearing chambers and strongly raised, beaded and curved sutures; 2b, umbilical view showing the primary umbilical aperture and coarsely hispid to beaded surface; 2c, edge view showing slightly convex spiral side, strongly convex umbilical side, subacute periphery, closely spaced double keel tending to faint peripheral band. × 115.

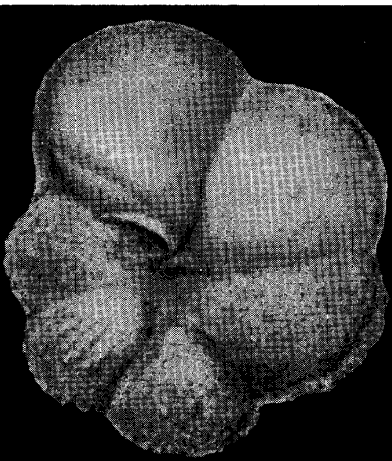
Figs. 3a–c. *Globotruncana schneegansi* Sigal .... p. 223
Hypotype, Stanford Univ. Paleo. Type Coll. No. 9800, from the core at 315–324 feet in the Funks Formation, in Diamond Core Hole No. 5, Section B. 3a, spiral view; 3b, umbilical view showing raised and beaded sutures on the periumbilical area; 3c, edge view showing single keeled periphery. × 160.

Figs. 4a–c. *Globotruncana tricarinata* (Quereau) .... p. 225
Hypotype, Stanford Univ. Paleo. Type Coll. No. 9805, from the core at 329–337 feet in the Forbes Formation, in Diamond Core Hole No. 5, Section A. 4a, spiral view; 4b, umbilical view; 4c, edge view showing the "third keel" formed by periumbilical extension of umbilical keel on the last chamber. × 220.

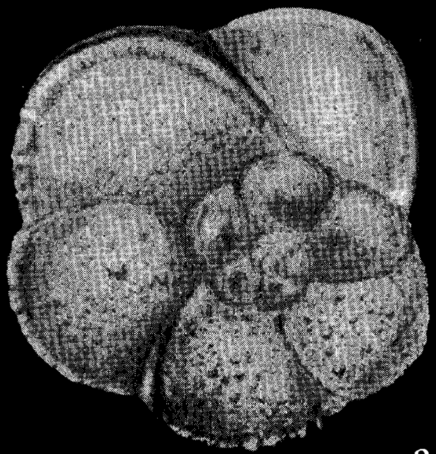
Plate 28

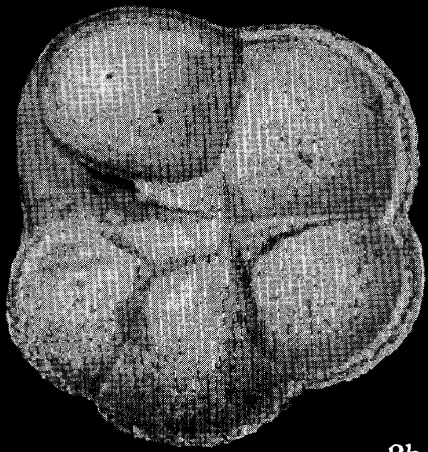
Figs. 1a–4c. *Globotruncana subcircumnodifer* (Gandolfi) .... p. 224
a, spiral view; b, umbilical view; c, edge view.
1a–c, hypotype, Stanford Univ. Paleo. Type Coll. No. 9801, from the core at 90–100 feet, × 230; 2a–c. hypotype, Stanford Univ. Paleo. Type Coll. No. 9802, from the core at 185–190 feet, × × 220, 3a-c, hypotype, Stanford Univ. Paleo. Type Coll. No. 9803. from the core at 271–274 feet, × 200; 4a–c, hypotype, Stanford Univ. Paleo. Type Coll. No. 9804, from the core at 320–330 feet, X 270: all in the Forbes Formation, in Diamond Core Hole No. 1, Section A. All specimens show variations in surface ornamentation and degree of development of double keel.


1a


1b


1c


2a

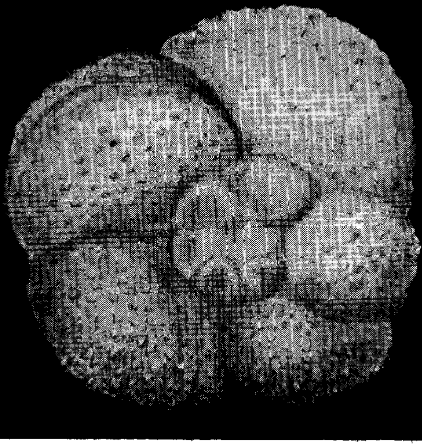

2b


2c


3a


3b


3c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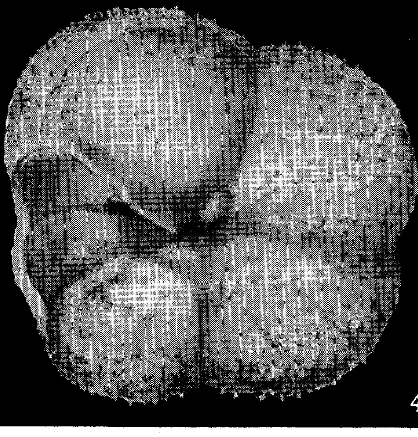
4b


4c

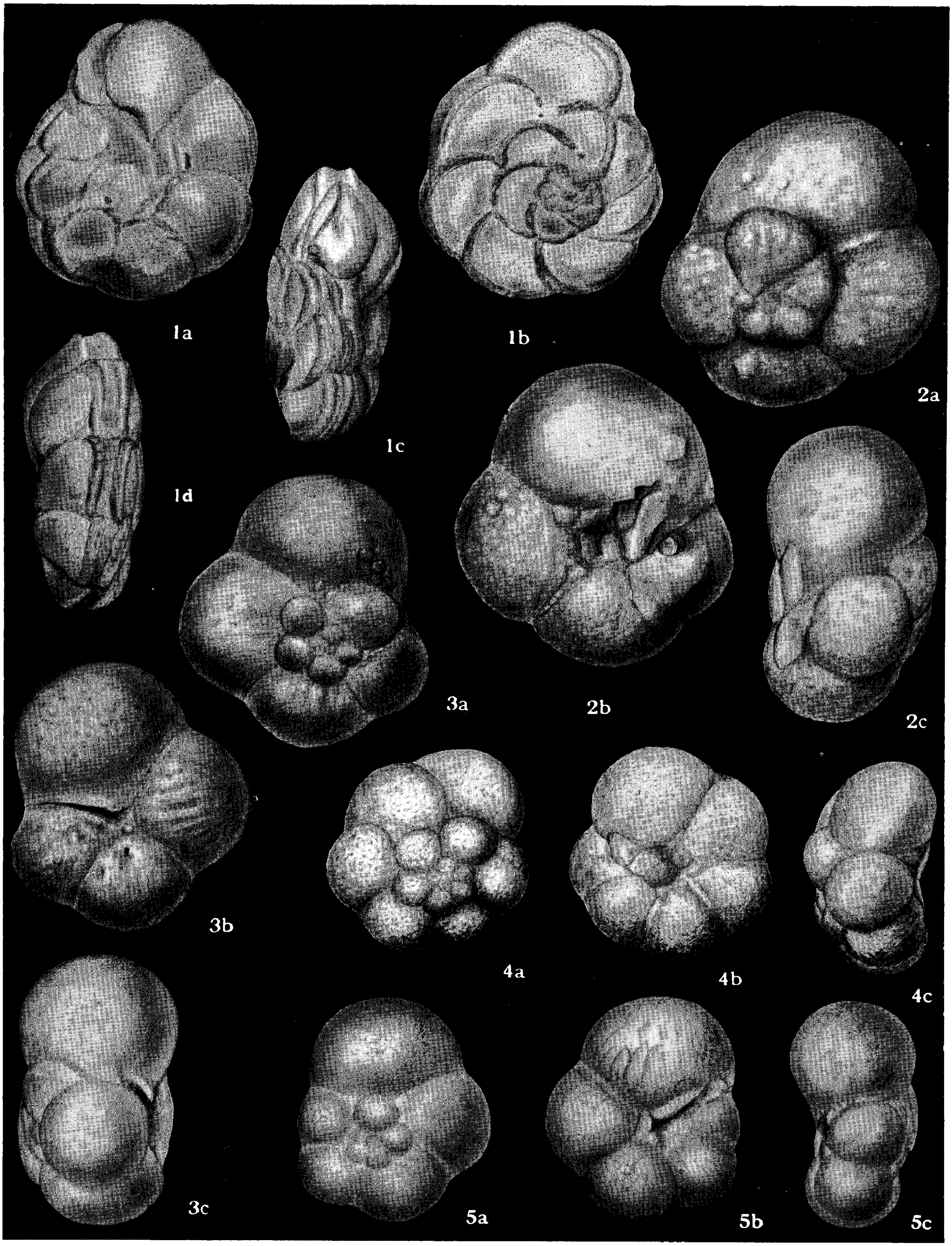
1a
1c
1b
2a
1d
2b
3a
2c
3b
4a
4b
4c
3c
5a
5b
5c

Plate 29

Figs. 1a–d. *Globotruncana ventricosa* White .... p. 226
Hypotype, Stanford Univ. Paleo. Type Coll. No. 9806, from the core at 341–345 feet in the Funks Formation, in Diamond Core Hole No. 6, Section B. 1a, spiral view; 1b, umbilical view; 1c, 1d, opposite side views, showing nearly flat spiral side and double keel, though the final chamber assumes aberrant appearance. × 86.

Figs. 2a–3c. *Rugoglobigerina bulbosa* Belford .... p. 227
a, spiral view; b, umbilical view; c, edge view. 2a–c, 3a–c, hypotypes, Stanford Univ. Paleo. Type Coll. Nos. 9807, and 9808, both from the core at 98–106 feet in the Funks Formation, in Diamond Core Hole No. 6, Section B. All × 175.

Figs. 4a–c. *Rugoglobigerina kingi* Trujillo .... p. 228
Hypotype, Stanford Univ. Paleo. Type Coll. No. 9809, from the core at 235–247 feet in the Funks Formation, in Diamond Core Hole No. 6, Section B. 4a, spiral view showing coarse hispid ornament; 4b, umbilical view showing radially depressed sutures and deep umbilicus; 4c, edge view. × 110.

Figs. 5a–c. *Rugoglobigerina rugosa* (Plummer) .... p. 228
Hypotype, Stanford Univ. Paleo. Type Coll. No. 9810, from the core at 325–328 feet in the Funks Formation, in Diamond Core Hole No. 5, Section B. 5a, spiral view; 5b, umbilical view showing partially preserved tegilla and rugose ornament; 5c, edge view. X 177.