BENTHIC FORAMINIFERAL DISTRIBUTION AT MIDDLE VALLEY, JUAN DE FUCA RIDGE: A NORTHEAST PACIFIC HYDROTHERMAL VENTING SITE

by

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A thesis submitted to
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Thesis Supervisor

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ABSTRACT

Since the discovery of life around hydrothermal vents at mid-ocean ridges, numerous organisms that exist nowhere else in the deep sea have been described. Benthic foraminifera from 19 surface samples collected from the Area of Active Venting (AAV) in Middle Valley, located at the northern end of Juan de Fuca Ridge, were examined and resulted in the identification of 159 taxa. Temperatures up to 274°C have been measured at major vent sites. Sample sites were selected near active or recently active vents. The sea floor beyond the mounds is characterized by unaltered soft hemipelagic mud and dominated by a calcareous foraminiferal assemblage. Within the AAV, there is increased dominance in agglutinated foraminifera, associated with proximity to hydrothermal activity. Areas in close proximity to active vent sites are colonized by a dense network of attached agglutinated foraminifera, which find the indurated sediment a suitable substrate. Two new species of agglutinated foraminifera, *Ropostrum amuletum* n. sp. and *Ropostrum kradeopsis* n. sp., are described from indurated sediments from an inactive vent in the northern AAV. Where clam beds are found in association with active hydrogen sulphide venting, benthic foraminifera occur rarely. This site consists of loose pyritic mud and is toxic to all but species (e.g. the clam *Calyptogena*) that co-exist symbiotically with sulphur-oxidizing bacteria.

The rare occurrence of calcareous benthic foraminifera in the vent area is the caused by increased carbonate dissolution caused by pH values of 5.2. Low foraminiferal abundance and species diversity directly at the site of active venting is the result of rapid environmental changes due to changing physical and chemical conditions controlled by hydrothermal vent waters.

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CHAPTER 1. INTRODUCTION

1.1 PURPOSE OF STUDY

Middle Valley is located at the northern end of the Juan de Fuca Ridge (northeast Pacific Ocean), approximately 200 km off the coast of Vancouver Island (Figure 1). The Area of Active Venting (AAV) in Middle Valley is characterized by exceptionally high heat flow and associated hydrothermal venting. In 1991, this site was selected as a target for Leg 139 of the Ocean Drilling Program. Middle Valley is the subject of an on-going joint study by Canadian and U.S. scientists to evaluate the processes and products of hydrothermal venting in the sediment covered rift valley (Davis *et al.*, 1987; Embley *et al.*, 1992).

Environmental conditions resulting from the processes of hydrothermal venting create a unique ecosystem for benthic organisms. This study describes the benthic foraminiferal fauna from samples collected around the hydrothermal vents and demonstrates the relationship between foraminiferal distribution and proximity to active hydrothermal vents.

1.2 GEOLOGICAL SETTING

The Juan de Fuca Ridge is one of a set of long spreading ridges in the northeast Pacific. It is a "medium-rate" spreading zone separating at 6 cm/yr (Davis *et al.*, 1987). Other important connected ridges are Gorda Ridge to the south and Explorer Ridge to the north. These ridges are located between the San Andreas and Queen Charlotte Fault systems. The Juan de Fuca Ridge is bounded by the Sovanco and the Blanco transform faults (Figure 1).

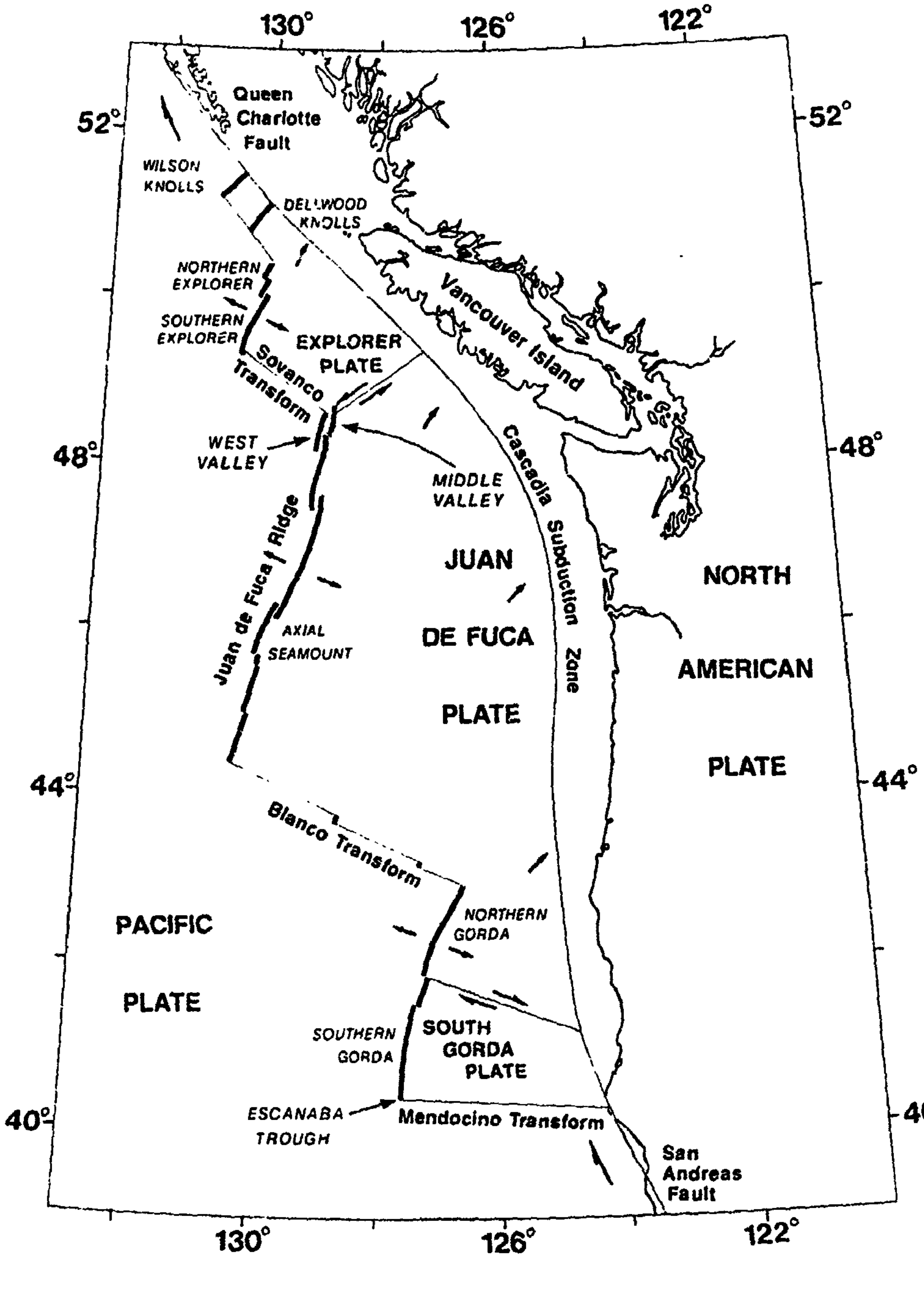

Figure 1. Location map showing the tectonic setting of the northern Juan de Fuca ridge and the sedimented Middle Valley rift. Arrows indicate plate movement. (Figure provided by D. E. Ames, Geological Survey of Canada).

West of the Juan de Fuca Ridge, the Pacific Plate is gradually moving northwestward (roughly parallel to the continental margin along the Queen Charlotte Islands), while east of the ridge, the Juan de Fuca Plate is moving northeastward toward the North American coast. As this plate approaches Vancouver Island and the states of Washington and Oregon, it is subducted beneath the North American Plate. The late Eocene marked the onset of Juan de Fuca plate subduction beneath the North American plate (Davis and Currie, 1993).

Middle Valley has a maximum crustal age of 100,000 years. Increased hydrothermal activity produced large massive sulphide deposits between 100,000 and 70,000 years ago. Sulphide deposition ceased at 70,000 years and rifting shifted to West Valley which is the present site of spreading. Middle Valley is therefore a failed rift lying parallel to and east of the Endeavour segment of the Juan de Fuca Ridge (Davis *et al.*, 1987).

Middle Valley is a very deep, heavily sedimented rift valley approximately 15 km wide by 50 km long, where local topographic relief ranges up to 500 m. Interbedded hemipelagic and turbidite sediments, derived from the adjacent continent over the past 100,000 years, fill the valley (Davis et al., 1987). Sediment thickness varies from 100 m at the margins to 1500 m in the centre (Goodfellow and Blaise, 1988). The deposits result from extremely high sedimentation rates, estimated at 190 cm/1000 years (Davis *et al.*, 1992, p. 304; Brunner, 1993).

Heat flow measurements in Middle Valley established that temperatures at the base of the sediments are generally high, in places exceeding 300°C (Davis *et al.*, 1987). Several large sulphide mounds, some of which project through the sediment surface, appear to represent extensive accumulations of subsurface sulphides above intrusive bodies and are spatially associated with present-day areas of high heat flow. The thick accumulations of sediment filling the valley thermally insulate the underlying young oceanic crust and reduce the conductive heat loss (Davis *et al.*, 1987). High sedimentation rates may have played a role in protecting sulphides from the oxidative effects of seawater.

In Middle Valley, the AAV is located at approximately 48°27.5'N and 128°42.5'W (Figure 1) at a mean depth of 2420 m. It is an elevated plateau 700 m long and 250 m across (Figure 2). The surrounding seafloor is flat and is at 2430 m below sea level.

Seismic reflections show altered, indurated sediments and intrusions within the thick turbidite layers (see fig. 6 of Davis and Currie, 1993). There are three main zones of hydrothermal activity in Middle Valley, including the AAV which has at least 25 active vent sites (Embley and Franklin, 1993) (Figure 2). Each site is composed of a distinctive mound between 3 and 18 m high and topped by a prominent anhydrite chimney. The active chimneys are 0.6 to 9.0 m high and composed of anhydrite, bitumen and minor pyrite (Embley and Franklin, 1993). The mounds are surrounded and underlain by an apron of highly indurated sediment. Uplifted slabs of baritic indurated sediment and anhydrite talus form the slopes of the mounds that grade into bioturbated mud flats. The slopes and aprons commonly contain warm springs inhabited by tube-worms, clams, and bacterial mats. Small baritic chimneys also form here (Embley and Franklin, 1993).

Submersible investigations, bottom photography and towed video traverses of the mounds (Jonasson *et al.*, 1993) has shown much of the muddy surface to be relatively featureless. However, outcrops of both

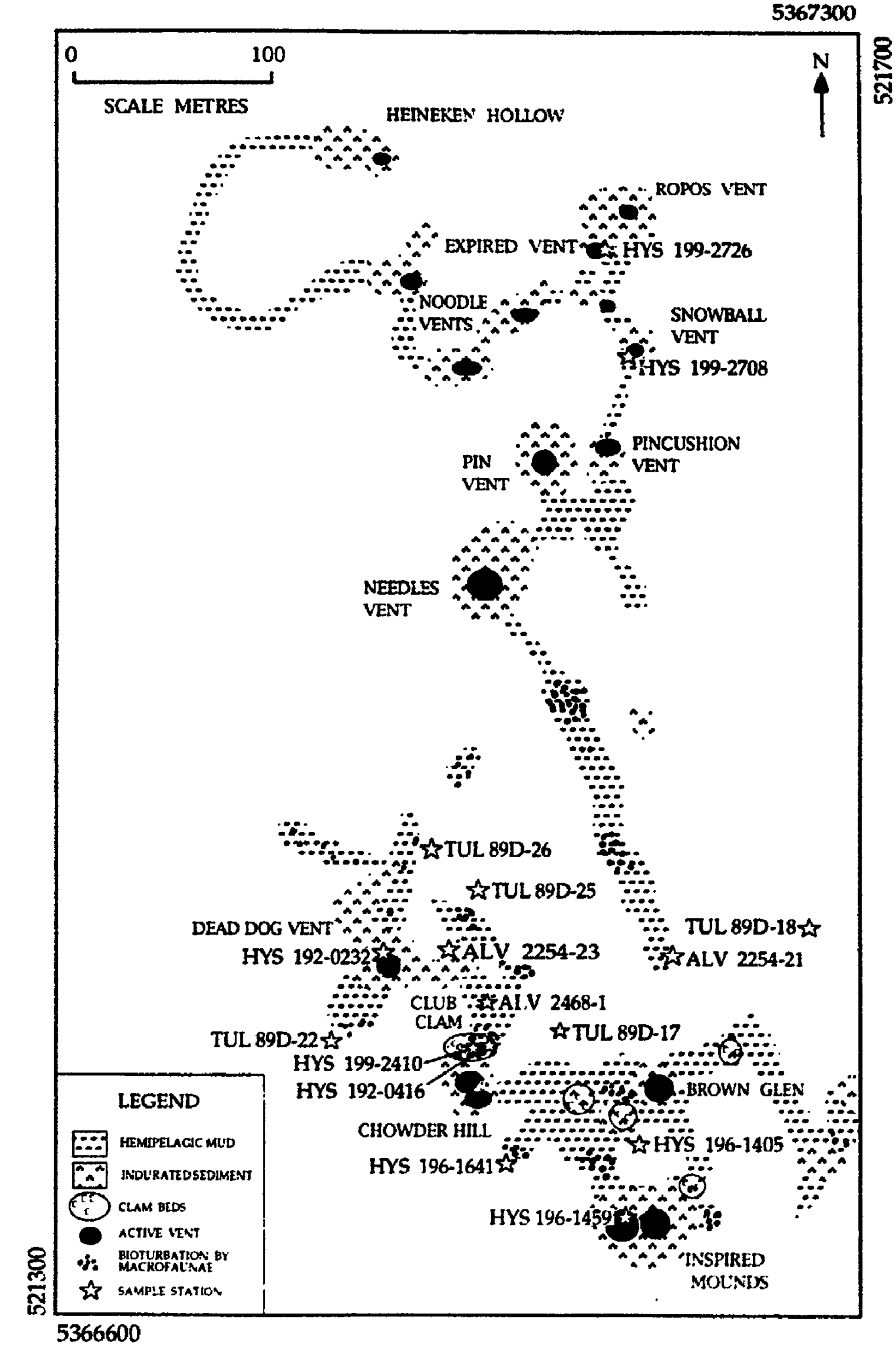

Figure 2. Observations from submersible traverses showing sample locations in the Area of Active Venting, Middle Valley. (Base figure provided by I.R. Jonasson, GSC).

massive blocks and layered indurated or semi-indurated material were observed near vents and, on subsequent visits to the AAV, were carefully mapped (Embley *et al.*, 1992). Video records of the sample sites of this present study are available from the ROPOS dive series of 1992 (Jonasson *et al.*, 1993).

1.3 VENT FLUIDS

The effects of vent fluids on foraminifera is not well known. At Middle Valley, the maximum temperature of hydrothermal fluid emitted from vents was measured at 274°C (Goodfellow and Blaise, 1988), while ambient seawater is 1.7°C. Modern venting consists of metasomatic fluids formed in the sedimentary sequence about 500 m below sea floor and is not presently forming massive sulphides, although these are being reworked. Metasomatic fluids are related to alteration resulting from emplacement of sills (J.M. Franklin, personal communication, 1992). These fluids circulate through the sediments rather than through the basaltic intrusions, and destroy the sulphide deposits. Vent fluids are rich in Ca, have low salinity, and are low in base and ferrous metals. Moreover, they are gas-enriched with hydrogen sulphide, carbon dioxide and methane, which when oxidized, produce sulphuric acid, generate the low pH values (about 5.2) and promote the dissolution of carbonate sediment (Tunnicliffe, 1991).

CHAPTER 2. PREVIOUS WORK

The deep sea foraminiferal faunas of the northeastern Pacific Ocean are not well known. The work of Brady (1881, 1884) aboard H.M.S. Challenger in the western Pacific was the first major study of Recent deep-sea benthic foraminifera. Cushman (1910, 1911, 1913, 1914, 1915, and 1917), Enbysk (1960), Smith (1973), Hessler and Jumars (1973), Saidova (1975), and Burbidge (1992) conducted foraminiferal studies using materials from the North Pacific Ocean. Bernstein *et al.* (1978) identified agglutinated foraminifera to the generic level in a study of sediments in the central North Pacific which were later illustrated and identified at the species level by Schröder *et al.* (1988). Schröder *et al.* (1988) noted the extreme abundance and diversity of foraminiferal faunas found in the deep sea. Schröder (1986) also examined benthic foraminifera from the North Atlantic, the Bermuda Rise and the Nares Abyssal Plain, providing evidence of the cosmopolitan distribution of many deep-sea agglutinated foraminiferal taxa.

To date, little work has been published on the benthic foraminiferal communities at hydrothermal settings such as Middle Valley. Clague *et al.* (1984) found that agglutinated foraminiferal species dominated most of the dredge samples from the northern part of Gorda Ridge (Escanaba Trough). Nienstedt and Arnold (1988) examined surface samples from seamounts near the East Pacific Rise (Galapagos Rift) and reported a predominantly agglutinated fauna in two samples. Van Dover *et al.* (1988) examined hard substrates placed around hydrothermal vents in the Galapagos Rift and the East Pacific Rise and found that two species of calcareous foraminifers were the most abundant organisms colonizing the site after about three years. Based on this evidence, they suggest that foraminifers may be significant components of the vent community. Molina-Cruz and Ayala-Lopez (1988) distinguished two foraminiferal assemblages from five cores collected from the Guaymas Basin in Mexico. One assemblage is distributed near and around active hydrothermal vents and a second assemblage occurs further away from the vents. Both are dominated by calcareous benthic foraminifera. The study found that the hydrothermal vents exert an influence on the geographic distribution of certain species. In the vent area, *Bulimina mexicana* (Cushman, 1926), *Oridorsalis umbonatus* (Reuss, 1851), *Fursenkoina cornuta* (Cushman, 1913), and *F. rotundata* (Parr, 1950) were the dominant assemblage. Selective dissolution of the larger and more fragile specimens (including agglutinated species) occurred in the subbottom sediments. Only the smaller foraminiferal species such as *Bulimina spinosa* (Heron-Allen and Earland, 1932) and *Bolivina* sp. are well-preserved. Lee *et al.* (1991) were unsuccessful in finding evidence of possible endosymbiotic chemolithotrophic bacteria in the protoplasm of a foraminiferal species inhabiting a hydrothermal vent area on the East Pacific Rise. Agglutinated foraminifera, recovered during deep sea drilling (ODP Leg 139) in Middle Valley, were reported in core tops by Brunner (1993). Benthic foraminifera from Escanaba Trough, a sedimented hydrothermally active rift valley similar to Middle Valley, were described by Quinterno (in press).

CHAPTER 3. MATERIALS AND METHODS

Piston core samples used in this study were collected from the AAV in 1989 on the fourth cruise (D) of the Canadian R/V *J.P. Tully*. Additional "pacman" scoop samples were collected in 1991 and 1992 by deep submersibles (viz., DSRV *Alvin* and ROV *Ropos*) during several legs of the NOAA Vents Program (Embley *et al.*, 1992). The locations and water depths for each of the sample stations from this study are listed in Table 1.

(i) Piston Core Samples

Core samples containing interbedded turbidite and hemipelagic and/or hydrothermal sediments were selected from five sites within the AAV (Figure 2). Sediment subsamples for foraminiferal analysis were obtained from the top 0-2 cm of the core for samples TUL 89D-18, 22, and 25. In samples TUL 89D-17 and 26 the 0-2 cm interval was missing and the 3-5 cm interval was sampled instead. These different sample intervals hinder a quantitative approach and allow only a more qualitative comparison between samples.

(ii) Scoop Samples

In the late summer of 1991, a single sample of hydrothermal sediment (ALV 2468-1) was collected by M. D. Hannington of the Geological Survey of Canada using the submersible DSRV *Alvin* during dive 2468. It is located in close proximity to two active vents (Figure 2).

A set of pacman scoop samples was collected using the seven-function manipulator of the HYSUB 5000 ROV *Ropos* in July 1992. The pacman scoop is designed to sample both mud and indurated materials to a depth of 5 cm, with a surface area approximately 20 cm by 20 cm. Eight localities were sampled and include the following sample stations: HYS 192-0232, HYS 192-

0416, HYS 196-1405, HYS 196-1459, HYS 196-1641, HYS 198-2319, HYS 199-2410, and HYS 199-2726 (Figures 2 and 3).

Samples were washed either over a 63µm or 75µm sieve to retain the foraminifera, and residues were dried. The use of two sieve sizes resulted from separate sample preparation by different people. To facilitate identification, foraminifera were picked and transferred to microslides.

(iii) Indurated Sediment Samples

Indurated sediment samples were collected in July 1992 using the seven-function manipulator of the ROV *Ropos* from the following locations: Expired Vent (HYS 199-2726B), Snowball Vent (HYS 199-2708B), and Chowder Hill clam bed (HYS 192-0416B). Previously, Dead Dog Mound (ALV 2254-23) and a barite hydrocarbon chimney site (ALV 2254-21) had been sampled in 1991 using *Alvin*'s manipulator arm (Figure 2).

Due to different sampling equipment and variable sample quality, quantitative analyses of the foraminiferal content were not carried out. Also, the total number of specimens in numerous samples were not sufficient for statistical counts.

Selected specimens were illustrated with the JEOL Digital Analytical Scanning Electron Microscope (JSM-6400) with Energy Dispersive (EDS) X-ray Analyser (Link eXL LZ4) using videoprints and Polaroid NP 55 film. Specimens of the agglutinated taxa identified in the sediments of Middle Valley are figured in plates 1-8. Specimens from the indurated samples, including one new genus with two new species, are figured in plates 12-16.

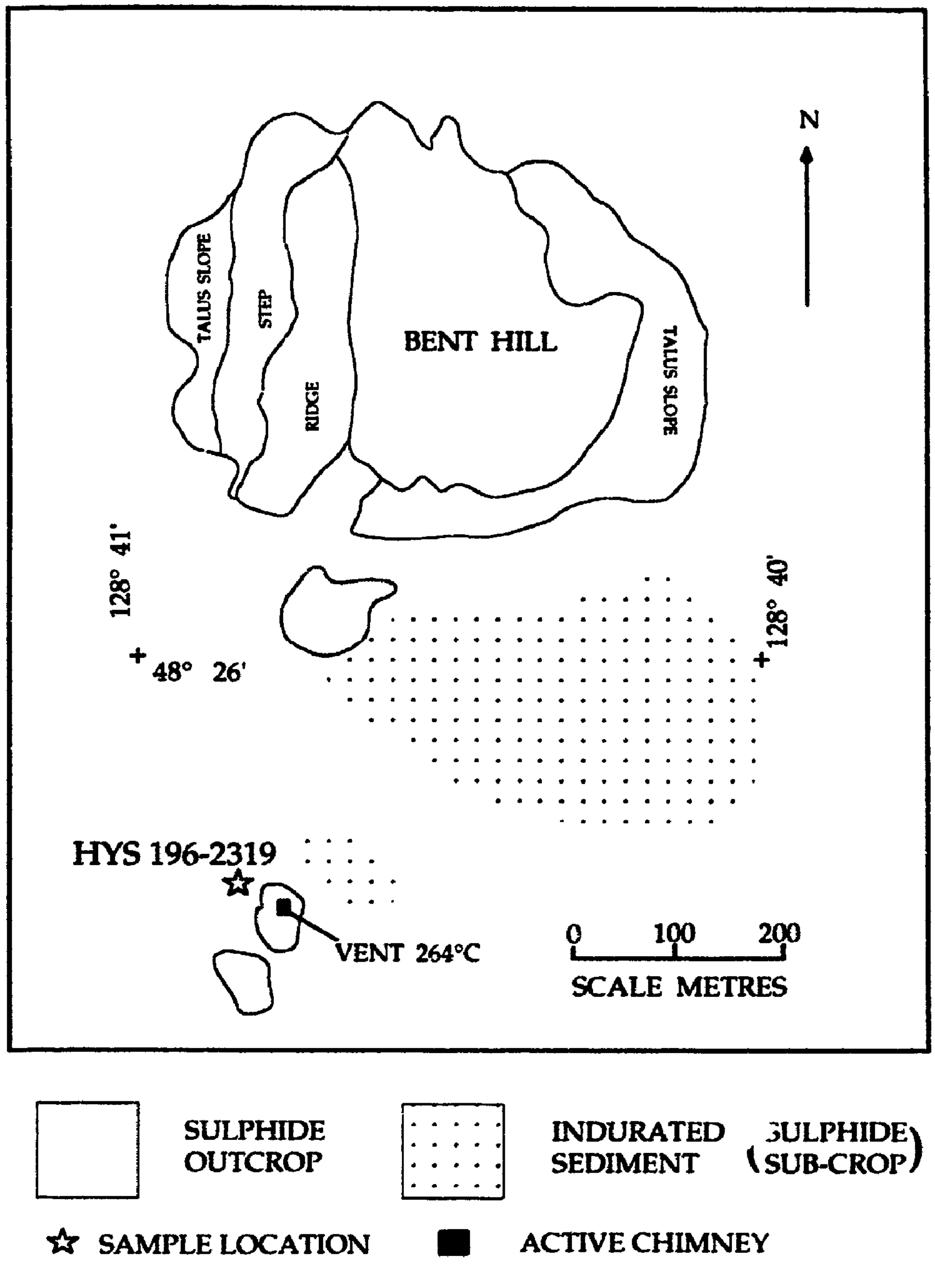

Figure 3. Location of sample HYS 198-2319 near Bent Hill, Middle Valley. (Modified after Ames and others, 1993).

Sample Number	Type	Water Depth (m)	Latitude N	Longitude W	UTM (X)	UTM (Y)
AAV						
TUL 89D-17	piston core	2425	48° 27.383'	128° 42.517'	521546	5366749
TUL 89D-18	piston core	2434	48° 27.400'	128° 42.417'	521673	5366802
TUL 89D-22	piston core	2422	48° 27.367'	128° 42.600'	521433	5366740
TUL 89D-25	piston core	2430	48° 27.417'	128° 42.550'	521512	5366825
TUL 89D-26	piston core	2428	48° 27.433'	128° 42.567'	521491	5366846
ALV 2468-1	scoop	2428	48° 27.383'	128° 42.550'	521514	5366764
ALV 2254-21	indurated muds	2432	48° 27.400'	128° 42.467'	521611	5366789
ALV 2254-23	indurated muds	2427	48° 27.400'	128° 42.567'	521489	5366788
HYS 192-0232	scoop	2417	48° 27.400'	128° 42.583'	521463	5366788
HYS 192-0416	scoop	2415	48° 27.383'	128° 42.550'	521514	5366741
HYS 192-0416B	indurated muds	2415	48° 27.383'	128° 42.550'	521514	5366741
HYS 196-1405	scoop	2417	48° 27.350'	128° 42.650'	521593	5366687
HYS 196-1459	scoop	2415	48° 27.333'	128° 42.483'	521586	5366650
HYS 196-1641	scoop	2419	48° 27.350'	128° 42.533'	521529	5366680
HYS 199-2410	scoop	2416	48° 27.317'	128° 42.550'	521510	5366636
HYS 199-2708B	indurated muds	2411	48° 27.567'	128° 42.483'	521590	5367111
HYS 199-2726	scoop	2412	48° 27.600'	128° 42.500'	521570	5367166
HYS 199-2726B	indurated muds	2412	48° 27.600'	128° 42.500'	521570	5367166
BENT HILL						
HYS 198-2319	scoop	2455	48° 26.050'	128° 40.933'	523513	5364291

Table 1. Locations and water depths of samples in Middle Valley

CHAPTER 4. RESULTS

4.1 Faunal Distribution in Vent Areas

During traverses from normal hemipelagic sediment towards low to high temperature vents, six different environments within the AAV were sampled, including hemipelagic muds, mixed hemipelagic and hydrothermal muds, hydrothermal muds, the base of a chimney (apron breccia), a clam bed, and an active vent. The study of benthic foraminifera in five core tops, nine pacman scoop samples, and five indurated samples collected from the AAV in Middle Valley yielded 159 foraminiferal species, of which 75 taxa are agglutinated and 84 are calcareous. Estimates of species abundance and species diversity of agglutinated and calcareous foraminifera in the samples are given in Table 2. Abundance data of agglutinated and calcareous species in each sample is provided in Tables 3 and 4, respectively, where samples are grouped into their respective environments.

Species diversity of benthic foraminifera in each of the six environments sampled in the AAV is illustrated in Figure 4. Agglutinated foraminifera were found to dominate in the hydrothermal muds, the clam bed, and on the active vent. Calcareous species are most abundant in the hemipelagic muds. Agglutinated and calcareous foraminifera are equally abundant in the mixed hemipelagic and hydrothermal muds and in the apron breccia (Figure 4). Planktic taxa are present in six samples representing hemipelagic mud, mixed hemipelagic and hydrothermal mud, the apron breccia, and the active vent. The distribution of agglutinated species by family in these six environments is illustrated in Figures 6a-f.

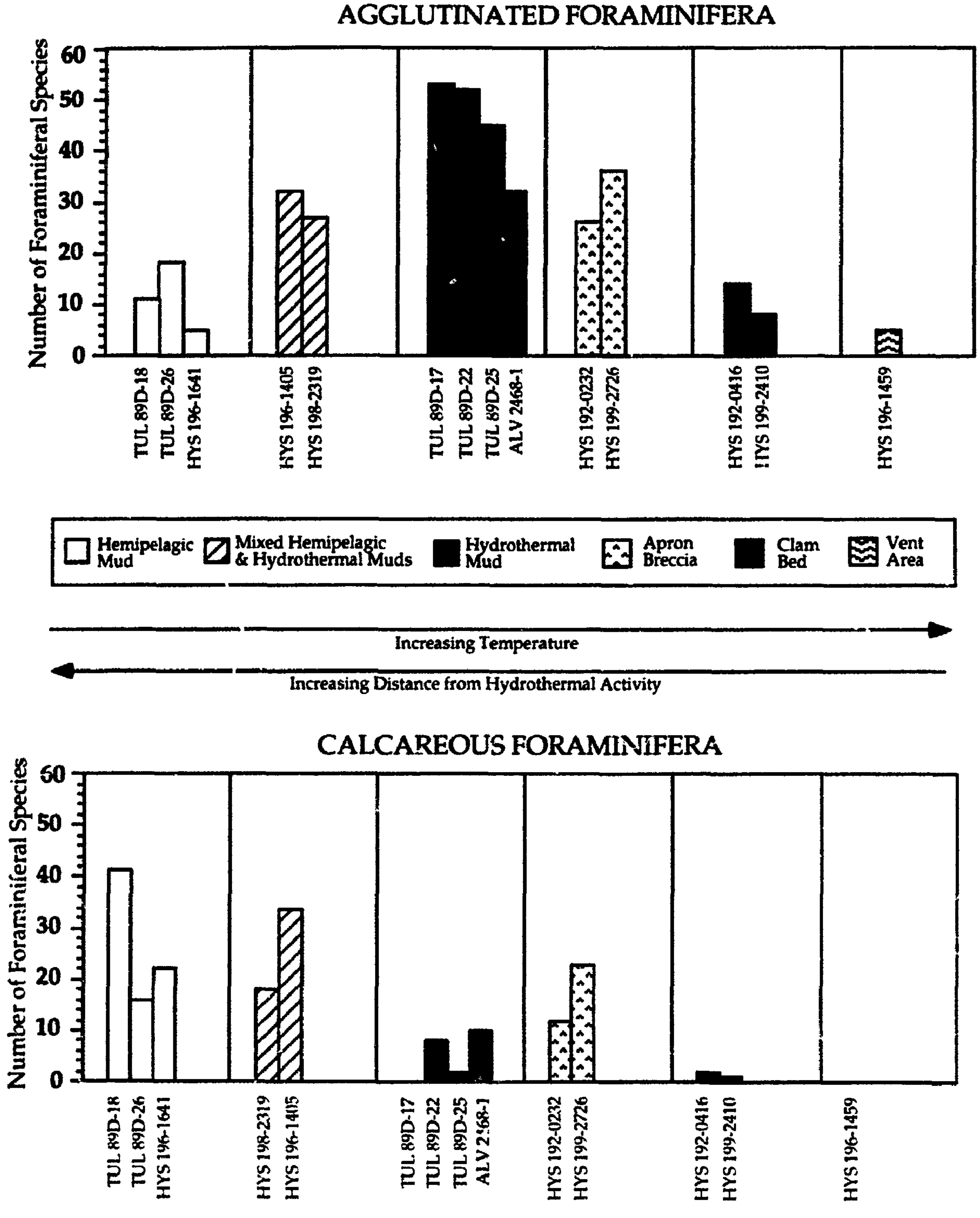

Figure 4. Species diversity of benthic foraminifera in representative samples of six vent environments of the AAV.

4.2 Hemipelagic Mud

Three samples (TUL 89D-18, TUL 89D-26, and HYS 196-1641) were collected in hemipelagic sediment. Each of these sample sites is located more than 50 m from an active vent. The environment is characterized by relatively flat topography, minor bioturbation (small burrows and tracks) and sticky grey mud (Plate 9, figure 1). The samples contained up to 40 calcareous benthic foraminiferal species, whereas agglutinated species form a less dominant component of the assemblage with a maximum of 20 taxa (Figure 4). *Alabaminella weddellensis* (Earland, 1936) is the most abundant calcareous species, accompanied by *Globocassidulina oblonga* (Reuss, 1850), *Islandiella helenae* Feyling-Hanssen and Buzas, 1976, *Paliolatella cucullata* (Silvestri, 1902), *Stainforthia seminuda* (Cushman, 1911), *Triloculina tricarinata* d'Orbigny, 1826 and *Uvigerina senticosa* Cushman, 1927 (Table 4). In the agglutinated assemblage, *Reophax bilocularis* Flint, 1899, *Ammobaculites agglutinans* subsp. *filiformis* Earland, 1934, *Eggerella bradyi* (Cushman, 1911), and *Glomospira gordialis* (Jones and Parker, 1860) are common (Table 3).

The presence of typical shelf foraminifera such as *Lobatula fletcheri* (Galloway and Wissler, 1927), *Quinqueloculina seminulum* (Linné, 1758), *Cribroelphidium foraminosum* (Cushman, 1939), *Islandiella helenae*, *Globobulimina pacifica* Cushman, 1927, *Nonionella*, *Pullenia salisburyi* Stewart and Stewart, 1930, and *Elphidiella hannai* (Cushman and Grant, 1927) in this deep water locality indicates possible transport by turbidites. Brunner (1992) identified turbidite sequences in cores from Middle Valley. Agglutinated species dominate at sites closer to the vents. Planktic foraminifera were abundant, but not identified.

4.3 Mixed Hemipelagic and Hydrothermal Muds

Samples HYS 198-2319 and HYS 196-1405 are composed mainly of weakly altered grey-coloured hemipelagic mud mixed with rubble and talus from nearby mounds. Anhydrite makes up 70% of the samples. Both sample sites are located approximately 40 m from an active hydrothermal vent, and are therefore close to ambient temperatures (~1.7°C). Calcareous and agglutinated foraminifera are present in this environment, in more or less equal numbers (about 40 species each, Figure 4). Dominant agglutinated species include *Bathysiphon rufum* de Folin, 1886, *Hormosina globulifera* Brady, 1879, and *Reophanus ovicula* (Brady, 1879) (Table 3). Large, well preserved specimens of *Bathysiphon rufum* occur in HYS 196-1405. Dominant calcareous species include *Sphaeroidina bulloides* d'Orbigny, 1826 and *Euvigerina peregrina* (Cushman, 1923), with common occurrences of *Globobulimina* spp. and *Uvigerina* spp. (Table 4). Planktic foraminifera are common.

4.4 Hydrothermal Mud

Four samples (TUL 89D-17, TUL 89D-22, TUL 89D-25, and ALV 2468-1) were collected from hydrothermal muds. These muds are characterized by their brownish oxidized colour which is caused by hydrothermal alteration. The hydrothermal mud is strongly bioturbated and shows many large (up to 10 cm) shrimp burrows (Plate 9, figure 2). A diverse agglutinated fauna of 66 species predominates in the hydrothermal environment (Figure 4). Among the most abundant species are *Ammobaculites agglutinans* subspecies *filiformis*, *Bathysiphon rufum*, *Eratidus foliaceus* (Brady, 1881), *Hormosina globulifera*, *Glomospira gordialis*, *Nodellum membranaceum* (Brady, 1879), *Reophax bilocularis* and *Rhizammina algaeformis* Brady, 1879 (Table 3). The fine-grained nature of sample TUL 89D-22 is reflected in numerous species with small tests including fragile species such as *Rhizammina algaeformis* and *Vanhoeffenella gaussi* Rhumbler, 1905. Sample ALV 2468-1 is characterized by large agglutinated species including *Bathysiphon rufum*, *Cribrostomoides subglobosus* (G. O. Sars, 1872), and *Nodellum membranaceum*. Smaller agglutinated species include *Repmanina charoides* (Jones and Parker, 1860) and *Adercotryma glomerata* (Brady, 1878). The calcarecus component of samples TUL 89D-22, TUL 89D-25 and ALV 2468-1 is depauperate, and TUL 89D-17 is barren of calcareous specimens. Only 16 species of calcareous benthic taxa are found in the hydrothermal muds (Table 4). The most common species is *Bulimina* sp., with all other calcareous species being rare. Planktic species were absent.

4.5 Apron Breccia

Samples HYS 192-0232 (from Dead Dog Mound) and HYS 199-2726 (from Expired Vent) were composed of rubble (gravel to cobble-sized particles) from the apron of indurated sediment at the base of the chimney (eg. Plate 11, figure 1) of two different vent sites. Although it was once warm, the present substrate at Expired Vent is cold, as evidenced by the extent of burrowed ground. There are also traces of H_2S in the mud matrix. Expired Vent is presently inactive and probably has been for a few years (I. R. Jonasson, personal communication, 1993). The vent at Dead Dog, however, is still active, with dead tube worms attached to the base of the otherwise barren chimney. Dead Dog Mound is representative of the mound and chimney morphology of active vents in the AAV. Dead Dog is an active vent about 15 m high and culminates in a 14 m pinnacle vent with two small 1 m spires at the base. The vent emits a fluid with a temperature of 274°C (*Alvin* 1990). Overall, temperatures at the Dead Dog site were a few tenths of a degree above ambient. Each sample has a diverse agglutinated fauna (44 species, Table 3) and a calcareous assemblage (30 species, Table 4). Abundant agglutinated species include *Cribrostomoides subglobosus*, *Hormosina globulifera*, *Ammodiscus incertus* (d'Orbigny, 1839), and *Bathysiphon rufum*, as well as many other commonly occurring species (Table 3). The most common calcareous species include *Gyroidina* spp., *Quinqueloculina seminulum* and *Uvigerina senticosa* (Table 4). Planktic foraminifera were present at these sites as well.

4.6 Clam Bed

Two samples were collected from the sulphidic (pyrite) sediments of the clam bed near Chowder Hill (Figure 5), HYS 192-0416 and HYS 199-2410 (Plate 10, figures 1, 2). This environment is enriched in NH_3 and the mud has a strong odour of H_2S. Temperatures measured in the subsurface sediments between 5 and 8 cm depth varied between 2.45 °C and 7.35 °C and showed an increase with depth. The pH of the fluids emanating through these sediments was approximately 5.2. Agglutinated forms dominate but are poorly preserved. Specimens were bleached and many were fragmented. Species diversity increases slightly towards the edge of the clam bed (HYS 192-0416, with 14 taxa) compared to the centre (HYS 199-2410) where only 9 species were found (Figure 4). Agglutinated foraminifera were represented by many rare species and a few commonly occurring species such as *Bathysiphon rufum*, *Hormosina globulifera*, *Cribrostomoides subglobosus*, *Reophanus*

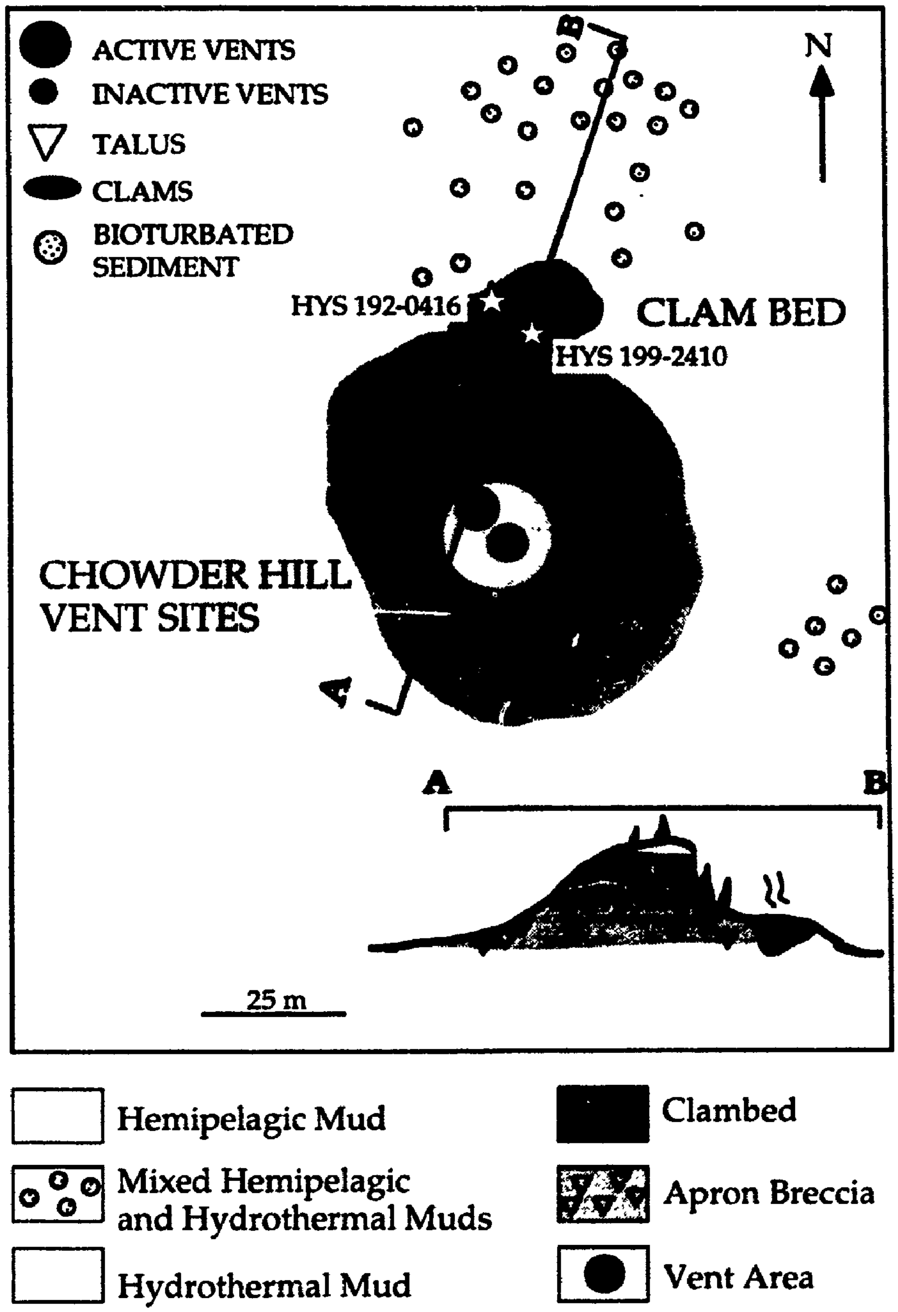

Figure 5. Schematic diagram of the vents and clam bed at Chowder Hill - to scale. (Base figure provided by J. M. Franklin, GSC).

ovicula, and *Rhizammina algaeformis* (Table 3). Due to poor preservation of the three calcareous taxa present, only *Fontbotia wuellerstorfi* (Schwager, 1866) could be identified (Table 4). HYS 199-2410 contained abundant small gastropods and radiolarians. Planktic foraminifera were absent in samples collected in the clam bed.

4.7 Active Vent

Sample HYS 196-1459 was collected from the "palm worm oasis" at Inspired Mounds. The site is a terrace or apron on a low hill about 1-2 m below the top of the mound (Plate 11, figure 2). This site is similar to the clam bed in that shimmering warm sulphidic fluids are venting through the sediments. Palm worms are abundant on the warm hard substrate. Unfortunately, the temperature was not measured at this site. The sample is made up of a loose breccia of indurated sediment and anhydrite. Small marine gastropods are the most abundant organism and ostracods are common. Four species of agglutinated foraminifera are present, including single occurrences of *Hormosina globulifera*, *Trochammina globulosa* Cushman, 1920, and *Ammoglobigerina globigeriniformis* (Parker and Jones, 1865), and two specimens of *Cribrostomoides subglobosus* (Table 3). Calcareous benthic foraminifera were absent. A single specimen of the planktic species *Orbulina universa* was found.

4.8 Distribution of Agglutinated Families

The hemipelagic environment is characterized by generally low species diversity due to the dominance of calcareous taxa (Figure 6a). Diversity increases in the mixed environment, with Rhabdamminidae and

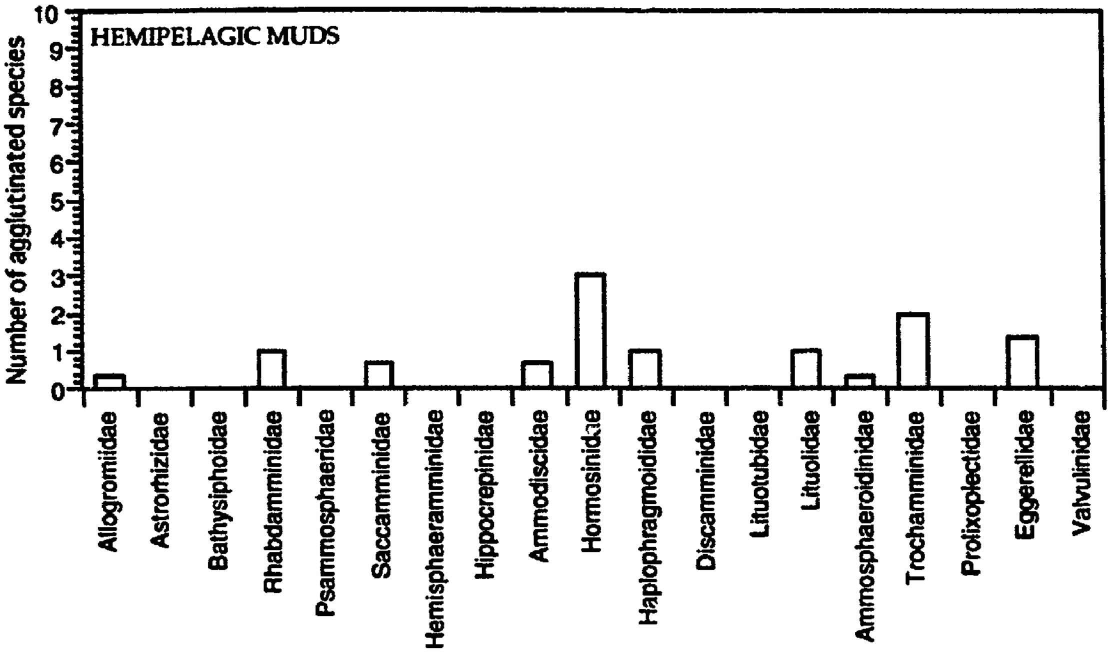

Figure 6a. Average number of agglutinated species in each family found in the hemipelagic muds of the AAV.

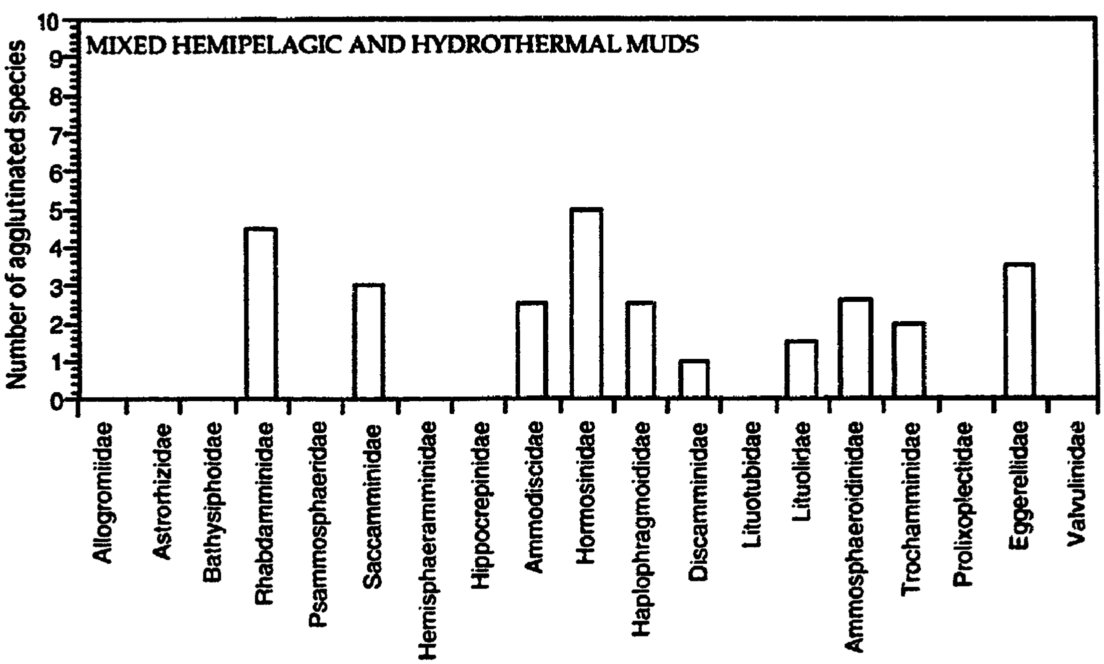

Figure 6b. Average number of agglutinated species in each family found in the mixed hemipelagic and hydrothermal muds in the AAV.

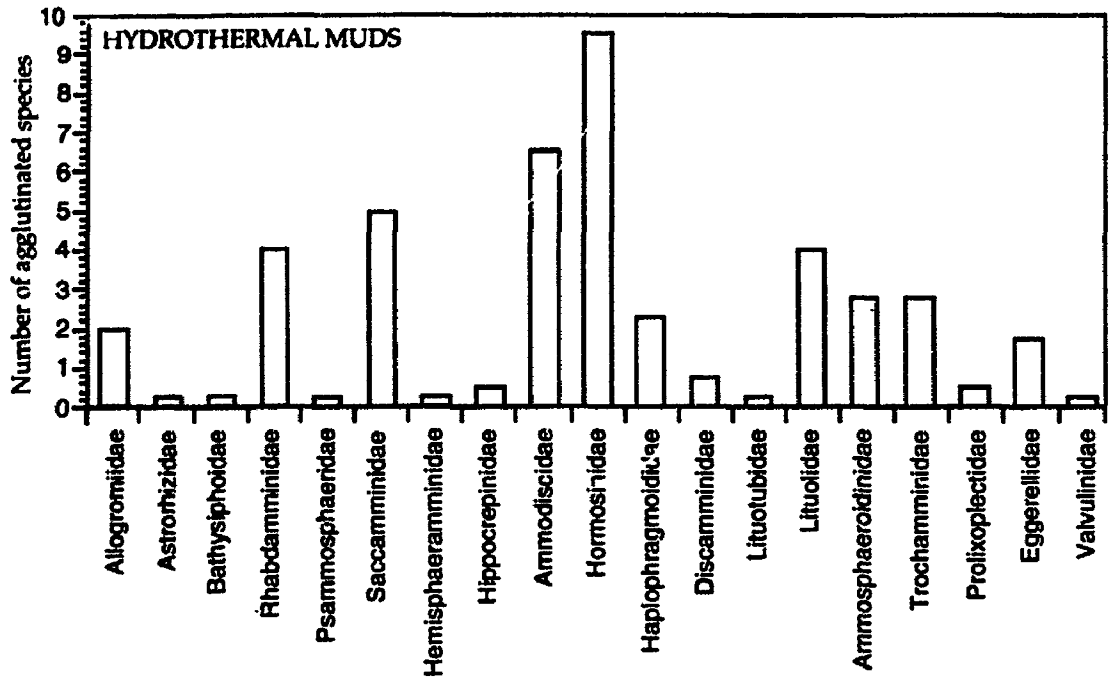

Figure 6c. Average number of agglutinated species found in each family in the hydrothermal muds in the AAV.

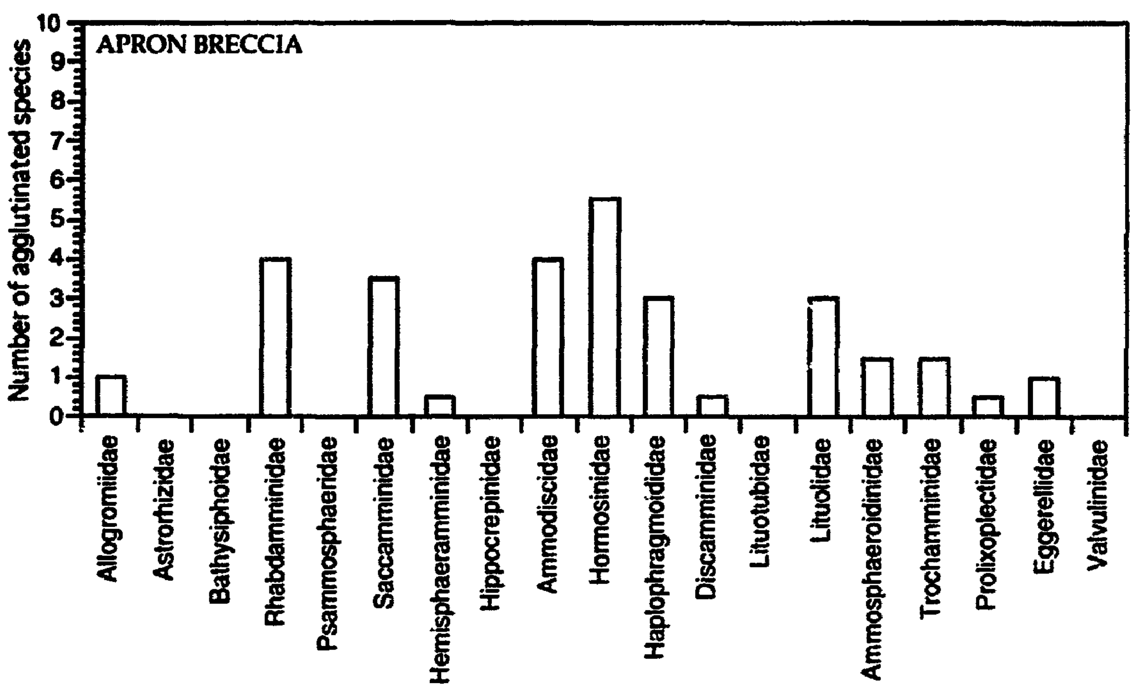

Figure 6d. Average number of agglutinated species found in each family in the apron breccia in the AAV.

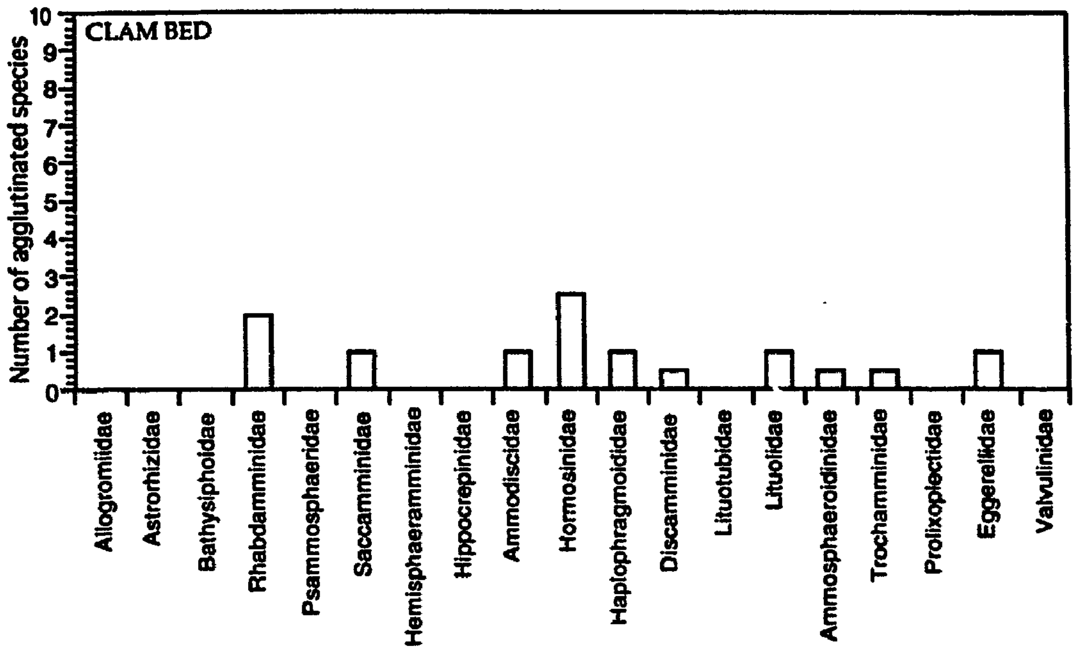

Figure 6e. Average number of agglutinated species in each family found in the Clam Bed in the AAV.

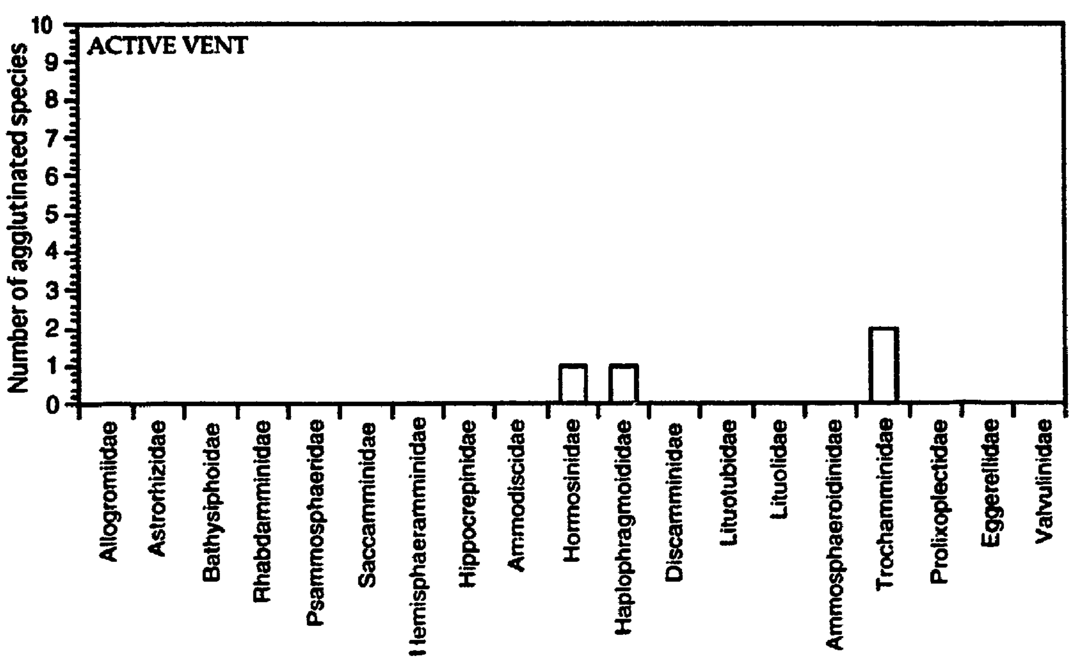

Figure 6f. Average number of agglutinated species found in each family at the active vent site in the AAV.

Hormosinidae dominating (Figure 6b). A further increase in diversity is noted with an increase in the family Ammodiscidae in the hydrothermal muds. As is evidenced by Figure 6c, this is the preferred environment for agglutinated foraminifera. Figures 6d-f show a progressive decrease in diversity with increasing proximity to the active vent site.

4.9 Foraminiferal Associations on Indurated Sediments

Five samples of indurated sediments collected from the AAV were examined for benthic foraminifera. Sample localities include Snowball Vent, Expired Vent, Dead Dog Vent, Chowder Hill's clam bed, and an inactive barite chimney east of Chowder Hill (Figure 2). All samples with the exception of the clam bed sample were colonized by attached foraminifera and less common benthic forms which are also present in the surrounding sediments. The most dominant attached species is *Tolypammina vagans* (Brady) 1879.

Sample HYS 199-2708B was taken from the apron of Snowball Vent (Figure 2) within 1 m of the anhydrite chimney formed by the active vent. Snowball Vent emits a fluid with a temperature of 227°C and the porous substrate around the vent is warm (about 7°C). The anhydrite chimney itself is barren of microorganisms. The sample consists of a piece of well-indurated mudstone measuring 16 x 12 x 3 cm. Attached species such as *Tolypammina vagans* and *Hemisphaerammina* sp. and free tests of *Trochammina globulosa* were observed on the sample. The shelf foraminifer *Patellina corrugata* Williamson, 1858 was the only calcareous benthic species found on this sample. Both species diversity and species abundance are low.

A block of indurated sediment, HYS 199-2726B, measuring 20 x 12 x 8 cm was collected from the collapsed edge of Expired Vent. This inactive vent is located about 20 m south of the main active vent in the northern AAV (Figure 2), and about 40 m north of the hydrothermal activity at Snowball Vent. The Expired Vent sample is characterized by the abundant occurrence of *Patellina corrugata*. Agglutinated species are more diverse compared to the active vent and include *Trochammina globulosa*, *Lana spissa* Schröder, Medioli and Scott, 1989, *Subreophax adunca* (Brady, 1882), *Cribrostomoides subglobosus*, *Lituotuba lituiformis* (Brady, 1879), *Ammomarginulina* sp., *Hemisphaerammina* sp., *Tolypammina vagans*, *Astrorhiza limnicola* Sandahl, 1858, as well as two new species of a new genus of attached agglutinated foraminifera, *Ropostrum amuletum* n. sp. and *Ropostrum kradeopsis* n. sp. Glass sponges were commonly noted (on video tape) in the vicinity of the sample site, and small specimens are found on the indurated block.

Sample ALV 2254-21 is from the flat base of a barite/hydrocarbon chimney, and consists of well-indurated mud with filled worm burrows and dispersed barite crusts. Bitumous hydrocarbon (present as tarry black spheres and veinlets) formed from the pyrolysis of organic remains at high temperatures generated in sediments beneath vent mounds (Simoneit *et al.*, 1992). Foraminifera were scarce with only a few attached specimens of *Subreophax adunca* and *Tolypammina vagans* present.

A sample of the chimney at Dead Dog Vent (ALV 2254-23) was collected near the active vent. The fluid temperature here was measured at 274°C. Free tests of *Karreriella bradyi* (Cushman, 1911) and *Ammoglobigerina globigeriniformis*, and attached specimens of *Tolypammina vagans* were among the agglutinated benthic species observed on the sample.

Sample HYS 192-0416B, collected from the clam bed located on a ledge of the indurated mound at Chowder Hill, was found to be barren of foraminifera. Surface material in the clam bed is characteristically hard altered lumps of bioturbated sediment, consisting of clay and possibly barite, as well as black fibrous to massive anhydrite impregnated with hydrocarbon. The clam bed is colonized by two different species of clams, *Calyptogena* sp. and *Solemya* sp. (Juniper *et al.*, 1992). At the edge of the clam bed other organisms were observed and photographed, including tube worms, crabs, and brittle stars.

Sample Number	Benthic Abundance Agglutinated Foraminifera	Benthic Abundance Calcareous Foraminifera	Benthic Diversity Agglutinated Foraminifera	Benthic Diversity Calcareous Foraminifera	Planktic Taxa
TUL 89D-17	A	o	53	0	absent
TUL 89D-18	R	A	11	44	present
TUL 89D-22	A	R	52	8	absent
TUL 89D-25	A	VR	45	2	absent
TUL 89D-26	C	C	18	16	present
ALV 2468-1	C	R	32	10	absent
HYS 192-0232	R	R	26	13	absent
HYS 192-0416	VR	VR	14	2	absent
HYS 196-1405	C	R	32	20	present
HYS 196-1459	VR	o	4	0	present
HYS 196-1641	VR	C	5	23	absent
HYS 198-2319	C	C	27	32	present
HYS 199-2410	VR	VR	8	1	absent
HYS 199-2726	C	C	36	22	present

Table 2. Faunal characteristics of core and scoop samples

[A (abundant), more than 500 specimens; C (common), 100-500 specimens; R (rare), 10-100 specimens; VR (very rare), fewer than 10 specimens; o, barren]

AGGLUTINATED SPECIES	Hemipelagic Mud			Mixed Muds		Hydrothermal Mud				Apron Breccia		Clambed		Vent Area
	18	26	1641	1405	2319	17	22	25	2468-1	232	2726	416	2410	1459
Adercotryma glomerata		R		R	C	C	R	C	R	R				
Ammobaculites agglutinans				R		R	C	R	R					
A. agglutinans var. filiformis		C				C	A	A	R	R	R			
A. agglutinans var. 1		R	R			R	C	R						
Ammodiscus cretaceus				R	R	C	C	C	R	R	C	R		
A. incertus		R		C	C	R	R	C	R	R	A	R		
Ammodiscus sp. 1						R	R	R						
Ammoglobigerina globigeriniformis	R		R	R	C	R	R	R	R	R	R		R	R
Aschemonella scabra						R								
Astrammina rara				R		C	R	R	R	R	R			
Bathysiphon rufum		R		A	A	C	C	A	A	C	A	C		
Bathysiphon sp. 1					R									
Cribrostomoides subglobosus	R	R		C	C	C	C	C	C	A	A	R		R
C. wiesneri		R		R	R	C	R	C		R	R			
Cylindroclavulina bradyi						R								
Cystammina pauciloculata						R				R				
Eggerella advena	R	R					R	R						
Eggerella bradyi		C			R	C	C	C	R	R			R	
Eratidus foliaceus				R		C	A	C		R	C	R		
Evolutinella rotulata				R							R	R		
Glaphyrammina americanus				R	C	R	R	C		R			R	
Glomospira gordialis		C				C	C	A	R		C			
Glomospira sp. 1						R	R	R	R		R			
Hormosina globulifera	R	R		A	A	A	C	A	A	A	A	C	R	R
Hormosinella distans				R		R	R	R		R	R			
Hyperammina sp. 1						R	R							
Karreriella bradyi					C						R			
Karreriella sp. 1					R									

Table 3. Agglutinated foraminiferal species listed in alphabetical order from the six environments of the AAV in Middle Valley [A (abundant), more than 20 specimens; C (common), 6-20 specimens; R (rare), 1-5 specimens]

AGGLUTINATED SPECIES	Hemipelagic Mud			Mixed Muds		Hydrothermal Mud				Apron Breccia		Clambed		Vent Area
	18	26	1641	1405	2319	17	22	25	2468-1	232	2726	416	2410	1459
Karreriella sp. 2					R									
Kutsevella sp. 1					R	R		R		R	R		R	
Labrospira scitula				R		R			R		R			
Lagenammina tubulata				R		R	R	R						
Lituotuba lituiformis							R							
Loeblichopsis cylindrica							R	R	R		R			
Marsipella elongata						R	C							
Martinottiella bradyana		R		R	R				R			R		
Micrometula sp. 1						R	R							
Nodellum membranaceum		R				C	A	A	R	R	R			
Nodulina dentaliniformis					R	R	R	R	R				R	
Prolixoplecta exilis							C	R			R			
Recurvoides contortus				R	R	R	R	R	R		R	R		
R. turbinatus				R			R		C					
Reophanus ovicula	R			R	A	C	C	C	R	C				
Reophax bilocularis	C	A				C	C	C		R				
R. difflugiformis	R	R		R		C	C	C		R		R		
R. guttifer		R	R	R	R	A	A	A	R	R	C	R		
R. pilulifera					R	R	R				R			
R. scorpiurus						R	R	R						
Reophax sp. 1						R	R	R						
Repmanina charoides						C	R	C						
Resigella moniliformis							R	R						
Rhabdammina sp. 1	R			C	C	C	C	R	C	R	R			
Rhabdammina sp. 2				R	C				R		R			
Rhabdammina sp. 3				C		C		R						
Rhabdammina sp. 4								R	R					
Rhabdammina sp. 5					R								R	

Table 3. Agglutinated foraminiferal species listed in alphabetical order from the six environments of the AAV (cont.) [A (abundant), more than 20 specimens; C (common), 6-20 specimens; R (rare), 1-5 specimens]

AGGLUTINATED SPECIES	Hemipelagic Mud			Mixed Muds		Hydrothermal Mud				Apron Breccia		Clambed		Vent Area
	18	26	1641	1405	2319	17	22	25	2468-1	232	2726	416	2410	1459
Rhabdammina sp. 6				R							C			
Rhabdammina sp. 7						R	R				C	R		
Rhabdammina sp. 8											R			
Rhizammina algaeformis	R	R		C	R	A	A	R		C	R	R	R	
Rhizammina sp. 1							R							
Saccammina socialis						R		R	R		R			
S. sphaerica				R	R	R	R				R		R	
Subreophax adunca						R								
Tholosina bulla				R					R		R			
Thurammina favosa						R				R				
Thurammina papillata	R					C	R	R		R	R			
Thurammina sp. 1			R	R	R	R	R	R	R			R		
Thuramminopsis sp. 1							R							
Tolypammina vagans				R		R	R	R	R	R	R			
Trochammina globulosa	R	R		R	R	R	R	C			R			R
Trochammina sp. 1		R	R			C	R	C	R					
Vanhoeffenella gaussi							R							
unknown sp. 1				R	C	R	R	R	R	R	C			
unknown sp. 2				R										

Table 3. Agglutinated foraminiferal species listed in alphabetical order from the six environments of the AAV (cont.) [A (abundant), more than 20 specimens; C (common), 6-20 specimens; R (rare), 1-5 specimens]

CALCAREOUS SPECIES	Hemipelagic Mud			Mixed Muds		Hydrothermal Mud			Apron Breccia		Clambed		Vent Area
	18	26	1641	1405	2319	22	25	2468-1	232	2726	416	2410	1459
Alabaminella weddellensis	A		C		R			R		R			
Ammomassilina alveoliniformis	R												
Astrononion gallowayi	R				R								
Bolivina barbata	R												
Bolivina sp. 1			R										
Bolivinellina pacifica	R									R			
Bulimina alazanensis	R	R			R								
Bulimina sp.1						C							
Chilostomella oolina	R	R		R	R	R		R					
Cibicidoides bradyi			R	R	R				R	R			
Cibicidoides mundulus	R	R		R	C	R			R	R	R		
Cribroelphidium foraminosum									R				
Elphidiella hannai		R							R				
Euuvigerina aculeata	R												
Euvigerina dirupta				R									
Euvigerina peregrina	R	R	R		A					R			
Fissurina lucida			R										
Fontbotia wuellerstorfi	R	R	R	R	R				R	R		R	
Globobulimina auriculata	R				C								
Globobulimina pacifica	R	R		R	C			R					
Globobulimina sp. 1		R		R	C								
Globobulimina sp. 2					R			R					
Globobulimina sp. 3					R								
Globocassidulina oblonga	C		R		R								
Gyroidina altiformis		R	R										
Gyroidina spp.	R		R	R	R	R			R	C			
Gyroidinoides neosoldanii	R				R								
Haynesina sp. 1	C				R								

Table 4. Calcareous benthic foraminiferal species listed in alphabetical order from the six environments of the AAV in Middle Valley [A (abundant), more than 20 specimens; C (common), 6-20 specimens; R (rare), 1-5 specimens]

CALCAREOUS SPECIES	Hemipelagic Mud			Mixed Muds		Hydrothermal Mud			Apron Breccia		Clambed		Vent Area
	18	26	1641	1405	2319	22	25	2468-1	232	2726	416	2410	1459
Heronallenia sp. 1										R			
Hoeglundina elegans					R					R			
Homalohedra apiopleura	R												
Hyalinonetrion dentaliniforme		R											
Hyalinonetrion sahulense	R				R								
Islandiella helenae	C												
Lagena feildeniana	R												
Lagena striata		R											
Lagena sp. 1	R												
Lenticulina nikobarensis				R		R							
Lobatula fletcheri	R									R			
Melonis barleeanum	R		R		R					R			
Melonis pompiloides	R			R	R					R			
Nodosaria filiformis					R								
Nodosaria sp. 1										R			
Nonion sp. 1	R		R					R					
Nonionella stella	R		R										
Nummulopyrgo globulus			R					R	R	R			
Oolina sp. 1				R									
Oridorsalis tenera			R										
Paliolatella cucullata	C												
Patellina corrugata										R			
Procerolagena meridionalis	R												
Pullenia bulloides	R		R		R								
Pullenia quinqueloba		R			R								
Pullenia salisburyi	R	R	R	R	R	R		R					
Pullenia sp. 1								R					
Pygmaeoseistron hispidulum	R												

Table 4. Calcareous benthic foraminiferal species listed in alphabetical order from the six environments of the AAV (cont.) [A (abundant), more than 20 specimens; C (common), 6-20 specimens; R (rare), 1-5 specimens]

CALCAREOUS SPECIES	Hemipelagic Mud			Mixed Muds		Hydrothermal Mud			Apron Breccia		Clambed		Vent Area
	18	26	1641	1405	2319	22	25	2468-1	232	2726	416	2410	1459
Pyrgo depressa					R				R				
Pyrgo lucernula										R			
Pyrgo murrhina	R				R								
Pyrgo sp. 1				R									
Quadrimorphina sp. 1	R												
Quinqueloculina seminulum				R	R				R	C			
Quinqueloculina sp. 1				R									
Quinqueloculina sp. 2			R										
Sphaeroidina bulloides	R	R	R	R	A		R	R					
Spiroloculina tenuiseptata									R	R			
Stainforthia concava	R									R			
Stainforthia exilis				R									
Stainforthia feylingi	R									R			
Stainforthia seminuda	C												
Suggrunda sp. 1	R												
Triloculina tricarinata	C		R	R	R					R			
Uvigerina hispida			R		C								
Uvigerina senticosa	C	R		R	C				C	C			
Uvigerina spinicostata			R					R					
Uvigerina sp. 1		R				R	R		R				
Uvigerina sp. 2	C		R		R								
unknown sp. 1		R				R		R					
unknown sp. 2	R									R			
unknown sp. 3					R								
unknown sp. 4			R							R			
unknown sp. 5										R			
unknown sp. 6					R								
unknown sp. 7			R							R			

Table 4. Calcareous benthic foraminiferal species listed in alphabetical order from the six environments of the AAV (cont.) [A (abundant), more than 20 specimens; C (common), 6-20 specimens; R (rare), 1-5 specimens]

CHAPTER 5. DISCUSSION

5.1 Relationship of Foraminiferal Distribution to Vents

The use of deep submersibles such as DSRV *Pisces IV*, DSRV *Alvin*, and ROV *Ropos* has enabled biologists to identify blankets of bacteria and unusual symbiota-bearing species of giant clams, gastropods, and various tube worms thriving around hydrothermal vents. These faunas survive in an environment of total darkness, high temperatures, and elevated levels of minerals such as barite, anhydrite and pyrite. They are sustained by chemosynthesis which means that their survival is based on the derivation of energy from chemical reactions between oxygenated sea water and vent fluids enriched with hydrogen sulphide (Tunnicliffe, 1991). It is not yet certain whether any species of foraminifera exhibit chemotrophic behaviour, as very little research has been done in this area. A study by Lee *et al.* (1991) directed at analyzing supposed chemotrophic symbiotic bacteria found in the protoplasm of a species of foraminifera was inconclusive. Such bacteria would allow the foraminifera to benefit from chemical energy available in the environment. The scarcity of benthic foraminifera in the actual vent habitat would suggest that such a symbiotic relationship is not likely.

Juniper *et al.* (1992) observed that surficial and subsurface geological features influence hydrothermal fluid venting and control organism distribution and densities. Increased heat flow and the presence of sulphides corresponds to the occurrence of large decapod crustaceans and clams in the clam beds, and palm worms in the warm substrate at Inspired Mounds. In contrast, foraminiferal diversity and abundance decrease towards active vent sites. Environmental factors which influence the distribution of organisms in a hydrothermal setting are temperature (of the substrate and the water), pH of vent fluids, and the nature of substrates. All of these change with proximity to vents. It is most likely the combined effect of these factors which controls the distribution of foraminifera in the AAV.

5.2 Temperature

Environmental conditions of hydrothermal vents are unique due to increased temperatures of substrates and bottom waters as compared to the surrounding deep-sea region. Foraminiferal distribution indicates that agglutinated species are better adapted to these high temperature regions. Foraminifera follow the trend of the vent macrofauna by inhabiting the slope and basal areas of the mounds where temperatures range from 2-20 °C. Large bacterial mats have been documented at hydrothermal vent sites around the world (Jannasch, 1985) providing abundant nutrients for foraminiferal and macrofaunal communities.

5.3 Substrate

Substrate is another important controlling factor on the distribution of foraminifera, especially for agglutinated species (Schröder, 1986). In the deep sea, the AAV provides a consolidated substrate on the indurated sediment. A high diversity of attached agglutinated foraminifera have taken advantage of this habitat. Other mat like encrusting organisms of unknown affinity are also found on the hydrothermal mounds.

While attached foraminiferal taxa are common on the altered mudstone layer found at the base of chimneys and mounds, unstable surfaces such as the friable anhydrite chimneys are barren of benthic foraminifera.

Foraminifera probably have difficulty colonizing anhydrite because it is physically unstable in this environment. Anhydrite not only precipitates quickly, but also dissolves rapidly in cold sea water. It requires sustained elevated water temperatures (in excess of 150 °C) for long term stability in sea water. At temperatures greater than 150 °C, gypsum forms, but again quickly redissolves if temperatures fall. In addition to providing unfavourable sites for foraminiferal attachment, an anhydrite substrate is also unsuitable due to the lack of stable sediment grains for test construction.

Rates of recruitment of marine invertebrates to hard substrates at deep-sea hydrothermal vent sites was studied by Van Dover *et al.* (1988). Results generally indicated that higher levels of recruitment of invertebrate species occurred within the hydrothermal vent community compared to sites further away from vents. Secondly, these reseachers determined that, over a period of 3.3 years, foraminifera were the most successful (i.e., abundant) organisms colonizing the vent site (Table 6 of Van Dover *et al.*, 1988; Clam Acres hydrothermal vent field, East Pacific Rise, 21°N). Kaminski *et al.*, (1988) also observed that recolonization by benthic foraminifera is more rapid than among macrofaunal invertebrates. Effective colonizers are species of the genus *Reophax* (family Hormosinidae), which are also observed in increased abundances in the AAV.

5.4 Proximity to Vents

The observed increased dominance of agglutinated foraminifera with increased proximity to hydrothermal vents of this study is in contrast to the results of a study of the foraminifera characterizing a hydrothermal vent area in the Guaymas Basin, Gulf of California (Molina-Cruz and Ayala-Lopez, 1988). In that study, a dominantly calcareous foraminiferal assemblage was documented. Based on their results, Molina-Cruz and Ayala-Lopez (1988) concluded that proximity to hydrothermal vents does affect the distribution of benthic foraminifera, although agglutinated taxa were not identified.

AIn another study, a site of hydrothermal activity on the East Pacific Rise (at a depth of 1225 m - well above the CCD) was also characterized by low species diversity and abundance in a predominantly agglutinated foraminiferal assemblage (Nienstedt and Arnold, 1988). These findings were similar to the results of this study.

5.5 pH in the Vent Habitat

Another ecological factor resulting in a dominantly agglutinated fauna is the low pH conditions at sites of active venting. Values of 5.2 in hydrothermal fluids, compared to 8.2 for normal sea water, are not conducive to the existence or preservation of calcareous foraminifera in the vent habitat.

Evidence of preferential loss of epifaunal species due to dissolution is provided based on observations of clams at Middle Valley. The anterior buried end of the clam shells is usually well-preserved, whereas the posterior half of the shell above the sediment-water interface shows signs of dissolution (Juniper *et al.*, 1992).

The shelf foraminifera *Patellina corrugata* was found on the indurated crusts of one active and one inactive vent site. Occurrences of this calcareous species in a deep-sea, hydrothermal environment is somewhat puzzling because it is previously only reported from shallow water depths (Bergen and O'Neill, 1979; Culver and Buzas, 1985). It is notable that *P. corrugata* is the only calcareous taxa found on the indurated sediment. Due to its attached mode of life, *P. corrugata* is obviously able to withstand both high temperatures and fluids of unusual chemical composition. The presence and perfect preservation of numerous delicate tests of *P. corrugata* makes increased calcium carbonate dissolution as a blanket explanation for the absence of an abundant calcareous component in this environment questionable.

Agglutinated tests are bleached and have a whitish colour. This might be the result of sulphate reduction processes where the iron of the cement has been utilized for pyrite formation (Schröder and McNeil, in press). In both the clam bed and active vent habitat, bleached specimens are common.

5.6 Development of Foraminiferal Faunas Near Hydrothermal Vents

Macrofaunal communities at Middle Valley are distinctly different from other sites along the ridge due to habitat dissimilarity, isolation, and age of the sites (Juniper *et al.*, 1992). The age of Middle Valley is estimated at ~100,000 years which accounts for its macrofaunal species diversity. Among 55 macrofaunal taxa documented at Middle Valley, 15 are probably new species (Juniper *et al.*, 1992).

Similar ecological parameters might have played a role in colonization of microorganisms. Due to limited material only two new species (*Ropostrum amuletum* and *Ropostrum kradeopsis*) are described here. Further study of this unique benthic habitat will undoubtedly reveal additional new taxa.

CHAPTER 6. CONCLUSIONS

The study of benthic foraminifera in 19 samples collected from the AAV hydrothermal area in Middle Valley yielded 159 taxa. Samples represent six environments within the AAV, including hemipelagic muds, mixed hemipelagic and hydrothermal muds, hydrothermal muds, apron breccia, a clam bed, and an active vent. Results from this study show that:

(1) In the AAV, under normal hemipelagic sedimentation, at a depth above the CCD and distant from the effects of hydrothermal activity, calcareous foraminifera dominate. However, numerous species are allochthonous, being derived from the shelf via turbidite flows into the valley.

(2) The presence of hydrothermal mounds in Middle Valley's AAV causes local temperature anomalies in the sediments and at the sediment-water interface. As a result, there is an increased dominance of agglutinated foraminifera associated with proximity to vent activity. However, like the macrofauna observed near hydrothermal vents, foraminifera do not venture into the extreme habitats where the temperatures are greater than 20°C.

(3) Corresponding to two types of substrate (muds vs. indurated sediment), two different agglutinated assemblages have developed. The indurated sediment is colonized by a dense network of attached species, whereas the muds are characterized by free tests of agglutinated species.

(4) Species of the family Hormosinidae, subfamily Reophacinae dominate in the hydrothermal habitat because of their success at colonization.

(5) Low abundance and species diversity of calcareous foraminiferal species is attributed to the low pH (of 5.2) of hydrothermal fluids in the vent

habitat, where dissolution of calcium carbonate is readily observed in the macrofauna (clams).

(6) The vent habitat poses problems for foraminiferal colonization due to toxicity of vent emissions. Only certain macrofaunal species with sulphur-oxidizing symbionts are able to adapt to this environment.

This study was based on material which was originally sampled for different scientific purposes. Further research on the foraminiferal fauna based on high quality surface samples will undoubtedly reveal new, undescribed species and provide more information on their adaption to this unique deep-sea environment.

CHAPTER 7. SYSTEMATICS

The suprageneric classification used for the foraminifera identified in the course of this study is based on Loeblich and Tappan (1987). New taxa listed herein are not to be considered as introduced into the literature, as a thesis does not constitute a publication within the International Code of Zoological Nomenclature (ICZN Article 9 (11)).

Order FORAMINIFERIDA Eichwald, 1830

Suborder ALLOGROMIINA Loeblich and Tappan, 1961

Family ALLOGROMIIDAE Rhumbler, 1904

Subfamily ARGILLOTUBINAE Avnimelech, 1952

Genus *Micrometula* Nyholm, 1952

Micrometula sp. 1

Plate 1, Figure 1

Genus *Nodellum* Rhumbler, 1913

Nodellum membranaceum (Brady, 1879)

Plate 1, Figure 2

Reophax membranacea BRADY, 1879, p. 53, pl. 41, fig. 9.

Nodellum membranaceum (Brady) BARKER, 1960, pl. 32, figs. 1-4; SMITH, 1973, pl. 1, fig. 1; SCHRÖDER, 1986, p. 28, pl. 1, fig. 3; LOEBLICH and TAPPAN, 1987, p. 17, pl. 10, figs. 1-2; CLARK, 1990, p. 27, pl. 10, fig. 8.

Chitinosiphon rufescens THALMANN and BERMUDEZ, 1954, p. 53, textfigs. 1-4.

Genus *Resigella* Loeblich and Tappan, 1984a

Resigella moniliformis (Resig, 1982)

Plate 1, Figure 3

Nodellum moniliforme RESIG, 1982, p. 977, pl. 1, figs. 1-2.

Resigella moniliformis (Resig) LOEBLICH and TAPPAN, 1987, p. 17, pl. 9, figs. 11-12.

Suborder TEXTULARIINA Delage and Hérouard, 1896

Superfamily ASTRORHIZACEA Brady, 1881

Remarks. Placement of the following new genus and new species into Family and Subfamily is still under discussion, and must therefore be placed under the Superfamily taxonomic level.

Genus *Ropostrum* n. gen

Type Species. Ropostrum amuletum n. gen., n. sp.

Description. Test attached, small, to one mm in length, consisting of a series of chambers (up to six), having stoloniferous chamber connections; wall agglutinated, perforate, thin, surface rough; aperture not distinguished.

Derivation of Name. Ropos-, named for the Remotely Operated Platform for Ocean Science deep submersible (ROPOS) which was used in the collection of the specimens; *-trum*, suffix denoting tool, instrument, means, apparatus.

Measurements. max. length one mm.

Types and Occurrence. Holocene. Area of Active Venting, Middle Valley, Juan de Fuca Ridge.

Ropostrum amuletum n. sp.

Plate 12, Figures 1-3

Description. Test attached (appears to be anchored at the chambers), consists of a series of three to six hemispherical chambers connected by a single, elongate stolonlike tube, chambers remain consistent, but do not increase in size, chambers appear flattened, however, this may be an artifact of collection and drying of the sample; wall agglutinated, thin, composed of smaller calcareous foraminifera, coccoliths, sponge spicules, and sediment grains; surface rough, resembling surrounding substrate, perforate; seems to form an entosolenian tube which is joined to, or a continuation of, the stoloniferous tubes interconnected between the chambers; aperture not distinguished.

Derivation of Name. From the Latin, ***amuletum***, a magic object worn as a charm against evil and disease, with reference to its resemblance to amulets or charms on a necklace.

Measurements: max. length one mm, diameter of chambers 114 µm; *Locality:* Expired Vent, AAV, Middle Valley, Juan de Fuca Ridge; *Date:* July 1992; *Depth:* 2412 m; *Collector:* I. R. Jonasson, G.S.C.

Remarks. *Ropostrum amuletum* superficially resembles *Placopsilina flouestri* Terquem, 1866, described from the Lias, however, *R. amuletum* is not smooth, and no description of the composition of the test wall was given for *P. flouestri*.

Ropostrum kradeopsis Jonasson n. sp.

Plate 13, Figures 1-3

Description. Test attached to substrate, small, consisting of a series of irregular elongate chambers which taper into a single short tube (up to 120 µm in length), chambers arranged on alternating sides of the tube like a fig branch; wall agglutinated, thin, composed of debris from the surrounding substrate, surface rough; aperture not distinguished.

Derivation of Name. From the Greek, *krade-*, fig branch; *-opsis*, suffix denoting likeness.

Measurements: max. length one mm; diameter of chambers 100 μm; *Locality:* Expired Vent, AAV, Middle Valley, Juan de Fuca Ridge; *Date:* July 1992; *Depth:* 2412 m; *Collector:* I. R. Jonasson, G.S.C.

Remarks. Differs from *R. amuletum* for the irregular-shaped chambers which taper into the interconnecting tubes.

Family ASTRORHIZIDAE Brady, 1881

Genus *Astrorhiza* Sandahl, 1858

Astrorhiza limnicola Sandahl, 1858

Astrorhiza limnicola SANDAHL, 1858, p. 301.

Astrorhiza limicola BARKER, 1960, p. 38, pl. 19, figs. 1-4.

Subfamily VANHOEFFENELLINAE Saidova, 1981

Genus *Vanhoeffenella* Rhumbler, 1905

Vanhoeffenella gaussi Rhumbler, 1905

Vanhoeffenella gaussi RHUMBLER, 1905, p. 97-106, figs. 1-9, (pl. 1, figs. 14-15); SCHRÖDER, 1986, p. 32, pl. 3, fig. 3; LOEBLICH and TAPPAN, 1987, p. 21, pl. 12, figs. 5-8.

Remarks: The extreme fragility of the test may account for the singular occurrence of this species in only one sample.

Family BATHYSIPHOIDAE Avnimelech, 1952

Genus *Bathysiphon* M. Sars, in G.O. Sars, 1872

Bathysiphon rufum de Folin, 1886

Plate 1, Figures 4a, b

Bathysiphon rufum de Folin, 1886, p. 283, pl. 6, fig. 8(a-c).

Bathysiphon rufus de Folin, GOODAY, 1988, p. 84, figs. 12-14.

Bathysiphon sp. 1

Plate 1, Figure 5

Family RHABDAMMINIDAE Brady, 1884

Subfamily RHABDAMMININAE Brady, 1884

Genus *Marsipella* Norman, 1878

Marsipella elongata Norman, 1878

Plate 1, Figure 6

Marsipella elongata NORMAN, 1878, p. 281, pl. 16, fig. 7; BARKER, 1960, pl. 24, figs. 10-19; SCHRÖDER, 1986, p. 33-34, pl. 5, fig. 4(a-b); LOEBLICH and TAPPAN, 1987, p. 23, pl. 15, fig. 2.

Genus *Rhabdammina* M. Sars, in Carpenter, 1869

Rhabdammina spp.

Plate 1, Figures 7-12

Remarks: A variety of coarsely agglutinated cylindrical fragments are tentatively assigned to *Rhabdammina*. Some specimens occur as fragments of extremely coarse-grained tubes, sometimes branching.

Genus *Rhizammina* Brady, 1879

Rhizammina algaeformis Brady, 1879

Plate 2, Figure 1

Rhizammina algaeformis BRADY, 1879, p. 39, pl. 4, figs. 16-17; BARKER, 1960, pl. 28, figs. 1-11; SCHRÖDER, 1986, p. 32, pl. 4, fig. 1(a-h); LOEBLICH and TAPPAN, 1987, p. 24, pl. 15, figs. 6-8.

Rhizammina sp. 1

Family PSAMMOSPHAERIDAE Haeckel, 1894

Subfamily PSAMMOSPHAERINAE Haeckel, 1894

Genus *Thuramminopsis* Haeusler, 1883

Thuramminopsis sp. 1

Plate 2, Figure 2

Family SACCAMMINIDAE Brady, 1884

Subfamily SACCAMMININAE Brady, 1884

Genus *Lagenammina* Rhumbler, 1911

Lagenammina tubulata (Rhumbler, in Wiesner, 1931)

Plate 2, Figure 3

Saccammina tubulata RHUMBLER, in Wiesner, 1931, p. 82, pl. 23, fig. 1.

Proteonina tubulata (Rhumbler) EARLAND, 1933, p. 62, pl. 1, figs. 30-31.

Lagenammina tubulata (Rhumbler) SCHRÖDER, 1986, p. 37, pl. 10, fig. 2; SCHRÖDER and others, 1988, p. 34, pl. 4, fig. 4.

Genus *Saccammina* Carpenter, 1869

Saccammina socialis Brady, 1884

Plate 2, Figure 4

Saccammina socialis BRADY, 1884, p. 255, pl. 18, figs. 18, 19.

Saccammina sphaerica M. Sars, 1869

Plate 2, Figure 5

Saccammina sphaerica M. SARS, 1869, p. 248; CUSHMAN, 1928, p. 72; GOËS, 1894, p. 13, pl. 3, figs. 16-18; BARKER, 1960, p. 36, pl. 18, figs. 11-15, 17; SCHRÖDER, 1986, p. 37, pl. 10, fig. 4(a-b).

Subfamily THURAMMININAE A. D. Miklukho-Maklay, 1963

Genus *Astrammina* Rhumbler, 1931

Astrammina rara Rhumbler, in Wiesner, 1931

Plate 2, Figures 6, 7

Astrammina rara RHUMBLER, in Wiesner, 1931, p. 78, pl. 2, fig. 19; LOEBLICH and TAPPAN, 1987, p. 33, pl. 22, figs. 1-2; pl. 23, figs. 10-14.

Genus *Thurammina* Brady, 1879

Thurammina favosa Flint, 1899

Plate 2, Figure 8

Thurammina favosa FLINT, 1899, p. 278, pl. 21, fig. 2.

Thurammina papillata Brady, 1879

Plate 2, Figure 9; Plate 3, Figure 1

Thurammina papillata BRADY, 1879, p. 45, pl. 5, figs. 4-8; BARKER, 1960, pl. 36, figs. 7-18; SMITH, 1973, p. 13, pl. 1, fig. 7; SCHRÖDER, 1986, p. 38, pl. 10, fig. 9(a-b).

Thurammina sp. 1

Plate 3, Figure 2

Family HEMISPHAERAMMINIDAE Loeblich and Tappan, 1961

Subfamily HEMISPHAERAMMININAE Loeblich and Tappan, 1961

Genus *Hemisphaerammina* Loeblich and Tappan, 1957

Hemisphaerammina sp. 1

Genus *Tholosina* Rhumbler, 1895

Tholosina bulla (Brady, 1881)

Plate 3, Figure 3

Placopsilina bulla BRADY, 1881, p. 51.

Tholosina bulla (Brady) BARKER, 1960, p. 72, pl. 35, figs. 16-17; LOEBLICH and TAPPAN, 1987, p. 38, pl. 26, figs. 3-4.

Superfamily KOMOKIACEA Tendal and Hessler, 1977

Family KOMOKIIDAE Tendal and Hessler, 1977

Genus *Lana* Tendal and Hessler, 1977

Lana spissa Schröder, Medioli and Scott, 1989

Lana spissa SCHRÖDER, MEDIOLI and SCOTT, 1989, p. 30, pl. 2, fig. 3.

Superfamily HIPPOCREPINACEA Rhumbler, 1895

Family HIPPOCREPINIDAE Rhumbler, 1895

Subfamily HYPERAMMININAE Eimer and Fickert, 1899

Genus *Hyperammina* Brady, 1878

Hyperammina sp. 1

Plate 3, Figure 4

Superfamily AMMODISCACEA Reuss, 1862

Family AMMODISCIDAE Reuss, 1862

Subfamily AMMOVOLUMMININAE Chernykh, 1967

Genus *Ammodiscus* Reuss, 1862

Ammodiscus cretaceus (Reuss, 1845)

Plate 3, Figure 5

Operculina cretacea REUSS, 1845, p. 35, pl. 13, figs. 64-65.

Ammodiscus incertus (d'Orbigny, 1839)

Plate 3, Figures 6, 7

Operculina incerta D'ORBIGNY, 1839, p. 49, vol. 8, pl. 6, figs. 16-17.

Ammodiscus incertus (d'Orbigny) BARKER, 1960, pl. 23, figs. 1-3; POAG, 1981, p. 96-97, pl. 7-8, fig. 2; SCHRÖDER, 1986, p. 39, pl. 10, fig. 10(a-b).

Remarks: Clark (1990) has determined that *A. tenuis* is the megalospheric form of *A. incertus*.

Ammodiscus sp. 1

Plate 3, Figure 8

Subfamily TOLYPAMMININAE Cushman, 1928

Genus *Tolypammina* Rhumbler, 1895

Tolypammina vagans (Brady, 1879)

Plate 4, Figure 1

Hyperammina vagans BRADY, 1884, p. 33, pl. 5, fig. 3.

Tolypammina vagans (Brady) SCHRÖDER, 1986, p. 39, pl. 11, figs. 7-9.

Subfamily AMMOVERTELLININAE Saidova, 1981

Genus *Glomospira* Rzehak, 1885

Glomospira gordialis (Jones and Parker, 1860)

Plate 4, Figure 2

Trochammina squamata subsp. *gordialis* JONES and PARKER, 1860, p. 304.

Ammodiscus gordialis (Jones and Parker) BRADY, 1884, p. 333, pl. 38, figs. 7-9.

Gordiammina gordialis (Jones and Parker) CUSHMAN, 1910, p. 76-77, figs. 98-100.

Glomospira gordialis (Jones and Parker) CUSHMAN, 1918, p. 99, pl. 36, figs. 7-9; BARKER, 1960, pl. 38, figs. 7-9; SMITH, 1973, pl. 1, fig. 8(a-b); SCHRÖDER, 1986, p. 39, pl. 11, figs. 1-2; LOEBLICH and TAPPAN, 1987, p. 50, pl. 38, figs. 5-6.

Glomospira sp. 1

Plate 4, Figure 3

Subfamily USBEKISTANIINAE Vyalov, 1968

Genus *Repmanina* Suleymanov, in Arapova and Suleymanov, 1966

Repmanina charoides (Jones and Parker, 1860)

Plate 4, Figures 4a, b

Trochammina squamata subsp. *charoides* JONES and PARKER, 1860, p. 304.

Glomospira charoides (Jones and Parker) BARKER, 1960, pl. 38, figs. 10-16; POAG, 1981, p. 96-97, pl. 7-8, fig. 4; SCHRÖDER, 1986, p. 39, pl. 11, figs. 3-4.

Repmanina charoides (Jones and Parker) CLARK, 1990, p. 32, pl. 11, fig. 3.

Superfamily HORMOSINACEA Haeckel, 1894

Family HORMOSINIDAE Haeckel, 1894

Subfamily REOPHACINAE Cushman, 1910

Genus *Hormosinella* Shchedrina, 1969

Hormosinella distans (Brady, 1881)

Plate 4, Figure 5

Reophax distans BRADY, 1881, p. 50; BRADY, 1884, p. 296, pl. 31, figs. 18-22; CUSHMAN, 1910, p. 85-86, fig. 119; BARKER, 1960, p. 64, pl. 31, figs. 18-22; SMITH, 1973, p. 13, pl. 1, fig. 11; SCHRÖDER, 1986, p. 44, pl. 16, figs. 3-5, 9.

Genus *Nodulina* Rhumbler, 1895

Nodulina dentaliniformis (Brady, 1881)

Plate 4, Figure 7

Reophax dentaliniformis BRADY, 1881, p. 49; BRADY, 1884, p. 293, pl. 30, figs. 21-22; BARKER, 1960, p. 62, pl. 30, figs. 21-22; SMITH, 1973, p. 13, pl. 1, fig. 9.
Nodulina dentaliniformis (Brady) LOEBLICH and TAPPAN, 1987, p. 58, pl. 44, figs. 10, 11.

Genus *Reophax* de Montfort, 1808

Reophax bilocularis Flint, 1899

Reophax bilocularis FLINT, 1899, p. 273, pl. 17, fig. 2; SCHRÖDER, 1986, p. 42, pl. 14, figs. 8-13.

Reophax difflugiformis Brady, 1879

Plate 4, Figure 9

Reophax difflugiformis BRADY, 1879, p. 51, pl. 4, fig. 3(a-b).

Reophax guttifer Brady, 1881

Plate 5, Figure 1

Reophax guttifer BRADY, 1881, p. 49; BARKER, 1960, pl. 31, figs. 10-15; SCHRÖDER, 1986, p. 44, pl. 15, figs. 12-13.

Reophax pilulifera Brady, 1884

Plate 5, Figure 2

Reophax pilulifera BRADY, 1884, p. 292, pl. 30, figs. 18-20.

Reophax pilulifer Brady CUSHMAN, 1910, p. 85, figs. 117-118; BARKER, 1960, p. 62, pl. 30, figs. 18-20; SMITH, 1973, p. 14; SCHRÖDER, 1986, p. 45, pl. 15, figs. 1-5.

Reophax scorpiurus de Montfort, 1808

Plate 5, Figure 3

Reophax scorpiurus DE MONTFORT, 1808, p. 331, text-fig.; BRADY, 1884, p. 291, pl. 30, figs. 12, 14-17; BARKER, 1960, pl. 30, figs. 15-17; SMITH, 1973, p. 14, pl. 1, fig. 13; SCHRÖDER, 1986, p. 42, pl. 14, figs. 1-5.

Reophax sp. 1

Plate 5, Figure 4

Genus *Subreophax* Saidova, 1975

Subreophax adunca (Brady, 1882)

Plate 5, Figure 5

Reophax adunca BRADY, in Tizard and Murray, 1882, p. 715.

Reophax aduncus (Brady) BARKER, 1960, pl. 31, figs. 23-26.

Subreophax adunca (Brady) SCHRÖDER, 1986, p. 46, pl. 16, figs. 6-8.

Subfamily HORMOSININAE Haeckel, 1894

Genus *Hormosina* Brady, 1879

Hormosina globulifera Brady, 1879

Plate 5, Figures 6, 7

Hormosina globulifera BRADY, 1879, p. 60, pl. 4, figs. 4-5; BRADY, 1884, p. 326, pl. 39, figs. 1-6; CUSHMAN, 1910, p. 93-95, figs. 136-137; BARKER, 1960, pl. 39, figs. 1-6; SCHRÖDER, 1986, p. 41, pl. 13, figs. 1-3.

Remarks: Generally present as fragments recognizable by the texture of the wall.

Genus *Loeblichopsis* Hofker, 1967

Loeblichopsis cylindrica (Brady, 1884)

Plate 4, Figure 8

Reophax cylindrica BRADY, 1884, p. 299, pl. 32, figs. 7-9.

Loeblichopsis cylindrica (Brady) LOEBLICH and TAPPAN, 1987, p. 61, pl. 46, figs. 1-4.

Genus *Reophanus* Saidova, 1970

Reophanus ovicula (Brady, 1879)

Plate 4, Figure 6

Hormosina ovicula BRADY, 1879, p. 61, pl. 4, fig. 6; BARKER, 1960, pl. 39, figs. 7-9.

Reophanus ovicula (Brady) LOEBLICH and TAPPAN, 1987, p. 61, pl. 46, fig. 10.

Superfamily LITUOLACEA de Blainville, 1827

Family HAPLOPHRAGMOIDIDAE Maync, 1952

Genus *Cribrostomoides* Cushman, 1910

Cribrostomoides subglobosus (G. O. Sars, 1872)

Plate 5, Figure 8

?*Haplophragmium latidorsatum* (Bornemann) BRADY, 1884, p. 307, pl. 34, figs. 7-8, 10.

? *Haplophragmoides subglobosum* (G. O. Sars) CUSHMAN, 1910, p. 105-106, figs. 162-164.

? *Labrospira subglobosa* (G. O. Sars) HÖGLUND, 1947, p. 144-145, pl. 11, fig. 2, text-fig. 126.

Alveolophragmium subglobosum (G. O. Sars) BARKER, 1960, p. 70, pl. 34, figs. 7-8, 10; SMITH, 1973, p. 15, pl. 1, fig. 20(a-b).

Lituola subglobosa SARS, G. O., 1872, p. 252.

Cribrostomoides subglobosum (G.O. Sars) POAG, 1981, p. 100-101, pl. 11-12, fig. 2.

Cribrostomoides subglobosus (G. O. Sars) SCHRÖDER, 1986, p. 48, pl. 17, figs. 15-16.

Cribrostomoides wiesneri (Parr, 1950)

Plate 5, Figure 9

Labrospira wiesneri PARR, 1950, p. 272, pl. 4, fig. 25-26.

? *Labrospira arctica* PARKER, 1952, p. 399, pl. 2, figs. 7, 12.

Alveolophragmium wiesneri (Parr) PARKER, 1954, p. 488, pl. 1, fig. 23; BARKER, 1960, pl. 40, figs. 14-15; SMITH, 1973, p. 15, pl. 2, fig. 1(a-b).

Cribrostomoides wiesneri (Parr) SCHRÖDER, 1986, p. 48, pl. 17, figs. 10-12.

Genus *Evolutinella* Myatlyuk, 1971

Evolutinella rotulata (Brady, 1881)

Plate 5, Figure 10

Lituola (Haplophragmium) rotulatum BRADY, 1881, pl. 34, figs. 5-6.

Genus *Labrospira* Höglund, 1947

Labrospira scitula (Brady, 1881)

Plate 6, Figure 1

Haplophragmium scitulum BRADY, 1881, p. 50; BRADY, 1884, p. 308, pl. 34, figs. 11-13.

?*Alveolophragmium scitulum* (Brady) PARKER, 1954, p. 487; BARKER, 1960, p. 70, pl. 34, figs. 11-13; SMITH, 1973, p. 15, pl. 1, fig. 19(a-b).

Recurvoides scitulus (Brady) SCHRÖDER, 1986, p. 48, pl. 17, figs. 1-4.

Family DISCAMMINIDAE Mikhalevich, 1980

Genus *Glaphyrammina* Loeblich and Tappan, 1984a

Glaphyrammina americanus (Cushman, 1910)

Plate 6, Figure 2

Ammobaculites americanus CUSHMAN, 1910, p. 117, figs. 184-185(a-b).

Glaphyrammina americanus (Cushman) LOEBLICH and TAPPAN, 1987, p. 68, pl. 51, figs. 7-10.

Family LITUOTUBIDAE Loeblich and Tappan, 1984b

Genus *Lituotuba* Rhumbler, 1895

Lituotuba lituiformis (Brady, 1879)

Plate 6, Figure 3

Trochammina lituiformis BRADY, 1879, p. 52, pl. 5, fig. 16.

Lituotuba lituiformis (Brady) BARKER, 1960, pl. 40, figs. 4-7.

Family LITUOLIDAE de Blainville, 1827

Subfamily AMMOMARGINULININAE Podobina, 1978

Genus *Ammobaculites* Cushman, 1910

Ammobaculites agglutinans (d'Orbigny, 1846)

Plate 6, Figure 4

Spirolina agglutinans D'ORBIGNY, 1846, p. 137, pl. 7, figs. 10-12.

Haplophragmium agglutinans (d'Orbigny) BRADY, 1884, p. 301, pl. 32, figs. 19-21, 24-26.

Ammobaculites agglutinans (d'Orbigny) CUSHMAN, 1910, p. 115, fig. 176; BARKER, 1960, p. 66, pl. 32, figs. 19-21, 24-26; SCHRÖDER, 1986, p. 50, pl. 21, figs. 1-4.

Ammobaculites agglutinans subspecies *filiformis* Earland, 1934

Plate 6, Figure 5

Ammobaculites agglutinans subspecies *filiformis* EARLAND, 1934, p. 92, pl. 3, figs. 11-13; BARKER, 1960 pl. 32, fig. 22; SCHRÖDER, 1986, p. 50, pl. 21, figs. 5-6.

Ammobaculites agglutinans subspecies 1

Plate 6, Figure 6

Ammobaculites agglutinans subsp. *filiformis* BARKER, 1960, pl. 32, fig. 23.

Ammobaculites agglutinans subsp. 1 SCHRÖDER, 1986, p. 51, pl. 21, figs. 7-8.

Genus *Ammomarginulina* Wiesner, 1931

Ammomarginulina sp. 1

Genus *Kutsevella* Dain, 1978

Kutsevella sp. 1

Plate 6, Figure 7

Genus *Eratidus* Saidova, 1975

Eratidus foliaceus (Brady, 1881)

Plate 6, Figures 8, 9

Haplophragmium foliaceum BRADY, 1881, p. 50; BRADY, 1884, p. 304-305, pl. 33, figs. 20-25.

Ammomarginulina foliacea (Brady) BARKER, 1960, pl. 33, figs. 20-25; SMITH, 1973, p. 16, pl. 2, fig. 6; SCHRÖDER, 1986, p. 51, pl. 21, figs. 10-13.

Eratidus foliaceus (Brady) LOEBLICH and TAPPAN, 1987, p. 75, pl. 59, figs. 1-3.

Superfamily HAPLOPHRAGMIACEA Eimer and Fickert, 1899

Family AMMOSPHAEROIDINIDAE Cushman, 1927

Subfamily AMMOSPHAEROIDININAE Cushman, 1927

Genus *Adercotryma* Loeblich and Tappan, 1952

Adercotyrma glomerata (Brady, 1878)

Plate 6, Figure 10

Lituola glomerata BRADY, 1878, p. 433, pl. 20, fig. 1.

Adercotryma glomeratum (Brady) LOEBLICH and TAPPAN, 1952, p. 141-142, figs. 1-4.

Adercotryma glomerata (Brady) BARKER, 1960, pl. 34, figs. 15-18; SMITH, 1973, p. 14, pl. 1, fig. 14; SCHRÖDER, 1986, p. 47, pl. 16, figs. 10-11.

Genus *Cystammina* Neumayr, 1889

Cystammina pauciloculata (Brady, 1879)

Plate 6, Figure 11

Trochammina pauciloculata BRADY, 1879, p. 58, pl. 5, figs. 13-14.

Cystammina pauciloculata (Brady) BARKER, 1960, pl. 41, figs 1-2; SCHRÖDER, 1986, p. 54, pl. 18, figs. 14-15.

Subfamily RECURVOIDINAE Alekseychik-Mitskevich, 1973

Genus *Recurvoides* Earland, 1934

Recurvoides contortus Earland, 1934

Plate 7, Figure 1

Recurvoides contortus EARLAND, 1934, p. 91, pl. 10, figs. 7-19.

Recurvoides turbinatus (Brady, 1881)

Plate 7, Figures 2a, b

Haplophragmium turbinatum BRADY, 1881, p. 50.

Superfamily TROCHAMMINACEA Schwager, 1877

Family TROCHAMMINIDAE Schwager, 1877

Subfamily TROCHAMMININAE Schwager, 1877

Genus *Ammoglobogerina* Eimer and Fickert, 1899

Ammoglobigerina globigeriniformis (Parker and Jones, 1865)

Plate 7, Figures 3a, b

Lituola nautiloidea globigeriniformis PARKER and JONES, 1865, p. 407, pl. 15, figs. 46-47.

Haplophragmium globigeriniforme (Parker and Jones) BRADY, 1884, p. 312, pl. 35, figs. 10-11.

Trochammina globigeriniformis (Parker and Jones) CUSHMAN, 1910, p. 124, 125, figs. 193-195.

Ammoglobigerina globigeriniformis (Parker and Jones) BARKER, 1960, p. 72, pl. 35, figs. 10-11; SMITH, 1973, p. 17, pl. 3, fig. 1; LOEBLICH and TAPPAN, 1987, p. 120, pl. 128, figs. 9-10.

Genus *Trochammina* Parker and Jones, 1859

Trochammina globulosa Cushman, 1920

Plate 7, Figure 4

Trochammina globulosa CUSHMAN, 1920, p. 77, pl. 16, figs. 3-4; SCHRÖDER, 1986, p. 52, pl. 19, figs. 9-11.

Trochammina sp. 1

Plate 7, Figure 5

Superfamily VERNEUILINACEA Cushman, 1911

Family PROLIXOPLECTIDAE Loeblich and Tappan, 1985

Genus *Prolixoplecta* Loeblich and Tappan, 1985

Prolixoplecta exilis (Cushman, 1936a)

Plate 7, Figure 6

Gaudryina filaformis Berthelin BRADY, 1884, p. 380, pl. 46, fig. 12.

Dorothia exilis CUSHMAN, 1936a, p. 30, fig. 17; BARKER, 1960, pl. 46, fig. 12; SMITH, 1973, p. 18, pl. 3, fig. 3.

Prolixoplecta exilis (Cushman) LOEBLICH and TAPPAN, 1987, p. 131, pl. 139, figs. 1-3.

Remarks: Extremely minute forms, narrow elongate test and subglobular chambers.

Superfamily TEXTULARIACEA Ehrenberg, 1838

Family EGGERELLIDAE Cushman, 1937

Subfamily EGGERELLINAE Cushman, 1937

Genus *Eggerella* Cushman, 1922

Eggerella advena (Cushman, 1922)

Plate 7, Figure 7

Verneuilina advena CUSHMAN, 1922, p. 141.

Eggerella advena (Cushman) LOEBLICH and TAPPAN, 1953, p. 36, pl. 3, figs. 8-10.

Eggerella bradyi (Cushman, 1911)

Plate 7, Figure 8

Verneulina bradyi CUSHMAN, 1911, p. 54, fig. 87.

Eggerella bradyi (Cushman) LOEBLICH and TAPPAN, 1987, p. 170, pl. 189, figs. 1-4; HERMELIN, 1989, p. 32, pl. 2, figs. 1-2.

Genus *Karreriella* Cushman, 1933

Karreriella bradyi (Cushman, 1911)

Plate 8, Figure 1

Gaudryina bradyi CUSHMAN, 1911, p. 67, fig. 107.

Karreriella sp. 1

Plate 8, Figure 2

Karreriella sp. 2

Plate 8, Figure 3

Genus *Martinotiella* Cushman, 1933

Martinotiella bradyana (Cushman, 1936)

Plate 8, Figure 4

Listerella bradyana CUSHMAN, 1936, p. 40, pl. 6, fig. 11.

Martinotiella bradyana (Cushman) BARKER, 1960, p. 98, pl. 48, figs. 1-2.

Family VALVULINIDAE Berthelin, 1880

Subfamily VALVULININAE Berthelin, 1880

Genus *Cylindroclavulina* Bermúdez and Key, 1952

Cylindroclavulina bradyi (Cushman, 1911)

Plate 8, Figure 5

Clavulina bradyi CUSHMAN, 1911, p. 73, figs. 118-119.

Cylindroclavulina bradyi (Cushman) BARKER, 1960, p. 98, pl. 48, figs. 32-38.

Suborder SPIRILLININA Hohenegger and Piller, 1975

Family PATELLINIDAE Rhumbler, 1906

Subfamily PATELLININAE Rhumbler, 1906

Genus *Patellina* Williamson, 1858

Patellina corrugata Williamson, 1858

Patellina corrugata WILLIAMSON, 1858, p. 46, pl. 3, figs. 86-89; BARKER, 1960, p. 178, pl. 86, figs. 1-7; LOEBLICH and TAPPAN, 1987, p. 306, pl. 320, figs. 4-14.

Suborder MILIOLINA Delage and Hérouard, 1896

Superfamily MILIOLACEA Ehrenberg, 1839

Family SPIROLOCULINIDAE Wiesner, 1920

Genus *Nummulopyrgo* Hofker, 1983

Nummulopyrgo globulus (Hofker, 1976)

Pseudopyrgo globulus HOFKER, 1976, p, 112.

Nummulopyrgo globulus (Hofker) LOEBLICH and TAPPAN, 1987, p. 330, pl. 339, figs. 7-14.

Genus *Spiroloculina* d'Orbigny, 1826

Spiroloculina tenuiseptata Brady, 1884

Spiroloculina tenuiseptata BRADY, 1884, p. 153, figs. 5-6; BARKER, 1960, p. 20, pl. 10, figs. 5-6.

Family HAUERINIDAE Schwager, 1876

Subfamily SIPHONAPERTINAE Saidova, 1975

Genus *Ammomassilina* Cushman, 1933

Ammomassilina alveoliniformis (Millett, 1898)

Spiroloculina asperula Karrer BRADY, 1884, p. 152, pl. 8, figs. 13-14.

Massilina asperula (Karrer) CUSHMAN, 1921, p. 39.

Massilina alveoliniformis MILLETT, 1898, p. 609, pl. 13, figs. 5-7; CUSHMAN, 1928, p. 39.

Ammomassilina alveoliniformis (Millett) CUSHMAN, 1933, p. 32; BARKER, 1960, p. 16, pl. 8, figs. 13-14.

Subfamily HAUERININAE Schwager, 1876

Genus *Quinqueloculina* d'Orbigny, 1826

Quinqueloculina seminulum (Linné, 1758)

Serpula seminulum LINNÉ, 1758, p. 786.

Quinqueloculina seminulum (Linnaeus) D'ORBIGNY, 1826, p. 303, No. 44; CUSHMAN, 1917, p. 44, pl. 11, fig. 2.

Quinqueloculina sp. 1

Quinqueloculina sp. 2

Subfamily MILIOLINELLINAE Vella, 1957

Genus *Pyrgo* Defrance, 1824

Pyrgo depressa (d'Orbigny, 1826)

Biloculina depressa D'ORBIGNY, 1826, p. 298, fig. 5; CUSHMAN, 1917, p. 74, pl. 28, figs. 1-2.

Pyrgo depressa (d'Orbigny) BARKER, 1960, p. 4, pl. 2, figs. 12, 16-17; p. 6, pl. 3, figs. 1-2.

Pyrgo lucernula (Schwager, 1866)

Biloculina lucernula SCHWAGER, 1866, p. 202, pl. 4, figs. 14, 17; CUSHMAN, 1917, p. 79; pl. 32, fig. 2.

Pyrgo lucernula (Schwager) BARKER, 1960, p. 4, pl. 2, figs. 5-6.

Pyrgo murrhina (Schwager, 1866)

Biloculina murrhina SCHWAGER, 1866, p. 203, pl. 4, fig. 15; CUSHMAN, 1917, p. 75, pl. 28, fig. 3, pl. 29, fig. 1.

Pyrgo murrhina (Schwager) HERMELIN, 1989, p. 36, pl. 2, figs. 12, 15-16.

Pyrgo murrhyna (Schwager) BARKER, 1960, p. 4, pl. 2, figs. 10-11, 15.

Pyrgo sp. 1

Genus *Triloculina* d'Orbigny, 1826

Triloculina tricarinata d'Orbigny, 1826

Triloculina tricarinata D'ORBIGNY, 1826, p. 299, no. 7, mod. no. 94, fig. 8; CUSHMAN, 1917, p. 66, pl. 25, figs. 1-2; BARKER, 1960, p. 6, pl. 3, fig. 17; HERMELIN, 1989, p. 38, pl. 3, figs. 6-7.

Suborder LAGENINA Delage and Hérouard, 1896

Superfamily NODOSARIACEA Ehrenberg, 1838

Family NODOSARIIDAE Ehrenberg, 1838

Subfamily NODOSARIINAE Ehrenberg, 1838

Genus *Nodosaria* Lamarck, 1812

Nodosaria filiformis Reuss, 1845

Nodosaria (Dentalina) filiformis REUSS, 1845, p. 28, pl. 12, fig. 28.

Nodosaria sp. 1

Family VAGINULINIDAE Reuss, 1860

Subfamily LENTICULININAE Chapman, Parr, and Collins, 1934

Genus *Lenticulina* Lamarck, 1804

Lenticulina nikobarensis (Schwager, 1866)

Crisellaria nikobarensis SCHWAGER, 1866, p. 243, pl. 6, fig. 87.

Family LAGENIDAE Reuss, 1862

Genus *Hyalinonetrion* Patterson and Richardson, 1988

Hyalinonetrion dentaliniforme (Bagg, 1912)

Lagena dentaliniforme BAGG, 1912, p. 45, pl. 13, figs. 1-2.

Hyalinonetrion sahulense Patterson and Richardson, 1988

Hyalinonetrion sahulense PATTERSON and RICHARDSON, 1988, p. 243, figs. 5-6.

Genus *Lagena* Walker and Jacob, 1798

Lagena feildeniana Brady, 1878

Lagena feildeniana BRADY, 1878, p. 434, pl. 20, fig. 4; CUSHMAN, 1913, p. 29, pl. 15, figs. 1-2; BARKER, 1960, p. 120, pl. 58, figs. 38-39; HERMELIN, 1989, p. 41, pl. 4, fig. 8.

Lagena striata (d'Orbigny, 1839)

Oolina striata D'ORBIGNY, 1839, p. 21, pl. 5, fig. 12.

Lagena striata (d'Orbigny) CUSHMAN, 1913, p. 19, pl. 7, figs. 4-5; BARKER, 1960, p. 118, pl. 57, figs. 22, 24; HERMELIN, 1989, p. 43, pl. 4, fig. 14.

Lagena sp. 1

Genus *Procerolagena* Puri, 1954

Procerolagena meridionalis Wiesner, 1931

Lagena gracilis Williamson subsp. *meridionalis* WIESNER, 1931, p. 117, pl. 18, fig. 211.

Lagena meridionalis Wiesner LOEBLICH and TAPPAN, 1953, p. 62, pl. 12, fig. 1.

Genus *Pygmaeoseistron* Patterson and Richardson, 1988

Pygmaeoseistron hispidulum (Cushman, 1913)

Lagena hispidula CUSHMAN, 1913, p. 14, pl. 5, figs. 2-3; BARKER, 1960, p. 114, pl. 56, figs. 10-11, ? not 13.

Pygmaeoseistron hispidulum (Cushman) PATTERSON and RICHARDSON, 1988, p. 243, pl. 7-10.

Family ELLIPSOLAGENIDAE A. Silvestri, 1923

Subfamily OOLININAE Loeblich and Tappan, 1961

Genus *Homalohedra* Patterson and Richardson, 1987

Homalohedra apiopleura (Loeblich and Tappan, 1953)

Lagena apiopleura LOEBLICH and TAPPAN, 1953, p. 59, pl. 10, figs. 14-15.

Homalohedra apiopleura (Loeblich and Tappan) PATTERSON, 1986, p. 98, pl. 17, figs. 6-7.

Genus *Oolina* d'Orbigny, 1839

Oolina sp. 1

Subfamily ELLIPSOLAGENINAE A. Silvestri, 1923

Genus *Fissurina* Reuss, 1850

Fissurina lucida (Williamson, 1848)

Entosolenia marginata (Montagu) subsp. *lucida* WILLIAMSON, 1848, p. 17, pl. 2, fig. 17.

Genus *Paliolatella* Patterson and Richardson, 1987

Paliolatella cucullata (Silvestri, 1902)

Lagena orbignyana subsp. *variabilis* WRIGHT, 1891, p. 482, pl. 20, fig. 9(a-c).

Fissurina cucullata SILVESTRI, 1902, p. 146, figs. 23-25.

Suborder ROBERTININA Loeblich and Tappan, 1984b

Superfamily CERATOBULIMINACEA Cushman, 1927

Family EPISTOMINIDAE Wedekind, 1937

Subfamily EPISTOMININAE Wedekind, 1937

Genus *Hoeglundina* Brotzen, 1948

Hoeglundina elegans (d'Orbigny, 1826)

Rotalia elegans D'ORBIGNY, 1826, p. 276, pl. 12, fig. 142.

Hoeglundina elegans (d'Orbigny) VAN MORKHOVEN, BERGGREN and EDWARDS, 1986, pl. 29, figs. 1-2; CLARK, 1990, p. 196, pl. 5, figs. 6-8.

Suborder ROTALIINA Delage and Hérouard, 1896

Superfamily BULIMINACEA Jones, 1875

Family BOLIVINIDAE Glaessner, 1937

Genus *Bolivina* d'Orbigny, 1839

Bolivina barbata Phleger and Parker, 1951

Bolivina barbata PHLEGER and PARKER, 1951, p. 13, pl. 6, figs. 12-13.

Bolivina sp. 1

Family BOLIVINELLIDAE Hayward, 1980

Genus *Bolivinellina* Saidova, 1975

Bolivinellina pacifica (Cushman and McCulloch, 1942)

Bolivina acerosa Cushman subsp. *pacifica* CUSHMAN and MCCULLOGH, 1942, p. 185, pl. 21, figs.2-3.

Superfamily CASSIDULINACEA d'Orbigny, 1839

Family CASSIDULINIDAE d'Orbigny, 1839

Subfamily CASSIDULININAE d'Orbigny, 1839

Genus *Globocassidulina* Voloshinova, 1960

Globocassidulina oblonga (Reuss, 1850)

Cassidulina oblonga REUSS, 1850, p. 376, pl. 48, figs. 5-6.

Genus *Islandiella* Nørvang, 1959

Islandiella helenae Feyling-Hanssen and Buzas, 1976

Islandiella helenae FEYLING-HANSSEN and BUZAS, 1976, p. 155, text-figs. 1-4.

Cassidulina teretis Tappan LOEBLICH and TAPPAN, 1953, p. 121, pl. 24, figs. 3-4.

Superfamily TURRILINACEA Cushman, 1927

Family STAINFORTHIIDAE Reiss, 1963

Genus *Stainforthia* Hofker, 1956

Stainforthia concava (Höglund, 1947)

Virgulina concava HÖGLUND, 1947, p. 257.

Stainforthia exilis (Brady, 1884)

Bulimina elegans d'Orbigny subsp. *exilis* BRADY, 1884, p. 339, pl. 50, figs. 5-6.

Bulimina exilis Brady LOEBLICH and TAPPAN, 1953, p. 110, pl. 20, figs. 4-5.

Stainforthia feylingi Knudsen and Seidenkrantz, (in press)

Virgulina schreibersiana Czjzek FEYLING-HANSSEN, JØRGENSEN, KNUDSEN, and ANDERSON, 1971, p. 240, pl. 7, figs. 6-8 (not *Virgulina schreibersiana* Czjzek, 1848).

Stainforthia feylingi KNUDSEN and SEIDENKRANTZ, (in press), pl. 1, figs. 1-32; pl. 2, figs. 1-6, 8.

Stainforthia seminuda (Cushman, 1911)

Bolivina seminuda CUSHMAN, 1911, p. 34, text-fig. 55; HERMELIN, 1989, p. 60, pl. 10, figs. 17-18.

Superfamily BULIMINACEA Jones, 1875

Family BULIMINIDAE Jones, 1875

Genus *Bulimina* d'Orbigny, 1826

Bulimina alazanensis Cushman, 1927

Bulimina alazanensis CUSHMAN, 1927, p. 161, pl. 25, fig. 4.

Bulimina sp. nov. BARKER, 1960, p. 104, pl. 51, figs. 18-19.

Bulimina sp. 1

Genus *Globobulimina* Cushman, 1927

Globobulimina auriculata (Bailey, 1851)

Bulimina auriculata BAILEY, 1851, p. 12, pl., figs. 25-27, 67.

Globobulimina pacifica Cushman, 1927

Globobulimina pacifica CUSHMAN, 1927, p. 67.

Globobulimina sp. 1

Globobulimina sp. 2

Globobulimina sp. 3

Family UVIGERINIDAE Haeckel, 1894

Subfamily UVIGERININAE Haeckel, 1894

Genus *Euuvigerina* Thalmann, 1952

Euuvigerina aculeata (d'Orbigny, 1846)

Uvigerina aculeata D'ORBIGNY, 1846, p. 191, pl. 11, figs. 27-28.

Euuvigerina aculeata (d'Orbigny) BARKER, 1960, p. 156, pl 75, figs. 1-3.

Euuvigerina peregrina (Cushman, 1923)

Uvigerina peregrina CUSHMAN, 1923, p. 166, pl. 42, figs. 7-10; HERMELIN, 1989, p. 66, pl. 12, figs. 6-8.

Euuvigerina dirupta (Todd, 1948)

Uvigerina peregrina Cushman subsp. *dirupta* TODD, 1948, p. 267, pl. 34, fig. 3.

Genus *Uvigerina* d'Orbigny, 1826

Uvigerina hispida Schwager, 1866

Uvigerina hispida SCHWAGER, 1866, p. 249, pl. 7, fig. 95; HERMELIN, 1989, p. 65.

Uvigerina senticosa Cushman, 1927

Uvigerina senticosa CUSHMAN, 1927, p. 159, pl. 3, fig. 14.

Uvigerina spinicostata Cushman and Jarvis, 1929

Uvigerina spinicostata CUSHMAN and JARVIS, 1929, p. 12, pl. 3, figs. 9-10.

Uvigerina sp. 1

Uvigerina sp. 2

Superfamily FURSENKOINACEA Loeblich and Tappan, 1961

Family FURSENKOINIDAE Loeblich and Tappan, 1961

Genus *Suggrunda* Hoffmeister and Berry, 1937

Suggrunda sp. 1

Superfamily DISCORBACEA Ehrenberg, 1838

Family EPONIDIDAE Hofker, 1951

Subfamily EPONIDINAE Hofker, 1951

Genus *Alabaminella* Saidova, 1975

Alabaminella weddellensis (Earland, 1936)

Eponides weddellensis EARLAND, 1936, p. 57, pl. 1, figs. 65-67.

Nuttalides weddellensis (Earland) PATTERSON, 1986, p. 173, pl. 39, figs. 7-10.

Family SPHAEROIDINIDAE Cushman, 1927

Genus *Sphaeroidina* d'Orbigny, 1826

Sphaeroidina bulloides d'Orbigny, 1826

Sphaeroidina bulloides D'ORBIGNY, 1826, p. 267, no. 1, mod. no. 65; BARKER, 1960, pl. 84, figs. 1-2?, 5; HERMELIN, 1989, p. 58, pl. 5, figs. 16-17.

Superfamily GLABRATELLACEA Loeblich and Tappan, 1964

Family HERONALLENIIDAE Loeblich and Tappan, 1986

Genus *Heronallenia* Chapman and Parr, 1931

Heronallenia sp.1

Superfamily PLANORBULINACEA Schwager, 1877

Family CIBICIDIDAE Cushman, 1927

Subfamily CIBICIDINAE Cushman, 1927

Genus *Cibicidoides* Saidova, 1975

Cibicidoides bradyi (Trauth, 1918)

Truncatulina bradyi TRAUTH, 1918, p. 235; BRADY, 1884, op. cit., pl. 95, fig. 5.

Cibicides bradyi (Trauth) BARKER, 1960, p. 196, pl. 95, fig. 5; PFLUM and FRERICHS, 1976, pl. 3, figs. 6-7.

Cibicidoides bradyi (Trauth) VAN MORKHOVEN, BERGGREN, and EDWARDS, 1986, pl. 30, figs. 1-2; HERMELIN, 1989, p. 85, pl. 17, figs. 2-4.

Cibicidoides mundulus (Brady, Parker and Jones, 1888)

Truncatulina mundula BRADY, PARKER and JONES, 1888, p. 228, pl. 45, fig. 25.

Cibicides kullenbergi PLFUM and FRERICHS, 1976, pl. 2, figs. 6-8.

Cibicidoides mundulus (Brady, Parker and Jones) BARKER, 1960, p. 196, pl. 95, fig. 6; VAN MORKHOVEN, BERGGREN and EDWARDS, 1986, pl. 21, fig. 1.

Genus *Fontbotia* González-Donoso and Linares, 1970

Fontbotia wuellerstorfi (Schwager, 1866)

Anomalina wuellerstorfi SCHWAGER, 1866, p. 258, pl. 17, figs. 105, 107.

Planulina wuellerstorfi (Schwager) BARKER, 1960, p. 192, pl. 93, fig. 9; ENBYSK, 1960, pl. 16, fig. 12, pl. 17, figs. 1-2, 5-6; BARKER, 1960, pl. 93, fig. 9.

Cibicides wuellerstorfi (Schwager) PFLUM and FRERICHS, 1976, pl. 4, figs. 2-4.

Fontbotia wuellerstorfi (Schwager) LOEBLICH and TAPPAN, 1987, p. 583, pl. 634, figs. 10-12, pl. 635, figs. 1-3; CLARK, 1990, p. 325, pl. 5, figs. 1-3.

Genus *Lobatula* Fleming, 1828

Lobatula fletcheri (Galloway and Wissler, 1927)

Cibicides fletcheri GALLOWAY and WISSLER, 1927, p. 64, pl. 10, figs. 8-9.

Superfamily NONIONACEA Schultze, 1854

Family NONIONIDAE Schultze, 1854

Subfamily NONIONINAE Schultze, 1854

Genus *Haynesina* Banner and Culver, 1978

Haynesina sp. 1

Genus *Nonion* de Montfort, 1808

Nonion sp. 1

Genus *Nonionella* Cushman, 1926

Nonionella stella Cushman and Moyer, 1930

Nonionella miocenica Cushman subsp. *stella* CUSHMAN and MOYER, 1930, p. 56, pl. 7, fig. 17.

Subfamily ASTRONONIONINAE Saidova, 1981

Genus *Astrononion* Cushman and Edwards, 1937

Astrononion gallowayi Loeblich and Tappan, 1953

Astrononion gallowayi LOEBLICH and TAPPAN, 1953, [op. cit. p. 90, pl. 17, figs. 4-7, hypotypes] =*Astrononion stellatum* CUSHMAN and EDWARDS, 1937, p. 32, pl.

3, figs. 9-11=*Astrononion stelligerum* (d'Orbigny) CUSHMAN, 1948, op. cit. p. 55, pl. 6, fig. 6.

Subfamily PULLENIINAE Schwager, 1877

Genus *Melonis* de Montfort, 1808

Melonis barleeanum (Williamson, 1858)

Nonionina barleeana WILLIAMSON, 1858, p. 32, pl. 3, figs. 68-69.

Gavelinonion barleeanum (Williamson) BARKER, 1960, p. 224, pl. 109, figs. 8-9.

Melonis barleeanus (Williamson) PLFUM and FRERICHS, 1976, pl. 7, figs. 5-6.

Melonis barleeanum (Williamson) HERMELIN, 1989, p. 88, pl. 17, fig. 12; CLARK, 1990, p. 345, pl. 4, figs. 3-4.

Melonis pompiloides (Fichtel and Moll, 1798)

Nautilus pompiloides FICHTEL and MOLL, 1798, p. 31, pl. 2, fig. (a-c).

Melonis pompiloides (Fichtel and Moll) ENBYSK, 1960, pl. 10, figs. 21-22; PFLUM and FRERICHS, 1976, pl. 7, figs. 7-8; VAN MORKHOVEN, BERGGREN and EDWARDS, 1986, pls. 23A-E, figs. 1-2; HERMELIN, 1989, p. 88, pl. 17, figs. 13-14.

Genus *Pullenia* Parker and Jones, in Carpenter, Parker and Jones, 1862

Pullenia bulloides (d'Orbigny, 1826)

Nonionina bulloides D'ORBIGNY, 1826, p. 293, model no. 2.

Nonionina bulloides D'ORBIGNY, 1846, p. 107, pl. 5, figs. 9-10.

Pullenia sphaeroides (d'Orbigny) CUSHMAN, 1914, p. 20, pl. 11, fig. 2.

Pullenia bulloides (d'Orbigny) BARKER, 1960, p. 174, pl. 84, figs. 12-13; HERMELIN, 1989, p. 78, pl. 15, figs. 4-5; CLARK, 1990, p. 347, pl. 10, figs. 4-5.

Pullenia quinqueloba (Reuss, 1851)

Nonionina quinqueloba REUSS, 1851, p. 71, pl. 5, fig. 31.

Pullenia salisburyi R.E. Stewart and K. C. Stewart, 1930

Pullenia salisburyi STEWART and STEWART, 1930, p. 72, pl. 8, fig. 2; BURBIDGE, 1992, p. 38, pl. 1, figs. 6-7.

Pullenia sp.1

Superfamily CHILOSTOMELLACEA Brady, 1881

Family CHILOSTOMELLIDAE Brady, 1881

Subfamily CHILOSTOMELLINNAE Brady, 1881

Genus *Chilostomella* Reuss *in* Czyzek, 1849

Chilostomella oolina Schwager, 1878

Chilostomella oolina SCHWAGER, 1878, p. 513, pl. 1, fig. 16; BARKER, 1960, p. 112, pl. 55, figs. 14, 17-18, not 12-13; ENBYSK, 1960, pl. 21, figs. 21-23; BARKER, 1960, p. 112, pl. 55, figs. 12-14, 17-18; HERMELIN, 1989, p. 76, pl. 14, fig. 5.

Family QUADRIMORPHINIDAE Saidova, 1981

Genus *Quadrimorphina* Finlay, 1939

Quadrimorphina sp. 1

Family ORIDORSALIDAE Loeblich and Tappan, 1984b

Genus *Oridorsalis* Andersen, 1961

Oridorsalis umbonatus (Reuss, 1851)

Rotalina umbonatus REUSS, 1851, p. 75, pl. 5, fig. 35.

Truncatulina tenera BRADY, 1884, p. 665, pl. 95, fig. 11(a-c).

Eponides (?) *tenera* (Brady) BARKER, 1960, p. 196, pl. 95, fig. 11(a-c).

Eponides umbonatus (Reuss) BARKER, 1960, p. 216, pl. 105, fig. 2.

Oridorsalis tener tener (Brady) PFLUM and FRERICHS, 1976, pl. 6, figs. 2-4.

Oridorsalis tener umbonatus (Brady) PFLUM and FRERICHS, 1976, pl. 6, figs. 5-7.

Oridorsalis umbonatus (Reuss) CLARK, 1990, p. 355, pl. 8, figs. 1-6.

Family GAVELINELLIDAE Hofker, 1956

Subfamily GYROIDINOIDNAE Saidova, 1981

Genus *Gyroidinoides* Brotzen, 1942

Gyroidinoides neosoldanii (Brotzen, 1936)

Rotalia soldanii (d'Orbigny)BRADY, 1884, p. 706, pl. 107, fig. 6(a-c), 7(a-c) (not *Rotalia soldanii* D'ORBIGNY, 1826).

Gyroidina neosoldanii BROTZEN, 1936, p. 158; BARKER, 1960, pl. 107, figs. 6-7.

Subfamily GAVELINELLINAE Hofker, 1956

Genus *Gyroidina* d'Orbigny, 1826

Gyroidina altiformis R.E. Stewart & K. C. Stewart, 1930

Gyroidina soldanii d'Orbigny subsp. *altiformis* STEWART and STEWART, 1930, p. 67, pl. 9, fig. 2(a-c).

Gyroidina spp.

Superfamily ROTALIACEA Ehrenberg, 1839

Family ELPHIDIIDAE Galloway, 1933

Subfamily ELPHIDIINAE Galloway, 1933

Genus *Cribroelphidium* Cushman and Brönnimann, 1948

Cribroelphidium foraminosum (Cushman, 1939)

Elphidium hughesi subsp. *foraminosum* CUSHMAN, 1939, p. 49, pl. 13, figs. 8(a-b).

Genus *Elphidiella* Cushman, 1936b

Elphidiella hannai (Cushman and Grant, 1927)

Elphidium hannai CUSHMAN and GRANT, 1927, p, 77, pl. 8, figs. 1-2.

Generic Taxa Erroneously Regarded as Foraminifers (according to Loeblich and Tappan, 1987):

Class Xenophyophorea

Genus *Aschemonella* Brady, 1879

Aschemonella scabra Brady, 1879

Aschemonella scabra BRADY, 1879, p. 44; LOEBLICH and TAPPAN, 1987, p. 726, pl. 42, figs. 17-18.

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NBS 1010a ANSI/ISO #2 EQUIVALENT

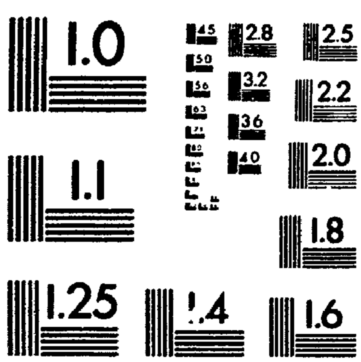

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PLATE 1

Plate 1

1. *Micrometula* sp., sample Tul 89D-17, x80
2. *Nodellum membranaceum* (Brady), sample Tul 89D-22, x130
3. *Resigella moniliformis* (Resig), sample Tul 89D-22, x430

4a, b. *Bathysiphon rufum* de Folin, sample ALV 2468-1, a. x16, b. detail of test surface, x2700

5. *Bathysiphon* sp. 1, sample HYS 198-2319, x80
6. *Marsipella elongata* Norman, sample Tul 89D-22, x150
7. *Rhabdammina* sp. 1, sample HYS 199-2726, x60
8. *Rhabdammina* sp. 2, sample ALV 2468-1, x75
9. *Rhabdammina* sp. 3, sample HYS 199-2726, x55
10. *Rhabdammina* sp. 4, sample HYS 198-2319, x100
11. *Rhabdammina* sp. 6, sample HYS 199-2726, x55
12. *Rhabdammina* sp. 7, sample HYS 199-2726, x65

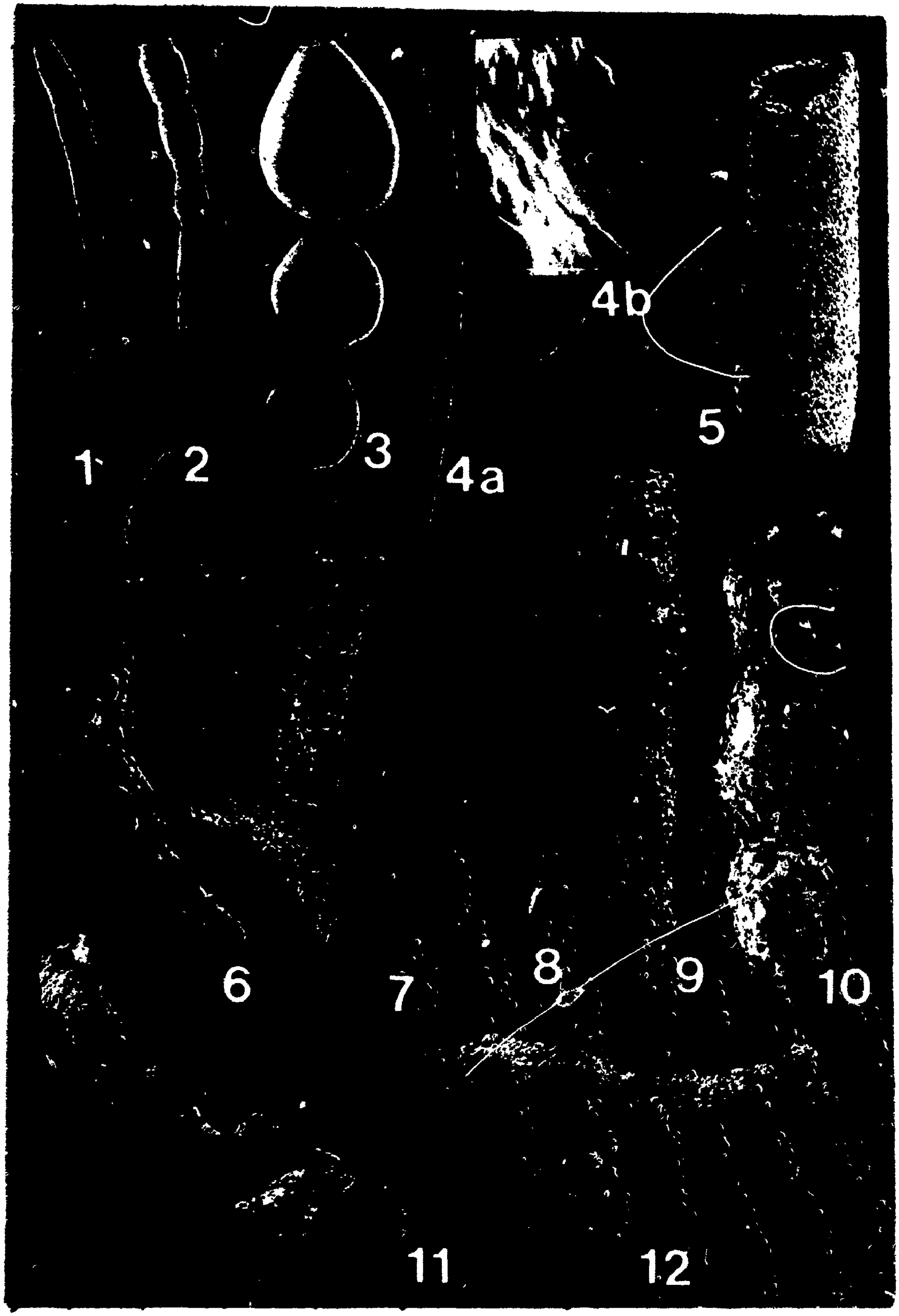
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PLATE 2

Plate 2

1. *Rhizammina algaeformis* Brady, sample Tul 89D-22, x140
2. *Thuramminopsis* sp. 1, sample Tul 89D-22, x200
3. *Lagenammina tubulata* (Rhumbler), sample Tul 89D-17, x330
4. *Saccammina socialis* Brady, sample HYS 192-0232, x250
5. *Saccammina sphaerica* Brady, sample HYS 198-2319, x160

6, 7. *Astrammina rara* Rhumbler, 6. sample Tul 89D-22, x230; 7. sample Tul 89D-17, x230

8. *Thurammina favosa* Flint, sample Tul 89D-17, x190
9. *Thurammina papillata* Brady, sample Tul 89D-17, x160

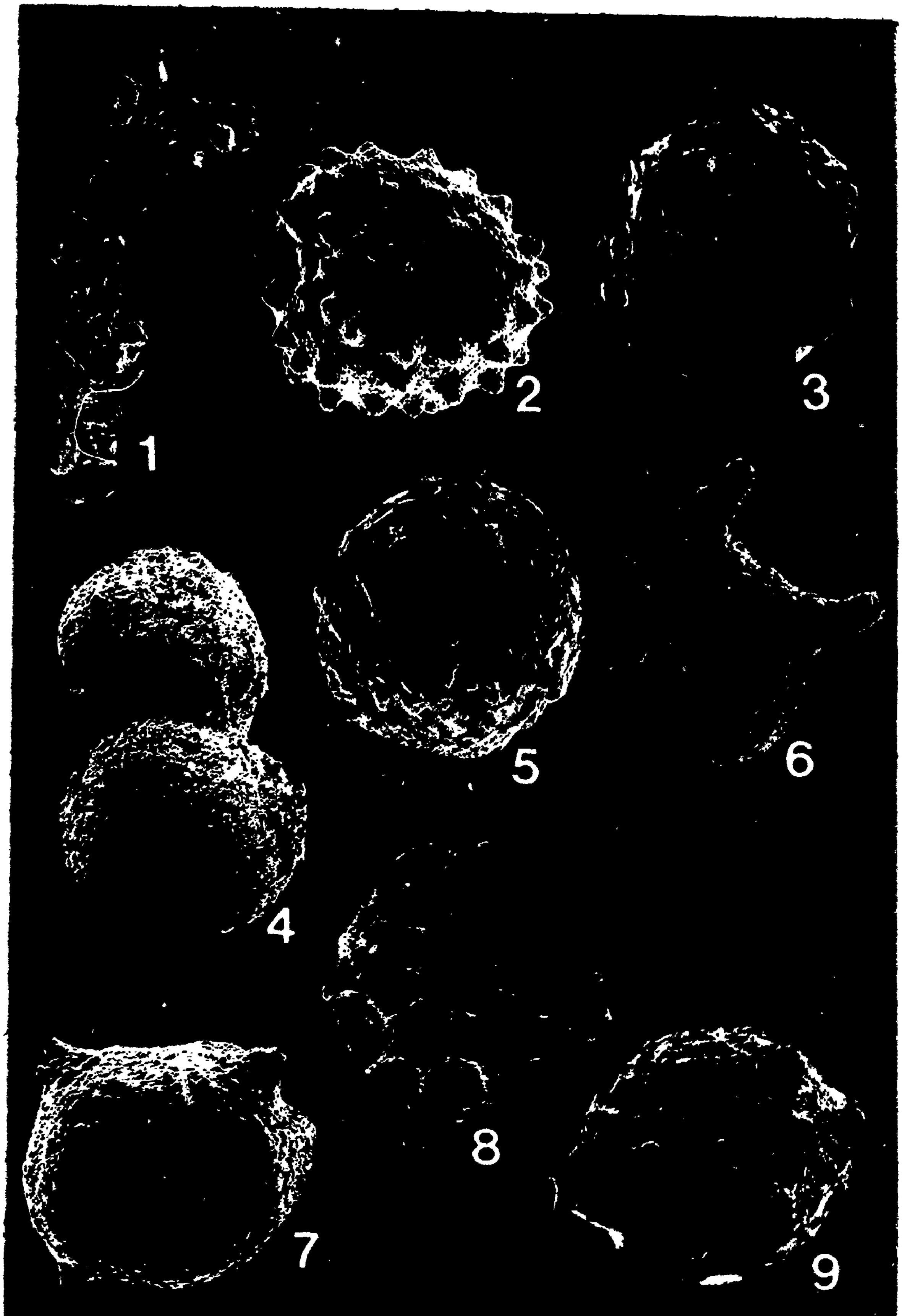
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PLATE 3

Plate 3

1. *Thurammina papillata* Brady, sample HYS 196-1405, x200; specimen is attached to a piece of anhydrite
2. *Thurammina* sp. 1, sample HYS 196-1405, x130
3. *Tholosina bulla* (Brady), sample HYS 199-2726, x350
4. *Hyperammina* sp. 1 Tul 89D-17 x160
5. *Ammodiscus cretaceus* (Reuss) ALV 2468 x100
6. *Ammodiscus incertus* (d'Orbigny), micospheric generation , sample Tul 89D-17, x270
7. *Ammodiscus incertus* (d'Orbigny), megalospheric generation, sample ALV 2468-1, x100
8. *Ammodiscus* sp. 1, sample Tul 89D-25, x150

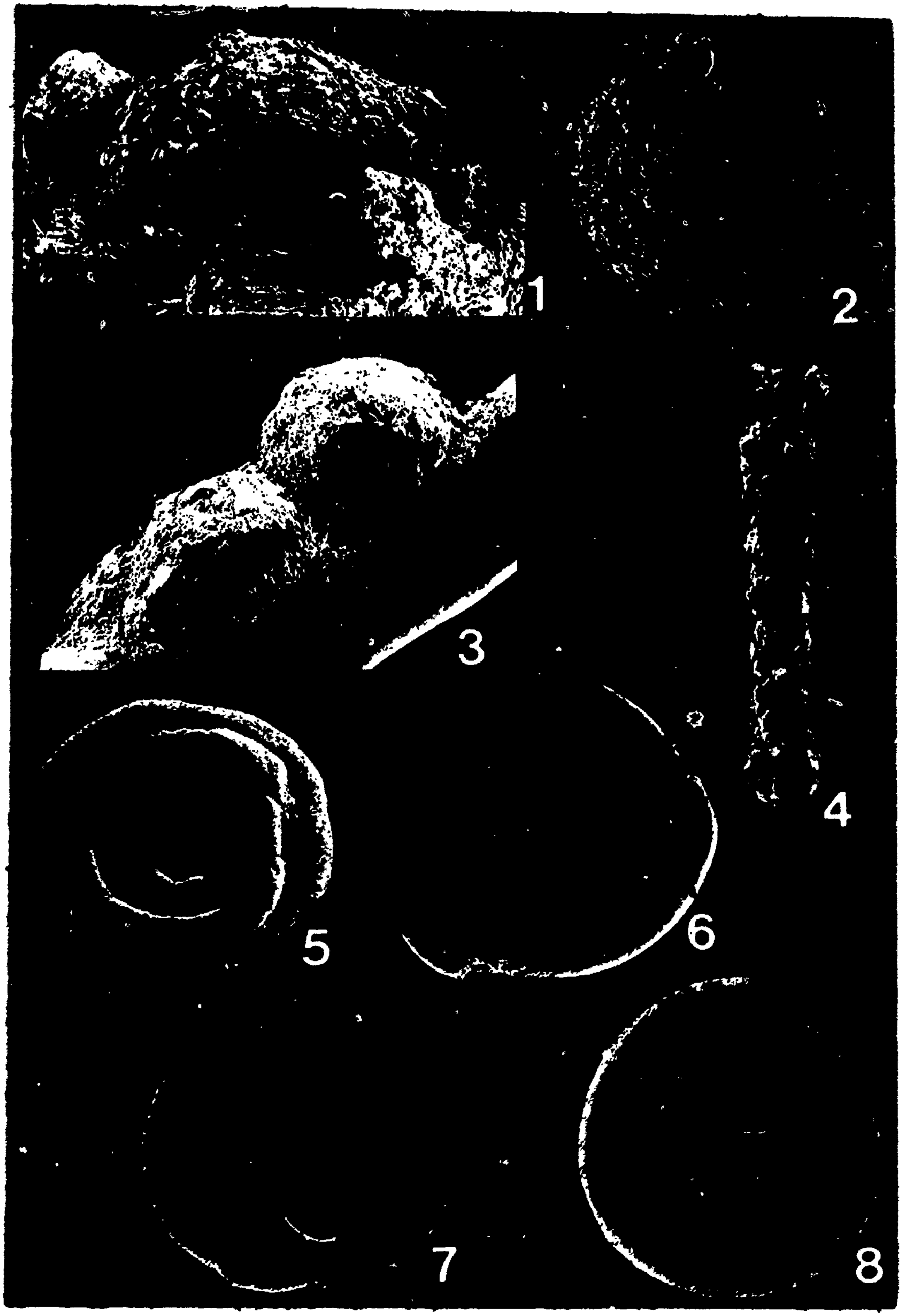
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PLATE 4

Plate 4

1. *Tolypammina vagans* (Brady), sample HYS 199-2726, x100
2. *Glomospira gordialis* (Jones & Parker) Tul 89D-17 x450
3. *Glomospira* sp. 1, sample Tul 89D-22, x250

4a, b. *Repmanina charoides* (Jones & Parker), sample Tul 89D-17 a. x370; b. x400

5. *Hormosinella distans* (Brady), sample HYS 192-0232, x60
6. *Reophanus ovicula* (Brady) , sample Tul 89D-25, x40
7. *Nodulina dentaliniformis* (Brady), sample Tul 89D-22, x230
8. *Loeblichopsis cylindrica* (Brady), sample Tul 89D-22, x190
9. *Reophax difflugiformis* Brady, sample Tul 89D-17, x300

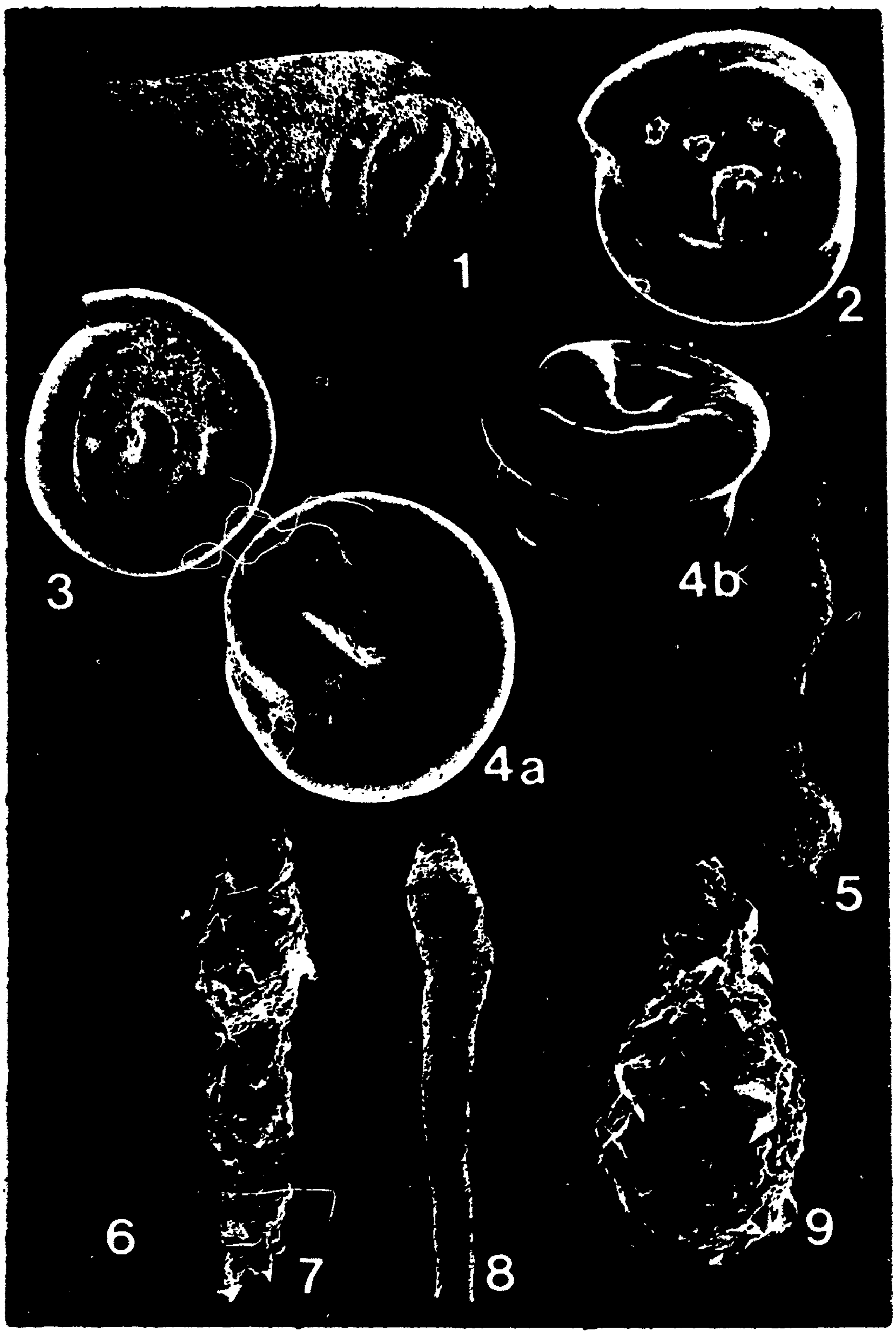
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PLATE 5

Plate 5

1. *Reophax guttifer* Brady, sample Tul 89D-22, x200
2. *Reophax pilulifera* Brady, sample HYS 192-0232, x250
3. *Reophax scorpiurus* de Montfort, sample Tul 89D-17, x250
4. *Reophax* sp. 1, sample Tul 89D-22, x200
5. *Subreophax adunca* (Brady), sample Tul 89D-17, x250

6, 7. *Hormosina globulifera* Brady, 6. sample Tul 89D-22, x80; 7. sample ALV 2468 -1, x65

8. *Cribrostomoides subglobosus* (G. O. Sars), sample ALV 2468, x65
9. *Cribrostomoides wiesneri* (Parr), sample Tul 89D-22, x330
10. *Evolutinella rotulata* (Brady), sample HYS 199-2726, x85

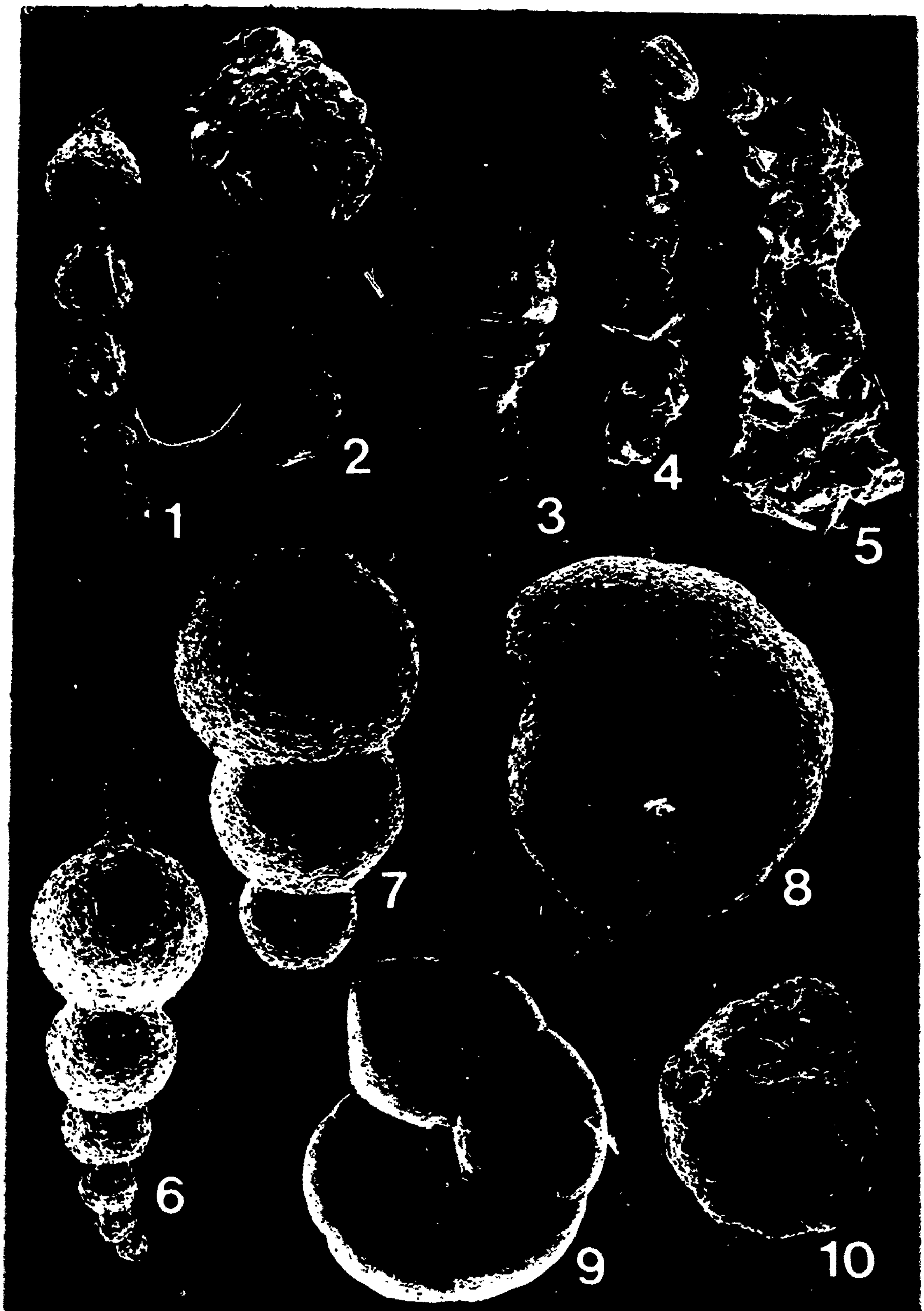
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PLATE 6

Plate 6

1. *Labrospira scitula* (Brady), sample ALV 2468-1, x95
2. *Glaphyrammina americanus* (Cushman), sample HYS 196-2319, x330
3. *Lituotuba lituiformis* (Brady), sample Tul 89D-22, x200
4. *Ammobaculites agglutinans* (d'Orbigny), sample Tul 89D-25, x200
5. *Ammobaculites agglutinans* var. *filiformis* Earland, sample Tul 89D-22, x220
6. *Ammobaculites agglutinans* var. 1, sample Tul 89D-26, x350
7. *Kutsevella* sp., sample Tul 89D-17, x130

8, 9. *Eratidus foliaceus* (Brady) 8. sample HYS 199-2726, x200; 9. sample Tul 89D-17, x220

10. *Adercotryma glomerata* (Brady), sample Tul 89D-17, x300
11. *Cystammina pauciloculata* (Brady), sample Tul 89D-17, x330


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PLATE 7

Plate 7

1. *Recurvoides contortus* Earland, sample ALV 2468-1, x110
2a, b. *Recurvoides turbinatus* (Brady), sample ALV 2468-1, a. x95
3a, b. *Ammoglobigerina globigeriniformis* (Parker and Jones), sample ALV 2468-1
a. dorsal side, x120; b. ventral side, x110
4. *Trochammina globulosa* Cushman, sample HYS 199-2726, x120
5. *Trochammina* sp. 1, sample Tul 89D-25, x500
6. *Prolixoplecta exilis* (Cushman), sample Tul 89D-17, x330
7. *Eggerella advena* (Cushman), sample Tul 89D-26, x650
8. *Eggerella bradyi* (Cushman), sample Tul 89D-17, x200

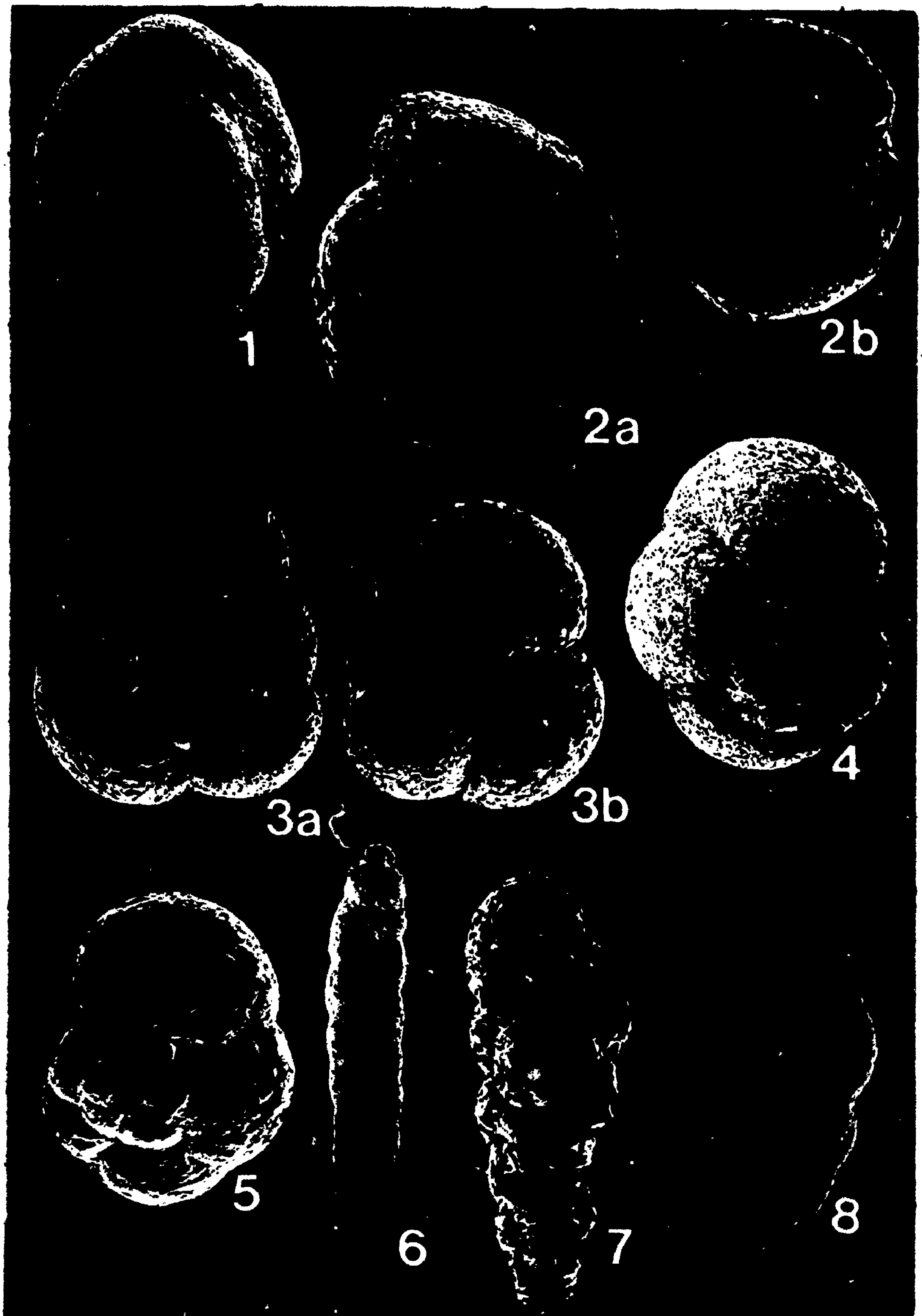
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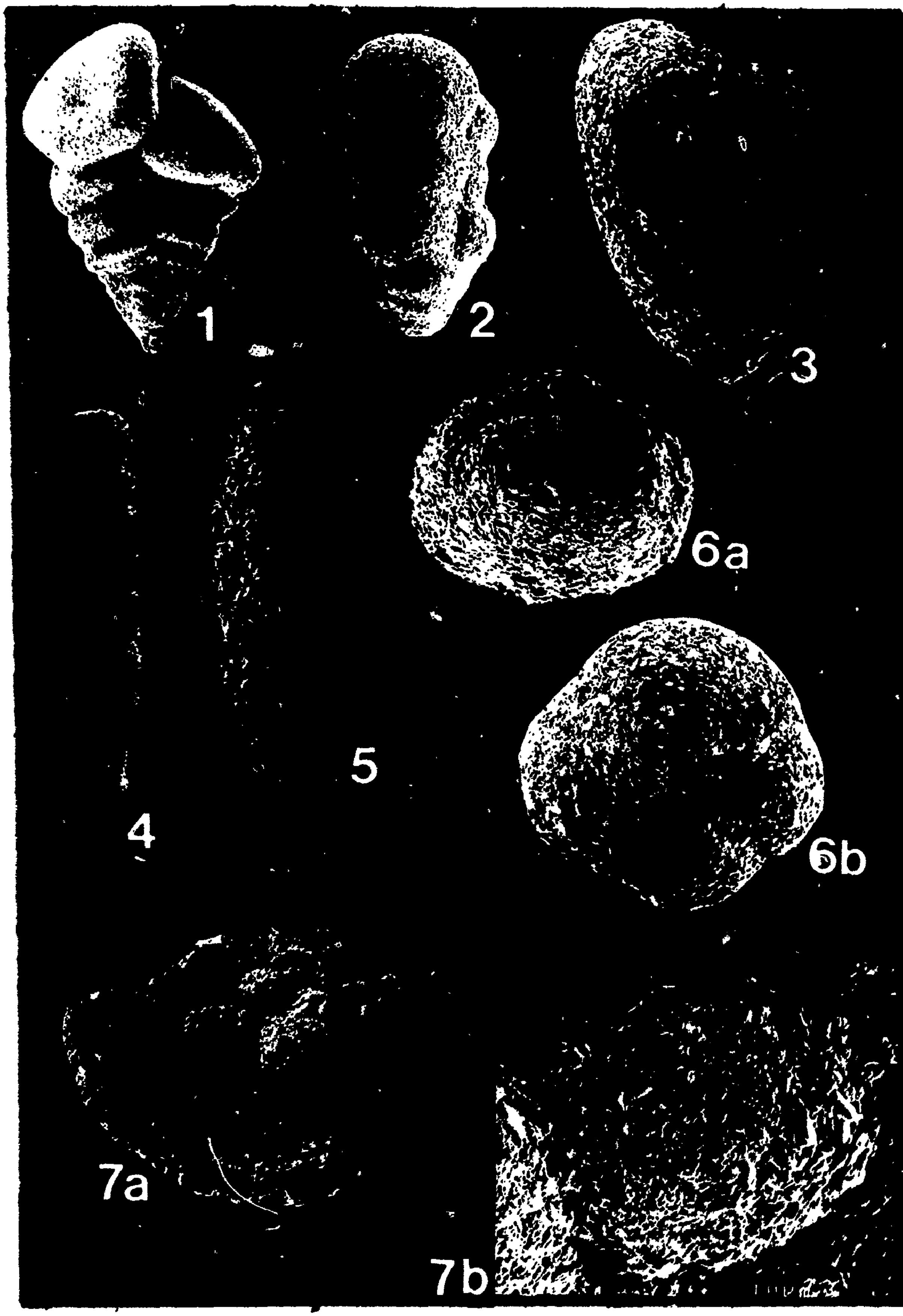
PLATE 8

Plate 8

1. *Karreriella bradyi* (Cushman), sample HYS 199-2726, x75
2. *Karreriella* sp.1, sample HYS 198-2319, x120
3. *Karreriella* sp. 2, sample HYS 198-2319, x120
4. *Martinotiella bradyana* (Cushman), sample ALV 2468-1, x33
5. *Cylindroclavulina bradyi* (Cushman), sample Tul 89D-17, x100
6. unknown species 1, sample HYS 198-2319, a. x160; b. x180 apertural view
7. unknown species 2, attached to interior of broken test, sample HYS 196-1405, a. x160; b. x650 (close-up of one chamber)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6a
6b
7a
7b

PLATE 9

Plate 9

Figure 1. Unaltered hemipelagic mud near Inspired Mounds (HYS 196-1641), showing minor bioturbation (trails and small burrows a few centimetres in diameter).

Figure 2. Altered hydrothermal mud (viz. samples TUL 89D-17, TUL 89D-22, TUL 89D-25 and ALV 2468-1). Large (up to 10 cm) shrimp burrows occur in areas of higher heat flow near each hydrothermal mound.

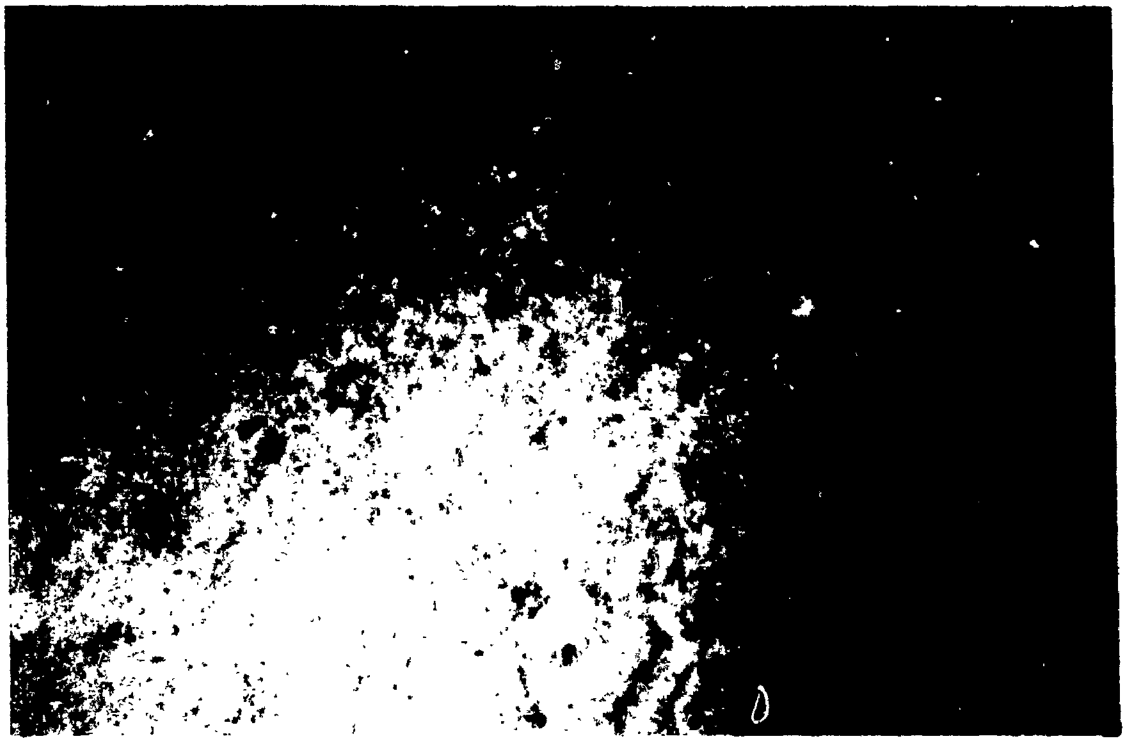


PLATE 10

Plate 10

Figure 1. Indurated mud and talus, derived from the mound at Chowder Hill, at the edge of the clam bed (HYS 192-0416), "Club Clam". A variety of organisms which inhabit the warm ground, including the worms, crabs, and clams, can be seen in this photo.

Figure 2. The clam bed at Chowder Hill is densely populated with the symbiotic clam *Calyptogena* which thrive in the sulphidic sediments. Live clams bury their anterior ends in the sediment. This photo shows location of sample HYS 199-2410.


1

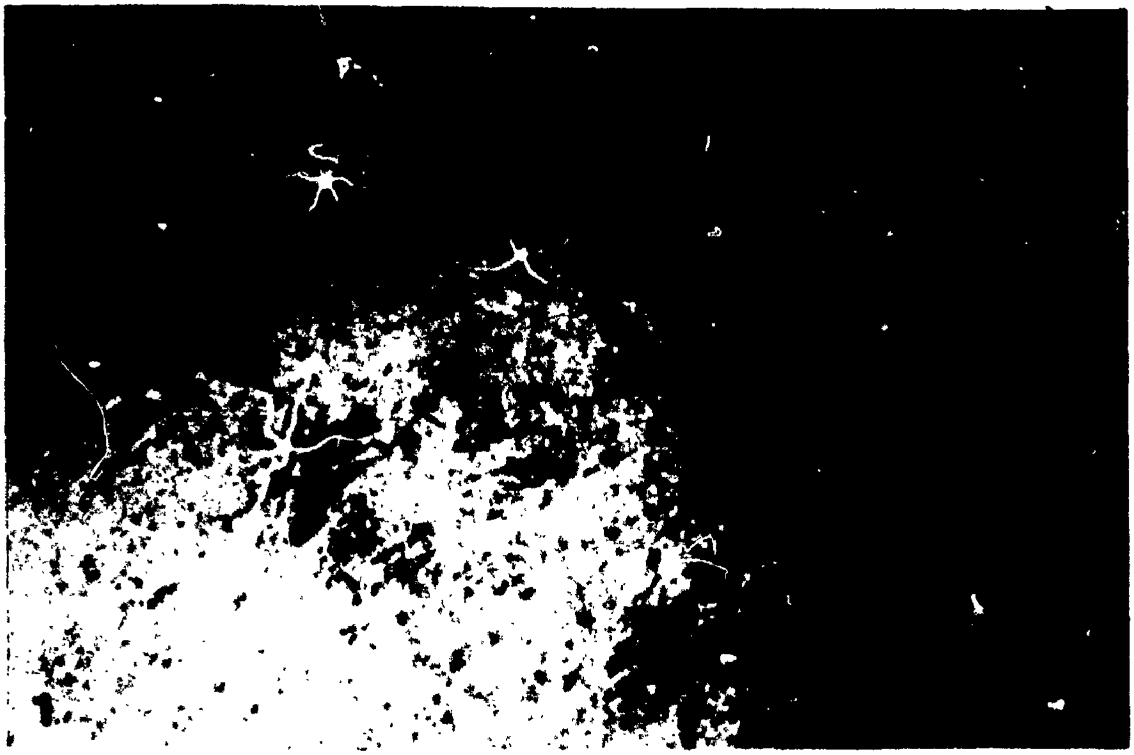

2

PLATE 11

Plate 11

Figure 1. Indurated sediment on the apron of Dead Dog hydrothermal vent (HYS 192-0232). Brittle stars and sea lilies (crinoids) are visible on the baked mud.

Figure 2. The base of the chimney at Inspired Mounds is the sampling site for HYS 196-1459. The chimney in the right foreground is emitting a vent fluid with a temperature of 254°C.



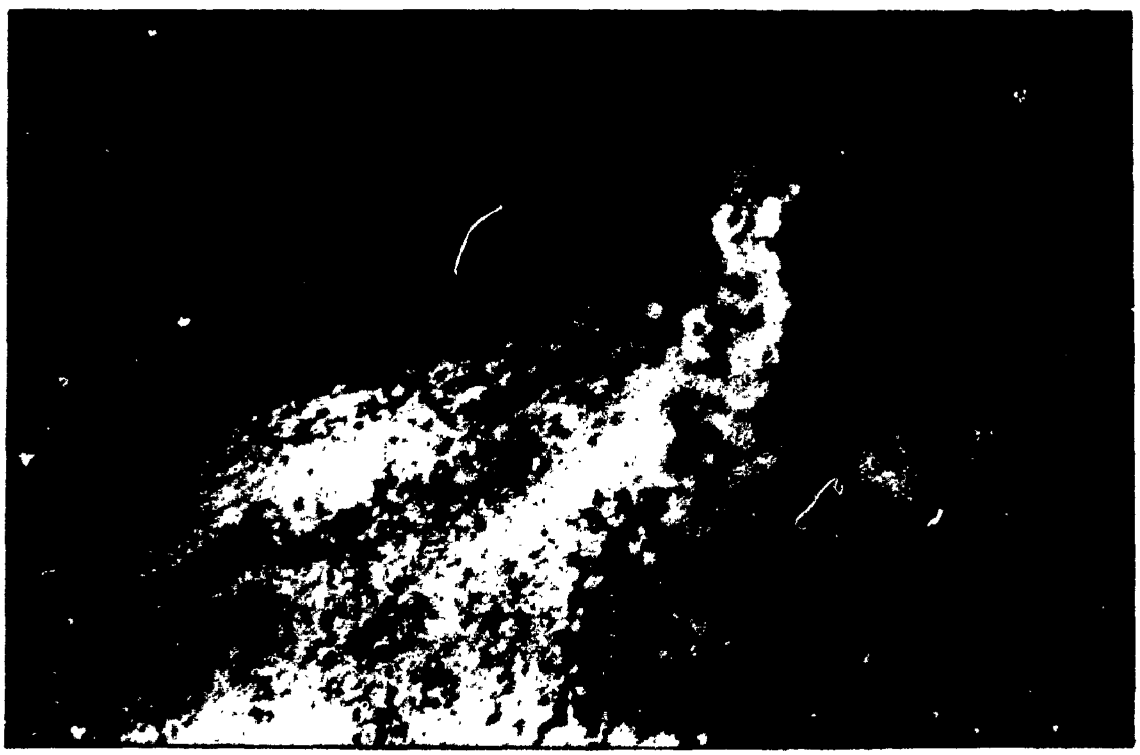


PLATE 12

Plate 12

All specimens from Expired Vent HYS 199-2726B.

1, 2. A specimen of *Ropostrum amuletum* Jonasson, attached to the indurated sediment, x170; 2. Detail of test of central globular chamber of *Ropostrum amuletum* , showing sponge spicules, calcareous foraminifers, broken debris of diatoms, and radiolarians incorporated into the test, x1400

3. View inside globular chamber of *Ropostrum amuletum*, x500

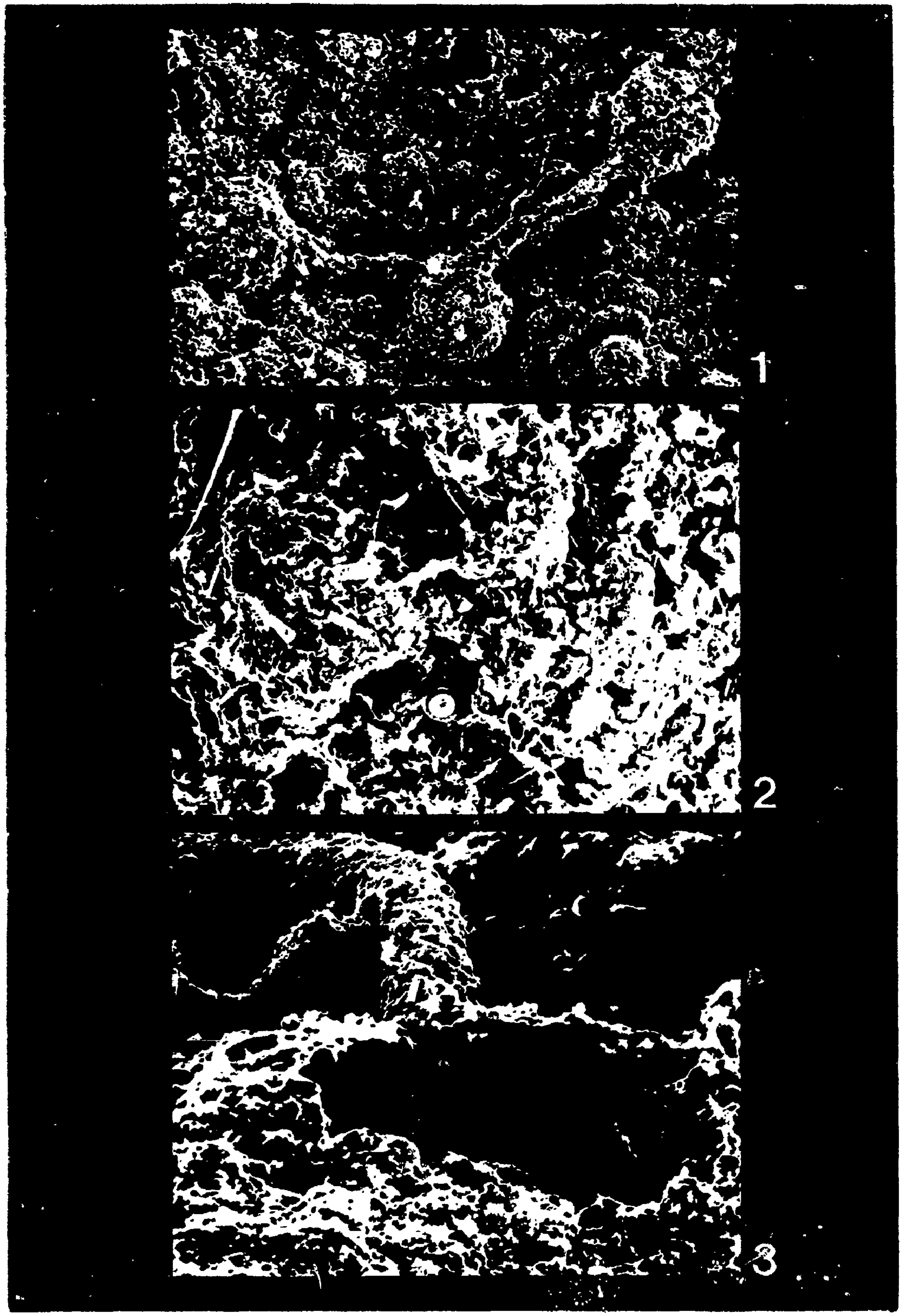

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PLATE 13

Plate 13

All specimens from Expired Vent HYS 199-2726B.

1-3. A specimen of *Ropostrum kradeopsis* Jonasson, x80; 2. View of irregular elongate chambers of *Ropostrum kradeopsis,* x250. Opening at lower chamber might reflect aperture; 3. Detail of surface from a more globular chamber of *Ropostrum kradeopsis*, x350.

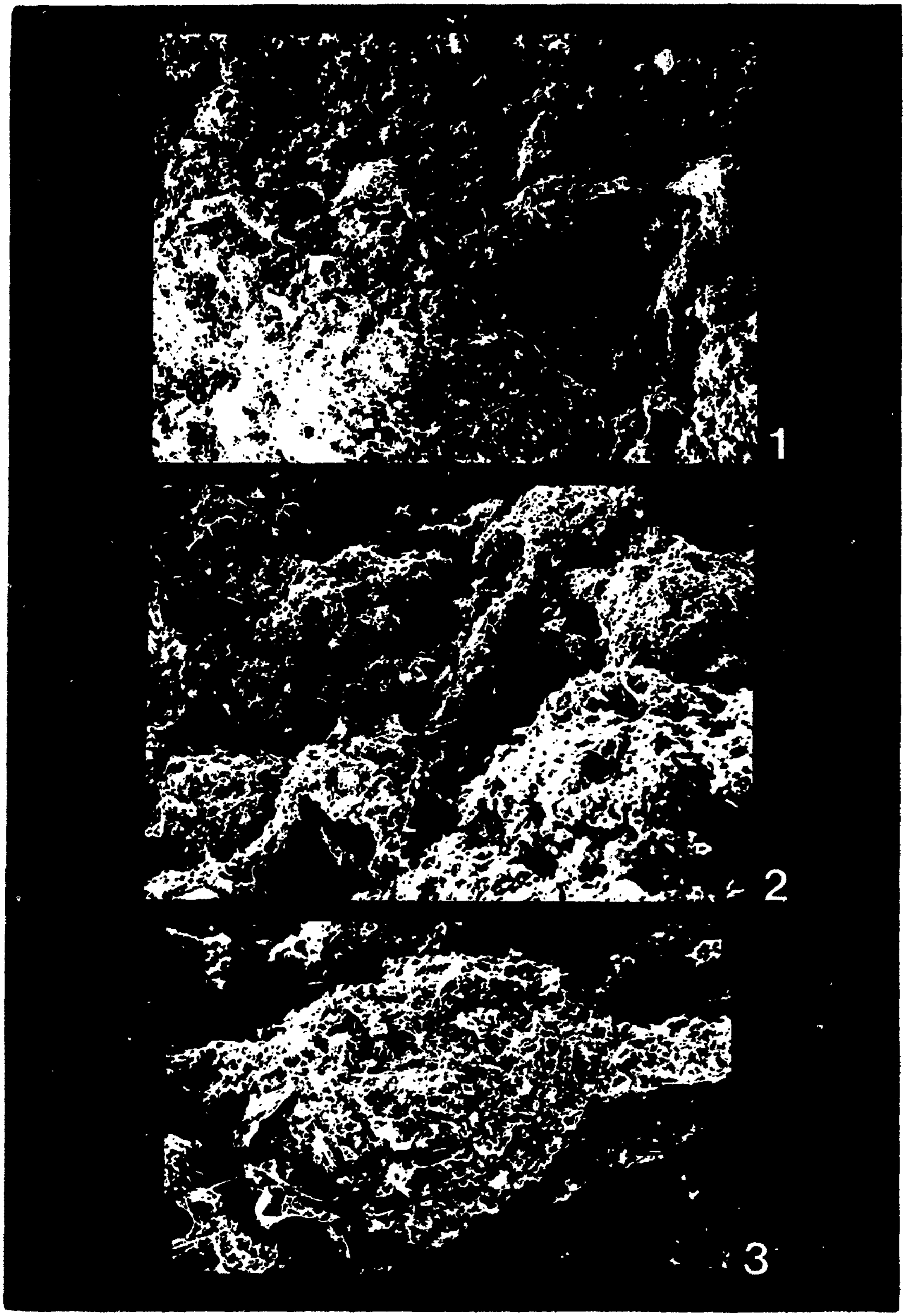
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PLATE 14

Plate 14

1. Unidentified species of the subfamily Reophacinae from the hydrocarbon chimney sample ALV 2254-21, x 25

2, 3. *Lana spissa* Schröder-Adams, Medioli and Scott - Expired Vent HYS 199-2726B, x40; 3. Detail of branches, x140

4. An unidentified attached species of the superfamily Komokiacea - Expired Vent HYS 199-2726B, x40


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PLATE 15

Plate 15

All specimens from Expired Vent, HYS 199-2726B.

1. Overview of a sample from indurated sediment showing several specimens of *Ropostrum amuletum*, *Ropostr: :n kradeopsis*, and *Tolypammina vagans*, x30

2. View of a sample from indurated sediment with an attached specimen of *Tolypammina vagans* and an unknown agglutinated species with irregular globular chambers, x130

3. An unidentified species of the family Lituolidae, x150

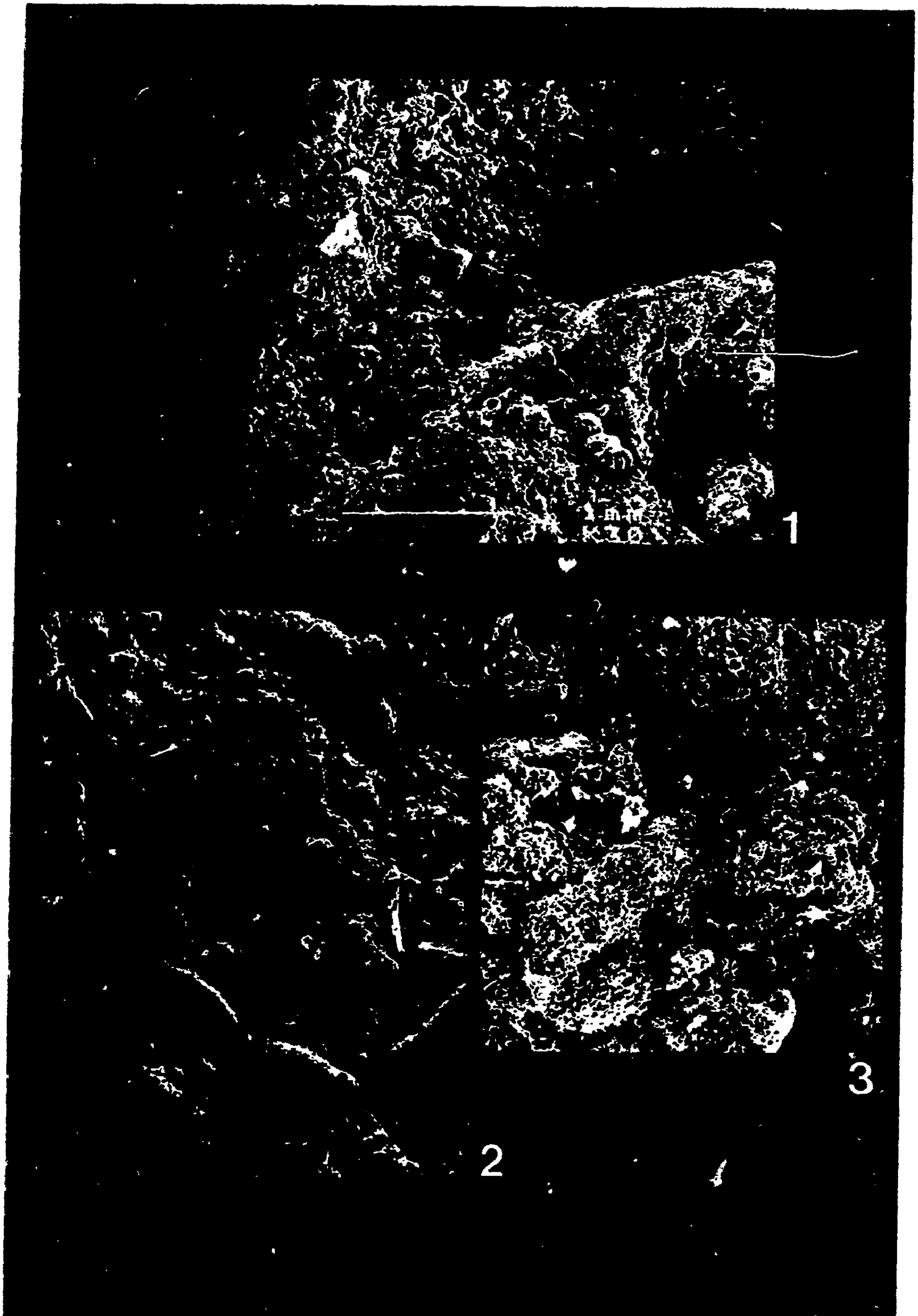
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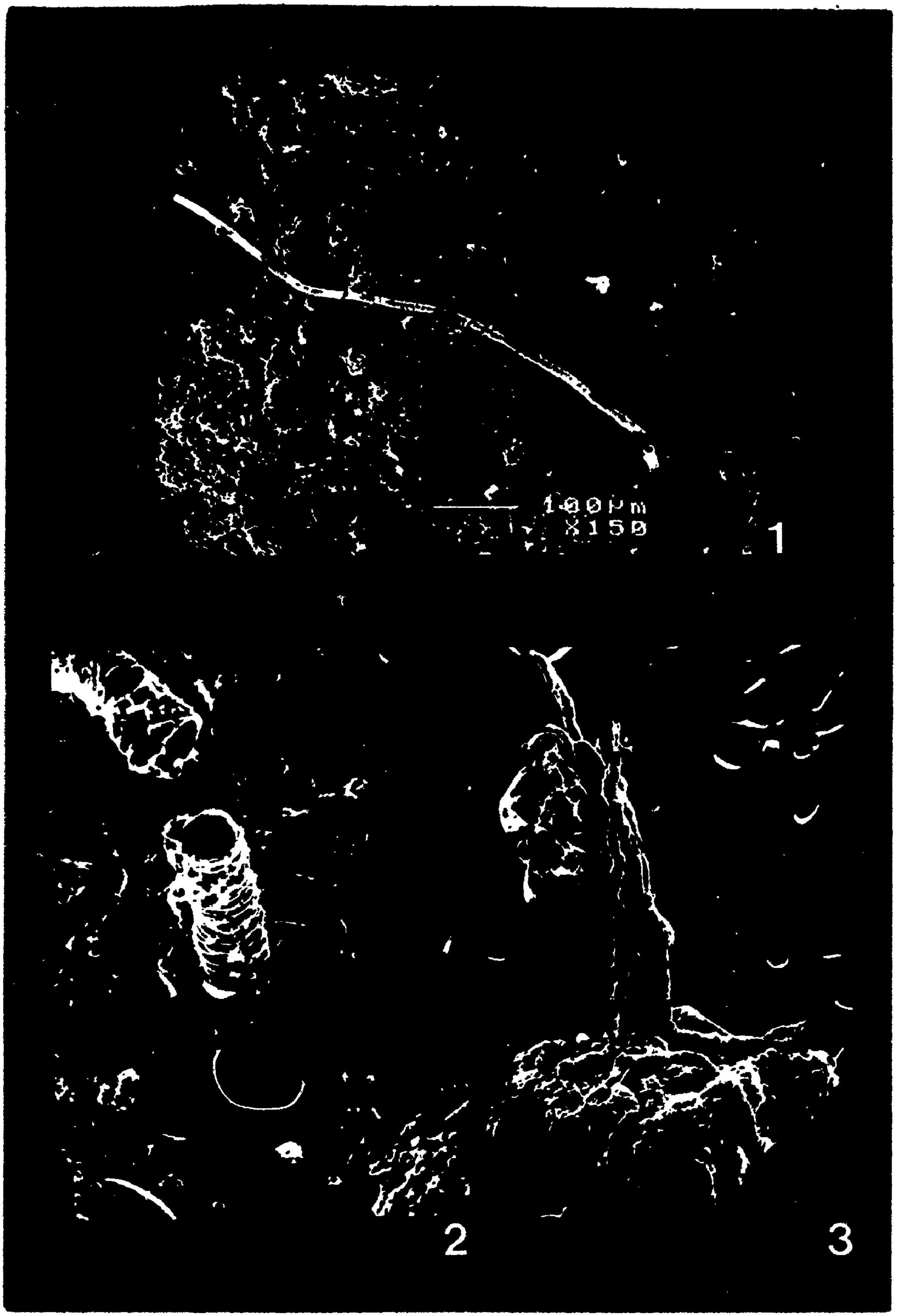
PLATE 16

Plate 16

1, 2. Overview of an unidentified siliceous tubular organism from Expired Vent, sample HYS 199-2726B, x150; 2. Detail of basal attachment, x 1000

3. Unidentified branched species from Snowball Vent, sample HYS 199-2708B, x35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