RUDOLOCULINA HOOPERI, A NEW MILIOLID WITH AN AGGLUTINATED OUTER SURFACE FROM THE NORTHEASTERN PACIFIC OCEAN

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ABSTRACT

Rudoloculina hooperi, **a new miliolid from Holocene and modern shelf sediments of the northeastern Pacific Ocean, is characterized by chambers that are quadrate in cross-section and by a test wall with embedded agglutinated grains, some of which consist of miliolid-type shell material (subparallel calcite laths). The agglutinated grains are either calcareous and low in magnesium (Mg/Ca ≤ 0.01) or silicic.** *Rudoloculina hooperi* **has previously been mistakenly reported from the same region as** *Quinqueloculina agglutinata* **Cushman. The morphologically similar genus** *Cycloforina* **has been reported mostly from warmer waters, suggesting that** *R. hooperi* **is near the northern limit of its range in the Gulf of Alaska.**

INTRODUCTION

The present study arises from paleoceanographic research carried out on Quaternary to Recent sediments of the British Columbia shelf (Patterson, 1993; Patterson and others, 1995; Guilbault and others, 1997). A species was observed that previous researchers in the region (e.g., Todd and Low, 1967) had referred to *Quinqueloculina agglutinata* Cushman (1917), originally described from off southern Alaska. However, examination of the literature and the holotype of *Quinqueloculina agglutinata* indicated that the specimens in our material differ from all described genera and species. Thus a new genus and species is required to accommodate these specimens.

MATERIAL

Specimens used for this study were found at three sites. Two sites were piston cores collected in Dixon Entrance in 1990 by Canadian research vessel CSS Endeavour. Dixon Entrance is an east-west channel between coastal islands situated at the Canada-Alaska border. Core END 90A-03 was collected at 54°25.02′N and 132°30.71′W, in a water depth of 277 m, and Core END 90A-07 at 54°34.92′N and 131°43.07′W, at a water depth of 394 m. In these cores, the new species was observed in four samples (two in each core) that, although undated, were considered to be of Holocene age (Guilbault and others, 1997). A few specimens were collected from the sediment/water interface with a Soutar Van Veen grab sampler (''Alaska 62'' sample) by the U.S. Geological Survey in 1976 at 57°39.05′N and 150°32.48′W in the Gulf of Alaska, at a water depth of 102 m.

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METHODS

This description is based on 23 specimens picked out of the 4 samples. Many more specimens were left unpicked in the samples, most of them smaller than the illustrated material however. Photographs were taken using a JEOL 6400 Scanning Electron Microscope (SEM) at the Carleton University Research Facility for Electron Microscopy; accelerating potential was 10 to 15 kV. Specimens were also examined using a LINK exL L24 X-ray analyzer coupled to the same JEOL 6400 SEM. X-ray spectra were collected at 20 kV accelerating potential and measured both semi-quantitatively (molecular weight percent) and in counts (live counting time of 100 seconds). For sectioning, specimens were embedded in Lakeside 70 and carefully ground on 15 μm wet/dry emery paper until the inner structure of the test was exposed. Light photographs of cross sections were obtained using a Javelin video camera mounted on an Olympus SZH stereo microscope. Imagery was transferred to an Apple Macintosh computer using an ATI Xclaim VR capture board. Plates were digitally produced using Photoshop version 2.5 on an Apple Macintosh computer and printed using an Epson Stylus 1520 printer.

SYSTEMATIC DESCRIPTION

Suborder MILIOLINA Delage and Hérouard, 1896
Superfamily MILIOLACEA Ehrenberg, 1839
Family HAUERINIDAE Schwager, 1876
Subfamily HAUERININAE Schwager, 1876
Genus *Rudoloculina* n. gen.
Plate 1, Figures 1–12.
Plate 2, Figures 1–5.

Type species. *Rudoloculina hooperi* n. sp.

Diagnosis. A quinqueloculine genus of the Hauerininae with superficial agglutination and a cycloforinid chamber arrangement.

Description. Test free, elongate, compressed, quinqueloculine throughout, with 5 chambers visible from exterior; chambers one half coil in length, added against the previous whorl without a separate chamber floor; wall calcareous, imperforate, porcelaneous, with superficial agglutination; aperture circular, at the produced end of the final chamber; with simple to T-shaped tooth.

Range. Holocene.

Distribution. Northeast Pacific.

Material. Twenty-three specimens of the type (and only) species.

Etymology. From the Latin *rudus* meaning rough; *-loculus* meaning cell, compartment; *-ina*, feminine diminutive suffix.

Remarks. *Rudoloculina* differs from *Cycloforina* Luczkowska (1972) by having surficial agglutinated material in the walls. We did not include the type species under *Siphonaperta* Vella because we found the description of that genus incomplete. On one hand, Vella (1957) does not include the finely agglutinated *Q. parvaggluta* under *Siphonaperta* but on the other hand, he does so for the coarser-grained species *Siphonaperta macbeathi* and *Siphonaperta crassa*. Vella (1957) does not say why *Q. parvaggluta* was not included in *Siphonaperta* but it is likely that his placement was not based on coarseness of agglutination. Luczkowska (1972) and Loeblich and Tappan (1988) do not discuss the concept of *Siphonaperta* and pending additional research, we prefer not to use the genus *Siphonaperta*. Based on this lack of information we also prefer not to emend the genus *Siphonaperta*. *Siphonaperta* as conceived by Vella (1957) was described as a
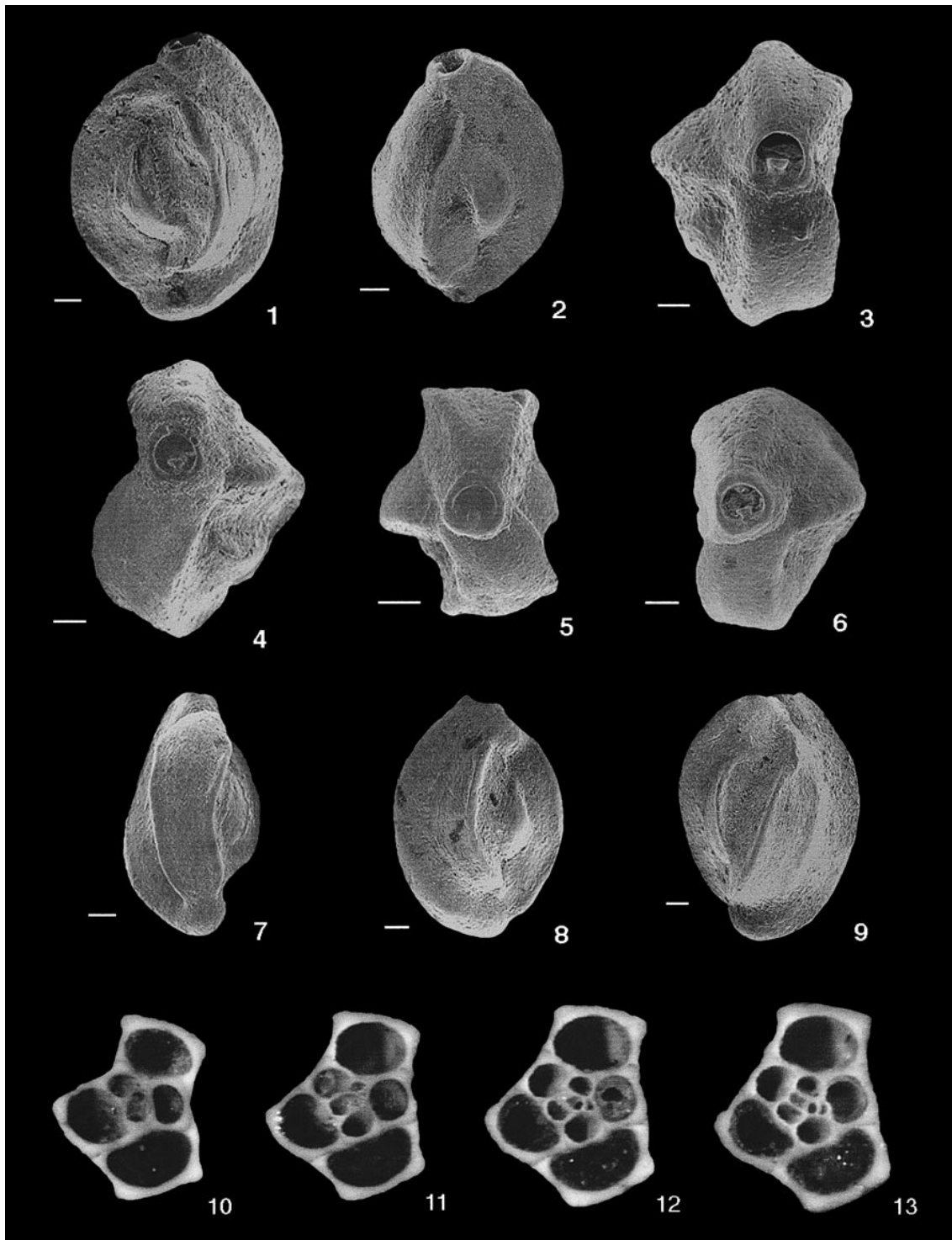
PLATE 1

1–13: *Cycloforina hooperi* n. sp. 1–9: SEM pictures; scale bar is 100 μm. 1, 4. Holotype (USNM 497808), Dixon Entrance, Core END 90A-03, 12–14 cm. 1: Side view. 4: Apertural view. 2, 5. Paratype from Dixon Entrance (USNM 497809), Core END 90A-03, 12–14 cm. 2. Side view showing aperture. 5. Apertural view. 3. Apertural view of paratype (USNM 497810) from Dixon Entrance, Core END 90A-03, 12–14 cm. Ridges less sharp, aperture slightly oblate. 6. Apertural view of less angular paratype (USNM 497811) from the Gulf of Alaska ("Alaska 62" grab sample), water depth: 102 m. 7. Edge view of paratype (USNM 497812) from Dixon Entrance, Core END 90A-03, 12–14 cm. 8. Side view of paratype (USNM 497813) from the Gulf of Alaska ("Alaska 62" grab sample). 9. Side view of paratype (USNM 497814) from Dixon Entrance, Core END 90A-03, 12–14 cm. 10–13: Succession of cross-sectional views in reflected light of a paratype (USNM 497815) from Dixon Entrance, Core END 90A-03, 2–4 cm, showing regular quinqueloculine coiling, thickening of chamber walls at their base but absence of chamber floor, and thickening of longitudinal ridges. 10. 6 chambers visible. 11. 8 chambers visible. 12. 10 chambers visible. 13. Equatorial cross-section with 12 chambers visible including the proloculus. Magnification: 50×.
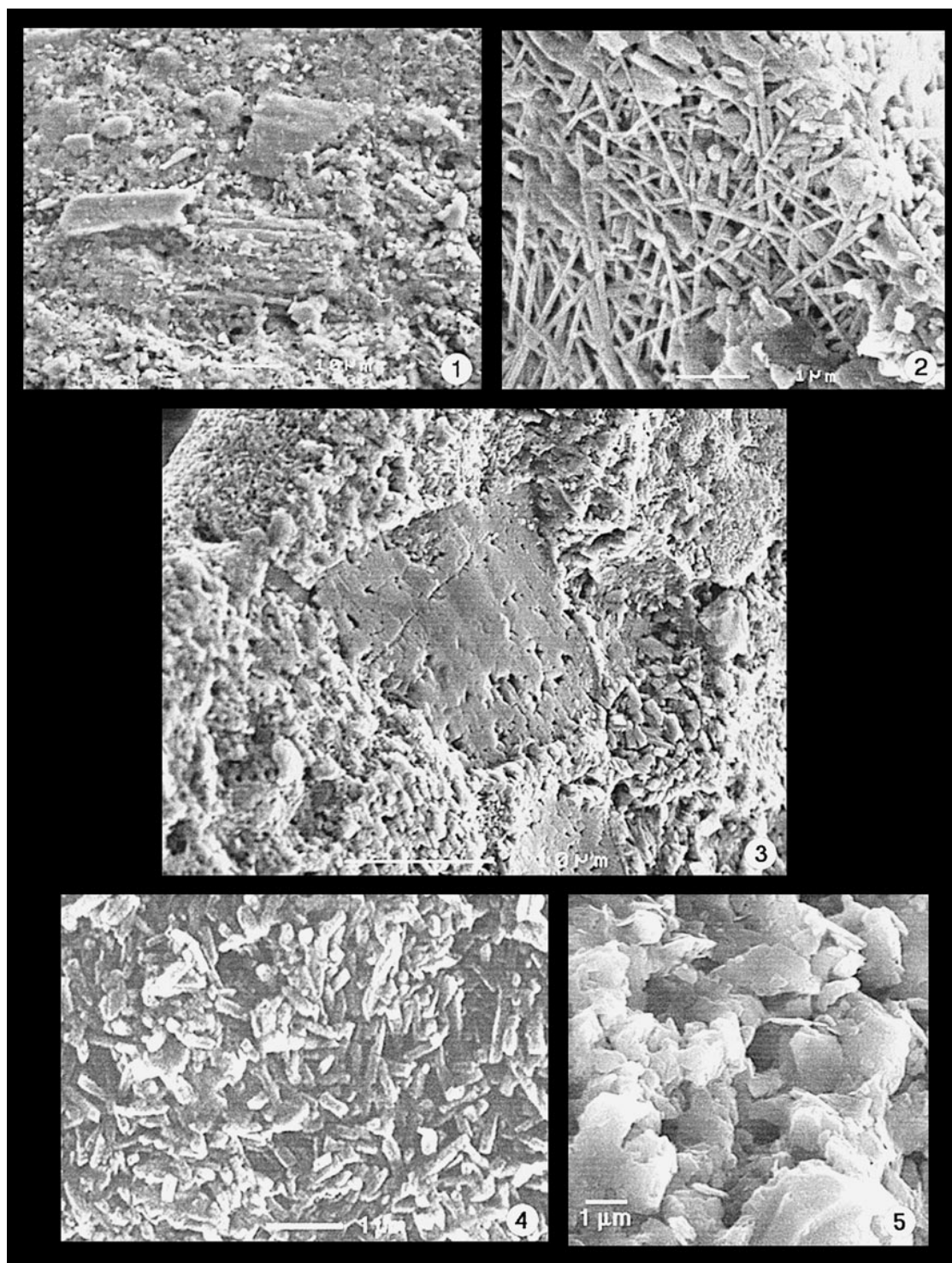
PLATE 2

1–5. *Cycloforina hooperi* n. sp.; high magnification SEM pictures. 1. View of outside of wall showing agglutinated grains. The large striated grain in the middle is the ''parallel-ribbed grain'' in Table 1; it is calcareous and probably biogenic. Some of the grains in this view were examined at very high magnification but none showed the typical lath structure of miliolids. Same specimen as Plate 1, fig. 9. 2. Cross-sectional view through test wall showing the middle layer composed of randomly oriented micron-sized laths and (upper right) part of outer surface, composed of micron-sized subparallel laths. Paratype (USNM 497816) from Dixon Entrance, Core END 90A-03, 2–4 cm. 3. View of cross-section (fracture) through wall of paratype (USNM 497817) from Dixon Entrance, Core END 90A-03, 2–4 cm, showing agglutinated grains with miliolid texture; note the parallel laths on the central grain. 4. View of the apertural rim showing crystals and absence of agglutinated particles. In this view, the outer layer of parallel laths must have been destroyed leaving bare the randomly oriented laths of the middle layer. Same specimen as Plate 1, Fig. 5. Dixon Entrance. 5. View of outside of wall showing fine agglutinated mineral grains, no ''autosomes'' and no calcite laths. Same specimen as Plate 1, Fig. 8. Gulf of Alaska.

Sigmoilopsina with a quinqueloculine chamber arrangement, whereas *Rudoloculina* is a Hauerinina with a cycloforinid geometry and outer agglutination. Even though the description of the subfamily Hauerini-nae (Loeblich and Tappan, 1988) does not specifically mention super-ficial agglutination, we do not think it is necessary to establish a new subfamily. As described in the remarks below, some taxa already in-cluded in the Hauerinina exhibit agglutination.

Rudoloculina hooperi n. sp.
Plate 1, Figures 1–12.
Plate 2, Figures 1–5.

Quinqueloculina agglutinata Cushman; TODD and LOW, 1967, p. A18, pl. 2, fig. 16 (*non Q. agglutinata* CUSHMAN, 1917, p. 43, pl. 9, fig. 2a-c).
Siphonaperta sp. GUILBAULT and OTHERS, 1997, p. 174, no illus-tration.
Siphonaperta agglutinata (Cushman); PATTERSON and OTHERS, 1998; p. 5, pl. 27, figs. 5–7.

Diagnosis. A species of *Rudoloculina* with chambers showing a quadrate cross-section and angular periphery. Aperture usually com-pletely circular at tip of short neck with a tooth that is bifid (T-shaped) in fully-developed specimens. Wall covered by very fine-grained ag-glutinated matter.

Description. Test free, color white to gray, approximately 1.5 times longer than broad; chamber arrangement regularly quinqueloculine throughout, five chambers visible in the last whorl; chambers one half coil in length, added against the previous whorl, quadrate in cross-section, angles forming sharp, at times thickened, longitudinal ridges; no separate chamber floor is visible in cross-section even in the adult stage, although there is a broad widening of the base of the wall at the contact with the previous whorl. Wall imperforate, of porcelaneous low-magnesian calcite, consisting of three layers: outer surface com-posed of micron-sized subparallel laths; middle layer composed of ran-domly oriented micron-sized laths; inner layer smooth, comprised of parallel laths. Larger, rounded to angular grains (rarely up to a few tens of μm) of adventitious material embedded in wall give test a slightly roughened appearance. Most grains are of unknown origin but some look like shell fragments and some are of probable miliolid or-igin, as they are composed of subparallel laths. Area around the ap-erture smooth with only occasional agglutinated grains. Aperture usu-ally circular, situated at tip of short neck (produced end of final cham-ber); when neck is very short, aperture may be oblate on side that rests against the previous whorl. Apertural tooth bifid in larger specimens, having shape of horizontal plate supported by pillar (T-shaped); tooth in smaller (juvenile) specimens simple and rectangular.

Etymology. In honor of Professor Kenneth Hooper, the first micro-paleontologist in the Department of Earth Sciences at Carleton Uni-versity.

Dimensions. Maximum length: 1,200 μm; maximum width 850 μm.

Material. Twenty-three specimens, including two specimens that were deliberately broken to show the interior.

Types and occurrence. The figured holotype, figured paratypes, and unfigured paratypes are deposited in the United States National Mu-seum, Washington, DC. The holotype (USNM 497808), plate 1, figs. 1 and 4, comes from 12–14 cm depth in piston core END 90A-03. The figured paratypes came from Core END 90A-03, samples 2–4 cm and 12–14 cm and from the "Alaska 62" grab sample. In all cases, *R. hooperi* was observed in sandy sediment very rich in foraminifera and shell material.

Remarks. *Rudoloculina hooperi* most closely resembles *Quinquel-oculina parvaggluta* Vella from the Holocene of Cook Strait, New Zealand and *Quinqueloculina subagglutinata* Asano from the Neogene of southwestern Hokkaido Island, northern Japan. According to Hugh Grenfell, Auckland Museum (1997, personal communication), the fine granulate nature of the wall of *Q. parvaggluta* is visible from magni-fications of 40× upward. This is not very different from what we observe on *R. hooperi*. As the agglutinated grains are approximately the same size in both species the most obvious difference between the taxa is that the ridges are more sharply angular on *R. hooperi*. Loeblich and Tappan (1994) illustrated *Q. parvaggluta* specimens from the Sa-hul Shelf (Timor Sea) that differ from our material and from Vella's (1957) in having more slender chambers; the same remark can be made of *Quinqueloculina pittensis* Albani (1974) from the Recent of New

South Wales, Australia. Both of these forms definitely belong to a different species than *R. hooperi*. *Q. subagglutinata* has quadrangular chambers but they are more slender than in *R. hooperi* and the agglu-tinated grains are much coarser, being described as "sand grains" by Asano (1936). With some taxa the coarseness of agglutination may be of questionable systematic importance. However, *R. hooperi* is always finely agglutinated despite the ample availability of all sizes of suitable agglutinating material in the sediment where we found it. We can there-fore only conclude that this species exercises selectivity in building its test.

Based on its outer morphology, *Rudoloculina hooperi* resembles representatives of the genus *Cycloforina* whose chambers have a quad-rate cross-section. In particular, it is similar to *Cycloforina contorta* (d'Orbigny) from the Miocene of the Vienna Basin; also, it is close to *Cycloforina bicostata* (d'Orbigny), *Cycloforina bidentata* (d'Orbigny), and *Cycloforina polygona* (d'Orbigny), all from Cuba. However, *R. hooperi* differs from all four d'Orbigny species in being agglutinated. *Cycloforina contorta* contains no agglutination at all, as can be seen in the SEM reillustration of d'Orbigny's material by Papp and Schmid (1985). *C. bicostata* is described by d'Orbigny (1839) as very smooth and polished. *C. bidentata* is rough in appearance but the type descrip-tion does not mention any agglutination. *C. polygona* is smooth and in addition is much too elongated to be confused with *R. hooperi*. Note that chambers in *C. polygona* and *C. bicostata* are described by d'Orbigny (1839) as having a "furrow" between the ridges (i.e., the space between ridges is depressed). *R. hooperi* does not show this character; however, the illustration of *C. bicostata* by Phleger and Parker (1951) and of *C. polygona* by Brooks (1973) do not show it either, and it may be of limited help.

Of the numerous miliolids illustrated by Haig (1988), only *Quin-queloculina* cf. *Q. rugosa* has an outline in apertural view that closely resembles *R. hooperi*. The projecting neck and the seemingly double tooth set it definitely apart from our species. Since no description is given, it is impossible to know whether *Q.* cf. *rugosa* is agglutinated or just rough-surfaced.

Another similar species is *Quinqueloculina agglutinans* d'Orbigny. That agglutinated species has an overall shape and chamber morphol-ogy similar to that of *R. hooperi* but its aperture shows internal cren-ulation instead of the normal quinqueloculinid tooth. *Quinqueloculi-na*(?) *fanda* reported by McCulloch (1977) from Antarctic waters dif-fers from *R. hooperi* in that it is more coarsely agglutinated and it has no apertural tooth.

Rudoloculina hooperi has been reported as *Quinqueloculina agglu-tinata* Cushman (1917) by Todd and Low (1967). *Q. agglutinata* was described initially from the North Pacific Ocean, off Alaska, in the same general area as *R. hooperi*. We examined the type specimen of *Q. agglutinata* and found that it differed from *R. hooperi* in many ways. Although parts of the wall of *Q. agglutinata* are smooth and shiny, a sprinkling of large grains occur over the whole test which is tan in color. Also, the chambers of *Q. agglutinata*, in apertural view, have a triangular outline, their sides seeming to radiate from the axial region of the test. As a consequence, each chamber is considerably expanded in its median part. By contrast, the chambers of *R. hooperi* are rectangular with subparallel sides, resulting in chambers that are only slightly enlarged in their middle part. The aperture in *Q. agglu-tinata* is relatively smaller than in *R. hooperi*, projects further upward and its tooth is halfway between a rectangular plate and a rounded flap. We found the type illustration of *Q. agglutinata* to conform closely to the details of the holotype and believe that reillustration is not neces-sary.

The name *Quinqueloculina agglutinata* has also been used by many authors worldwide to designate forms different both from the present species and from the type *Q. agglutinata*. Loeblich and Tappan (1953) were among the early users of that name for cold water species. Sub-sequently, the name was used to describe agglutinated miliolids from either cold waters or glacial marine deposits. Although probably all the same species, these forms are distinct from *R. hooperi* and also from *Q. agglutinata*.

Guilbault and others (1997) considered *R. hooperi* as "temperate" on the grounds that it was not reported north of the southern Bering Sea. Species mentioned above that resemble *R. hooperi* (quadrate-chambered cycloforinids) are all from warm temperate to tropical wa-ters or from deposits believed to have formed in similarly warm waters: the Miocene of both the Vienna Basin (d'Orbigny, 1846; Papp and

TABLE 1. Results of X-ray analysis.

Speci-men	Surface analyzed	Mg/Ca	Other elements (not quantitative)
1	*Rudoloculina hooperi,* section in wall	0.0030	
1	*R. hooperi,* surface at 45° angle	0.0020	
1	*R. hooperi,* surface showing dissolution, 90°	0.0051	
1	*R. hooperi,* smooth surface	0.0095	
2	*R. hooperi,* smooth grain	0.0014	
2	*R. hooperi,* parallel-ribbed grain (see Plate 2, fig. 1)	0.0003	
2	*R. hooperi,* small grain	—	Si, K, Ca, Al, Fe
2	*R. hooperi,* irregular grain inside aperture	—	Si, Al, K, Fe
2	*R. hooperi,* small grain near aperture	—	Si, Al, K, Fe
3	*Pyrgo lucernula* (surface)	0.0053	
4	*Quinqueloculina akneriana* (surface)	0.0106	
5	*P. lucernula* (surface)	0.0058	
6	*Quinqueloculina* sp. (surface)	0.0107	
7	*P. lucernula* (surface)	0.0041	
8	*P. lucernula* (surface)	0.0037	

Origin of specimens: 1, 7, 8—Alaska 62 sample (Gulf of Alaska). 2, 5, 6—Core END 90A-03, 12–14 cm (Dixon Entrance). Specimen 2 is the same as Fig. 9, Plate 1. 3, 4—Core END 90A-03, 2–4 cm (Dixon Entrance).

Schmid, 1985) and the Polish Carpathians (Luczkowska, 1972), the Neogene of Japan (Asano, 1936), the modern Cook Strait in New Zealand (Vella, 1957), the Timor Sea (Loeblich and Tappan, 1994), the Gulf of Mexico (Phleger and Parker, 1951), Cuba (d'Orbigny, 1839), and Puerto Rico (Brooks, 1973). *Quinqueloculina*(?) *fanda* McCulloch from the Antarctic differs considerably from *R. hooperi* and we think should not be included in this list. *R. hooperi*, despite its superficial resemblance to cycloforinids, may be particularly adapted to cool waters. However, the species could also be a warm water species near the northern limit of its range in the Gulf of Alaska. Further research is required to more precisely delineate its range.

Quadrate-chambered cycloforinids have seldom been reported from the west coast of North America. Apart from *R. hooperi*, Todd and Low (1967, pl. 2, fig. 28) illustrate, from the same area as *R. hooperi*, a non-agglutinated, quadrate-chambered cycloforinid under the name of *Quinqueloculina arctica* Cushman. Contrary to their specimen, chambers in *Q. arctica*, a true quinqueloculinid, have one major, median, longitudinal ridge and one or two lateral ridges; Todd and Low's specimen seems close to *Cycloforina bidentata* instead. The presence of quadrate-chambered cycloforinids is attested also by Lankford and Phleger (1973) who report and illustrate *Quinqueloculina angulostriata* and *Quinqueloculina elongata*, the first from San Diego to southern Baja California and the second, as far north as northernmost California. Douglas and others (1980) report the same two species from the southern California borderland. Furthermore, McGlasson (1959) reports *Q. bidentata*, without illustration, from around Santa Catalina Island, off southern California. This apparent scarcity may be due as much to the lack of attention given by authors who tend to lump quinqueloculinids as to natural, environmental causes.

Some of the agglutinated grains were tested with X-ray spectrometry and found to contain mostly calcium with a Mg/Ca ratio of 0.01 or less (Table 1). This was the case for the grains that appeared to be of biologic origin and in particular for those showing miliolid laths. The same composition was found when X-rays were directed at the middle layer of the wall, in an exposed fracture. Some finer irregularly-shaped grains had a composition (Si, Al, K, Fe, plus in one case Ca) suggestive of silicates. We made our measurements on three specimens and found no miliolid-type grains on the first two, but an abundance of them on the third. The results of Table 1 pertain to those measured specimens without miliolid grains, where we tested 8 grains plus a wall fracture. For the third specimen we did not obtain quantitative values but the observed spectrum indicated an extremely low Mg content for the miliolid grains.

The low Mg content of all tested high-Ca grains is difficult to explain. If the foraminifer collected any kind of calcareous fragment on the seafloor to cover its test, some grains with a higher Mg/Ca ratio might be expected. The specimens reported here come from shell- and foraminifer-rich sediments and it therefore would be easy for individuals to collect shell fragments. However, specifically collecting miliolid fragments would be difficult because miliolids are few in these *Islandiella*-dominated assemblages. We tested a few specimens of *Quinqueloculina akneriana* and *Pyrgo lucernula* from the same samples (Table 1) and found them to have Mg/Ca ratios in the same range as the agglutinated fragments on *R. hooperi*.

Several hypotheses possibly explain the observed results (Plate 2, fig. 3): 1) the agglutinated miliolid-type grains might have been generated by the individual itself. This hypothesis explains the observed uniformity in miliolid grain composition. However, these grains show a subparallel lath arrangement that can appear only in a thin superficial organic layer in miliolids (Debenay, personal communication, 1997 and Debenay and others, 1998) and thus could not have been generated within the protoplasm as, for example, autosomes in the genus *Carterina* Brady; 2) agglutinated fragments might be detached from earlier chambers of the same individual or resulted from irregular chamber growth. However, such mechanisms have never been reported and nothing in these analyses provide confirmation that they exist; 3) the miliolid fragments were selectively collected from the seafloor. Even though collecting so many grains must represent a considerable expenditure of energy for these foraminifer this hypothesis is best supported by the existing data.

ACKNOWLEDGMENTS

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