A new Cenozoic forminiferal biostratigraphy, paleoecology (biofacies) and strontium isotope study of Shell Canada exploration wells from the Tofino Basin, offshore Vancouver Island, British Columbia

By

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ABSTRACT

During the past thirty years hydrocarbon exploration has been suspended within the coastal waters of British Columbia by a moratorium imposed by the Province of British Columbia and Government of Canada. During the late 1960's, Shell Canada Ltd. drilled and abandoned six exploratory wells (Shell Canada Apollo J-14, Zeus I-65, Zeus D-14, Prometheus H-68 and Cygnet J-100 wells) in the Tofino Basin (TB). Currently, with the possibility of the moratorium being lifted, there is renewed interest in reassessing energy resource potentials and in understanding the geology and tectonic evolution of this region.

Shell Canada's large database of drill cutting (microfossil) subsamples were previously studied to develop preliminary stratigraphic ages, but no detailed taxonomic studies were carried out. This present micopaleontological study of Cenozoic foraminifers was initiated by the SSHRC/NSERC Coasts Under Stress Project. Through reassessment of the existing Shell Canada well samples, made available by the Geological Survey of Canada, Pacific, this study examines the thick Cenozoic clastic marine sequence in TB and provides: 1) the first detailed taxonomic descriptions and SEM illustrations of Cenozoic TB foraminifers, 2) clarification and refinement to the stratigraphic ages and paleoenvironments, 3) new strontium (Sr) isotope age data and 4) correlation potentials with Vancouver Island and other North American sequences.

A database of over 2000 Shell Canada drill cutting subsamples of foraminifer microfossil slides, from the six Shell wells and several Eocene and Oligocene (Carmanah

Group) surface samples from western Vancouver Island, were examined. Detailed taxonomic study of 159 foraminifer species (141 benthic and 18 planktic) and their distributions supports a diverse Northeast Pacific faunal assemblage and contributes to the first TB offshore biostratigraphy. Eleven new and/or redefined foraminifer interval zones are defined, based on last appearance datums (LADs) of short-ranging taxa and range from the late Eocene/Oligocene to the Holocene. These are the *Cassidulina galvanensis*, *Turrilina alsatica*, *Rectuvigerina branneri*, *Baggina washingtonensis*, *Bolivina wissleri*, *Uvigerina hootsi*, *Bulimina subacuminata*, *Elphidiella hannai*, *Uvigerina peregrina* and *Cassidulina reniforme*/*Cribroelphidium excavatum* f. *clavatum* zones. Correlations of the late Eocene/Oligocene strata within the TB with Vancouver Island (Carmanah Group) Eocene and Oligocene strata (*C. galvanensis* and *T. alsatica* zones) are possible.

The diverse assemblage of foraminiferal taxa within the TB wells, represents biofacies that range from the inner neritic (0-50 m) to the lower bathyal (2,000 m+). Paleobathymetric estimates from biofacies changes indicate a shoaling upwards trend throughout the Oligocene with deep biofacies encountered during the early Miocene and early Pliocene, reflecting a major transgression. Late Pliocene-Pleistocene inner to outer neritic biofacies, cool-water faunal assemblages and coarser-grained lithology indicate a regressive phase and regional onset of glaciation.

Initial Sr isotope analysis of 31 onshore and 44 offshore taxa-samples resulted in successful offshore Sr ages ranging from 37.3 Ma (million years; late Eocene) to 1.3 Ma (Pleistocene). Results nearly complement the foraminiferal biostratigraphy and provide improved resolution. Age reversals within Oligocene and Miocene strata indicate apparent stratigraphic reversals. Strontium isotope studies were successful in the TB but proved unsuitable for onshore samples, suggesting possible contamination and/or overprinting by pore-fluids from Jurassic and Pleistocene strata. Only a single onshore sample yielded a Late Eocene age of 37.8 Ma.

Since the Eocene, the TB has undergone episodic uplift, tectonic underthrusting, climatic cooling and eustatic fluctuations resulting in complex facies changes and stratigraphic breaks and structural complexities. New and/or updated biostratigraphic and combined Sr isotope results provide significant tools for constraining regional geological events and in providing improved/high resolution analysis, correlations and paleoenvironmental interpretations. These results provide baseline data for future taxonomic and biostratigraphic studies in regional basins, and provide essential information for basin modeling and energy resource assessment.

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1. INTRODUCTION

1.1. West Coast Cenozoic basins

The Tofino (TB) and Queen Charlotte (QC) basins and adjacent shelf areas, along the westcoast of Canada (Figure 1.1), are situated along the tectonically active North American margin (Figure 1.2; Engebretson et al., 1985; Atwater, 1990; Yorath et al., 1999). Both basins evolved throughout the Mesozoic and Cenozoic eras and have complex tectonostratigraphic histories (Shouldice, 1971; Tiffin et al., 1972; Murray and Tiffin, 1974; Yorath et al., 1999; Hannigan et al., 2001; Johnston and Acton, in press). Diverse and disputed depositional environments (Jeletzky, 1973; Cameron, 1980), represented in isolated outcrops along western Vancouver Island, extend offshore into the TB and demonstrate fluctuations in sea level (Shouldice, 1971; Haq et al., 1988) and episodes of tectonic uplift and faulting (Shouldice, 1971; Tiffin et al., 1972; Yorath et al., 1999; Johnston and Acton, in press).

From this study of the TB, analogies can be made with other offshore basins. The Taranaki Basin, for example, located offshore New Zealand has a complex sedimentary and tectonic history throughout much of the Cenozoic (King and Thrasher, 1996). The Tofino and Taranaki basins share similarities with respect to being formed and influenced by episodic tectonism and eustatic changes, and in preserving a thick sequence of Cenozoic strata with similar microfaunas (Hayward et al., 1999). Their geological history and evolution is significant for potential hydrocarbon exploration, but the TB has had only limited exploration activity (Hannigan et al., 2001), whereas the Taranaki Basin has had moderate initial exploration (King and Thrasher, 1996). Recently, interest in offshore basins has been expanding worldwide and is influenced by regional economic significance and advances in geophysical data (seismic reflection) complementing geological (tectonics, sequence stratigraphy) and micropaleontological (e.g. foraminifers, palynomorphs, diatoms, and ichthyoliths) studies.

1.2. Previous offshore exploration and present initiatives

Shell Canada's west coast exploration program in Hecate Strait, Queen Charlotte and Tofino basins (Figure 1.1), began in 1963 and ended in 1969, without encountering any

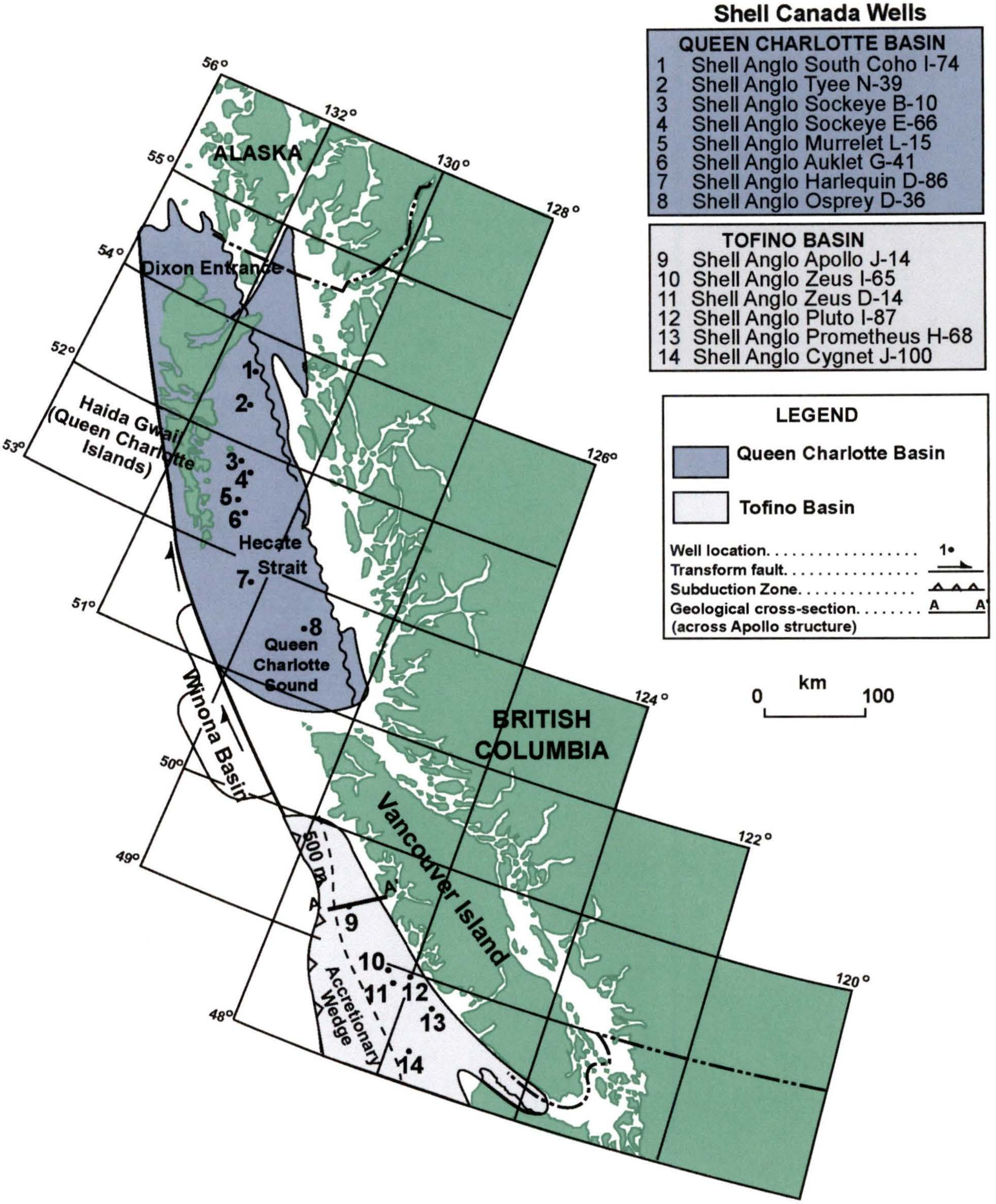


Figure 1.1. Map of the Tofino and Queen Charlotte basins with the location of 14 wells drilled in the late 1960's as part of Shell Canada's west coast exploration program. The approximate location of the accretionary wedge, Winona Basin and Hecate Strait are shown. In the Tofino Basin a geological cross-section was made to study the Apollo structure (from A to A'; Yorath, 1980) (modified from Hannigan et al., 2001).

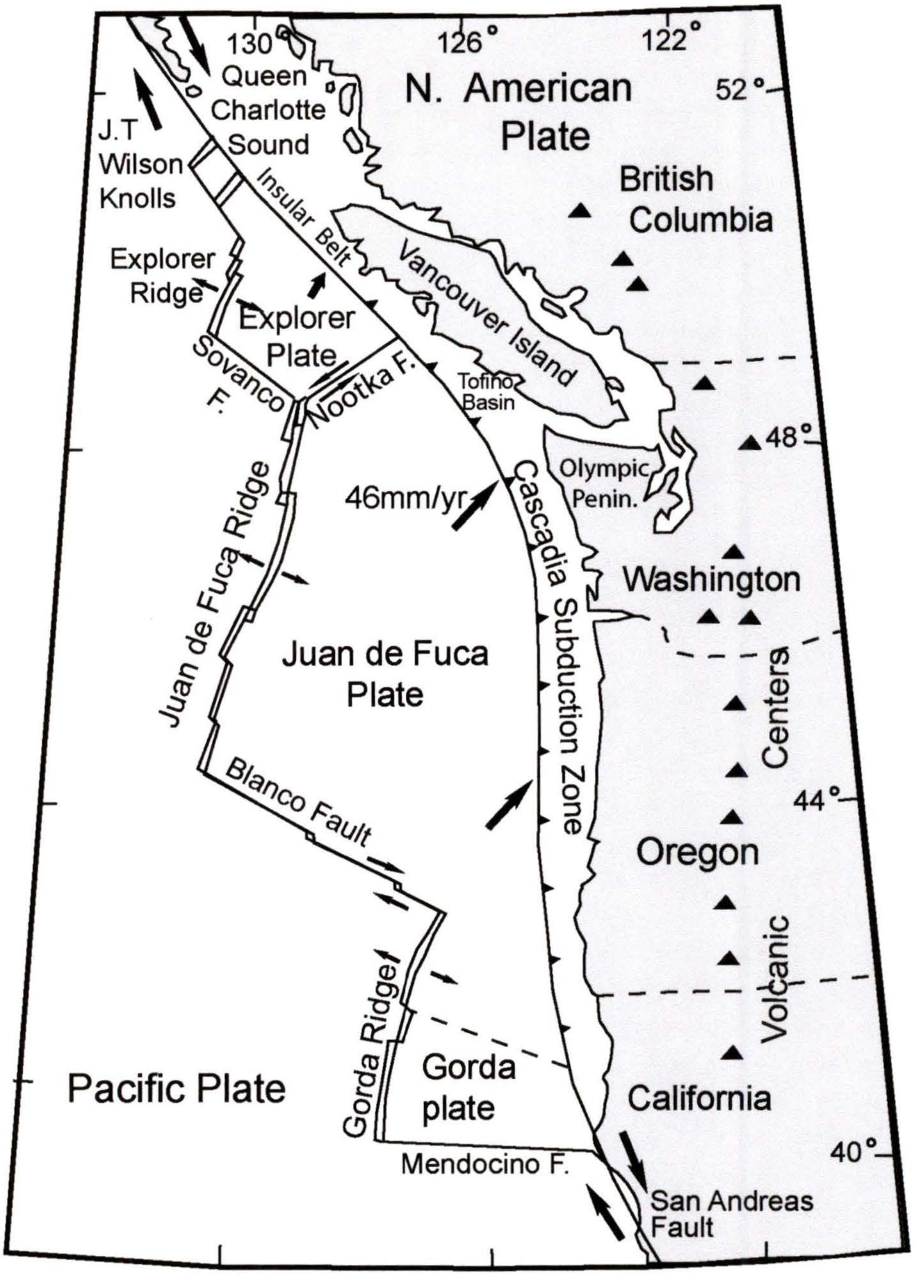


Figure 1.2. Map showing the tectonic elements of the Pacific Coast in relation to Vancouver Island, the offshore Tofino Basin and adjacent shelf areas (modified from Riddihough et al., 1983; Hyndman et al., 1990).

permeable reservoirs, and only minor hydrocarbon shows (Shell Canada Ltd., 1968; 1969). Shell Canada conducted aeromagnetic and seismic surveys of the basins (Shell Canada Ltd., 1968; 1969; Shouldice, 1971; Hannigan et al., 2001). Fourteen Shell wells were drilled (Figure 1.1), 8 in the QCB/Hecate Strait including: South Coho I-74, Tyee N-39, Sockeye E-66, Sockeye B10, Auklet G-41, Osprey D-36, Harlequin D-86, Murrelet K-15; Shell Canada Ltd., 1968; 1969); and 6 in the TB including: Shell Anglo Cygnet J-100, Prometheus H-68, Zeus D-14, Zeus I-65, Pluto I-87, and Apollo J-14. From these regions, Shell Canada Ltd. provided more than 1300 dart cores and multiple rotary well cutting subsamples from their offshore wildcat wells (Tiffin et al., 1972).

In 1972, the Government of Canada imposed a moratorium on crude oil tanker transport and hydrocarbon exploration in the coastal waters between Valdez, Alaska and the Dixon Entrance, Hecate Strait and Queen Charlotte Sound (Figure 1.1; AGRA Earth and Environmental Limited, 1998). The Provincial Government of British Columbia followed by reinforcing the Federal moratorium in 1981, for an indefinite period of time, thus ending any seafloor exploration in the west coast offshore (AGRA Earth and Environmental Limited, 1998).

It has been 30 years since the moratorium was imposed and there is now renewed interest in reassessment of the offshore energy resource potentials (Hannigan et al., 2001) and progress by the Federal and Provincal governments for its lifting. This present study was initiated as a subproject (Arm 4, case study 2) within the Coasts Under Stress (CUS) Project (since April 2000) as a timely opportunity to address the impacts of social and environmental restructuring on the environment and human health in coastal communities on Canada's east and west coasts. The CUS Project is a major collaborative research initiative between Memorial University of Newfoundland and the University of Victoria, British Columbia. Major funding for this project is provided by the Natural Sciences and Engineering Council of Canada (NSERC) and the Social Sciences and Humanities Research Council of Canada (SSHRC).

Since the early stages of exploration in this region, advances in geological (tectonic, structural and lithological) and geophysical (seismic) understanding has resulted in an improved interpretation of the geological evolution of West Coast basins. These advances provide the impetus for reassessment of existing data and to increase our limited knowledge of the offshore basins, in order to reassess future energy resource potentials. Several geological, geophysical and geochemical studies that have increased structural knowledge of the TB include Shell Canada's multichannel seismic lines (Shell Canada Ltd. 1968; 1969; Shouldice 1971; Tiffin et al. 1972; Hannigan et al. 2001), which have been used to investigate the Apollo structure (Yorath 1980); and the Geological Survey of Canada's (GSC) side-scan sonar imagery and 3.5 kHz sub-bottom profiles were used to provide an understanding of the Apollo structure (Yorath 1980; Hannigan et al. 2001). Seismic surveys by University of Victoria, LITHOPROBE geological studies (Clowes, 1984; Yorath, 1999) and the GSC have provided significant details of onshore and offshore regions (Chase et al., 1975; Yorath, 1980; Davis and Riddihough, 1982; Clowes, 1984; Yorath et al., 1985; Clowes et al., 1987; Yorath et al., 1987; Hyndman et al., 1990; Hyndman, 1995; Yorath et al., 1999; Hannigan et al., 2001; Johnston and Acton, in press). However, knowledge of offshore stratigraphy and depositional environments is limited. The present micropaleontological study of offshore strata provides substantial new information for this region.

1.3. Cenozoic foraminifer

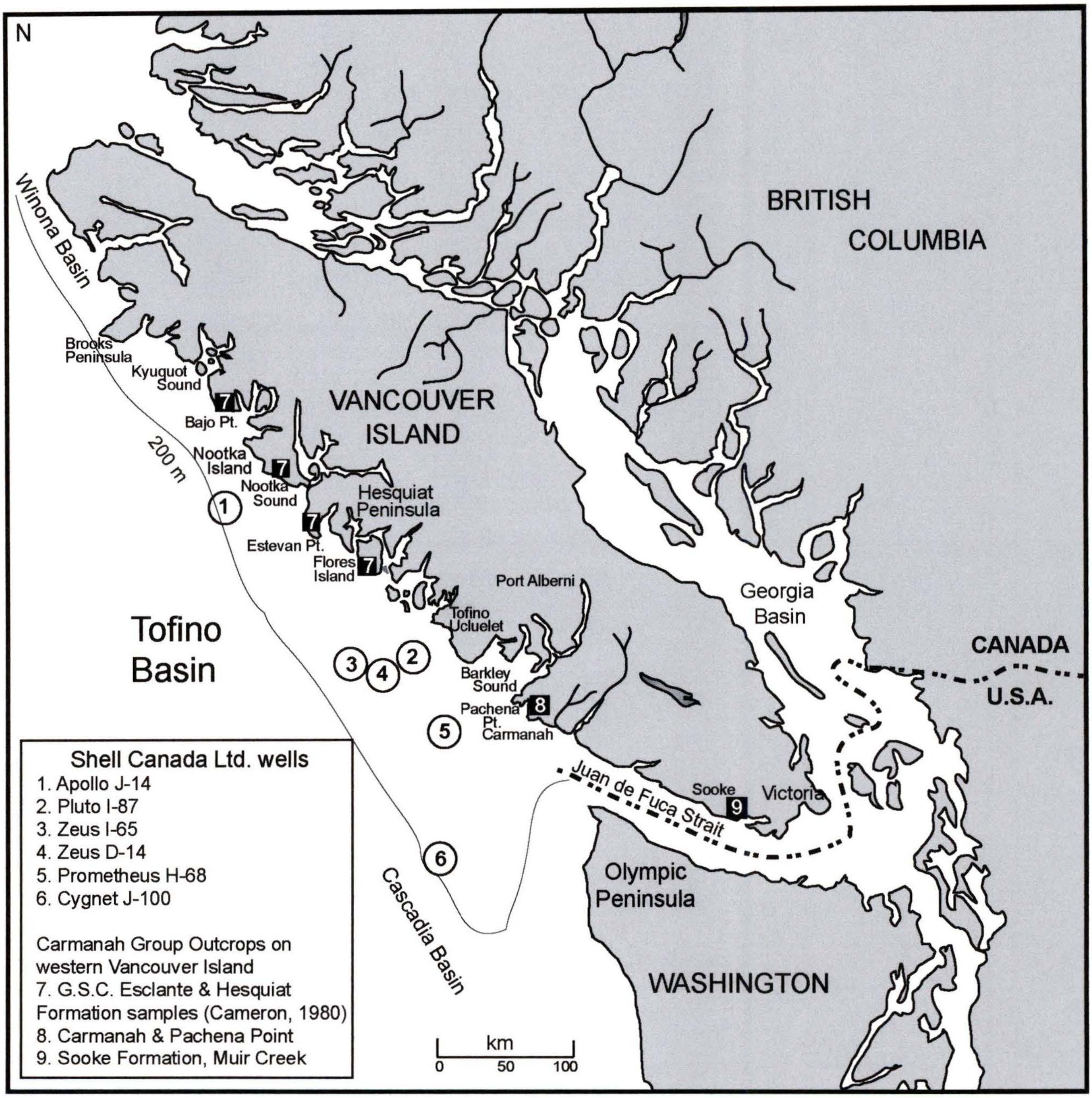
This study provides the first detailed taxonomic and biostratigraphic analysis of Cenozoic foraminifers from the six Shell Canada wells in the TB. Foraminiferal assemblages and interval biozones are recognized, coupled with geochemistry (strontium isotopes) data to provide a refinement of the relative stratigraphic ages. Studies of foraminifers from Shell Canada wells Shell Anglo Murrelet L-15, Harlequin D-86, and Osprey D-36, drilled in the QCB (Figure 1.1), and Quaternary core samples taken from the Queen Charlotte Sound and Hecate Strait, were carried out by Patterson (1989; 1993) and Patterson et al. (1998). Most of this previous work has focused on Quaternary shelf environments.

Foraminifera are heterotrophic, single celled protozoans (Kingdom Protista), typically smaller than one millimetre across, that secrete a shell ("test") composed of calcium carbonate and/or agglutinated sediments. Their calcitic nature, small size, widespread occurrence, rapid evolution and abundance in seafloor sediments have established their excellent potential in biostratigraphic and paleoenvironmental studies (Hayward et al., 1999; Sen Gupta, 2001). Their usefulness in recognizing paleoceanographic changes (temperature, salinity), interpreting depositional environments (biofacies, paleobathymetry) and geochronology, serves as a rationale for their use in this study. The taxonomic and paleoecological studies of benthic foraminifers from shelf (neritic) to deep sea (bathyal) environments is a cost effective method for the recognition, identification and interpretation of depositional environments. Planktic taxa evolve more rapidly, are widespread and are more reliable for global correlation and relative age determination than benthic taxa. However, benthic foraminiferal biozonation has successfully been utilized in correlation and chronostratigraphic differentiation of Pacific Coast strata (Prothero, 2001).

1.4. Location of study

The TB (including the Winona Basin (WB) and the accretionary wedge) located offshore Vancouver Island, west of the Barkley Sound region, covers a total area of 25, 000 km^2 of the continental shelf (Figures 1.1, 1.3) (Murray and Tiffin, 1969; Shouldice, 1971; Niem and Snavely Jr., 1991; Hannigan et al., 2001). Although there is limited knowledge of the geometry of the TB, Shell Canada's aeromagnetic surveys show that the structural trends in the basin are long and linear (Figure 1.1) and approximately parallel to the western coastline (Shouldice, 1971; Hannigan et al., 2001). The westernmost margin of the TB is presently undefined, and may extend to the foot of the continental slope (Shouldice, 1971). The basin extends southwards and beneath the Juan de Fuca Strait (Barr, 1974; Niem and Snavely Jr., 1991; Hannigan et al., 2001) and northwards to the Brooks Peninsula (where the continental shelf narrows from 65 km to about 10 km; Figure 1.3) (Tiffin et al., 1972). South of the Brooks Peninsula (Brooks Fracture Zone; Tiffin et al., 1972), the shelf strata of the TB, has been uplifted to expose late Eocene to Holocene strata. To the north, Pliocene-Pleistocene strata of the WB occurs along a narrow shelf and steeply seaward dipping slope. The WB extends from the Scott Islands (north of Vancouver Island) to the Brooks Peninsula (Figure 1.1; 1.3; Tiffin et al., 1972; Hannigan et al., 2001).

The six Shell Canada wells were drilled on the continental shelf in less than 200 metres water depth (Figures 1.1, 1.3). Shell Anglo Cygnet J-100 was drilled approximately 80 km (50 miles) south of Ucluelet (48° 20', 125° 30'); Prometheus H-68,



Shell Canada Ltd. wells
1. Apollo J-14
2. Pluto I-87
3. Zeus I-65
4. Zeus D-14
5. Prometheus H-68
6. Cygnet J-100

Carmanah Group Outcrops on western Vancouver Island
7. G.S.C. Esclante & Hesquiat Formation samples (Cameron, 1980)
8. Carmanah & Pachena Point
9. Sooke Formation, Muir Creek

Figure 1.3. Map of Vancouver Island and the offshore region, showing the approximate location of the six Shell Canada wells drilled in the Tofino Basin and locations of onshore outcrop sampled by the Geological Survey of Canada (and B.E.B. Cameron) from the Escalante, Hesquiat, Pachena Point/Carmanah and Sooke formations (Carmanah Group).

32 km (20 miles) south of Uclulet (48° 40', 125° 30'); Zeus D-14, 32 km (20 miles) south of Tofino (49° 00', 126° 30'); Zeus I-65, 16 km (10 miles) south of Tofino (49° 00', 126° 00'); Pluto I-87, 32 km (20 miles) south of Tofino (49° 00', 125°, 45'); and Apollo J-14, 32 km (20 miles) southwest of Nootka Sound (49° 00', 126° 00').

Along the southwest coast of Vancouver Island (from Sooke to the Nootka Sound region), narrow isolated outcrop belts of Cenozoic strata (mid to late Eocene and early Miocene) occur forming the Carmanah Group (Figure 1.3), which consists of three formations (Figure 1.4). This sequence comprises marine conglomerate, fine grained sandstone, mudstone and shale of the Escalante (mid-late Eocene), Hesquiat (latest Eocene to middle Oligocene) and the Sooke formations (late Oligocene to early Miocene; Cameron, 1980; Muller et al., 1981). The Carmanah Group defines the easternmost extent of the TB strata (Shouldice, 1971; Burwash, 1986). Its southernmost extent is seen in the Olympic Peninsula, Washington (Rau, 1970; Shouldice, 1971; Brandon et al., 1998; Campbell and Nesbitt, 2000). The tectonic framework and stratigraphy of the TB are further discussed in the section "Regional Geological Setting."

1.5. Objectives

The purpose of this study is to describe, evaluate and interpret Cenozoic (late Eocene to Plio-Pleistocene) foraminifer faunas recovered from cuttings of the six Shell Canada exploration wells drilled in the offshore TB (Shell Anglo Cygnet J-100, Prometheus H-68, Zeus D-14, Zeus I-65, Pluto I-87, and Apollo J-14). Initial studies of the flora (spores and pollen) and fauna (foraminifers) were conducted by Shell Canada but the results were only briefly reported in the Shell Canada well history reports (Shell Canada Ltd., 1968; 1969). There are no other detailed published studies and sources of information provided for these wells. Specifically, the main objectives of this thesis are to:

1. Present a detailed systematic taxonomic study of foraminiferan taxa present in the six Shell Canada wells.
2. Establish an improved foraminiferal biostratigraphy for the TB
    2.1. Identify define new and/or redefine existing foraminiferal interval zones and/or assemblages.

    - 2.2. Correlate the offshore biostratigraphy with the regional Carmanah Group biostratigraphy, and other Pacific Coast biostratigraphies.
3. Determine the stratigraphic age of sediments within the TB
    - 3.1. Interpret and integrate new strontium isotope age data with the newly developed biostratigraphic results.
    - 3.2. Revise/refine previous relative age interpretations for both the offshore (Shell Canada; Shoudice, 1971) and onshore (Jeletzky, 1954; 1973; 1975; Cameron, 1980) sequences.
4. Establish foraminiferan biofacies and interpret paleoenvironments
    - 4.1. Identify and interpret foraminiferal biofacies and their interpreted paleobathymetries and possible depositional environments present in the TB. Suggest some implications of these results for interpretation of regional eustacy and tectonics.

1.6. Materials and methodology

1.6.1. General overview

Initially, Shell Canada assessed drill cuttings and sidewall core samples for permeability and evidence of hydrocarbon shows. In this study, foraminifers from approximately 2030 microscope slides (microfossil data) from Shell Canada well cutting subsamples were examined taxonomically. Sidewall core samples were unattainable for this study, they appear to have been utilized completely by Shell Canada and to have been largely unconsolidated. The process of recovery of microfossils was not reported in the Shell Canada well history reports. For this study, subsamples of the cuttings were first dried and then processed in detergent (Quaternary O) by soaking, heating and oscillating on a hotplate to disaggregate the sediment until it was no longer muddy (pers. comm., M.J. Johns, 2001). Then samples were sieved, washed and dried [coarse (>1 mm) and fine (<1 mm and >65 or 75 μm]. Residues of 75 μm were retained and contained microfossils, sand, silt and other grains. Some original "raw" (unprocessed) well material was available and a few samples of foraminiferal tests were selected for strontium isotope analysis.

The samples and copies of the Shell Canada well history reports for each of the 14 wells (including the eight QCB wells) were loaned by the Geological Survey of Canada, Pacific (Sidney), to Dr. C.R. Barnes at the School of Earth and Ocean Sciences, University of Victoria for the purpose of this study. In addition, foraminifer samples and laboratory data collected and prepared by B.E.B. Cameron were also loaned by the GSC and Pacific PaleoQuest for comparison with the offshore samples. Approximately 1025 microfossil slides were available. Several specimens were examined for faunal comparison, correlations and for use in Sr isotope analysis.

Most foraminifer specimens had been previously picked (GSC Pacific) (under a dissecting microscope) from the fine residue, (usually) sorted into the lowest taxonomic level identifiable, and mounted onto microscope slides, using water-soluble glue (a mixture of gum tragacanth and water). In this study, the foraminifers from each of the six Shell Canada wells (Shell Anglo Cygnet J-100, Pluto I-87, Promethius H-68, Zeus D-14, Zeus I-65, and Apollo J-14) were taxonomically identified using a Wild Heerbrugg dissecting microscope. Northern Eclipse (version 5.0) image analysis software was used to photograph details of the test for taxonomic clarification and scanning electron micrographs (SEM) were taken with a Hitachi S-3500N SEM. Ichthyoliths (microscopic fish teeth and scales) from these samples were picked and examined by M.J. Johns, Pacific PaleoQuest.

Shell well cutting samples were examined from the "top" down in order to identify any contamination by wall-spalling from shallower depths. The deepest possible faunal assemblages were used to interpret paleobathymetry (foraminifer biofacies) and possible depositional environments (as described in Ingle, 1980). The original units used to express the stratigraphic (depth) interval of each sample are feet and the use of footage is retained when referring to well samples. The general methods and procedures used to address objectives in this thesis were:

1) Review of literature to develop an understanding of the TB and the regional geological and tectonic regime. Examination of foraminiferal literature.
2) Initial review of samples. The wells were examined for foraminifer preservation, abundance and research potential.

3) Systematic taxonomic study and illustration of all taxa using digital scanning electron micrographs (SEM).
4) Establish faunal assemblages and define regional foraminifer zones, correlate with the Pacific coast biostratigraphic standard for North America, and make comparisons and correlations with the established biostratigraphy of the Carmanah Group, Vancouver Island.
5) Assess ancient seawater composition at deposition, by measuring strontium isotope (^{87}Sr / ^{86}Sr) signatures preserved in unaltered, calcite tests of foraminifers, from both the offshore and onshore. The Cenozoic unidirectional strontium isotope curve is used to determine the relative age of stratigraphic sequences, and to complement the biostratigraphy. Strontium isotope analysis was undertaken by J.A. Trotter (2001, 2002), CSIRO Petroleum Laboratories, Sydney, Australia.
6) Provide interpretations of regional geology (lithostratigraphy), depositional environments (based on foraminifer bathymetry data) and regional tectonic interpretation.

1.6.2. Shell Canada wells: brief well history and materials examined

Shell Anglo Cygnet J-100 was drilled to test an anticlinal structure for hydrocarbon accumulation (Shell Canada Ltd., 1969b). The well was spudded (drilling initiated) January 26, 1969 and conventional open hole logs, drill cuttings and sidewall samples were obtained. It was abandoned February 20, 1969, after penetrating a total depth (TD) of 8070 ft (~2460 m) of Cenozoic strata. No permeable reservoirs or hydrocarbon shows were encountered. Cuttings were taken, on average, every 30 ft, from 1171 to 8070 ft. Approximately 200 previously picked microfaunal slides were available and examined by this study. Sidewall samples were unavailable. Cutting and sidewall lithologies, and microfaunal age determinations were reported in the Shell Canada well history reports for all of the wells listed below.

Shell Anglo Prometheus H-68 was drilled to test an anticlinal structure for hydrocarbon accumulation (Shell Canada Ltd., 1968b). The well was spudded on June 11, 1967 and conventional open hole logs, drill cuttings and sidewall samples were obtained. It was abandoned August 9, 1967 after penetrating a TD of 7662 ft (~2335 m) of Cenozoic strata and Eocene volcanics, and without encountering any permeable reservoirs, although a gas show was encountered. Cuttings were taken every 30 ft, between 628 to 4100 ft; every 20 ft between 4100 to 5150 ft; and every 10 ft, between 5150 to 7662 ft. A total of 232 previously picked microfaunal slide samples, from 2318 to 7650 ft, were available and examined in this study.

Shell Anglo Zeus D-14 was spudded on February 24, 1968, and conventional open hole logs, drill cuttings and sidewall samples were obtained (Shell Canada Ltd., 1968c). It was abandoned March 27, 1967 after penetrating a TD of 7980 ft (~2432 m) of Cenozoic strata and Eocene volcanics, and without encountering any permeable reservoirs or hydrocarbon shows. Cuttings were taken every 10 ft, between 730 to 770 ft; every 30 ft, between 770 to 1950 ft; every 20 ft, between 1950 to 4650 ft; and every 10 ft, between 4650 to 7980. A total of 234 microfaunal slide samples, from 2318 to 7650 ft were available and examined in this study.

Shell Anglo Zeus I-65 was drilled to test the Zeus anticlinal structure for hydrocarbon accumulation (Shell Canada Ltd., 1968d). The well was spudded on November 4, 1967, and abandoned February 3, 1968 after penetrating a TD of 9981 ft (3042 m), and without encountering any permeable reservoirs or hydrocarbon shows. Cuttings were taken every 20 ft, between 975 to 2800 ft.; and every 10 ft, between 2800 to 9981 ft. Over 800 microfaunal slide samples, from 730 to 9980 ft, were available and examined in this study. Faunas were extremely sparse and poorly preserved below 5000 ft, where lithified, quartzitic sandstone was encountered.

Shell Anglo Pluto I-87 was drilled to test the Pluto anticline for hydrocarbon accumulation (Shell Canada Ltd., 1968a). The well was spudded August 11, 1967 and conventional logs and sidewall samples were obtained. It was abandoned October 9, 1967, after penetrating a TD of 12,225 ft (~3726 m). No permeable reservoirs were encountered, however, a gas show in a thin sand unit at 1890 ft was indicated. Cuttings were taken every 30 ft, between 740 to 3000 ft; every 20 ft, between 3000 to 4900 ft; and every 10 ft, between 4900 to 12,225 ft. Over 320 microfaunal slide samples, from 5210 to 12,225 ft, were available and examined in this study.

Shell Anglo Apollo J-14 was drilled to test the Apollo anticlinal structure for hydrocarbon accumulation (Shell Canada Ltd., 1969a). The well was spudded on November 23, 1968, and conventional logs and sidewall samples were obtained. It was abandoned January 21, 1969 after penetrating a TD of 10,152 ft (~3094 m) and without encountering any permeable reservoirs or hydrocarbon shows. Cuttings were taken every 30 ft, between 1000 to 5019 ft.; and every 10 ft, between 5019 to 10,152 ft. No samples were obtained between 6340 to 6420 ft. Over 150 microfaunal slide samples from 3970 to 10,152 ft were available and examined in this study.

1.7. Previous studies

1.7.1. Introduction–Pacific Coast chronostratigraphy

Chronostratigraphic correlations of Cenozoic strata became possible after Charles Weaver (1942) and Weaver et al. (20 authors; 1944) established a standardized time scale for the Pacific Coast. Initially, Cenozoic biostratigraphic studies were based on a molluscan faunal time scale for California (Merriam, 1896; Arnold, 1906; Jeletzky, 1950; 1954). After World War I, and the prominence of the oil and gas industry (in California), it was soon realized that foraminifers, which occurred in abundance in drill cuttings, were more useful than molluscs in correlating strata. Schenck and Kleinpell (1936), Kleinpell (1938), Natland (1952) and Mallory (1958) established the first biostratigraphically defined benthic foraminiferal stages. These stages are recognized and used from California to Washington (Rau, 1981; 1999) Vancouver Island (Cameron, 1980) and the TB (this study) (Figure 1.4). Although the broadly defined foraminiferal biostratigraphic stages are generally recognized, smaller units or faunal biozones initially established for California, were not entirely recognizable in Oregon, Washington and British Columbia (Rau, 1981). It was soon realized that smaller biostratigraphic units (i.e., biozones) were only as widespread as the local depositional environments permitted, since benthic faunas reflect paleobathymetry and facies changes rather than phyletic evolution, making correlation extremely difficult or impossible (McDougall, 1980; Rau, 1981; Prothero, 2001). Also, from the controversy surrounding the placement of the Eocene and Oligocene boundary (Refugian vs. Zemorrian stages; Lipps, 1965; Cameron, 1980; Rau, 1981; Prothero, 2001; Prothero et al., 2002), the time-transgressive nature of benthic

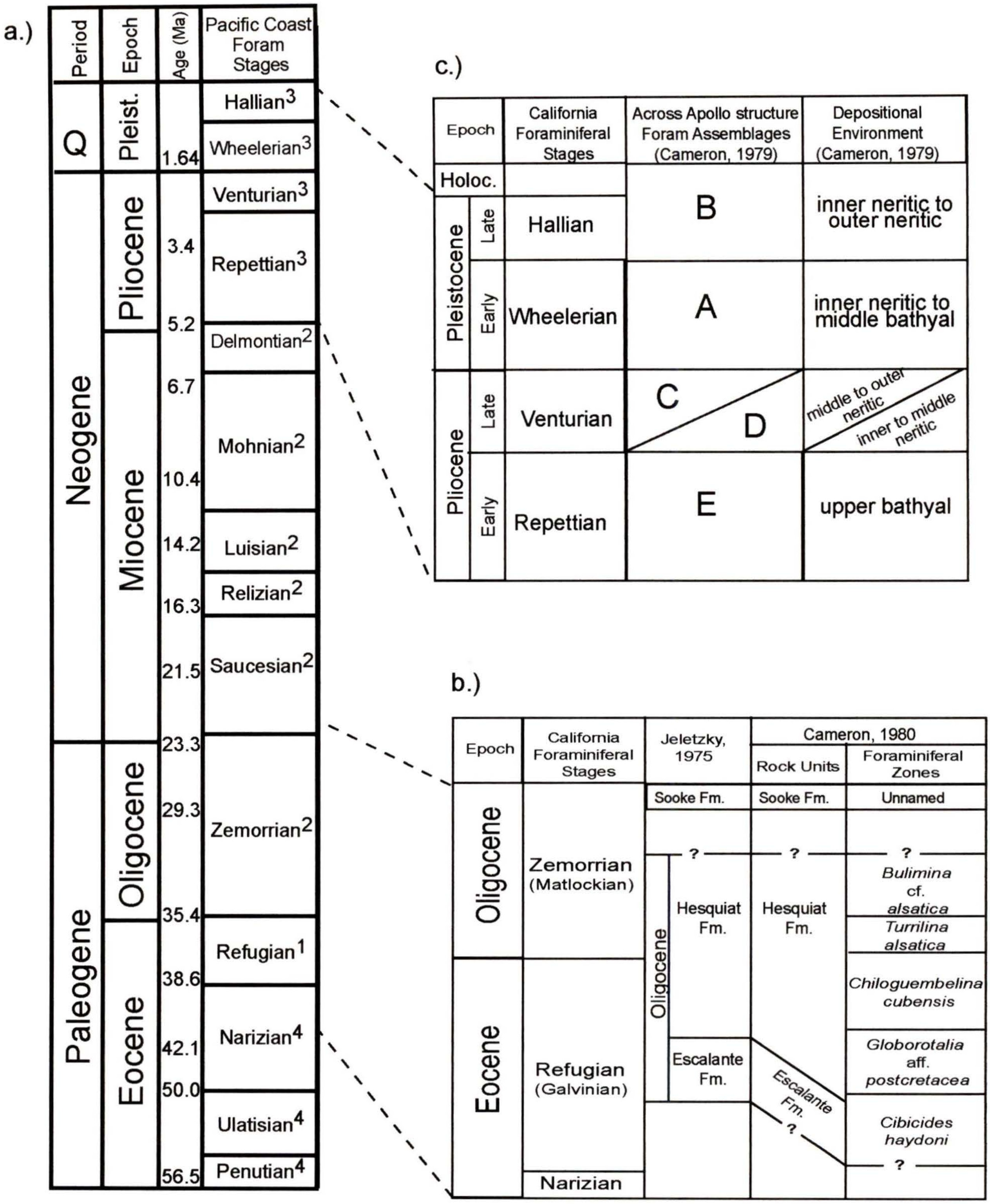


Figure 1.4. Cenozoic chronostratigraphy and foraminifer biozonations showing: a) the Pacific Coast Standard Foraminiferal Stages, established by (1) Kleinpell and Schenck (1936), (2) Kleinpell (1938), (3) Natland (1952), and (4) Mallory (1958) (modified from Rau, 1981); b) foram zones established for the Escalante and Hesquiat formations, Carmanah Group (Jeletzky, 1973, 1975; Cameron, 1980); c) ages, foraminifer assemblages and associated biofacies recognized by Cameron (1979) across the Apollo structure, Tofino Basin.

foraminiferal zones/stages was interpreted by other Pacific Coast biostratigraphers (Cameron, 1980; McDougall, 1980; Prothero, 2001 and several studies listed therein). A planktic foraminiferal zonation was developed later for the Pacific Coast and used to resolve correlation problems and disputes regarding the Eocene, Oligocene and Miocene boundaries (Lipps, 1964, 1967; Ingle, 1967; Bandy, 1972; Mckeel and Lipps, 1972, 1975). Due to high sedimentation rates and shelf depths, planktic taxa are rare, especially in older sections of the TB (this study) Vancouver Island (Cameron, 1980; this study), Olympic Peninsula (Rau, 1981) and the Pacific Coast (Prothero, 2001). The potential for stratigraphic correlation using planktic foraminifers in this region, is still in its early stages of development.

1.7.2. Tofino Basin (offshore) stratigraphic studies

No previous detailed taxonomic or biostratigraphic studies were undertaken on the six, TB Shell Canada wells. However, Shell Canada initially examined microfaunal (foraminifers) and palynology (diatoms, pollen and spores) data and established preliminary stratigraphic ages and well lithostratigraphy (Figure 1.5), as presented in the Shell Canada well history reports and published in Shouldice (1971). Cameron (1979) reported on foraminiferal assemblages recovered from 61 dart cores samples taken by Shell Canada Ltd. (in 1964) across the Apollo structure (Yorath, 1980) in the TB (Figure 1.4c). His interpretations include five foraminiferal assemblages of early Pliocene to Holocene age, from inner neritic to upper bathyal water depths (Figure 1.4c).

1.7.3. Vancouver Island (onshore) stratigraphic studies

Cenozoic deposits on Vancouver Island have been known since Merriam (1896) recognized Cenozoic marine macrofossils collected by Charles Newcombe (Royal British Columbia Museum, Victoria, B.C.) from the Sooke and Carmanah Point areas (near the Carmanah Point lighthouse). Based on the paleontological studies of Merriam (1896) and Clarke and Arnold (1923), it became evident that the macrofossils from Carmanah Point were older than the Sooke faunas of southwestern Vancouver Island. The Cenozoic

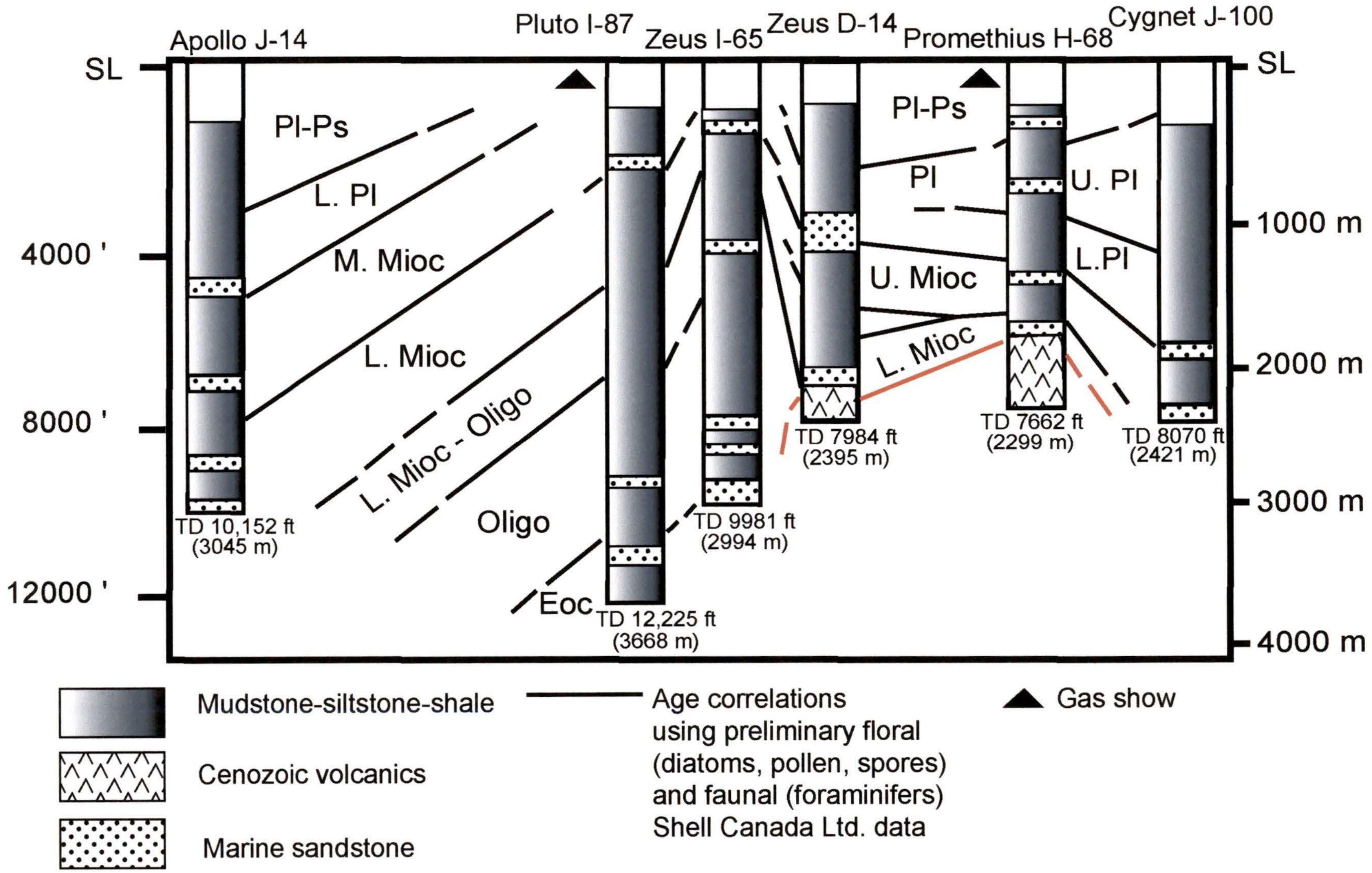


Figure 1.5. Correlation of the six Shell Canada wells in the Tofino Basin. Lithologies, stratigraphic ages and preliminary correlations are based on initial examination of well cuttings, side-wall cores, microflora (pollen, spores) and fauna (mainly foraminifers). Offshore volcanics were encountered at the base of Zeus D-14 and Prometheus H-68 wells. Hydrocarbon (gas) shows were also encountered in Pluto I-87 and Prometheus H-68 wells (modified from Shouldice, 1971).

stratigraphy (Clapp, 1912; Clapp and Cook, 1917; Jeletzky, 1954; Cameron, 1971a, b; 1973) and biostratigraphy (Jeletzky, 1954; 1975; Cameron, 1980) have since been extensively studied (Muller et al., 1981). Burwash (1986) has conducted the last lithological study of the Carmanah Group.

The Carmanah Group is subdivided into three formations, the Escalante (Muller, 1977; Muller et al., 1981), Hesquiat (Jeletzky, 1954; 1975; Cameron, 1980; Muller et al., 1981), and Sooke formations (Clapp and Cook, 1917; Clarke and Arnold, 1923, Muller, 1977) (Figure 1.4b). The best exposures of the Escalante and Hesquiat formations are located on Nootka Island and the Hesquiat Peninsula region (Nootka Sound Map Area, Figure 1.6: Cameron, 1980). The Escalante and Hesquiat formations overlie unconformably the metamorphic (~40 Ma) Leech River Complex (Fairchild and Cowan, 1982; Muller et al., 1981). The Hesquiat Formation is overlain unconformably by the Sooke Formation (Muller et al., 1981).

The Escalante and Hesquiat formations are approximately equivalent to the Twin River Group, which consists of the Hoko River, Makah and Pysht formations of Northwestern Washington (Olympic Peninsula). The Pysht Formation (previously the Twin River Formation) extends from the Refugian to the early Saucesian stages; Makah from the Refugian to the Zemorrian (Snavely et al., 1980), indicating some overlap of these formations (Snavely et al., 1978; Prothero, 2001; pers. comm., E. A. Nesbitt, 2003). The Clallam Formation overlaps the Twin River Group and spans the latest Zemorrian Stage (~24 Ma; Prothero, 2001; pers. comm., E.A. Nesbitt, 2003).

Previous biostratigraphic studies from the Carmanah Group rocks have used foraminifers (Cameron, 1971b; 1980) and molluscs (Jeletzky, 1954; 1973; 1975) from several localities on Vancouver Island including the Hesquiat Peninsula, Nootka Island, Flores Island and Tatchu Point (Figure 1.6). The interpretation and use of nomenclature (e.g. stage names) by Jeletzky (1954; 1973; 1975) and Cameron (1971b; 1973; 1975; 1980) has been at times conflicting. Disagreements have included the placement of temporal boundaries (i.e., the base of the Oligocene as Refugian or Zemorrian stages) and in their interpretations of the depositional environments of the Escalante Formation as discussed below (Jeletzky, 1975; Cameron, 1980; Muller et al., 1981).

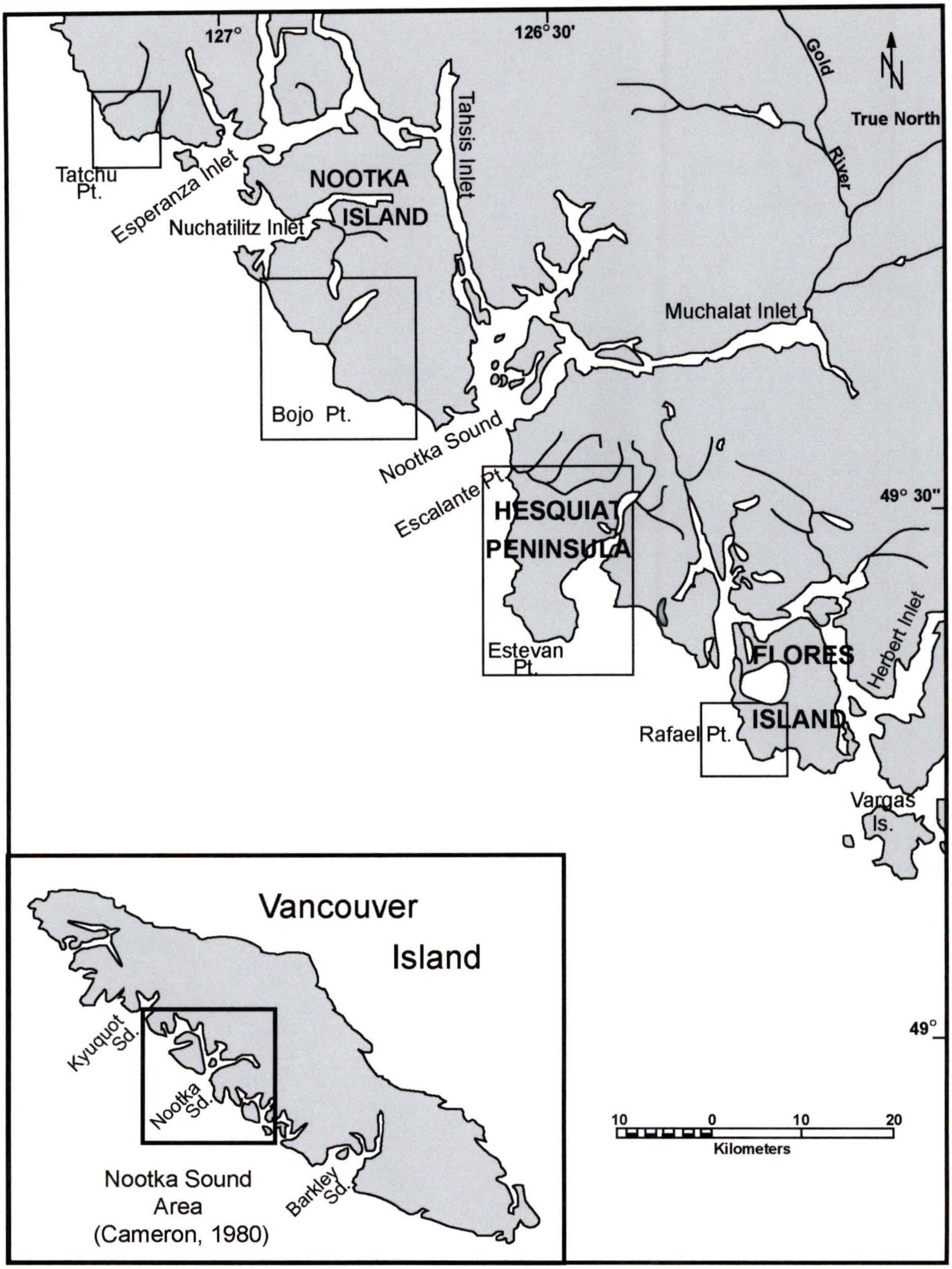


Figure 1.6. Map of the Nootka Sound Area showing the location of limited Cenozoic (Eocene and Oligocene) sequences of the Carmanah Group. The thickest exposures were encountered on the Hesquiat Peninsula and Nootka Island. Approximately 1025 surface samples were collected from western Vancouver Island (modified from Cameron, 1980).

1.7.3.1. Escalante Formation

The oldest strata (mid-late Eocene) of the Carmanah Group were assigned to the Escalante Formation (Bancroft, 1937; Cameron, 1971; 1980; Muller, 1977; Muller et al., 1981). The type section at Escalante Point reaches a thickness of approximately 140 m (Cameron, 1980) and approximately 300 m in other areas. The basal beds consist mainly of calcareous sandstone, relatively minor lenticular shelly conglomerate, argillaceous sandstone, disseminated carbonaceous material and rare plant debris (Cameron, 1980; Muller et al., 1981). Calcareous sandstone with lenticular beds of shelly, pebble conglomerate, abundant calcareous nodules and concretions, commonly containing plant debris, occur higher in the formation (Cameron, 1980; Muller et al., 1981). The Escalante Formation unconformably overlies the Mesozoic West Coast Crystalline Complex (or Bonanza volcanics; Muller et al., 1981). Contact of the Escalante with the overlying Hesquiat Formation is gradational, with beds grading from calcareous sandstone to softer argillaceous sandstone/siltstone with shale interbeds (Cameron, 1980; Muller et al., 1981).

Jeletzky (1954; 1975) and Cameron (1980) carried out the last biostratigraphic studies, and each had a different interpretation of the depositional environment. Jeletzky (1954; 1973; 1975) interpreted the depositional environment as a shallow (littoral to supratidal), high energy (in places) and marine estuarine, possibly neritic at the base and outer littoral or inner neritic in the upper parts of the Escalante Formation. Jeletzky's interpretations were based on his studies of macrofossils, mainly molluscs (bivalves) and crustaceans (crabs), found concentrated in conglomerate lenses. Cameron (1971; 1980) disputed Jeletzky's interpretation and instead favoured outer neritic to upper bathyal water depths, based on lithological evidence and good to excellent foraminiferal assemblages. Cameron (1980) considered the broken and disarticulated bivalves found concentrated in conglomerate lenses to have been transported and re-deposited. However, the fossilized crabs were well preserved in concretions and were presumed by Jeletzky (1975) to occur as original death assemblages of shallow water affinity. The concretions may be reworked (rather than the crabs within them), but show little indication of reorientation by transport (Cameron, 1980). Therefore, this issue remained unresolved as to whether these deposits show some degree of sediment transport and/or reworking by bioturbation.

The Escalante Formation was assigned to the late Eocene Refugian and Narizian stages (Rau, 1966; Cameron, 1980). The foraminiferal zone *Cibicides haydoni* is found within the type section at Escalante Point (Hesquiat Peninsula; Cameron, 1980). Its occurrence there suggests that this area contains older (Narizian Stage) rocks than is seen in other sections of the Escalante Formation (Cameron, 1980; Muller et al., 1981). The overlying zone is defined by the planktic foraminifer *Globorotalia* aff. *postcretacea* assemblage in other Escalante Formation deposits (e.g. Nootka Island, Flores Island). This stratigraphic unit is diachronous (time-transgressive) in the Hesquiat Peninsula and Flores Island (Cameron, 1980).

1.7.3.2. Hesquiat Formation

The middle sequence of the Carmanah Group is the Hesquiat Formation (late Eocene to early Miocene; Jeletzky, 1975; Cameron, 1980; Muller et al., 1981). It is the thickest unit at approximately 1100 m in the type section (Cameron, 1980). The lower contact is gradational with the underlying Escalante and the top of the formation is rarely exposed; it is in fault contact with the overlying Sooke Formation (Cameron, 1980). The type section outcrops along the western side of the Hesquiat Peninsula (Cameron, 1981). Jeletzky (1954) recognized initially four lithostratigraphic units (A-D). Division A, the basal conglomerate and sandstone unit, later became the Escalante Formation and Division C became equivalent to the Hesquiat Formation (Jeletzky, 1975).

Two contrasting lithofacies were recognized within the Hesquiat Formation: 1) distal facies, and 2) proximal facies (Cameron, 1980; Muller et al., 1981). The distal facies is exposed on Nootka Island and consists of predominantly fissile, blocky silty shale and mudstone, interbedded with argillaceous siltstone and fine grained sandstone, calcareous concretions and pyrite nodules (Cameron, 1980; Muller et al., 1981). Megafossils are rare, whereas microfossils are abundant and were used to infer bathyal water deposition (Cameron, 1980; Muller et al., 1981). The proximal facies, best exposed at the type section (west side of the Hesquiat Peninsula; Jeletzky, 1954; 1975), consists of interbedded sandy shale, graded cyclic sandstone-silty shale-shale interbeds, pebbly mudstone, and lenticular boulder and pebble conglomerate (Cameron, 1980; Muller et al., 1981). Cameron (1980) suggested that the complex lithological association of graded sediments found in the latter facies were deposited by a mass flow process (turbidite facies), that occurred at bathyal water depths (slope deposits), possibly influenced by storm deposition. However, Jeletzky (1975) interpreted the Hesquiat Formation sediments as channel fill deposits on a shallow water (neritic / littoral) submarine fan. The Hesquiat Formation deposits in the type section represent a relatively uncommon lithofacies among other West Coast units (Muller et al., 1981).

Jeletzky (1973; 1975) assigned the rocks of the Hesquiat Formation to the "Lincoln" and "Blakeley" and the Escalante Formation to the lower "Lincoln" Molluscan Stages (Weaver et al., 1944; Cameron, 1980), therefore suggesting that strata were older, entirely within the Oligocene age. Jeletzky followed an older interpretation (no longer applied) which placed the Eocene-Oligocene boundary below the base of the "Lincoln" Stage (Cameron, 1980; Muller et al., 1981) and not at the "Lincoln"-"Blakeley"boundary agreed upon by other workers (Weaver, 1944; Armentrout, 1975; 1977; 1987).

Cameron's assignment follows other Pacific Coast biostratigraphic studies, which are in general agreement with placing the Eocene-Oligocene boundary at the top of the Refugian-Zemorrian foraminiferal stages (Figure 1.4.b; Cameron, 1980; Rau, 1981; Amentrout, 1987; Prothero, 2001). Cameron's, (1980) *Chiloguembelina cubensis* Zone occurs at the Eocene-Oligocene boundary in the Hesquiat Formation (Nootka Sound map area). Four other foraminiferal zones were also established for the Hesquiat Formation (Cameron, 1980; Figure 1.4b).

1.7.3.3. Sooke Formation

The youngest unit of the upper Carmanah Group is the Sooke Formation (late Oligocene-early Miocene; Clapp, 1912; Clapp and Cook, 1917). The detailed paleontological studies of Merriam (1896) and Clarke and Arnold (1923) led to the identification of the Sooke Formation fauna and its placement at a younger age than other Carmanah Group faunas. The formation is less than 45 m thick in the type area (at Kirby Creek) and directly, but unconformably, overlies the early Eocene Metchosin Igneous Complex (Muller, 1980). Contact with the underlying Hesquiat Formation is uncertain (Muller et al., 1981). Lithologically, the Sooke Formation consists of fine to medium grained, cross-stratified marine sandstone, conglomerate, and with some carbonaceous lenses (Muller et al., 1981; Bream, 1987; Cockburn et al., 1999). The formation is fossiliferous, containing abundant molluscs (bivalves and gastropods), and also barnacles, tubeworms, brachiopods, echinoderms, corals and whale and desmostylian mammalian bones and teeth (Cockburn et al., 1999). The depositional setting was possibly a high energy environment, nearshore (littoral), and in part possibly fluvial-deltaic to shallow marine (Clapp and Cooke, 1917; Clark and Arnold,1923; Muller et al., 1981; Bream, 1987).

1.8. Economic significance of the Tofino Basin

Shell Canada encountered hydrocarbon shows in two of six wells (Figure 1.5; Shell Prometheus H-68 and Pluto I-87) drilled in the TB (Shell Canada Ltd., 1968; Shouldice, 1971). The absence of permeable reservoirs encountered in the Shell wells does not suggest that the basin lacks any economically significant reservoirs (Niem and Snavely Jr., 1991; Hannigan et al., 2001). The thick Cenozoic marine sequences and structural features such as anticlinal (curvilinear) folds and shale diapirs (Shouldice, 1971; Yorath, 1980; Niem and Snavely Jr., 1991; Hannigan et al., 2001) are important considerations for possible hydrocarbon occurrences. Whereas Shouldice (1971) reported low porosities, recent studies by Hannigan et al., (2001) suggest that the outer neritic to bathyal thick sequences of mudstone, siltstone and relatively minor interbedded and lenticular sandstone and conglomerate, exhibit fair to good porosities. Only three percent of the TB sequence indicated reservoir potential, but poor source rock potential, based on the low organic carbon content (terrestrial Type III organic matter) of the sediments in the wells(Hannigan et al., 2001). The lithostratigraphy and structure of the basin suggests good potential for stratigraphic traps within the basin. Hannigan et al., (2001) assessed that the TB as potentially gas-prone rather than oil-prone, with a gas resource potential of 9.4 trillion cubic feet (TCF) of in-place natural gas.

Unlike the TB, the Queen Charlotte Basin (QCB) to the north (Figure 1.1.a,b), covers an area of 40,000 km^2 (Dietrich, 1995) and is estimated to contain significant quantities of oil and gas (Dietrich, 1995; Hannigan et al., 2001). The latest estimates on potential reserves for the QCB, reach 9.8 billion barrels of in-place oil and 25.9 TCF of in-place natural gas (Hannigan et al., 2001). The assessments of hydrocarbon potential (Niem and Snavely Jr., 1991; Hannigan et al., 2001) are encouraging and new microfossil data provided by this study and CUS seismic and geochemical studies will provide important data towards re-evaluation of the energy resource potential of the TB and QCB.

2. REGIONAL GEOLOGICAL SETTING OF THE TOFINO BASIN AND SOUTHERN VANCOUVER ISLAND

2.1. Introduction

Southern Vancouver Island and the Tofino Basin (TB) shelf are regions of current geological, geophysical and geochemical interest with the possibility of removal of the federal-provincial moratorium on offshore hydrocarbon exploration. Ongoing multidisciplinary and interdisciplinary geoscientific research has been spearheaded by projects such as LITHOPROBE, the Ocean Drilling Project (ODP) and Coasts Under Stress (CUS), and including studies by Hyndman et al. (1990), Hyndman (1995), Calvert (1996), Yorath et al. (1999), Hannigan et al. (2001), Johnston (2001) and Johnston and Acton (in press).

2.2. Tectonic Setting

Vancouver Island, the Queen Charlotte Islands and the adjacent continental shelf areas (Figure 1.1) occupy a complex tectonostratigraphic setting of the Insular Belt/Superterrane along the western continental margin of Canada (Tiffin et al., 1972; Hyndman et al., 1990; Gabrielse et al., 1991; Riddihough and Hyndman, 1991; Monger et al., 1995; Yorath et al., 1999), bounded to the west by the Cascadia subduction zone and Queen Charlotte transform fault. It is a region of modern plate-tectonic activity (Figure 1.2) (Atwater, 1970; 1990; Engebretson et al., 1985; Hyndman et al., 1990). The region is underlain by a late Paleozoic and Mesozoic basement of metamorphic, sedimentary and igneous rocks, partly underthrust by Cenozoic volcanic arc (oceanic) and clastic accretionary wedge sediments (Yorath et al., 1999).

Three accreted terranes (Muller, 1977; Gabrielse et al., 1991; Yorath et al., 1999), the: 1) Paleozoic Wrangelia (including the Alexander Terrane of Alaska); 2) Mesozoic Pacific Rim; and 3) Cenozoic Crescent Terrane (Gabrielse et al., 1991; Babcock et al., 1992, 1994; Yorath et al., 1999) constitute Vancouver Island and the TB. These terranes are juxtaposed along the Leech River Fault (Figure 2.1a) (Yorath et al., 1999; Johnston and Acton, in press). The latter two terranes were the last to join North America,

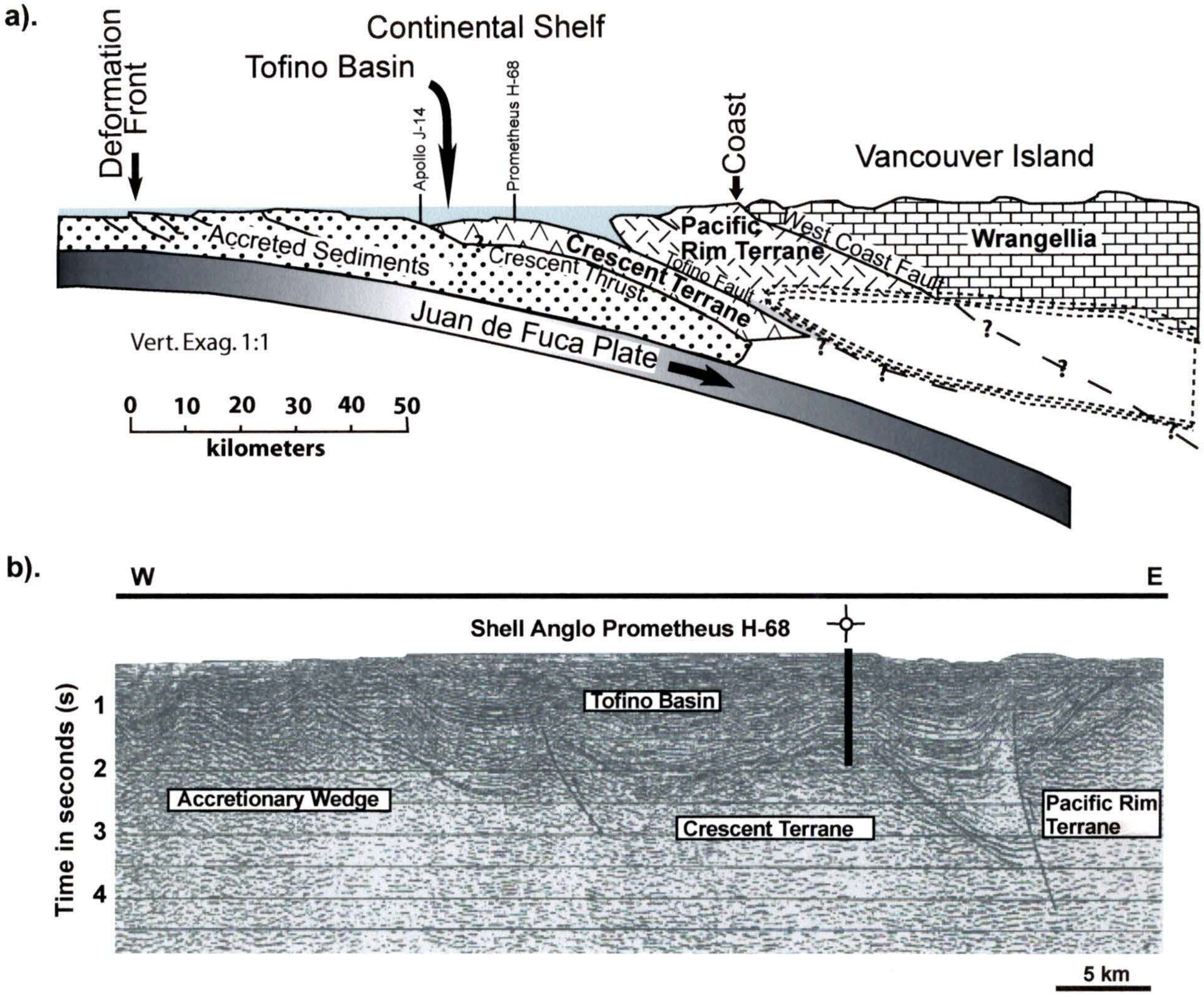


Figure 2.1. a). Tectonic cross-section of the offshore Vancouver Island subduction zone, showing the location of accreted sediments and terranes, and the approximate position of Shell Canada exploration wells Apollo J-14 and Prometheus H-68 (modified from Hyndman et al., 1990; b). Offshore seismic reflection profile, showing the deformed accretionary wedge strata, the Crescent Terrane and Mesozoic metasedimentary rocks of the Pacific Rim Terrane below the Tofino Basin sediments. Prometheus H-68 well is shown penetrating volcanic strata of the Eocene Cresent Terrane (modified from Hyndman et al., 1990).

accreting southwest of Wrangelia, at about 54 and 42 million years ago, respectively (Hyndman et al., 1990; Gabrielse et al., 1991; Yorath et al., 1999).

Along southern Vancouver Island, the Pacific Rim Terrane is underlain by the Jurassic-Cretaceous Leech River Complex (arc volcanics and melange) (Yorath et al., 1999; Johnston and Acton, in press), and the Metchosin Igneous Complex (basalts, breccia, tuff and volcanic sandstone), which is equivalent to the Eocene Crescent Terrane in the TB (Muller et al., 1981; Duncan, 1982; Massey, 1986; Yorath et al., 1999). The latter is also correlative with the Crescent Formation of northwestern Washington (Olympic Peninsula) across the Juan de Fuca Strait (Niem and Snavely Jr., 1991; Dehler and Crowes, 1992; Babcock et al., 1994; Brandon et al., 1998; Yorath et al., 1999). In summary, both offshore and onshore, tectonic features (plate movements, transform faults, folding and diapirism) (e.g. Nootka Fault, Kyuquot Uplift; Tiffin et al., 1972, Cameron, 1980; Yorath et al., 1999) are significant (to this study) and responsible for the complex tectonostratigraphic setting observed on the continental shelf and slope in the offshore TB.

2.3. Tofino Basin: Structure, Stratigraphy and Correlations

The TB is a forearc sedimentary basin formed at the juncture of the North America and Juan de Fuca plates, possibly as a result of underplating along the Cascadia subduction zone (Figure 1.2; Yorath et al., 1987; Hyndman et al., 1990; Hyndman et al., 1995; Johnston and Acton, in press). Seismic profiles reveal a thick Cenozoic sequence of nearly ~3650 m of marine clastic sediments (Figure 1.5, 2.1b) (Shouldice, 1971) that range in age from the Eocene to Pliocene (Yorath et al., 1987; Hyndman, 1995). These are overlain by Pleistocene clayey silts (up to 50 m) and Holocene relict sediments (~60 m thick) that constitute a thin cover over the continental shelf (Shouldice, 1971; Carter, 1973).

The TB was initiated during the Eocene as Cenozoic strata were thrust over rocks of the Mesozoic Pacific Rim Terrane and the Eocene volcanic Crescent Terrane (Muller, 1980; Massey, 1986). A modern accretionary wedge is formed beneath and against the Crescent Terrane by the scraping of sediments of the subducting Juan de Fuca Plate against the North America Plate (Hyndman et al., 1990; Dehler and Clowes, 1992).

The Crescent Terrane in the TB ('Prometheus' volcanics; MacLeod et al., 1977), consists of an Early Eocene ophiolite sequence of layered gabbros, sheeted dykes, pillow basalts, breccia and tuff (Massey, 1986; Muller, 1977; Yorath, 1999) and is encountered at the base of the Shell Anglo Prometheus H-68 and Zeus D-14 wells (Shouldice, 1971). This basaltic basement is unconformably overlain with Eocene and younger sediments (Shouldice, 1971; Yorath, 1980), and is responsible for the Prometheus magnetic anomaly discussed below (Macleod et al., 1977; Yorath, 1980; Johnston and Acton, in press). Accretion of the Crescent Terrane at 42 Ma may have been coeval with the initiation of the TB (Hyndman et al., 1990; Hyndman, 1995; Johnston and Acton, in press).

The complete geometry of the TB is unknown, and the structural framework is different from that of the Queen Charlotte Basin (Shouldice, 1971). Significant structural features are indicated by the Prometheus magnetic anomaly and Apollo anticlinal structure (Yorath, 1980; 1999) seen on the LITHOPROBE multichannel reflection seismic line (85-01; Hyndman, 1995; Yorath et al., 1987; Johnston and Acton, in press). The Prometheus anomaly is centralized in the basin and extends linearly from near the tip of the Olympic Peninsula to just south of the Hesquiat Peninsula (Yorath, 1980). This prominent feature is coincident with a basement high that does not preserve Eocene and/or Oligocene strata (Yorath, 1980; Johnston and Acton, in press). Johnston and Acton (in press) consider this prominent basement high to represent a horst and graben geometry following basin extension.

The Apollo structure was encountered when the Shell Anglo Apollo J-14 well was drilled nearby (Shouldice, 1971; Yorath, 1980). It represents a northwest aligned, gentle (curvilinear) anticline, developed with low relief (up to ~20m) on the surrounding flat, smooth, shelf surface (Yorath, 1980). The anticline developed within Neogene (Plio-Pleistocene) marine sediments that are separated by a detachment surface from underlying, deformed Paleogene rocks (Yorath, 1980). This structure may have been induced by periodic seaward sliding (or creep) of younger Neogene strata (no Eocene-Oligocene strata preserved), as a result of subduction of the Juan de Fuca Plate and accretionary wedge beneath the basin (Figure 2.1a) (Yorath, 1980; Hyndman et al., 1990; Hannigan et al., 2001).

The dominant lithologies within the offshore basin are deep-water mudstone, siltstone with relatively minor lenticular and argillaceous sandstone, conglomerate, breccia and volcanics of the Crescent Terrane (Figure 1.5) (Shell Canada, 1968; 1969; Shouldice, 1971). The Vancouver Island Cenozoic outcrop sequence occurs in narrow isolated outcrops (Figure 2.2) and is comparatively thinner (Shouldice, 1971; Cameron, 1980; Muller et al., 1981). It is of late Eocene to earliest Miocene age, while most of the Island is underlain by Paleozoic/Mesozoic strata (Figure 2.2). Comparatively, the TB Miocene and Pliocene sequences (in the offshore) are much thicker and more complete (Figure 1.5). The uplift of Vancouver Island and the Coast Range generated the thick Cenozoic sequence in the TB.

Site 177 of Leg 18 of the Deep Sea Drilling Project (Ingle, 1973) located at the northwestern end of the Paul Revere Ridge west of Vancouver Island within the Winona Basin (Murray and Tiffin, 1969; Tiffin et al., 1972; Ingle, 1973) near the triple junction (Atwater, 1970; 1990) provides additional geological/stratigraphic and foraminiferal evidence of the complex sedimentological and tectonic history of this region. The late Cenozoic deposits of this region represent the uplifted distal portion of the accretionary wedge dated using benthic and planktic foraminifers to the Plio-Pleistocene (Ingle, 1973). A turbidite origin was suggested for this site, based on lithologic evidence and by the presence of bathyal foraminifers (*Melonis pomiloides*, *Pullenia bulloides*, *Uvigerina senticosa*) and displaced littoral/inner neritic taxa (*Cribroelphidium* spp, *Nonionellina labradorica*) (Ingle, 1973). A similar Plio-Pleistocene biofacies is encountered within the Cygnet J-100 well in the TB.

Stratigraphic correlation of the TB units with those of onshore Vancouver Island and Washington are possible (Figure 2.3). Older Paleogene strata of the Tofino Basin correlate with the Carmanah Group (Hesquiat Formation) on Vancouver Island (Cameron, 1971; 1980) and partly with the Twin River Group (Hoko River, Makah, and Pysht formations) and Clallam Formation of the Olympic Peninsula of Washington (Snavely et al., 1980; Babcock et al., 1994; Rau, 1999; Prothero, 2001). Early Miocene age strata in the TB (Niem and Snavely Jr., 1991; Rau, 1999; this study) correlate with the Astoria(?)/Lincoln Creek Formations in southwestern (Grays Harbor Basin) Washington (Rau, 1981; 1999; Rau and Armentrout, 1983; Babcock et al., 1994) and

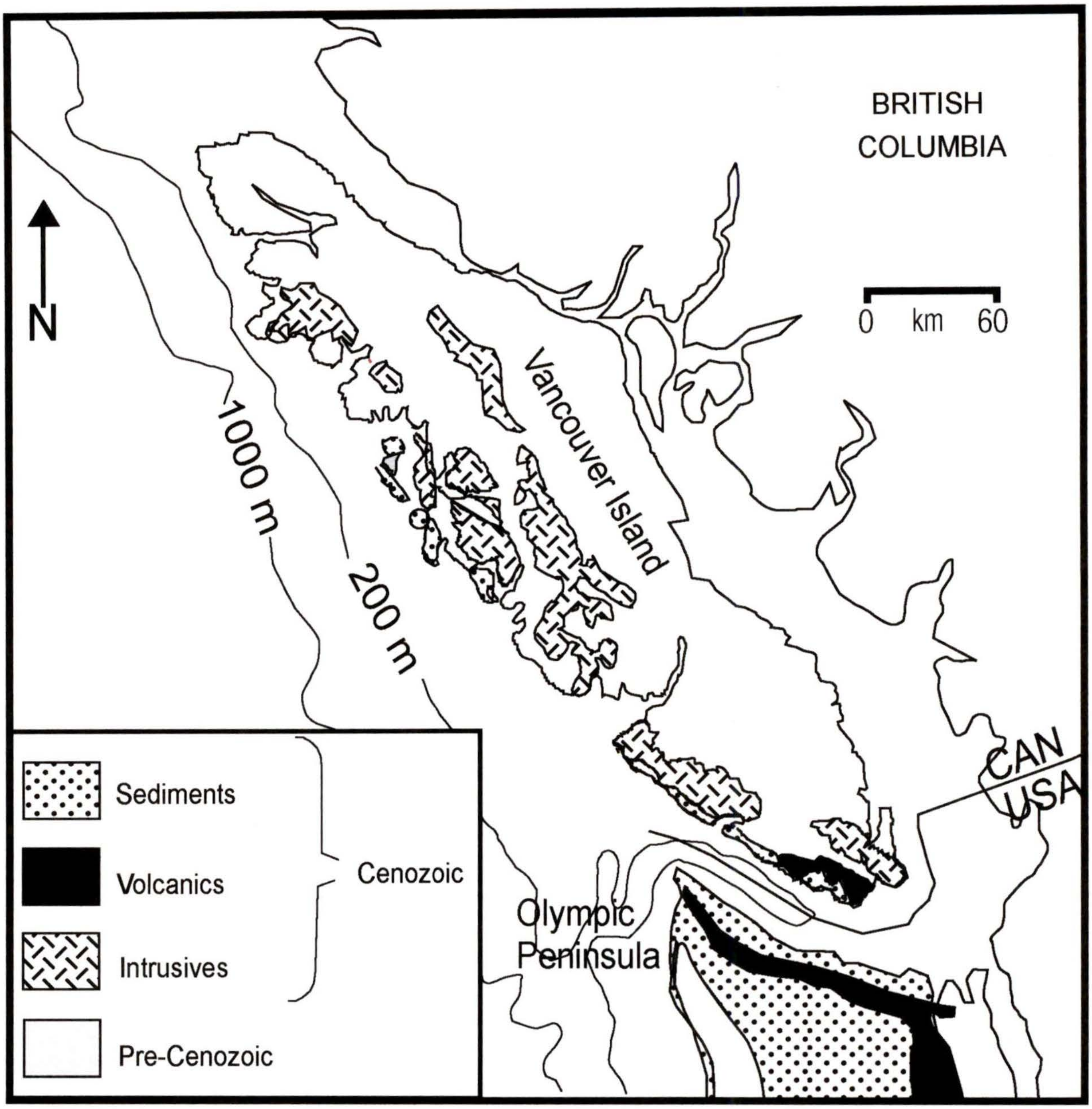


Figure 2.2. Generalized onshore geology of Vancouver Island and the Olympic Peninsula, Washington showing the extent of Cenozoic versus Paleozoic/Mesozoic strata. Cenozoic strata (~1200 m) of the Caramanah Group occur in limited and isolated outcrops along the western coastline of Vancouver Island (modified from Shouldice, 1971).

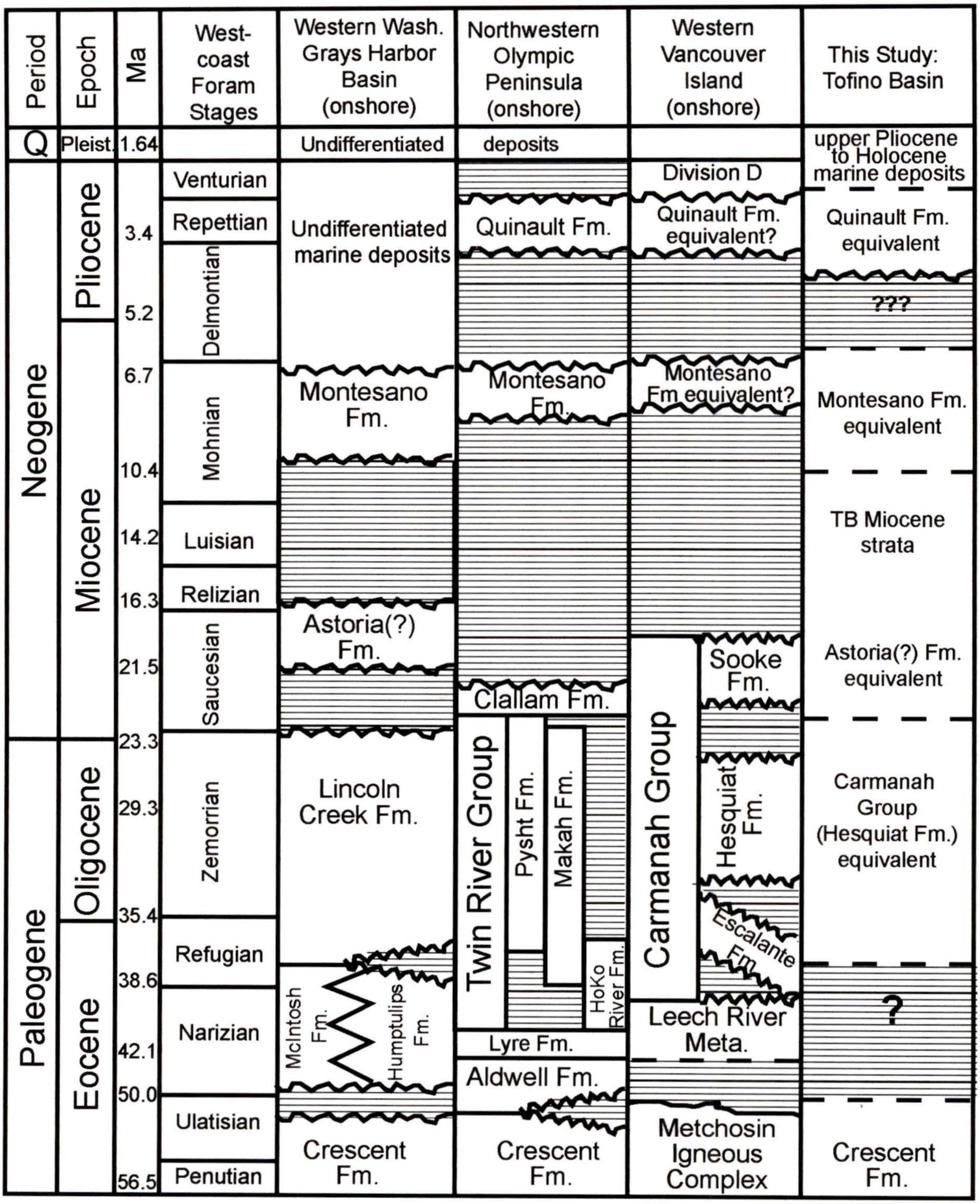


Figure 2.3. Correlation chart of regional stratigraphic sections including Grays Harbour Basin, southwestern Washington (Rau, 1981; Rau and Armentrout, 1983; Babcock et al., 1994; Rau and Johnson, 1999; Prothero, 2001), Olympic Peninsula, Washington (Snavely et al., 1979; Babcock et al., 1994; Prothero, 2001), Vancouver Island (Cameron, 1971; 1980; Jeletzky, 1975; Muller et al. 1981; Babcock, 1994) and the Tofino Basin (Snavely and Lander, 1983; Niem and Snavely, 1991; Rau, 1999; this study). Shaded areas indicate intervals of nondeposition and/or erosion.

middle to late Miocene strata are equivalent to the Mohnian Stage, Montesano Formation of Washington (Rau, 1981; 1999; Babcock et al., 1994; Rau, 1999, Prothero, 2001). The lower Pliocene strata of the TB are equivalent to the Quinault Formation of Washington (Campbell and Nesbitt, 2000). Also, Montesano and Quinault formation equivalents were found to occur in limited outcrops on Flores Island, British Columbia (Cameron, 1973). Although, several unconformities limit studies of onshore Miocene and Pliocene sequences and correlations.

The following major geological events have influenced the stratigraphic framework in the TB: 1) widespread Eocene submarine volcanic activity; 2) initial uplift and subsequent subsidence in the late Eocene; 3) transgressions during the Oligocene and early/middle Miocene; 4) crustal deformation, uplift and regression during the middle Miocene; 5) late Miocene transgression; 6) early Pliocene transgression; and 7) regression and sedimentation during the late Pliocene-Pleistocene (Figure 2.4; Shouldice, 1971). The foraminiferal biostratigraphic and paleoecological evidence from this study will be used as evidence to document and constrain changes in eustasy in the TB over time (discussed in the following chapter).

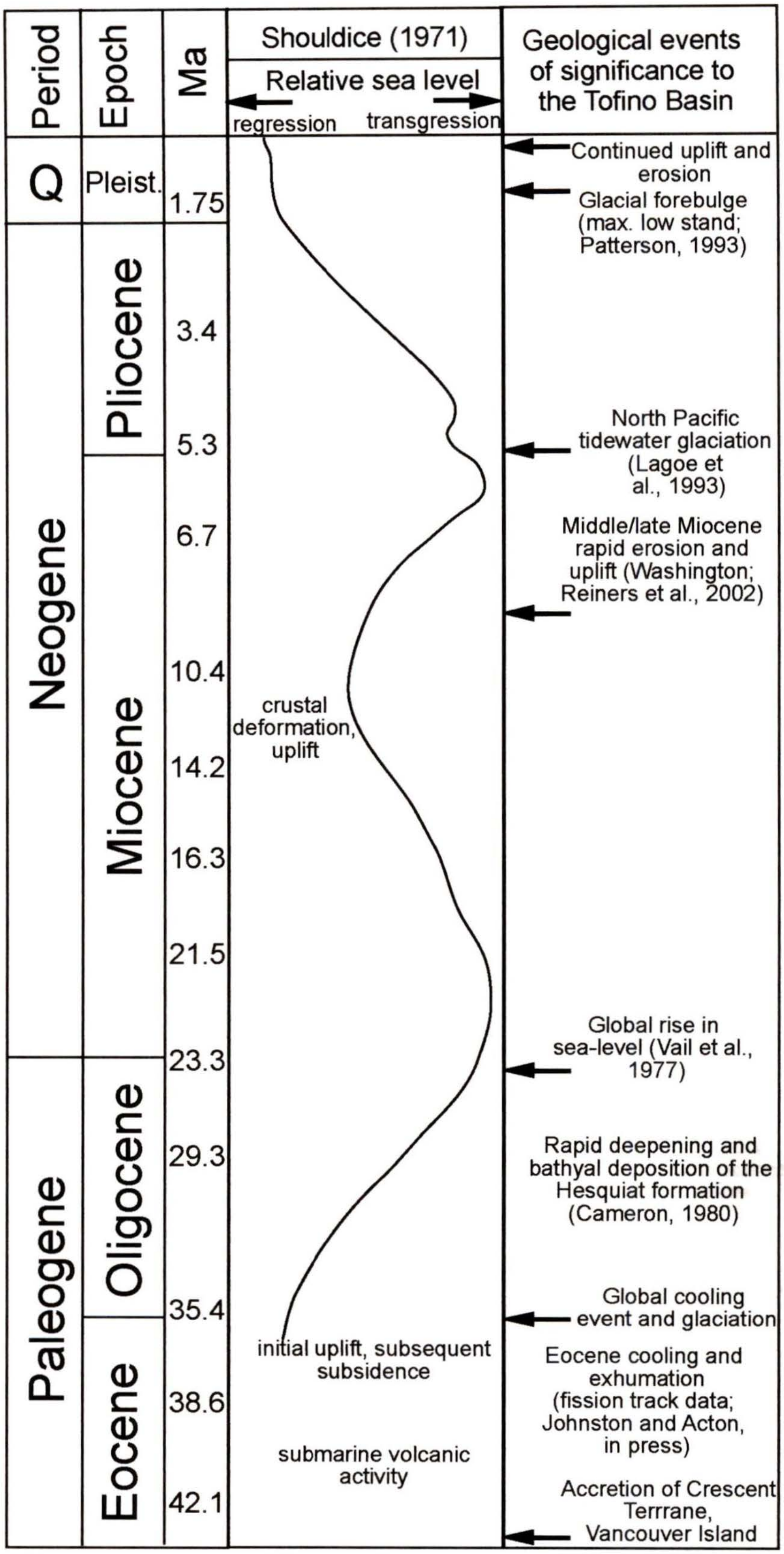


Figure 2.4. Summary diagram of the relative sea-level interpretations for the Tofino Basin (Shouldice, 1971) and other major geological events of significance.

3. BIOSTRATIGRAPHY AND PALEOECOLOGY

3.1. Introduction–Pacific Coast biostratigraphy

Marine sequences of the Northwest Pacific Coast preserve excellent records of Cenozoic strata, including the Eocene ('greenhouse') to Oligocene ('icehouse') transition (Durham, 1950; Thomas, 1989; Prothero and Berggren, 1992; Hickman, 2000; Oleinik, 2000; Nesbitt, 2002; Prothero et al., 2002). However, the development of high resolution biostratigraphy of Pacific Coast strata within the global timescale (Berggren et al., 1995) has been arduous because planktic microfossils, which are most useful for dating outer neritic to (upper/middle) bathyal sedimentary rocks (Cifelli and Scott, 1986; Scott et al., 1990; Hayward et al., 1999), are rare (usually <10% in samples) or absent (McKeel and Lipps, 1975; Haller, 1980; Rau, 1981; Cameron, 1980) in the usually discontinuous sections of Cordilleran marine outcrops (Rau, 1981).

Initially, relative stratigraphic ages were determined using molluscs (Weaver, 1942; Jeletzky, 1954; Armentrout, 1973; 1975; 1981) that were not readily correlative with the global or European timescales. Later, benthic foraminifera were used, but they were notorious for being: 1) more locally representative and facies-dependant (reflecting paleobathymetric rather than evolutionary changes) (Cameron, 1980; Ingle, 1980; Rau, 1981; Prothero, 2001); 2) time-transgressive (McDougall, 1980; Cameron, 1980; Rau, 1981; Prothero, 2001); and, 3) affected by biogeographic provinciality along the Pacific Coast (Nesbitt, 2002). Recent studies have successfully used benthic foraminifers to date shallow marine strata and determine past depositional environments as well as assess the impacts of pollution in environmentally sensitive regions (Patterson, 1990; Scott and Lipps, 1995; Hayward et al., 1999).

Magnetostratigraphy (Prothero, 2001; Prothero et al., 2001) and strontium isotopic ages (in this study), combined with high resolution biostratigraphic studies (particularly using rare planktic foraminifers and diatom microfossils) have enabled more precise stratigraphic correlations of Pacific Coast sections and improved chronostratigraphy of the Berggren et al. (1995) timescale. Planktic foraminifer biostratigraphy later gained impetus through offshore exploration, the Deep Sea Drilling

Program (DSDP) and the Ocean Drilling Project (ODP) (Ingle, 1973; Dowsett and Ishman, 1995; Spiegler, 1996; Chaisson and Hondt, 2000).

3.2. Previous regional biostratigraphic studies

In this study, the previous biostratigraphic schemes of Cameron (1980), Rau (1981; 1999) and McNeil (1989; 1997) are recognized and revised (Figure 3.1). The first two have regional correlative implications and the third includes some of the biozones recognized in this study. Cameron (1979) recognized five early Pliocene to Holocene foraminiferal assemblages and paleoenvironments, across the Apollo structure in the Tofino Basin (TB) (Figure 1.4c; 3.1). Several studies in the North Pacific including Site 177 (Paul Revere Ridge) of DSDP Leg 18 and ODP Site 883 report on common Pliocene through Pleistocene foraminifer taxa (Ingle, 1973; Dowsett and Ishman, 1995). While no detailed biostratigraphic studies were conducted, significant faunal and paleobathymetric comparisons can be made with this study and with that of Cameron's (1979) study across the Apollo structure.

One drawback of the onshore biostratigraphic schemes of Cameron (1980) and Rau (1981; 1999) is that they are established for incomplete onshore marine Cenozoic sequences. On Vancouver Island, Miocene and younger strata have only been initially described from Bajo Point (Figure 1.6; Cameron, 1971); in Washington, Miocene and Pliocene strata are present, particularly in central western Washington (Astoria(?) and Montesano formations). However the strata are truncated by intervals of non-deposition or erosion and their foraminiferal assemblages defined as 'undifferentiated assemblages' by Rau (1981; 1999).

Cameron (1980) established five new foraminiferal assemblage zones for the Escalante and Hesquiat formations (late Eocene to middle Oligocene) of the Hesquiat Peninsula and Nootka Island (Figures 1.6; 3.1). In stratigraphic order from the oldest to youngest, they are the 1) *Cibicides haydoni*, 2) *Globorotalia* sp. aff. *G. postcretacea*, 3) *Chiloguembelina cubensis*, 4) *Turrilina alsatica* and 5) *Bulimina* sp. cf. *B. alsatica* zones. Of these, two zones (2 and 3) were based on planktic taxa. Cameron provided faunal lists but did not define the zones and no taxonomic study was published; only a few taxa were considered to be short ranging. Two zones (4) *Turrilina alsatica* and 5) *Bulimina* sp. cf.

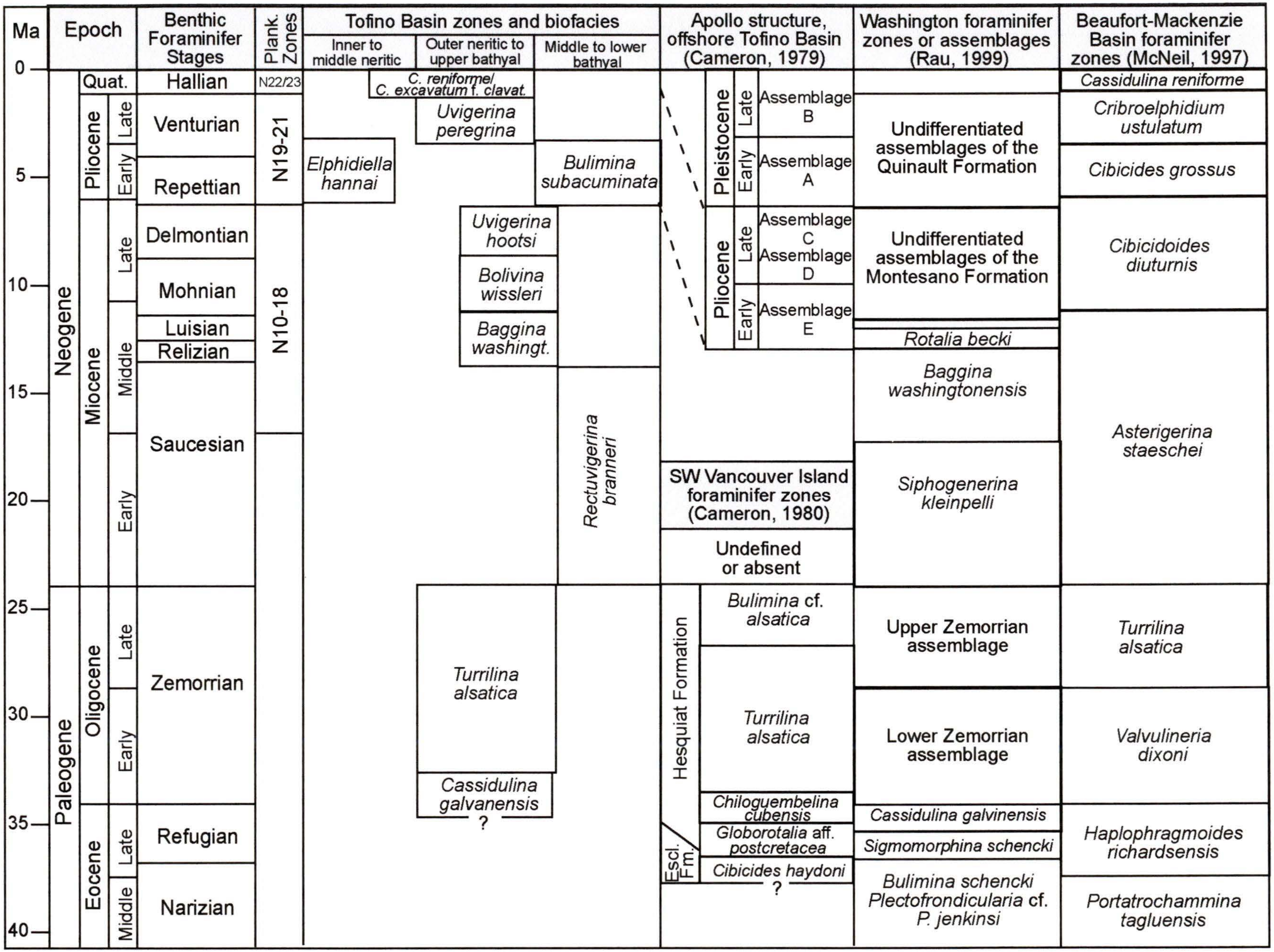


Figure 3.1. Tofino Basin foraminifer zonation and correlations with the previously established Pacific Coast and Canadian Arctic foraminifer biozones and assemblages of Cameron (1979, 1980), Rau (1999) and McNeil (1997).

B. alsatica zones) were considered to be similar, with the possibility of reduction to one zone or subzone (Cameron, 1980; addressed in the following section). In the present study, Cameron's (1980) *Turrilina alsatica* (section 3.4.2) was recognized and integrated into the offshore TB biostratigraphy. An age equivalent zone to the *Chiloguembelina cubensis* Zone (=*Cassidulina galvanenis*) is defined and discussed in this study (in section 3.4.1).

Rau (1948; 1966; 1967; 1970; 1981; 1999) defined eight new foraminiferal zones and five assemblage zones for Paleocene to Pliocene strata (Ynezian to Venturian Stages or Ypresian to Placenzian European Stages) in the Pacific Northwest (Figure 3.1). Associated taxa were listed and systematic taxonomies published. Oligocene, upper Miocene and Pliocene strata were poorly defined. A detailed marine biostratigraphy was not possible in coastal sections of Washington where faunas are sparse and incomplete sections are structurally complicated (Rau, 1981; 1999). Rau (1981; 1999) referred to these as "lower/upper Zemorrian assemblages" for Oligocene formations and "undifferentiated assemblages" for the upper Miocene Montesano and Pliocene Quinault formations. The Montesano Formation occurs in southwestern Washington (Fowler, 1965; Rau, 1967; 1981) and the Quinault Formation lies within the Point Grenville-River Raft coastal area of Washington (Rau, 1970; 1981). In this present study, two of Rau's zones are recognized, the *Cassidulina galvanensis* Zone (Rau, 1966; 1981; 1999) (equivalent to Cameron's (1980) *Chiloguembulina cubensis* Zone) and the middle/lower Miocene *Baggina washingtonensis* Zone (Rau, 1967; 1981; 1999).

Two zones established by McNeil (1997) from the Canadian Arctic that are recognized by this study include the Oligocene *Turrilina alsatica* Zone and the Pleistocene/Holocene *Cassidulina reniforme* Zone (Figure 3.1). The former species was also defined by Cameron (1980), and assemblages that include the latter species have been well recognized in other high latitude studies (Feyling-Hanssen, 1990; Osterman, 1996).

3.3. Tofino Basin foraminiferal biostratigraphic zones

Biostratigraphy is the differentiation of rock units based on the fossils contained within them (Salvador, 1994). Biostratigraphic units, or biozones, can be defined in several ways. There are six principal types of biozone (Figure 3.2); 1) range zone (taxon-range and concurrent-range zone); 2) interval zone (partial-range zone); 3) lineage zone; 4) assemblage zone (Oppel zone); and 5) abundance or acme zone (Salvador, 1994). The biozones defined in this study are based on results from TB Shell Canada well cuttings, therefore they are herein defined as interval zones, based on the highest known occurrence (first occurrence downward or last appearance datum, LAD) of specified taxa (Salvador, 1994).

For the first time, eleven provisional foraminiferal zones are defined from the six Shell Canada wells for the TB (Figure 3.1, 3.3; Table 3.1). One regional zone was previously established for Vancouver Island by Cameron (1980), two in Washington State by Rau (1981; 1999), two in the Mackenzie-Beaufort region by McNeil (1997) and six new zones/assemblages initially established for other Pacific Coast regions (California, Oregon). In the following section, the foraminiferan zones are presented in stratigraphic order of appearance, from the oldest (upper Eocene?/lower Oligocene) to the youngest (Pleistocene-Holocene) strata in the wells. However, during this study, wells were studied from the top-down and "tops" or last appearance datums (LAD's) were recognized, to detect contamination and reduce misinterpretation from wall-spalling of the wells, a common problem associated with drill cuttings.

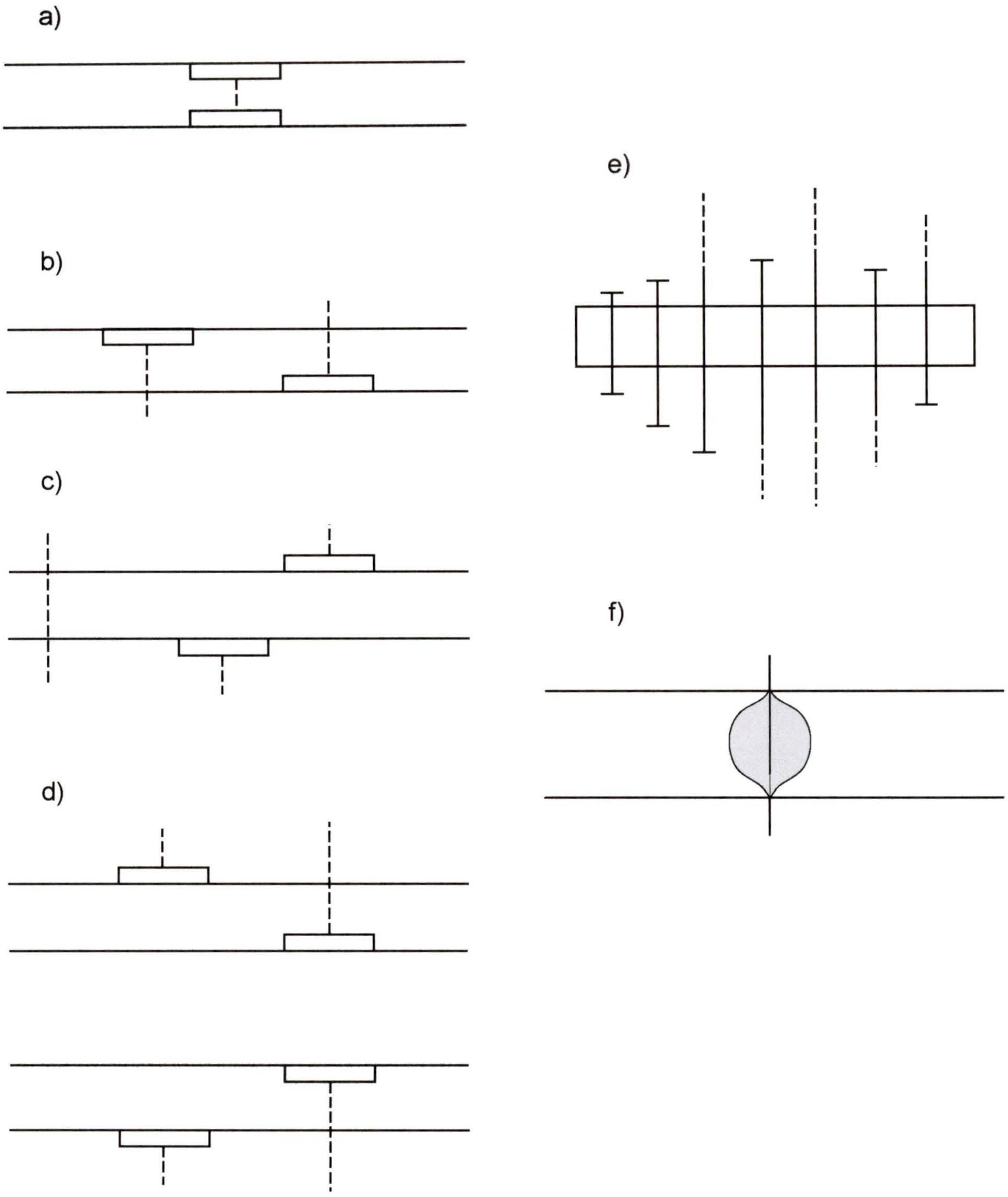


Figure 3.2. The six types of biozones used in biostratigraphy a) taxon range zone; b) concurrent range zone; c) interval (partial range) zone; d) lineage zone; e) assemblage zone; and f) abundance (acme) zone (modified from Salvador, 1994).

Table 3.1. Summary of the foraminiferal biozones (this study) recognized in the six Shell Canada Ltd. Tofino Basin wells showing the last appearance datums (LAD's) and biofacies recognized (including: inner neritic (0-50 m, 0-150 ft); outer neritic (50-150 m, 150-470 ft); upper bathyal (150-500 m; 460-1560 ft); upper middle bathyal (500-1500 m, 1560-4700 ft); lower middle bathyal (1500-2000 m; 4700-6250 ft); and lower bathyal (2000+ m, 6250+ ft) (Ingle. 1980).

a.) Cygnet J-100:

Depth (LAD) (ft)	Age/Stage	Tofino Basin zones	Biofacies
1171'	Pleistocene-Holocene	*Cassidulina reniforme/ Cribroelphidium excavatum* f. *clavatum*	Middle-outer neritic
1326'	upper Pliocene (Venturian)	*Uvigerina peregrina*	Outer neritic to upper bathyal
4581'	lower Pliocene (Repettian)	*Bulimina subacuminata*	Upper bathyal to lower middle bathyal

b.) Prometheus H-68:

Depth (LAD) (ft)	Age (Stage)	Tofino Basin zones	Biofacies
2318'	upper Pliocene (Venturian)	*Uvigerina peregrina*	Outer neritic to upper bathyal
3550'	lower Pliocene (Repettian)	*Bulimina subacuminata*	Upper bathyal to lower middle bathyal
5250'	lower/middle Miocene (Mohnian)	*Baggina washingtonensis*	Upper bathyal
5310'	lower Pliocene (Repettian)	*Bulimina subacuminata*	See above
5350'	middle/upper Miocene (Mohnian/Del.	*Uvigerina hootsi*	Upper to upper middle bathyal

5440’	middle Miocene (Mohnian)	*Bolivina wissleri*	Upper bathyal to upper middle bathyal
5480’	lower/middle Miocene (Mohnian)	*Baggina washingtonensis*	See above
5620’	lower Miocene (Saucesian)	*Rectuvigerina branneri.*	Upper middle bathyal

c.) Zeus D-14:

Depth (LAD) (ft)	Age/Stage	Tofino Basin zones	Biofacies
2460’	lower Pliocene (Repettian)	*Bulimina subacuminata*	Upper bathyal to lower middle bathyal
3080’	middle/upper Miocene (Mohnian/ Delmontian?)	*Uvigerina hootsi*	Upper to upper middle bathyal
4890’	middle Miocene (Mohnian)	*Bolivina wissleri*	Upper bathyal to upper middle bathyal
5430’	lower/middle Miocene (Mohnian)	*Baggina washingtonensis*	Upper bathyal
5990’	lower Miocene (Saucesian)	*Rectuvigerina branneri*	Upper middle bathyal

d.) Zeus I-65:

Depth (LAD) (ft)	Age/Stage	Tofino Basin zones	Biofacies
730’	Pliocene-Pleistocene	*Cassidulina reniforme/ Cribroelphidium excavatum* f. *clavatum*	Inner to middle neritic
1040’	lower Pliocene (Repettian)	*Elphidiella hannai*	Inner neritic
2260’+ below	Oligocene(?)-Miocene	Agglutinated spp. assemblage Unzoned Interval	middle to lower bathyal

e.) Pluto I-87:

Depth (LAD) (ft)	**Age/Stage**	**Tofino Basin zones**	**Biofacies**
5210’	lower Miocene (Saucesian)	*Rectuvigerina branneri* (G)	Upper middle bathyal
5740’	lower-upper Oligocene (Zemmorian)	*Turrilina alsatica* (H)	Outer neritic to upper bathyal
7010’	upper Eocene/lower Oligocene (Refugian)	*Cassidulina galvanensis* (I)	Upper bathyal

f.) Apollo J-14:

Depth (LAD) (ft)	**Age/Stage**	**Tofino Basin zones**	**Biofacies**
3970’	lower Pliocene (Repettian)	*Bulimina subacuminata* (C)	Upper bathyal to lower middle bathyal
4049’	upper Pliocene (Venturian)	?*Uvigerina peregrina* (B)	Outer neritic to upper bathyal
4060’	middle/upper Miocene (Mohnian-Delmontian?)	*Uvigerina hootsi* (D)	Upper bathyal to upper middle
4940’	lower/middle Miocene (Mohnian	*Baggina washingtonensis* (F)	Upper bathyal
8160’	lower Pliocene (Repettian)	?*Bulimina subacuminata* (C)	Upper bathyal to lower middle bathyal

3.3.1. *Cassidulina galvanensis* Interval Zone

Index species.—*Cassidulina galvanensis* Cushman and Frizzell (Pl. 4, fig. 18).

Reference section (LAD).—Shell Anglo Pluto I-87, at 7010 ft (Figure 3.3b).

Stratigraphic age.—Upper Eocene/lower Oligocene, Refugian Stage.

Associated foraminifers.—*Ammodiscus* spp., *Cyclammina pacifica, Guttulina frankei, G. hantkeni, Nodosaria dusenburyi, Oridosalis umbonatus, Plectofrondicularia packardi, Protoglobobulimina pseudotorta*; and planktic taxa: ?*Chiloguembelina cubensis, Globigerina praebulloides, G. euapertura.*

Tofino Basin Definition.—The top of this zone is herein redefined by the last appearance (LAD) of *Cassidulina galvanensis.* Also, the last appearance of *Guttulina hantkeni* occurs within the middle part of this zone. Other taxa restricted to this zone include *Guttulina frankei* and *Nodosaria dusenburyi.* No older zone has been determined because strata are diagenetically altered and faunal preservation is consistently poor. Rare altered *Sigmomorphina schencki* specimens indicate that the Refugian Stage *S. schencki* Zone originally defined by Rau (1948; 1981) is also questionably present. The *S. schencki* Zone overlaps with the *C. galvanensis* Zone (McDougall 1972; 1980; pers comm., E. A. Nesbitt, 2003). One species, *Uvigerina mioshwageri*, considered to be restricted to Miocene strata (Hornibrook et al., 1989), was recovered from near the base of this zone at 10,550 ft and supports possible faulting and stratigraphic repetition in the Pluto I-87 well.

Remarks.—The *C. galvanenis* Zone Rau (1966, 1981) was first defined from surface and well sections in the Lincoln Creek Formation of Washington. It lacked clear definition of the base and top, due to gradational faunal changes with the overlying zone and many of the associated taxa were long ranging into the overlying zone(s). It appeared to be defined loosely as an assemblage zone ("Oppellian" zone) based on the highest and lowest appearance of taxa. The *Cassidulina galvanensis* Zone appears to represent a slightly deeper biofacies (bathyal) than the overlying *Turrilina alsatica* Zone, the latter, which is characterized by numerous arenaceous foraminifer species that suggest a possible outer neritic and upper bathyal biofacies (Ingle, 1980).

The *C. galvanensis* Zone is used instead of Cameron's (1980) *Chiloguembelina cubenis* Zone because *C. galvanensis* is more common and the *C. cubensis* is rare and specimens are slightly fragmented/abraded. Regionally, *C. cubensis* has an erratic occurrence in shallower (marginal) deposits (Berggren et al., 1995), whereas *C. galvanensis* has a wide occurrence and is characteristic of the upper bathyal biofacies (Ingle, 1980). The appearance of both taxa in Vancouver Island outcrops and in the Shell wells is significant in correlation of biozones and depositional environments into the offshore. No other identifiable planktic taxa were recovered from this zone.

Cassidulina galvanensis is short-ranging within the lower strata of Pluto I-87 well (Figure 3.3b). It first appeared in clayey siltstone beds, slightly above a lithologic change (7080 ft) to unconsolidated sand, where it disappeared and reappeared below in predominantly mudstone, silty mudstone, siltstone and muddy siltstone down to near the base of the well (10,050 ft interval) (Figure 3.3b).

The planktic *C. cubensis* LAD Zone is important for global correlation of early Oligocene age strata (estimated at ~29 Ma, Rupelian/Zemmorian Stage; Jenkins, 1971; Berggren et al., 1995). It is equivalent to the P21a planktic zone (*Globorotalia angulisuturalis* / *Chiloguembelina cubensis* Concurrent Range Zone; Berggren and Miller, 1988; Berggren et al., 1995, p. 157). Cameron (1980) places the *C. cubensis* Zone in older upper Eocene/Refugian Stage strata. In this region, it is still difficult to correlate benthic zones to the Berggren et al. (1995) timescale. Therefore until planktic correlations are better developed along the Pacific Coast, the general agreement between foraminifer workers is that the *C. galvanensis* Zone straddles the Eocene/Oligocene boundary. Based on paleomagnetic data, Prothero (2001) placed the Refugian Stage at the Eocene/Oligocene boundary, thereby indicating the latest Eocene as Refugian. Therefore, evidence from this study indicates that the *C. galvanenesis* Zone marks the oldest defined strata in the Tofino Basin wells by representing the lowest biozone of the Refugian Stage late Eocene/early Oligocene age, in agreement with Cameron (1980), McDougall (1980).

Two California biozones *Cibicides haydoni* and *Uvigerina atwilli* are equivalent to the *C. galvanensis* Zone in the offshore TB, Washington and Oregon. The *C. haydoni* and *U. atwilli* zones are time-transgressive, as they are known from the Narizian Stage in California (McDougall, 1980; pers comm., E.A. Nesbitt, 2003) and in the Nootka Sound Area, Vancouver Island (Cameron, 1980).

3.3.2. *Turrilina alsatica* Interval Zone

Index species.—*Turrilina alsatica* Andreae (Pl. 4, figs. 7-9).

Reference section (LAD).—Shell Anglo Pluto I-87, at 5740 ft (Figure 3.3b).

Stratigraphic age.—Middle to upper Oligocene, Zemmorian Stage.

Associated foraminifers.—*Budashaevella multicamerata*, *Bulimina subcalva*, *Cibicides elmanensis*, *Cyclammina incisa*, *C. pacifica*, *Globigerina* sp. A, *Globobulimina pacifica*, *Globorotalia gemma*, *Guttulina frankei*, *G. irregularis*, *Gyroidinoides rotundimargo*, *Lenticulina* spp., *Melonis pompiloides*, *Oridosalis umbonatus, Plectofrondicularia packardi, Protoglobobulimina pseudotorta*, *Pullenia bulloides, Recurvoides* spp., *Reticulophragmium projectus*, *Spirosigmoilina tenuis*; and planktic taxa: *Globigerina praebulloides*, *Globigerina* sp. cf. *G. euapertura*, ?*Tenuitellinata angustiumbilicata*.

Tofino Basin Definition.—This zone is herein redefined by the LAD of *Turrilina alsatica*. The first appearance of this species in the Pluto I-87 well was near the extinction of *C. galvanensis* (at approximately 7000 ft). Another calcareous, benthic taxon that dominated and has its LAD in this zone is *Pullenia bulloides*.

Remarks.—Cameron (1980) established this zone for the upper part of the Hesquiat Formation of the Hesquiat Peninsula and Nootka Island (lower Oligocene, Zemmorian Stage). It was characterized by the abundance of *T. alsatica*, and the first occurrences of the following: *Cassidulinoides* sp., *Globigerina* sp., *Globorotalia gemma*, *Pseudoparella* sp., *Siphonodosaria* spp. and *Stilostomella* spp (Cameron, 1980; p. 22). Of these, only *T. alsatica* and *Globigerina praebulloides* were identified from the Shell well (Pluto I-87). Other taxa listed (Cameron, 1980; p.23) and also identified from the Shell well include: *Chiloguembelina* sp., *Cibicides elmanensis*, *Cyclammina pacifica*, *Globobulimina pacifica* (=to Cameron's ?*Globobulimina* sp.), *Gyroidinoides rotundimargo* (=to Cameron's ?*G. keenani*), *Lenticulina smileyi* (=to Cameron's ?*Lenticulina* sp.) *Melonis pompiloides* and *Plectofrondicularia packardi*. Those not observed include: *Anomalina* sp. cf. A. *californiensis*, *Bolivina* sp. cf. *B. marginata*, *Cassidulina globosa*, *Chilostomella* sp., *Cibicides haydoni*, *Cibicides* sp., and *Martinottiella eocenica*. Faunas observed in both the Tofino Basin and Vancouver Island samples are similar, but differ slightly by being sparser and with lower diversity (fewer species of calcareous taxa) in the offshore. Shallow-water agglutinated taxa, from both regions, suggests mixing or down-slope transport of foraminifers characteristic of the marginal marine/inner neritic biofacies (Cameron, 1980). The overall depositional environment suggested by common occurrences of calcareous *Melonis pompiloides*, *Oridosalis umbonatus Plectofrondicularia packardi* and *Turrilina alsatica* is that of a bathyal biofacies.

Cameron (1980) provisionally placed the *Bulimina* sp. cf. *B. alsatica* Zone (highest zone of the Hesquiat Formation) above the *T. alsatica* Zone. He stated that this zone had much in common with the *T. alsatica* zone and may be reduced to a subzonal status. Reworked foraminifers were found to occur within this biozone.

In the offshore, several long-ranging *Bulimina* species, identified herein as *Bulimina subclava*, had rare occurrences within the *T. alsatica* Zone. No *Bulimina alsatica* species were identified. There is question as to whether *B. alsatica* is a possible junior synonym of *B. subcalva*. In this study, *Bulimina* sp. cf. *B. alsatica* Zone is not recognized. It is important to note that *Bulimina alsatica* Cushman and Parker and *Turrilina alsatica* Andreae are not conspecific. *Turrilina alsatica* can be best distinguished from other species by its elongate, triserial tests, inflated chambers and radiate wall structure (Ulleberg, 1974), while *Bulimina* sp. has short, tapering tests, ornamented by plate-like costae (ribs) ending in plate-like spines (Cushman and Parker, 1937).

Rau (1981; 1999) did not establish the *T. alsatica* Zone in Washington, instead he divided the Oligocene Zemmorian Stage informally into the upper and lower Zemorrian assemblages of the Lincoln Formation, Washington. It is characterized by common long-ranging taxa (from below and above the Zemorrian Stage) that are not biostratigraphically valuable. The foraminifer assemblage (e.g. *Buliminella subfusiformis*, *Cornuspira byramensis* and *Plectofronidularia packardi*) suggests a wide paleobathymetric range (Ingle, 1980; Rau, 1981). However, his assemblage contains forms (above) that make it approximately equivalent to the *T. alsatica* Zone.

McNeil (1989; 1997) established the *T. alsatica* Interval Zone in the Beaufort-Mackenzie Basin, Arctic Canada, and many agglutinated taxa, generally long ranging, were identified (Schröeder-Adams and McNeil, 1994; McNeil, 1997). A few restricted species (i.e., *Budashevaella multicamerata*, *Recurvoides* spp., *Reticuloghragmium projectus*) was present in the offshore Shell well samples and are the basis for correlation.

A late Oligocene age for this zone had been established by inter-regional correlations from the North Atlantic to the Canadian Arctic (Cameron, 1980; Rau, 1981; 1999; McNeil, 1989; 1997). Studies from Europe (Denmark) have suggested a middle Oligocene age (Christensen and Ulleberg, 1974; Ulleberg, 1974). Results from this present study suggest a late early to late Oligocene age in the Tofino Basin.

The stratigraphic interval is predominantly mudstone, silty mudstone, and minor interbedded siltstone/sandstone Pluto I-87 well. Pyrite, ironstone, calcite veins and bivalve fragments were common (Figure 3.3b).

3.3.3. Unzoned interval (agglutinated assemblage)

Reference section.—Shell Anglo Zeus I-65, at ~2850+ ft to base (9980 ft) (Figure 3.3c).

Stratigraphic age.—?Oligocene (Zemorrian Stage) to early/middle Miocene.

Associated foraminifers.—*Ammodiscus incertus*, *Bathysiphon eocenica*, *Bathysiphon* sp. *cf. B. nodosariaformis*, *Budashaevella multicamerata*, *Bulimina subcalva*, *Cribrostomoides veleronis*, *Cyclammina incisa*, *C. pacifica*, *C. tani*?, *Glomospira gordialis*, *Hormosina* sp. cf. *H. pilulifer, Nothia excelsa*?, *Recurvoides* spp., *Reticulophragmium projectus, Rhabdammina abyssorum, Rheophax nodulosus.*

Remarks.—A large portion of the the Zeus I-65 well yielded long ranging, poorly preserved agglutinated taxa that were relatively undiagnostic biostratigraphically. Rare calcareous taxa were recovered and showed signs of severe recrystallization, making features indistinguishable. A questionable Oligocene age assignment is suggested for the lower portion of the well (below >6000 ft), based on a single, poorly preserved specimen of ?*Turrilina alsatica* and common occurrences of *Budashaevella multicamerata* and *Reticulophragmium projectus* that can be used to approximately correlate this interval with the *T. alsatica* Zone in the Pluto I-87 well.

This stratigraphic interval is predominantly a monotonous sequence of mudstone, silty mudstone and argillaceous siltstone. Common sandstone beds are encountered in the middle and lower portions of the well (Figure 3.3c). The biofacies indicated an agglutinated foraminifer assemblage, characterized by the appearance of unilocular (single chambered), tubular, branching forms (agglutinated morphogroup A) that suggest a lower-middle bathyal bathymetries (Jones and Charnock, 1985; Schröeder-Adams and

McNeil, 1994; Osterman and Spiegler, 1996; Mancin, 2001 and references listed therein). Planispiral/lenticular agglutinated forms, typical of neritic and marginal marine biofacies (agglutinated morphogroup B) were also present, not as abundant, and were possibly transported into the deep water environment (Jones and Charnock, 1985; Mancin, 2001).

3.3.4. *Rectuvigerina branneri* Interval Zone

Index species.—*Rectuvigerina branneri* (Bagg) (Pl. 7, figs. 16-17, 21-23).

Reference section (LAD).—Pluto I-87, at 5210 ft (Figure 3.3b); Zeus D-14, at 5990 ft (Figure 3.3d); and Prometheus H-68, at 5620 ft (Figure 3.3e).

Stratigraphic age.—Lower Miocene, Saucesian Stage to Relizian(?) Stage.

Associated foraminifers.—*Bulimina alligata, Dentalina* sp. cf. *D. frobisherensis, Gyroidinoides rotundimargo, Lagena spiratiformis*?, *Lenticulina smileyi, Melonis pompiloides, Nodogenerina lepidula*?, *N. sagrinensis*?, *Oridosalis umbonatus, Planulina retia, Proxifrons advena, Pseudonodosaria obtuissima, Rectuvigerina* sp. cf. *R. loeblichi, R. smithi*? *R. transversa, Reussoolina simplex, Siphonodosaria advena, S. montereyana, Suggrunda kleinpelli, Uvigerina gallowayi, U. gallowayi*?, *U. subperegrina*, *Uvigerinella ornata*.

Tofino Basin Definition.—This new zone is herein redefined by the LAD of *Rectuvigerina branneri.* Several other LAD's of associated taxa occur within this zone including *Bulimina alligata*, *Planulina retia*, *Uvigerina gallowayi*, and *Uvigerinella ornata*. Short ranging lower-middle(?) Miocene taxa make their first appearances in this zone, including *Lenticulina smileyi*, *Rectuvigerina* spp., and *Valvulineria asanoi*.

Remarks.—The *Rectuvigerina branneri* Zone is newly recognized in the Tofino Basin. It was initially established for the lower Miocene of California (originally the *Siphogenerina* (=*Rectuvigerina*) *branneri* Bagg Zone (Kleinpell, 1938; Kleinpell, 1980; Finger, 1992). Kleinpell (1938, as discussed in Finger, 1992) placed the LAD of this zone within his *Siphogenerina reedi* Zone of the Luisian Stage. Kleinpell (1938) and Kleinpell et al. (1980) subdivided the lower Miocene strata into numerous zones; these zones/subzones were not recognized in the Shell wells possibly because they were based on localized water/temperature conditions of the Monterey depositional environment (Kleinpell, 1980; Finger, 1992). Nonetheless, the *R. branneri* Zone is distinct from underlying and overlying zones and marks a faunal change by indicating a transgressive shift of the biofacies (see paleoecology discussion).

Tofino Basin lower Miocene bathyal strata are not preserved on Vancouver Island (Cameron, 1980). The Sooke Formation is considered to be lower Miocene, however, it represents littoral depositional environment (Clark and Arnold, 1923; Cockburn et al., 1999). Rau (1967; 1981) assigned the lowermost Miocene to his *Siphogenerina kleinpelli* Zone, initially recognized in the Saucesian Stage Astoria(?) Formation of Washington (that spans ±17-20 Ma; Prothero, 2001). The *Siphogenerina kleinpelli* species was not identified in the Tofino Basin, however it is probably close to or conspecific with the long-ranging *Rectuvigerina transversa* species, discussed by Rau (1951). The *R. branneri* Zone is correlative with the *S. kleinpelli* Zone of Washington as it represents a similar age and biofacies (this study).

Patterson (1989) identified foraminifer species (*Pseudononion costiferum, Rectuvigerina transversa, Uvigerinella ornata*, but not *R. branneri*) associated with this zone, near the base of the Osprey D-36 well (from 1687 m to base) in the Queen Charlotte Basin. Some associated faunas from this well match those illustrated and described by Finger and Lipps (1990) and Finger (1990, 1992) for the Miocene formations of California. The overall faunal assemblages encountered in the *R. branneri* Zone are most characteristic of the upper middle bathyal biofacies (Ingle, 1980).

This zone represents the lowest Miocene (Saucesian Stage) strata in the Shell wells. It is recognized from the Pluto I-87, Zeus D-14, and Prometheus H-68 wells (Figures 3.3b, d, e). In the former two wells, it overlies a mixed stratigraphic interval over a possible unconformity and volcanic basement. The *R. branneri* Zone was recognized from limited samples, starting from ~5200 ft and possibly represents the lower part of the zone. This stratigraphic interval occurs is predominantly mudstone, silty mudstone, interbedded siltstone/sandstone lithologies with minor shell fragments, pyrite and siderite (Pluto I-87 well), and with abundant microfossils and a few volcanic pebbles (in Prometheus H-68 and Zeus D-14 wells). In the Pluto I-87 well, a large interval from the uppermost portion (above 5200 ft) of the well was not available (missing) for use in this study.

3.3.5. ***Baggina washingtonensis*** Interval Zone

Index species.—*Baggina washingtonensis* Rau (Pl. 3, figs. 5-8).

Reference section (LAD).—Zeus D-14, at 5430 ft (Figure 3.3d); Prometheus H-68, at 5250 ft (upsection repeat interval) and at 5480 ft (Figure 3.3e).

Stratigraphic age.—Upper lower Miocene to lower middle Miocene?, Saucesian to lower Mohnian? Stage.

Associated foraminifers.—*Bulimina alligata*, *B. subcalva*, *Buliminella subfusiformis*, *Dentalina sp.* A, *Gyroidinoides rotundimargo*, *Melonis pompiloides*, *Lenticulina miocenica*, *Nodogenerina lepidula*?, *Oridosalis umbonatus*, *Pseudonodosaria discreta*, *Pseudononion basispinatum*, *P. costiferum*, *Pullenia quinqueloba*, *Rectuvigerina transversa*, *Sphaeroidina chilostomata*, *Uvigerina gallowayi*, *Uvigerinella ornata*; and planktic taxa *Globigerina praebulloides*, *Orbulina universa*, *Tenuitellinata angustiumbilicata*.

Tofino Basin Definition.—The *B. washingtonensis* zone is herein redefined by the LAD of *Baggina washingtonensis*. Also, LAD's of *Pseudononion basispinatum*, *P. costiferum* and *Sphaeroidina chilostomata* are found within this zone. Several taxa make an appearance in this zone including *Sphaeroidina chilostomata* and *Bolivina* spp.,

Remarks.—The *Baggina washingtonensis* Zone correlates with the same zone in Washington, defined by Rau (1967; 1981) for the Saucesian Stage (Prothero, 2001) Astoria(?) Formation. The upper portion of the zone was initially referred to the middle Miocene Relizian Stage and the lower portion to the lower to middle Miocene Saucesian Stage. Rau (1981) suggested a neritic biofacies based on the faunal characteristics of the zone. Previous studies have supported an upper bathyal biofacies indicated by taxa such as *Baggina washingtonensis*, *Gyroidinoides rotundimargo*, *Sphaeroidina chilostomata* and *Uvigerinella ornata* (Ingle, 1980; Finger, 1990; Rau, 1999). The present study further supports an upper bathyal biofacies.

Wissler (1943) and Natland (1952) recognized the *Baggina californica* Zone in the Los Angeles Basin and in Southern California. Kleinpell et al. (1980; as modified by Finger, 1992), placed the LAD of *B. californica* within their *Bolivina wissleri* Zone (first appearance in the lower Relizian Stage). In the present study, *Baggina washingtonensis* is distinguished from *B. californica*, although a close relationship can be inferred (see

Systematic Paleontology section). Herein, the *Baggina washingtonensis* Zone is recognized separately from the overlying *Bolivina wissleri* Zone, which is represented by a distinct, foraminifer assemblage. Also *B. wissleri* specimens were not recovered from the Tofino Basin *B. washingtonensis* Zone (or vice versa), instead the LAD of the *Bolivina wissleri* was used to define the overlying zone.

This zone is best recognized from the Zeus D-14 well, where more complete lower middle Miocene strata were encountered (Figure 3.3d), whereas it occured in a thin interval in the Prometheus H-68 well (Figure 3.3e) and from a questionable interval in the Apollo J-14 well (LAD at 4940 ft, based on a single specimen recovered; Figure 3.3a). In the Prometheus H-68 well, this zone was possibly fault repeated or reworked into younger overlying strata, because it occurred in a narrow interval (LAD at 5250 ft) above three overlying zones and again down-well above the *R. branneri* Zone (LAD at 5480 ft). In the Pluto I-87 well, *B. washingtonensis* and associated taxa were recovered from a few samples at the top of the available sampled interval in the *R. branneri* Zone, suggesting that the *B. washingtonensis* Zone occurred above and is represented by a few abraded specimens that probably spalled-down the well. This stratigraphic interval occurred predominantly in a mudstone (Zeus D-14) and "gumbo" (sticky-wet mud)-muddy siltstone (Prometheus H-68; Shell Canada 1968b) lithology with abundant microfossils, traces of glauconite, ironstone and shell fragments (Figure 3.3d, e).

3.3.6. *Bolivina wissleri* Interval Zone

Index species.—Bolivina wissleri Kleinpell and Tipton (Pl. 3, figs. 14, 16).

Reference section (LAD).—Zeus D-14, at 4890 ft (Figure 3.3 d); Prometheus H-68, at 5440 ft (Figure 3.3e);.

Stratigraphic age.—Middle Miocene, Mohnian Stage.

Associated foraminifers.—Bolivina blakei, B. churchi, B. foraminata, B. ornata, Bulimina alligata, B. subcalva, Buliminella bassendorfensis, B. californica?, B. curta Buliminella subfusiformis, Cibicidoides mckannai, Dentalina sp. A, *Hopkinsina magnifica, Oridosalis umbonatus, Planulina retia, Pseudonodosaria discreta, Suggrunda kleinpelli, Uvigerina dirupta, U. hannai?, U. hootsi, U. subperegrina, Valvulineria* *asanoi*; and planktic taxa: *Globigerina bulloides*, *G. quinqueloba, G. praebulloides*, *Orbulina universa*, *Tenuitellinata angustiumbilicata*.

Tofino Basin Definition.—This zone is herein redefined by the LAD of *Bolivina wissleri*. Several taxa made their first appearance including *Uvigerina hootsi* and *Hopkinsina magnifica* (Finger, 1992). Also, *Bolivina* and *Buliminella* species were well represented within this zone.

Remarks.—The *Bolivina wissleri* Zone is redefined for the Tofino Basin, based on the LAD of *B. wissleri*. It was initially established for middle Miocene (Mohnian) strata in California (Kleinpell and Tipton, 1980; Finger, 1992). Several associated taxa that were considered to have their first or last appearances in this zone (Kleinpell, 1938; Kleinpell and Tipton) were not found in a previous study by Finger (1992) for the same sections, or in this Tofino Basin study. Restricted facies-controlled benthic assemblages are one possible explanation for this distribution. The appearance of numerous, possibly closely related *Bolivina* species, *Uvigerina hootsi* and *Hopkinsina magnifica* in the Tofino Basin supports a closely related foraminiferal assemblage from an upper to upper middle bathyal biofacies. Middle and lower-upper(?) Miocene strata were largely confined to the Montesano Formation in southwest Washington. Rau (1967; 1981; 1999) did not formalize a name for the faunal assemblage, but instead called it the 'undifferentiated assemblages of the Montesano Formation'. The lowermost part of Rau's assemblage is correlative with the *B. wissleri* Zone in the Tofino Basin.

This zone is best defined within the Zeus D-14 well (Figure 3.3d) because faunas were more abundant and better preserved. In the Prometheus H-68 well (Figure 3.3e) this zone occured in a narrow (~40 ft thick) interval. This stratigraphic interval is predominantly mudstone (non-silty) with abundant microfossils in the Zeus D-14 well and silty mudstone grading to muddy siltstone lithologies with thin beds (<5%) of fine-grained quartz sandstone in the Prometheus H-68 well.

3.3.7. *Uvigerina hootsi* Interval Zone

Index species.—*Uvigerina hootsi* Rankin (Pl. 8, figs. 18-19).

Reference section (LAD).—Zeus D-14, at 3080 ft (Figure 3.3d); Prometheus H-68, at 5350 ft (Figure 3.3e).

Stratigraphic age.—Middle/upper(?) Miocene, Mohnian/Delmontian(?) Stage.

Associated foraminifers.—*B. blakei, B. churchi, Buliminella californica*?, *B. curta, B. elegantissima, B. subfusiformis, Cassidulina carinata, Cibicidoides mckannai, Epistominella pacifica, E. smithi, Globobulimina pyrula, Gyroidinoides altiformis, G. rotundimargo, Hopkinsina magnifica, Islandiella californica, I. helenae, I. limbata, Lingulina* sp. A, *Nonionella stella, Oridosalis umbonatus, Pullenia* spp., *Uvigerina dirupta, U. hannai*?, *U. hootsi*, *U. subperegrina*, *Valvulineria asanoi*; and planktic taxa: *Globigerina bulloides*, *G. quinqueloba*, *G. praebulloides*, *G. woodi*?, *Globigerinita glutinata*?, *Globorotalia scitula*, *Neogloboquadrina pachyderma*, *Orbulina universa*, *Tenuitellinata angustiumbilicata*,

Tofino Basin Definition.—This new zone is herein defined by the LAD of *Uvigerina hootsi*. Also, the LAD's of a few *Bolivina* species, first known to appear in the underlying *Bolivina wissleri* Zone are recognized.

Remarks.—The *U. hootsi* Zone correlates with the 'undifferentiated assemblages of the Montesano Formation' (Mohnian Stage; Prothero, 2001) of Washington (Rau, 1981;1999). *Uvigerina hootsi* was recorded as one of the common and/or characteristic species of this formation (Rau, 1981). In California, the *Bolivina obliqua* Zone was established for upper Miocene, Delmontian Stage strata (Kleinpell, 1938; Kleinpell and Tipton, 1980; Kleinpell et al., 1980; Finger, 1992). Neither his latter zone nor its key taxa were recognized in the Tofino Basin.

The *Uvigerina hootsi* Zone is distinct in both the Prometheus H-68 and Zeus D-14 wells. It occured in predominantly mudstone lithologies that contain abundant microfossils. Previously it had not been identified for upper Miocene Pacific Coast strata, although Natland (1952) initially used *Uvigerina hootsi* as a "zonal" species to differentiate upper Miocene strata in southern California.

The faunal assemblage within the *U. hootsi* Zone grades into those of the underlying and overlying zones. The overall biofacies present within this zone ranges from the upper bathyal to upper middle bathyal (Ingle, 1980).

3.3.8. *Bulimina subacuminata* Interval Zone

Index species.—*Bulimina subacuminata* Cushman and R.E. Stewart (Pl. 3, figs. 26-28).

Reference section (LAD).—Apollo J-14, at 3970 ft and at ?8160 ft (possible repeat section; Figure 3.3a); Zeus D-14, at 2460 ft (Figure 3.3d); Prometheus H-68, at 3550 ft (Figure 3.3e); Cygnet J-100, at 4581 ft (Figure 3.3f).

Stratigraphic age.—Lower Pliocene, Repettian Stage;

Associated foraminifers.—*Bulimina subcalva, Cyclammina cancellata, C. incisa, Cassidulina carinata, Cibicides lobatulus, Cibicidoides mckannai, Dorothia* sp. aff. *D. bradyana, Epistominella pacifica, Gaudryina subrotunda, Globigerina bulloides, Globobulimina pacifica, Gyroidinoides altiformis, Haplophragmoides* spp., *Islandiella californica, Islandiella helenae, Islandiella limbata, Martinotiella communis, Melonis pompiloides, Neogloboquadrina pachyderma, Neouvigerina proboscidea, Oridosalis umbonatus, Planulina wullerstorfi, Pullenia bulloides, Protoglobobulimina auriculata, Pseudoparrella subperuviana, Sigmoilina celata, Spirosigmoilina tenuis, Uvigerina dirupta, U. hannai?, U. latalata, U. subperegrina*; and planktic taxa: *Globigerina bulloides, G. falconensis, G. quinqueloba, G. umbilicata, Globigerinita glutinata?, G. uvula, Neogloboquadrina pachyderma, Orbulina universa.*

Tofino Basin Definition.—This new zone is herein defined by the LAD of *Bulimina subacuminata*. Also, the LAD of *Neouvigerina proboscidea* is found within this zone.

Remarks.—The *B. subacuminata* "zonal/assemblage" name was widely applied in previous studies to lower Pliocene strata of the Coast Range (Woodring, 1952; Wissler, 1943; Natland, 1952; Haller, 1980). However it was not formalized. *Bulimina subacuminata* may be misidentified as the longer-ranging *B. subcalva* or the *B. inflata*. However, *B. subacuminata* is distinguished from the latter two species by 1) having longitudinal costae (ribs) on all chambers 2) being fusiform in shape (less inflated) and by 3) lacking blunt (marginal) spines. These species are probably closely related and may represent an evolutionary lineage (Haller, 1980). The LAD's of the restricted *B. subacuminata* and *N. proboscidea* are useful markers for lower Pliocene strata along the Pacific Coast. *Neouvigerina proboscidea* is considered to be indicative of low oxygen conditions (Dowsett and Ishman, 1995).

In Washington, ‘undifferentiated assemblages’ of the Quinault Formation, were included in the lower Pliocene strata (Cushman et al., 1949; Rau, 1970; 1981; 1999; Campbell and Nesbitt; 2000; Prothero, 2001). The *Bulimina subacuminata* species was recorded within Rau’s Quinault Formation assemblage and is herein correlated with the newly established *B. subacuminata* Zone in the Tofino Basin (Rau, 1970; 1981).

In the Gulf of Alaska and in the Canadian Arctic, the *Cibicides grossus (=C. lobatulus* var. *grossus*) Zone was previously established for the early Pliocene (McNeil, 1989; 1997; Feyling-Hanssen, 1990). This species is recognized in the Tofino Basin as *Cibicides lobatulus* and was found to range from Pliocene into the Pleistocene-Holocene deposits at high latitudes (Todd and Low, 1967; Smith, 1978; Bergen and O’Neil, 1979; Lagoe, 1979; Echols and Armentrout, 1980; Osterman, 1996; Polyak et al., 2002). Therefore, in agreement with Osterman (1996), caution should be used in placing *C. lobatulus* as a lower Pliocene marker.

The *Bulimina subacuminata* Zone is present in all but two (Zeus I-65 and Pluto I-87) of the Shell Canada wells and is most complete in the Cygnet J-100 well. The LAD of *Bulimina subacuminata* is used because it is a common, short-ranging species of lower Pliocene strata in the Tofino Basin. The lithology characteristic of the zone is predominantly mudstone (Cygnet J-100, Zeus D-14 and Apollo J-14 wells), silty mudstone (Prometheus H-68) and muddy siltstone (Zeus D-14), within thin argillaceous beds (Prometheus H-68) and abundant microfossils and minor bivalve fragments.

The *B. subacuminata* Zone correlates with Blow’s (1969) N19 zone. This is based on the common occurrence of the following planktic taxa in the *B subacuminata* Zone: *Globigerina bulloides*, *Globigerinita glutinata*?, *Globorotalia scitula*, *Neogloboquadrina pachyderma* and *Orbulina universa*. Blow’s zone can be approximately correlated with Berggren et al.’s (1995) P11/P12 planktic zones (latest Miocene (?) to early Pliocene, estimated at 5.6-4.18 Ma; Ingle, 1973; Berggren et al., 1995; Chaisson and Hondt, 2000).

Lower Pliocene, upper middle bathyal (Ingle, 1980) faunas of the Pacific Coast indicated warm temperate to subtropical surface temperatures, supporting a temporary climatic warming event that led to a northward migration of the 15-20° isotherm (Ingle, 1973; Haller, 1980; Lagoe and Zellers, 1996). In addition, this is supported by the occurrence of predominantly dextrally-coiled *Neogloboquadrina pachyderma* in samples (especially from Cygnet J-100 well), which suggests warmer sea surface temperatures during the early Pliocene (Ingle, 1973; Dowsett and Ishman, 1995). The inner neritic age equivalent zone to the *U. peregrina* Zone of this present study is the *Elphidella hannai* Zone (following section).

3.3.9. ***Elphidiella hannai*** **Interval Zone**

Index species.—*Elphidiella hannai* (Cushman and Grant) (Pl. 5, fig. 21).

Reference section (LAD).—Zeus I-65, at 1040 ft (Figure 3.3c).

Stratigraphic age.—Lower Pliocene.

Associated foraminifers.—*Buliminella elegantissima, Cribroelphidium excavatum* f. *clavatum, Elphidiella oregonense Elphidiella* sp. A, *Elphidium* sp. cf. *E. hispidulum, Epistominella pacifica, Islandiella helenae, I. limbata, I. norcrossi, Metapolymorphina charlottensis, Nonionella novozealandica, Nonionella stella, Quinqueloculina latidentella?, Quinqueloculina akneriana, Pullenia salisburyi.*

Tofino Basin Definition.—This new zone is herein defined by the LAD of *Elphidiella hannai*. Also, the LAD of *Elphidiella oregonense* can be used to define this zone because it commonly occurred in association with *E. hannai* and was restricted to the same interval and biofacies.

Remarks.—This faunal assemblage was initially described from the Pliocene of California by Cushman and Grant (1927) and has since been recognized from Washington to the Gulf of Alaska and the Canadian Arctic. It was a widespread inner neritic assemblage that included taxa (i.e., *Elphidiella oregonense*, *Metapolymorphina charlottensis* and *Nonionella stella*) indicative to cool-temperate water conditions (Rau, 1970).

Cameron (1971) identified *E. hannai* species from a narrow sequence of Pliocene deposits at Bajo Point, Nootka Island (equivalent to Jeletzky's Division D) and correlated it to the upper part of the Quinault Formation of Washington (lower Pliocene). This foraminiferal assemblage was not encountered in any other samples from the Hesquiat Peninsula. Cameron (1979) recognized "Assemblage A" of early Pleistocene age that represented inner to middle neritic water depths across the Apollo structure in the Tofino

Basin. *Elphidiella hannai* and *E. oregonese* were listed as characteristic taxa. His "Assemblage A" is herein considered correlative with the *Elphidiella hannai* Zone. Also, *Elphidiella hannai* (as *E. nitida*) was described from the Shell Canada Murrelet L-15 well in the Queen Charlotte Basin, and was considered to be restricted to the Miocene (Patterson, 1989; Patterson et al., 1998).

The *Elphidiella hannai* species and associated fauna have been identified from the Point Grenville coastal area in the upper part of the "undifferentiated assemblages of the Quinault Formation" in Washington (Rau, 1970; 1981). This assemblage is correlated to the Tofino Basin *E. hannai* Zone. Its short restrictive occurrence in lower Pliocene strata and inner neritic depositional environments are in agreement with this present study. The *E. hannai* Zone has been recognized from several studies in the Gulf of Alaska (Lagoe, 1994; Echols and Armentrout, 1980), Arctic (equivalent to the *Elphidium* spp. Zone by Osterman, 1996) and in Greenland (equivalent to the *Elphidiella rolfi* Zone by Feyling-Hanssen, 1990).

The *E. hannai* Zone is characterized by taxa restricted to the inner neritic (sublittoral), brackish water biofacies, including *Buliminella elegantissima*, *Elphidiella hannai*, *E. oregonense* and *Metapolymorphina charlottensis* (Echols and Armentrout, 1980). Other taxa such as *Islandiella* spp., *Nonionella novozelandica*, *N. stella* and *Quinqueloculina* spp. ranged towards the outer neritic limits of the zone. *Epistominella pacifica* has commonly been described from the upper middle bathyal biofacies along the Pacific Coast (Ingle, 1980), however it was found to have a shallower occurrence in the Tofino Basin (this study) and also in Yakataga, Gulf of Alaska (Echols and Armentrout, 1980). This is supported by the absence of planktic taxa in this interval. Also, *Elphidiella hannai*, and *E. oregonense* do not range into the Holocene and *C. excavatum* replaces these species in younger strata. The lithology and macrofauna characteristic of this zone is predominantly silty mudstone, argillaceous and/or muddy siltstone with minor fine-grained sandstone interbeds, with bivalve fragments and echinoid spines (Figure 3.3c; Shell Canada 1968; 1969).

3.3.10. *Uvigerina peregrina* Interval Zone

Index species.—*Uvigerina peregrina* Cushman (Pl. 8, figs. 22-25).

Reference section (LAD).—?Apollo J-14, at 4049 ft (Figure 3.3a); Prometheus H-68, at 2318 ft (Figure 3.3e); Cygnet J-100, at 1326 ft (Figure 3.3f).

Stratigraphic age.—Upper Pliocene-lower Pleistocene.

Associated foraminifers.—*Brizalina fragilis, B. subaenariensis, Cassidulina carinata, Cibicides lobatulus, Cibicidoides mckannai, Cribrostomoides veleronis, Epistominella pacifica, Euuvigerina juncea, Fissurina barkeri, Glandulina* sp. cf. *G. contracta, Globobulimina pacifica, Homalohedra apiopleura, Islandiella californica, I. helenae, I. islandica, I. limbata, I. norcrossi, Karreriella baccata, Lagena flatulenta, Nonionella stella, Nonionellina labradorica, Quinqueloculina akneriana Planulina wullerstorfi, Protoglobobulimina auriculata, P. borealis?, P. salisburyi, Pyrgo murrhina, P. sarsi?, Rutherfordoides virga, Stainforthia concava, Trifarina fluens, Uvigerina latalata, U. subperegrina*; and planktic taxa: *Globigerina bulloides*, *G. falconensis*, *G. megastoma?*, *G. quinqueloba*, *G. umbilicata*, *Globigerinita glutinata?*, G. *uvula*, *Globigerinoides extremus?*, *Orbulina universa*, *Neogloboquadrina asanoi*, *N. incompta* and *N. pachyderma*.

Tofino Basin Definition.—This new zone is herein defined by the LAD of *Uvigerina peregrina*. Also, the LAD of *Karreriella baccata* occured within this zone.

Remarks.—The *U. peregrina* "zonal/assemblage" name was widely applied in previous studies to refer to the middle/upper Pliocene sections of the Pacific Coast, but was not formalized (Woodring et al., 1952; Wissler, 1943; Natland, 1952; Ingle, 1973; Haller, 1980). Faunal assemblages characteristic of the *U. peregrina* Zone were recognized in several DSDP Leg 18 sites along the Pacific Coast, and suggest that the assemblage is consistently developed on the outer neritic to upper bathyal slopes off California to the Gulf of Alaska (Ingle, 1973).

Cameron (1979) recognized foraminiferal "Assemblage C" as late Pliocene age and represented middle to outer neritic paleo water depths, "Assemblage E" was early Pliocene age and represented upper bathyal depths, across the Apollo structure in the

Tofino Basin. These assemblages included *Uvigerina peregrina* and associated taxa and are correlated with the *U. peregrina* Zone (this study).

In the Gulf of Alaska and the Canadian Arctic, the *U. peregrina* Zone is not recognized, instead shallow water zones such as the *Cribroelphidium ustulatum* Zone (McNeil, 1997) and the *Elphidium albiumbilicatum* Zone (Osterman, 1996) have been established. These are representative of the inner neritic/marginal marine biofacies, whereas the *U. peregrina* Zone contained faunas (*U. peregrina* and *E. pacifica* rich) that range from the outer neritic to the upper bathyal/upper middle bathyal biofacies (Ingle, 1980; Echols and Armentrout, 1980).

The *U. peregrina* Zone shows the highest diversity and greatest abundance of taxa in the Tofino Basin. The fauna was dominated by numerous calcareous imperforate, perforate and few common planktic taxa. *Karreriella baccata* was the dominant agglutinated species. Particularly characteristic were the strongly bladed and costate *Uvigerina peregrina* and *U. subperegrina*, large thick-walled *Islandiella* species, *Nonionellina labradorica*, *Trifarina fluens*, and rotalids including *Epistominella pacifica* and *Cibicides lobatulus*. *Islandiella* species commonly occured with *C. lobatulus* (Echols and Armentrout, 1980). The upper part of the zone was dominated by deep water *Brizalina* spp. and *Epistominella pacifica*. The occurrence of fragmentary *Cribroelphidium excavatum* specimens suggests possible down-well spalling from younger strata. Most of the associated taxa were common components of cool temperate to polar outer neritic to upper bathyal biofacies of the Pliocene to Holocene and have been recognized in the Queen Charlotte Basin wells (Patterson, 1989; Patterson et al., 1998). This zone and its associated assemblage suggest that a cooling trend was already underway in the late Pliocene. The lithology characteristic of the zone is predominantly mudstone (Cygnet J-100, Apollo J-14) and silty mudstone (Prometheus H-68) with abundant microfossils and minor bivalve fragments.

3.3.11. *Cassidulina reniforme / Cribroelphidium excavatum* f. *clavatum* Interval Zone

Index species.—*Cribroelphidium excavatum* (Terquem) (Pl. 5, figs. 12-18); *Cassidulina reniforme* (Nørvang) (Pl. 4, figs. 19-22).

Reference section (LAD).—Zeus I-65, at 730 ft (Figure 3.3c); Cygnet J-100, at 1171 ft (Figure 3.3f);.

Stratigraphic age.—Pleistocene to Holocene.

Associated foraminifers.—*Buliminella elegantissima, Cribroelphidium excavatum f. clavatum, Cibicides lobatulus, Epistominella pacifica, Islandiella helenae I. islandica, I. limbata, I. norcrossi, Nonionellina labradorica, Quinqueloculina latidentella?, Quinqueloculina akneriana, Pullenia borealis?,P. salisburyi*; and planktic taxa: *Globigerina bulloides, G. falconensis, G. quinqueloba, Globigerinita glutinata*?, *Neogloboquadrina dutertrei, N. incompta, N. pachyderma.*

Definition.—This zone is herein redefined by the LAD (and/or the highest sample interval available from the Cygnet J-100 and Zeus I-65 wells) of both *Cassidulina reniforme* and *Cribroelphidium excvatum* f. *clavata*, which ranged into the Holocene.

Remarks.—This zone is newly established for the Tofino Basin. The *Cribroelphidium excavatum* f. *clavatum* Zone and/or associated faunal assemblage have been recognized by other high latitude studies (Loeblich and Tappan, 1953; Hald et al., 1994; Osterman, 1996; McNeil, 1997; Korsun and Hald, 1998; Polyak et al., 2002) and the *Cassidulina reniforme* Zone has been established in the Arctic of Canada (McNeil, 1997). The faunal assemblage characteristic to this zone is an indicator of post-glacial, oxygenated paleoenvironments (Patterson and Kumar, 2002).

In the Tofino Basin, the Quaternary strata occured in a thin interval (of available samples) at the top of the Zeus I-65 and Cygnet J-100 wells (Figure 3.3c, f). The *C. reniforme/C. excavatum* f. *clavatum* Zone was established based on the co-occurrence of *C. reniforme* (~40-60% of fauna in zone) and *C. excavatum* f. *clavatum* (~10% of fauna in zone). However, Hald et al. (1994) reported similar occurrences of these taxa in Quaternary sediments of the Arctic deposited during the Last Glacial Maximum (LGM; between 17,500 and 13,600 years). Future study of Tofino Basin Quaternary strata may warrant separation of this zone into the *C. reniforme* Zone and the *C. excavatum* f. *clavatum* Zone. This separation was not possible, based on this present study.

The faunal assemblage contains common taxa reported from the underlying *Uvigerina peregrina* and/or *Elphidiella hannai* zones, but represents the middle(?) to outer neritic biofacies. Common taxa (comprising 10-30% of fauna in zone) include

Cibicides lobatulus, *Epistominella pacifica*, *Nonionellina labradorica* and *Pullenia salisburyi*.

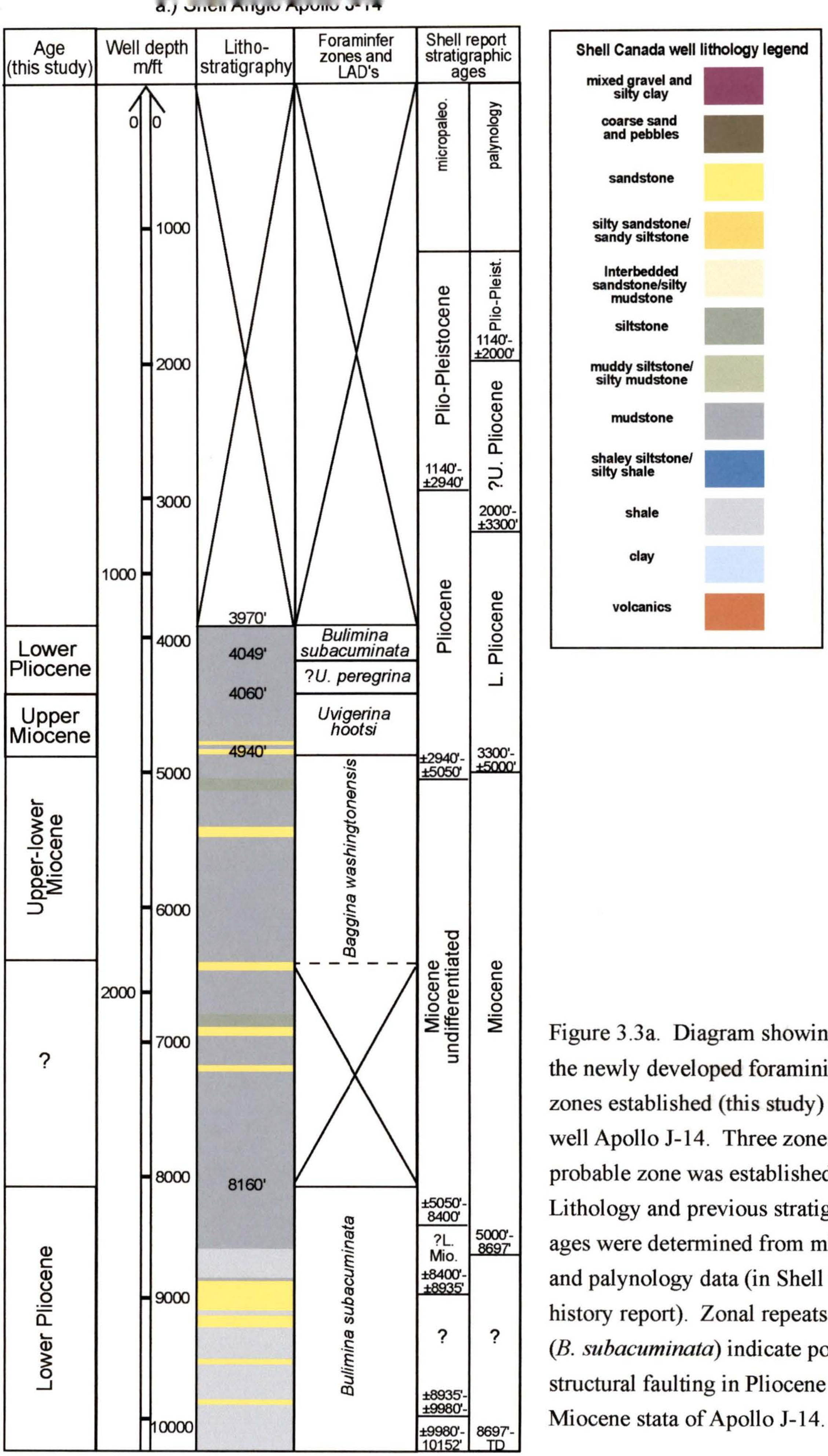


Figure 3.3a. Diagram showing the newly developed foraminiferal zones established (this study) for Shell well Apollo J-14. Three zones and one probable zone was established. Lithology and previous stratigraphic ages were determined from microfaunal and palynology data (in Shell well history report). Zonal repeats (*B. subacuminata*) indicate possible structural faulting in Pliocene and Miocene stata of Apollo J-14.

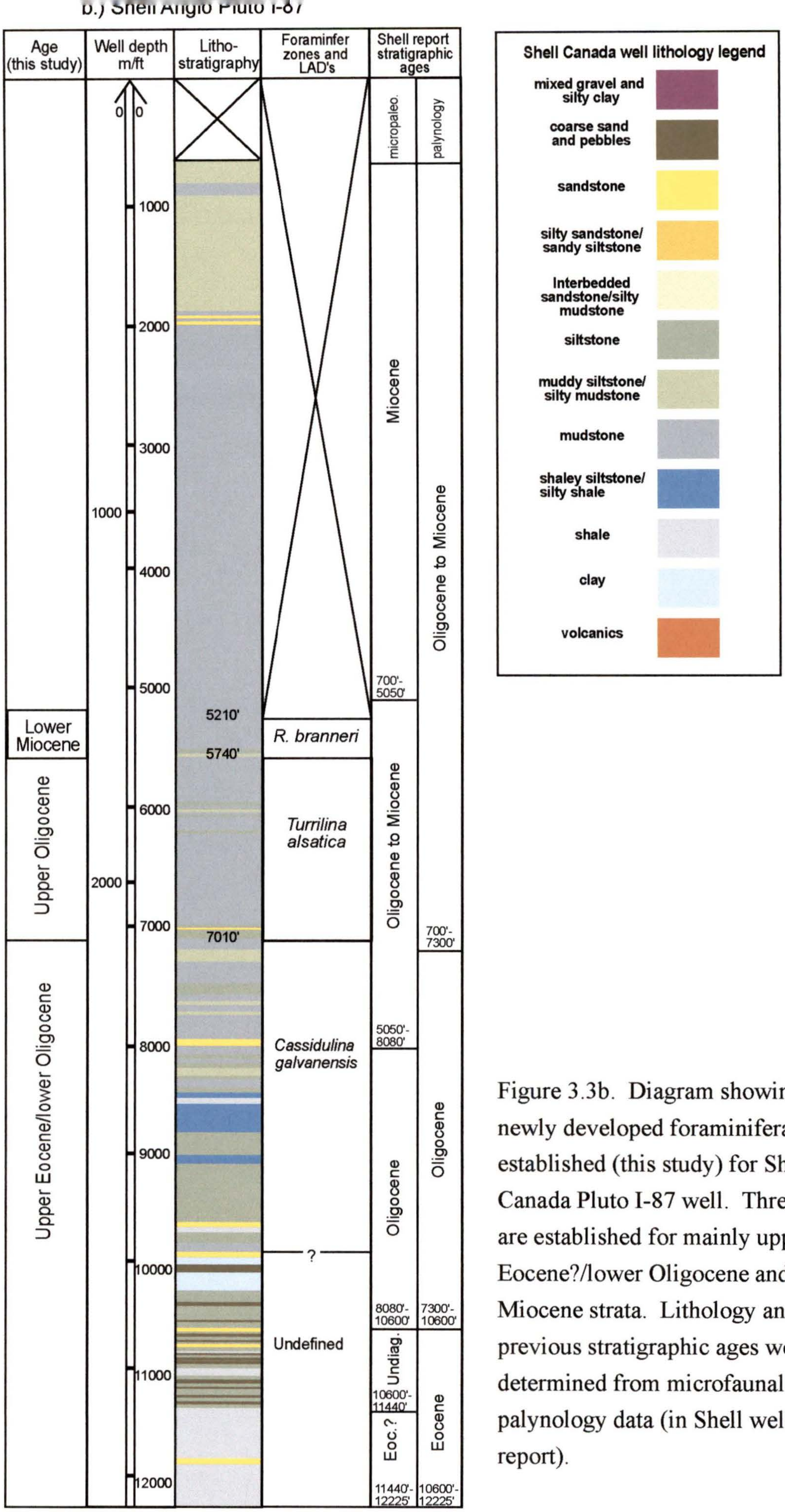


Figure 3.3b. Diagram showing the newly developed foraminiferal zones established (this study) for Shell Canada Pluto I-87 well. Three zones are established for mainly upper Eocene?/lower Oligocene and lower Miocene strata. Lithology and previous stratigraphic ages were determined from microfaunal and palynology data (in Shell well history report).

c.) Shell Anglo Zeus I-65

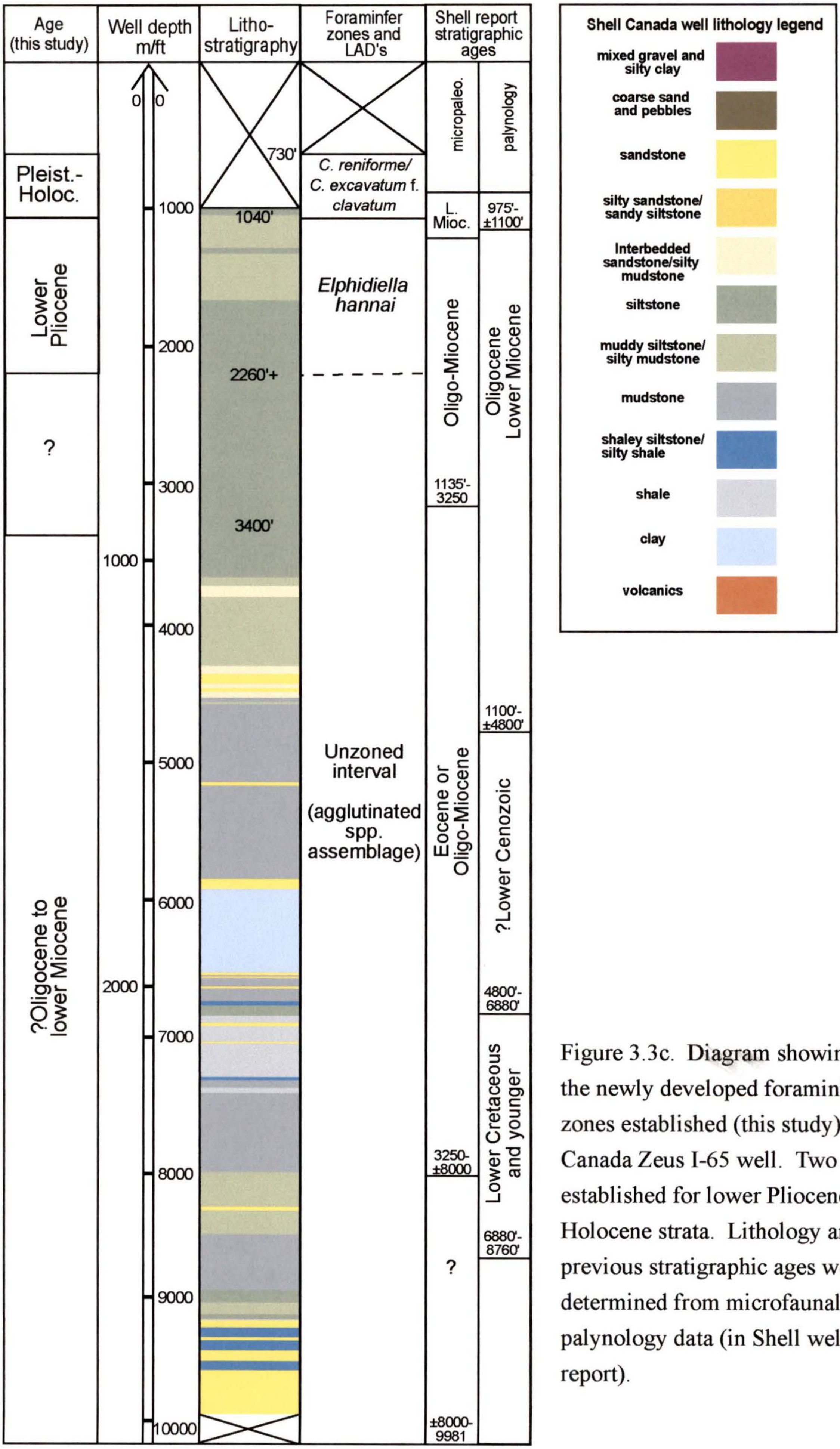
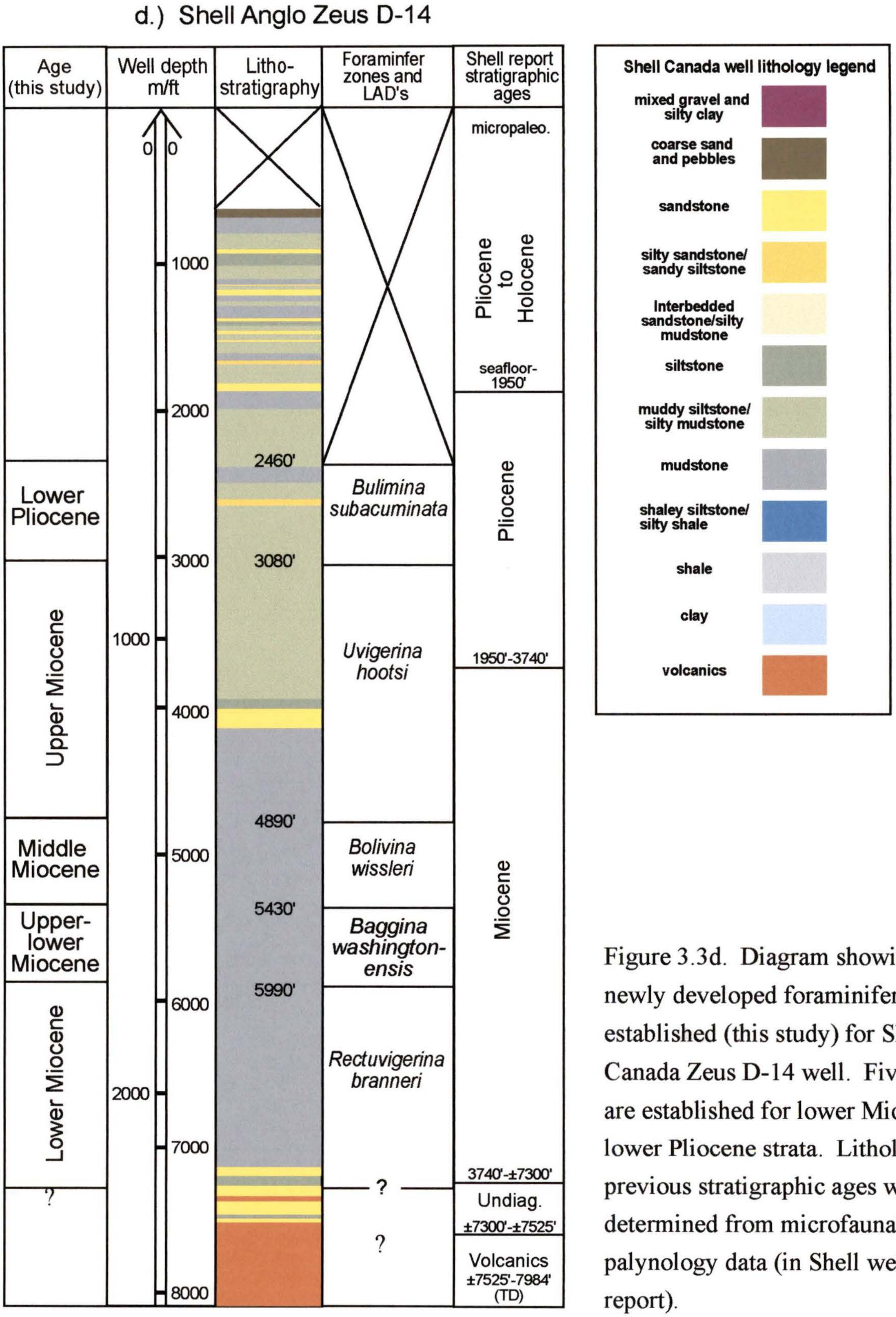


Figure 3.3c. Diagram showing the newly developed foraminiferal zones established (this study) for Shell Canada Zeus I-65 well. Two zones are established for lower Pliocene to Holocene strata. Lithology and previous stratigraphic ages were determined from microfaunal and palynology data (in Shell well history report).



d.) Shell Anglo Zeus D-14

Figure 3.3d. Diagram showing the newly developed foraminiferal zones established (this study) for Shell Canada Zeus D-14 well. Five zones are established for lower Miocene to lower Pliocene strata. Lithology and previous stratigraphic ages were determined from microfaunal and palynology data (in Shell well history report).

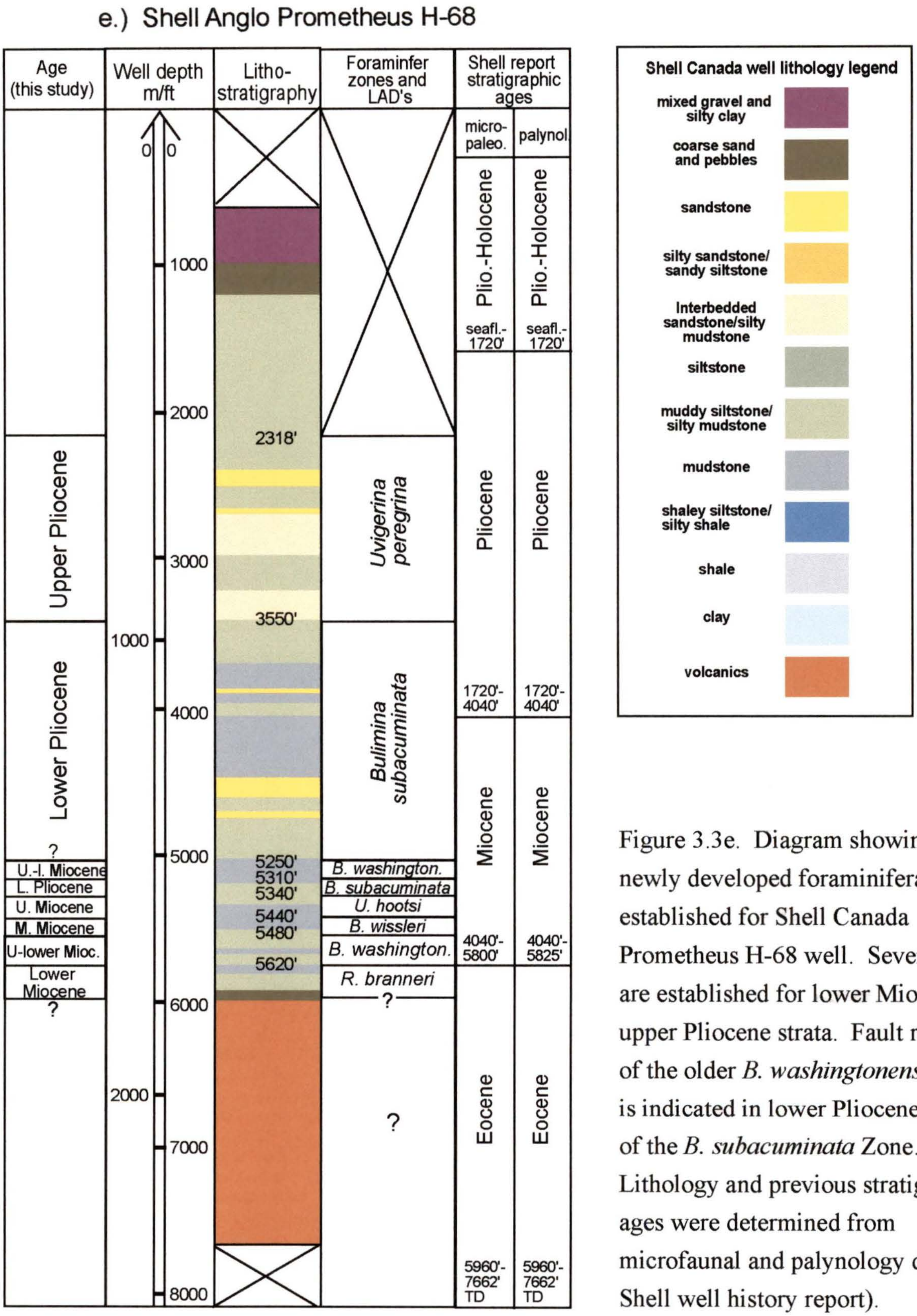


Figure 3.3e. Diagram showing the newly developed foraminiferal zones established for Shell Canada Prometheus H-68 well. Seven zones are established for lower Miocene to upper Pliocene strata. Fault repetition of the older *B. washingtonensis* Zone is indicated in lower Pliocene strata of the *B. subacuminata* Zone. Lithology and previous stratigraphic ages were determined from microfaunal and palynology data (in Shell well history report).

f.) Shell Anglo Cygnet J-100

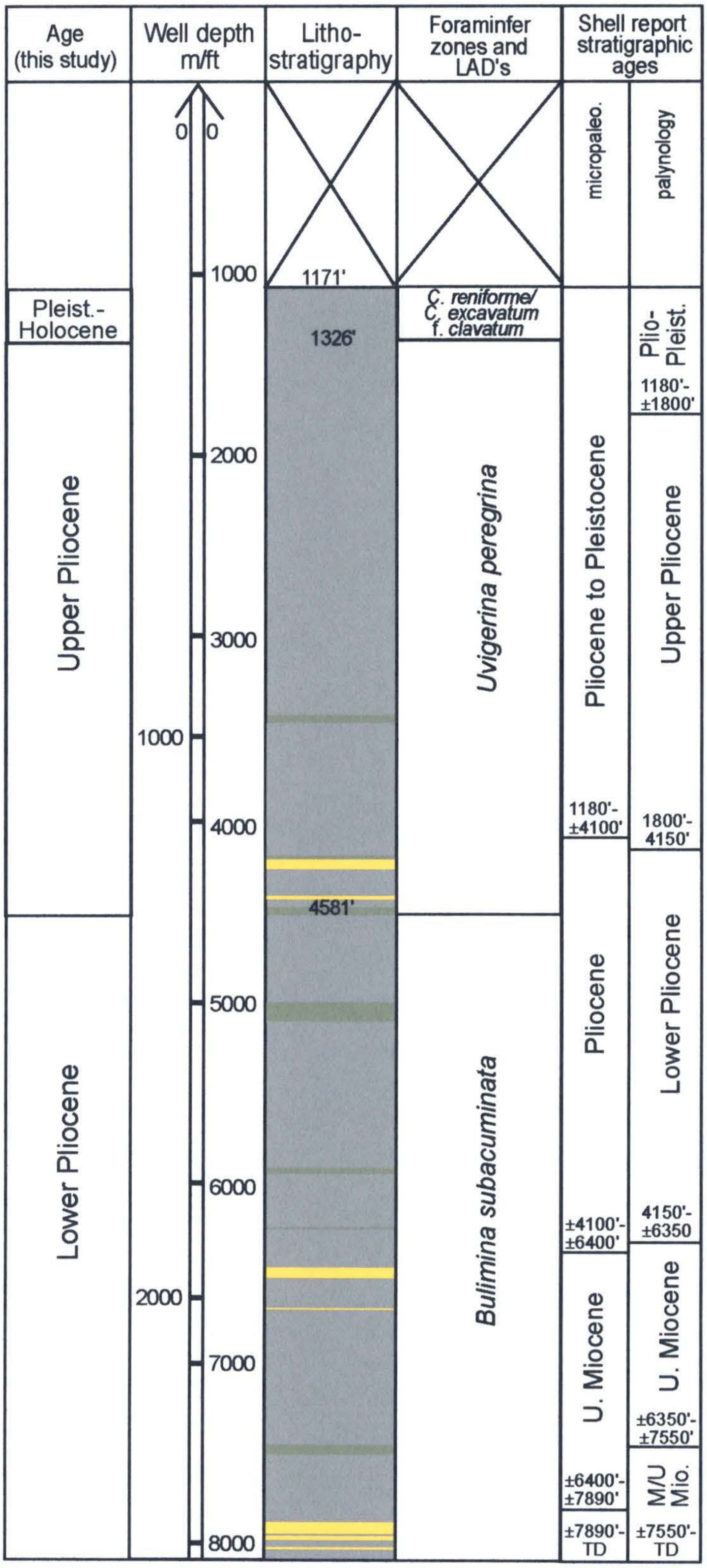


Figure 3.3f. Diagram showing the newly developed foraminiferal zones established for Shell Canada Cygnet J-100 well. Three zones are established for lower Pliocene to Holocene strata. Lithology and previous stratigraphic ages were determined from microfaunal and palynology data (in Shell well history report).

3.4. Discussion: Tofino Basin biostratigraphic correlations

The 11 new and/or redefined foraminiferal interval zones established by this study for upper Eocene(?)/lower Oligocene to Holocene strata in the offshore Tofino Basin are the *Cassidulina galvanensis*, *Turrilina alsatica*, *Rectuvigerina branneri*, *Baggina washingtonensis*, *Bolivina wissleri*, *Uvigerina hootsi*, *Bulimina subacuminata*, *Elphidiella hannai*, *Uvigerina peregrina* and the *Cassidulina reniforme*/*Cribroelphidium excavatum* f. *clavatum* zones (Figures 3.1, 3.3). Correlations between the six Shell Canada wells (north to south transect) are illustrated in Figure 3.4. The oldest stratum and the deepest portion of the basin occured northwards offshore from Tofino, Vancouver Island, while uplifted, younger sequences were encountered southwards in the Tofino Basin (Shouldice, 1971; this study).

A questionable occurrence of upper Eocene strata is based on rare and diagenetically altered *Sigmomorphina schencki* specimens recovered from near the base of the Pluto I-87 well (Figure 3.3b). Possible fault repetition is suspected for the lower portion of the well and supported by strontium isotope analysis. Rau (1958; 1981) established the *Sigmomorphina schenki* Zone in Washington, but it was not established for the Tofino Basin given the paucity of identifiable specimens. Cameron (1971) recognized the *Sigmomorphina schencki* Zone on Nootka Island and the Hesquiat Peninsula in facies representing bathyal depositional environments. Also, Cameron (1980) identified potentially reworked specimens of *S. pseudoschencki* from his *Bulimina* cf. *alsatica* Zone.

The stratigraphically lowest (Oligocene) *Cassidulina galvanensis* and *Turrilina alsatica* interval zones established in the Tofino Basin, correlate with the *Chiloguembelina cubensis* and *Turrilina alsatica* zones of the onshore Carmanah Group (Cameron, 1980). In Washington, the zones correlate with the *Cassidulina galvanensis* Zone and the upper/lower Zemorrian assemblage (Rau, 1999). The *Turrilina alsatica* Zone is correlated to the same name zone, established for the upper Oligocene strata in the Arctic of Canada (McNeil, 1989; 1997).

A Pacific Coast Miocene biostratigraphy has been studied in detail from the Monterey and Modelo formations of California (Kleinpell, 1938; Kleinpell, 1980; Finger and Lipps, 1990; Finger, 1992) to the Astoria(?) Formation of Washington (Rau, 1948;

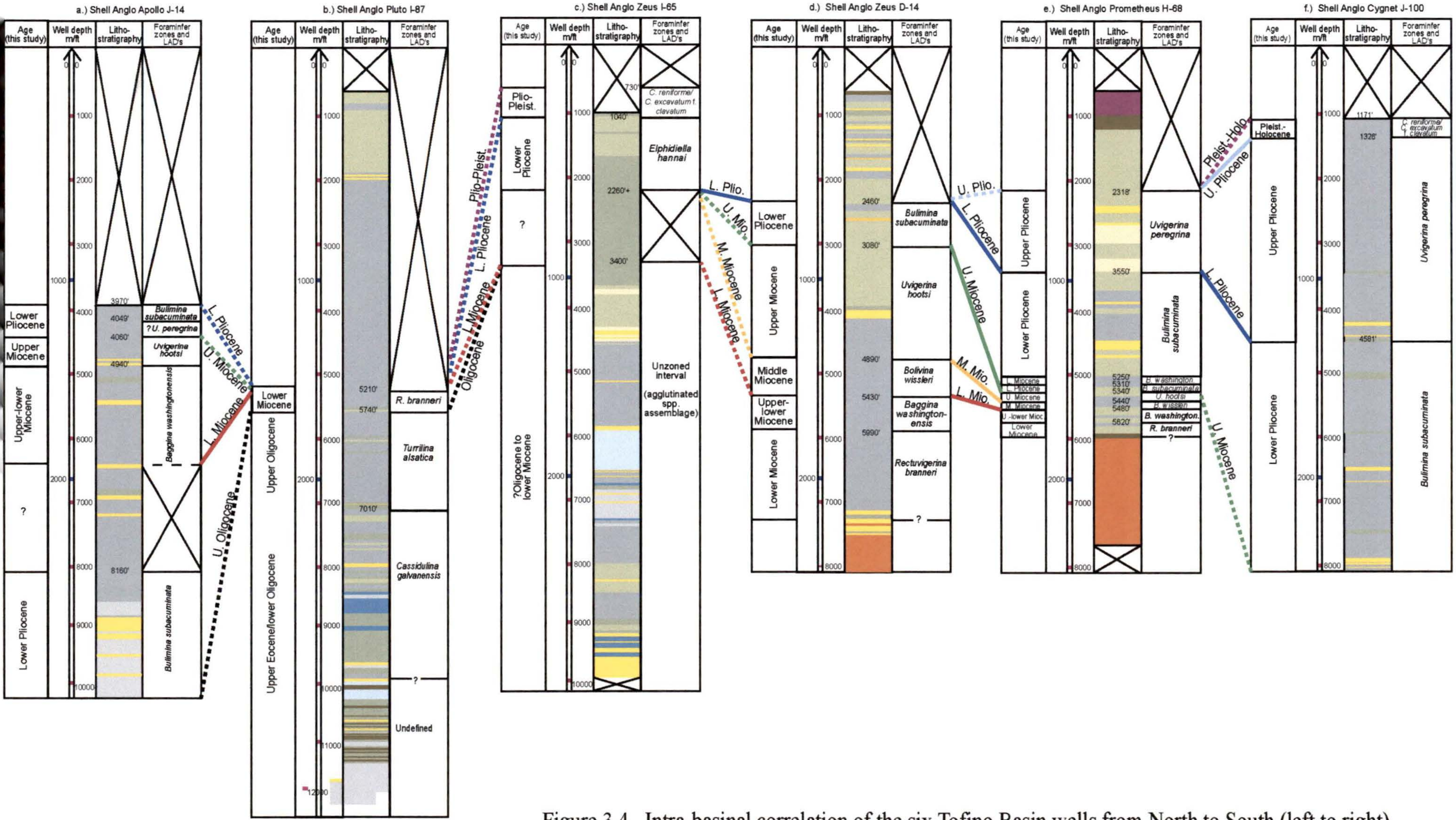


Figure 3.4. Intra-basinal correlation of the six Tofino Basin wells from North to South (left to right). Lines of stratigraphic age correlation are based on the foraminiferal biostratigraphic results (this study).

1981). Kleinpell's Miocene Oppelian zonation scheme was based on evolutionary successions of benthic species of *Bolivina* and *Rectuvigerina* (Kleinpell, 1938; Kleinpell et al., 1980). Several of his zones were used to establish the California biostratigraphy, based on restricted occurrences and first and last appearances of taxa (Kleinpell et al., 1980; Finger, 1992). Many of these zones are confined to local correlations and are based on taxa that were not clearly distinguished from other related forms, making them difficult for interbasinal correlations (Arnal et al., 1980; Finger and Lipps, 1990; Finger, 1992).

The Tofino Basin Miocene faunas are similar to the diverse faunas from the Miocene of California. This similarity is possibly a result of facies controlled geographic distribution of faunas (Barron, 1986). Four Miocene zones are established by the present study. The last appearance of diagnostic and restricted Miocene taxa such as *Rectuvigerina branneri* and *Baggina washingtonensis*, *Bolivina wissleri* and *Uvigerina hootsi* are used to establish a modified Tofino Basin zonation scheme from that seen in California or Washington. In the present study the *R. branneri* Zone is correlated approximately to the Relizian Stage *R. branneri* Zone in California and the Saucesian Stage *Siphogenerina kleinpelli* Zone in Washington. The Tofino Basin *R. branneri* Zone differs from the latter zones by being based on the LAD of *R. branneri* and containing a less diverse faunal assemblage of the upper middle bathyal biofacies.

The *Baggina washingtonenis* Zone established in Washington (Rau, 1967, 1981) is redefined for the Tofino Basin, based on the LAD of *B. washingtonensis* (Figure 3.3d, e). The *B. washingtonensis* Zone is correlated based on the occurrence of the short-ranging *B. washingtonensis* and associated faunal assemblage and contains a more diverse fauna than in Washington (Rau, 1981, 1999), but both represent an upper bathyal biofacies.

Kleinpell et al., (1980; and as modified in Finger, 1992) established the Late Middle Mohnian *Bolivina wissleri* Zone in California. The *Bolivina wissleri* Zone in the Tofino Basin is redefined by the LAD of the short ranging *B. wissleri* and associated assemblage of middle Miocene strata. The Tofino Basin zone differs by lacking several taxa included within the California zone. However, similarities include the occurrences of key *Bolivina* spp., *Buliminella* spp. and a similar upper/upper middle bathyal biofacies

(Finger and Lipps, 1990; Finger, 1992). This zone has not been observed in Washington sequences.

The *Uvigerina hootsi* Zone is a new regionally defined zone based on the LAD of *Uvigerina hootsi*. It is approximately correlated to the undifferentiated assemblages of the Montesano Formation, Mohnian/Delmontian Stage, of Washington (Rau, 1981; 1999), which contained similar taxa to those in the Tofino Basin, including *Cibicidoides mckannai*, *Epistominella smithi*, *Uvigerina hootsi* and *Uvigerina subperegrina*.

In the Carmanah Group, upper Miocene/lower Pliocene foraminiferal assemblages were preliminarily identified from Bajo Point, Nootka Island and are possibly biostratigraphically equivalent to the Montesano Formation (middle/upper Miocene, Mohnian Stage; Prothero, 2001) and possibly to the Astoria(?) Formation (lower Miocene, Saucesian Stage; Prothero, 2001) in Washington (Cameron, 1971). The Montesano Formation in Washington covers a short time interval (~2 m.y.) within the Mohnian and unconformably overlies the Saucesian (±17-20 Ma) Astoria(?) Formation (Prothero, 2001; Pers. comm., E.A. Nesbitt, 2003). Based on the presence of *Globigerina bulloides* and *Nonionella miocenica*, the Bajo Point strata questionably correlates with the *Uvigerina hootsi* Zone in the Tofino Basin, although more information on the foraminiferal assemblage is required for definite correlation. Otherwise, Miocene zones are disrupted by erosion or non-deposition and Miocene biozones have not been established for the Carmanah Group sequence. From Shell Canada well cuttings taken from the Queen Charlotte Basin, lower and middle Miocene foraminiferal faunas were identified that are similar to those recovered from the Tofino Basin, however, no zones were established and/or correlated (Patterson, 1989).

Limited long-ranging planktic taxa were recorded from mainly middle and upper Miocene intervals in the Shell wells (Prometheus H-68 and Zeus D-14) including: *Globigerina bulloides*, *Globigerina* sp. cf. *G. euapertura*, *G. praebulloides*, *Globigerinita glutinata*?, *Globorotalia scitula* and *Orbulina universa*, *Tenuitellinata angustiumbilicata*. This planktic assemblage suggests approximate correlation with planktic Zone N10 (middle Miocene) upwards to Zone N18 (late Miocene) (Blow, 1969; Ingle, 1973; Chaisson and Hondt, 2000).

The lower Pliocene biostratigraphy in Washington comprises the undifferentiated assemblages of the Quinault Formation (Rau, 1981; 1999). Isolated Pliocene sequences encountered in outcrop at Bajo Point, Nootka Island have not been extensively studied, but have been correlated to the upper part of the undifferentiated assemblages of the Quinault Formation by Cameron (1971). In the Tofino Basin, a complete Pliocene sequence is preserved (Figure 3.3f). Cameron (1979) initially identified Pliocene foraminiferal assemblages from Shell dart cores taken across the Apollo structure. Herein, two early Pliocene, *Bulimina subacuminata* and *Elphidiella hannai* zones and one late Pliocene *Uvigerina peregrina* Zone are established and correlated based on diagnostic and short-ranging taxa identified in the Tofino Basin.

Planktic taxa identified from the Pliocene zones (excluding *E. hannai* Zone) include: *Globigerinita glutinata*?, G. *uvula*, *Globigerina bulloides*, *G. falconensis*, *G. megastoma*?, *G. quinqueloba*, *G. umbilicata*, *Globigerinoides extremus*?, *Orbulina universa*, *Neogloboquadrina asanoi*, *N. incompta* and *N. pachyderma* (mainly sinistrally-coiled). This planktic assemblage is correlated approximately to the Pliocene planktic zones N19-N21 (Blow, 1969; Dowsett and Ishman, 1995; Lagoe and Zellers, 1996; Spiegler, 1996; Chaisson and Hondt, 2000).

A thin Pleistocene-Holocene interval in the Shell Zeus I-65 (Figure 3.3c) and Cygnet J-100 (Figure 3.3f) wells is characterized by the *Cassidulina reniforme*/*Cribroelphidium excavatum* Zone and represented an inner(?) to outer neritic environment. This zone is correlated with the *Cassidulina reniforme* Zone established in the Canadian Arctic by McNeil (1989, 1997) and to the *Elphidium excavatum* f. *clavata* Zone established at ODP Site 910, Yermak Plateau, Arctic by Osterman (1996). Additional studies of the Quaternary strata within the Tofino Basin may warrant separation of the *C. reniforme*/ *C. excavatum* f. *clavatum* Zone into two separate zones. However, both taxa co-occur in the limited Quaternary intervals in the wells and separation was not possible by this study.

The occurrence of Quaternary planktic taxa including: *Globigerina bulloides*, *Globigerina quinqueloba*, *Neogloboquadrina dutertrei*, and dextrally-coiled *Neogloboquadrina pachyderma* in the upper portion of the Cygnet J-100 well (*Uvigerina* *peregrina* Zone) are used to correlate with planktic zones N22-N23 (Blow 1969; Ingle, 1973; Spiegler, 1996; Chaisson and Hondt, 2000).

3.5. Tofino Basin paleoecological (biofacies) implications

Recognition of foraminiferal biofacies within the thick Cenozoic sequences of the Tofino Basin are herein interpreted based on paleobathymetric estimates of common calcareous and agglutinated taxa from several studies including those of Cameron (1979, 1980) Ingle (1980), Lagoe et al. (1994), Hayward et al. (1999) and Mancin (2001). Precise paleoenvironmental interpretations are difficult due to possible downhole contamination and/or reworking. Biofacies were interpreted based on composition of the overall foraminiferal assemblage and by determining the upper depth limit of the deepest dwelling taxa in the samples (Ingle, 1980; Finger and Lipps, 1990).

The biofacies results from this study have implications for interpretation of the depositional history of the Tofino Basin including regional eustacy and tectonics (uplift and subsidence). Pacific Coast foraminiferal biofacies associations and inferred paleobathymetric estimates follow Ingle (1980) and are defined as follows: (1) littoral/inner neritic, 0-50 m (1-150 ft); (2) outer neritic, 50-150 m (150-470 ft); (3) upper bathyal, 150-500 m (460-1,560 ft); (4) upper middle bathyal, 500-1,500 m (1,560-4,700 ft); (5) lower middle bathyal, 1,500-2,000 m (4,700-6,250 ft); and (6) lower bathyal, greater than 2,000 m (>6,250 ft) (Figure 3.5).

While most studies have documented deep water (outer neritic to bathyal) assemblages/biofacies, few studies have documented littoral or inner neritic foraminiferal biofacies (Ingle, 1980; Finger and Lipps, 1990; Olson, 1990; Hayward et al., 1999). A cautionary approach was taken when using biofacies estimates based on studies from other Pacific Coast basins. *Epistominella pacifica*, for example, is considered characteristic of the upper middle bathyal biofacies in California basins (Echols and Armentrout, 1980; Ingle, 1980) and was found to have a broader range from inner neritic to the upper bathyal depths in the Tofino Basin. Similar shallow-water occurrences of *E. pacifica* have been recorded in the Gulf of Alaska (Echols and Armentrout, 1980).

In the Tofino Basin, taxa consistently characteristic of the inner neritic (e.g. *Cribroelphidium excavatum clavatum*, *Elphidiella hannai*, *Nonionella stella*), outer

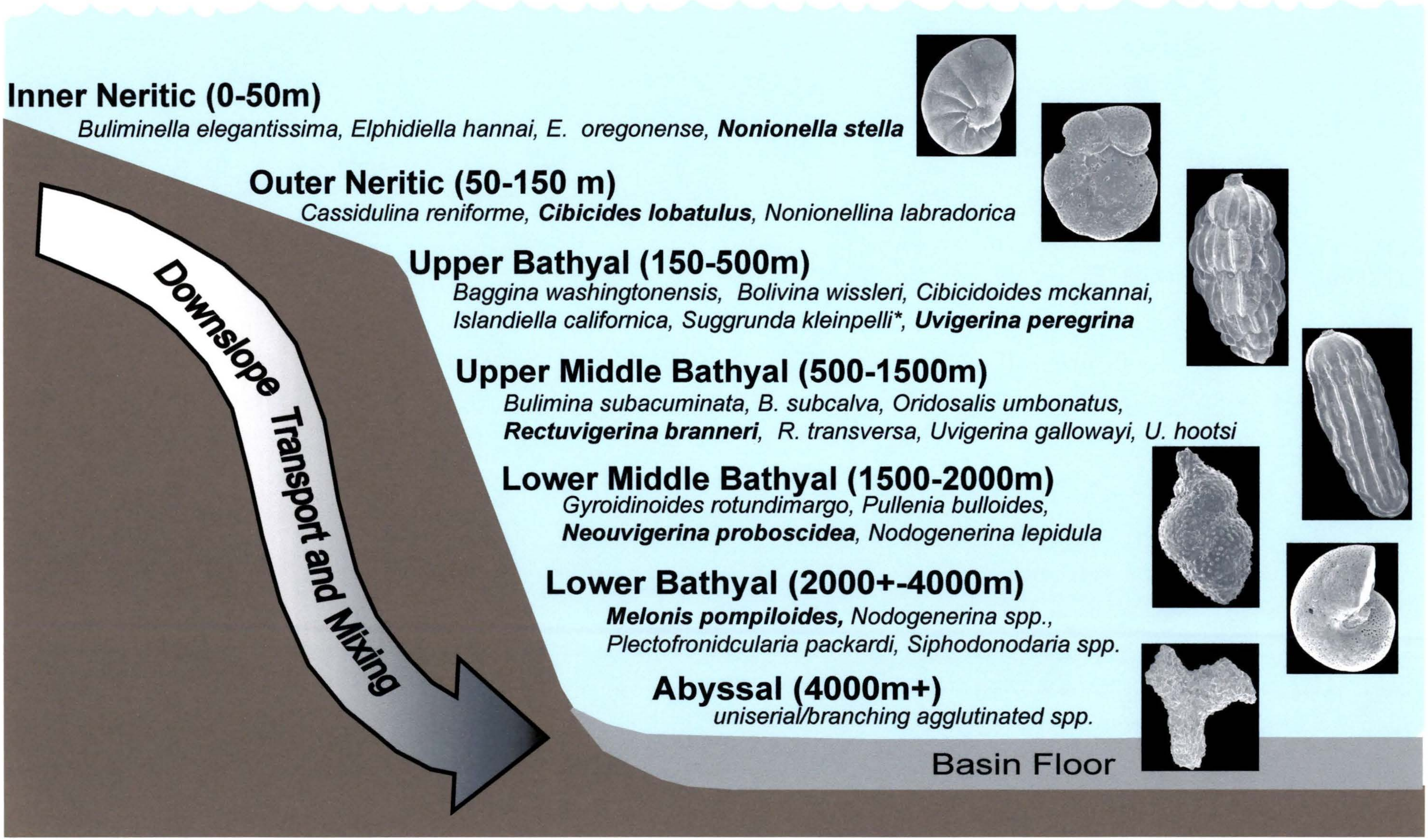


Figure 3.5. Paleobathymetric model used to interpret foraminiferal biofacies (with illustratons of selected taxa) encountered in the Tofino Basin (modified from Ingle, 1980; Finger and Lipps, 1990). Species in bold text are illustrated on the right.

neritic/upper bathyal (e.g. *Baggina washingtonensis*, *Nonionellina labradorica*) to lower bathyal (e.g. *Melonis pompiloides, Proxifrons advena*) biofacies occur (Ingle, 1973, 1980). Observed paleobathymetric trends in the Tofino Basin are interpreted as the following: 1) Eocene-Oligocene regression from glaciation and a global cooling event (Prothero et al., 2002); 2) lower Oligocene to lower Miocene transgression; 3) middle Miocene to upper Miocene regression; 4) lower Pliocene transgression; and 5) lower Pliocene to Quaternary shoaling upwards (Shouldice, 1971; this study). Maximum deepening in the Tofino Basin occurred during the early Miocene and in the early Pliocene (in the deepest part of the basin for the latter).

Oligocene strata in the wells (*Turrilina alsatica* Zone) contained a mixed calcareous-agglutinated assemblage. The samples contained mainly agglutinated foraminifers belonging to morphogroup B (trochospiral forms) and represented outer neritic to bathyal depths (Jones and Charnock, 1985; Mancin, 2001). The presence of relatively few calcareous taxa (~10%) including *Bulimina subcalva*, *Melonis pompiloides*, *Plectofrondicularia packardi* and *Pullenia bulloides* indicate an upper middle to lower bathyal biofacies (Ingle, 1980). *Reticulophragmium* spp. were common Cenozoic (Oligocene to Miocene) deep-water, agglutinated foraminifers. Silicified preservation of these forms suggested bathyal to abyssal environments supported by the absence of calcareous foraminifers in the middle and lower portions of the Zeus I-65 well. The uppermost portion of the Pluto I-87 well contained a lower Miocene assemblage (*Rectuvigerina branneri* Zone) of upper middle bathyal affinity that is correlative with the lower Miocene strata in the Prometheus H-68 and Zeus D-14 wells.

The lower portion of the Prometheus H-68 and Zeus D-14 wells contains a similar foraminiferal assemblage that is characteristic of the upper middle to lower middle biofacies (Ingle, 1980; Finger, 1990). Common taxa include *Oridosalis umbonatus*, *Rectuvigerina* spp., *Uvigerina gallowayi* and *Valvulineria asanoi*. In these wells agglutinated taxa were rare (constituting less than 5% of fauna) and suggest little transport of neritic/shelf taxa. In the upper portion, an outer neritic to upper bathyal biofacies is indicated.

The Zeus I-65 well contained an inner neritic biofacies in the uppermost portion of the well (above 2260 ft). The foraminiferal assemblage includes innermost calcareous taxa (e.g. *Cribroelphidium excavatum* f. *clavatum Elphidiella oregonense*, *Nonionella stella*, *Nonionella novozealandica*) similar to that found in the glacio-marine environments in the Gulf of Alaska and the Arctic (Bergen and O'Neil, 1979; Hald et al., 1994; Lagoe et al., 1994; Polyak et al., 2002). *Cribroelphidium excavatum* forma *clavatum* is the most dominant and adaptable species in late Quaternary deposits of high latitude regions (e.g. Arctic shelves) where temperatures may range between 1°C to -1.8°C (Hald et al., 1994; Osterman, 1996; Polyak et al., 2002).

The lowermost portion (below 3400 ft; Figure 3.3c) of Zeus I-65 well contained a mixed agglutinated faunal assemblage characterized by taxa belonging to morphogroup A (primitive tubular, cylindrical or branching forms) and B (planispiral tubular, coiling and trochospiral forms) (Jones and Charnock, 1985; Mancin, 2001). Commonly occurring taxa: *Bathysiphon* spp., *Cyclammina* spp., *Glomospira gordialis*, *Recurvoides* spp., *Reticulophragmium projectus*, and *Rhadammina abyssorum*, represent a lower middle bathyal biofacies (Gradstein and Kaminski,1989; Mancin, 2001). The reduced diversity of the fauna and absence of calcareous taxa may be a strong indication of hypoxic conditions (Gradstein and Kaminski, 1989).

Two biofacies are recognized in Cygnet J-100. The lower part of the well (below 4581 ft) contains taxa (e.g. *Bulimina subacuminata*, *Melonis pompiloides*, *Neouvigerina proboscidea*) characteristic of the upper middle bathyal to lower bathyal biofacies (Ingle, 1980). Also, this biofacies is recognized in the upper and part of the lower portion (possible repeat section) of the Apollo J-14 well.

Globigerina bulloides, *G. falconensis*, *G. quinqueloba*, *G. umbilicata Globigerinita glutinata*?, *Neogloboquadrina asanoi* and *N. dutertrei* were the most common planktic species in Cygnet J-100 and Apollo J-14 wells. *Neogloboquadrina pachyderma* (mainly dextrally coiled) were comparatively few in number. The appearance of this planktic assemblage in lower/middle Pliocene TB strata supports slightly warmer paleoceanographic conditions (possibly similar to today) and deepening of the oxygen minimum zone, than what was seen in Pleistocene strata in the North Pacific (Dowsett and Ishman, 1995). Upsection (in Cygnet *Uvigerina peregrina* Zone) *Neogloboquadrina incompta*, sinistrally-coiled *N. pachyderma*, and fewer *G. bulloides* indicate cooler water temperatures during the late Pleistocene (Dowsett and Ishman, 1995).

In the *Cassidulina reniforme*/*Cribroelpidium excavatum* f. *clavatum* Zone in Cygnet J-100 well, a shallower biofacies of outer neritic to upper bathyal biofacies was present. Although no samples were available for the uppermost portion (between 0 to 1171 ft), the occurrence of fragmented/abraded tests of several *Cribroelphidium* species from possible downwell-spalling suggests the presence of an inner/middle to outer neritic biofacies (Ingle, 1980; Hald et al., 1994). The lithofacies throughout the Cygnet J-100 well was mudstone.

The faulted well stratigraphy of the Apollo J-14 well was interpreted to conatin a mainly middle/late(?) Miocene to lower Pliocene strata. The biofacies represented in the Apollo J-14 well ranged within bathyal depths (lower middle to upper bathyal). A planktic species assemblage similar to that seen in the Cygnet J-100 well was present.

Biofacies recognized in this study, provide important implications for interpretation of the major geological events that have influenced the stratigraphic framework of the Tofino Basin since the upper Eocene/lower Oligocene. The oscillations in water depths (mainly bathyal) over time were most likely a result of eustasy (Haq et al., 1988) and subsidence (Hyndman et al., 1990).

During the Eocene, subduction may have been initiated in combination with widespread submarine volcanic activity, followed by uplift and subsidence during the Eocene, and initiation of plate subduction (Shouldice, 1971; Hyndman et al., 1990). A thick volcanic unit of possibly Eocene age (Hyndman et al., 1990) occured unconformably beneath possibly lower Miocene and Oligocene(?) mixed strata in the Shell Zeus D-14 (458 ft or 140 m thick) and Prometheus H-68 wells (1812 ft or 552 m thick). Eocene foraminiferal biofacies could not be interpreted as strata were either absent or the foraminifers too diagenetically altered. Upper Eocene strata are present onshore and suggested outer neritic to upper bathyal conditions (Cameron, 1980). However, the absence of strata older than the upper Eocene in the Shell wells suggests an erosional unconformity (Shouldice, 1971; Hyndman et al., 1990).

Eocene-Oligocene global cooling occurred at 33.7 Ma (Berggren et al., 1995) and is well documented along the Pacific Coast (Prothero and Berggren, 1992; Greenwood and Wing, 1995; Nesbitt, 2002; Prothero et al., 2002). It is uncertain whether this interval is present in the Shell Canada wells. Its preservation onshore in Vancouver Island and Washington State confirms its possible but restricted (to structural lows) occurrence in the Tofino Basin (Hyndman et al., 1990). The stratigraphic record of Oligocene (34.2-23.6 Ma) eustasy compared to high resolution foraminiferal $\delta^{18}O$ records, indicates a lowstand in sea-level (glacio-eustatic lowerings), large $\delta^{18}O$ increases (cooling phase) and subsequent rapid rise in sea-level (Pekar et al., 2002). Biofacies of the lower to upper Oligocene strata in the wells, support Shouldice's (1971) interpretation of a major transgression underway during the Oligocene to early Miocene. Low diversity Oligocene faunas, dominated primarily by agglutinated taxa, were replaced by higher diversity faunas that represented a deeper biofacies by the early Miocene. The basin was deepest during the early Miocene as represented by faunas of the *Rectuvigerina branneri* Zone (upper middle bathyal biofacies). In the onshore strata in Washington State, local basin deposition was apparently the deepest during the early part of the Miocene (Rau, 1981). High resolution benthic foraminiferal carbon and oxygen isotope studies (ODP Site 929) have indicated a global warming trend during the late Oligocene to early Miocene, coinciding with increased oceanic productivity and a strong northward deepwater circulation until the middle Miocene (Flower et al., 1997; Hilary et al., 2000; Zachos et al., 1994, 1997, 1999).

The middle Miocene biofacies suggests slight shallowing of bathyal biofacies (Rau, 1948; 1981) characterisitic of the *Baggina washingtonensis* and *Bolivina wissleri* zones (in Zeus D-14 and Prometheus H-68 wells). During this time regional crustal deformation, uplift and regression occurred (Shouldice, 1971; Reiners et al., 2002). It was suggested previously that a middle Miocene unconformity occurred in the Tofino Basin, based on structure within the Apollo J-14 well (Shouldice, 1971; Yorth, 1980), however, the middle Miocene interval is present in the Prometheus H-68 and Zeus D-14 wells, represented by the *Bolivina wissleri* Zone.

Uplift of the Coast Mountains of British Columbia and the Washington Cascade Range occurred during the late Miocene (Reiners et al., 2002). For the Tofino Basin, Shouldice (1971) interpreted a major transgression and this present study supports a middle/late(?) Miocene bathyal biofacies of the *Uvigerina hootsi* Zone with faunal assemblages characteristic of the upper bathyal and upper middle bathyal biofacies. Therefore, there are inconsistencies between tectonic interpretations and paleocological data. One possible interpretation is that depths within the TB were deep enough to mask or overcome the effects of regional uplift. Another possibility is a latest Miocene (Delmontian Stage) erosional unconformity. In the Montesan Formation, Washington, the middle/late Miocene Mohnian Stage is briefly (~2 million years) present with an unconformity with the overlying lower Pliocene Quinault Formation (Campbell and Nesbitt, 2000; Prothero, 2001). Some mixing of faunas of the *Uvigerina hootsi* and *Bulimina subacuminata* zones, at this level in the Shell wells suggests a possible erosional unconformity or non-deposition of the late Miocene strata, which may have represented a regressive phase, but cannot be supported by this present study.

A transgressive phase continued into the early Pliocene, where taxa of the lower bathyal biofacies (*Bulimina subacuminata* Zone) occured, although a predominantly inner neritic biofacies (*Elphidiella hannai* Zone in Zeus I-65 well) was present in part of the basin (close to the present-day shoreline). This suggests faunal provinciality occurred within the basin during the early Pliocene.

The late Pliocene-Pleistocene regressive phase (Shouldice, 1971) is supported by a predominantly outer neritic/upper bathyal cold-water biofacies (*Uvigerina peregrina* and *Cassidulina reniforme*/*Cribroelphidium excavatum* f. *clavatum* zones) associated with glacial or near-glacial depositional environments (Patterson, 1993; Hald et al., 1994; Osterman, 1996).

3.6. Summary and conclusions

In this study, 11 new and/or redefined Cenozoic foraminiferal interval biozones were established from six Shell Canada wells for a thick (~3600 m) upper Eocene/lower Oligocene to Quaternary succession in the Tofino Basin. From lowest to highest, in stratigraphic order, they are the: *Cassidulina galvanensis*, *Turrilina alsatica*, *Rectuvigerina branneri*, *Baggina washingtonensis*, *Bolivina wissleri*, *Uvigerina hootsi*, *Bulimina subacuminata*, *Uvigerina peregrina*, *Elphidiella hannai* and *Cassidulina reniforme* / *Cribroelphidium excavatum* f. *clavatum* zones. The lowest *C. galvanensis* and *T. alsatica* zones correlate with the zones established for the Carmanah Group, Vancouver Island. Miocene to Quaternary zones are correlated to Washington strata and the Canadian Arctic.

Paleobathymetry estimates from foraminiferal biofacies indicate that a range of biofacies from the inner neritic/littoral (0-50 m) to the lower bathyal (>2,000 m) are present in the Tofino Basin. Results support outer neritic to upper bathyal deposition during the upper Eocene/lower Oligocene, followed by a major transgression into the lower Miocene as represented by a bathyal biofacies. Throughout the Miocene, bathyal sediments were deposited with a gradual shoaling-upwards trend into the upper Miocene. A lower Pliocene transgression is represented by a bathyal biofacies and is followed by an upper Pliocene-Pleistocene regressive phase and global cooling. In summary, the stratigraphic framework, including unconformities and structural complexities within the Tofino Basin, have been influenced by a complex interplay of episodic uplift, tectonic underplating, eustatic fluctuations and episodes of climatic cooling.

4. STRONTIUM ISOTOPE STRATIGRAPHY

4.1. Introduction

Strontium (Sr) isotope geochemistry of biogenicaly precipitated skeletal components is applied to marine micropaleontology, to: 1) provide a high resolution chronostratigraphy (DePaolo and Ingram, 1985; DePaolo 1986; Elderfield, 1986; Froelich, 1993; Smalley et al., 1994; Farrell et al., 1995; Diener et al., 1996; Qing et al., 1998; Veizer et al., 1999; McArthur et al., 2001); 2) interpret and reconstruct paleoenvironments (Schmitz et al., 1991; Reinhardt et al., 1994; 1998a; 1998b; 1999; Allan et al., 2000), paleoceanography (DePaolo and Ingram, 1985; Hess et al., 1986; Ingram and Sloan, 1992; Barnes, 1999; Veizer et al., 1999) and paleoclimate (DePaolo and Ingram, 1985; Ingram and Sloan, 1992; Clemens, 1993; Martin et al., 2001).

Sr isotopic composition of biogenic carbonates (mainly foraminifer tests) from five Shell Canada well cuttings (Cygnet J-100; Prometheus H-68; Zeus D-14; Zeus I-65 and Pluto I-87) and western Vancouver Island, Carmanah Group surface samples, have provided improved stratigraphic resolution to the offshore Tofino Basin Cenozoic marine sequences. This pilot study was limited by sporadic sampling, poor preservation (diagenetically alteration) of outcrop samples, and an incomplete (at the time) offshore foraminiferal biostratigraphy. However, this present study demonstrate the usefulness of Sr isotope analysis as a potential correlation tool, in conjunction with a revised foraminiferal biostratigraphy for other Pacific Coast sequences.

4.1.1. Seawater strontium

Strontium enters the oceans through two main sources: 1) rivers carrying dissolved Sr as products of continental weathering (average from rivers is 0.712), and by 2) the Earth's mantle, via mid-oceanic ridge and hydrothermal processes (average from hydrothermal fluids is 0.712) (Burke et al., 1982; Elderfield, 1986; Raymo et al., 1988; Raymo and Ruddiman, 1992; Harris, 1995; Zachos, 1999). Strontium isotope ratios ($^{87}Sr/^{86}Sr$) are uniform throughout the oceans due to the long residence time of Sr in seawater (average of ~2.5 million years; Hodell et al., 1990) and the rapid mixing rate of the oceans (~10^3 year; Burke et al. 1982; Veizer, 1989).

The homogeneity of seawater Sr and its secular variation through geological time is the basis of Sr isotope stratigraphy, a potentially high-resolution tool for precise correlation and dating of marine sequences (Burke et al. 1982; DePaolo and Ingram, 1985; Elderfield, 1986; Hess et al. 1986; Farrell et al., 1995). Biostratigraphically dated samples along with resulting Sr ages can be globally correlated in conjunction with the most recent chronostratigraphic time scale of Berggren et al. (1995). Some advantages of Sr isotope stratigraphy over biostratigraphy are that it: 1) requires only a small amount of marine carbonate; 2) can be used in regions with endemic faunas (i.e. low vs. high latitudes), that are difficult to correlate biostratigraphically (Martin et al., 1999); and 3) can have greater resolution for certain time intervals, providing improved interpretation of geological structure and stratigraphy of a basin.

Strontium is chemically similar to calcium (Ca) and can readily substitute into the carbonate lattice during precipitation. Since Sr does not undergo isotopic fractionation, $^{87}Sr/^{86}Sr$ can directly reflect conditions of seawater at the time of deposition (Grossman, 1984; DePaolo and Ingram, 1985). However, diagenetic alteration can overprint the primary isotopic composition (DePaolo and Ingram, 1985; DePaolo 1986; Hess et al., 1986; Richter et al., 1992; Smalley et al., 1994; Reinhardt et al., 1999), obscuring the original Sr signal and this must be considered when selecting samples for Sr isotopic analysis. Recent advancements in the precision of analytical methods for detecting diagenesis have improved sample selection (Reinhardt et al., 2000). Low magnesium (Mg) calcite tests of Cenozoic foraminifers are considered relatively resistant to diagenetic alteration and are generally more reliable for Sr isotope analysis than bivalves, which are composed of aragonite or high Mg calcite (Veizer, 1989).

Strontium isotope geochemistry depends on: 1) the global uniformity of seawater $^{87}Sr/^{86}Sr$ (Burke et al., 1982; Hodell et al., 1990; Clemens et al., 1993); 2) isotopic equilibrium of the sample precipitate with seawater (Hess et al., 1986; Veizer, 1989); 3) sample integrity, such that the primary isotopic composition is not compromised by diagenetic masking and out-of –sequence contaminants (e.g. reworking, cavings) (Hess et al., 1985; Veizer, 1989); and, 4) good biostratigraphic control of samples (DePaolo and Ingram, 1985). Assessment of sample integrity and biostratigraphic control are essential aspects of isotopic studies, which best constrain geochemical data (pers comm., J.A. Trotter, 2002).

4.1.2. Seawater Sr evolution curve and the global Cenozoic $^{87}Sr/^{86}Sr$ trend

The secular variation of $^{87}Sr/^{86}Sr$ through geological time has been age-calibrated to produce seawater Sr evolution curves. The first comprehensive Sr curve for the Phanerozoic Eon was constructed by Burke et al. (1982) and sections of the curve have since been refined by several studies, especially for the Cenozoic (Denison et al., 1993; Hodell et al., 1991; Oslick et al., 1994; Smalley et al., 1994; Farrell et al., 1995; McArthur et al., 2001). The McArthur et al. (2001) seawater Sr curve is incorporated by this study because it can be defined numerically (using linear regression equations) rather than graphically ("eye-balling"; Burke et al., 1982). One advantage of the McArthur curve is that it utilizes the global time scales of Shackleton et al. (1995; 0-6.4 Ma) and Berggren et al. (1995; 6.4-70 Ma; based on Cande and Kent, 1995).

A steep, unidirectional increase in the seawater $^{87}Sr/^{86}Sr$ (Burke et al., 1982; DePaolo, 1986), particularly for 0-40 Ma, is widely documented for the Cenozoic and the causes have been addressed by several studies (Raymo et al., 1988; Hoddell et al., 1990; Edmond, 1992; Raymo and Ruddiman, 1992; Harris, 1995; Zachos et al., 1999). Major linkages are ascribed to the Himalayan-Tibetan and Cordilleran uplifts and subsequent exhumation, which enhanced the riverine input of ^{87}Sr-enriched, silicate rocks into the ocean basins. The results from this present study supports a Cenozoic unidirectional increase in seawater $^{87}Sr/^{86}Sr$ in the Tofino Basin (Figure 4.1).

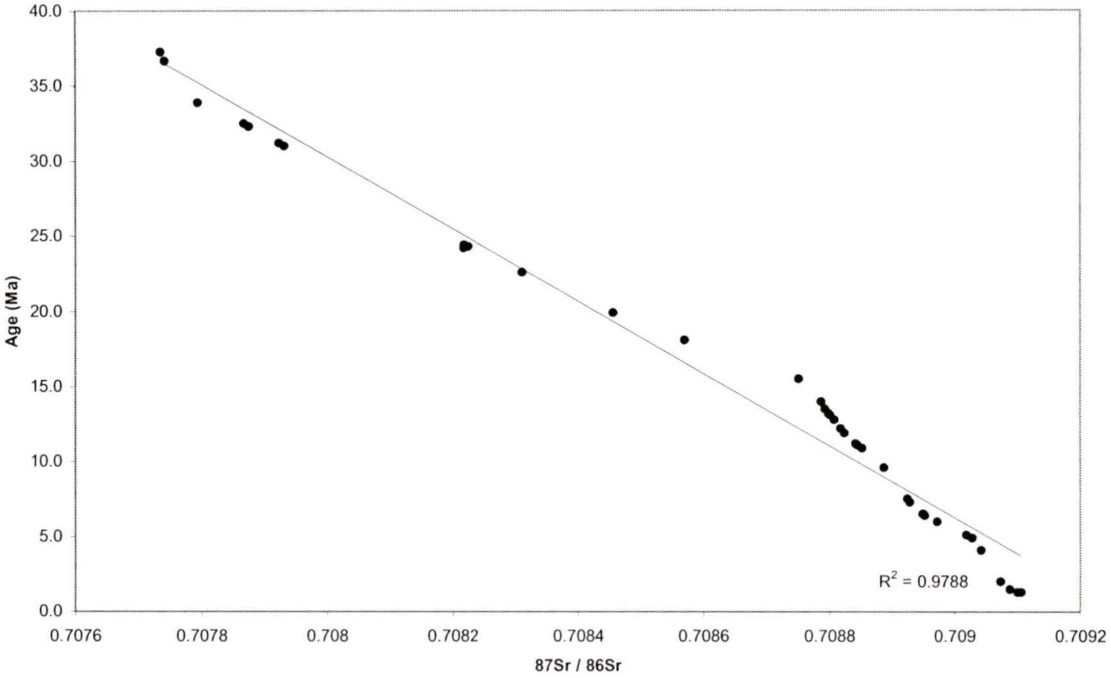


Figure 4.1. Strontium (Sr) isotope results from (the successful) analysis of 42 offshore Tofino Basin samples from the five Shell Canada wells (Cygnet J-100, Prometheus H-68, Zeus D-14, Zeus I-65 and Pluto I-87). The Sr ages are based on McArthur et al. (2001) and range from the late Eocene (37.3 Ma) to the Pleistocene (1.3 Ma). These results support a global Cenozoic seawater increase in $^{87}Sr/^{86}Sr$.

4.2. Materials and methodology

Marine carbonate samples are required for Sr isotopic analysis and well preserved biogenic calcite, such as foraminifer tests, mollusc and brachiopod shells, are preferred over bulk (whole) rock carbonates. However the latter has more calcite preserved, making it ideal for large-scale geochemical studies (DePaolo and Ingram, 1985; DePaolo, 1986; Hess et al., 1986; Smalley et al., 1994; Reinhardt et al., 1998). Biogenic carbonates preserved within clastic lithologies (i.e., this study) provide a means for applying Sr isotope stratigraphy to non-carbonate sequences. In this study, foraminifer tests, a few mollusc/shell fragments and a few ichthyolith bone fragments were hand-picked for strontium isotope analysis.

Petrographic examination is an essential step in reducing errors associated with diagenesis, and should be utilized to help discriminate potentially erroneous isotopic results (DePaolo and Ingram, 1985; DePaolo, 1986; Smalley et al., 1994). Other potential errors include: sampling problems, such as misidentification and/or mislabeling; and measurement errors, associated with the precision and accuracy of isotope ratio determinations, but these are rigorously evaluated in the laboratory and comparatively insignificant (Whitford et al., 1996).

Biogenic carbonate material was extracted from a total of 44 (including reruns/split samples) well cuttings from the 5 Shell Canada wells and 31 (including reruns/split samples) onshore (Carmanah Group) samples, for Sr isotope analysis. Foraminifer tests from the well samples showing significant abrasion/fragmentation, discoloration (e.g. iron staining), mineral replacement (e.g. pyritization or silicification), and sediment infilled chambers, were rejected for analysis. Weathering was observed (yellow/brown coloration and some silicification) in the onshore samples and the least weathered specimens were selected for analysis. Other biogenic carbonate material, such as mollusc (bivalve and/or gastropod), bryozoan/echinoderm and ichthyolith bone fragments, were analyzed where good foraminifer specimens were lacking. Sample sizes were variable and depended on test size, but typically ranged from 1 to 10 individual foraminifers. All specimens selected for analysis were photographed using the Eclipse Image Analysis software Version 3.0.

Samples were sent to the CSIRO Petroleum, North Ryde Laboratories, Australia, for Sr isotopic analysis (by J.A. Trotter) and petrographic examination (by S. Barclay). Strontium isotopic composition was measured using a VG 354 Thermal Ionization Mass Spectrometer at the CSIRO Radiogenic Isotope Facility. Samples rejected, unsuccessful analyses and the petrographic reports are detailed in Appendix A.

4.3. Results: Tofino Basin Sr isotope analyses

Sr isotope results including well samples and the number of specimens analyzed per sample are presented in Table 4.1. Strontium isotope ratios measured for 31 onshore samples (with 6 unsuccessful; Appendix A), yielded both anomalously low and high ages. Mollusc shell fragments yielded Pleistocene ages. Foraminifer tests yielded a Late Jurassic or Late Jurassic/Cretaceous ages, with the exception of sample BC-74-7 (0-39'), which yielded a late Eocene age and samples BC-74-6 (123-147') and BC-72-15 (#10) yielded Pleistocene ages. One sample containing both foraminifer tests and a mollusc shell, yielded a Pleistocene age and not a Jurassic age. This trend was reproduced by a sample split (BC-69-2, 3520-3540'), the foraminifer fraction containing late Eocene/Oligocene *Uvigerina cocoaensis* tests (Cameron, 1980; Rau, 1999) yielded a Late Jurassic age, whereas the mollusc shell yielded a Pleistocene age. However, sample BC-72-15, (#10) yielded Pleistocene ages for both the foraminifer and mollusc shells in the samples.

Strontium isotope ratios were measured for 44 offshore samples (3 unsuccessful; Appendix A). The resulting Sr ages ranged between 4.1 Ma (early Pliocene) and 37.3 (Late Eocene), based on the McArthur et al., (2001) Sr seawater curve. Seven samples from Pluto I-87 yielded Sr ages ranging from 14.0 Ma (middle Miocene) to 37.3 Ma (middle?/late Eocene). Sample 6900-6910' (ichthyolith bone fragments) was unsuccessful because it was too low in Sr. Strontium age reversals were apparent within the middle and lower portions of the well (e.g. 37.3 Ma at 6020-6030' and 24.2 Ma at 9820-9830').

Eleven samples from Zeus I-65 well yielded ages ranging from 1.3 Ma (Pleistocene) to 18.1 Ma (early Miocene). Strontium age reversals were apparent in the uppermost part of the well (Pliocene-Pleistocene strata) and also within the middle part of

Table. 4.1. A summary of strontium isotopic composition and age calculations for the five (Cygnet J-100, Prometheus H-68, Zeus D-14, Zeus I-65, Pluto I-87) of the 6 Tofino Basin Shell well samples, and several Vancouver Island onshore samples. Strontium age calculations are based on McArthur et al., (2001). The foraminifer taxa and approximate number of specimen analyzed are shown in the final two columns.

The ^{87}Sr / ^{86}Sr ratios were normalized to ^{86}Sr / ^{88}Sr = 0.1194; ^{87}Sr / ^{87}Sr ratios were normalized to the standard NBS987 ^{87}Sr / ^{86}Sr = 0.710235; measured NBS987 87Sr / 86Sr = 0.710252 ±0.0020% (±0.000014; 95% confidence limits); 2 sem = 2 standard errors of the mean ($2\sigma/\sqrt{n}$); Δsw = (^{87}Sr / ^{86}Sr unknown-^{87}Sr/^{86}Sr modern seawater) x 10^5. Modern seawater was calculated at ^{87}Sr / ^{86}Sr = 0.709168 (Mobil, Denison, 1990; CSIRO Petroleum, Australia).

Tofino Basin (Shell wells) and Van. Isle. Onshore	Shell well and outcrop samples (depths) in ft/(run #)	^{87}Sr / ^{86}Sr	2 sem (%)	Δsw	Age(Ma) McArthur	Epoch (E=early M=middle L=late)	# Specimen analyzed	Taxa analyzed
Cygnet J-100	6731-7445 (1)	0.709042	0.0020	-12.6	4.1	E. Pliocene	~22	*Cassidulina reniforme, Epistominella pacifica, Martinotiella communis, Pullenia salisburyi, Uvigerina peregrina*
Cygnet J-100	6731-7445 (2)	0.709019	0.0019	-14.9	5.1	E. Pliocene	As above	As above
Prometheus H-68	2318	0.709028	0.0011	-14.0	4.9	E. Pliocene	11	*Cassidulina limbata, Dentalina sp. A, Euvigerina juncea, Islandiella islandica, Melonis pompiloides*
Prometheus H-68	5050-5450 (+5250-5260)	0.708818	0.0014	-35.0	12.2	M. Miocene	~23	*Cassidulina spp., Cibicides mckannai, Buliminella subsiformis, Uvigerina hannai, U. hootsi*
Prometheus H-68	5620-5630	0.707742	0.0019	-142.6	36.7	L. Eocene	19	Ichthyolith bone fragments
Zeus D-14	2460-3180 (1)	0.708949	0.0017	-21.9	6.5	L. Miocene	~40	*Cassidulina spp., Cibicides mckannai, Epsitominella pacifica, Islandiella californica,*
Zeus D-14	2460-3180 (2)	0.708952	0.0013	-21.6	6.4	L. Miocene	As above	As above

Zeus D-14	3080-3100	0.708949	0.0014	-21.9	6.5	L. Miocene	6	*Uvigerina hootsi*
Zeus D-14	3480-3500	0.708972	0.0012	-19.6	6.0	L. Miocene	4	*Cassidulina limbata, Euvigerina juncea, Uvigerina hannai?*
Zeus D-14	3960-3980	0.708845	0.0012	-32.3	11.1	M. Miocene	8	*Uvigerina hootsi, Protoglobobulimina auriculata*
Zeus D-14	4645-4650	0.708787	0.0016	-38.1	14.0	E. Miocene	8	*Buliminella elegantissima, B. subfusiformis, Hopkinsinia magnifica, Uvigerina hootsi*
Zeus D-14	4790-4800	0.708824	0.0013	-34.4	11.9	M. Miocene	10	*Uvigerina hootsi*
Zeus D-14	5130-5140	0.708842	0.0016	-32.6	11.2	M. Miocene	10	*Uvigerina hootsi*
Zeus D-14	5190-5200	0.708842	0.0013	-32.6	11.2	M. Miocene	10	*Uvigerina hootsi, Buliminella subfusiformis, B. curta*
Zeus D-14	5230-5240	0.708852	0.0018	-31.6	10.9	M. Miocene	10	*Uvigerina hootsi, U. hannai*
Zeus D-14	5430-5440	0.708799	0.0009	-36.9	13.2	E. Miocene	6	*Baggina washingtonensis*
Zeus D-14	6040-6050	0.708752	0.0012	-41.6	15.5	E. Miocene	3	*Rectuvigerina branneri*
Zeus D-14	6260-6270	0.708311	0.0014	-85.7	22.6	E. Miocene	2	*Rectuvigerina branneri*
Zeus D-14	6320-6380	0.708801	0.0016	-36.7	13.1	E. Miocene	4	*Uvigerinella ornata*?
Zeus D-14	6540-6450	0.707868	0.0013	-130.0	32.5	E. Oligocene	2.5	*Rectuvigerina branneri, R. transversa?*
Zeus D-14	7010-7020	0.707932	0.0012	-123.6	31.0	E. Oligocene	3	*Rectuvigerina branneri*
Zeus D-14	7170-7180	0.708218	0.0018	-95.0	24.4	L. Oligocene	4	*Rectuvigerina branneri, Uvigerina hootsi*
Zeus D-14	7310-7320	0.707924	0.0014	-124.4	31.2	E. Oligocene	6	*Rectuvigerina branneri, Uvigerina hootsi, Uvigerinella ornata*?.
Zeus D-14	7370-7380	0.708224	0.0016	-94.4	24.3	L. Oligocene	6	*Rectuvigerina branneri, Uvigerina hootsi*
Zeus D-14	7560-7570	0.708808	0.0014	-36.0	12.8	M. Miocene	10	*Uvigerina hootsi, Uvigerinella ornata*?
Zeus I-65	1040-1070 (1)	0.709106	0.0010	-6.2	1.3	Plio./Pleist.	7	*Cassidulina reniforme, Cibicides mckannai, Epistominella pacifica, Euvigerina juncea*
Zeus I-65	1040-1070 (2)	0.709042	0.0014	-12.6	4.1	E. Pliocene	1	Shell (bivalve) fragment
Zeus I-65	1170-1610 (1)	0.709073	0.0017	-9.5	2.0	L. Pliocene	~45	*Cribroelphidium excavatum* f. *clavatum, Epistominella pacifica, Islandiella norcrossi, Nonionellina labradorica*
Zeus I-65	1170-1610 (2)	0.709088	0.0017	-8.0	1.5	Plio./Pleist.	As above	As above
Zeus I-65	1450-1480	0.709100	0.0011	-6.8	1.3	Pleistocene	11	*Cassidulina limbata, C. reniforme, Elphidiella hannai, Epistominella pacifica, Islandiella* islandica
Zeus I-65	1610-1640	0.708887	0.0018	-28.1	9.6	L. Miocene	1	Shell (bivalve) fragment
Zeus I-65	1970-1980	0.708924	0.0015	-24.4	7.5	L. Miocene	1	Shell (bivalve) fragment
Zeus I-65	2040-2060	0.708570	0.0016	-59.8	18.1	E. Miocene	1	Shell (bivalve) fragment
Zeus I-65	2260-2280	0.708793	0.0015	-37.5	13.5	M. Miocene	1	Shell (bivalve) fragment
Zeus I-65	2420-2500	0.708950	0.0019	-21.8	6.5	L. Miocene	13	*Cassidulina limbata, Uvigerina peregrina*
Zeus I-65	2480-2500	0.708928	0.0017	-24.0	7.3	L. Miocene	11	*Islandiella californica, Uvigerina peregrina*
Zeus I-65	9370-9380	0.705603	0.0013	-356.5	N/A	N/A	4	Shell (bivalve) fragment
Pluto I-87	5300-5320	0.708456	0.0014	-71.2	19.9	E. Miocene	13	*Baggina washingtonensis, Cassidulina californica, Cyclammina incise, Dentalina* sp. A, *Oridosalis umbonatus, Rectuvigerina branneri, Siphonodosaria montereyana*

Pluto I-87	5560-5570	0.708787	0.0072	-38.1	14.0	E. Miocene	4	Ichthyolith bone fragments
Pluto I-87	6020-6030	0.707735	0.0016	-143.3	37.3	L. Eocene	6	*Cyclammina pacifica*
Pluto I-87	6900-6910	0.706784	0.0011	-238.4	N/A	N/A	7	Ichthyolith bone fragments
Pluto I-87	7820-7830	0.707794	0.0016	-137.4	33.9	L. Eocene	8	*Cyclammina inscisa?/pacifica*?, x? *Dentalina*? sp., x? *Oridosalis umbonatus*,
Pluto I-87	8420-8430	0.707876	0.0016	-129.2	32.3	E. Oligocene	13	*Cyclammina pacifica*?/*incisa*?, x8 *Dentalina*? sp., *Globobulimina pacifica*
Pluto I-87	9820-9830	0.708217	0.0014	-95.1	24.2	L. Oligocene	9	x4 *Dentalina*? sp., x2? *Cassidulina galvanensis*, x1? *Uvigerina cocoaensis*, x1*Cyclammina pacifica*, x1? *Oridosalis umbonatus*
BC-69-2	1360-1380	0.706895	0.0014	-227.3	N/A	L. Jurassic	4	x2 *Globorotalia postcretacea*?; x2 *Siphonodosaria* sp. A
BC-69-2	2660-2680	0.707227	0.0017	-194.1	N/A	Jura./Cret.	1	x1 *Bolivina marginata*
BC-69-2	2860-2880	0.707049	0.0025	-211.9	N/A	L. Jurassic	6	x5 *Cibicides* sp. A, x1 *Siphonodosaria* sp. A
BC-69-2	3000-3020	0.706847	0.0013	-232.1	N/A	L. Jurassic	9	x1 *Dentalina* sp. A, x2 *Hansenica* (*Gyroidina*) *keenani*, x1 *Plectofrondicularia packardi*, x3 *Pseudonodosaria* sp. cf. *P. inflata*, x2 *Siphonodosaria* sp. A,
BC-69-2	3380-3400	0.707077	0.0016	-209.1	N/A	L. Jurassic	9	x1 *Dentalina dusenburyi*, x8 *Hansenica (Gyroidina) orbiculus?*,
BC-69-2	3460-3480	0.707194	0.0016	-197.4	N/A	Jura,/Cret.	4	x1 *Dentalina dusenburyi*, x2 *Siphonodosaria* sp. ? x1 *Uvigerina cocoaensis*?
BC-69-2	3480-3500	0.709157	0.0016	-1.1	0.1	Pleistocene	1	Shell (bivalve) fragment
BC-69-2	3520-3540 (1)	0.706932	0.0014	-223.6	N/A	L. Jurassic	2	x2 *Uvigerina cocoaensis*
BC-69-2	3520-3540 (2)	0.709177	0.0016	0.9	N/A	Pleistocene	2	Shell (bivalve) fragment
BC-71-1	267-280	0.709176	0.0016	0.8	N/A	Pleistocene	1	Shell (oyster/barnacle?) fragment
BC-71-1	695	0.709157	0.0016	0.8	0.1	Pleistocene	1	Shell (bivalve) fragment
BC-71-1	985-1025	0.709162	0.0015	-0.6	0.0	Pleistocene	1	Shell (gastropod)
BC-71-2	190-203	0.709163	0.0015	-0.5	N/A	Pleistocene	1	Bryozoan (?) fragment
BC-71-5	179-187	0.709154	0.0013	-1.4	0.2	Pleistocene	1	Shell (gastropod)
BC-71-5	318-337	0.709173	0.0015	0.5	N/A	Pleistocene	1	Shell (oyster/barnacle?) fragment
BC-71-5	525-570	0.709166	0.0015	-0.2	N/A	Pleistocene	1	Shell (oyster/barnacle?) fragment
BC-72-12	#7: 300	0.709151	0.0017	-1.7	0.4	Pleistocene	1	Shell (bivalve) fragment
BC-72-15	#4	0.709160	0.0017	-0.8	0.1	Pleistocene	1	Shell (gastropod)
BC-72-15	#10 (1)	0.709135	0.0014	-3.3	0.8	Pleistocene	1	Shell (bivalve) fragment
BC-72-15	#10 (2)	0.709155	0.0017	-1.3	0.2	Pleistocene	6	x5 *Elphidiella hannai*?, x1 *Bucella* sp.,
BC-74-1	#2: 34-51	0.709152	0.0015	-1.6	0.3	Pleistocene	1	Shell (oyster/barnacle?) fragment
BC-74-1	143-160	0.709169	0.0013	0.1	N/A	Pleistocene	7	x1 shell (oyster/barnacle frag), x1 shell (bivalve) frag., x1 shell (gastropod) frag., x2 *Cibicides* sp. A, x2 *Elphidiella hannai*
BC-74-1	#12: 243-255	0.709146	0.0016	-2.2	0.5	Pleistocene	3	Shell (oyster/barnacle?) fragment
BC-74-6	123-147	0.709159	0.0016	-0.9	0.1	Pleistocene	9	x3 *Cibicides* sp. A, x4 *Elphidiella hannai*
BC-74-6	147-171	0.709175	0.0015	0.7	N/A	Pleistocene	2	Shell (bivalve-umbo) fragment

BC-74-7	#1,2: 0-39	0.707693	0.0015	-147.5	N/A	Late Eocene	3	x1 echinoderm plate, x2 *Globorotalia* sp. A
BC-74-7	#6: 84-114	0.706793	0.0017	-237.5	N/A	Late Jurassic	7	x2 *Pseudonododaria sp. cf. P. inflata*, x3 *Pseudoparella* sp.
BC-74-7	#7	0.707084	0.0016	-208.4	N/A	N/A	10	Ichthyolith bone fragments
BC-74-7	#8	0.706770	0.0011	-239.8	N/A	N/A	4	Icthyolith bone fragments
BC-74-7	#10: 226-264	0.706854	0.0015	-231.4	N/A	Late Jurassic	4	x1 *Dentalina* sp. A, x1 *Pseudonodosaria* sp. cf. *P. inflata*, x2 *Globocassidulina globosa*?
BC-74-7	264-307	0.706753	0.0016	-241.5	N/A	Late Jurassic	4	x1 *Cibicides elmanensis*, x2 *Globortalia* sp. A, x1 *Cassidulina sp.*?

the well (Miocene strata). Three large agglutinated species analyzed from sample 8530-9370' did not produce a Sr signal and this sample was aborted. From sample 9700-9710' a calcite (mollusc) shell fragment was analyzed and resulted in extremely low (0.705603) $^{87}Sr/^{86}Sr$. These preliminary results suggest that the lowermost portion of Shell Canada Zeus I-65 contains insufficient biogenic calcite, and further Sr isotope analyses were not possible.

Twenty samples were analyzed from the Zeus D-14 well and yielded ages ranging from 6.0 Ma (late Miocene) to 32.5 Ma (early Oligocene). Strontium age reversals were apparent in the middle and lowermost part of the well (middle and lower Miocene strata).

Three samples from the Prometheus H-68 well yielded McArthur Sr ages ranging from 4.9 Ma (early Pliocene) to 36. 7 Ma (late Eocene). The lowest sample analyzed (5620') was an ichthyolith bone fragment.

Lastly, two of the three samples analyzed from the Cygnet J-100 well yielded early Pliocene ages (4.1 and 5.1 Ma; McArthur et al., 2001). Sample 2595-2626' was unsuccessful (too low in Sr).

4.4. Discussion

Two consistent trends (with few exceptions; Table 4.1) resulted from the Sr isotope analysis of onshore samples: 1) Jurassic Sr ages for the foraminifers and 2) Pleistocene ages for mollusc shell fragments. Non-foraminifer shell material, and only three foraminifer samples (BC-72-15, BC-74-1, BC-74-6) yielded Pleistocene ages. Possible explanations considered are: 1) the analysis of Jurassic/Pleistocene foraminifers (and molluscs); and 2) contamination of samples and their isotopic signatures by overprinting by pore-waters from Jurassic and/or Pleistocene sediments.

The onshore split-sample BC-72-15 (#10) that yielded Pleistocene ages for both the mollusc shell and foraminifers proved to be successful and the identification of the foraminifera taxa supports the Sr results. Taxa analyzed included inner neritic, cold-water species *Cribroelphidium excavatum* and *Buccella* sp. (possibly *B. frigida*), of Pleistocene-Holocene deposits (Smith, 1978; Hald et al., 1994; Lagoe et al., 1994). *Cribroelphidium excavatum* was also present in two other samples (BC-74-1, 143-160' and BC-74-6, 123-147') that yielded Pleistocene ages. Sample BC-72-15 (#4) yielded a Pleistocene age for a single gastropod shell analyzed. The high $^{87}Sr/^{86}Sr$ of onshore samples indicates that chemical weathering rates and dissolved riverine fluxes increased to a maximum during the Pleistocene (Hodell et al., 1990).

Examination (of digital images) of some of the tests used in the analysis suggests that these foraminifer and mollusc shells were probably not in-situ, based on their abraded/weathered or slightly fragmented nature. They were probably reworked into late Eocene/Oligocene strata from Plio-Pleistocene strata, possibly by erosional processes. This is supported by a single 37.8 Ma (late Eocene) Sr age result from analysis of a planktic species and (echinoderm?) shell fragment in sample BC-74-7 (0-39').

Cameron (1980) placed these sections within the Oligocene of the Hesquiat Formation. The lithostratigraphy is predominantly shale, with interbedded shale-siltstone-sandstone unit with concentrated conglomerate lenses, assumed to have been deposited through mass-flow with faulting present at the top of the section, which is covered by Pleistocene drift (Cameron, 1980). Lower to middle Pliocene (and possibly Pleistocene?) assemblages have been encountered at Bajo Point, Nootka Island (Cameron, 1971). However, Cameron stated that these faunal assemblages had not yet been found in samples of the Hesquiat Peninsula, suggesting that they could possibly be present there.

A sample-split of BC-69-2 (3520-3540') resulted in: 1) a Late Jurassic Sr age for the foraminifers; and, 2) Pleistocene age result for the mollusc shell fragments. Furthermore, all (seven; Table 4.1) of the foraminifer fractions from the BC-69-2 samples resulted in older Jurassic/Cretaceous ages. The Pleistocene mollusc shells, from samples BC-69-2, 3480-3500' and 3520-3540'(split) may have been reworked, as discussed above. Foraminifer taxa analyzed from BC-69-2 are not Late Jurassic/Cretaceous species and do not range into this Period (Cameron, 1980; Rau, 1981; 1999). For example, *Uvigerina cocoaensis* has been previously recorded from late Eocene (Refugian Stage) of the *Sigmomorphina schencki* Zone in Washington and Oregon (Rau, 1981, 1999) and the *Cibicides haydoni* and *Globorotalia* aff. *postcretacea* zones on western Vancouver Island (Cameron, 1980). The BC-69-2 section was placed within the Hesquiat Formation (Carmanah Group) on Nootka Island (Cameron, 1980).

Cameron (1980) encountered well preserved Jurassic taxa in several areas of the Escalante Formation (Carmanah Group). Eocene/Oligocene foraminifer taxa including *Cibicides elmanensis*, *Dentalina dusenburyi*, *Globorotalia postcretacea* (?), *Plectofrondicularia packardi*, *Pseudonodosaria* sp. cf. *P. inflata* and *Uvigerina cocoaensis* were the oldest in-situ, foraminifers analyzed and all are restricted to the Cenozoic. The Eocene/Oligocene foraminifer tests displayed signs of dissolution or recrystallization and this suggested diagenetic alteration of specimens from outcrop samples BC-69-2. Based on preservational evidence, a possible explanation for the Jurassic Sr ages (for the foraminifer fractions) was contamination by pore-fluids from underlying Jurassic sediments and overprinting of the original isotopic compositions of the faunas, with compositions similar to that of the underlying volcanic rocks. The species analyzed do not suggest contamination or bioturbation by Jurassic/Cretaceous foraminifers.

The Sr isotope analysis results of the five offshore Shell Canada wells confirms: 1) the presence of a late Eocene/Oligocene to Pleistocene sequence, providing improved stratigraphic resolution; and, 2) provides Sr isotope evidence (age reversals) for potential structural faulting. Strontium isotope stratigraphy of the offshore complements (with few exceptions) the newly developed foraminiferal biostratigraphy for the Tofino Basin. One major limitation of utilizing foraminifers from Shell Canada well cuttings was the potential for caving (wall-spalling) and the necessity for biostratigraphic control was significant. The identification of last appearance datums (LAD's) and the stratigraphic ranges of foraminifer species in the wells were used to constrain wall-spalling of the wells, transported and bioturbated (mixed) units.

Late Eocene (37.3 Ma) to early Miocene (14 Ma) Sr ages resulted from the analysis of seven (and one unsuccessful) samples from the Pluto I-87 well (Table 4.1; Figure 4.2a). Three zones are established for this well. Samples at 5300' and 5560' were taken from the lower Miocene *Rectuvigerina branneri* Zone (LAD at 5300'). The resulting Sr age of 19.9 Ma, supports a lower Miocene biostratigraphic age. A sample at 6020' taken from the Oligocene *Turrilina alsatica* Zone (LAD at 5740') resulted in a Sr age of 37.3 Ma, which corresponds to a late Eocene age. Sample 6900' also taken from the *R. branneri* Zone, was not successful in providing an age. Faulted strata are

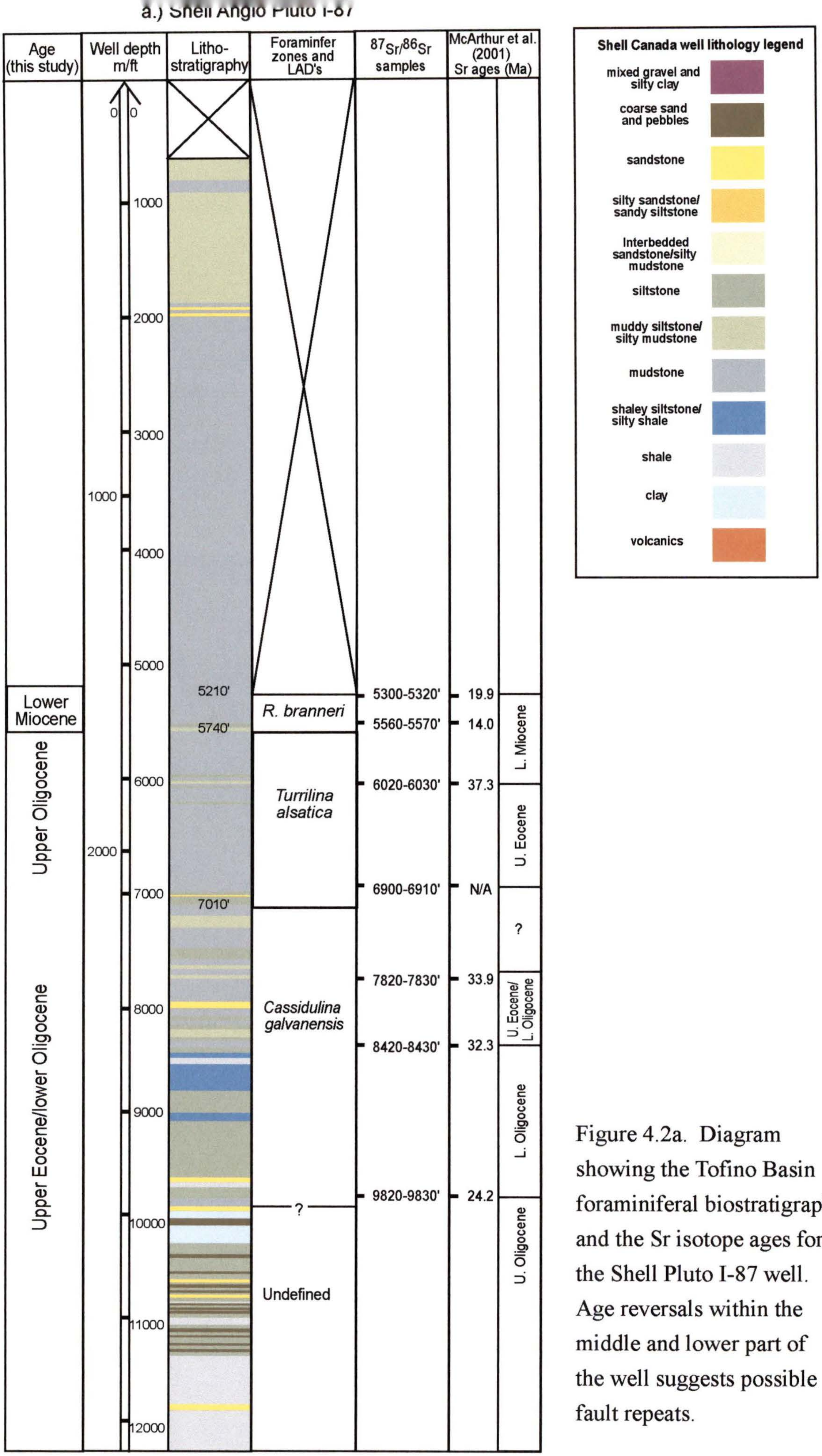


Figure 4.2a. Diagram showing the Tofino Basin foraminiferal biostratigraphy and the Sr isotope ages for the Shell Pluto I-87 well. Age reversals within the middle and lower part of the well suggests possible fault repeats.

suspected for this interval and for the lower portion of the well. Lower samples at 7820', 8420, 8420' and 9820' from the late Eocene/early Oligocene *Cassidulina galvanensis* Zone (LAD at 7010') produced Sr ages of late Eocene, early Oligocene and late Oligocene, respectively. Faulting is indicated by slicken-sided structures reported in the Shell well history lithology report. Below 7020 ft faunal abundance and diversity is drastically reduced, and there is indication of diagenesis of samples below ~10,600 ft where specimen appear black and thermally altered. Sr ages approximately complement the Tofino Basin biostratigraphy and provide correlation to the onshore Vancouver Island sample BC-74-7 (0-39').

Early Miocene (18.1 Ma) to Pleistocene (1.3 Ma) Sr ages resulted from the analysis of twelve (one unsuccessful) samples from the Zeus I-65 well (Table 4.1; Figure 4.2b). Two zones are established for the uppermost portion of the well. Samples 1040' (2 runs), 1170' (2 runs), 1450', 1610', and 1970' were taken from the early Pliocene *Elphidiella hannai* Zone. Foraminifers analyzed from 1040', 1170' and 1450' included a mixed assemblage of Pliocene and Pleistocene-Holocene species. Resulting Sr ages ranged within the Plio-Pleistocene. Inner neritic, cool temperate faunas were analyzed including: *Cassidulina reniforme*, *Cribroelphidium excavatum* f. *clavatum*, *Elphidiella hannai*, *Epistominella pacifica*, *Islandiella spp.*, *Nonionellina labradorica*. A single mollusc shell analyzed from 1040' (LAD of the *E. hannai* Zone) resulted in an early Pliocene age and supported the biostratigraphy. Mollusc shells analyzed from samples 1610' and 1970' resulted in a late Miocene age. Also, mollusc shells from samples at 2040', 2260' 2420' and 2480' resulted in Miocene ages and Sr age reversals suggests potential faulting. No calcareous foraminifers were available for analysis below 2420' in the well and agglutinated tests showed dissolution and recrystalization. Strontium isotope ages could not be successfully determined from mollusc shell fragments in the lower portion (9820') of this well.

Early Oligocene (32.5 Ma) to late Miocene (6.0 Ma) Sr ages resulted from analysis of twenty samples from the Zeus D-14 well (Table 4.1; Figure 4.2c). Strontium age reversals resulted from a sample (4645-4650') in the upper-middle part of the well and several from the middle and lower parts of the well (mainly below sample 6040') and

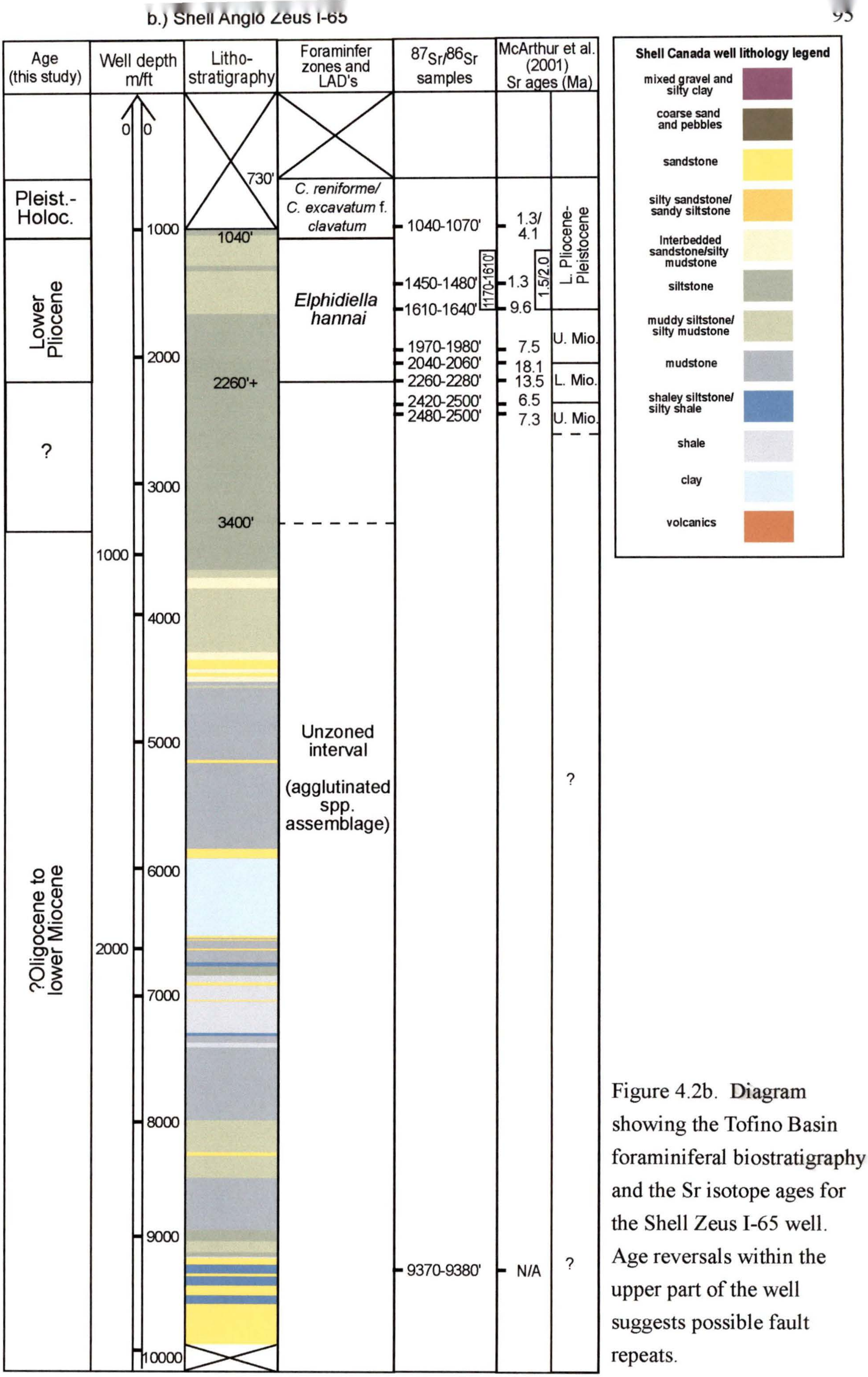


Figure 4.2b. Diagram showing the Tofino Basin foraminiferal biostratigraphy and the Sr isotope ages for the Shell Zeus I-65 well. Age reversals within the upper part of the well suggests possible fault repeats.

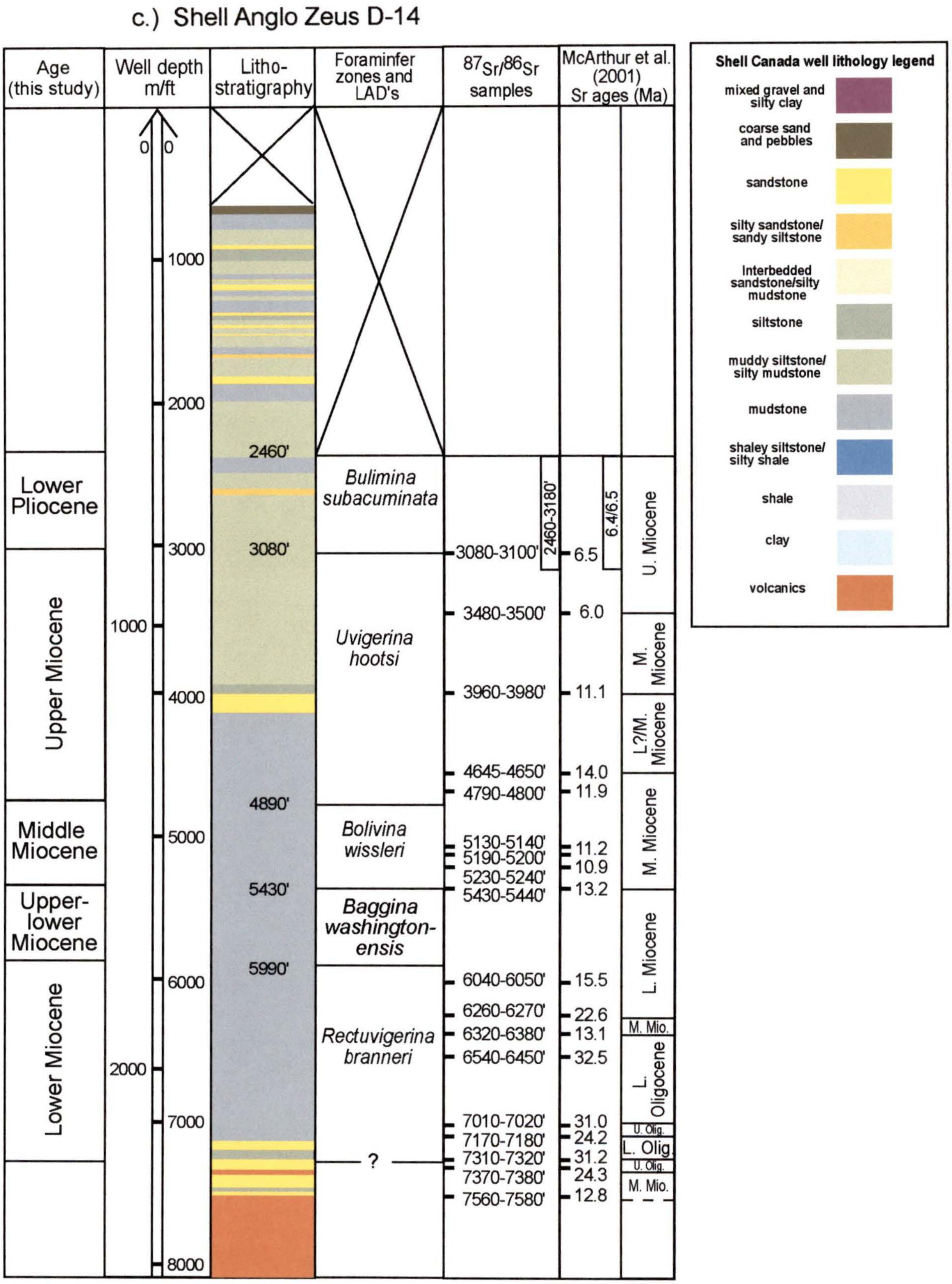


Figure 4.2c. Diagram showing the Tofino Basin foraminiferal biostratigraphy and the Sr isotope ages for the Shell Zeus D-14 well. Age reversals within the lower part of the well suggests possible fault repeats within the lower Miocene *Rectuvigerina branneri* Zone.

suggests possible structural faulting. Samples from five Tofino Basin biozones were analyzed. The sample at 2460' occurs at the LAD of the early Pliocene *Bulimina subacuminata* Zone. The Sr age result was ~6.5 Ma for this level and complements the biostratigraphy. Samples at 3080', 3480', 3960', 4645' and 4790' were taken from the late Miocene *Uvigerina hootsi* Zone (LAD at 3080') and the resulting Sr ages were within the middle and late Miocene. Samples at 5130', 5190', and 5230' were taken from the thin middle Miocene *Bolivina wissleri* Zone and Sr ages support a middle Miocene age for this interval. A single sample at 5430' was taken from the LAD of the late-early Miocene *Baggina washingtonensis* Zone and the resulting Sr age of 13.1 Ma supports a late-early Miocene age. Nine samples (Table 4.1) from the lower Miocene *Rectuvigerina branneri* Zone were analyzed and provided Sr ages from 13.1 Ma (early Miocene) to 32.5 Ma (Oligocene). Within this zone, Sr age reversals are apparent and suggest possible contamination/mixing and/or structural faulting. The latter case is strongly supported by Sr age reversals from 22-24 Ma and 31-32 Ma. No Oligocene foraminifers were analyzed, *Rectuvigerina branneri*, *Rectuvigerina transversa*, *Uvigerina hootsi* and *Uvigerinella* sp. are considered restricted to the early and middle Miocene (Rau, 1981; 1999; Finger and Lipps, 1990; Finger, 1990; 1992; Olson, 1990). Noticeable dissolution and staining of the tests suggests overprinting by pore-fluids from underlying volcanic unit. Petrographic analysis of a sample at 7370', shows possible dissolution as pore spaces were occluded by clays(?), and woody/straw-like material, suggesting possible contamination from drilling muds. Ichthyolith biostratigraphy in the Zeus D-14 well supports the occurrence of rare, reworked and older Oligocene age ichthyoliths at 4040', 5030', 5040', 6060' and significant reworking or faulting below 6360' (pers. comm., M.J. Johns, 2003). In both the Prometheus H-68 and Zeus D-14 wells the lower Miocene strata unconformably overlies a mixed unit and a thick volcanic unit of possibly the Eocene Crescent Terrane. The presence of Oligocene strata was indicated by the Sr and it may represent a mixed (incomplete Oligocene/Miocene) unit overlying the volcanics at the base of the wells. Nonetheless, the resulting Sr age reversals are still significant in suggesting faulting has occurred within the Shell well strata, particularly within the middle and basal portion of the well.

Late Eocene (36.7 Ma) to early Pliocene (4.9 Ma) Sr ages resulted from analysis of three Prometheus H-68 well samples (Table 4.1; Figure 4.2d). A sample at 2318' was taken from the *Uvigerina peregrina* Zone. The resulting Sr age was 4.9 Ma (early Pliocene) and is close to the biostratigraphically determined late Pliocene age. A large sample interval at 5050-5450' confirms middle Miocene strata in this well complementing the biostratigraphic results. This sample was a pre-study to acquire an Sr signal from foraminiferal tests. The sample from 5620-5630' was an analysis of ichthyolith bone fragments. The resulting 36.7 Ma (late Eocene) Sr age was too old and did not complement the foraminiferal biostratigraphy, which suggests an early Miocene age and occurs at the LAD of the *Rectuvigerina branneri* Zone in the Tofino Basin. The resulting Sr age is possibly a result of reworked ichthyolith fossils (M.J. Johns, 2003). Sr age reversal or fault repeats were not apparent from the few samples analyzed. However, the biostratigraphy suggested a late-early Miocene (*Baggina washingtonensis* Zone) repeat section within early Pliocene (*Bulimina subacuminata* Zone) strata.

Early Pliocene Sr ages (4.1 and 5.1 Ma) resulted for two Cygnet J-100 samples taken from the *Bulimina subacuminata* Zone (Table 4.1; Figure 4.2e). A few species (i.e. *Cassidulina reniforme*, *Uvigerina peregrina*) analyzed from this lower strata in the well had caved-down from the overlying Pleistocene-Holocene strata. The initial Shell Canada well history report placed this lower portion of Cygnet J-100 well in the Miocene. The Sr isotope ages and foraminifer biostratigraphy (this study) confirms an early Pliocene age for this strata in the Tofino Basin. The $^{87}Sr/^{86}Sr$ for this age interval was much higher than Oligocene or Miocene Tofino Basin strata (Table 4.1), suggesting possible increased dissolved riverine flux into the basin (Hodell et al., 1990). An attempt to analyze a late Pliocene sample (2595-2626') of the *Uvigerina peregrina* Zone was unsuccessful, possibly due to low Sr (pers comm., Trotter, 2002).

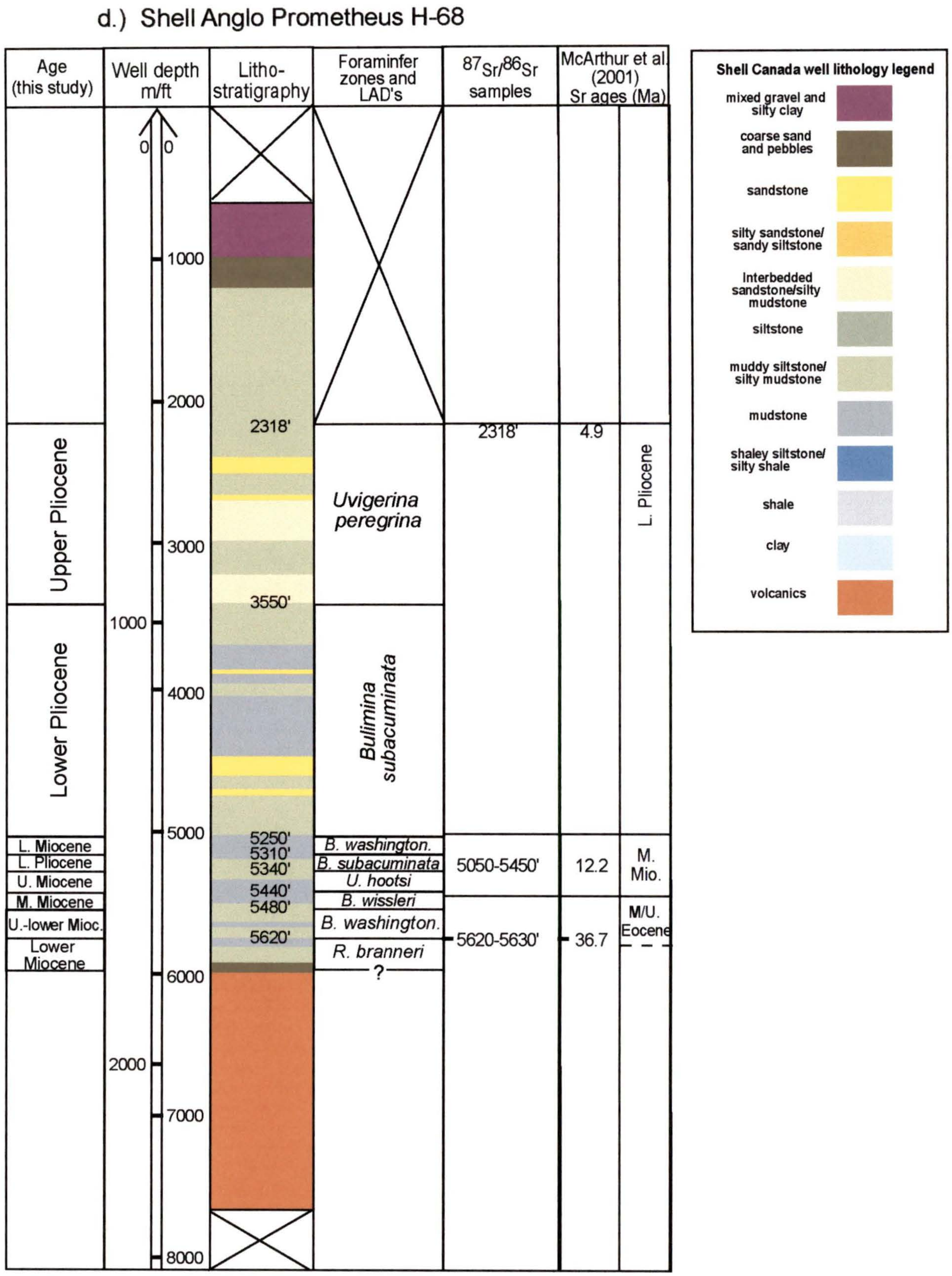


Figure 4.2d. Diagram showing the Tofino Basin foraminiferal biostratigraphy and the Sr isotope ages for the Shell Prometheus H-68 well. A middle/upper Eocene Sr age does not complement a lower Miocene biostratigraphic age and suggests possible contamination or overprinting by pore fluids from the lower volcanic unit.

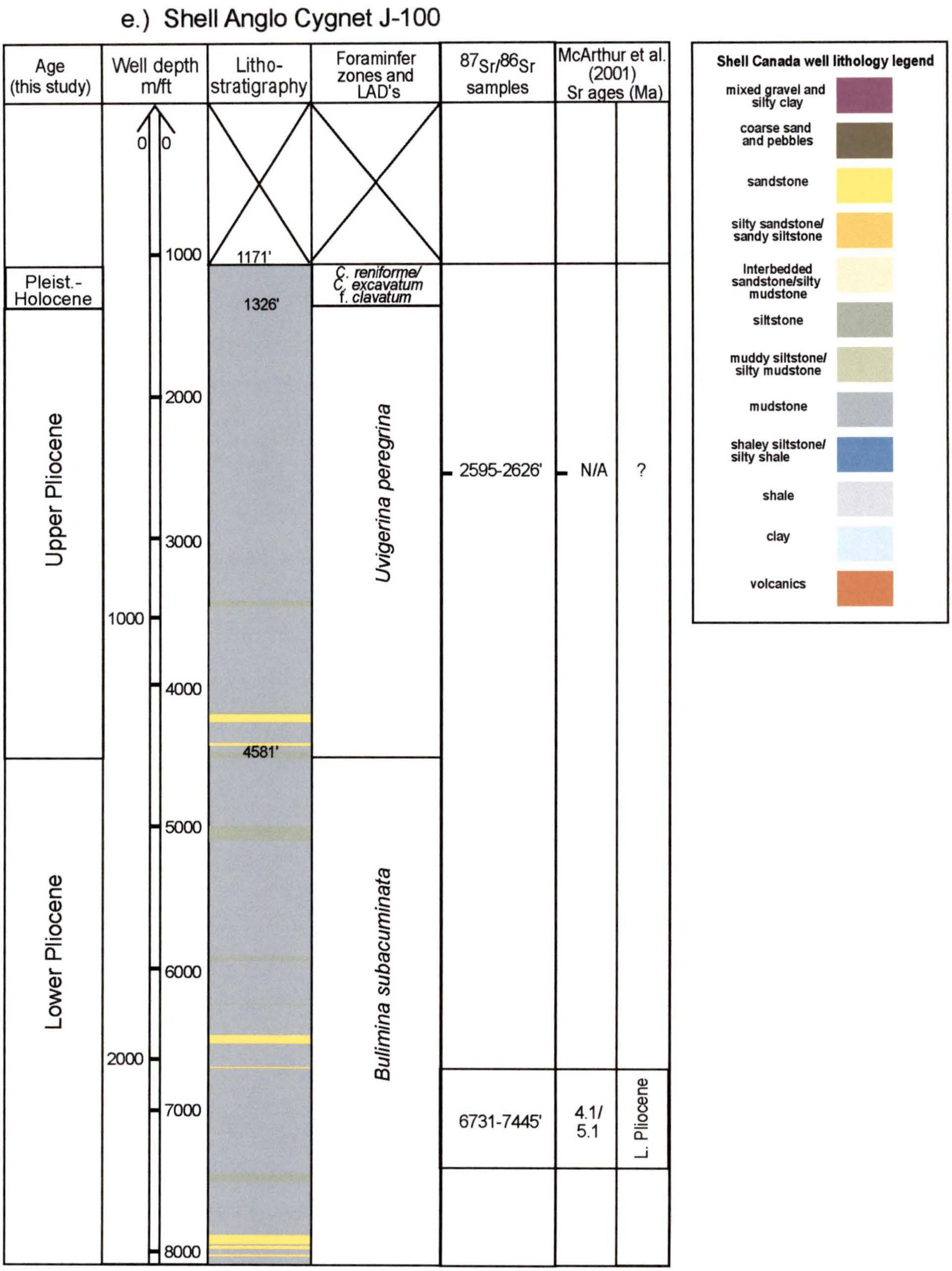


Figure 4.2e. Diagram showing the Tofino Basin foraminiferal biostratigraphy and the Sr isotope ages for the Shell Cygnet J-100. A lower Pliocene Sr age for the lower part of the well complements the biostratigraphic age.

4.5. Summary and conclusions

Sr isotope analyses of 31 Vancouver Island outcrop (Carmanah Group) and 44 offshore Tofino Basin samples from the five Shell Canada wells (Cygnet J-100, Prometheus H-68, Zeus D-14, Zeus I-65 and Pluto I-87), yielded Sr ages ranging from 1.3 Ma (Pleistocene) to 37. 3 (late Eocene). Overall results support a consistent increase in the $^{87}Sr/^{86}Sr$ during the Cenozoic. For the onshore samples Sr isotope ages resulted in anomalously low Jurassic/Cretaceous ages for foraminifers and high Pleistocene ages for mollusc shells. Strontium isotope stratigraphy was unresolved for the onshore samples and suggests possible contamination and/or overprinting by pore-waters from Jurassic and Pleistocene sediments.

For the offshore samples the overall Sr isotope age results were consistent with the newly developed foraminiferal biostratigraphy and provides a better stratigraphic resolution of the Tofino Basin Cenozoic sequence. Strontium isotope age reversals indicate possible faulting within the late Eocene through early Pliocene strata of the structurally complex Tofino Basin. In summary, Sr isotope stratigraphy combined with foraminifer biostratigraphy was an appropriate tool for unraveling the stratigraphic framework of the offshore Tofino Basin.

This study demonstrates that biostratigraphic studies alone, may be insufficient for high-resolution age calibrations, primarily due to limitations of long-ranging species, poor faunal preservation, mixed/transported units, stratigraphic breaks and overall structural complexities. Mixed, transported, reworked, and wall-spalling of the wells requires serious consideration in future studies. However, good biostratigraphic and petrographic control in addition to careful selection of well preserved samples is significant for continuing geochemical studies.

In future Sr isotope studies, more intensive sampling for Sr isotope analyses within continuous sections that have biostratigraphic control should be pursued, to provide internally consistent data for the effective resolution of age and structure. With an improved and integrated biostratigraphy, Sr isotope analyses offers a powerful tool to help resolve basin architecture and to define a high-resolution stratigraphy and correlations with other Pacific Coast basins. Additionally, as a proxy for paleoceanography, paleoecology and paleoclimates, strontium isotope analyses can also provide a greater understanding of the geological factors that may have influenced taxonomic diversity, radiations, and extinctions in this region.

5. CONCLUSIONS AND FUTURE PERSPECTIVES

The complex geological history of the offshore Tofino Basin (TB) is partly reflected by the thick (~3600 m) and relatively complete Cenozoic clastic marine sequence. The Shell well data, logs, cuttings and foraminifer microfossil samples from the six Shell Canada wells drilled in the 1960s allowed a re-examination of the TB stratigraphic framework and improved chronostratigraphic development through: 1) new and/or revised regional biostratigraphic data of Cenozoic foraminifers; 2) new complementary Sr isotope data; and, from 3) foraminiferal biofacies and interpreted paleobathymetries.

The diverse and ecologically distinct Tofino Basin foraminifers studied taxonomically include 141 benthic and 18 planktic species. In this study, no new species were identified, and most taxa represent common Pacific Coast (California to Gulf of Alaska) taxa. Some common and rare long-ranging species (e.g. *Cibicides lobatulus*, *Nonionellina labradorica*) have been recognized in modern shelf environments in other North American sediments including the Arctic and Atlantic coasts of Canada. Several zonal species (e.g. *Baggina washingtonensis*, *Bolivina wissleri*, *Rectuvigerina branneri*, *Uvigerina hootsi*) show biogeographical ranges that are restricted (as so far known) to the Pacific Coast. The detailed taxonomic work undertaken by this study provides a source of reference for future planned taxonomic work in regional basins.

A newly developed Tofino Basin biostratigraphy is established with eleven new and/or redefined benthic foraminiferal interval zones determined from last appearance datums (LADs) in the Shell wells. These are the *Cassidulina galvanensis*, *Turrilina galvanensis*, *Rectuvigerina branneri*, *Baggina washingtonensis*, *Bolivina wissleri*, *Uvigerina hootsi*, *Bulimina subacuminata*, *Elphidiella hannai*, *Uvigerina peregrina* and *Cassidulina reniforme*/*Cribroelphidium excavatum* f. *clavatum* zones. These foraminiferal zones allow: 1) intrabasinal correlation of the six Tofino Basin Shell wells; 2) correlation of the offshore upper Eocene/Oligocene strata with the Eocene and Oligocene sequences of the Carmanah Group, Vancouver Island; and, 3) correlation with other North American Cenozoic sequences; correlation of upper Miocene to Holocene Tofino Basin strata to planktic zones and allows approximate correlations to the Berggren et al. (1995) global time-scale.

Foraminifer biofacies and their interpreted paleobathymetries range from the inner neritic (0-50 m) to the lower bathyal (>2000 m). Tofino Basin paleoenvironmental reconstructions through this study indicate mainly outer shelf to deep water paleoenvironments from the early Oligocene to the early Pliocene, with the deepest depositional environments during the early Miocene and early Pliocene (in part of the basin). Neritic biofacies predominate in Pliocene-Pleistocene strata.

The Sr isotope study provides improved resolution to the biostratigraphy in the Tofino Basin. It demonstrates the successful use of offshore TB foraminifers for Sr isotope studies, provided there is: 1) good biostratigraphic age control; and, 2) sampling of whole, diagenetically unaltered tests. From analysis of 44 offshore samples, the overall conclusions support the presence of: 1) upper Eocene (37.3) to Pleistocene (1.3 Ma) sequences and 2) possible faulting of Oligocene and Miocene strata. Unfortunately, the overall Sr isotope results from another 31 samples from the onshore Carmanah Group cannot resolve previous stratigraphic age disputes or provide Sr age correlations for the onshore Carmanah Group. Possible contamination and/or overprinting of a majority of these samples by pore-fluids from Jurassic/Cretaceous and/or Pleistocene strata was a controlling factor. No Jurassic or Cretaceous foraminifers were analyzed.

The present Cenozoic foraminiferal biostratigraphic and Sr isotope studies, provide support to interpretations of episodic oscillations in sea-level, climatic cooling, facies changes, uplift, stratigraphic breaks and structural complexities within the Tofino Basin. These changes are linked to major global events such as the Eocene/Oligocene climatic cooling, Miocene transgressions and climatic warmings and the Pliocene-Pleistocene regressive phase and cooling.

This study lays the groundwork for future west coast Cenozoic foraminifer (microfaunal) biostratigraphic studies. Higher resolution sampling of in-place sequences may produce further refinements to the stratigraphic ages presented herein. Foraminifer Sr isotope analysis gives both a proxy for paleoceanography and improved biostratigraphic resolution. It also provides preliminary data for future geological investigations and interpretations in this region.

6. SYSTEMATIC PALEONTOLOGY

6.1. Introduction

The Tofino Basin foraminifers described and illustrated in this section include agglutinated, calcareous imperforate, calcareous perforate and planktic species. Most taxa are common to the Pacific Coast waters with a few rare species present. Paleoenvironments range from the inner neritic to lower bathyal. Cenozoic foraminifera classification and terminology mainly follows the Treatise on Invertebrate Paleontology, Part C-Protista (Loeblich and Tappan 1964), and modifications of families and genera presented in Loeblich and Tappan (1987). Identifications of foraminifer specimens were made through extensive literature review, comparisons with Cameron (1980) Vancouver Island onshore assemblage slides, and biotypes deposited at the Geology and Paleontology Division Collection of the Thomas Burke Memorial Museum, University of Washington, Seattle, Washington and the Paleontology Museum, University of California Berkeley.

Identifications and digital SEM illustrations are provided for 141 benthic species and 18 planktic species. Taxa are listed alphabetically and assigned to the appropriate family. The synonomy lists are kept to a minimum where possible, because species listed herein have been previously described elsewhere. The reader is referred to the most recent and complete publication, in which all the references listed are in agreement with the present taxonomic assignment. The synonomy lists include the original species description and other significant (useful accessible descriptions and figures) and/or most recent reference(s) that can be used to define or clarify the species.

Full systematic paleontology format is followed for most species including complete description, taxonomic remarks and where known, the stratigraphic age ranges of species. Taxonomic remarks may include general discussion on evolution, paleoecology (and/or geographic distribution), and comparisons with other closely related taxa. The format for taxonomy and synonymies follows the style used by the Journal of Foraminiferal Research.

The taxonomic section and the plates are prepared to present species included in the above four categories: arenaceous families, calcareous imperforate families, calcareous perforate families and planktic families. Taxa are listed alphabetically, under the assigned family and genus names. Specimens studied and identified in this thesis are archived in the Geological Survey of Canada's (GSC), National Type Collections, Ottawa. All foraminifers were photographed at the University of Victoria, using a Hitachi S-3500N scanning electron microscope.

In the following section, uncertainty in assignment will be indicated by a question mark. Latin terms and abbreviations commonly used include: aff. (*affinis*), which indicates that a taxon has affinity (relation) with a known taxon, but is not identical to it; cf. (*confer*), indicates a taxon is comparable or identification is provisional; f (*forma*) refers to form and is a morphological term; sp. (*species*) is used when specific identification is not possible; and spp. (*species*) indicates species pleural (Schenk and McMasters, 1956; Bengston, 1988).

Kingdom PROTISTA
Phylum PROTOZOA
Subphylum SARCODINA Schmarda, 1871
Class RHIZOPODA von Siebold, 1845
Order FORAMINIFERIDA Eichwald, 1830

6.2. Agglutinated families

Family Ammodiscidae Reus, 1862
Subfamily Ammodiscidae Reuss, 1862
Genus *Ammodiscus* Reuss, 1862
Ammodiscus incertus (d'Orbigny, 1839)
Plate 1, figures 1-2

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

Spirillina arenacea WILLIAMSON, 1858, p. 93, pl. 7, fig. 203.

Ammodiscus incertus (d'Orbigny), BRADY, 1884, p. 330, pl. 38, figs. 1-3; RAU, 1951, p. 428, pl. 63, fig. 1; McDOUGALL, 1980, p. 33, pl. 1, figs. 4-5; FINGER, 1992, p. 67, pl. 1, figs. 2-5.

Ammodiscus pacificus Cushman and Valentine, CUSHMAN and McCULLOCH, 1939, p. 69, pl. 5, figs. 1-2.

Ammodiscus arenaceous (Williamson), TODD and LOW, 1967, p. A14, pl. 2, fig. 12.

Description.—Test large, planispiral, coiled, four to five whorls; chambers tubular and slightly inflated, proloculum nearly spherical, slightly raised; wall finely agglutinated, smooth; aperture a circular opening, formed at open end of tube.

Remarks.—This rare species with its large test, similar shape, chamber development and large raised proloculus, may be conspecific with *A. arenaceous* and *A. pacificus*. Also, *A. incertus* have been recorded from the Twin River Group (Hoko, Pysht and Lyre formations) of Washington (McDougall, 1972) and Carmanah Group (Hesquiat Formation), Vancouver Island (Cameron, 1980). It is characteristic of the lower middle bathyal biofacies (Ingle, 1980) and represents agglutinated foram morphogroup B (tubular-coiled-flattened; Jones and Charnock, 1985; Mancin, 2001)

Age range.—Eocene to Holocene.

Subfamily Ammovertellininae Saidova, 1981

Genus *Glomospira* Rzehak, 1885

Glomospira gordialis (Jones and Parker, 1860)

Plate 1, figures 3-4

Trochammina squamata Jones and Parker var. *gordialis* JONES and PARKER, 1860, p. 304.

Glomospira gordialis (Jones and Parker), SCHRÖDER-ADAMS and McNEIL, 1994, p. 36, pl. 3, figs. 10-12.

Description.—Test small, discoidal, streptospiral, slightly compressed, periphery rounded; chambers slightly tubular, second streptospirally coiled, looped and twisting, slightly inflated; sutures distinct depressed, wall finely arenaceous, smooth; aperture small opening at end of tube, fairly indistinct.

Remarks.—Specimens placed in *G. gordialis* are distinguished by their discoidal test where tubular chambers are streptospirally enrolled, into ball-like forms. It is close to *G. irregularis* but differs slightly by irregular coiling of the second chamber. It is characteristic of the lower middle bathyal biofacies (Ingle, 1980) and represents morphogroup B (Jones and Charnock, 1985; Mancin, 2001).

Age range.—Oligocene to Holocene.

Family Astrorhizidae Brady, 1881

Genus *Rhabdammina* M. Sars, 1869

Rhabdammina abyssorum M. Sars, 1869

Plate 1, figures 5-6

Rhabdammina abyssorum M. SARS, 1869, p. 266, pl. 21, figs. 1-3, 6; CUSHMAN and McCULLOCH, 1939, p. 31, pl. 1, figs. 2-3; TODD and LOW, 1967, p. A12, pl. 1, fig. 1; VILKS, 1969, p. 43, pl. 1, fig. 2.

Description.—Test free, unilocular, consists of usually two to four elongate tubule or branch-like arms that radiate from a central chamber, usually triradiate, walls medium to coarsely agglutinated, sand-grains held together by ferruginous cement.

Remarks.—Specimens are usually fragmentary and can be misidentified as *Hyperammina* sp., which is also elongate but does not possess branching arms. *Rhabdammina abyssorum* is characteristic of the lower middly bathyal to lower bathyal biofacies (Ingle, 1980) and represents morphogroup A (unilocular, tubular or branching; Jones and Charnock, 1985; Mancin, 2001).

Age range.—Oligocene to Holocene.

Family Bathysiphonidae Avnimelech, 1952

Genus *Bathysiphon* M. Sars, 1872

Bathysiphon eocenica Cushman and G.D. Hanna, 1927

Plate 1, figure 7

Bathysiphon eocenica CUSHMAN and G.D. HANNA, 1927, p. 210, pl. 13, figs. 2-3; CUSHMAN and McMASTERS, 1936, p. 508, pl. 74, fig. 1; CUSHMAN and SIEGFUS, 1942, p. 400, pl. 15, fig. 1; SMITH, 1957, p. 148, pl. 17, fig. 1; McDOUGALL, 1972, p.33, pl. 1, fig. 1; McDOUGALL, 1980, p. 33, pl. 1, fig. 1.

Rhabdammina robusta (Grzybowski), SCHRÖDER-ADAMS and McNEIL, 1994, p. 33, pl. 1, fig. 4.

Description.—Test free, unilocular, large (up to one mm), elongate, cylindrical and slightly compressed, width nearly half the length; walls smooth (unpolished), thick and opaque, finely agglutinated.

Remarks.—In general size, shape and appearance, specimens agree with *B. eocenica* species illustrated and described in the above literature. It is comparatively larger, more compressed and not as smooth walled as *B. sanctaecrucis* Cushman and Kleinpell. It is characteristic of the lower bathyal biofacies (Ingle, 1980).

Age range.—Eocene to Oligocene (?).

Bathysiphon sp. cf. *B. nodosariaformis* Subbotina, 1950

Plate 1, figure 8

cf. *Bathysiphon nodosariaformis* SUBBOTINA, 1950, p. 67, pl. 1, fig. 4; SCHRÖDER-ADAMS and McNEIL, 1994, p. 33, pl. 1, figs. 1-2, pl. 2, figs. 5-6.

Description.—Test free, elongate, cylindrical and slightly compressed (flat); walls smooth, and thin, finely agglutinated, with faint annular constrictions.

Remarks.—Fragments were usually found and variations occur in the diameter of the test. Specimen recovered are close to *B. nodosariformis* by their thin and fine-grained, slightly polished walls that contains a large amount of hard siliceous cement. It is characteristic of the lower bathyal biofacies (Ingel, 1980).

Age range.—Late Eocene to late Miocene (Schröder-Adams and McNeil, 1994).

Genus *Nothia* Plaumann, 1964

Nothia excelsa? (Grzybowski, 1898)

Plate 1, figures 9-10

?*Dendrophyra excelsa* GRZYBOWSKI, 1898, p. 272, pl. 10, figs. 1-4.

?*Nothia excelsa* SCHRÖDER-ADAMS and McNEIL, 1994, p. 33, pl. 2, figs. 1-4.

Description.—Test elongate, slender, slightly angled to straight, highly compressed; wall coarsely agglutinated, roughened.

Remarks.—These extremely fragile specimens are recorded in low numbers in the Tofino Basin. They differ from the type material by being slightly more compressed and distinctly curved in the middle of the test. However, variations occur that show irregularity in curvature. It is characteristic of the continental slope (biofacies 5; Schröder-Adams and McNeil, 1994).

Age range.—Oligocene to middle Miocene (Schröder-Adams and McNeil, 1994).

Family Cyclamminidae Marie, 1941

Genus *Cyclammina* Brady, 1879

Cyclammina cancellata H.B. Brady, 1876

Plate 1, figure 11

Cyclammina cancellata H.B. BRADY, 1876, p. 214; CUSHMAN, 1910, p. 110, pl. 1, figs. 110-111; CUSHMAN and LAIMING, 1931, p. 94, pl. 9, fig. 10; ASANO, 1951, p. 5, pt. 10, figs. 14-15; PHLEGER and PHLEGER, 1951, p. 3, pl. 1, fig. 15; BARKER, 1960, p. 76, pl. 37, figs. 8-16; SMITH, 1973, p. 14, pl. 1, fig. 18.

Description.—Test large, planispiral, compressed, periphery broadly rounded, slightly depressed in umbilical region; chambers numerous, 10-15 in final whorl; sutures distinct, slightly depressed slightly sigmoid; walls smooth, finely arenaceous; aperture an elongate concave slit at base of apertural face, supplementary pores usually are visible on apertural face.

Remarks.—This species differs from *C. pacifica* by its larger more compressed test and numerous chambers. It is close to *C. japonica* Asano (1951), but differs in having slightly fewer chambers. Supplementary pores on the apertural face were not observed due to poor preservation, or they may not be developed. It is characteristic of the shelf and marginal marine biofacies (morphogroup B3; Brock, 1999), but has also been recorded from the lower middle bathyal biofacies (Ingle, 1980).

Age range.—Miocene to Holocene.

Cyclammina incisa (Stache, 1864)

Plate 1, figures 12-15

Haplophragmoides incisum STACHE, 1865, p. 165, pl. 21, fig. 1.

Cyclammina incisa CUSHMAN and LAIMING, 1931, p. 93, pl. 9, fig. 6; CUSHMAN and BARBAT, 1932, p. 32, pl. 5, fig. 2; ASANO, 1951, p. 6, pt. 10, figs. 18-19; FINGER, 1992, p. 67, pl. 1, figs. 17-18.

Description.—Test large, compressed, umbilicate; chambers numerous, eight to 10 in final whorl, irregular in size; sutures distinct, straight to slightly curved, incised and depressed; wall finely arenaceous, smooth; aperture, arched slit at base of apertural face.

Remarks.—*C. incisa* is close to *C. cancellata*, however, *C. incisa* is slightly smaller with a fewer number of chambers. Both have highly compressed tests. The final chamber is slightly pointed or narrow at the apertural end and projects upwards. It is characteristic of the shelf and marginal marine biofacies (morphogroup B3; Brock, 1999), but has also been recorded from the lower middle bathyal biofacies (Ingle, 1980).

Age range.—Eocene to Holocene.

Cyclammina pacifica Beck, 1943

Plate 1, figures 16-18

Cyclammina pacifica BECK, 1943, p. 591, pl. 98, figs. 2-3; DETLING, 1946, p. 352, pl. 46, fig. 1; CUSHMAN, STEWART and STEWART, 1947, p. 74, pl. 9. figs. 1-2; RAU, 1948, p. 157, pl. 27, figs. 7-8; RAU, 1951, p. 429, pl. 63, fig. 18.

Cyclammina sp. cf. C. pacifica Beck, ASANO, 1951, p. 6, pt. 10, figs. 18-19.

Description.—Test large, planispiral, slightly compressed, broadly rounded periphery; chambers 10-12 in final whorl, slightly inflated and slightly irregular in shape; sutures distinct, depressed, incised; wall finely arenaceous; aperture at base of apertural face, fairly indistinct.

Remarks.—*C. pacifica* is close to *C. incisa*, however, its chambers are slightly inflated, the test is not as compressed, and has a more rounded periphery, and it tends to be slightly smaller in size. It is characteristic of the shelf and marginal marine biofacies (morphogroup B3; Brock, 1999), but has also been recorded from the lower middle bathyal biofacies (Ingle, 1980).

Age range.—Eocene to Pliocene.

Cyclammina tani? Ishizaki, 1941

Plate 1, figure 19

?*Cyclammina tani* ISHIZAKI, 1941, p. 25, pl. 4, figs. 1-5; ASANO, 1951, p. 7, pt. 10, figs. 28-29.

Description.—Test planispiral, large, compressed; chambers numerous, 12 or more in final whorl, periphery rounded; sutures distinct, depressed, distinctly sigmoid; wall smooth, finely arenaceous; aperture at base of apertural face.

Remarks.—*C. tani* was originally described from Eocene and Miocene formations of Taiwan and Japan. It is close to or may be conspecific with *C. simiensis* that Cushman and McMasters (1936) described from the Eocene of California. However, it differs from *C. simiensis* by having more chambers (greater than 10 in the adult), more depressed sigmoid sutures, and non-distinct pore openings on the apertural face. Superficially, *C. tani* also may resemble *C. cancellata*, particularly in the presence of sigmoid sutures and in size and shape of the test. However, the test of the latter is less compressed and the periphery more broadly rounded. It is characteristic of the shelf and marginal marine biofacies (morphogroup B3; Brock, 1999), but has also been recorded from the lower middle bathyal biofacies (Ingle, 1980).

Age range.—Eocene to Holocene.

Genus *Reticulophragmium* Maync, 1955

Reticulophragmium projectus Shröder-Adams and McNeil, 1994

Plate 1, figures 20-21

Reticulophragmium projectus SCHRÖDER-ADAMS and McNEIL, 1994, p. 181, pl. 5, figs. 1-16.

Description.—Test planispiral, rounded periphery and slightly crenulated edge; chambers numerous (nine to 11), slightly inflated and wedge shaped; sutures distinct straight to slightly curved, pinched or deflected forward along peripheral crest; wall finely agglutinated, thick and alveolar; umbilicus slightly depressed; aperture basal, low arch on apertural face.

Remarks.—Specimens are best referred to *R. projectus* described from the Oligocene sequence of the Beaufort-Mackenzie Basin. They match the original descriptions for the species, by the presence of a characteristic forward projecting ridge along the apertural face and sutures that appear to bulge forward at the crest of the periphery. Variations occur in wall composition with mainly smooth agglutinated to siliceous forms that occur in the Tofino Basin. Superficially, this species may resemble *Cyclammina incisa*, however, the sutures are not deflected forward along the peripheral crest as in *R. projectus*. It is characteristic of the deep basinal biofacies (biofacies 3; Schröder-Adams and McNeil, 1994), or the lower bathyal (?) biofacies (Ingle, 1980).

Age range.—Oligocene to Miocene.

Family Eggerelidae Cushman, 1937

Genus *Martinotiella* Cushman, 1933

Martinotiella communis (d'Orbigny), 1846

Plate 1, figure 22

Clavulina communis D'ORBIGNY, 1826, p. 268, pl. 12, figs. 1-2; CUSHMAN STEWART and STEWART, 1930, p. 51, pl. 1, figs. 5,6.

Clavulina patens CUSHMAN and LAIMING, 1931, p. 96, pl. 10, fig. 2.

Martinottiella communis (d'Orbigny), FINGER 1992, p. 68, pl. 1, fig. 26.

Description.—Test elongate, nearly cylindrical, tapering towards basal end; chambers numerous, slightly inflated, early ones, triserial, stout, indistinct and later ones uniserial, slender and distinct; sutures distinct and depressed only in later portion; walls finely arenaceous, smooth; aperture terminal, oval to rounded.

Remarks.—This species has a distinct elongate, slender uniserial shape and chamber arrangement, that separates it from other *Martinotiella* spp. that are generally more robust, stout and with fewer chambers. It is common and abundant in the Pliocene (particularly lower Pliocene) strata of the Tofino Basin. It is characterisitic of the upper middle bathyal biofacies (Ingle, 1980).

Age range.—Miocene to Holocene.

Family Haplophragmoididae Maync, 1952

Genus *Budashevaella* Loeblich and Tappan, 1964

Budashevaella multicamerata (Voloshinova, 1961)

Plate 1, figure 23

Circus multicameratus VOLOSHINOVA, 1961, p. 201, pl. 7, fig. 6; pl. 8, figs. 1, 6.

Budashevaella multicamerata (Voloshinova), LOBLICH and TAPPAN, 1964, p. C262, figs. 2-3; SCHRÖDER-ADAMS and McNEIL, 1994, p. 40, pl. 6, fig. 4.

Description.—Test large, evolute, streptospirally enrolled, compressed, periphery rounded and slightly lobulate, deeply umbilicate, slightly asymmetrical; chambers numerous, 10-15 in final whorl, inflated; sutures distinct, depressed; wall calcareous medium to fine grained, tightly cemented, smooth; aperture interomarginal, narrow slit with a slight lip.

Remarks.—This species is similar to *Recurvoides contortus*, but differs by being larger with more sutures. It also differs from *R. torquis* by having more distinct and numerous sutures and a slight lip developed on the aperture. It is characteristic of the prodelta/muddy shelf (biofacies 2; Schröder-Adams and McNeil, 1994) or the inner neritic biofacies (Ingle, 1980).

Age range.—Late Eocene to Oligocene? (Schröder-Adams and McNeil, 1994).

Genus *Cribrostomoides* Cushman, 1910

Cribrostomoides veleronis (Cushman and McCulloch, 1939)

Plate 1, figure 24

Haplophragmoides veleronis CUSHMAN and McCULLOCH, 1939, p. 82, pl. 7, fig. 2.
Haplophragmoides scitulum CUSHMAN and McCULLOCH, 1939, p. 78, pl. 6, fig. 4.
Alveophragmium veleronis (Cushman and McCulloch), UCHIO 1960, pl. 2, fig. 1.
Cribrostomoides veleronis (Cushman and McCulloch), TODD and LOW, 1967, p. A15, pl. 1, fig. 22.

Description.—Test planispiral, evolute, large, deeply and broadly umbilicate, periphery broadly rounded; chambers numerous 10-12, distinct, slightly inflated, increasing in size; sutures distinct; wall smooth, finely arenaceous; aperture an elongate, slightly curved slit at base of last chamber, slight rim or lip developed.

Remarks.—*C. veleronis* is similar in size, shape and wall composition to *C. scitulus*. It differs by being deeply umbilicate, not completely involute, and less compact. The aperture of *C. scitulus* has a distinct lip or rim around it, while only a slight lip is observed in *C. veleronis*. In both *C. scitulus* and *C. veleronis*, the periphery of the test is broadly rounded, however in the latter species the test appears to be flattened. *Haplophragmoides scitulum* Brady, illustrated and described by Cushman and McCulloch (1939), is probably conspecific to *C. veleronis*. It is characteristic of the mudline biofacies (Lagoe et al., 1994) or the inner to outer neritic biofacies (Ingle, 1980).

Age range.—Pliocene (?) to Holocene.

Genus *Haplophragmoides* Cushman, 1910

Haplophragmoides carinatus Cushman and Renz, 1941

Plate 2, figures 1-4

Haplophragmoides carinatus CUSHMAN and RENZ, 1941, p. 2, pl. 1, fig. 1; VOLOSHINOVA and RENZ, 1961, p. 187, pl. 2, fig. 9-11; pl. 3, figs. 16,18; SCHRÖDER-ADAMS and McNEIL, 1994, p. 38, pl. 4, figs. 9-13.

Description.—Test small to medium size, planispiral involute, umbilicate, periphery carinate and slightly lobulate, slightly compressed; chambers numerous (eight to 10 in final whorl), increasing gradually in size as added; sutures distinct, depressed, slightly curved; wall finely arenaceous, smooth; aperture small, low opening on face of final chamber.

Remarks.—*Haplophragmoides carinatus* is distinguished by its highly carinate and slightly lobulate test. The test is smooth and finely arenaceous, often showing a degree of silicification. Although much smaller and less compressed, this species slightly resembles *Cyclammina samanica*, which also has a distinct and broad keel. It is characteristic of the prodelta/muddy shelf (biofacies 2; Schröder-Adams and McNeil, 1994) or inner neritic biofacies (Ingle, 1980).

Age range.—Eocene to late Miocene (?) (Schröder-Adams and McNeil, 1994).

Haplophragmoides sp. cf. H. columbiense Cushman, 1925

Plate 2, figures 5-6

cf. *Haplophragmoides columbiense* CUSHMAN, 1925, p. 39, pl. 6, fig. 2.

Description.—Test small, compressed, trochospiral, slightly umbilicate, periphery rounded; chambers distinct, few six to eight, slightly inflated, increasing gradually in size as added; sutures distinct, slightly depressed, slightly curved; wall coarsely arenaceous, few angular fragments; aperture an elongate slit near base of last formed chamber.

Remarks.—Based on the above characters, these specimens are close to or conspecific with *H. columbiense*. However very few specimens are available for comparative purposes and therefore only a close relation can be inferred. It may be close to *H. hancocki*, where both have chambers that become evolute and slightly umbilicate, but it differs in being larger and less compressed. It is characteristic of the inner neritic biofacies (Ingle, 1980).

Age range.—Holocene.

Genus *Recurvoides* Earland, 1934

Recurvoides contortus Earland, 1934

Plate 2, figure 7

Recurvoides contortus EARLAND, 1934, p. 91, pl. 10, figs.7-19; 1936, p. 35, pl. 1, figs. 20-22.; TODD and LOW, 1967, p. A16, pl. 1, fig. 29; SCHRÖDER-ADAMS and McNEIL, 1994, p. 40, pl. 6, figs. 7-8.

Haplophragmoides sp. cf. H. emaciatum (Brady), ASANO, 1951, p. 3, pt. 10, fig. 3.

Description.—Test large streptospiral, evolute, umbilical bulge on one side and slightly to deeply excavated on other, periphery broadly rounded and slightly flattened; chambers distinct, numerous, 10-13 in final whorl; sutures distinct, deeply depressed; wall smooth, fine to medium/coarsely arenaceous; aperture interomarginal, rimmed.

Remarks.—This species differs from *R. torquis* by its larger size and deeply sutured streptospiral test. There are some similarities between *R. contortus* and *Cribrostomoides veleronis*. The original *Haplophragmoides veleronis* Cushman and McCulloch (1939) may be conspecific or close to *R. contortus*, as both are evolute, with slight overlapping of the final coil, and both have numerous distinct chambers and distinct sutures. The test of *R. contortus* is commonly deformed in the Tofino Basin samples. It is characteristic of the deep basinal (biofacies 3; Schröder-Adams and McNeil, 1994), or the lower middle to lower bathyal biofacies (Ingle, 1980).

Age range.—Oligocene to Holocene.

Recurvoides sp. cf. *R. torquis* Schröder-Adams and McNeil, 1994

Plate 2, figure 8

cf. *Recurvoides torquis* SCHRÖDER-ADAMS and McNEIL, 1994, p. 181, pl. 4, figs. 1-17.

Description.—Test large, slightly streptospiral and planispiral, subglobular slightly compressed, periphery broadly rounded; chambers numerous, increasing in size, final slightly subrectangular; sutures indistinct; wall finely arenaceous; aperture, a subaerial slit.

Remarks.—Specimens are rare, poorly preserved and slightly deforemed in the Tofino Basin. Chambers and sutures are fairly indistinct due to preservation. Test shape and coiling of the chambers place it close to *R. torquis*. This closely-coiled form is similar to *Cribrostomoides scitulus* (Brady) however, a deep umblicus is absent. This species is close to *Recurvoides turbinatum* Brady, which is characterized by a streptospirally coiled test and elongate areal aperture set at an angle (Todd and Low, 1967). It is characteristic of the deep basinal (biofacies 3; Schröder-Adams and McNeil, 1994), or the lower middle to lower bathyal biofacies (Ingle, 1980).

Age range.—Late Eocene to Miocene (Schröder-Adams and McNeil, 1994).

Family Reophacidae Cushman, 1927

Genus *Hormosina* Brady, 1879

Hormosina sp. cf. *H. pilulifer* (Brady, 1884)

Plate 2, figure 10

cf. *Reophax pilulifer* BRADY, 1884, p. 292, pl. 30 figs. 18-20.

cf. *Hormosina pilulifer* (Brady), CHARNOCK and JONES, 1990, p. 162, pl. 4, fig. 5; pl. 15, fig. 7; SCHRÖDER-ADAMS and McNEIL, 1994, p. 37, pl. 4, fig. 3.

Description.—Test large, uniserial, slightly angled; chambers numerous, globose, increasing in size rapidly as added, tapered towards base; sutures distinct, depressed; wall coarsely agglutinated; aperture small, central on apex of final chamber, produced on short mammillate protuberance.

Remarks.—This species is composed of coarse sand grains and characteristically has large uniserial, globular chambers that increase in size rapidly as added, and are compactly built without a tubular neck. Only one specimen was recovered from the Shell Canada wells. It is characteristic of the continental slope (biofacies 5; Schröder-Adams and McNeil, 1994).

Age range.—Oligocene to late Miocene (Schröder-Adams and McNeil, 1994).

Genus *Reophax* Montfort, 1808

Reophax nodulosus Brady, 1879

Plate 2, figure 9

Reophax nodulosus BRADY, 1879, p. 52, pl. 4, figs. 7-8; SCHRÖDER-ADAMS and McNEIL, 1994, p. 37, pl. 4, fig. 4.

Description.—Test elongate, uniserial, slender, straight to slightly arcuate; chambers distinct, numerous, rounded, inflated, increasing in size gradually as added, slightly tapering; sutures distinct, depressed; wall coarsely arenaceous; aperture terminal, fairly indistinct.

Remarks.—Specimens are distinguished by their elongate tests, and uniserial, roughly textured globular chambers. Only one specimen was recovered from Oligocene strata of the Tofino Basin. It is characteristic of the continental slope (biofacies 5; Schröder-Adams and McNeil, 1994).

Age range.—Oligocene to Holocene.

Family Textulariidae Ehrenberg, 1838

Genus *Textularia* Defrance, 1824

Textularia sp. A

Plate 2, figure 11

Description.—Test elongate, biserial, small, compressed, broad and slightly triangular, tapered towards base and broad at apertural end, periphery rounded; chambers numerous (six to eight pairs), low, slightly inflated, more broad than high; sutures distinct and slightly curved, slightly depressed; wall smooth, coarsely arenaceous, composed of grayish/white crystalline sand grains; aperture a low broad opening on inner margin of final chamber.

Remarks.—Test appears slightly distorted (twisted) and the apertural region is difficult to observe due to its preservation. It may be close to *Textularia lancea* Lalicker and McCulloch in test shape and chamber arrangement. However, poor preservation and rarity of this species precludes a species designation. It is characteristic of the inner neritic (Ingel, 1980) or marginal marine biofacies (morphogroup C2; Brock, 1999).

Age range.—Pliocene(?) to Holocene.

Family Valvulinidae Berthelin, 1880

Genus *Dorothia* Plummer, 1931

Dorothia sp. aff. *D. bradyana* Cushman 1937

Plate 2, figure 12

aff. *Dorothia bradyana* CUSHMAN, 1937, p. 99, pl. 11, fig. 6.

aff. *Dorothia sp. aff. D. bradyana* TODD and LOW, 1967, p. A17, pl. 2, figs. 1-2.

Description.—Test large, compressed, slightly elongate; biserial, periphery subacute, slightly lobulate, flaring; chambers distinct, broad and inflated, increasing in size, eight to ten pairs; sutures distinct, depressed, incised, straight to slightly curved; wall smooth, finely arenaceous; aperture, near base of inner margin of last formed chamber, fairly indistinct.

Remarks.—This species has affinities with *D. bradyana*. They both share elongate stout tests with broad chambers. However, its test is slightly larger than *D. bradyana*, and its chambers are more inflated. It is characteristic of the outer neritic biofacies (Ingle, 1980).

Age range.—Late Miocene to Holocene.

Genus *Karreriella* Cushman, 1933

Karreriella baccata (Schwager, 1866)

Plate 2, figures 13-14

Gaudryina baccata SCHWAGER, 1866, p. 2, pl. 4, fig. 12.

Karreriella baccata (Schwager), CUSHMAN, 1937, p. 133, pl. 15, figs. 20-24; TODD and LOW, 1967, p. A17, pl. 2, fig. 10.

Karreriella baccata (Schwager) var. *alaskaensis* CUSHMAN and TODD, 1947, p. 61, pl. 14, figs. 10-11.

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

cf. *Karreriella bradyi* (Cushman), PATTERSON, BURBIDGE and LUTERNAUER, 1998, p. 5, pl. 1, figs. 4-5.

Description.—Test large, elongate, biserial, broadly triangular in side view, width strongly tapering towards base, periphery broadly rounded in upper portion, slightly compressed in lower portion; chambers distinct, numerous 10-12, strongly inflated and enlarged in upper portion; sutures straight and oblique, indistinct to slightly depressed near base, deeply depressed in upper portion; wall smooth finely to coarsely arenaceous; aperture, distinct, elongate, broad, low, lipped, slightly curved slit at base of last formed chamber.

Remarks.—This distinct species is characterized by its smoothly finished (fine grained sand), club-shaped, biserial and tapering test, rapidly increasing chambers, and elongate slit-like and lipped aperture. It is close to *K. bradyi*, but differs by having a test that is more elongate (larger), less short and stout and less sharply tapered at the base. It is characteristic of the outer neritic biofacies (Ingle, 1980).

Age range.—Pliocene to Holocene.

Family Verneuilinidae Cushman, 1927

Genus *Gaudryina* d'Orbigny, 1839

Gaudryina subrotunda Schwager, 1866

Plate 2, figure 15

Gaudryina subrotunda SCHWAGER, 1866, p. 198, pl. 4, fig. 9; CUSHMAN and BARBAT, 1932, p. 34, pl. 5, figs. 8-9.

Description.—Test elongate, early portion triserial, triangular, slightly tapered, later portion biserial, subcylindrical, periphery lobulate; chambers distinct in later portion, slightly inflated, low, six to eight pairs; sutures distinct, slightly depressed in later portion, nearly straight; wall smooth, finely arenaceous; aperture a low arch at base of inner margin of last chamber.

Remarks.—Specimens are placed in *G. subrotunda*, based on the characteristic tapered triserial to elongated and slender biserial test. Also, it may be close to *G. arenaria* Galloway and Wissler, a highly variable species that is widely distributed along the eastern Pacific (Cushman and McCulloch, 1939). *Gaudryina subrotunda* differs from *G. arenaria* by having a less angled test that has a slightly rounded periphery. It is characteristic of the outer neritic biofacies.

Age range.—Pliocene to Holocene.

6.3. Calcareous imperforate families

Family Cornuspiridae Schultze, 1854

Genus *Cornuspira* Schultze, 1854

Cornuspira involvens (Reuss, 1850)

Plate 2, figures 16-17

Operculina involvens REUSS, 1850, p. 370, pl. 46.

Cornuspira involvens LOEBLICH and TAPPAN, 1994, p. 36, pl. 56, figs. 14-15; HAYWARD, GRENFELL, REID and HAYWARD, 1999, p. 94, pl. 3, fig. 16.

Description.—Test small, circular, planispiral, discoidal, compressed, periphery rounded, four to six whorls; chambers tubular, slightly inflated; sutures distinct, slightly depressed; wall calcareous, translucent, smooth, imperforate aperture terminal at open end of tube.

Remarks.—This rare species is smaller than other known *Ammodiscus* spp. and is distinguished by three planispiral whorls in the adult form. Specimens are rare in the Tofino Basin. It is characteristic of the inner to outer neritic biofacies (Ingle, 1980).

Age range.—Pliocene to Holocene.

Family Miliolidae d'Orbigny, 1846

Genus *Miliolinella* Wiesner, 1931

Miliolinella sp. cf. *M. heligmateira* Loeblich and Tappan, 1994

Plate 2, figure 18

cf. *Miliolinella heligmateira* LOEBLICH and TAPPAN, 1994, p. 51, pl. 84, figs. 16-18; pl. 89?, figs. 12-14?.

Description.—Test large, pseudotriloculine, ovate, periphery broadly rounded; chambers rounded, strongly inflated, three visible in final whorl; sutures distinct, depressed; walls smooth, porcelaneous imperforate; aperture terminal, flap-like and thickened.

Remarks.—A single specimen was recovered from Shell Anglo Zeus I-65 (3620'-3630'), with the aperture poorly preserved. However, the distinct, large globular test and inflated pseudotriloculine chambers (in a quinqueloculine arrangement) are not unlike the imaged specimen of Loeblich and Tappan (1994). Since the characteristics of the aperture are distorted or damaged and an apertural tooth was not observed, it is difficult to make conclusions on their second set of images (pl. 89, figs 12-14).

Age range.—Plio-Pleistocene to Holocene.

Genus *Quinqueloculina* d'Orbigny, 1826

Quinqueloculina akneriana d'Orbigny, 1846

Plate 2, figures 19-21

Quinqueloculina akneriana D'ORBIGNY, 1846, p. 290, pl. 18, figs., 16-21; GALLOWAY and WISSLER, 1927, p. 38, pl. 7, fig. 3; TODD and LOW, 1967, p. A18, pl. 2, fig. 22; LAGOE, 1977, p. 119, pl. 1, figs. 8-9; PATTERSON, 1989, p. 239, pl. 10.1, figs. 6, 9; PATTERSON, BURBRIDGE and LUTERNAUER, 1998, p. 6, pl. 27, figs. 3-4.

Quinqueloculina sp. LAGOE, 1977, p.119, pl. 1, fig. 19.

Description.—Test large, ovate and sub-triangular, periphery rounded and tapering, broad in middle and tapering towards either end; chambers distinct, three to four visible in final whorl; sutures distinct; wall porcellaneous imperforate, smooth, highly polished; aperture semi-circular, with a simple plate-like tooth projecting into aperture.

Remarks.—This species can be distinguished from other *Quinqueloculina* spp. by its polished ovate chambers that slightly taper at each end, and large semi-circular aperture containing a simple, tooth that is not bifid. Similar characteristics of the test and aperture suggest a close relationship with *Quinqueloculina auberiana* d'Orbigny, described from the Recent of New Zealand (Hayward et al. 1999). Lagoe (1977) excluded his *Quinqueloculina* sp. A since it lacked the characteristic bifid tooth of that species. He considered it to closely resemble *Q. akneriana*. However, it is considered herein as *Q. akneriana* due to the presence of its simple plate-like apertural tooth. It has been described as possessing a simple tooth-like plate (original description) and also a (thick) bifid tooth by others (Patterson et al., 1998). It is possible that the variations may be due to abrasion and/or fragmentation during preservation. It is characteristic of the inner (to outer?) neritic biofacies (Ingle, 1980).

Age range.—Miocene to Holocene (Todd and Low, 1967).

Quinqueloculina latidentella? Loeblich and Tappan, 1994

Plate 2, figure 22

?*Quinqueloculina latidentella* LOEBLICH and TAPPAN, 1994, p. 49, pl. 80, figs. 10-12.

Description.—Test small, ovate, periphery rounded; chambers quinqueloculine, inflated; sutures distinct, depressed, oblique; walls calcareous imperforate, smooth to slightly irregular (abraded?); aperture terminal, semi-circular, broadly rounded, distinct flaring apertural lip, broad bifid tooth projects into opening.

Remarks.—This species slightly differs from the one described and illustrated by Loeblich and Tappan (1994) by not having branches connecting the bifid tooth to the margin of the aperture. However, since all other characteristics comply, it is possible that these "branches" may have broken off, because the test shows some minor abrasion. As with other *Quinqueloculina* spp., it is probably characteristic of the inner neritic biofacies (Ingle, 1980).

Age range.—Holocene.

Quinqueloculina vandiemeniensis Loeblich and Tappan, 1994

Plate 2, figure 23

?*Quinqueloculina arctica*(Cushman), McDOUGALL, BROUWERS and SMITH, 1986, p. 54, pl. 4, fig. 3.

Quinqueloculina vandiemeniensis LOEBLICH and TAPPAN, 1994, p. 51, pl. 83, figs. 1-3.

aff. ?*Triloculinella hornibrooki* (Vella), HAYWARD, GRENFELL, REID and HAYWARD, 1999, p. 106, pl. 5, figs. 33-35.

Description.—Test small, elongate, quinqueloculine, periphery acute; chambers quinqueloculine, narrow, ovate; sutures distinct, depressed and straight; walls porcellaneous imperforate smooth and highly glossy (shiny); aperture semicircular, narrow, with a short, bifid apertural plate.

Remarks.—The elongate quinqueloculine test, narrow, ovate chamber arrangement, smooth shiny test and semicircular aperture with bifid tooth are similar to that of *Quinqueloculina arctica* and *Triloculinella hornibrooki*. These characteristics suggest some possible affinity of *Q. vandiemeniensis* to *T. hornbrooki*. However, in lateral view, *Q. vandiemeniensis* has a distinct subacute edge to the chambers, while the periphery of *Q. arctica* and *T. hornibrooki* are rounded. As with other *Quinqueloculina* spp., it is probably characteristic of the inner neritic biofacies (Ingle, 1980).

Age range.—Holocene.

Genus *Triloculina* d'Orbigny, 1826

Triloculina sommeri Tinoco, 1955

Plate 2, figure 24

cf. *Quinqueloculina imperialis* HANNA and HANNA, 1924, p. 58, pl. 13, figs. 7-8, 10; BECK, 1943, p. 592, pl. 98, figs. 9-10; McDOUGALL, 1980, p. 37, pl. 5, figs. 11-12

Triloculina sommeri TINOCO, 1955, p. 24, pl. 2, figs. 8-9; LOEBLICH and TAPPAN, 1994, p. 56, pl. 84, figs. 1-12.

Description.—Test large, rotund, width nearly equal to length, broadly rounded periphery, slightly compressed; chambers inflated, only three visible externally; sutures distinct, depressed; wall smooth, imperforate; aperture semicircular, broad, with an elongate bar-like bifid tooth projecting into apertural opening, covering most of opening.

Remarks.—This species resembles *Quinqueloculina imperialis* originally described from the Cowlitz Formation (Eocene) of Washington. Also, it is known from the Oligocene Lincoln Formation of Washington (Cushman and Frizzell, 1943). It is similar to *Q. imperialis* by its large rotund test, inflated chambers, and large semicircular apertural opening with its broad plate-like bifid tooth projecting into and covering most of the opening. It is distinguished from *Q. imperialis* by its triloculine (not quinqueloculine) chambers in which only three are visible externally on both sides of the test and three are seen in aperture view. In the quinqueloculine arrangement, four chambers are visible on one side, three on the other side and five in apertural view. It is probably characteristic of the inner neritic biofacies (Ingle, 1980).

Age range.—Eocene(?) to Holocene.

Genus *Pyrgo* Defrance, 1824

Pyrgo murrhina (Schwager, 1866)

Plate 3, figure 1

Biloculina murrhina SCHWAGER, 1866, p. 203, pl. 4, fig. 15

Pyrgo rotalaria (Loeblich and Tappan) LAGOE, 1977, p. 119, pl. 2, fig. 21; SMITH, 1978, p. 137, pl. 1, fig. 5.

Pyrgo murrhina (Schwager) BERGEN and O'NEIL, 1979, p. 1292, pl. 2, fig. 25; HERMELIN, 1989, p. 36, pl. 2, figs. 12, 15-16; BURKE, BERGER, COULBOURN and

VINCENT, 1993, p. 31, pl. 1, fig. 6; LOBLICH Jr. and TAPPAN, 1994, p. 54, pl. 91, figs. 11-15; DOWSETT, 1995, pl. 1, fig. 2.

Description.—Test large, biloculine, subcircular, periphery moderately carinate; chambers one-half coil in length, inflated; sutures distinct, depressed; wall calcareous, imperforate, porcellaneous; aperture terminal, at end of an ovate tubular neck, with short bifid tooth.

Remarks.—This species is distinguished from *P. rotalaria* Loeblich and Tappan by its slightly elongate (oval) test, sharply defined periphery, and a circular, projecting apertural neck with a large rounded apertural opening containing a short, blunt bifid tooth. *Pyrgo rotalaria* illustrated in Lagoe (1977) and Smith (1978) shows the development of a short neck and blunt apertural plate, and is herein considered as *P. murrhina*. It differs from *P. lucernula* (Schwager) by having a shorter projecting, ovate, apertural neck with a blunt and sharper periphery. A sinus is present at the posterior end (opposite aperture) of the test in *P. murrhina*. It is characteristic of the lower middle bathyal biofacies (Ingle, 1980) of the eastern North Pacific (Bandy and Arnal, 1957; Hermelin, 1989).

Age range.—Middle Miocene to Pleistocene (Hermelin, 1989).

Pyrgo sarsi? (Schlumberger, 1891)

Plate 3, figure 2

?*Biloculina sarsi* SCHLUMBERGER, 1891, p. 166, pl. 9, figs. 55-59, text-figs. 10-11.

cf. *Pyrgo fornasinii* Chapman and Parr, BARKER, 1960, p. 4, pl. 2, fig. 7; TODD and LOW, 1980, p. 24, pl. 2, fig. 16.

cf. *Pyrgo abyssorum* Goës, TODD and LOW, 1967, p. A20, pl. 2, fig. 25.

?*Pyrgo sarsi* (Schlumberger), LOEBLICH and TAPPAN, 1994, p. 54, pl. 94, figs. 1-9.

Description.—Test small to medium size, circular, inflated, periphery obtusely rounded, produced at oral end, carinate at aboral end; chambers biloculine, one-half coil in length, strongly inflated on both sides; sutures distinct, depressed; walls calcareous, imperforate, porcellaneous; aperture terminal, slightly recurved slit with a non-curving, short, broad flap partially filling aperture, leaving a cresentric-shaped opening.

Remarks.—*Pyrgo sarsi*? is probably closest to *P. abyssorum* and P. *fornasinii*. They all share similar apertural characteristics by having a short, broad apertural plate that is non-bifid, non-curving and partially fills the aperture, leaving a narrow recurved slit for an opening. Also its obtuse test shape is similar in all three species. The illustrated specimen slightly differs from *P. sarsi* by possessing a carinate aboral end and a shorter, broader (less elongate) aperture plate that covers less of the opening. Based on the above characteristics, all three are possibly synonomous, with only slight differences in the aperture. Also, this species differs from *P. rotalaria* Loeblich and Tappan, by being smaller, not as compressed, lacking the distinct carinate border, and having an elongate slit-like aperture with a broad plate (not appearing bifid), covering most of the opening. It is characteristic of the lower middle bathyal biofacies (Ingle, 1980)

Age range.—Pliocene to Holocene.

Genus *Sigmoilina* Schlumberger, 1887

Sigmoilina celata (Costa, 1855)

Plate 3, figure 3

Spiroloculina celata COSTA, 1855, p. 126, pl. 1, fig. 14.

Sigmoilina celata (COSTA); CUSHMAN, STEWART and STEWART, 1930, p. 52, pl. 2, fig. 3; HALLER 1980; p. 232, pl. 2, fig. 8.

?*Sigmoilina*? sp. CUSHMAN and SIEGFUS, 1942, p. 404, pl. 15, fig. 18.

?*Sigmoilina schlumbergeri* Silvestri, PHLEGER and PARKER, 1951, p. 8, pl. 4, fig. 6.

?*Sigmoilopsis schlumbergeri* (Silvestri) BARKER, 1960; p. 16, pl. 8, figs. 1-4.

Description.—Test elongate, ovate, highly compressed; chambers one test length long, early ones sigmoid and inflated, later ones 180° apart and much compressed; sutures fairly indistinct; walls calcareous imperforate, may appear arenaceous or chalky; aperture terminal, small, rounded, with small (difficult to observe) apertural tooth.

Remarks.—This species is tentatively placed in *Spirosigmoilina tenuis* (Czjzek). However, it differs by being slightly larger, more compressed and elongate. The test appears to be slightly twisted near the base and the aperture is located on a much shorter neck. It may be conspecific with *S. schlumbergeri* which, has a test that is more arenaceous. It is characteristic of the outer neritic biofacies (Ingle, 1980).

Age range.—Oligocene to Holocene.

Genus *Spirosigmoilina* Parr, 1942

Spirosigmoilina tenuis (Czjzek, 1848)

Plate 3, figure 4

Qinqueloculina tenuis CZJZEK, 1848, p. 149, pl. 13, figs. 31-34.

Sigmoilina tenuis (CZJZEK), CUSHMAN, 1946, p. 32, pl. 5, figs. 13-15; BARKER, 1960, p. 20, pl. 10, figs. 7, 8, 11; UCHIO, 1960, p. 57, pl. 3, figs. 1,2; HALLER 1980, p. 232, pl. 2, fig 9; McDOUGALL, 1980, p. 37, pl. 5, fig. 10.

Spirosigmoilina tenuis (Czjzek), PATTERSON, BURBRIDGE and LUTERNAUER, 1998, p. 6, pl. 2, figs. 1-2; ?HAYWARD, GRENFELL, REID and HAYWARD, 1999, p. 104, pl. 5, figs. 21-22.

Description.—Test small, ovate, compressed, periphery rounded; chambers sigmoid, and slightly inflated in early ones; sutures distinct, depressed; walls calcareous imperforate, porcellaneous; aperture terminal, rounded, developed on a short neck.

Remarks.—Specimens are tentatively placed within *S. tenuis* on the basis of the aperture and sigmoid arrangement of the chambers. The illustrated specimen is different from *S. tenuis* illustrated in Hayward et al. (1999) where the test is highly compressed and chambers are more numerous with early ones being sigmoid and later ones 180° apart. It is characteristic of the outer neritic biofacies (Ingle, 1980).

Age range.—Middle Eocene to Holocene (Hayward et al., 1999).

6.4. Calcareous perforate families

Family Bagginidae Cushman, 1927

Genus *Baggina* Cushman, 1926

Baggina washingtonensis Rau, 1948

Plate 3, figures 5-8

Baggina washingtonensis RAU, 1948, p. 779, pl. 119, figs. 24-27.

Baggina notoensis ASANO, 1953, p. 10, pl. 3, fig. 17.

Baggina saito ASANO and MURATA, 1958, p. 51, pl. 8, fig. 16.

Description.—Test subglobular to subovate, trochoid, periphery broadly rounded, lobulate, slightly compressed, ventral side umbilicate; chambers few, four to five in final whorl, inflated, increasing rapidly in size as added, final one making up over one-third of test, lunate, later chambers comparatively more inflated; sutures distinct, depressed, slightly curved; wall calcareous, hyaline, smooth, finely perforate; aperture large, at base of final chamber, elliptical and elongate, with distinct dentitions along inner margins of early chambers and bordering aperture.

Remarks.—This species is distinguished by its rapidly increasing, subovate chambers and distinct aperture. It is close to *B. californica* Cushman and differs by being slightly larger (more chambers) with more inflated chambers on the ventral side, and possessing "dentitions at the base of the apertural margin. It somewhat resembles *B. robusta* Kleinpell however, the test in the latter species is more flattened, more elongate, less globular or inflated and lacks the apertural characteristics. *Baggina notoensis* and *B. saito* are herein considered junior synonyms because their original descriptions match that of *B. washingtonensis*. This species was originally described from Miocene strata of the Astoria Formation in southwestern Washington. It is characterisitic of the upper bathyal biofacies (Ingle, 1980).

Age range.—Early to Middle Miocene (Rau, 1948).

Genus *Valvulineria* Cushman, 1926

Valvulineria asanoi Kim, 1965

Plate 3, figure 10

Valvulineria asanoi KIM, 1965, p. 92, pl. 5, figs. 15-20.

Description.—Test small, trochioid, periphery rounded, lobulate, two whorls visible, umbilicate; chambers inflated, five to seven in final whorl, short umbilical flaps developed, on ventral side chamber edges near umbilicus; sutures distinct, depressed, oblique on ventral side, slightly curved on dorsal side; wall calcareous, hyaline, coarsely perforate; aperture interomarginal, extraumbilical-umbilical, with short broad apertural flap, slightly towards ventral side of periphery.

Remarks.—Specimen are placed within this species based on the presence of umbilical chamber flaps seen in ventral view. It may be close to or conspecific with *Valvulineria miocenica* Cushman in test shape and chamber arrangement. However, the original description of *V. miocenica* does not include umbilical chambers flaps on the ventral side of the test and the aperture of *V. asanoi* is not the unusual, nearly tripartite type initially described. The species is characteristic of the outer shelf biofacies (Ingle, 1980; Finger, 1990 for *V. miocenica*).

Age range.—Early Miocene (Saucesian) to middle Miocene (Luisian; for *V. miocenica*; Finger, 1990.

Family Bolivinidae Glaessner, 1937

Genus *Bolivina* d'Orbigny, 1839

Bolivina blakei Finger and Lipps, 1990

Plate 3, figure 9

Bolivina floridana CUSHMAN, 1918, p. 49, pl. 10, fig. 4.

Bolivina blakei FINGER and LIPPS, 1990, p. 38, pl. 4, fig. 12; FINGER, 1990, p. 30, pl.-figs. 1-9; 1992, p. 78, pl. 16, figs. 2-4.

Description.—Test small, biserial, elongate, periphery and end view rounded, gradually tapering towards initial chamber, moderately compressed, slightly twisted; chambers numerous (eight to ten pairs), inflated, later ones slightly higher; sutures slightly distinct, slightly depressed, crenulated; wall calcareous, moderately perforate except on apertural face where it is smooth; aperture an elongate, narrow loop at base of apertural face.

Remarks.—This species resembles *B. ornata* Cushman, however, it differs by having broadly rounded, less tapered test and sutures that are crenulate. It lacks longitudinal costae. Instead, the basal portion of the test contains numerous undulating striae-like ornaments. *Bolivina blakei* is rare in Tofino Basin strata. It is characteristic of the upper middle bathyal biofacies (Ingle, 1980; Finger, 1990).

Age range.—Oligocene to Late Miocene (Finger, 1990).

Bolivina churchi Kleinpell and Tipton, 1980

Plate 3, figures 11-12

Bolivina chuchi KLEINPELL and TIPTON, 1980, p. 72, pl. 9, figs. 11-12; FINGER and LIPPS, 1990, p. 45, pl. 4, figs. 7-11; FINGER, 1990, p. 38, pl.-figs. 1-11; 1992, p. 78, pl. 15, figs. 1, 39-49.

Description.—Test small, biserial, moderately compressed, broad for the genus, greatest width near apertural end, margin slightly serrate; chambers numerous (eight to ten pairs), low, slightly inflated except near median line where they are more inflated and form knobs; sutures distinct, depressed, limbate and nearly sigmoid near chamber median and strongly curving downward distally; wall calcareous, smooth, finely perforated, unornamented; aperture an elongate, narrow loop at base of apertural face.

Remarks.—This species can be distinguished from other *Bolivina* spp. by its short (for this genus), broad test and characteristic medially inflated chambers and sharply downward curving sutures. The initial chamber (proloculus) may be lobulate or distinctly rounded. It is characteristic of the outer shelf/upper bathyal transitional biofacies (Ingle, 1980; Finger, 1990).

Age range.—Early to Middle/Late Miocene (Finger, 1990).

Bolivina foraminata Stewart and Stewart, 1930

Plate 3, figure 15

Bolivina seminuda Cushman var. *foraminata* STEWART and STEWART, 1930, p. 66, pl. 8, figs. 5.

Bolivina foraminata Stewart and Stewart, FINGER, 1990, p. 40, pl.-figs. 1-9; 1992, p. 78, pl. 16, figs. 5-7.

Description.—Test small, elongate, periphery rounded; chambers numerous, slightly inflated, and overlapping, higher towards apertural end; sutures distinct, depressed, slightly limbate; wall calcareous hyaline, lower two-thirds of each chamber coarsely perforate, remainder (thin band) smooth, clear, transparent/whitish imperforate to finely perforate bands; apertural region smooth, finely perforate; aperture a narrow elongate loop at base of apertural face.

Remarks.—Test of specimens are slightly broken near the base and apertural end. However, this species is distinguished by its distinct ornamentation of coarsely perforate or foraminate chambers with distinct imperforate bands on part of the chambers that appear to cross or overlap. It is characterisitic of the upper middle bathyal biofacies (Ingle, 1980; Finger, 1990).

Age range.—Lower Miocene (Saucesian) to Pliocene (Finger, 1990).

Bolivina ornata Cushman, 1925

Plate 3, figure 13

Bolivina advena Cushman var. *ornata* CUSHMAN, 1925, p. 29, pl. 5, fig. 2.

Bolivina advena Cushman var. *striatella* CUSHMAN, 1925, p. 30, pl. 5, fig. 3.

Bolivina advena ornata FINGER, 1990, p. 26, pl.-figs. 1-7; 1992, p. 78, pl. 15, figs. 7-11.

Description.—Test small, biserial, tapered towards initial end, slightly compressed, periphery rounded; chambers numerous, eight to ten pairs, inflated, early ones narrow and low, later ones higher; sutures distinct, depressed, slightly limbate; wall calcareous, smooth, coarsely perforated, ornamented with numerous (10 to 12 pairs), fine, longitudinal costae that may be slightly crenulated and extend over half-way up test from base, later portion smooth; aperture a narrow loop at base of apertural face.

Remarks.—This former subspecies is herein elevated to species level, since it can be morphologically distinguished from *B. advena* by its numerous fine costae extending up most of the test, leaving the later chambers smooth. It is synonomous with *B. advena* var. *striatella*, which was initially described as having the surface of the early portion ornamented with very fine, numerous, longitudinal costae and the later portion smooth (Cushman, 1925) making it identical to the illustrated specimen in this study. However, there is variation in the thickness and length of the longitudinal costae, that does not warrant separation to variety or to subspecies level. Therefore, forms that show varying thicknesses of longitudinal costae extending up most of the test from the base to just over the mid-point are placed within *B. ornata*. It is characteristic of the upper bathyal biofacies (Ingle, 1980; Finger, 1990).

Age range.—Oligocene to Holocene (Finger, 1990).

Bolivina wissleri Kleinpell and Tipton, 1980

Plate 3, figures 14, 16

Bolivina wissleri KLEINPELL and TIPTON, 1980, p. 74, pl. 8, figs. 14-16; FINGER, 1990, p. 54, pl.-figs. 1-9; 1992, p. 79, pl. 21, figs. 27-28.

Description.—Test elongate, two to three times long as wide, periphery slightly rounded, rounded in cross-section, tapered, initial end rounded to bluntly pointed, test slightly twisted about the longitudinal axis; chambers numerous, eight to10 pairs), slightly inflated, last three pairs making up nearly half of test, gradually increasing in size as added; sutures distinct, depressed, strongly crenulated and lobate, angled; wall calcareous, hyaline, smooth, finely perforated, ornamented by longitudinal nodular projections; aperture elongate, narrow slit, bordered by a slight lip on face of final chamber.

Remarks.—This species is easily distinguished from other *Bolivina* spp., by its distinct crenulated sutures and slightly twisted and tapering test. It is most closely related to *B. blakei* with which it shares a rounded, tapered test. It differs by having weakly crenulated sutures and less lobulate chambers than *B. wissleri*. It is characteristic of the upper bathyal to upper middle bathyal biofacies (Ingle, 1980; Finger, 1990).

Age range.—Middle Miocene (Mohnian; Finger, 1990).

Genus *Brizalina* O.G. Costa, 1856

Brizalina argentea (Cushman, 1926)

Plate 3, figure 17

Bolivina argentea CUSHMAN, 1926, p. 42, pl. 6, fig. 5; MARTIN, 1952, p. 128, pl. 21, figs. 5-6; FINGER, 1990, p. 28, pl.-figs. 1-10.

Bolivina subargentea UCHIO, 1960, p. 64, pl. 6, figs. 21-22.

Description.— Test elongate, twice as long as wide, lanceolate, compressed, periphery subacute, usually not keeled; chambers numerous, eight to 10 pairs, slightly inflated; sutures distinct, depressed, initial ones less limbate than later ones; wall calcareous, hyaline, smooth, finely perforate, ornamented with costae on initial chamber and one or more of following chambers, some with short apical chamber spines; aperture an elongate loop extending up face from base of final formed chamber, with internal tooth plate.

Remarks.—This species has a similar test shape and chamber arrangement as *B. subaenariensis*. However, the test is shorter and broader, sutures are less depressed with a lobulate initial chamber and the marginal keel is less developed. These slight variations may be phenotypic. Several phenotypic variations are known and include variations in width-length-ratios, length and presence of costae, and length of the basal spine; they reflect slope to basin transitions (Lutze, 1964). The species is characteristic of the upper middle bathyal biofacies (Ingle, 1980; Finger, 1990).

Age range.—Pliocene to Holocene (Finger, 1990).

Brizalina fragilis (Phleger and Parker, 1951)

Plate 3, figure 18

Bolivina fragilis PHELGER and PARKER, 1951, p. 13, pl. 6, figs. 14, 23-24;

Brizalina fragilis PATTERSON, BURBIDGE and LUTERNAUER, 1998, p. 14, pl. 13, figs. 6-7.

Description.—Test elongate, slender, slightly angled, biserial throughout, lanceolate three times as long as wide, compressed, slightly tapering, narrow marginal keel, and a short apical spine at initial end; chambers numerous 10-14 pairs, increasing in size gradually as added, slightly inflated; sutures imperforated, distinct depressed, highly curved, slightly limbate; wall calcareous, hyaline, smooth, finely perforated, ornamented with few longitudinal costae extending one-quarter to half-way up test from initial end; aperture an elongate loop with internal tooth plate, extending high up face of highly curved final chamber.

Remarks.—This species is close to *B. subaenariensis*, however it differs by being more elongate, delicate and slender with a higher aperture and a narrower, sharper marginal keel along the sides of the test. It is characterisitic of the upper bathyal and/or upper middle bathyal biofacies (Ingle. 1980).

Age range.—Pliocene to Holocene.

Brizalina subaenariensis (Cushman, 1922)

Plate 3, figures 19-23

Bolivina subaenariensis CUSHMAN, 1922, p. 46, pl. 7, fig. 6; TODD and LOW, 1967, p. A27, pl. 4, fig. 8.

Brizalina subaenariensis PATTERSON, BURBIDGE and LUTERNAUER, 1998, p. 14, pl. 13, figs. 8-9.

Description.—Test elongate, biserial throughout, lanceolate, over two times as long as wide, highly compressed, periphery rounded to carinate, may be tapered or rounded at basal end, commonly with a single, short apical chamber spine; chambers numerous, 10 to 12 pairs, gradually increasing in size as added; sutures imperforate, smooth, distinct, depressed, limbate, highly curved downwards; wall calcareous, hyaline, finely perforate, commonly ornamented with one to two longitudinal costae, which extend entire length of test or are restricted near basal end; aperture an elongate loop extending up the face from base of final formed chamber, with internal tooth plate.

Remarks.—This species is close to *B. argentea and B. fragilis.* However, it differs from *B. argentea* in being larger, more compressed, elongate, and tapered. It differs from *B. fragilis* by being less tapered/slender and elongate. It is probably characteristic of the outer shelf to upper bathyal biofacies (Ingle, 1980).

Age range.—Pliocene to Holocene.

Family Buliminidae Jones, 1875

Subfamily Bulimininae Jones, 1875

Genus *Bulimina* d'Orbigny, 1826

Bulimina alligata Cushman and Laiming, 1931

Plate 3, figure 24

Bulimina inflata Seguenza *alligata* CUSHMAN and LAIMING, 1931, p. 107, pl. 11. fig. 17.

Bulimina alligata CUSHMAN and PARKER, 1947, p. 112, pl. 26, fig. 14; FINGER, 1992, p. 82, pl. 20, fig. 12.

Description.—Test small to medium size, elongate, twice as long as wide, tapered at initial end and widest at apertural end, consisting of six whorls; chambers fairly indistinct, numerous, somewhat inflated in later portion; sutures fairly indistinct in early portion, depressed in later portion; wall calcareous, hyaline, finely perforate and smooth in final whorl, remainder ornamented by thick, low, plate-like, costae arranged longitudinally, broken at sutures; aperture large, loop-shaped, elongate, with a slight lip, at inner margin of final chamber.

Remarks.—This species differs from *B. rinconensis* and *B. subacuminata* in that the costae are arranged in a regular and longitudinal series, running the length of the test. It is characteristic of the upper middle bathyal biofacies (Ingle, 1980).

Age range.—Early Miocene to Pliocene (Cushman and Parker, 1947).

Bulimina rinconensis Cushman and Laiming, 1931

Plate 3, figure 25

Bulimina rinconensis CUSHMAN and LAIMING, 1931, p. 107, pl. 11, fig. 18; CUSHMAN and PARKER, 1947, p. 112, pl. 26, fig. 15.

Description.—Test medium to large, twice as long as wide, tapered at initial end, widest at apertural end, consisting of five to six whorls; chambers distinct, inflated, somewhat angular; sutures distinct, depressed; wall calcareous, hyaline, finely perforate, ornamented by bladed, pointed broad and slightly rounded costae at base of chamber in last few whorls and across whole chamber in earlier whorls; aperture elongate, loop-shaped, with a slight lip, placed high on final chamber.

Remarks.—This species is close to *B. subacuminata*, but differs in that the costae are thicker and blunt or rounded. It also differs from *B. alligata* in that the test is more fusiform, the aperture is higher and closer to the apex of the test, and the costae do not form in a linear series along the length of the test. It is characteristic of the upper middle bathyal biofacies (Ingle, 1980).

Age range.—Oligocene (Zemorrian) to Pliocene (Cushman and Parker, 1947).

Bulimina subacuminata Cushman and and R.E. Stewart, 1930

Plate 3, figures 26-28

Bulimina subacuminata CUSHMAN and R.E. STEWART, 1930, p. 65, pl. 5, figs. 2-3; CUSHMAN and PARKER, 1947, p. 116, pl. 27, fig. 8; RAU, 1970, p. 25, pl. 2, fig. 1; FINGER and LIPPS, 1990, p. 45, pl. 5, fig. 2; FINGER, 1990, p. 64, pl.-figs. 1-7; 1992, p. 82, pl. 20, figs. 17-18.

Description.—Test small to medium length, slightly elongate, tapered at initial, broad near apertural end, circular in cross-section; chambers numerous, inflated, especially in final whorl; sutures distinct, depressed; wall calcareous, hyaline, smooth, finely perforated, ornamented by a series of longitudinal high and thin plates or costae with lower ends thickly serrated; aperture elongate, loop-shaped and high on inner face of final chamber.

Remarks.—*Bulimina subacuminata* is similar to *B. subcalva*, however, the former species is distinguished by having costae on all chambers, whereas the latter species only has costae present on the lower half of the test (Finger, 1990). Haller (1980) placed *B. subcalva* as a junior synonym of *B. subacuminata*. However, in his emendation, it appears to be a distinct species. It also resembles *B. rinconensis* but differs in having thinner and higher costae and more inflated chambers. *Bulimina subacuminata* commonly occurs in the lower Pliocene strata of the Tofino Basin. It is characteristic of the upper middle bathyal biofacies (Ingle, Jr., 1980; Finger, 1990).

Age range.—Early Miocene (Saucesian) to Pliocene in California (Finger, 1990).

Bulimina subcalva Cushman and K.C. Stewart, 1930

Plate 3, figures 29-33

Bulimina subcalva Cushman and K.C. Stewart, 1930, p. 66, pl. 1-8; CUSHMAN and PARKER, 1947, p. 116, pl. 27, fig. 7; FINGER and LIPPS, 1990, p. 45, pl. 5, fig. 3; FINGER, 1990, p. 66, pl.-figs. 1-8; 1992, p. 82, pl. 20, fig. 19.

Description.—Test slightly elongate, triserial, longer than broad, periphery rounded, tapering towards initial end, broadest at apertural end; chambers numerous, inflated, later ones slightly bulbous, higher in later stages; sutures distinct, depressed; wall calcareous, hyaline, smooth, finely to roughly perforate, roughed by texture of ornamentation in earlier chambers, later chambers smooth, finely perforate with no ornamentation; costae distinct and plate-like, on earlier part of test, do not cross sutures; aperture large (for this genus), elongate, loop-shaped, with slight lip.

Remarks.—This species is close to *B. subacuminata*, however, it differs in having plate-like costae, restricted to earlier chambers. Variations exist between micropheric and megalospheric forms. It is characterisitic of the upper middle bathyal biofacies (Ingle, 1980; Finger, 1990).

Age range.—Early Miocene (Saucesian) to Pliocene (Finger, 1990).

Genus *Globobulimina* Cushman, 1927

Globobulimina pyrula (d'Orbigny, 1846)

Plate 4, figures 1-2

Bulimina pyrula D'ORBIGNY, 1846, p. 184, pl. 11, figs. 9-10; CUSHMAN and PARKER, 1947, p. 104, pl. 25, fig. 2.

Description.—Test medium size, oval to pyriform, slightly involute, broadest near base just below mid-point, tapering near base, apertural end broadly rounded, periphery broadly oval, two to three whorls, last formed whorl composes most of the test and is much inflated; chambers few (three in final whorl); sutures distinct, slightly depressed; wall calcareous, hyaline, translucent, smooth, finely perforate; aperture elongate, trough-like, and comma-shaped with tooth-plate, slightly elevated border or lip.

Remarks.—This species most closely resembles *G. pacifica* Cushman and may be misidentified as the latter species. It is similar to *G. pacifica* by its broadly rounded base and few whorls. It differs from *G. pacifica* in having a more pyriform and inflated test. It also slightly resembles *G. perversa* (Cushman) and differs by having a slightly involute test that tapers to a point near the base. It is characteristic of the upper bathyal biofacies.

Age range.—Miocene to Holocene.

Globobulimina pacifica Cushman, 1927

Plate 4, figure 3

Globobulimina pacifica CUSHMAN, 1927, p. 67, pl. 14, fig. 12; CUSHMAN and PARKER, 1947, p. 134, pl. 29, fig. 37; LOEBLICH and TAPPAN, 1994, p. 125, pl. 243, figs. 13-16.

Description.—Test large, slightly elongate subglobular to ovate, slightly involute, periphery rounded, basal end rounded, widest at or slightly below mid-point close to base, only slightly tapering towards apertural end, last whorl making up almost entire test, rounded in cross-section; chambers few (two to three in final whorl), embracing entire test, slightly inflated first chamber more strongly inflated than two chambers on either side of it; sutures fairly indistinct; wall calcareous, thin, smooth, finely perforate; aperture terminal, an elongate, comma-shaped with simple tooth-plate surrounded by a distinct slightly elevated border.

Remarks.—*Globobulimina pacifica*, a commonly occurring species has previously included numerous other *Globobulimina* forms, possibly because the original description this species was fairly vague. Adding to this are extremely fragile tests, which are usually replaced by iron sulphides (Haller, 1980). Specimens are placed within *G. pacifica* because they have an elongate ovate test, a broadly rounded base a few chambers visible in the final whorl and comma-shaped apertural characteristics. This species may be close to *Praeglobobulimina galliheri* (Kleinpell) in apertural features, however, it is elongate and ovate (than pyriform) with chambers that show reduced inflation. It is characteristic of the upper bathyal biofacies (Ingle, 1980).

Age range.—Eocene to Holocene (Cushman and Parker, 1947).

Genus *Protoglobobulimina* Hofker, 1951

Protoglobobulimina auriculata Bailey, 1851

Plate 4, figure 4

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

Bulimina (*Desinobulimina*) *auriculata* Bailey, CUSHMAN and PARKER, 1947, p. 129, pl. 29, figs. 22-24; ASANO, 1950, p. 5, figs. 19-20.

Globobulimina hanzawai, ASANO, 1958, p. 10, pl. 2, figs. 4-6.

Globobulimina auriculata (Bailey), TODD and LOW, 1967, p. A26, pl. 3, fig. 38.

cf. *Bulimina pupoides* D'ORBIGNY, 1846, p. 185, pl. 11, figs. 11-12; CUSHMAN and PARKER, 1947, p. 105, pl. 24, figs. 3-7.

cf. *Protoglobobulimina pupoides* (d'Orbigny), LOEBLICH and TAPPAN, 1994, p. 125, pl. 244, figs. 8-10; PATTERSON, BURBIDGE and LUTERNAUER, 1998, p. 17, pl. 17, figs. 7-8.

Description.—Test elongate, fusiform tapering towards basal end, three whorls, last formed whorl consists of nearly three-fourths of test, broadest just below mid point; chambers slightly inflated, few in final whorl, partially involute, slightly overlapping; sutures distinct, slightly depressed; wall calcareous, hyaline, thin, translucent, smooth, finely perforate; aperture large, terminal, elongate, trough-like with a slightly curved toothplate, with a slightly elevated surrounding border.

Remarks.—*Globobulimina hanzawai* Asano is herein considered a junior synonym, it may be slightly more slender otherwise it does not differ greatly from *G. auriculata*. This species close to *P. pupoides* d'Orbigny, by having a similar test shape and by possessing an elongate aperture with an internal toothplate that is connected to the chambers. It differs in being more slender and/or fusiform and in having less inflated chambers a slightly curved toothplate. It is characterisitic of the upper bathyal and/or upper middle bathyal biofacies (Ingle, 1980).

Age range.—Pliocene to Holocene (Cushman and Parker, 1947).

Protoglobobulimina pseudotorta Cushman, 1926

Plate 4, figures 5-6

Bulimina pseudotorta CUSHMAN, 1926, p. 55, pl. 7, fig. 3; CUSHMAN and PARKER, 147, p. 111, pl. 26, fig. 13.

Bulimina montereyana KLEINPELL, 1938, p. 254, pl. 13.

Bulimina (*Desinobulimina*) *montereyana* Kleinpell, CUSHMAN and PARKER, 1947, p. 129, pl. 29, figs. 20-21.

Protoglobobulimina pseudotorta (Cushman), FINGER, 1990, p. 197, pl.-figs. 1-11; 1992, p. 82 pl. 20, figs. 26-33.

Description.—Test large size, elongate, tapering slightly from broadly rounded base to slightly truncate apertural end, periphery lobulate, greatest width near apertural end, four to five whorls visible; chambers distinct, few, inflated, slightly angular; sutures distinct, depressed; wall calcareous, hyaline, smooth, finely perforate; aperture terminal, elongate, comma-shaped, with a small tooth-plate.

Remarks.—This species is distinguished by its large lobulate test and characteristic aperture that looks slightly cruciform in side view. However, there is slight variability in lobulation and test envelopment (Finger, 1990). The slightly larger *Bulimina montereyana* is herein considered a junior synonym. It does not greatly vary from *P. pseudotorta* and may represent an ecophenotypic variation. This species differs from *Protoglobobulimina pupoides* by being larger, more lobulate, having slightly angled and inflated chambers, and a more elongate comma-shaped aperture. It is characteristic of the upper middle bathyal biofacies (Ingle, 1980; Finger, 1990).

Age range.—Oligocene (Zemorrian) to Holocene (Finger, 1990).

Subfamily Turrilininae Cushman, 1927

Genus *Turrilina* Andreae, 1884

Turrilina alsatica Andreae, 1884

Plate 4, figures 7-9

Turrilina alsatica ANDREAE, 1884, p. 120, pl. 8, fig. 18; CUSHMAN, 1927, p. 65 (emend.); LOEBLICH and TAPPAN, 1964, p. 543, fig. 427; ULLEBERG, 1974, p. 277, pl. 6, figs. 3-4.

Description.—Test small to medium size, elongate, high, flaring, close, tapering abruptly to a bluntly rounded base, periphery lobulate, broadest near aperture; chambers numerous, distinct, initial ones small, biserially arranged, low, and slightly compressed, later ones triserially arranged, high, greatly inflated and globular, increasing in size rapidly as added; sutures distinct, depressed, oblique; wall calcareous, hyaline, smooth, finely perforate, appearing slightly roughened/arenaceous; aperture small, loop-shaped interomarginal arch at base of final chamber, beneath a slightly thickened, raised border.

Remarks.—The test of these specimens shows slight dissolution, giving it a slightly roughened texture, however, it is calcareous not arenaceous. The tapered pyramidal test and inflated later chambers makes this species look (superficially) similar to planktic *Chiloguembelina* spp., however, the test of the latter species is smaller, not as flared and the chambers are biserially arranged (not triserial as in *T. alsatica*). *Turrilina alsatica* is similar to *Eggerella bradyi* (Cushman) (=*Verneuilina brady* not *Gaudryina bradyi* Cushman, the latter is now recognized as *Karreriella bradyi* (Cushman)), in its pyramidal test shape and inflated triserial chambers. It differs by having fewer than five chambers in the vertical series, a calcareous (not finely arenaceous) wall and a small aperture with a broad base at the basal margin of the final chamber. The *T. alsatica* Zone was identified for Oligocene on Vancouver Island (Cameron, 1980) and also middle and late Oligocene of the Arctic of Canada (McNeil, 1997). It is characteristic of the outer neritic-upper bathyal biofacies (Ulleberg, 1974; Ingle, 1980).

Age range.—Early to late Oligocene (Zemorrian) (Ulleberg, 1974; Cameron, 1980; McNeil, 1989; 1997).

Family Buliminellidae Hofker, 1951

Genus *Buliminella* Cushman, 1911

Buliminella bassendorfensis Cushman and Parker, 1937

Plate 4, figure 10

Buliminella bassendorfensis CUSHMAN and PARKER, 1937, p. 40, pl. 4, fig. 13.

Buliminella subfusiformis FINGER, 1990, p. 74, pl.-figs. 1, 5-6, non 2-4, 7-9; 1992, p. 82, pl. 20, fig. 40, non figs. 39, 41-45.

Eubuliminella bassendorfensis (Cushman and Parker), REVETS, 1993, p. 142, pl. 2, figs. 3-4.

Description.— Test elongate, four to five whorls, arcuate, periphery distinctly lobulate, sides nearly parallel, initial end tapered and bluntly rounded; chambers numerous, four to five to a whorl, inflated, ovate to globular; sutures distinct, oblique, depressed; wall calcareous, smooth, finely perforate; aperture small loop/comma-shaped, with a small toothplate, formed in a small semi-circular depression on face of final chamber.

Remarks.—This species is close to and commonly co-occurs with *B. subfusiformis* Cushman. It may prove to be an ecophentypic variant (Finger, 1990). Its chambers slightly differ in being more ovate, slightly angled and with fewer whorls to the test, and therefore, herein this species is separated from *B. subfusiformis*. Also, no ornamentation (presence of small spines as per original description) was recorded in the available specimens. It is characterisitic of the outer neritic and/or upper bathyal biofacies (Ingle, 1980).

Age range.—Oligocene (Zemorrian) to Holocene (for *B. subfusiformis*, Finger, 1990).

Buliminella californica? Cushman, 1925

Plate 4, figure 11

?*Buliminella californica* CUSHMAN, 1925, p. 33, pl. 5, fig. 15; OLSON, 1990, p. 299, pl. 1, fig. 14.

?*Eubuliminella californica* REVETS, 1993, p. 142, pl. 2, fig. 7.

Description.—Test small to medium, elongate, slightly tapered to subacute initial end, sides nearly parallel, three to four whorls; chambers numerous, fairly indistinct, slightly inflated; sutures fairly indistinct, slightly depressed; wall calcareous, hyaline, smooth, finely perforate; aperture small, narrow, loop-shaped, with a short tooth-plate, at base of final chamber, surrounded by a crista.

Remarks.—Specimens are placed with question in this species based on its slightly tapering test with chambers that are comparatively less inflated and smaller than other *Buliminella* spp., particularly *B. subfusiformis*. The original description for this species describes it to be subcylindrical with nearly parallel sides and a non-lobulate periphery. Specimens show a slightly lobulate periphery and the test is more fusiform than subcylindrical with sides nearly parallel; the apertures are similar. It is characterisitic of the outer neritic biofacies (Ingle, 1980).

Age range.—Miocene.

Buliminella curta Cushman, 1925

Plate 4, figure 13

Buliminella curta CUSHMAN, 1925, p. 33, pl. 5, fig. 13; RAU, 1970, p. 24, pl. 1, fig. 18; PATTERSON, 1989, p. 237, pl. 10.5, figs. 1-2; FINGER, 1990, p. 68, pl.-figs. 1-8; 1992, p. 82, pl. 20, figs. 36-38; OLSON, 1990, p. 299, pl. 1, fig. 15.

Eubuliminella curta (Cushman), REVETS, 1993, p. 143, pl. 2, fig. 12.

Description.—Test elongate, fusiform, periphery lobulate, initial end tapering and rounded, apertural end broad; chambers numerous, five to six, inflated, lobulate; sutures slightly depressed; wall calcareous, hyaline, smooth, finely perforate; aperture comma-shaped with a broad tooth-plate, in a slightly concave depression of final chamber, flanked by a crista surrounding aperture on final chamber.

Remarks.—This species with its large globose chambers is close to *B. brevior* and *B. subfusiformis*. They all share a similar morphograde. It differs from *B. brevior* by being more elongate and with a lesser degree of coiling of the chambers in the earlier portion of the test. It is similar to *B. subfusiformis* but differs in that the latter species is more elongate and slender. *Buliminella curta* occurs with the latter species, but at lower frequency than *B. subfusiformis*. This species is recorded in low numbers (rare) in the Miocene and Pliocene strata of Washington (Rau, 1970) and the Tofino Basin. *Buliminella curta* is characterisitic of the outer shelf biofacies (Ingle, 1980; Finger, 1990).

Age range.—Oligocene (Zemorrian) to Holocene (Finger, 1990).

Buliminella elegantissima (d'Orbigny, 1839)

Bulimina elegantissima D'ORBIGNY, 1839, p. 51, pl. 7, figs. 13-14.

Buliminella elegantissima (d'Orbigny), RAU, 1970, p. 24, pl. 1, fig. 17; PATTERSON, 1989, p. 237, pl. 10.3, fig. 11; FINGER and LIPPS, 1990, p. 45, pl. 5, fig. 4; FINGER, 1990, p. 70, pl.-figs. 1-8; 1992, p. 82, pl. 20, figs. 48-50; PATTERSON, BURBIDGE and LUTERNAUER, 1998, p. 17, pl. 16, figs. 6-7; HAYWARD, GRENFELL, REID and HAYWARD, 1999, p. 133, pl. 9, figs. 18-19.

Description.— Test elongate, twice as long as wide, slender, fusiform, two to three whorls in a high and embracing spiral, final whorl ~75% of length; chambers numerous, high, narrow, embracing, slightly inflated; sutures distinct, depressed; wall calcareous, hyaline, smooth, finely perforate; aperture loop-shaped with internal tooth-plate.

Remarks.—This species is distinguished by its elongate, spiraled test with numerous chambers to a few whorls. It has a cosmopolitan geographic distribution (Murray, 1991; Hayward et al., 1999) and has sporadic but persistent occurrence in low numbers (rare to few; Rau, 1970). It is characteristic of the inner neritic biofacies (Ingle Jr., 1980; Finger, 1990; Hayward et al., 1999).

Age range.—Wide ranging, Oligocene (Zemorrian) to Holocene (Finger, 1990; Hayward et al., 1999).

Buliminella subfusiformis Cushman, 1925

Plate 4, figures 12, 14

Buliminella subfusiformis CUSHMAN, 1925, p. 33, pl. 5, fig. 12; RAU, 1951, p. 439, pl. 65, fig. 5; MARTIN, 1952, p. 134, pl. 23, fig. 6; FINGER and LIPPS, 1990, p. 45, pl. 5, figs. 5-8; FINGER, 1990, p. 74, pl.-figs. 2-4, 7-9, non 1, 5-6; 1992, p. 82, pl. 20, figs. 39, 41-45, non fig. 40.

Eubuliminella subfusiformis (Cushman), REVETS, 1993, p. 144, pl. 4, figs. 5-6.

Description.—Test elongate, subcylindrical, periphery lobate, sides nearly parallel, initial end tapered and bluntly rounded; chambers numerous, four to five to a whorl, inflated, globular; sutures distinct, depressed; wall calcareous, smooth, finely perforate;

aperture ovate to comma-shaped, with a small toothplate, formed in a small semi-circular depression on face of final chamber.

Remarks.—Several ecophenotypic variations exist (Finger, 1990), which show differences in elongation of the test, inflation of the chambers (slender vs. stoutness) and apertural characteristics. The most typical consists of forms that are slender, elongate with numerous inflated globose chambers in a distinct oblique series. Other forms approach the stout test, broad chamber form of *B. bassendorfensis* and *B. curta*. Certain illustrated figures in Finger 1990 and 1992 (in synonomy list), best fit the original illustration and description for *B. bassendorfensis*. It is characterisitic of the upper bathyal biofacies (Ingle, 1980; Finger, 1990).

Age range.—Oligocene (Zemorrian) to Holocene (Finger, 1990).

Family Cassidulinidae d'Orbigny, 1839

Genus *Cassidulina* d'Orbigny, 1826

Cassidulina carinata Silvestri, 1896

Plate 4, figures 15-17

Cassidulina laevigata d'Orbigny var. *carinata* SILVESTRI, 1896, p. 104, pl. 2, fig. 10.

Cassidulina carinata RODRIGUES, HOOPER, and JONES, 1980, p. 54, pl. 5, figs. 3, 6, 9; LOEBLICH and TAPPAN, 1994, p. 114, pl. 220, figs. 7-12; HAYWARD, GRENFELL, REID and HAYWARD, 1999, p. 127, pl. 8, figs. 23-24.

Islandiella carinata FINGER and LIPPS, 1990, p. 47, pl. 8, figs. 31-32; FINGER, 1990, p. 140, pl.-figs. 1-8; 1992, p. 80, pl. 19, figs. 14-18.

Description.—Test medium sized, planispiral, compressed, biconvex, periphery moderately to strongly keeled, acute; chambers few (four to five pairs in final whorl), rhomboid, slightly inflated; sutures distinct, slightly depressed; wall calcareous, hyaline, coarsely perforate, granular; aperture narrow, elongate, slightly curved, slit parallel to the periphery at base of final chamber, nearly closed by a broad apertural flap.

Remarks.—This species is distinguished by its strong peripheral keel. It is close to *C. neocarinata* and differs by have a more rounded periphery (less lobulate) and by having an apertural flap. Carinate *Cassidulina* spp. are long ranging and particularly abundant in the early Pliocene (Ostermann, 1996). Finger and Lipps (1990) and Finger (1990) placed this species in the genus *Islandiella*, based on the optically radial walls type observed in their specimen. Specimens observed in this study have optically granular walls and apertural tooth-plates that partially close the aperture. These characteristics agree with Rodrigues et al. (1980) therefore this species is referred to the genus *Cassidulina*. It is characterisitic of the outer neritic(?)/upper bathyal biofacies (Ingle, 1980).

Age range.—Early Miocene to Holocene (Hayward et al., 1999).

Cassidulina galvinensis Cushman and Frizzel, 1940

Plate 4, figures 18, 27

Cassidulina galvinensis CUSHMAN and FRIZZELL, 1940, p. 43, pl. 8, fig. 10; RAU, 1951, p. 449, pl. 67, fig. 6; McDOUGALL, 1980, p. 34, pl. 26, fig. 1-2.

Description.—Test small, periphery rounded to subovate, subacute, slightly lobulate, slightly compressed; chambers distinct, wide, wedge-shaped, four pairs in the final whorl, slightly inflated; sutures, distinct, depressed, slightly flush with surface; wall calcareous, hyaline, finely perforate; aperture elongate, parallel to periphery, bordered by outer infolded margin, forming a weak lip that partially closes opening.

Remarks.—This species resembles to the Pliocene *C. reniforme*, however, it is larger with more chambers that appear to be added at right angles to each other. The illustrated specimen shows more inflation of the chambers than is described in the original species description. Specimens from the Tofino Basin are recorded from the Lower Oligocene strata, and have been previously recorded in Washington and Vancouver Island. This species may be regionally restricted to the Pacific Northwest Eocene/Oligocene strata (Cameron, 1980, Rau, 1981). It is characteristic of the upper bathyal biofacies (Ingle, 1980).

Age range.—Late Eocene to Early Oligocene (Rau, 1981, 1999; Cameron, 1980).

Cassidulina reniforme Nørvang, 1945

Plate 4, figures 19-22

Cassidulina crassa d'Orbigny var. *reniforme* NØRVANG, 1945, p. 41, fig. 6.

Cassidulina reniforme RODRIGUES, HOOPER and JONES, 1980, p. 58, pl. 2, figs. 2,4,6; pl. 3, figs. 3,6,9,11,12; pl. 5, figs. 10-12; FEYLING-HANSSEN, 1990, p. 22, pl. 4, figs. 4-9. PATTERSON, BURBIDGE and LUTERNAUER, 1998, p. 15, pl. 14, figs. 3-4; POLYAK, KORSUN, FEBO, STANOVOY, KHUSID, HALD, PAULSEN and LUBINSKI, 2002, p. 269, pl. 2, fig. 12.

Description.—Test small, planispiral, slightly compressed, periphery rounded; chambers four to six pairs in final whorl, slightly inflated, final chamber comparatively more inflated; sutures distinct, slightly depressed, slightly flush with the surface; wall calcareous, hyaline, smooth, finely perforate, granular; aperture, narrow, arched, elongate slit, parallel to periphery, at base of final chamber, nearly closed by a broad apertural flap.

Remarks.—This species differs from *Cassidulina* spp. by having a small, broadly rounded, slightly compressed test (sides nearly parallel in side view) with a distinct aperture. The degree of compression of the test slightly varies among specimens. It may resemble juvenile forms of *Islandiella islandica* (Nørvang) and can be distinguished by its apertural characteristics, compressed test, and less porcellaneous walls. This species is commonly recorded in high abundance from high latitudes, and cold water environments (Sejrup and Guilbault, 1980), particulary from Pliocene strata (Ostermann, 1996). It is characteristic of the outer neritic biofacies (Ingle, 1980)

Age range.—Pliocene (Osterman, 1996).

Genus *Islandiella* Nørvang, 1958

Islandiella californica (Cushman and Hughes, 1925)

Plate 4, figures 23-26

Cassidulina californica CUSHMAN and HUGHES, 1925, p. 12, pl. 2, fig. 1; TODD and LOW, 1967, p. A37, pl. 5, fig. 13.

Islandiella californica (Cushman), RODRIGUES, HOOPER, and JONES, 1980, p. 49, pl. 3, figs. 1, 4, 7, 10; FINGER, 1990, p. 138, pl.-figs. 1-6; 1992, p. 80, pl. 18, figs. 19-20.

Description.—Test large, globular to subovate, broadly oval in side view, sides nearly parallel, periphery rounded, slightly lobulate, slightly compressed; chambers distinct, four to five in final whorl, inflated, planispirally enrolled; sutures distinct, depressed, flush with surface, slightly limbate; wall calcareous, thick, matte-like (porcelaneous-appearance), finely perforate, optically radial; aperture, elongate, slightly ovate, slightly curved, at base of apertural face, with tooth-plate partially filling aperture.

Remarks.—This species is closest to *I. islandica*. It differs by having a thick wall and matte-like appearance (Rodrigues et al., 1980). Also, the test is slightly more compressed than the more subglobular *I. islandica*. It is originally described from Pliocene strata of Timms Point, California, and also widely recorded from Pleistocene-Holocene strata of the North Pacific, including Washington and British Columbia (Todd and Low, 1967). It is characterisitic of the upper bathyal biofacies (Ingle, 1980).

Age range.—Early?/middle Miocene to Holocene (Finger, 1990).

Islandiella helenae Feyling-Hanssen and Buzas, 1976

Plate 4, figures 28-29

Islandiella helenae FEYLING-HANSSEN and BUZAS, 1976, p. 155, figs. 1-4; RODRIGUES, HOOPER, and JONES, 1980, p. 49, pl. 1, figs. 1, 3, 5; pl. 4, figs. 3, 6, 9; pl. 6, figs. 1, 2; PATTERSON, BURBIDGE and LUTERNAUER, 1998, p. 15, pl. 31, figs. 1-3;

Description.—Test biconvex, lenticular, periphery subacutely thickened, broadly rounded, evolute, umbilical region thickened and clear with previous whorls visible; chambers, four pairs in final whorl, biserially arranged, large, rhomboid shaped, slightly inflated; sutures distinct, flush with surface; wall calcareous, hyaline, translucent, smooth, moderately perforate, distinctly radial in polarized light; aperture short, broad slit, parallel to peripheral margin, with outward projecting apertural tongue.

Remarks.—This species commonly occurs with numerous other *Islandiella* spp. in the coastal waters off Canada, Alaska and Greenland (Feyling and Buzas, 1980; Patterson et al., 1998). Within British Columbia shelf environments, it has been a good indicator of low salinity conditions (Patterson et al., 1998). It is similar in size and test shape to *I. norcrossi*, a species with which it commonly occurs. It has a different chamber arrangement and the position of the aperture is located in the plane of coiling in the latter species.

Age range.—Holocene (Feyling and Buzas, 1980).

Islandiella islandica (Nørvang, 1945)

Plate 4, figures 30-33

Cassidulina islandica NØRVANG, 1945, p. 41, text-fig. 7.

Islandiella islandica (Nørvang), RODRIGUES, HOOPER and JONES, 1980, p. 49, pl. 1, figs. 2, 4, 6; pl. 3, figs. 2, 5, 8; McDOUGALL, BROUWERS and SMITH, 1986, p. 52, pl. 1, fig. 3; PATTERSON, 1989, p. 238, pl. 10.5, fig. 5.

Description.—Test large, rounded to subovate, periphery rounded; chambers few, four to five pairs in final whorl, inflated, slightly lobulate, final chamber usually more inflated than others; sutures distinct, flush with surface, slightly limbate; wall calcareous, hyaline, smooth matte (porcelaneous), finely perforate, optically radial; aperture elongate, slightly triangular, parallel to periphery, with a thin apertural plate, bordered on outer margin by a lip formed from infolded chamber wall.

Remarks.—This species is closest to *I. californica*. It differs mainly by having thinner walls and greater inflation of the chambers (see "Remarks" for *I. californica*). It is characteristic of the outer neritic (?)/upper bathyal biofacies (Ingle, 1980).

Age range.—Pliocene to Holocene.

Islandiella limbata (Cushman and Hughes)

Plate 4, figures 34-36

Cassidulina limbata CUSHMAN and HUGHES, 1925, p. 12, pl. 2, fig. 2; TODD and LOW, 1967, p. A37; RAU, 1970, p. 29, pl. 3, fig. 2.

Islandiella limbata (Cushman and Hughes), PATTERSON, 1989, p. 238, pl. 10.5, fig. 3.

Description.—Test nearly circular, biconvex, periphery slightly lobulate, slightly carinate, slighty compressed; chambers numerous, five to six alternating pairs in final whorl, tibia-shaped, final chamber slightly projecting; sutures distinct, depressed, broadly limbate, curved; wall calcareous, smooth, finely perforate, distinct, central umbo of clear shell material, optically radial; aperture, narrow, elongate, parallel to axis of coiling, with slight lip and small tooth-plate.

Remarks.—This species is distinguished from other *Islandiella* spp. by its numerous curved, tibia-shaped chambers, distinctly limbate sutures, clear umbo and apertural features. Based on its optically radial walls, Feyling-Hanssen and Buzas (1980) suggested that this species be placed in the genus *Islandiella*. It is characteristic of the upper bathyal biofacies (Ingle, 1980).

Age range.—Miocene to Holocene (Todd and Low, 1967; Rau, 1970).

Islandiella norcrossi (Cushman, 1933)

Plate 4, figures 37-39

Cassidulina norcrossi CUSHMAN, 1933, p. 7, pl. 2, fig. 7. LOEBLICH and TAPPAN, 1953, p. 120, pl. 24, fig. 2; TODD and LOW, 1967, p. A37, pl. 5, fig. 11.

Islandiella norcrossi (Cushman), RODRIGUES, HOOPER and JONES, 1980, p. 49, pl. 4, figs. 1, 4, 7; pl. 6, figs. 8, 9; McDOUGALL, BROUWERS and SMITH, 1986, p. 52, pl. 1, fig. 4; PATTERSON, BURBIDGE and LUTERNAUER, 1998, p. 15, pl. 14, figs. 1-2; pl. 31, figs. 4-6; POLYNAK, KORSUN, FEBO, STANOVOY, KHUSID, HALD, PAULSEN and LUBINSKI, 2002, p. 269, pl. 2, fig. 13.

Description.— Test biconvex, lenticular, strongly compressed, periphery slightly keeled, evolute, umbilical region clear with previous whorls visible; chambers four to five pairs in final whorl, planispirally enrolled, triangular in shape (appearing star-shaped) and reaching umbilical boss, slightly inflated; sutures distinct, slightly curved; wall calcareous, hyaline, translucent, smooth, finely perforate, distinctly radial in polarized light; aperture elongate, loop-shaped slit in plane of coiling, with internal apertural tooth-plate.

Remarks.—This species is close to *I. helenae*, in test size and shape, and can be distinguished by the characteristics of the chambers and an aperture that is situated in the plane of coiling rather than the peripheral margin (see "Remarks" for *I. helenae*). It is characterisitic of the upper bathyal biofacies (Ingle, 1980).

Age range.—Holocene.

Family Cibicididae Cushman, 1927

Genus *Cibicides* de Montfort, 1808

Cibicides conoideus Galloway and Wissler, 1927

Plate 5, figure 1

Cibicides conoideus GALLOWAY and WISSLER, 1927, p. 63, pl. 10, fig. 7; RAU, 1970, pl. 3, fig. 13.

Description.—Test small, planoconvex, spiral side evolute with a distinct large, clear umbonal boss, opposite side involute and umbilicate, periphery broadly rounded; chambers eight to nine in final whorl, slightly inflated; sutures distinct, depressed, slightly curved, slightly limbate; walls coarsely perforate; aperture small, slightly lipped slit, at base of final chamber.

Remarks.—This species has been described from Pliocene-Pleistocene strata and the Pliocene Quinault Formation of Washington. It is fairly distinct, but rare with a restricted occurrence. It is similar to the *Cibicidoides barnetti* (Bermúdez) in its shape, large clear umbo, and lipped aperture. However, it differs in having a planoconvex, not biconvex test, fewer chambers and coarsely perforated walls that give a rough textured appearance. Like *C. mckannai*, it is probably characteristic of the upper bathyal biofacies (Ingle, 1980).

Age range.—Pliocene to Holocene.

Cibicides elmanensis Rau, 1948

Plate 5, figures 2-3

Cibicides elamanesis RAU, 1948, p. 173, pl. 31, figs. 18-26; 1963, p. 143, pl. 13, fig. 6; McDOUGALL, 1980, p.45, pl. 22, figs. 10-12; pl. 23, figs. 1-3.

Description.—Test biconvex, umbilical side more convex than spiral side, periphery limbate, with an umbilical plug; chambers numerous eight to 10 in final whorl, slightly inflated, especially last two; sutures slightly depressed and/or flush with surface; wall thick, coarsely perforate (large pores); aperture low interomarginal arch at base of last chamber, extending to spiral side.

Remarks.—This species resembles *Cibicides lobatulus*, but it is biconvex (not planoconvex) it lacks a strongly lobulate periphery and the arcuate chamber arrangement, and it may share an evolutionary relationship with *C. lobatulus*. As with *C. lobatulus*, it displays great morphological variation (Rau, 1963). It was originally described from Oligocene strata from the Lincoln Formation of Washington (Rau, 1948). It has been recorded in older Eocene/Oligocene strata (McDougall, 1980) and the early Miocene of western Washington (Rau, 1963). Biofacies assignment is uncertain, but is probably outer nertic (Ingle, 1980) based on other co-occurring taxa.

Age range.—Middle Eocene (Ulatisian) to Early Miocene (Saucesian).

Cibicides lobatulus (Walker and Jacob, 1798)

Plate 5, figures 4-6

Nautilus lobatulus WALKER and JACOB, 1798, p. 672, pl. 14, fig. 36.

Truncatulina lobatulus (Walker and Jacob), BAGG, 1912, p. 82, pl. 24, figs. 9-14.

Cibicides lobatus (Walker and Jacob), GALLOWAY and WISSLER, 1927, p. 64, pl. 11, fig. 1; BANDY, 1950, p. 279, pl. 42, fig. 9; RAU, 1964, p. G24, pl. 7, fig. 9.

Cibicides lobatulus (Walker and Jacob), CUSHMAN and GRAY, 1946, p. 45, pl. 8, fig. 14; CUSHMAN and TODD, 1947, p. 23, pl. 4, fig. 6.; TODD and LOW, 1967, p. 34, pl. 5, figs. 1, 2, 4; SMITH, 1978, p. 154, pl. 6, fig. 12; HALLER, 1980, p. 266, pl. 18, fig 5; HOLBURN and HENDERSON, 2002, p. 16, figs. 3.1-3.

cf. *Cibicides grossa* (Dam and Walker), OSTERMAN, 1996, p. 192, pl. 1, figs. 10-11.

Description.—Test planoconvex, medium to highly compressed, trochospiral, dorsal side slightly concave, ventral with slightly depressed umbilical region, periphery lobate, angled and keeled; imperforate periphery; chambers slightly inflated, arcuate, seven to nine in final whorl where they markedly increase in size; sutures distinct and re-curved, slightly oblique and depressed on umbilical side; walls thick, coarsely perforate; aperture narrow interomarginal, with a lip, located at base of last chamber, extending to spiral side.

Remarks.—This cosmopolitan, long ranging species demonstrates a wide range of morphological variation that reflects its life mode. It lives attached to a hard or an algal substrate (Nyholm, 1961). It is distinguished from other *Cibicides* species by its thickened test and distinct lobate periphery. It differs from *Cibicides* (*Lobatula*) *fletcheri* Galloway and Wissler, by lacking a well developed, translucent umbilical boss; it is less robust than *C. grossa*. It is considered characteristic of the inner neritic biofacies (Ingle, 1980),

Age range.—Late Pliocene to Holocene.

Genus *Cibicidoides* Thalman, 1939

Cibicidoides mckannai (Galloway and Wissler, 1927)

Plate 5, figures 7-8

Cibicides mckannai GALLOWAY AND WISSLER, 1927, p. 65, pl. 10, figs. 5, 6. HALLER, 1980, p. 266, pl. 18, figs. 1, 2.

Cibicides spiralis NATLAND 1942, p.151 , pl. 7, fig. 7.

Cibicides mckannai Galloway and Wissler var. *suppressus*, MARTIN, 1952, p. 126, pl. 20, fig. 3.

Cibicidoides mckannai (Galloway and Wissler), FINGER, 1992, p. 86, pl.-figs. 1-8.

Lobatula mckannai (Galloway and Wissler), PATTERSON, BURBIDGE AND LUTERNAUER, 1998, p. 19, pl. 19, figs. 7-9.

Description.—Test biconvex, trochoid, periphery slightly rounded and keeled, umbo region contains clear shell material; chambers numerous nine to 10 in final whorl; sutures curved dorsally, thickened and slightly depressed ventrally; wall coarsely perforate; aperture low interomarginal with a distinct lip, peripheral and extending slightly towards dorsal and ventral sides.

Remarks.—Previous generic assignment for this species includes *Cibicides*, *Cibicidoides* and *Lobatula*. Placement within *Cibicidoides* is favored herein, because the test is biconvex and biumbonate, rather than the umbilical side being strongly convex and the spiral side being flat to excavated, as in *Cibicides* (*Lobatula*). Also, on the spiral side, a series of coarse, large pores are visible near the spiral suture in the earlier portion of the test. It is characteristic of the upper bathyal biofacies (Ingle, 1980; Finger, 1990).

Age range.—Miocene to Pliocene.

Family Ellipsolagenidae Silvestri, 1923

Subfamily Oolininae Loeblich and Tappan, 1961

Genus *Homalohedra* Patterson and Richardson, 1987

Homalohedra apiopleura (Loeblich and Tappan, 1953)

Plate 5, figure 9

Lagena apiopleura LOEBLICH and TAPPAN, 1953, p. 59, pl. 10 figs. 14-15; OLSON, 1990, p. 300, pl. 3, fig. 8.

Oolina apiopleura TODD and LOW, 1967, p. A28, pl. 3, fig. 24.

Homalohedra apiopleura (Loeblich and Tappan), PATTERSON, BURBIDGE and LUTERNAUER, 1998, p. 11, pl. 28, figs. 4-5.

Description.—Test ovoid, unilocular, base rounded with slight development at the aboral end; chamber singular; wall calcareous, finely perforate, ornamented; costae numerous, longitudinal, elevated, separated, thick, strong and merge at the upper part of test; aperture circular located at end of a short, tapered neck.

Remarks.—This species is closely related to *Homalohedra* (*Oolina*) *borealis* (Loeblich and Tappan). Both have strong longitudinal ribs (costae). It differs from *H. borealis* by being smaller and more ovate than globular. Also, the ribs merge and become fewer in number forming a collar at the base of the apertural neck, whereas the collar is smooth in the latter species. It has a cosmopolitan distribution in cold water environments. Biofacies assignment is uncertain, but possibly a bathyal depth.

Age range.—Plio-Pleistocene to Holocene.

Subfamily Ellipsolageninae Silvestri, 1923

Genus *Fissurina* Reuss, 1850

Fissurina barkeri Ujiié, 1990

Plate 5, figure 10

Fissurina barkeri UJIIÉ, 1990, p. 23, pl. 7, fig. 12.

cf. *Fissurina orbignyana* SEGUENZA, 1862, p. 66, pl. 2, figs. 19-20; HAYWARD, GRENFELL, REID and HAYWARD, 1999, p. 120, pl. 7, fig. 24.

Description.—Test unilocular, ovate, slightly compressed periphery carinate, tapered towards apertural end; wall calcareous, hyaline, smooth, finely perforate; keels three, outer and inner narrow, middle thick and blunt, all fused at oral end and at base end fused to produce a distinct projection that appears to bifurcate; aperture terminal, an elongate fissure with short, central, entosolenian tube, located at the end of a broad and slightly rounded, tapering apertural neck.

Remarks.—This species is similar to *F. orbignyana* in test shape and in the presence of three keels around the periphery of the test. It differs by having only a strong central keel, and a basal process where the three keels appear to fuse. The outer keel shows some breakage in this specimen. It is characteristic of the outer neritic biofacies (Ingle, 1980).

Age range.—Late Pliocene to Holocene.

Family Elphidiidae Galloway, 1933

Genus *Cribroelphidium* Cushman and Brönnimann, 1948

Cribroelphidium excavatum f. *clavatum* Cushman, 1930

Plate 5, figures 11-17

Elphidium incertum (Williamson) var. *clavatum* CUSHMAN, 1930, p. 20, pl. 7, fig. 10.

Elphidium clavatum Cushman, LOEBLICH and TAPPAN, 1953, p. 98, pl. 19, figs. 8-10; TODD and LOW, 1967, p. A33, pl. 4, figs. 16-17; LAGOE, 1979, pl. 1, figs. 3, 5-6.

Elphidium excavatum (Terquem) *alba* Feyling-Hanssen, McDOUGALL, BROUWERS and SMITH, 1986, p. 53, pl. 2, fig. 6.

Elphidium excavatum (Terquem) forma *clavata* Cushman, AUSTIN and SEJRUP, 1994, p. 120, pl. 2, fig. 11; OSTERMAN, 1996, p. 192, pl. 1, fig. 3.

Elphidium excavatum (Terquem) forma *clavatum* Cushman, HAYWARD and HOLLIS, 1994, pl. 5, figs. 6-8; HAYWARD, GRENFELL, REID and HAYWARD, 1999, p. 165, pl. 17, figs. 11-12.

Elphidium excavatum clavatum Cushman, HAYWARD, HOLLIS, GRENFELL, 1997, p. 76, pl. 8, figs., 14-17; pl. 9, figs. 1-8.

Description.—Test small to medium sized, planispiral, involute, periphery broadly rounded, slightly lobulate, umbilicate, with small central boss, umbilicus flush with surface to slightly raised; chambers distinct, numerous, 10 to 14 in final whorl, slightly inflated, increase gradually in size as added; sutures distinct, depressed, slightly curved; sutural pits in a single row, circular or elliptical, separated by short, wide sutural/septal bridge, ornamented by scattered pappilae; wall calcareous, hyaline, smooth, coarsely perforate, except on imperforate umbilical boss and apertural face; aperture interomarginal, a series of multiple small circular pores at base of apertural face.

Remarks.—This species is distinguished from *Cribroelphidium excavatum* f. *excavatum* by its imperforate umbilical collar and comparatively small umbonal boss, and in lacking the large, depressed star-shaped umbilicus, lined with papillae seen in the latter species.

Also it is distinguished from *Cribroelphidium foraminosum* by having scattered pappilae lining its sutural pits. The degree of lobulation of the test and the size and shape of the sutural pits appears to vary among specimens. It is characterisitic of the inner neritic biofacies (Ingle, 1980) or sheltered, slightly brackish environments (Hayward et al., 1997). The distribution of this species has been linked to cold, turbid water and glaciomarine environments (Hald et al., 1994).

Age range.—Miocene to Holocene (Hayward et al., 1997).

Cribroelphidium foraminosum? (Cushman, 1939)

Plate 5, figures 18-19

?*Elphidium hughesi* Cushman and Grant var. *foraminosum* CUSHMAN, 1939, p. 49, pl. 13, fig. 8.

?*Elphidium hughesi* Cushman and Grant, BERGEN and O'NEIL, 1979, p. 1290, pl. 1, figs. 1-2.

?*Cribroelphidium foraminosum* PATTERSON, BURBIDGE and LUTERNAUER, 1998, p. 22, pl. 24, figs. 6-8.

Description.—Test small to medium size, planispiral, involute, periphery broadly rounded, biumbonate; chambers distinct, numerous 10 to 12 in final whorl, slightly inflated increase gradually in size as added; sutures distinct, depressed, slightly curved; sutural pits in a single row, large rounded to slightly elongate/ovate sutural rows, separated by short sutural/septal bridges; wall calcareous, hyaline, smooth, coarsely perforate, except on imperforate umbilical boss and apertural face; aperture interomarginal, a series of multiple small circular pores at base of apertural face.

Remarks.—This species is probably close to or probably *Cribroelphidium excavatum clavatum* by having a slightly lobulate, broadly rounded periphery of the the test and sutural patterns. It slightly differs by not having scattered papillae in its sutural pits and by having noticeably more sutural pores. These reasons suggest only questionable placement within *C. foraminosum*. This species is characterisitic of the inner neritic biofacies (Ingle, 1980).

Age range.—Pliocene (Cushman, 1939) to Holocene (?).

Genus *Elphidiell*a Cushman, 1936

Elphidiella hannai (Cushman and Grant, 1927)

Plate 5, figure 20

Elphidium hannai CUSHMAN and GRANT, 1927, p. 77, pl. 7, fig. 1

Elphidiella nitida CUSHMAN, 1941, p. 35, pl. 9, fig. 4; BERGREN and O'NEIL, 1979, p. 1290, pl. 1, figs. 3-4; PATTERSON, 1989, p. 238, pl. 10.10, fig. 3.

Elphidiella hannai (Cushman) emend., HALLER, 1980, p. 242, pl. 6, fig. 4; FEYLING-HANSSEN, 1990, p. 29, pl. 7, figs. 1-7; PATTERSON, BURBIDGE and LUTERNAUER, 1998, p. 22, pl. 26, figs. 3-4.

Description.—Test of medium to large size, lenticular, planispiral involute, periphery rounded; chambers distinct, numerous, 13 to 15 in final whorl, not inflated; sutures distinct, depressed, thickened, slightly curved, bordered by a double row of sutural pores extending from periphery to umbilical region; wall calcareous, hyaline, smooth, irregulary postulose at and near apertural face, optically radial; aperture interomarginal, large, distinct, consisting of a row of pores at base of apertural face of final chamber, and numerous irregularly scattered over outer wall near apertural face.

Remarks.—This species can be distinguished from other *Elphidiella* spp. by its planispiral involute test and distinct, slightly pustulose irregulary shaped and sized pores, scattered over the entire apertural face, and slightly extending to the umbilicus on either side of the test. *Elphidiella nitida* is considered a junior synonym because its original description is nearly identical to that of *E. hannai*. It is characteristic of the inner neritic biofacies (Ingle, 1980).

Age range.—Pliocene (Cushman and Grant, 1927; Haller, 1980).

Elphidiella oregonense (Cushman and Grant, 1927)

Plate 5, figures 21-22

Elphidium oregonense CUSHMAN and GRANT, 1927, p. 79, pl. 8, fig. 3; TODD and LOW, 1967, p. A34, pl. 4, fig. 18.

Elphidiella oregonensis (Cushman and Grant) HALLER, 1980, p. 242, pl. 6, fig. 2.

Description.—Test large, complanate, stongly compressed, periphery rounded, umbilical region strongly biumbonate with a extremey large rounded umbonal boss of clear shell material, umbonal areas smooth, not depressed; chambers numerous, up to or greater than 20 in the final whorl, slightly inflated; sutures distinct, slightly depressed, bordered by a double row of large sutural pores infilled with fine papillae, slightly limbate; wall calcareous, hyaline, smooth, thick, finely perforate; aperture interomarginal, small, low, broad opening in face of apertural face, with circular pores irregularly scattered in middle of flattened walls of apertural face.

Remarks.—This species is easily distinguished by its large biumbonate test and characteristic oblong apertural face. It has a rare, sporadic occurrence in Pliocene/Pleistocene strata of the Tofino Basin. It is characteristic of the inner neritic biofacies (Ingle, 1980) and commonly occurs with *E. hannai.*

Age range.—Pliocene to Holocene (Todd and Low, 1967).

Elphidiella sp. aff. *E. oregonense*

Plate 5, figure 23

aff. *Elphidium oregonense* CUSHMAN and GRANT, 1927, p. 79, pl. 8, fig. 3; TODD and LOW, 1967, p. A34, pl. 4, fig. 18.

aff. *Elphidiella oregonensis* (Cushman and Grant) HALLER, 1980, p. 242, pl. 6, fig. 2.

Description.—Test of large size, bilaterally symmetrical, planispiral involute, strongly compressed, slightly elongate, periphery acute, not keeled; chambers numerous 15 to 17 in final whorl, non-inflated, umbonal region fairly flat, clear; sutures depressed, slightly flush, slightly curved, double row of rounded sutural pores present separated by short, thin sutural/septal bridges, evenly spaced; wall calcareous, hyaline, smooth, finely perforate; aperture interomarginal, a series of circular pores scattered on flattened apertural face; apertural face long and narrow.

Remarks.—The single specimen recovered appears to have slightly weathered tests and sutural pores are infilled with sediment. It is similar to *E. oregonense* in shape and size, but differs by lacking the characteristic large umbonal boss, having less distinct sutures and fewer chambers. Since it was found to occur with *E. hannai* and *E. oregonense*, it is possibly characteristic of the inner neritic biofacies (Ingle, 1980).

Age range.—Pliocene-Pleistocene.

Elphidiella sp. A

Plate 5, figure 24

Description.—Test of large size, bilaterally symmetrical, planispiral, involute, biumbonate, slightly compressed, periphery acute, slightly lobulate, umbonal regional flattened with a faint, slightly raised reticulate pattern; chambers numerous, 14 to 17 in final whorl, non-inflated to slightly inflated; sutures depressed, slightly flush, slightly curved, double row of sutural pores ornamented by fine papillae, eight to10 short sutural/septal bridges; wall calcareous, hyaline, smooth, finely perforate; aperture interomarginal, a series of circular pores at base of apertural face; apertural face long and narrow.

Remarks.—This species is distinguished from other *Elphidiella* spp. by its slightly reticulate umbonal region and presence of fine papillae within and around sutural pores. The species may have some affinity with *Elphidium*(?) *jenseni* (Cushman) in the regular arrangement of the sutural lines and the presence of fine papillae in the the umbilical region. A double row of sutural pores that are more distinct towards the peripheral margin of the test were observed in this specimen placing it in the genus *Elphidiella*. Also, the test is larger and more compressed than *E. oregonense*. Only one specimen was found to occur with *E. hannai* and *E. oregonense* and is characteristic of the inner neritic biofacies (Ingle, 1980)

Age range.—Pliocene-Pleistocene.

Genus *Elphidium* Montfort, 1808

Elphidium sp. cf. *E. hispidulum* Cushman, 1936

Plate 5, figure 25

cf. *Elphidium hispidulum* CUSHMAN, 1936, p. 83, pl. 14, fig. 13; HAYWARD, HOLIS and GRENFELL, 1997, p. 82, pl., 1, fig. 14; pl. 12, figs. 5-7.

Description.—Test medium to large size, planispiral, involute, biconvex, discoidal, stout, periphery acutely rounded, lobulate, peripheral margin not keeled; strong umbonal boss present; chambers numerous, 16 to 20 in final whorl, increase in size gradually as added; sutures distinct, strongly limbate, slightly curved; wall calcareous, hyaline, coarsely perforate; costae strong, irregular, form distinct concentric ribs near margin (slightly projecting), span several chambers, hispid papillae-like in early series of chambers, strengthened on earlier chamber, join to form anastomosing pattern on later chambers; aperture indistinct (broken).

Remarks.—Specimens are distinguished by their strongly hispid/ribbed ornamentation developed in a concentric series. Specimen are usually abraded and recovered with broken apertural regions. This species is close to *E. hispidulum* Cushman. It differs by having slightly 2-3 more chambers and elevated, thickened ribs that give the test a strong and resilient appearance. No comparisons could be made on the apertural region. Also, it may be close to *E. reticulosum* with its development of concentric, anastomosing ribs. It differs by lacking the reticulate (worm-like riblet) ornamentation found in *E. reticulosum*. It is characteristic of the inner neritic biofacies (Ingle, 1980; Hayward et al., 1997).

Age range.—Pliocene-Pleistocene (this study) to Holocene (Hayward et al., 1997).

Family Fursenkoinidae Loeblich and Tappan, 1961

Genus *Fursenkoina* Loeblich and Tappan, 1961

Fursenkoina schreibersiana (Cžjžek, 1848)

Plate 5, figures 26-27

Virgulina schriebersiana CŽJŽEK, 1848, p. 147, pl. 13, figs. 18-21.

Fursenkoina schreibersiana (Cžjžek), LOEBLICH and TAPPAN, 1994, p. 131, pl. 257, figs. 1-12; HAYWARD, GRENFELL, REID and HAYWARD, 1999, p. 136, pl. 9, fig. 29.

Description.—Test elongate, narrow, fusiform, rounded to ovate in cross-section, tapered and rounded towards base; chambers numerous eight to 11, slightly inflated, slightly elongate, slightly globular in early stages, triserially arranged in early stages, later biserially arranged; sutures distinct, depressed; wall calcareous, hyaline, smooth, finely perforate, thick; aperture elongate, across final chamber, narrow slit, bordered by a lip.

Remarks.—This species has been called *Virgulina schreibersiana*, *Stainforthia schreibersiana* and *Fursenkoina schreibersiana*. A study by Schmid (1985; reiterated in Knudsen and Seidenkrantz, 1994), concluded that *F. schreibersiana* is a junior synonym of *Fursenkoina acuta* (d'Orbigny, 1846 as *Polymorphina acuta*). The original description of *Polymorphina acuta* d'Orbigny, describes a radiate aperture, not an elongate narrow slit across the final chamber. Therefore *F. acuta* is not considered the senior synonym, herein, and this species is retained in *Fursenkoina* where the aperture is an elongate slit rather than in *Virgulina* and *Stainforthia* where the aperture is loop-shaped opening. *Fursenkoina schreibersiana* has a cosmopolitan distribution (Loeblich and Tappan, 1994; Hayward et al., 1999), and occurs in low numbers in the Tofino Basin. It is characteristic of the inner to outer neritic biofacies (Ingle, 1980; Hayward et al., 1999)

Age range.—Late Eocene to Holocene (Hayward et al., 1999).

Genus *Rutherfordoides* McCulloch, 1981

Rutherfordoides virga (Nomura, 1983)

Plate 5, figure 28

Hastilina virga NOMURA, 1983, p. 84, pl. 2, fig. 15.

Rutherfordoides virga (Nomura), LOEBLICH and TAPPAN, 1994, p. 132, pl. 258, figs. 8-14.

Description.—Test elongate, slightly compressed in initial end, periphery not lobulate; chambers fairly distinct, four to five pairs biserially arranged, initially closely coiled, narrowly rounded, later stages rectilinear, last formed chamber suboval in shape; sutures slightly depressed, appearing straight, oblique, slightly curved towards periphery, not limbate; wall calcareous, hyaline, polished, smooth, finely perforate; aperture subterminal, large, elongate, narrow loop-shaped opening, extending from base of final chamber to its apex, with narrow inner lip.

Remarks.—The original description for this species includes two forms (possible ecophenotypic variants). The first is characterized by a more slender test, sharply pointed initial end and elongate loop-shaped aperture. The second is characterized by an elongate test, with a bluntly rounded initial end and, and a slightly curved loop-shaped aperture. Specimens from the Tofino Basin match the second form, with a short, distinctly rounded initial end and elongate, rectilinear in later stages. This species is close to *R. tenuis* (Phleger and Parker), sharing apertural characteristics and a similar chamber arrangement. It differs by being larger, less slender and with less inflated chambers. The biofacies assignment is uncertain but is probably an outer neritic/upper bathyal environment (Ingle, 1980).

Age range.—Pliocene to Holocene.

Genus *Suggrunda* Hoffmeister and Berry, 1937

Suggrunda kleinpelli Bramlette, 1951

Plate 5, figure 29

Suggrunda kleinpelli BRAMLETTE, in Woodring and Bramlette, 1951, p. 59, pl. 23, figs. 4-5, 9; FINGER, 1990, p. 232, pl.-figs. 1-8; 1992, p. 83, pl. 23, figs. 23-28.

Description.—Test small, cunieform, biserial, thickened medially, edges serrated; chambers numerous eight to 10 pairs, slightly inflated, quadrate, later ones higher and broader and backwards directed, slightly overlapping, increase in size gradually as added; sutures distinct, depressed, nearly straight to slightly downward curving; wall calcareous, smooth, finely perforate; aperture a hook-shaped loop on the inner margin at base of final chamber.

Remarks.—This species is close to *S. eckisi* Natland and *S. inflata* Finger and Lipps. It differs from the latter two species by having more quadrate, lower (less angled) chambers with downward projecting and greatly tapered corners. It differs from *S. inflata* which has a broadly ovate test with rounded edges, comparatively highly inflated chambers that increase in size rapidly as added, and a lower margin angle. It differs from *S. eckisi*, which has slightly fewer chambers that increase in size rapidly as added, a higher margin angle, and more spinose chamber margins. It is characteristic of the upper bathyal biofacies (Ingle, 1980; Finger, 1990).

Age range.—Early Miocene (Saucesian) to Holocene (Finger, 1990).

Family Gavelinellidae Hofker, 1956

Subfamily Gyroidinoidinae Saidova, 1981

Genus *Gyroidinoides* Brotzen, 1942

Gyroidinoides altiformis (Stewart and Stewart, 1930)

Plate 5, figures 30-31

Gyroidina soldanii d'Orbigny var. *altiformis* STEWART and STEWART, 1930, p. 67, pl. 9, fig. 2.

Gyroidina neosoldanii LOEBLICH and TAPPAN, 1994, p. 163, pl. 362, figs. 4, 6, 7; non pl. 361, figs. 13-15, non pl. 362, figs. 1-3, 5.

Hansenisca altiformis (Stewart and Stewart), FINGER, 1990, p. 124, pl.-figs. 1-8; 1992, p. 88, pl. 37, figs. 1-3.

Gyroidinoides altiformis (Stewart and Stewart), PATTERSON, BURBIDGE and LUTERNAUER, 1998, p. 21, pl. 22, figs. 4-7.

Description.—Test medium size, plano-convex, trochospiral, periphery bluntly rounded and angled, dorsal (spiral) side flattened, ventral (umbilical) side strongly convex and deeply umbilicate; chambers distinct, numerous, nine to 12 in final whorl, slightly curved; sutures distinct, depressed, limbate, on dorsal side slightly oblique, ventral side radial and slightly curved; wall calcareous, hyaline, smooth, finely perforate, granular; aperture low interomarginal slit, extends from peripheral margin to ventral side, with an apertural flap and apertural face that is flattened.

Remarks.—This species was originally considered to be a variation of *Gyroidina soldanii*, which has since been assigned to the genus *Hansenisca* (Loeblich and Tappan, 1987). The form of the aperture (a single, more extensive, low interomarginal slit) precludes this species from the genera *Gyroidina* and *Hansenisca*. *Gyroidina neosoldanii* is considered a junior synonym because it is identical in description to *Gyroidinoides altiformis*. It differs from *G. rotundimargo* a species with which it commonly occurs, by its less rouned periphery and curved chambers on the spiral side. It is common in the lower Pliocene of the Tofino Basin. This species is characteristic of the upper bathyal biofacies (Ingle, 1980; Finger 1990).

Age range.—Oligocene (Zemorrian) to Holocene.

Gyroidinoides rotundimargo (Stewart and Stewart, 1930

Plate 5, figures 32-34

Gyroidina soldanii d'Orbigny var. *rotundimargo* STEWART and STEWART, 1930, p. 68, pl. 9, fig. 3.

Hansenisca rotundimargo (Stewart and Stewart), FINGER and LIPPS, 1990, p. 46, pl. 9, figs. 7-12; FINGER, 1990, p. 128. pl.-figs. 1-9; 1992, p. 89, pl. 37, figs. 10-24.

Description.—Test medium size, plano-convex, trochospiral, periphery rounded, dorsal (spiral) side flattened and rounded, ventral (umbilical) side strongly convex and deeply umbilicate; chambers numerous, 10-12 in final whorl, slightly curved; sutures distinct, depressed, not limbate, on dorsal side slightly oblique, ventral side radial and slightly curved, nearly at right angle to direction of coiling; wall calcareous, hyaline, smooth, finely perforate, granular; aperture low interomarginal slit, extending from peripheral margin to ventral side, with apertural flap, apertural face slightly flattened.

Remarks.—This species is closest to *G. altiformis*, a species with which it normally occurs. It differs by having rounded periphery, deeply umbilicate ventral side, being distinctly inflated with wider chambers and sutures that are normal to the direction of coiling. It is characteristic of the upper middle bathyal biofacies (Ingle, 1980; Finger, 1990).

Age range.—Middle (Relizian) to late (Delmontian) Miocene (Finger, 1990).

Family Glandulinidae Reuss, 1860

Subfamily Glandulininae Reuss, 1860

Genus *Glandulina* d'Orbigny, 1939

Glandulina sp. cf. *G. contracta* Cushman and Todd, 1947

Plate 6, figure 1

cf. *Glandulina contracta* CUSHMAN and TODD, 1947, p. 35, pl. 5, fig. 20.

aff. *Glandulina suezensis* McCULLOCH, 1977, p. 13, pl. 96, figs. 1, 3-4; LOEBLICH and TAPPAN, 1994, p. 97, pl. 168, fig. 12.

Description.—Test strongly fusiform, elliptical/ovate in side view, tapering rapidly towards both ends, but slightly rounded at apertural end, greatest width just below mid-line; chamber pyriform, embracing (final chambers covers up previous chambers), last one forming more than two-thirds of test; sutures fairly indistinct, flush with surface;

wall thick, smooth, finely perforate, opaque; aperture terminal, radiate and located on short, broad neck.

Remarks.—This species may have affinity with *G. suezensis* McCulloch. It lacks the short, hyaline basal spine and is tapered towards the ends. It is similar to *G. contracta* Cushman and Todd, comparable in size, shape and in lacking the basal spine. All of these forms differ from the genotype *Nodosaria* (*Glandulina*) *laevigata*, Orbigny, in being tapered and elongate. This species is characteristic of the upper middle bathyal biofacies (Ingle, 1980).

Age range.—Oligocene? to Holocene.

Family Lagenidae Reuss, 1862

Genus *Lagena* Walker and Jacob, 1798

Lagena flatulenta Loeblich and Tappan, 1953

Plate 6, figure 2

Lagena flatulenta LOEBLICH and TAPPAN, 1953, p. 60, pl. 11, figs. 9-10; PATTERSON, BURBIDGE and LUTERNAUER, 1998, p. 8, pl. 29, fig. 3.

Description.—Test unilocular, ovate, periphery rounded, circular in cross-section; chamber spherical; wall calcareous, hyaline, smooth, finely perforate; aperture terminal, rounded with a slight phialine lip, on end of an elongate, narrow and delicate tube-like neck.

Remarks.—Variablility in specimens include a rounded to flask-shaped test, and differences in the length of the neck, that are generally proportional to the size of the test. A bathyal biofacies is probable for this species.

Age range.—Pliocene to Holocene.

Lagena spiratiformis? McCulloch, 1981

Plate 6, figure 3

?*Lagena spiratiformis* McCULLOCH, 1981, p. 96, pl. 32, figs. 15-16; HAYWARD, GRENFELL, REID and HAYWARD, 1999, p. 116, pl. 7, figs. 6-7.

aff. *Lagena substriata* WILLIAMSON, 1858, p. 15, pl. 2, fig. 12; LOEBLICH and TAPPAN, 1994, p. 79, pl. 138, figs. 1-5.

cf. *Lagena sulcata* var. *spicata* CUSHMAN and McCULLOCH, 1950, p. 360, pl. 48, fig. 3-7.

cf. *Lagena spicata* Cushman and McCulloch, PATTERSON, BURBIDGE and LUTERNAUER, 1998, p. 9, pl. 29, figs. 4-5.

Description.—Test unilocular, subglobular, periphery rounded, widest at the midline, round in cross-section; chamber singular, spherical; wall calcareous, hyaline, finely perforate and smooth between costae; costae numerous (~25), long costae, which extend from base of test to base of apertural neck (broken in this specimen), a few discontinuous costae; aperture is broken.

Remarks.—The apertural neck and aperture of specimens are usually fragmented, hence species level placement is in question. However, there are numerous thick costae with a few shorter (discontinuous) ones interspersed between longer ones. It is similar to the illustrated specimen in Hayward et al. (1999). Hayward et al. (1999) consider *L. spiratiformis* as a possible junior synonym of *L. substriata*. *Lagena spiratiformis* differs by having slight variations in the number of costae and the test is more ovate or elongate than subglobular. Therefore, there is affinity with the *L. substriata*. This form is close to *L. spicata* (which is similar to *L. substriata*) in the number and arrangement of costae. It lacks the stout spine at the base of the test characterized in *L. spicata*, however, the spine may be broken off in this specimen. This is a rare species in the Tofino Basin. It is characteristic of a bathyal biofacies.

Age range.—Late Miocene to Holocene.

Genus *Procerolagena* Puri, 1954

Procerolagena meridionalis (Wiesner)

Plate 6, figure 4

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

Lagena meridionalis Wiesner, LOEBLICH and TAPPAN, 1953, p. 62, pl. 12, fig. 1; TODD and LOW, 1967, p. A24, pl. 3, fig. 21; Non HERMELIN, 1989, p. 42, pl. 4, fig. 12.

Procerolagena meridionalis (Wiesner), LOEBLICH and TAPPAN, 1994, p. 79, pl. 143, figs. 7-11; PATTERSON, BURBIDGE and LUTERNAUER, 1998, p. 9, pl. 4, fig. 7.

Description.—Test unilocular, ovate, elongate, apertural end tapered, base slightly rounded and broad; wall calcareous, hyaline, finely perforate between costae; costae numerous, longitudinal, alternate between short and long, extend from base to aperture; aperture terminal, small and rounded at end of a very short, blunt neck.

Remarks.—This species is characterized and differentiated from other *Procerolagena* spp. by having dual alternating costae that are blunt, thick and sharp costae, fewer in number, extend from the base of the test and terminate at the aperture. Numerous thinner costae alternate and extend up from the base and terminate at the base of the neck. The described and illustrated specimen in Hermelin (1989) is too elongate and tapered, with a pointed, not rounded base, and therefore is not considered to be *P. meridionalis* herein. The apertural end in specimens are not well developed and may be broken. This species is rare in Tofino Basin. It is characterisitic of the inner(?)/outer neritic biofacies (Ingle, 1980).

Age range.—Late Pliocene to Holocene.

Genus *Reussoolina* Colom, 1956

*Reussoolina sim*plex (Reuss, 1851)

Plate 6, figure 5

Oolina simplex REUSS, 1851, p. 22, pl. 2, fig. 2.

Reussoolina simplex (Reuss) FINGER, 1992, p. 74, pl. 8, figs. 6-7.

Description.—Test globose to subovate, unilocular, periphery rounded, widest at midline; wall calcareous, smooth, finely perforate; aperture small, terminal, radiate, at end of a short apical neck.

Remarks.—The globose test and aperture of this species is simple and closely resembles several other species (i.e. *Oolina globosa* (Montagu)). It best fits the original description and illustration. The features of the aperture are difficult to observe, however a radiate aperture rather than a simple round opening was observed in this specimen. Biofacies assignment is uncertain, but is probably bathyal.

Age range.—Miocene to Holocene.

Family Nodosariidae Ehrenberg, 1838

Subfamily Lenticulininae Chapman, Parr and Collins, 1934

Genus *Lenticulina* Lamarck, 1804

Lenticulina miocenica (Chapman, 1900)

Plate 6, figure 14

Cristellaria miocenica CHAPMAN, 1900, p. 250, pl. 30, fig. 1.

Lenticulina miocenica FINGER and LIPPS, 1990, p. 47, pl. 3, figs. 25-26; FINGER, 1990, p. 154, pl.-figs. 1-10; 1992, p. 71, pl. 3, figs. 49-57.

Description.—Test large, planispiral, slightly elongate, biumbonate particularly from mid point towards apertural end; slightly compressed, periphery slightly carinate; chambers numerous, 12-14 in final whorl, fairly indistinct, narrow, gradually increasing in size as added; sutures straight to slightly curved, flush with surface; wall calcareous, translucent, finely perforate; aperture, terminal, radiate, at peripheral angle.

Remarks.—These large specimens are easily distinguished from other *Lenticulina* spp. by the tendency for elongation of the test and chambers (Finger, 1990), particulary in the later portion of the test. This gives the test a slender lenticular appearance. The species is characterisitic of the upper middle bathyal biofacies (Ingle, 1980; Finger, 1990).

Age range.—Early (Saucesian) to early middle Miocene (Luisian; Finger, 1990).

Lenticulina smileyi (Kleinpell, 1938)

Plate 6, figures 15-16

Robulus smileyi KLEINPELL, 1938, p. 158, figs. 1-8.

Lenticulina smileyi FINGER and LIPPS, 1990, p. 47, pl. 3, figs. 31-32; FINGER, 1990, p. 158, pl.-figs. 1-8; 1992, p. 71, pl. 4, figs. 12-31.

Description.— Test large, planispiral, biumbonate, slightly compressed, periphery slightly carinate, umbilical area slightly raised, with clear central boss; chambers numerous, 12-14 in final whorl, fairly distinct, narrow, gradually increase in size as added; sutures straight to slightly curved, slightly limbate, flush with surface; wall calcareous, thick, translucent, finely perforate; aperture, terminal, radiate, at peripheral angle.

Remarks.—This species has a rounded periphery and less elongate test than *L. miocenica*. It is characteristic of the upper middle bathyal biofacies (Ingle, 1980; Finger, 1990).

Age range.—Oligocene (Zemorrian) to Middle Miocene (Mohnian; Finger, 1990).

Subfamily Lingulininae Loeblich and Tappan, 1961

Genus *Lingulina* d'Orbigny, 1826

Lingulina? sp. A

Plate 5, figure 13

Description.—Test stout, elongate, rectilinear, slightly compressed, with straight sides, apertural end broadly rounded and slightly produced; wall calcareous, smooth, finely perforate, with slight abrasion, giving a roughened appearance; aperture terminal, narrow, elongate slit.

Remarks.—This species is distinguished by its large rectilinear test, with nearly straight sides and a distinct aperture. Separate chambers or distinct sutures were not observed. Therefore this specimen was tentatively placed within *Lingulina* based on the apertural characteristics. It is probably characteristic of the outer neritic biofacies (Ingle, 1980).

Age range.—?Eocene to Holocene.

Subfamily Nodosariinae Ehrenberg, 1838

Genus *Dentalina* Risso, 1826

Dentalina sp. A

Plate 6, figure 6

Description.—Test uniserial, slightly arcuate; chambers few, two , inflated, nearly equidimensional, rounded to slightly tear-drop shaped, rounded protuberances developed terminally on both ends; sutures distinct, depressed, straight, horizontal; wall calcareous, smooth, finely perforate; aperture terminal, rounded, located on a rounded protuberance at apertural end.

Remarks.—This species slightly resembles *Dentalina pseudoobliqua* Finger and Lipps (1990). It differs by having a smaller, shorter, stouter test consisting of fewer chambers with terminal protuberances on the anterior and posterior ends. It is characteristic of a bathyal biofacies.

Dentalina sp. cf. *D. frobisherensis* Loeblich and Tappan, 1953

Plate 6, figures 7-9

cf. *Dentalina frobisherensis* LOEBLICH and TAPPAN, 1953, p. 55, pl. 10, figs. 1-9; McDOUGALL, 1980, p. 52, pl. 1, fig. 7.

Description.—Test large, elongate, slender, straight to slightly arcuate, rounded in cross-section; chambers numerous, increase in height as added, initial chamber (proloculus) apiculate; sutures not depressed; wall calcareous, smooth, finely perforate, appearing slightly roughened to weakly striate; aperture terminal (broken), slightly produced.

Remarks.—This species is similar to *D. frobisherenis* by having a slightly arcuate, elongate and slender shaped test. There is slight variation among specimen in the thickness and length of the apical spine on the initial chamber. Most specimens possess a fairly robust apical spine. It is characteristic of a bathyal biofacies.

Age range.—Pliocene to Holocene.

Genus *Nodosaria* Lamarck, 1812

Nodosaria dusenburyi (Beck, 1943)

Plate 6, figure 10

Dentalina dusenburyi BECK, 1943, p. 599, pl. 105, figs. 20, 23; RAU, 1948, p. 167, pl. 30, fig. 24; McDOUGALL, 1980, p. 34, pl. 6, figs. 8-10; SPENCER, 1984, p. 161, pl. 3, fig. 8.

cf. *Nodosaria frankei* FINGER and LIPPS, 1990, p. 26, pl. 1, fig. 18.

Description.—Test large, elongate, uniserial; chambers inflated, spherical, subequal, number uncertain; sutures, distinct, deeply incised; wall calcareous, smooth finely perforate; costae numerous, longitudinal, slightly oblique, well-developed, fine on basal portion of chambers, terminate at or beyond sutures, distinctly pinched across sutures; aperture terminal, (broken in specimen).

Remarks.—The test of this species is commonly found broken. It is distinguished by the numerous, well developed costae that appear to be oblique and pinched across the sutures. *Nodosaria frankei* is similar but has more numerous fine costae. This species, initially placed in *Dentalina*, is herein assigned to *Nodosaria*, based on a multilocular test that is rounded in cross-section and has distinct sutures. It is characteristic of the outer neritic biofacies (Ingle, 1980).

Age range.—Eocene to Miocene.

Genus *Pseudonodosaria* Boomgaart, 1949

Pseudonodosaria discreta (Reuss, 1850)

Plate 6, figure 11

Glandulina discreta REUSS, 1850, p. 366, pl. 46, fig. 3.

Pseudonodosaria discreta (Reuss), LOEBLICH and TAPPAN, 1994, p. 66, pl. 117, figs. 1-3, non 4-6.

?*Rectoglandulina kirschneri* TAPPAN, 1957, p. 216, pl. 16, figs. 17-18.

Description.—Test large, elongate rectilinear, circular in cross-section, ends tapered; chambers large, three visible, initial chamber (at base) inflated and cylindrical with a distinctly tapered base or projection, middle chamber less inflated and cylindrical, final (uppermost) chamber much inflated, large, ovate and tapered to produce an apex; sutures depressed, distinct, horizontal; walls calcareous hyaline, smooth, finely perforate; aperture terminal, radiate, at centre of the apex of uppermost (final) chamber, slightly produced on a short tapered neck.

Remarks.—This species is similar in shape and chamber arrangement to *Rectoglandulina kirschneri*, a possible junior synonym of *P. discreta*, but with fewer chambers than the latter and less overlap of succeeding chambers. There may be slight variation in the number of chambers from two to four. Specimens illustrated by Loeblich and Tappan (1994; Pl. 117, figs. 4-6) appear to be closer to *Pseudonodosaria elongata* (Reuss) than to *P. discreta*. *Pseudonodosaria discreta* is characterisitic of a bathyal biofacies.

Age range.—Miocene to Holocene?

Pseudonodosaria obtusissima (Reus, 1863)

Plate 6, figure 12

Glandulina obtusissima REUSS, 1863, p. 66, pl. 8, figs. 92-93.

Pseudonodosaria obtusissima FINGER, 1992, p. 69, pl. 2, fig. 75.

Description.—Test large globulose, uniserial to rectilinear, periphery rounded, tapered to a sharp point at apertural end, widest above mid-line; chambers embracing, inflated, two visible; sutures weakly depressed, horizontal; wall calcareous, smooth, finely perforate; aperture terminal, radiate, distinct, slightly produced on a short tapered to pointed neck.

Remarks.—This species is distinguished by its distinct globular test shape, apertural characteristics, and with both microspheric and megalospheric forms. It is rare in the Tofino Basin and may be restricted to the Northeastern Pacific. It is characteristic of a bathyal biofacies.

Age range.—Miocene.

Subfamily Plectofrondiculariinae Cushman, 1927

Genus *Plectofrondicularia* Liebus, 1902

Plectofrondicularia packardi (Cushman and Schenck, 1928)

Plate 6, figures 17-18

Plectofrondicularia packardi CUSHMAN and SCHENCK, 1928, p. 311, pl. 43; McDOUGALL, 1980, p. 37, pl. 10, fig. 16, pl. 11, figs. 1-2.

Description.—Test slightly elliptical, compressed, elongate, initial end bluntly rounded, periphery acute; chambers distinct, numerous, highest in middle and gradually tapering towards ends, earliest coiling at proloculum in megalospheric form, few biserial, later ones inverted V-shaped, U-shaped coiling of initial chambers; sutures distinct, slightly limbate; wall calcareous, thin, translucent, smooth, finely perforate; costae short, raised, two to three in earliest chambers; aperture (broken).

Remarks.—Specimens are delicate and most were fragmented. This species is distinguished by the characteristic U-shaped coiling of the initial chambers and the short costae present on the initial end of the test. It may be close to *Proxifrons advena*, because the chamber shape and arrangement are similar. However, the initial chamber is not coiled about the proloculum. As with *P. advena*, it is probably characteristic of the lower middle bathyal biofacies (Ingle, 1980).

Age range.—Late Eocene (Refugian) to Oligocene (Zemmorian; Cushman, 1927; Cameron, 1980; McDougall, 1980; Rau, 1981).

Genus *Proxifrons* Vella, 1963

Proxifrons advena (Cushman, 1923)

Plate 6, figure 19

Frondicularia advena CUSHMAN, 1923, p. 141, pl. 20, figs. 1-2; GALLOWAY and WISSLER, 1927, p. 47, pl. 8, figs. 7-8.

Proxifrons advena (Cushman) FINGER, 1990, p. 200, pl.-figs. 1-7; 1992, p. 70, pl. 3, figs. 20-22; FINGER and LIPPS, 49, pl. 9, fig. 22.

Description.—Test elongate, compressed, lanceolate, V-shaped, initial end bluntly rounded, periphery acute, slightly carinate; chambers numerous, arranged biserial-like, highest in middle and gradually tapered towards ends, inverted V-shaped, proloculum subsphaerical/bulbous at base of test in megalospheric forms; sutures distinct, depressed; wall calcareous, thin, translucent, smooth, finely perforate; aperture (broken) terminal, circular, along periphery of last formed chamber.

Remarks.—Specimens are delicate and most have broken apertures. They are placed in *P. advena* because of the general shape of the test, biserial arrangement of chambers, and the presence of a distinct, sphaerical initial chamber (proloculus). This species is close to *Proxifrons gracilis* (Smith) (also previoiusly assigned to *Plectofrondicularia*), in test shape, chamber arrangement and presence of a bulbous proloculum in the megalopheric form. *Proxifrons gracilis* differs by having plate-like costae oramenting the initial chambers at the base of the test. *Proxifrons advena* differs from *Plectofrondicularia packardi* (Cushman and Schenck), by not having a bulbous proloculum. It is characteristic of the lower middle bathyal biofacies (Ingle, 1980; Finger, 1990).

Age range.—Early Miocene (Saucesian) to Holocene (Finger, 1990).

Family Nonionidae Schultze, 1854

Genus *Melonis* de Montefort, 1808

Melonis pompilioides (Fichtel and Moll, 1798)

Plate 6, figures 20-24

Nautilus pompilioides FICHTEL and MOLL, 1798, p. 31, pl. 2, figs. A-C.

Nonionina pompilioides (Fichtel and Moll), D'ORBIGNY, 1826, p. 294; BRADY, 1884, p. 727, pl. 109, figs. 10-11.

Nonionina umbilicatus D'ORBIGNY, 1826, p. 293, pl. 15, figs. 10-12.

Nonion pompilioides (Fichtel and Moll) CUSHMAN, 1930, p. 4, pl. 1, figs. 7-11, pl. 2, figs. 1-2; PHLEGER and PARKER, 1951, p. 11, pl. 5, figs. 19-20; MARTIN, 1952, p. 123, pl. 19, fig. 2.

Melonis pompilioides (Fichtel and Moll), VOLOSHINOVA, 1958, p. 158, pl. 3, figs. 8-9; LOEBLICH and TAPPAN, 1987, p. 621, pl. 696, figs. 7-8; HERMELIN, 1989, p. 88, pl. 17, figs. 13-14; FINGER, 1990, p. 168, pl.-figs. 1-8; BURKE, BERGER, COULBOURN and VINCENT, 1993, pl. 3, figs. 12-13; LOEBLICH and TAPPAN, 1994, p. 159, pl. 347, figs. 8-10.

Description.—Test planispiral, involute, periphery broadly rounded; chambers numerous, eight to 10 in final whorl; sutures flush with surface, slightly curved; walls calcareous, hyaline, coarsely perforated; aperture terminal, low, broad arch extending from each umbilicus.

Remarks.—Several different names have been assigned to this species. However, they are all regarded as junior synonyms of *M. pompilioides*. This distinct species commonly occurs with *M. barleeanum*, however it can be differentiated from it by its more rounded test and broader, and lower arched aperture that extends from umbilicus to umbilicus. *Melonis barleeanum* closely resembles *M. affinis* (Reuss) and has a high arched, narrow aperture, and a test that is slightly longer than its width than that of *M. pompiloides*. Hermelin (1989) suggested that *M. barleeanum* is a possible ecophenotypic variation of *M. pompilioides* because they coexist together. However, further investigations by Finger (1990) clearly showed that they are distinct. The species is characteristic of the lower bathyal biofacies (Ingle, 1980).

Age range.—Miocene to Holocene (Hermelin, 1989).

Genus *Nonionellina* Cushman, 1926

Nonionellina labradorica (Dawson, 1860)

Plate 6, figure 25-26, 28

Nonionina scapha var. *labradorica* DAWSON, 1860, p.191, fig. 4.

Nonionina labradorica (Dawson), JONES, PARKER, and BRADY, 1866, pl. 12, figs. 44-45.

Nonion labradorica (Dawson), CUSHMAN, 1927, p. 148, pl. 2, figs. 44-45.

Nonion labradoricum (Dawson), CUSHMAN, 1930, p. 11, pl. 4, figs. 6-12; MARTIN, 1952, p. 123, pl. 19, fig. 1; LOEBLICH and TAPPAN, 1953, p. 86, pl. 17, figs. 1-2; ASANO, 1960, p. 191, pl. 21, fig. 8; POLYAK, KORSUN, FEBO, STANOVOY, KHUSID, HALD, PAULSEN and LUBINSKI, 2002, p. 269, pl. 2, fig. 10.

Florilus labradoricus (Dawson), TODD and LOW, 1967, p. A35, pl. 5, fig. 9.

Nonionellina labradorica (Dawson), COLE and FERGUSON, 1975, p. 38, pl. 6, figs. 12-13; SCHAFER and COLE, 1978, p. 28, pl. 9, fig. 4; PATTERSON BURBRIDGE and LUTERNAUER, 1998, p. 20, pl. 23, figs. 1-2.

Description.—Test trochospiral in early coiling. Later becoming planispiral, involute in adult, periphery bluntly rounded, bilaterally symmetrical, slightly lobulate, deeply umbilicate; chambers numerous 12 to 14 in final whorl; sutures distinct, curved; walls calcareous, hyaline, smooth, finely perforate; aperture a narrow, low arched slit at base of final chamber, apertural face broadly triangular extends from each umbilicus.

Remarks.—*Nonionellina labradorica* is a distinct cold-water species characterized by a broadly triangular apertural face and short bilaterally symmetrical test. It has been well documented along the Atlantic and Pacific coasts of Canada. It is characteristic of the inner/outer neritic biofacies (Ingle, 1980).

Stratigraphic age.—Pliocene to Holocene (Todd and Low, 1967)

Genus *Nonionella* Cushman, 1926

Nonionella stella Cushman and Moyer, 1930

Plate 6, figures 27, 29

Nonionina auis CUSHMAN, 1926, p. 91, pl. 13, fig. 4.

Nonionella miocenica RAU, 1951, p.437, pl. 64, figs. 26-28; LOEBLICH and TAPPAN, 1964, p. C748, fig. 613 (1); RAU, 1970, p. 23, pl. 1, fig. 14; PATTERSON, 1989, p. 239, pl. 10.8, figs. 11-13; FINGER, 1990, p. 182, pl.–figs. 1-8; 1992, p. 87, pl. 32, figs. 8-16.

Nonionella miocenica Cushman var. *stella* CUSHMAN and MOYER, 1930, p. 56, pl. 7, fig. 17; OLSON, 1990; p. 300, pl. 4, fig. 11;

Nonionella stella Cushman and Moyer, PATTERSON, BURBRIDGE and LUTERNAUER, 1998, p. 20, pl. 22, figs. 1-3.

Description.—Test small, initially trochospiral, becoming planispiral involute, slightly compressed, periphery rounded, weakly lobulate, spiral side partially evolute with large umbonal boss, opposite side involute, asymmetrical; chambers, wedge shaped, broad, low, eight to 10 in final whorl, final one overhangs and partially covers umbilicus to form a stellate lobe, increase rapidly in size as added; sutures distinct, depressed; walls calcareous, smooth, finely perforate; aperture interomarginal, low arch extending near periphery, extending slightly onto umbilical side, apertural face asymmetrical and flat.

Remarks.—This species appears to be similar to *Nonionellina flemingi* (Vella). It differs by being asymmetrical with the umbonal boss extending, overhanging and obscuring the umbilicus only on one side. *Nonionina aurus* is synonymous with *N. miocenica* (Cushman, 1926). There is some confusion regarding the acceptance of the name *N. stella* over *N. miocenica* (Finger, 1990; 1992; Patterson et al., 1998). Finger (1990) questioned the value in differentiation of this variety, which may represent a later ontogenetic stage. Although several variations exist (including slight variations in the development of the distinctly stellate lobe) the illustrated specimens best agrees with *N. stella* and this name will be retained herein. There are numerous records of this species (as *N. miocenica*) from the Miocene and Pliocene rocks of California to British Columbia and the Recent of Alaska. The species is well-known in the Pliocene Quinault Formation (Rau, 1970). It is characterisitic of the inner neritic biofacies (Ingle Jr., 1980).

Age range.—Oligocene (Zemmorian) to Holocene (Finger, 1990).

Nonionella novozealandica Cushman, 1936

Plate 6, figure 30

Nonionella novozealandica CUSHMAN, 1936, p. 88, pl. 13, fig. 16; HORNIBROOK, BRAZIER and STRONG, 1989, p. 97, fig. 20:10.

cf. *Nonionella stella* Cushman and Moyer, PATTERSON, BURBRIDGE and LUTERNAUER, 1998, p. 20, pl. 22, figs. 1-3.

aff. *Zeaflorilus parri* (Cushman), LOEBLICH and TAPPAN, 1987, p. 619, pl. 690, figs. 8-10; HAYWARD, GRENFELL, REID and HAYWARD, 1999, p. 160, pl. 15, figs. 18-20.

Description.—Test small, initially trochospiral, becoming planispiral involute, slightly compressed, periphery rounded, weakly lobulate, spiral side partially evolute with large modified umbonal boss, opposite side strongly planispiral involute, asymmetrical; chambers, wedge shaped, broad, low, 10 to 12 in final whorl, final one overhangs and partially covers umbilicus to form a bi-stellate lobe; increase rapidly in size as added; sutures distinct, strongly depressed; walls calcareous, smooth, finely perforate, slightly glossy; aperture interomarginal, low arch extends near periphery, extends slightly onto umbilical side, apertural face asymmetrical and flat.

Remarks.—This species most closely resembles *N. stella*. It differs by the peculiar and distinct development of the final chamber that extends and obscures the umbilicus by the formation of a single stellate lobe. In this species a single umbonal lobe is modified into two bifurcated lobes with short, stout digitate (finger-like) projections surrounding (wrapping-around) the umbilicus. This species is slightly more elongate, with approximately 2-3 more chambers, and the spiral side is strongly planispiral evolute. It may have affinity with *Zeaflorilus parri* Vella, that has numerous clasping chamber lobes covering the umbilicus. It is characterisitic of the inner neritic biofacies (Ingle, 1980).

Age range.—Miocene (Hornibrook et al., 1989).

Genus *Pseudononion* Asano, 1936

Pseudononion basispinatum (Cushman and Moyer)

Plate 6, figures 31-32

Nonion pizarrensis Berry var. *basispinata* CUSHMAN and MOYER, 1930, p. 54, pl. 17, fig. 18.

Florilus (*Nonionella*) *basipinatum* (Cushman and Moyer), RAU, 1970, p. 23, pl. 1, fig. 16.

Pseudononion basipinata (Cushman and Moyer), FINGER, 1992, p. 87, pl. 32, figs. 17-23; PATTERSON, BURBRIDGE and LUTERNAUER, 1998, p. 21, pl. 23, figs. 3-5.

cf. *Pseudononion granuloumbilicatum* ZHENG, 1979, p. 189, 229, pl. 25, fig. 9; LOEBLICH and TAPPAN, 1994, pl. 344, figs. 1-4, 7-9, non figs. 5-6.

Nonion costiferum (Cushman), OLSON, 1990, p. 300, pl. 4, fig. 8.

Description.—Test of medium size, planispiral involute, asymmetrical and compressed, peripheral margin slightly angled, acute and slightly flaring around aperture, umbilical region depressed and filled with bead-like granular material; chambers low, numerous, 10 to 14 in final whorl, rapidly increase in size as added; sutures depressed curved; wall calcareous, smooth, finely perforate; aperture elongate, narrow, interomarginal with a small equatorial opening at base of apertural face.

Remarks.—Although they are known to occur together, this species differs from *P. costiferum* (Cushman) by having fewer, lower, broader chambers and a narrow rather than flared apertural face. Further, the periphery of *P. costiferum* is slightly keeled. This species appears to be close to *P. granuloumbilicatum* by the presence of bead-like granular material, but differs in having a smaller, narrower test. *Pseudononion basispinatum* is characteristic of the inner neritic biofacies (Ingle, 1980).

Age range.—Miocene to Holocene.

Genus *Pullenia* Parker and Jones, 1862

Pullenia borealis? Saidova, 1975

Plate 6, figures 34-35

?*Pullenia borealis* SAIDOVA, 1975, p. 256, pl. 69, fig. 9; LOEBLICH and TAPPAN, 1994, p. 160, pl. 348, figs. 1-6.

Description.—Test biconvex, small, compressed, periphery slightly lobulate; chambers numerous (six), increase gradually in size as added; sutures slightly depressed, curved; wall calcareous, smooth, finely perforate; aperture low narrow arch at base of final chamber, extends to umbilicus on either side.

Remarks.—This specimen closely resembles *P. quinqueloba* (Reuss) but its test is not as compressed. Also, it slightly resembles *P. salisburyi*, but it is much smaller and its periphery is not as lobulate nor its chambers as inflated or distinct. This species could represent a juvenile form of *P. quinqueloba.* It is characteristic of the outer neritic biofacies (Ingle, 1980).

Age range.—Pliocene to Holocene.

Pullenia bulloides (d'Orbigny, 1826)

Plate 6, figures 36-37

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

Pullenia bulloides (d'Orbigny), CUSHMAN and TODD, 1943, p. 13, pl. 2, figs. 15-18; HERMELIN, 1989, p. 78, pl. 15, figs. 4-5.

Pullenia miocenica KLEINPELL, 1938, p. 338, pl. 14, fig. 6; FINGER, 1990, p. 214, pl.-figs. 1-8; 1992, p. 88, pl. 34, figs. 7-10.

Description.—Test small, planispiral involute, subsphaeroidal, periphery broadly rounded; chambers distinct, four to five in final whorl, inflated, broadly wedge-shaped, increasing gradually in size as added; sutures distinct, radial, flush with surface; wall calcareous, hyaline, smooth, finely perforate; aperture a low, narrow interomarginal arch, extending from one umbilicus to other, with a thin lip.

Remarks.—Specimens vary slightly from the original illustration by showing a higher, narrower apertural face (in aperture view), rather than the typical more robust forms with broad, low apertural faces. This species may be a phenotypic variant as some of the conspecific *P. miocenica* also show this characteristic (Finger, 1990). It is characterisitic of the lower middle bathyal biofacies (Ingel, 1980).

Age range.—Oligocene (Zemorrian; Finger, 1990) to Holocene (Hermelin, 1989),

Pullenia quinqueloba (Reuss, 1851)

Plate 6, figures 38-39

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

Pullenia jarvisi CUSHMAN, 1936, p. 77, pl. 13, fig. 6.

Pullenia inglei FINGER and LIPPS, 1990, p. 43, pl. 9, figs. 31-32; FINGER, 1990, p. 212, pl.-figs. 1-7; 1992, p. 88, pl. 34, figs. 1-6.

Description.—Test small, biconvex, planispiral involute, slightly compressed, slightly umbilicate, periphery broadly rounded and lobulate; chambers distinct, subglobular to rhomboidal (wedge-shape), five in final whorl, slightly inflated, increasing gradually in size as added; sutures, distinct, depressed and curved; walls calcareous, hyaline, smooth, finely perforated; aperture a long narrow slit at base of final chamber, extending from one umbilicus to the other.

Remarks.—This species may be a juvenile form of *P. salisburyi*, however it differs in its greatly reduced size, fewer chambers, more broader, slightly rhomboid test and lower apertural face. *Pullenia jarvisi* and *P. inglei* are herein considered a junior synonym, as their original descriptions do not greatly differ from that of *P. quinqueloba*. Several varieties of this species have previously been described including *P. quinqueloba* var. *angusta* Cushman and Todd and *P. quinqueloba* var. *aplata* Bandy. *Pullenia quinqueloba* differs from both by its less compressed test, broader, more wedge-like chambers and slightly angular edges. It is characteristic of the upper middle bathyal biofacies (Ingle, 1980).

Age range.—Middle Miocene, Relizian to Mohnian stages (Finger, 1990 for *P. inglei*).

Pullenia salisburyi Stewart and Stewart, 1930

Plate 6, figure 33

Pullenia salisburyi STEWART and STEWART, 1930, p.72, pl. 8, fig. 2; CUSHMAN and TODD, 1943, p. 20, pl. 3, figs. 10-11; RAU, 1951, p. 450, pl. 67, figs. 9-10; PATTERSON, 1989, p. 239, pl. 10.8, figs. 5-6; PATTERSON, BURBRIDGE and LUTERNAUER, 1998, p. 21, pl. 24, figs. 4-5.

Pullenia sp. cf. *P. salisburyi* Stewart and Stewart, RAU, 1970, p. 30, pl. 3, fig. 7.

Description.—Test large, biconvex, planispiral involute, compressed, periphery lobulated; chambers distinct, slightly inflated, seven in the final whorl, increase gradually in size as added; sutures, distinct, depressed and curved; walls calcareous, smooth, finely perforated; aperture a long narrow slit at base of final chamber, extending to umbilicus on either side.

Remarks.—Specimens appear to have a fringe-like, irregular edge along the base of the final chamber, covering the aperture. The final chamber is probably fragmented because the Tofino Basin specimens only have six chambers instead of the expected seven chambers described for this species. It closely resembles *P. jarvisi* Cushman and differs by having fewer chamber in the final whorl, and lacking a deep umbilici. This species closely resembles *P. elegans* (Cushman and Todd) in size and shape. *Pullenia elegans* may be a junior synonym. *Pullenia salisburyi* is widespread and common along the Pacific coast (Todd and Low, 1967). It is characteristic of the outer neritic biofacies (Ingle, 1980).

Age range.—Miocene to Holocene (Todd and Low, 1967).

Family Oridorsalidae Loeblich and Tappan, 1984

Genus *Oridorsalis* Andersen,1961

Oridorsalis umbonatus (Reuss, 1851)

Plate 7, figures 1-5

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

Oridosalis umbonata (Reuss), FINGER, 1990, p. 184, pl.-figs. 1-9; 1992, p. 88, pl. 35, figs. 12-17.

Oridorsalis umbonatus (Reuss), BURKE, BERGER, COULBOURN and VINCENT, 1993, p. 31, pl. 2, figs. 13-15; CLARK, PATTERSON and FISHBEIN, 1994, p1. 1, figs. 7-12; HAYWARD, GRENFELL, REID and HAYWARD, 1999, p. 160, pl. 15, figs. 24-26.

Description.—Test small to medium sized, trochospiral, periphery lobulate, rounded, ventral side planoconvex, dorsal side slightly flat; chambers four to five in final whorl, wedge-shaped, slightly inflated; sutures distinct, slightly depressed; wall calcareous, hyaline, smooth, finely perforate; aperture on ventral side, low interomarginal lipped-slit on final chamber on ventral side.

Remarks.—Two morphotypes apparently exist, the *Oridosalis umbonatus* "*umbonatus*" and "*tener*" (Clark et al., 1994). Differentiation between these two is difficult and was not carried out here. The latter is commonly assigned in *O. tenera* (Brady), based on a slightly thickened lip bordering a curved aperture. Otherwise the test, size, shape and chamber arrangement is identical to *O. umbonatus*. This species is characteristic of the upper middle bathyal facies (Ingle, 1980; Finger, 1990; Hayward et al., 1999). It rarely occurs in neritic water depths (Hayward et al., 1999).

Age range.—Late Eocene/Oligocene to Holocene (Finger, 1990; Hayward et al., 1999).

Family Planulinidae Bermúdez, 1952

Genus *Planulina* d'Orbigny, 1826

Planulina retia Belford, 1966

Plate 7, figure 7

Planulina retia BELFORD, 1966, p. 122, pl. 11, figs. 1-9; LOEBLICH and TAPPAN, 1994, p. 149, pl. 315, figs. 1-11, pl. 316, figs. 4-7.

Description.—Test medium sized, extremely compressed, planispiral, trochoid evolute periphery acute, lobulate, and slightly truncate, slightly keeled; chambers distinct, numerous, eight to 10 in final whorl, inflated, widest near umbilicus and narrows towards periphery, re-curved claw shape; sutures distinct, thickened, limbate, stongly curved, reflexed, spiral suture distinct; wall calcareous, coarsely perforated; aperture small, interomarginal slit.

Remarks.—This species has a similar test shape and chamber arrangement as *Holmanella* (*Planulina*) *baggi* (Kleinpell) illustrated and described by Kleinpell (1938) and Finger (1990). It differs from *H. baggi* by being more elongate and by showing chambers that increase in size more rapidly than in *H. baggi* and by having a slightly reticulate texture to the coarsely perforated test. As with *Holmanella baggi* it is probably most characteristic of the outer neritic biofacies (Ingle, 1980; Finger, 1990).

Age range.—Early Miocene (Saucesian) to Pleistocene (Belford, 1966; Finger, 1990 for *H. baggi*; Loeblich and Tappan, 1994).

Planulina wullerstorfi (Schwager, 1866)

Plate 7, figure 6

Anomalina wullerstorfi SCHWAGER, 1866, p. 258, pl. 7, figs. 105, 107.

Cibicides wuellerstorfi (Schwager), PARKER, 1954, p. 544, pl. 13, figs. 3, 6.

Planulina wuellerstorfi (Schwager), LOHMAN, 1978, p. 26, pl. 2, figs. 1-4; HORNIBROOK, BRAZIER and STRONG, 1989, p. 98, fig. 22:7; HOLBURN and HENDERSON, 2002, p. 25, fig. 5, 6-8.

Description.—Test compressed planoconvex, evolute, low trochospire, periphery with thickened keel, spiral side slightly flattened, umbilical side slightly convex; chambers distinct on dorsal side, numerous, eight to 10 in final whorl, early chambers low trochospiral and later ones nearly planispiral, slightly inflated, increase rapidly as added; sutures distinct, limbate, thickened between chambers, strongly curved, slightly depressed in final chambers on spiral side; wall calcareous, hyaline, smooth, coarsely perforate on spiral side and finely perforate on umbilical side; aperture interomarginal slit with a narrow lip.

Remarks.—This species had previously been referred to and/or reassigned to the following genera *Anomalina*, *Cibicides*, *Cibicidoides*, and *Fontbotia* and *Planulina*. Generic assignment to *Planulina*, after Lohman (1978) and Holburn and Henderson (2002) is followed herein. It is close to *P. renzi*, but differs by being smaller (less robust) and less flattened on the spiral side, and by having a more blunt keel aroung the periphery. It is characterisitic of the upper middle bathyal to lower bathyal biofacies (Ingle, 1980; Hornibrook et al., 1989; Holburn and Henderson, 2002), however, in Australia it has been reported from shallower depths (outer neritic, upper slope transition; Feary et al., 2000)

Age range.—Middle Miocene to Holocene (Holburn and Henderson, 2002).

Family Polymorphinidae d'Orbigny, 1839

Genus *Guttulina* d'Orbigny, 1839

Guttulina frankei Cushman and Ozawa, 1930

Plate 7, figure 8

Guttulina frankei CUSHMAN and OZAWA, 1930, p. 28, pl. 4, fig. 1; CUSHMAN and FRIZZELL, 1943, p. 84, figs. 17-18; RAU, 1948, p. 170, pl. 30, figs. 17-18; 1951, p. 435, pl. 64, figs. 14-15; ULLEBERG, 1974, p. 276, pl. 1, figs. 1-6; McDOUGALL, 1980, pl. 11, figs. 12-14.

?*Guttulina sylvestri* (Cushman and Ozawa), HAYWARD, GRENFELL, REID and HAYWARD, 1999, p. 117, pl. 7, fig. 9.

Description.—Test subcircular, periphery bluntly angled; chambers elongate inflated, central chamber strongly inflated, added in quinqueloculine arrangement; sutures slightly depressed; wall calcareous, smooth, finely perforate; aperture terminal radiate.

Remarks.—The species closely resembles *G. irregularis*. It differs by having a slightly more angled rather than rounded test periphery, and a more inflated central chamber. This species is probably conspecific with *Guttulina sylvestri* based on the inflated central chamber and the angled test. It has been commonly recorded in the Upper Eocene-Oligocene strata (Lincoln Formation) of Washington, and occurs in Late Eocene?-Oligocene strata of the Tofino Basin. It is characteristic of the outer neritic biofacies (Ingle, 1980).

Age range.—Late Eocene to Holocene.

Guttulina hantkeni Cushman and Ozawa, 1930

Plate 7, figure 9

Guttulina hantkeni CUSHMAN and OZAWA, 1930, p. 33, pl. 5, figs. 4-6; RAU, 1948, p. 169, pl. 30, figs. 11-12; McDOUGALL, 1980, pl. 12, figs. 1-3.

cf. *Guttulina bartschi* CUSHMAN and OZAWA, 1930, p. 23, pl. 1, fig. 10; LOEBLICH and TAPPAN, 1994, p. 82, pl. 145, figs. 10-13, non 5-9, 14-15; HAYWARD, GRENFELL, REID and HAYWARD, 1999, p. 117, pl. 1, fig. 10.

Description.—Test large, botryoidal, sharply rounded at base, slightly tapering towards ends, greatest width above centre; chambers ovate, inflated, added in quinqueloculine arrangement, longer than wide, widest below centre, each succeeding chamber removed farther from base; sutures depressed, distinct; wall calcareous smooth, finely perforate; aperture terminal, radiate.

Remarks.—The test of this species is distinct. Chambers resemble a person's nose and species closely resemble *G. bartschi*. However in *G. hantkeni* the apertural end is less tapered, and the chambers are flared and elongate (chambers greatly longer than wide). It is characteristic of the outer neritic biofacies (Ingle, 1980).

Age range.—Late Eocene and Oligocene.

Guttulina irregularis (d'Orbigny, 1846),

Plate 7, figures 10-11

Globulina irregularis D'ORBIGNY, 1846, p. 226, pl. 13, figs. 9-10.

Guttulina irregularis (d'Orbigny), CUSHMAN and OZAWA, 1930, p. 25, pl. 3, figs. 2-4, pl. 7, figs. 1-2; RAU, 1948, p. 169, pl. 30, fig. 7-8; 1951, p. 435, pl. 64, figs. 16-17; McDOUGALL, 1980, pl. 12, figs. 7-11; HAYWARD, GRENFELL, REID and HAYWARD, 1999, p. 117, pl. 7, figs. 10-11.

Description.—Test small, broad, subovate, slightly triangular, periphery rounded; chambers few, inflated, three in final whorl, added in quinqueloculine and clockwise arrangement; sutures slightly depressed, slightly flush; walls smooth, finely perforate, no ornamentation; aperture terminal, rounded.

Remarks.—This species is different from other *Guttulina* spp., by having a triangular shape in cross-section and an ovate and rounded periphery. Specimens show some dissolution, making the clockwise, quinqueloculine series of chambers difficult to observe. It commonlyoccurs in the Oligocene strata of the Twin River Formation, Washington, and is common in the Upper Eocene and Oligocene strata in the Tofino Basin wells (Pluto I-87). It is characteristic of the outer neritic biofacies (Ingle, 1980).

Age range.—?Cretaceous to Holocene.

Genus *Metapolymorphina* McCulloch, 1977

Metapolymorphina charlottensis Cushman, 1925

Plate 7, figure 18

Polymorphina charlottensis CUSHMAN, 1925, p. 41, pl. 6, fig. 9; RAU, 1970, p. 22, pl. 1, fig. 12; TODD and LOW, 1967, p. A25, pl. 3, fig. 13; HALLER, 1980, p. 238, pl. 4, fig. 16.

aff. *Polymorphina eximia* McCULLOCH, 1977, p. 168, pl. 74, figs. 1-4.

?*Pyrulinoides* sp. 2 HERMELIN, 1989, p. 45, pl. 5, fig. 15.

Metapolymorphina charlottensis (Cushman), PATTERSON, BURBIDGE and LUTERNAUER, 1998, p. 7, pl. 3, fig. 8.

Description.—Test large, elongate lanceolate, tapered, periphery rounded; chambers biserial, irregular, eight pairs, slightly inflated, slightly compressed, few overlapping;

sutures fairly distinct, mainly flush with surface, not depressed; wall thick, opaque, finely perforate, smooth; aperture neck terminal, radiate, on a short and blunt neck.

Remarks.—Variations exist between microspheric and megalospheric (dimorphic) forms (Patterson et al., 1998). The specimen illustrated herein, is possibly megalospheric because it is slightly shorter and broader and has a larger proloculus. *Polymorphina eximia* shows affinity but is quite slender and compressed. This species was initially described from dredges from the Queen Charlotte Sound. It is rare (only three specimens in the Tofino Basin samples). It is largely associated with cool, inner neritic taxa (e.g. *Elphidiella hannai* Zone) and possibly restricted to the northern Pacific (Todd and Low, 1967; Rau, 1970). It is characteristic of the inner neritic biofacies (Ingle, 1980). Its smooth, opaque test with slight abrasion may indicate transport from the innermost shelf to middle and outer neritic water depths.

Stratigraphic age.—Pliocene to Holocene.

Family Pseudoparellidae Voloshinova, 1952

Subfamily Pseudoparrellidae Voloshinova, 1952

Genus *Epistominella* Husezima and Maruhasi, 1944

Epistominella pacifica (Cushman, 1927)

Plate 7, figures 12, 19-20

Pulvinulinella pacifica CUSHMAN, 1927, p. 165, pl. 5, figs. 14, 15; CUSHMAN, STEWART, and STEWART, 1930, p. 73, pl. 6, fig. 5.

Epistominella pacifica (Cushman), MARTIN, 1952, p. 136, pl. 24, fig. 8; BANDY, 1953, p. 172, pl. 23, fig. 2; TODD and LOW, 1967, p. A32, pl. 5, fig. 18; RAU, 1970, p.28, pl. 2, fig. 20; FINGER, 1992, p. 86, pl. 29, figs. 16-18; PATTERSON, BURBIDGE and LUTERNAUER, 1998, p. 19, pl. 21, figs. 4-6.

Epistominella pulchella HUSEZIMA and MARUHASI, 1944, p. 398, pl. 84, fig. 10.

Description.—Test trochoid, planoconvex, evolute with flattened dorsal side and highly convex (nearly conical) ventral side, bluntly keeled; chambers distinct, with six to seven visible in final whorl; sutures oblique and curved on dorsal side, ventral sutures radial and slightly curved; wall calcareous, hyaline, and finely perforate; aperture interomarginal, narrow with an elongate lipped slit, almost parallel to peripheral keel and on umbilical (ventral) side.

Remarks—This species differs from *E. smithi* by lacking a slightly lobulate test periphery. It is common and abundant in the Upper Pliocene to Holocene strata of the Tofino Basin, North Pacific Basin and Gulf of Alaska (Todd and Low, 1967; Rau, 1970). It is characteristic of the upper bathyal?/upper middle bathyal biofacies (Ingle, 1980).

Age range.—Early Miocene (Saucesian) to Holocene (Finger, 1990).

Epistominella smithi (Stewart and Stewart, 1930)

Plate 7, figures 13-14

Pulvinulinella smithi STEWART and STEWART, 1930, p. 70, pl. 9, fig. 4.

Epistominella smithi (Stewart and Stewart), LIPPS, 1965, p. 129, pl. 2, fig. 6; FINGER, 1990, p. 98, pl.-figs. 1-8; 1992, p.86, pl. 29, figs. 1-15.

Description.—Test trochoid, planoconvex, with flattened dorsal side and moderately convex ventral side, thinly keeled; chambers distinct, slightly inflated (on ventral side) with five to seven chambers visible in final whorl; sutures oblique, curved and limbate on dorsal side, ventral sutures curved and slightly depressed; walls calcareous, hyaline, and finely perforate; aperture narrow, elongate, lipped slit, almost parallel to peripheral keel, on umbilical (ventral) side.

Remarks.—This species is similar to and commonly occurs with *E. pacifica*. It differs by having a more distinctly lobulate periphery and a thin peripheral keel. It is characteristic of the upper bathyal/upper middle bathyal transitional biofacies (Ingle, 1980; Finger, 1990).

Age range.—Early Miocene (Saucesian) to Holocene (Finger, 1990).

Genus *Pseudoparella* Cushman and ten Dam, 1948

Pseudoparella subperuviana (Cushman, 1926)

Plate 7, figure 15

Pulvinulinella subperuviana CUSHMAN, 1926, p. 63, pl. 9, fig. 9.

Pulvinulinella umbonifera CUSHMAN, 1933, p. 90, pl. 9, fig. 9.

Pseudoparella subperuviana (Cushman), FINGER, 1990, p. 210, pl.-figs. 1-9; 1992, p. 86, pl. 30, figs. 4-24.

Description.—Test small, planispiral, biconvex, distinctly and largely umbonate, periphery rounded, lobulate and appears fringe-like; chambers numerous, eight to 11 in final whorl, inflated, narrow, increase rapidly in size as added; sutures on dorsal side depressed and curved, on ventral side slightly depressed and nearly straight; wall calcareous, hyaline, smooth, finely perforate; aperture narrow, elongate slit in plane of coiling, on ventral side of final chamber.

Remarks.—This species is possibly conspecific with *P. umbonifera*, that was originally described as having a very distinctly umbonate area. It is close to *P. californica* (White) and differs by having a larger umbo and a lobulate (almost fringe-like) periphery. The genus and species has a similar test shape and apertural characteristics as *Megastomella* taxa (i.e. *Megastomella purisima* (Bramlette) (Finger, 1990). It is characteristic of the upper bathyal biofacies (Ingle, 1980).

Age range.—Oligocene (Zemmorian) to Holocene (Finger, 1990).

Family Siphogenerinoididae Saidova, 1981

Subfamily Tubulogenerininae Saidova, 1981

Genus *Rectuvigerina* Mathews, 1945

Rectuvigerina branneri (Bagg, 1905)

Plate 7, figures 16-17, 21-23

Sagrina branneri BAGG, 1905, p. 40, pl. 7, fig. 4.

Rectuvigerina branneri FINGER and LIPPS, 1990, p. 49, pl. 4, figs. 43-47; FINGER, 1990, p. 216, pl.-figs. 1-12; 1992, p. 81, pl. 21, figs. 7-56.

Description.—Test large, elongate slender, rectilinear, moderately to strongly tapered at initial end, sides nearly parallel, periphery slightly rounded; chambers closely set, numerous, 12-15, fairly indistinct, not inflated, initially triserial to uniserial arrangement; sutures, distinct, depressed, straight, limbate; wall calcareous, hyaline, finely perforate; costae numerous (greater than 10) thick/bladed, longitudinal, continuous over chambers, end before and/or at apertural neck; walls/septa between chambers arched, non-costate near aperture (final whorl); aperture terminal, large, rounded, on short, tubular neck with narrow phialine lip.

Remarks.—In his original description, Bagg (1905) stated that there were three distinct types or ecophenotypic variations of this species. The most distinct form is characterized by arched septa between chambers. Dimorphic (microspheric vs. megaspheric) variation is considerable, therefore, making separation into different species difficult. Added to this, specimens usually occurred near the base of the Shell Canada wells, in disturbed sediments and were usually abraded or broken. Therefore in this study, forms that fall within the above description are placed within *R. branneri*. This species is close to *Rectuvigerina transversa* (Parker and Jones) but differs by having more numerous bladed costae and being slightly longer and more slender. It was originally described from the lower Miocene strata of the Monterey Formation, California. It is characteristic of the upper middle bathyal biofacies (Ingle, 1980; Finger, 1990).

Age range.—Early Miocene (Saucesian) to middle Miocene (Mohnian; Finger, 1990).

Rectuvigerina sp. cf. R. *loeblichi* Finger and Lipps, 1990

Plate 7, figure 24

cf. *Rectuvigerina loeblichi* FINGER and LIPPS, 1990, p. 40, pl. 4, figs. 37-42; FINGER, 1990, p. 220, pl.-figs. 1-12; 1992, p. 81, pl. 21, figs. 63-76.

Description.—Test elongate, very slightly tapered towards initial end, rounded in cross-section, periphery slightly lobulate; chambers slightly inflated, low, triserial initially, becoming uniserial or biserial in later stages; sutures distinct, slightly depressed; wall calcareous, hyaline, smooth, finely perforate; costae weak to well-developed, fine, low longitudinal, slightly waved, few discontinuous; aperture terminal (broken), rounded, on short neck with phialine lip.

Remarks.—This specimen is closest to *R. loeblichi* based on the presence of fine, slightly faint costae, and a slightly stout or rounded test. It is rarer than *R. branneri* and *R. transversa*. It is characteristic of the outer shelf/upper bathyal transitional biofacies (Ingle, 1980; Finger, 1990).

Age range.—Middle Miocene (Relizian; Finger, 1990).

Rectuvigerina smithi? (Kleinpell, 1938)

Plate 7, figure 25

?*Rectuvigerina smithi* KLEINPELL, 1938, p. 7, pl. 6, figs. 1-2.

Description.—Test large, elongate, longer than wide, periphery slightly lobulate, sides nearly parallel; chambers slightly to moderately inflated, initially triserial, becoming unierial; sutures distinct, depressed; wall calcareous, hyaline, finely perforate; costae numerous, strong, longitudinal, extend from initial end to aperture, continuous, slightly notched or wavy at sutures; aperture terminal, small, round, at end of a short neck.

Remarks.—The slight inflation of the chambers behind the longitudinal cosate, reveal a uvigerinid development of the test. Specimen are questionably placed within *R. smithi*. This species may be close to *R. nodifera* (Cushman and Kleinpell). It differs in being more elongate, less stout and showing slightly more numerous and stronger costae. It may show similarities to *R. branneri* in the general form of the test, longitiudinal costae development and apertural characteristics. However, its slightly inflated chambers, without the arched septa between chambers, brings this species closer to the uvigerinids (Kleinpell, 1938). It is characteristic of the upper middle bathyal biofacies (Ingle, 1980).

Age range.—?Oligocene to Miocene (Kleinpell, 1938).

Rectuvigerina transversa (Cushman, 1918)

Plate 7, figures 26-27, 34

Siphogenerina raphanus (Parker and Jones) var. *transversus* CUSHMAN, 1918, p. 64, pl. 22, fig. 8.

Transversigerina transversa (Cushman), PATTERSON, 1989, p. 240, pl. 10.4, figs 1-2.

Rectuvigerina transversa (Cushman), FINGER and LIPPS, 1990, p. 49, pl. 4, figs. 48-49; FINGER, 1990, p. 222, pl.-figs. 1-12; 1992, p. 82, pl. 21, figs. 1-6.

Siphogenerina raphana (Parker and Jones), HAYWARD, GRENFELL, REID and HAYWARD, 1999, p. 130, pl. 9, fig. 4.

Description.—Test medium to large, elongate, rectilinear, slightly tapered at initial end, sides nearly parallel, periphery slightly rounded, initial end slightly rounded; chambers closely set, fairly indistinct, slightly inflated, initially triserial to uniserial arrangement; sutures, distinct, depressed, straight, limbate; wall calcareous, hyaline, finely perforate;

costae numerous, five to eight, thick/bladed, longitudinal and run length of test from initial to apertural end, continuous over chambers; aperture terminal, large, rounded, on short, tubular neck with a slight phialine lip.

Remarks.—This species is close to *R. branneri* and differs by having comparatively fewer bladed, longitudinal costae and a smaller slightly stout test. It is characteristic of the upper middle bathyal biofacies (Ingle, 1980; Finger, 1990).

Age range.—Oligocene (Zemorrian) to middle Miocene (Luisian; Finger, 1990). Also recored from the Holocene in New Zealand (Hayward et al., 1999).

Family Sphaeroidinidae Cushman, 1927

Genus *Sphaeroidina* d'Orbigny, 1826

Sphaeroidina chilostomata Galloway and Morrey, 1924

Plate 7, figures 28-29, 35

Sphaeroidina bulloides d'Orbigny var. *chilostomata* GALLOWAY and MORREY, 1924, p. 32, pl. 5, fig. 1; FINGER, 1990, p. 230, pl.-figs. 1-8; 1992, p. 85, pl. 24, figs. 54-58.

Description.—Test small, subsphaerical, periphery broadly rounded; chambers three to four in the final whorl, globular, inflated, increase in size rapidly as added; sutures distinct, depressed; wall calcareous, hyaline, smooth, finely perforate; aperture a small slightly elongate, curved, thinly lipped slit, along base of the final chamber just above suture.

Remarks.—This species differs from *S. bulloides* by having a slightly larger, more globose test and a small, slightly curved lipped aperture. The apertures of several specimen were usually infilled with sediment. It is characteristic of the upper middle bathyal biofacies (Ingle, 1980; Finger, 1990).

Age range.—Oligocene (Zemorrian) to Holocene (Finger, 1990). It commonly occurs in the early (Saucesian) to middle Miocene (Luisian?) strata in the Tofino Basin.

Family Stainforthiidae Reis, 1963

Genus *Stainforthia* Hofker, 1956

Stainforthia concava Höglund, 1947

Plate 7, figure 30

Stainforthia concava HÖGLUND, 1947, p. 257, pl. 23, figs. 3-4; pl. 32, figs. 4-7; text figs. 273-275; KNUDSEN and SEIDENKRANTZ, 1994, p. 6, pl. 3, fig. 12-13.

Description.—Test elongate, fusiform, tapered to a broad point at basal end, ovate in cross-section, broadest just below aperture, slightly twisted, periphery slightly lobulate; chambers numerous, six to 10 pairs, slightly inflated, triserially arranged in early stages, later becoming biserial, increase rapidly as added; sutures distinct depressed, curved; wall calcareous, hyaline, thick, smooth, finely and densely perforate; aperture elongate, large, wide, loop-shaped, trough-like (concave/depressed), with narrow incurved lip on one side, opposite side with a broad tongue bending under lip, partially closing opening.

Remarks.—This species commonly occurs with the high latitude Holocene species *S. feylingi*, a common species on the westcoast of Canada (Knudsen and Seidenkratz, 1994; Patterson et al., 1998) and one that has been previously misidentified as *Fursenkoina schreibersiana* (*F. acuta*; Knudsen and Seidenkratz, 1994). *Stainforthia concava* is close to *S. stainforthia*. It can be differentiated from the latter species by having less elongated, globular chambers that are more angled (curved) and the apertural loop is broader and longer. It is characteristic of the outer neritic to upper bathyal biofacies (Ingle, 1980; Knudsen and Seidenkrantz, 1994).

Age range.—Holocene.

Family Stilostomellidae Finaly, 1947

Genus *Nodogenerina* Cushman, 1927

Nodogenerina lepidula? (Schwager, 1866)

Plate 7, figures 31-33

?*Nodosaria lepidula* SCHWAGER, 1866, p. 210, pl. 5, figs. 27-28.

?*Siphonodosaria lepidula* (Schwager) CUSHMAN and TODD, 1847, p. 356, pl. 88, figs. 27-28.

?*Nodogenerina lepidula* (Schwager) FINGER 1990, p. 172, pl.-figs. 1-9; LOEBLICH and TAPPAN, 1994, p. 133, pl. 261, figs. 18-20.

Description.—Test elongate, uniserial; chambers subglobular (bell-shaped), inflated, widest at midline, increase rapidly in size as added; sutures distinct, depressed; wall calcareous, smooth, finely perforated, ornamented by small blunt spines arranged linearly near chamber base; aperture terminal, not visible (broken).

Remarks.—This species is distinguished by its distinct bell-shaped chambers ornamented by a fringe of small blunt spines near the base of the chambers. Rarity and fragmentation of the specimen preclude definite assignment to this species. It is characteristic of the lower middle bathyal biofacies (Ingle, 1980; Finger, 1990).

Age range.—Lower?-middle Miocene to Pliocene (Finger, 1990).

Nodogenerina sagrinensis? (Bagg, 1912)

Plate 7, figures 36-39

?*Nodosaria sagrinensis* BAGG, 1912, p. 58, pl. 16, fig. 4.

?*Nodogenerina sagrinensis* FINGER, 1990, p. 174, pl.-figs. 1-7; 1992, p. 84, pl. 24, figs. 10-16.

Description.—Test elongate, uniserial tapered towards aboral end, circular in transverse section; chambers subglobular, distinct, inflated, increase rapidly in size as added, later ones more inflated, earliest chambers slightly overlapping later ones, become longer towards final chamber; sutures distinct, depressed; wall calcareous, finely perforated and smooth between coarse spinose/papilose ornamentation; aperture terminal, not observed (broken-off).

Remarks.—This species is tentatively placed in *Nodogenerina* based on its bell-shaped test, globose chambers test ornamentation and apertures with a flaring phialine lip. If there was a single apertural tooth, it would warrant placement in *Siphonodosaria*. The chambers of *N. sagrinensis* are similar to *N. lepidula* (Schwager) but vary in the arrangement of the spinose/papilose test ornamentation. The rarity and fragmentation of specimens, preclude definite assignment to this species. It is characteristic of the lower middle bathyal biofacies (Ingle, 1980; Finger, 1990).

Age range.—Miocene to Pliocene, ranges into the Holocene (Finger, 1990).

Genus *Siphonodosaria* Silvestri, 1924

Siphonodosaria advena (Cushman and Laiming, 1931)

Plate 8, figures 1-2

Nodogenerina advena CUSHMAN and LAIMING, 1931, p. 106, pl. 11, fig. 19; BARBAT and VON ESTORFF, 1933, p. 171, pl. 23, fig. 2.

Siphonodosaria advena FINGER and LIPPS, 1990, p. 49, pl. 1, figs. 26-27, 35-37; FINGER, 1990, p. 224, pl.-figs. 1-8.

Description.—Test elongate, uniserial, tapered towards base, circular in transverse section; chambers inflated, increase gradually in size as added (towards aperture); later ones slightly longer than earlier ones and less inflated; sutures distinct, depressed; wall calcareous, smooth, finely perforate, with faint longitudinal lines; aperture terminal (broken), extended, elliptical, with slight phialine lip.

Remarks.—The chambers are longer becoming siphon-like towards the base, rather than bell-shaped, therefore distinguishing this genera from *Nodogenerina*. This species is common in Miocene rocks in the Tofino Basin. It is characteristic of the upper middle bathyal biofacies (Ingle, 1980; Finger, 1990).

Age range.—Oligocene (Zemmorian) to Pliocene (Finger, 1990).

Siphonodosaria montereyana Finger and Lipps, 1990

Plate 8, figures 3-4

Siphonodosaria montereyana FINGER and LIPPS, 1990, p. 41, pl. 1, figs. 22-23; FINGER, 1990, p. 226, pl.-figs. 1-5.

Description.—Test elongate, uniserial, slightly angled or bowed; chambers inflated, slightly elongated, increase gradually in size as added, later ones overlap earlier ones, earliest chamber (proloculus) with a short, stout apical spine; sutures distinct, depressed, horizontal; wall calcareous, thickened, smooth, finely perforate; aperture (mostly broken) rounded with a slight phialine lip.

Remarks.—This species is similar to *Dentalina reussi* Neugeboren in the curvature of the test and presence of an apical spine. However, the test of the *D. reussi* differs by being more slender and by its radiate aperture. In *S. montereyana* some variations occur with respect to size and thickness of the apical spine, curvature (bowing) of the test and inflation of the chambers. In the Tofino Basin specimens, the apertures are rarely preserved and there is slight abrasion of the tests. This species, initially described from the Monterey Formation (Lower Miocene) of California is common in the Lower

Miocene strata in the Tofino Basin. It is characterisitic of the upper middle bathyal to lower middle bathyal biofacies (Ingle, 1980; Finger, 1990).

Age range.—Oligocene (Zemmorian) to Pliocene (Finger, 1990).

Family Uvigerinidae Haeckel, 1894

Genus *Euuvigerina* Thalmann, 1952

Euuvigerina juncea (Cushman and Todd, 1941)

Plate 8, figures 5-6

Uvigerina juncea CUSHMAN and TODD, 1941, p. 78, pl. 20, figs. 4-11; MARTIN, 1952, p. 137, pl. 25, fig. 4; RAU, 1970, p. 26, pl. 2, fig. 8.

Uvigerina peregrina Cushman, TODD and LOW, 1967, p. A30, pl. 4, fig. 1, non figs. 2-3.

Euuvigerina juncea PATTERSON, 1989, p. 238, pl. 10.3, figs. 3-5; PATTERSON, BURBIDGE and LUTERNAUER, 1998, p. 17, pl. 17, figs. 1-4.

Description.—Test elongate, slender, slightly tapered towards initial end, periphery lobulate, rounded in cross-section, five to seven whorls; chambers numerous, high in later portion, inflated, initially triserial, later tending to become biserial; sutures distinct, depressed; wall calcareous, finely perforate; costae numerous, fine, evenly-spaced low, longitudinal, extend from base to aperture, not continuous across sutures, best developed in middle of test; aperture terminal on a short neck, small, circular, bordered by a slightly flaring phialine lip, narrow internal tooth-plate present.

Remarks.—This species is distinguished from other *Euuivgerina* spp. and *Uvigerina* spp. by its slender, elongate test with low discontinuous costae, and a small, rounded aperture with a flaring apertural lip. It differs from *Uvigerina peregrina* by having a longer, less fusiform test (sides nearly parallel) with lower costae that are not strongly bladed. The original description describes costae degenerating into fine spines towards the apertural end; none were recovered in this study. Studies from the the Gulf of Alaska, report the presence of smaller more delicate forms of *E. juncea* with costae interrupted into spines (Echols and Armentrout, 1980). These smaller forms are most likely *U. dirupta* Todd. This species with its slender and delicately costate test is characteristic of the outer neritic biofacies (Bandy, 1953; Ingle, 1980; Echols and Armentrout, 1980).

Age range.—Pliocene to Holocene (Cushman and Todd, 1941; Rau, 1970).

Genus *Neouvigerina* Thalmann, 1952

Neouvigerina proboscidea (Schwager, 1866)

Plate 8, figures 7-9

Uvigerina proboscidea SCHWAGER, 1866, p. 250, pl. 7, fig. 96; FINGER, 1990, p. 244, pl.-figs. 1-8.

Uvigerina senticosa Cushman var. *adiposa* WHITE, 1956, p. 259, pl. 32, fig. 9.

Uvigerina senticosa adiposa (White), FINGER, 1990, p. 246, pl.-figs. 1-8.

Neouvigerina proboscidea HAYWARD, GRENFELL, REID, and HAYWARD, 1999, p. 134, pl. 9, fig. 22.

Description.—Test small to medium size, stout, one and one half times as long as wide, periphery lobulate, three to four whorls; chambers in early portion triserially arranged, small, closely appressed, later portion biserial, much inflated, globular; sutures distinct, depressed; wall calcareous, finely perforate, ornamented with numerous fine tubercles or papillae, appearing slightly spinose or granular; aperture terminal, rounded, at end of an elongate, papilliose neck with phialine lip.

Remarks.—This species is easily distinguished by its stout, papillose test with an elongate, trunk-like apertural neck. *Uvigerina senticosa adiposa* is herein considered a junior synonym because it was only separated based on papillose versus hispid ornamentation. *Neouvigerina proboscidea* shows variation in the grade of ornamentation, ranging from slightly hispid to tuberculose. It is characteristic of the lower middle bathyal biofacies (Ingle, 1980; Finger, 1990).

Age range.—Miocene to Holocene (Finger, 1990; Hayward et al., 1999).

Genus *Trifarina* Cushman, 1923

Trifarina fluens (Todd, 1947)

Plate 8, figures 10-11

Angulogerina fluens TODD in Cushman and Todd, 1947, p. 67, pl. 16, figs. 6-7; TODD in Cushman and McCulloch, 1948, p. 288, pl. 36, fig. 1; TODD and LOW, 1967, p. A30, pl. 4, fig. 5; SMITH, 1978, p. 144, pl. 2, figs. 11-12; PATTERSON, BURBIDGE AND LUTERNAUER, 1998, p. 18, pl. 16, figs. 4-5.

Trifarina fluens (Todd), FINGER and LIPPS, 1990, p. 49, pl. 10, fig. 5; FINGER, 1990, p. 236, pl.-figs. 1-7; 1992, p. 83, pl. 22, figs. 44-46; POLYAK, KORSUN, FEBO, STANOVOY, KHUSID, HALD, PAULSEN and LUBINSKI, 2002, p. 269, pl. 2, fig. 18.

Description.—Test elongate, slender, trigonal in cross-section, periphery slightly rounded and slightly carinate, slightly tapered towards the base, widest just above the midline, four to five whorls visible; chambers initially triserial, compact, later becoming high, irregulary inflated, slightly angled with flattened/compressed walls, rapidly increasing in size as added; sutures distinct, depressed and curved; wall calcareous, hyaline, finely perforate; costae numerous, low, curved, longitudinal, extend form base to aperture, confluent across sutures ; aperture terminal, elongate, oval, produced on a short neck and borderd by an elevated rim, internal tooth-plate visible.

Remarks.—This species is easily distinguished in the Tofino Basin material. It can be differentiated from co-occurring *T. angulosa* (Williamson) by having a less rounded periphery with distinct, strongly carinate chamber angles, and a test with discontinuous, shorter, longitudinal costae. *Angulogerina* is considered herein to be a junior synonym of *Trifarina* based on the initially triserial to later uniserial chamber arrangement (see Loeblich and Tappan, 1987; Hayward et al., 1999). The recorded upper depth limit of this species is inner neritic (Finger, 1990). It is found to range from the outer neritic to upper bathyal biofacies (Ingel, 1980).

Age range.—Oligocene to Holocene (Finger, 1990).

Genus *Uvigerina* d'Orbigny, 1826

Uvigerina dirupta Todd, 1948

Plate 8, figure 12

Uvigerina peregrina Cushman var. *dirupta* TODD in Cushman and McCulloch, 1948, p. 267, pl. 34, fig.3; HALLER, 1980, p. 250, pl. 7, figs. 13-14; BURKE, BERGER, COULBOURN and VINCENT, 1993, pl. 1, fig. 12.

Uvigerina peregrina Cushman, TODD and LOW, 1967, p. A30, pl. 4, fig. 2, non 1, 3.

cf. *Uvigerina pilulata* CUSHMAN and ELLISOR, 1939, p. 7, pl. 1, fig. 12.

Description.—Test small, elongate, fusiform, one and one half times as long as broad, tapered towards initial end, periphery slightly lobulate, four to six whorls; chambers slightly inflated, numerous, increase gradually in size as added, triserial arrangement throughout; sutures distinct, depressed; wall calcareous, hyaline, finely perforate; costae numerous, discontinuous, platy, bladed with crenulate edges, not well-developed in final chambers, intercostal spaces with a few, slightly spinose, tubercles; aperture terminal, rounded, on short tubular neck with phialine lip.

Remarks.—This rare species is distinguished from *Uvigerina peregrina* by having a short, slightly stout test with two types of ornamentation that gives the test a coarse textured, spinose appearance. It is close to *U. pilulata* (Cushman and Elisor) by having a short, stout test and numerous longitudinal costae that are very finely beaded at the outer edge giving the test a coarse perforate appearance. Gradational forms between *U. peregrina* and *U. latalata* may exist where the costae (especially near the apertural end) gradually become serrate but have not developed the spinose character (i.e. *U.* "*peregrina*" illustrated in Finger, 1990). It is characteristic of the upper middle bathyal biofacies (Ingle, 1980).

Age range.—Pliocene to Holocene (Todd, 1948; Burke et al., 1993).

Uvigerina gallowayi Cushman, 1929

Plate 8, figures 13-14

Uvigerina gallowayi CUSHMAN, 1929, p. 21, pl. 3, fig. 18; CUSHMAN and TODD, 1941, p. 45, pl. 13, fig. 11; CUSHMAN and SIMONSON, 1944, p. 200, pl. 32, fig. 18, non 19; FAIRCHILD, WESENDUNK and WEAVER, 1969, p. 56, pl. 12, figs. 14.

Description.—Test usually short, slighty subovate and broad in the microspheric form, more elongate and slightly fusiform in megalospheric form, periphery broadly rounded, rounded in cross-section, widest above midpoint; chambers numerous, fairly indistinct, inflated; sutures depressed; wall calcareous, hyaline, smooth, finely perforate; costae numerous, eight to 12, fairly high and slightly bladed, wavy, longitudinal, mostly discontinuous over chambers, usually extend over a few chambers before fading, well developed on initial chambers, can be strongly bladed near base, diminished on later chambers leaving them smooth; aperture terminal, rounded, on short cylindrical neck with phialine lip, centered on test in slight depression of last chamber.

Remarks.—This species is closest to *U. gesteri* Barbat and von Estorff but the latter species has a longer test, fewer and strongly continous costae (from base to aperture). The costae are present on the final chamber of *U. gesteri* but absent on the final chamber of *U. gallowayi*. It may be close to *U. mioshwageri* and differs by having fewer costae which are not as heavily sculptured near the base of the test. This species is characteristic of the upper middle bathyal biofacies (Ingle, 1980)

Age range.—Late Oligocene (Zemmorian)/early Miocene (Saucesian).

Uvigerina gallowayi? Cushman, 1929

Plate 8, figure 15

?*Uvigerina gallowayi* CUSHMAN, 1929, p. 21, pl. 3, fig. 18; CUSHMAN and TODD, 1941, p. 45, pl. 13, fig. 11; CUSHMAN and SIMONSON, 1944, p. 200, pl. 32, fig. 18, non fig. 19; FAIRCHILD, WESENDUNK and WEAVER, 1969, p. 56, pl. 12, fig. 14.

Description.—Test usually short, slighty subovate and broad in microspheric form, more elongate and slightly fusiform in megalospheric form, periphery broadly rounded, lobulate, rounded in cross-section, widest above midpoint; chambers numerous, fairly indistinct, greatly and irregularly inflated, rapidly increase in size as added; sutures depressed; wall calcareous, hyaline, smooth, finely perforate; costae few, longitudinal, fairly discontinuous, may appear continuous over several chambers, become less conspicuous or obsolete on later chambers, can be bladed or platy near base; aperture terminal, rounded on short, cylindrical neck with phialine lip, centered on test in depression of last chamber.

Remarks.—This specimen is placed with question within this species based on the slightly fewer costae that are lower and less conspicuous on later chambers (appearing worn). Also, later chambers of the test show a greater degree of inflation, becoming nearly bulbous or lobulate. There is some resemblance of this species to *U. schwageri* Brady. *Uvigerina schwageri* differs by having a tapered blunt initial end and chambers that are not as inflated. *Uvigerina gallowayi*? co-occurs with *U. gallowayi* and is characteristic of the upper middle bathyal biofacies (Ingel, 1980).

Age range.—Late Oligocene?(Zemmorian)/early Miocene (Saucesian).

Uvigerina hannai? Kleinpell, 1938

Plate 8, figures 16-17

Uvigerina californica HANNA, 1928, pl. 9, fig. 3.
?*Uvigerina hannai* KLEINPELL, 1938, p. 294; FINGER, 1990, p. 238, pl.-figs. 1-9; 1992, p. 82, pl. 22, figs. 7-9.

Description.—Test elongate, fusiform, medium size, slightly tapered, five to seven whorls, widest near apertural end; chambers distinct, slightly inflated, increase gradually in size as added; sutures distinct, depressed; wall calcareous, hyaline, finely perforate; costae ornament entire test, widely spaced, longitudinal, not continuous over sutures, earlier portion ornament may be sparse; aperture, terminal, small, rounded on short stout neck.

Remarks.—Specimens are placed within this species with uncertainty, because of similar test shape and sparse costae. It is probably close to, or conspecific with *U. sparsicostata* Leroy, which shares similar test features including sparse costae (Leroy, 1944), but is slightly larger. Because of its discontinuous sutures this species may be confused with *U. peregrina*, but differs in having costae that are extremely low and faint, are not thickly bladed, do not form jagged edges near the base of the chambers, and are better developed (visible) on the earlier chambers. Kleinpell (1938) synonomized *U. californica* Hanna (not Cushman). Also, he did not illustrate this species, which appears similar to the figures illustrated in Finger (1990). This species, like other *Uvigerina* spp., is probably characteristic of the upper bathyal and/or upper middle bathyal biofacies (Finger, 1990).

Age range.—Early Miocene to early Pliocene (Finger, 1990).

Uvigerina hootsi Rankin, 1934

Plate 8, figures 18-19

Uvigerina hootsi RANKIN in Cushman and Kleinpell, 1934, p. 22, pl. 3, figs. 8-9; MARTIN, 1952, p. 137, pl. 25, fig. 3; FINGER and LIPPS, 1990, p. 50, pl. 5, fig. 15; FINGER, 1990, p. 240, pl.-figs. 1-8; 1992, p. 82, pl. 22, figs. 1-6.

Description.—Test twice as long as wide, periphery strongly lobulate, widest above midpoint; chambers distinct, strongly inflated, globular, increase gradually in size as added, initially triserial becoming biserial; sutures distinct, depressed; wall calcareous, smooth, matte, finely perforate, with faint costae on earliest chambers; aperture terminal, small, rounded, on a short tubular neck with a phialine lip.

Remarks.—This species appears to be close to *Hopkinsinia magnifica* Bramlette. The juvenile forms of both are difficult to distinguish (Finger, 1990). The adult form of the latter species has a slightly larger test with more appressed chambers, a slight twist to the test, and chambers that occur in a slightly linear longitudinal sequence. The coiling of the test in *U. hootsi* is less symmetrical. Both species occur together with *H. magnifica* being the longer ranging of the two (possibly into the Holocene). This species is characteristic of the upper middle bathyal biofacies (Ingle, 1980; Finger, 1990).

Age range.—Middle to late Miocene (Rankin, 1934; Kleinpell, 1938).

Uvigerina latalata Stewart and Stewart, 1930

Plate 8, figure 20

Uvigerina peregrina Cushman var. *latalata* STEWART and STEWART, 1930, p. 66, pl. 8, fig. 7.

Uvigerina peregrina Cushman, BANDY, 1953, p. 177, pl. 25, fig. 10; BERGEN and O'NEIL, 1979, p. 1292, pl. 4, fig. 29, non fig. 17.

Description.—Test elongate, fusiform, widest near apertural end, periphery slightly rounded; chambers distinct, numerous, inflated; sutures distinct, depressed; wall calcareous, hyaline; costae numerous, raised, discontinous from chamber to chamber, longitudinal, offset and line up with intercostal spaces of the adjacent chambers, markedly thick/broad or wing-like with scalloped (notched) or slightly spinose edges, areas between costae smooth; aperture circular at end of a short tubular neck, with phialine neck.

Remarks.—This species is herein considered distinct from *Uvigerina peregrina* by having broad longitudinal costae, and therefore is elevated to the species level. Costae are stonger, plate or wing-like and the test has a greater jagged appearance than *U.*

peregrina. As with *U. peregrine*, it is characteristic of the upper bathyal biofacies (Ingle, 1980; Finger, 1990).

Age range.—Early Pliocene (Stewart and Stewart, 1930).

Uvigerina mioschwageri Finlay, 1939

Plate 8, figure 21

Uvigerina mioschwageri FINLAY, 1939, p. 103, pl. 12, figs. 15-17.

Uvigerina (*Euuvigeria*) *mioshwageri* Finaly, HORNIBROOK, FRAZIER and STRONG, 1989, p. 158, fig. 37:6.

Description.—Test medium size, elongate, fusiform, periphery broadly rounded, widest above midpoint; chambers numerous, fairly indistinct, inflated; sutures distinct, depressed; wall calcareous, hyaline, smooth, finely perforate; costae numerous, eight to 12, slightly bladed, wavy, longitudinal,discontinuous over chambers, extend from base to aperture or near aperture, well developed and stong on initial chambers, can be strongly bladed or "winged" near base forming platy/spiny apex, slightly faint and poorly developed on later chambers, thin-out on last chamber; aperture terminal, rounded, on short cylindrical neck with phialine lip, centered on test in slight depression of last chamber.

Remarks.—This species is distinguished from forms such as *U. gallowayi*, and *U. subperegrina* by a slightly larger, more fusiform test and numerous costae developed into flang-like spines on basal apex of the test. As with *U. gallowayi*, it is probably characteristic of the upper middle bathyal biofacies (Ingle, 1980).

Age range.—Middle Miocene (Hornibrook et al., 1989).

Uvigerina peregrina Cushman, 1923

Plate 8, figures 22-25

Uvigerina peregrina CUSHMAN, 1923, p. 66, pl. 8, fig. 7; 1927, p. 158, pl. 3, fig. 13; GALLOWAY and WISSLER, 1930, p. 76, pl. 12, figs. 1-2; MARTIN, 1952, p. 137, pl. 25, fig. 7; BERGEN and O'NEIL, 1979, p. 1292, pl. 4, figs. 17, non 29; OLSON, 1990, p. 301, pl. 5, fig. 8.

Euvigerina peregrina (Cushman) BARKER, 1960, p. 54, pl. 124, figs. 11-12.

Uvigerina "peregrina" (Cushman), FINGER, 1990, p. 242, pl.-figs. 1-8.

Description.—Test large elongate, fusiform two and one half times as long as broad, widest above midpoint, periphery rounded; chambers distinct, numerous, inflated; sutures depressed, fairly indistinct; wall calcareous, hyaline; costae numerous, approximately 10, thick, moderately bladed, jagged, longitudinal, not usually continuous across sutures to adjacent chambers, areas between costae are slightly granular and finely perforate; aperture circular at end of a short, distinct cylindrical neck, with a phialine lip.

Remarks.—This species has previously been divided into several varieties. The most typical form is fusiform with thick, bladed (and eight to 10) costae that are thickest in the middle of the chamber and discontinuous over the inflated chambers giving a jagged appearance to the chambers. In some forms, the costae are slightly weaker but conform to the original description, therefore not warranting separation into different varieties or subspecies. Forms that are sparsely costate and slightly spinose near the aperture or base are placed in *U. dirupta*. Other forms that are thickly bladed to form wing-like projections with scalloped edges are placed in *U. latalata*. Therefore, only costate forms (not hispidocostate; Echols and Armentrout, 1980) are herein considered to belong to *U. peregrina*. This species is more fusiform, shorter and more strongly costate than *Euvigerina juncea*. Water depth is a significant factor influencing the nature of costae developed in the *Uvigerina* spp. Species from deeper (upper middle bathyal) biofacies tend to show interruption of costate into spinose/tubercle-like ornamentation (e.g. *U. latalata*). This becomes more true with movement into the lower bathyal biofacies where forms such as *Neouvigerina proboscidea* are entirely spinose/papilose (Ingle, 1990). *Uvigerina peregrina* is characteristic of the upper bathyal biofacies (Ingle, 1980; Finger, 1990).

Age range.—Pliocene to Holocene (?) (Finger, 1990).

Uvigerina subperegrina Cushman and Kleinpell, 1934

Plate 8, figures 26-30

Uvigerina subperegrina CUSHMAN and KLEINPELL, 1934, p. 12, pl. 2, figs. 9-11; RAU, 1963, p. 140, pl. 12, fig. 11; 1970, p. 27, pl. 2, fig. 10; HALLER, 1980, p. 251, pl.

8, fig. 2; FINGER and LIPPS, p. 50, pl. 5, fig. 18; FINGER, 1990, p. 248, pl.-figs. 1-7; OLSON, 1990, p. 301, pl. 5, fig. 9; FINGER, 1992, p. 82, pl. 22, figs. 12-22.

Description.—Test medium sized, fusiform, slightly robust, fusiform, widest above midpoint, periphery rounded; chambers distinct, numerous, inflated; sutures distinct, depressed slightly oblique; wall calcareous, hyaline; costae numerous, approximately 10, fine, longitudinal, not continuous across sutures to adjacent chambers, last formed chamber slightly costate or smooth, areas between costae are slightly granular, finely perforate; aperture terminal, circular at end of a short, distinct cylindrical neck, with a phialine lip.

Remarks.—This species is close to *U. peregrina*. It differs by having a robust test with inflated chambers and comparatively low costae that are spaced evenly, but are not as numerous or as strongly bladed. Costae are not interrupted by spinose ornamentation. It differs from *U. hannai* by having a robust test and costae that are stronger and more distinct. This longer ranging species is commonly misidentified as *U. peregrina* (Rau, 1970). It is characteristic of the upper bathyal biofacies (Ingle, 1980; Finger, 1990).

Stratigrahphic range.—Oligocene (Zemorrian) to Holocene (Finger, 1990).

Genus *Uvigerinella* Cushman, 1926

Uvigerinella ornata? (Cushman, 1926)

Plate 8, figure 31

?*Uvigerina* (*Uvigerinella*) *californica* Cushman var. *ornata* CUSHMAN, 1926, p. 59, pl. 8, figs. 1,6.

?*Uvigerinella californica ornata* KLEINPELL and TIPTON, 1980, pl. 11, fig. 14; FINGER and LIPPS, 1990, p. 50, pl. 5, figs. 22, 23; FINGER, 1992, p. 83, pl. 22, figs. 36-43.

?*Uvigerinella ornata* (Cushman), PATTERSON, 1989, p. 240, pl. 10.3, figs. 6-9.

Description.—Test elongate, fusiform, periphery broadly rounded, widest above midpoint, slightly tapered towards initial end, three to four whorls, twisted very slightly; chambers distinct, numerous, three in each whorl, slightly inflated, increase gradually in size as added, final chamber slightly irregular and bearing a short, stout, slightly curved apertural neck; sutures distinct, depressed; wall calcareous, hyaline, smooth, finely perforated; costae numerous, low, longitudinal; aperture slightly ovate with a tooth-plate and slight phialine lip, on end of a short stout, slightly curved apertural neck (not cylindrical), located on final chamber.

Remarks.—Specimen are assigned as *U. ornata* with question as it slightly differs by having costae that are low (not greatly raised) as that described in the original description for this species. Slight weathering and recrystalization of the test may account for the apparently low costae. This species is close to *U. californica* and differs by having a shorter and less slender test and longitudinal costae. It is characteristic of the upper bathyal biofacies (Ingle, 1980; Finger, 1990).

Age range.—Late Oligocene? (Zemorrian)/Early Miocene (Saucesian) to middle Miocene (Mohnian) (Finger, 1990; for *U. californica*).

6.5. Planktic families

Family Candeinidae Cushman, 1927

Genus *Tenuitellinata* Li, 1987

Tenuitellinata angustiumbilicata (Bolli, 1957)

Plate 9, figures 1-2

Globigerina ciperoensis angustiumbilicata BOLLI, 1957a, p. 109, pl. 22, figs. 12-13; 1957b, p. 164, pl. 36, fig. 6.

Globigerina angustiumbilicata Bolli, BLOW, 1959, p. 172, pl. 7, figs. 33-34; JENKINS, 1960, p. 350, pl. 1, fig. 2; BLOW and BANNER, 1962, p. 85, pl. 9, figs. x-z; TAKAYANAGI and SAITO, 1962, p. 83, pl. 28, figs. 4-9; McKEEL and LIPPS, 1972, p. 87, pl. 2, fig. 3; KRASHENINNIKOV and HOSKINS, 1973, p. 123, pl. 5, figs. 8-10; STAINFORTH, LAMB, LUTERBACHER, BEARD and JEFFORDS, 1975, p. 253, figs. 105:1-6.

Globigerina (*Globigerina*) *ciperoensis angustiumbilicata* Bolli, JENKINS, 1971, p. 144, pl. 15, figs. 451-453.

Tenuitellinata angustiumbilicata (Bolli), emend LI, 1987, p. 311, pl. 2, figs. 15, 17-19; pl. 4, figs. 8-10; FINGER, 1990, p. 234, pl.-figs. 1-8; 1992, p. 76, pl. 22, figs. 12-13; UJIIE and UJIIE, 2000, p. 353, pl. 2, fig. 1.

Description.—Test small, medium trochospire, periphery lobulate, umbilicus closed; chambers five in final whorl, usually only one half of the fifth chamber visible, globular, inflated, increase gradually in size as added; sutures distinct, radial, depressed; wall calcareous, hyaline, rough with densely microperforate pustule ornamentations, finely perforate; aperture a low arch, opens at base of final chamber on ventral side.

Remarks.—This species is placed within the genus *Tenuitellinata* based on its characteristic microperforate and postulate walls. It is *Globigerina*-like, with five globular, inflated chambers in the final whorl, but differs by having a final chamber that is slightly bulla-like and oriented slightly forward (ventrally) to fully cover the umbilicus. This aberrant final chamber is similar to that of *Globigerina quinqueloba*, which is considered a descendant of *T. angustiumbilicata* (Parker, 1962; Saito, 1963). Also there is an apertural lip on the final chamber in *G. quinqueloba*. The aperture of *T. angustiumbilicata* is tiny or closed and this characteristic can differentiate from *Globigerina ciperoensis*, a short ranging zonal species. *Tenuitellinata angustiumbilicata* may be close to ?*Globigerina postcretacea* Myatiliuk, initially described from the Oligocene. Both show similarities in chamber arrangement, size and apertural characteristics. A conspecific relationship would make *T. angustiumbilicata* a junior synonmy of the latter species.

Age range.—Late Eocene to Holocene (Stainforth et al., 1975; Finger, 1992; Ujiie and Ujiie, 2000).

Genus *Globigerinita* Brönnimann, 1951

Globigerinita glutinata? (Egger, 1895)

Plate 9, figures 3-4

?*Globigerina glutinata* EGGER, 1893, p. 371, pl. 13, figs. 19-21.

?*Globigerinita glutinata* (Egger), PHLEGER , PARKER and PIERSON, 1953, p. 16, pl. 2, fig. 15 (non 12-14); PARKER, 1962, p. 246, pl. 9, figs. 1-16; PARKER, 1967, p. 146, pl. 17, figs. 3-5; ODA, 1977, p. 52, pl. 2, fig. 10; FINGER, 1992, p. 76, pl. 11, figs. 15-16; SPIEGLER, 1995, p. 166, pl. 1, fig. 10; UJJIE and UJJIE, 2000, p. 353, pl. 2, figs. 3-4.

?*Tinophodella ambitacrena* LOEBLICH and TAPPAN, 1957, p. , figs. 2-3.

?*Globigerinita glutinata* (Egger) *parkerae* BRÖNNIMAN and RESIG, 1971, p. 1303, pl. 23, figs. 1-4; pl. 50, fig. 6.

?*Globigerinita glutinata glutinata* BRÖNNIMAN and RESIG, 1971, p. 1306, pl. 23, fig. 5.

?*Tinophodella glutinata* (Egger), PATTERSON, BLENKINSOP and CAVAZZA, 1995, p. 14, figs. 10:1, 7.

Description.—Test small to medium, low to medium trochospire; chambers globular to slightly ovate with four in final whorl, increase in size gradually as added, moderately embracing; sutures distinct, may contain a bullae along sutures; wall calcareous smooth, finely perforated with fine pores, non-spinose; aperture umbilical, low symmetrical arch, weakly developed rim, secondary aperture may be developed.

Remarks.—This species differs from *Globigerina bulloides* by having a finely perforated test that is pustule-like rather than spinose, and a low but wide arched aperture, that may be covered by a bulla (a plate that covers the umbilicus). *Globigerinita* includes forms with supplementary apertures and a distinct umbilical plate. In the figured specimen, supplementary apertures were difficult to observe and therefore the specimen is questionably placed in *Globigerinita glutinata*.

Age range.—Middle Miocene (N13) to Holocene (N23).

Globigerinita uvula (Ehrenberg, 1861)

Plate 9, figure 5

Pylodexia uvula EHRENBERG, 1861, p. 276, 277, 308; 1873, pl. 2, figs. 24-25.

Globigerinita uvula (Ehrenberg), BRÖNNIMAN, 1971, p. 1305, pl. 22, figs. 7-8, non fig. 6; SAITO, THOMPSON and BREGER, 1981, p. 81, pl. 24, fig. 3; FINGER, 1992, p. 76, pl. 11, figs. 11-14.

Description.—Test with a high trochospire; chambers globular, numerous, 4-5 in final whorl, gradually increase in size as added; sutures distinct; wall calcareous, smooth, finely perforate; aperture interomarginal, umbilical, low arch.

Remarks.—This species is distinguished by its high trochospire and smooth test. It is a distinct but rare, high latitude species (Saito et al., 1981).

Age range.—Pliocene (N19) to Holocene (N23).

Family Globigerinidae Carpenter, Parker and Jones, 1862

Subfamily Globigerininae Carpenter, Parker and Jones, 1862

Genus *Globigerina* d'Orbigny, 1826

Globigerina bulloides d'Orbigny, 1826

Plate 9, figures 6-8

Globigerina bulloides D'ORBIGNY, 1826, p. 277; D'ORBIGNY, 1839, p. 132, pl. 2, figs. 1-3 (non fig. 28), BANNER and BLOW, 1960, p. 3, pl. 1, figs. 1, 4; TAKAYANAGI and SAITO, 1962, p. 84, pl. 24, fig. 12; POAG, 1972, p. 505, pl. 1, figs. 2-8; JENKINS, 1971, p. 141, pl. 14, figs. 408-410; SAITO, THOMPSON and BREGER, 1981, p. 40, pl. 7, fig. 1; FINGER, 1992, p. 77, pl. 13, figs. 22-24; SPIEGLER, 1996, p. 166, pl. 1, fig. 3; UJIIE AND UJIIE, 2000, p. 355, pl. 2, fig. 11.
Globigerina bulloides bulloides d'Orbigny, BRÖNNIMAN, 1971, p. 1292, pl. 6, fig. 3.

Description.—Test medium trochospire, periphery lobulate; chambers globular to slightly ovoid, three to five in final whorl, increase in size gradually; sutures distinct, incised; wall calcareous, densely, finely perforated (spines not observed); aperture interomarginal, umbilical with high symmetrical arch, usually with thin rimmed-lip.

Remarks.—A full and thorough description of *G. bulloides* was given by Banner and Blow (1960). This species is distinct from the smaller *G. praebulloides* by having of distinct (deep) sutures and a large umbilical aperture that has a high symmetrical arch over a deep umbilicus. It can be distinguished from *G. falconensis* by not having an apertural lip and having slightly asymmetrical chamber arrangement (best seen in spiral view). It commonly occurs in subtropical to subpolar-polar waters (Bé, 1967; Murray, 1971; Saito et al., 1981).

Age range and occurrence.—Jenkins (1971) recorded this species to range from the *Globigerina. angiporoides angiporoides* Zone to the *Neogloboquadrina pachyderma* D (dextral) 5 Subzone of the *Turborotalia inflata* Zone (Oligocene to Pleistocene) in New Zealand. Krasheninnikov and Hoskins (1973) reported it from the Late Miocene (Tortonian European Stage, *Globorotalia acostaensis-G. merotumid*a Zone) to Early Pliocene (*Sphaeroidinella dehiscens-Globoquadrina altispira* Zone). Most other studies record a range from the Late Miocene (Mohnian; N16) to the Holocene (N23).

Globigerina sp. cf. *G. euapertura* Jenkins, 1960

Plate 9, figure 9

cf. *Globigerina euapertura* JENKINS, 1960, p. 351, pl. 1, fig. 8; McKEEL and LIPPS, 1972, p. 8, pl. 2, fig. 5; HORNIBROOK, BRAZIER and STRONG, 1989, p. 126, fig. 26:2.

Catapsydrax unicavus JENKINS, 1960, p. 356, pl. 3, fig. 7

?*Sphaeroidinella disjuncta* FINLAY, 1940, p. 469, pl. 67, figs. 224-228; JENKINS, 1971, p. 171, pl. 17, figs. 536-538.

Description.—Test large, trochospiral, periphery rounded, tightly coiled; chambers globular, four in final whorl, strongly embracing, final chamber smaller than one before and slightly flattened; sutures distinct, deeply incised on ventral side; wall calcareous, thick, finely perforated, ornamented with tiny pustules; aperture interomarginal, umbilical, narrow, low arched and bordered by a weak non-perforate rim.

Remarks.—This species is distinguished by its thickened test, quadrilobate equatorial periphery and a thick calcareous wall that is smooth and finely perforate between tiny pustules (similar to some *Globigerina* spp., e.g. *G. bulloides*). It may be close to *Globigerina ampliapertura* Bolli, but differs by having smooth and finely perforated walls and a wide subqaudrilobate equatorial periphery instead of finely pitted walls, lobate equatorial periphery and high arched aperture of *G. ampliapertura*.

Age range and occurrence.—This species has been recorded from the *Globigerina brevis* Zone to the *Globigerina woodi connecta* Zone (early Oligocene to early Miocene) of New Zealand (Jenkins, 1971; Hornibrook et al., 1989).

Globigerina falconensis Blow, 1959

Plate 9, figures 10-12

Globigerina falconensis BLOW, 1959, p. 177, pl. 9, figs. 40-41; PARKER, 1962, p. 224, pl. 1, figs. 14, 16-19; TAKAYANAGI and SAITO, 1962, p. 86, pl. 24, fig. 13; KRASHENINNIKOV and HOSKINS, 1973, p. 124, pl. 7, figs. 9-11; BRÖNNIMAN, 1971, p. 1295, pl. 3, figs. 1-2, 4-8; JENKINS, 1971, p. 148, pl. 16, figs. 463-465; ODA, 1977, p. 50, pl. 1, figs. 8-9; SAITO, THOMPSON and BREGER, 1981, p. 40, pl. 7, fig. 2; UJIIE and UJIIE, 2000, p. 355, pl. 2, fig. 12.

Description.—Test small to medium, low trochospiral, periphery lobulate; chambers globular, final chamber slightly smaller, three to five in final whorl, increase gradually as added; sutures distinct, incised; wall calcareous, thick, coarsely perforated; aperture interomarginal, umbilical, opening partly obscured by final chamber and thick imperforate lip.

Remarks.—Although similar to *G. bulloides*, and *G. foliata*, *G. falconensis* is distinguished from both by a distinct and thick (imperforate) apertural lip, that slightly overhangs the low-arched apertural opening and the final chamber is ovoid and slightly smaller. It is rarer than *G. bulloides*, and occurs in subtropical to cold-temperate waters (Bé, 1967).

Age range.—Blow (1959) recorded this species from the Miocene to Pliocene (?) in Venezuela (*G. insueta* / *G. bispherica* Subzone to *G. bulloides* Zone), and Jenkins (1971) reported it from the upper part of the *Globigerinoides trilobus trilobus* Zone to the *Neogloboquadrina pachyderma* S (sinistral) 4 Subzone of the *Turborotalia inflata* Zone (middle Miocene to Pleistocene) in New Zealand. Saito et al. (1981) recorded a range from the Early Miocene (N7) to Holocene (N23) in Japan.

Globigerina megastoma? Earland, 1934

Plate 9, figures 13-14

?*Globigerina megastoma* EARLAND, 1934, p. 177, pl. 8 figs. 9-12; BANNER and BLOW, 1960, p. 14-15, pl. 1, fig. 3; SAITO, THOMPSON, and BREGER, 1981, p. 35, pl. 5, fig. 2

Description.—Test medium size, trochospiral; chambers sub-globular, slightly flattened, four to five in the final whorl, increase in size gradually, initial slightly conical; sutures distinct, deeply incised; wall calcareous, finely perforate, coarsely pitted, non-spinose; aperture wide, deep, interomarginal, umbilical, not rimmed.

Remarks.—This species appears to be very close to *G. bulloides*. It differs by having a fairly large apertural opening, ovoid chambers, a distinctive high trochospire, and chambers that do not increase in size as rapidly as in *G. bulloides*.

Age range.—Late Pliocene (N21) to Holocene (N23; Saito et al., 1981).

Globigerina quinqueloba Natland, 1938

Plate 9, figures 15-18

Globigerina quinqueloba NATLAND, 1938, p. 149, pl. 6, fig. 7; PARKER, 1962, p. 225, pl. 2, figs. 7-16; JENKINS, 1971, p. 155, pl. 18, figs. 539-544; SAITO, THOMPSON, and BREGER, 1981, p. 48, pl. 10, figs. 1-2; FINGER, 1992, p. 77, pl. 12, fig. 7; UJIIE and UJIIE, 2000, p. 355, pl. 2, fig. 14; PATTERSON and KUMAR, 2002, p. 120, pl. 1, fig. 6.

Turborotalita quinqueloba (Natland), DOWSETT and ISHMAN, 1995, p. 156, pl. 3, fig. 9; SPIEGLER, 1996, p. 166, pl. 1, figs. 14-15.

Remarks.—The test is small, trochospirally coiled and can be easily confused with *Neogloboquadina pachyderma* due to its size, five globular chambers in the final whorl that increase in size rapidly as added, and a final bulla-like chamber. It is distinguished from *N. pachyderma* by having an interomarginal, umbilical-extraumbilical aperture with a hooded lip that commonly covers the umbilicus and by having distinct, incised sutures. The calcareous wall is thick, finely perforated and hispid in *G. quinqueloba*, while the wall in *N. pachyderma* is thick, granular and coarsely pitted. It is commonly distributed in cold-water environments (Bé 1967; Murray, 1971). This species is regarded as a descendant of the Miocene *Tenuitellinata angustiumbilicata* (Asano et al. 1968; Oda, 1977).

Age range and occurrence.—In New Zealand it is recorded from the *Globigerina woodi connecta* Zone to the *Neogloboquadrina pachyderma* D5 Subzone of the Turborotalia inflate Zone (Early Miocene to Late Pleistocene). Other studies agree to a Miocene to Holocene range.

Globigerina praebulloides Blow, 1959

Plate 9, figures 19-20

Globigerina praebulloides BLOW, 1959, p. 180, pl. 8, fig. 47; pl. 9, fig. 48; TAKAYANAGI and SAITO, 1962, p. 90, pl. 25, fig. 4; POSTUMA, 1971, p. 268, p.-pl. 269; McKEEL and LIPPS, 1962, p. 89, pl. 2, fig. 6; KRASHENINNIKOV and HOSKINS, 1973, p. 123, pl. 9, figs. 10-12; FINGER, 1992, p. 77, pl. 12, figs. 28-30; pl. 13, figs. 1-3.

Remarks.—This species is similar to *G. bulloides* by having four inflated, globular chambers in the final whorl that increase rapidly in size, and smooth, finely perforated walls. It differs by having a lower trochospiral test, a lower arched aperture, and a less elongate equatorial profile than *G. bulloides*. Jenkins (1971) regarded *G. praebulloides* to be a junior synonym for *G. bulloides* in New Zealand strata, however, this species can be distinguished from *G. bulloides* by the characteristics mentioned above, and therefore should remain as *G. praebulloides*. It is recognized as the ancestor of *Globigerinoides primordius* Blow (Postuma, 1971).

Age range and occurrence.—Base of the *Globigerina ampliapertura* Zone to upper part of the *Neogloboquadrina (Globorotalia) dutertrei* Zone (Late Eocene(?) to late Miocene; Postuma, 1971).

Globigerina umbilicata Orr and Zaitzeff, 1971

Plate 9, figure 21

Globigerina umbilicata ORR and ZAITZEFF, 1971, p. 17, pl. 1, figs. 1-3; SAITO, THOMPSON and BREGER, 1981, p. 37, pl. 6, figs. 1-2.

Description.—Test large, low trochospire, peripheral margin rounded, equatorial periphery slightly lobulate; chambers globular to ovate, initial chamber slightly flattened/compressed, five to six chambers in final whorl, increase gradually in size as added; sutures distinct, depressed; wall calcareous, finely perforated, spinose; aperture large, umbilical to interomarginal, wide, open arch.

Remarks.—Specimens are placed in *G. umbilicata* based on the number of chambers in the final whorl, embracing, depressed spiral sutures and the large umbilical aperture opening. This species is reported to co-occur with *G. bulloides*, but differs by the above characteristics.

Age range and occurrence.—Pliocene of the Pacific Coast (Orr and Zaitzeff, 1971; Saito et al., 1981).

Globigerina woodi? Jenkins, 1960

Plate 9, figure 22

?*Globigerina woodi* JENKINS, 1960, p. 352, pl. 2, fig. 2; TAKAYANAGI and SAITO, 1962, p. 91, pl. 25, fig. 6.

?*Globigerina apertura* Cushman, HORNIBROOK, 1961, p. 148, pl. 21, figs. 432-433, 435. ODA, 1977, p. 50, pl. 1, fig. 1.

?*Globigerina druryi decoraperta* TAKAYANAGI and SAITO, 1962, p. 85, pl. 28, fig. 10.

?*Globigerina woodi woodi* JENKINS, 1971, p. 159, pl. 18, figs. 548-550; HORNIBROOK, BRAZIER and STRONG, 1989, p. 127, fig. 27, 4; fig. 30, 4.

?*Globigerina decoraperta* ODA, 1977, p. 50, pl. 1, figs. 4-6.

Description.—Test medium to large, high trochospire, peripheral margin rounded, equatorial margin quadrilobate; chambers globular to ovate, inflated with a tendency of final chamber to be slightly flattened, three to four chambers in final whorl; sutures distinct, depressed, radial, U-shaped; wall calcareous, thick, perforated, coarsely pitted; aperture interomarginal, umbilical, medium to high arch with a slight lip-like border.

Remarks.—This species appears to be close to *G. bulloides* by having medium height trochospire, 4 chambers in the final whorl, and a high-arched aperture. However, its features such as its thick, pitted wall and high-arched symmetrical aperture, and U-shaped sutures, place it within *G. woodi*. A faint rim is developed on the aperture. The size of the aperture is highly variable in this species and can range from being broadly semicircular (*G. apertura*) to narrow.

Age range and occurrence.—Late Miocene (N16) to Late (?) Pliocene (N21).

Genus G*lobigerinoides* Cushman, 1927

Globigerinoides extremus? Bolli and Bermundez, 1965

Plate 9, figure 23

?*Globigerinoides obliquus extremus* BOLLI and BERMUDEZ, 1965, p. 139, pl. 1, figs. 10-12; BOLLI and SAUNDERS, 1985, p. 194, fig. 20:11; SPIEGLER, 1996, p. 167, pl. 2, fig. 2.

?*Globigerinoides extremus* Bolli, KENNET and SRINIVASAN, 1983, p. 58, pl. 12, figs. 1-3.

Description.—Test medium large, high trochospire, peripheral margin rounded, equatorial periphery lobulate; chambers inflated, globular to ovate, arranged in two to three whorls, four chamber in final whorl, increase rapidly as added; sutures distinct, depressed, oblique on spiral side; wall calcareous, finely perforated, pitted; primary aperture large, wide/deep, high-arch, supplementary aperture small, low-arch, on final chamber.

Remarks.—Rare specimen (2) recovered from the Tofino Basin are placed in *G. extremus* with question, based on the overall appearance of the test, chamber arrangement and apertures. This species differs from *G. obliquus* by having inflated chambers in which the final chamber is slightly compressed. The first appearance of this species was recently reported to be lower than its published age and its last appearance in lower than its published last appearance (Chaisson and Hondt, 2000).

Age range and occurrence.—Middle Miocene to Late Pliocene (Bolli and Bermudez, 1965; Chaisson and Hondt, 2000).

Subfamily Orbulininae Schultze, 1854

Genus *Orbulina* d'Orbigny, 1839

Orbulina universa (d'Orbigny, 1839)

Plate 9, figure 24

Orbulina universa D'ORBIGNY, 1839, p. 2, pl. 1, fig. 1; CUSHMAN, 1914, p. 14, pl. 6, figs. 1-5; pl. 7, figs. 1-2; pl. 11, fig.3; BOLLI, LOEBLICH and TAPPAN, 1957, p. 35, pl. 7, figs. 1-5; JENKINS, 1971, p. 193, pl. 23, fig. 660; STAINFORTH, LAMB, LUTERBACHER, BEARD and JEFFORDS, 1975, p. 328, fig. 150, 1-5; SAITO, THOMPSON, and BREGER, 1981, p. 70, pl. 19, figs. 1-3 (non fig. 4); FINGER, 1992, p. 77, pl. 14, fig. 23; UJIIE and UJIIE, 2000, p. 356, pl. 3, fig. 15.

Globigerina bilobata D'ORBIGNY, 1846, p. 164, pl. 9, figs. 11-14; BANNER and BLOW, 1960, p. 2, pl. 3, fig. 9.

Biorbulina bilobata BLOW, 1956, p. 69, fig. 16, text-fig. 2; BERMÚDEZ, 1960, p. 1255, pl. 7, figs. 8-9.

Remarks.—This species is distinguished by its large, thin-walled test, consisting of one spherical chamber. The test wall contains two distinct sizes of coarsely perforated pores over the entire surface. The large pores are considered as the main apertures. The diameter and pore sizes along the test diameter of *O. universa* is latitudinally controlled (Stone, 1956; Jenkins, 1971; Bé et al., 1973; Stainforth et al., 1975; Saito et al., 1981). Smaller diameter forms predominate away from equatorial regions (Stone, 1956; Jenkins, 1971; Stainforth et al., 1975). *Orbulina universa* evolved from *O. suturalis*, its immediate ancestor (Jenkins, 1971; Stainforth et al., 1975), and can be differentiated from it and other spheroidinal forms (i.e. *Praeorbulina* spp.) by the absence of *Globigerina*-like earlier chambers visible on the final chamber. The evolutionary bioseries postulated to lead to *O. universa* is the following: *Globigerinoides sicanus* ? *Praeorbulina* spp.? *Orbulina suturalis*? *Orbulina universa* (Stainforth et al., 1975).

Age range and occurrence.—This species is reported from the *Globorotalia* (*T.*) *mayeri mayeri* Zone to the *G.* (*T.*) *pachyderma* D5 Subzone of the *G.* (*T.*) *inflata* Zone in New Zealand (Middle Miocene to Late Pleistocene). It is recorded from the Early Miocene (N9) to Holocene (N23) in Japan (Saito et al., 1981).

Family Globorotaliidae Cushman, 1927

Genus *Globorotalia* Cushman, 1927

Globorotalia scitula (Brady, 1882)

Plate 9, figures 25-26

Pulvinulina scitula BRADY, 1882, p. 716 (no figure), BANNER and BLOW, 1960, p. 27, pl. 5, fig. 5.

Globorotalia scitula (Brady), CUSHMAN, 1927, p. 175; CUSHMAN and HENBEST, 1940, p. 36, pl. 8, fig. 5; BOLLI, 1957, p. 120, pl. 29, figs. 11-12; PARKER, 1962, p. 238, pl. 6, figs. 4-6; KRASHENINNIKOV and HOSKINS, 1973, p. 131, pl. 28, figs. 1-3; STAINFORTH, LAMB, LUTERBACHER, BEARD and JEFFORDS, 1975, p. 313, fig. 140, 1-7; SAITO, THOMPSON, and BREGER, 1981, p. 137, pl. 46, fig. 2; CIFELLI and SCOTT, 1986, p. 39, fig. 16, f-h, k-o; HORNIBROOK , BRAZIER and STRONG, 1989, p. 134, fig. 28, 11; SCOTT, BISHOP and BURT, 1990, p. 78, figs. 51-52; PATTERSON, BLENKINSOP and CAVAZZA, 1995, p. 14, fig. 12-1, 4.

Globorotalia scitula praescitula BLOW, 1959, p. 221, pl. 19, fig. 128; JENKINS, 1960, p. 366, pl. 19, fig. 6; ODA, 1977, p. 60, pl. 6, fig. 8.

Globorotalia scitula scitula (Brady), BLOW, 1959, p. 219, pl. 19, fig. 12; TAKAYANAGI and SAITO, 1962, p. 80, pl. 26, fig. 2; ODA, 1977, p. 61, pl. 9, fig. 12.

Turborotalia scitula (Brady), LIPPS, 1967, p. 995, fig. 2.

Globorotalia (Turborotalia) praescitula Blow, JENKINS, 1971, p. 129, pl. 14, figs. 392-394.

Globorotalia (Turborotalia) scitula (Brady), BRÖNNIMAN, 1971, p. 1400, pl. 37, figs. 6, 8, 10; JENKINS, 1971, p. 131, pl. 13.

Description.—Test small to medium, low trochospire, without a peripheral keel, bluntly rounded; chambers wedge (ear-shaped), shows radial elongation, 4-5 in final whorl, earlier ones compressed, final one weakly inflated, increase in size gradually as added; sutures distinct, weakly curved and depressed on ventral side and recurved on spiral side; walls calcareous, smooth, non-spinose, with large well-spaced pores on earlier chambers and small pore pits on final chamber, pustulate near aperture; aperture interomarginal, umbilical-extraumbilical low asymetrical arch, with a thick-rimmed lip that covers opening.

Remarks.—Several *Globorotalia* species approach the morphology of *G. scitula* including *G. hirsuta*, *G. margaritae*, and *G. praemenardii*. An understanding of the evolutionary bioseries descending from *G. scitula* is significant in its identification. *Globorotalia praemenardii* apparently evolved from *G. scitula* by developing a weak imperforate keel along the periphery (Stainforth et al., 1975). *Globorotalia scitula* is distinguished from *Globorotalia hirsuta* and *G. margaritae* (which appear later) (Stainforth et al., 1975) by its smooth wall (lack of coarse pustules on test surface), tighter coil, lunate equatorial profile and thick-rimmed aperture. *Globorotalia margaritae*, which also shows development of a weak imperforate keel, is regarded as a direct descendant of *G. scitula*. Further development leads to the evolution of *G. hirsuta*. A detailed analysis of the evolutionary relationship of the scitulines is provided by Cifelli and Scott (1986). *Globorotalia scitula* is rare in the Upper Neogene strata of the Tofino Basin.

Age range and occurrence.—*Globorotalia scitula* has been recorded from the *G. fohsi barisanensis* Zone to *G. bulloides* Zone from the Miocene of Trinidad (Blow, 1959), and from the *G. (T.) mayeri mayeri* Zone to the *G (T.) pachyderma* S4 Subzone of the *G.(T.)*

inflata zone in New Zealand (Middle Miocene to Pleistocene; Jenkins, 1971). Postuma (1971) reported it from the *Globorotalia peripheroacuta* Zone (Middle Miocene, N10; Blow, 1969) to *Globorotalia truncatulinoides* Zone (Holocene, N23; Blow, 1969). In the North Pacific, it has been recorded from the Early Miocene (N10) to Holocene (N23; Saito et al., 1981). Overall this bioseries is a good indicator of post-Oligocene ages (Stainforth et al., 1975).

Genus *Neogloboquadrina* Bandy, Frerichs and Vincent, 1967

Neogloboquadrina asanoi (Maiya, Saito and Sato, 1976)

Plate 9, figures 27-28

Globoquadrina asanoi MAIYA, SAITO and SATO, 1976, p. 409, pl. 3, figs. 1-3.

Neogloboquadrina asanoi (Maiya, Saito and Sato), SAITO, THOMPSON and BREGER, 1981, p. 117, pl. 38, figs. 3-4; SPIEGLER, 1996, p. 166, pl. 1, figs. 5-6.

Description.—Test small, low trochospire, equatorial periphery lobulate; chambers subspherical to ovate, inflated, four in final whorl, increase gradually in size as added; sutures distinct, depressed, slightly incised towards umbilicus; wall calcareous, coarsely pitted, granular appearance, non-spinose; aperture interomarginal, umbilical, low arched, not rimmed.

Remarks.—This species is similar to *N. kagaenis* (Maiya, Saito and Sato) in test size shape and chamber arrangement, but differs by having an interomarginal, umbilical chamber not a umbilical-extraumbilical aperture. Also, it is also considered to resemble *N. conglomerata* (Schwager) in general appearance, but differs by its "protruding conical arrangement of early chambers on the spiral side" (Maiyo et al., 1976). There are similarities in appearance between *N. asanoi* and *N. incompta*, but the latter differs by having tightly embraced chambers and deeply incised sutures. The occurrence of *Neogloboquadrina asanoi* suggests episodic ingressions of warm water during the late Pliocene (Spiegler, 1995).

Age range and occurrence.—Late Pliocene (Zone N21) of the north Pacific and Arctic (Maiyo et al., 1976; Spiegler, 1995).

Neogloboquadrina dutertrei (D'Orbigny, 1839)

Plate 9, figures 29-31

Globigerina dutertrei, 1839, p. 84 pl. 4, figs. 19-21; BANNER and BLOW, 1960, p. 11, pl. 2, fig. 1; CIFELLI and SMITH, 1970, p. 21, pl. 2, figs. 1-2, text-fig. 13. STAINFORTH, LAMB, LUTERBACHER, BEARD and JEFFORDS, 1975, p. 347, fig. 163:1-6.

Globoquadrina dutertrei (D'Orbigny), PARKER, 1962, p. 242, pl. 7, figs.1-13 (non pl. 8, figs. 1-4); 1967, p. 168, pl. 25, fig. 7.

Neogloboquadrina dutertrei (D'Orbigny), BANDY, FRERICHS and VINCENT, 1967, p. 152, pl. 14, figs. 3-12; SAITO, THOMPSON and BREGER, 1981, p. 111, pl. 36, fig. 1; PATTERSON, BLENKINSOP and CAVAZZA, p. 14, fig. 10-1, 3; UJIIE and UJIIE, 2000, p. 352, pl. 1, figs. 3-4.

Globorotalia (Turborotalia) dutertrei (D'Orbigny), JENKINS, 1971, p. 116, pl. 11, figs. 273-275.

Neogloboquadrina dutertrei dutertrei (D'Orbigny), RÖGL and BOLLI, 1973, p. 9, figs. 1-3, 7-10; pl. 17, figs. 1-6; SRINIVASAN and KENNETT, 1976, p. 329-355; pl. 1, figs. 1-11; pl. 2, figs. 1-11; pl. 3, figs. 1-13; pl. 4, figs. 1-8; pl. 5, figs. 8-10, 13.

Globoquadrina himiensis MAIYO, SAITO and SATO, 1976, p. 410, pl. 4, figs. 1-2.

Description.—Test medium to large, medium trochospire, periphery ovate; chambers globular to slightly flattened, four to five in final whorl, increase gradually in size as added; sutures distinct, depressed; wall calcareous, finely perforated, surface coarsely pitted, non-spinose; aperture interomarginal, umbilical, wide opening, not rimmed.

Remarks.—This species is included within *Neogloboquadrina* based on its calcareous perforated, radial, non-spinose but coarsely pitted wall. It is distinguished from other *Neogloboquadrina* species by having a medium to large test, four to five subglobular chambers in the final whorl that increase gradually in size as added, and a final chamber that tends to be smaller than the previous, slightly flattened and displaced towards the umbilical side. It is distinguished from *N. eggeri*, by having higher trochopire and an aperture that is less umbilical. *Neogloboquadrina dutertrei* shows close resemblance to *N. humerosa* (Takayanagi and Sato). Several studies have regarded *N. humerosa* to be conspecific (Jenkins, 1971) or a subspecies (as *Globorotalia dutertrei humerosa*; Bolli, 1970), and have included it within their broad concept of *N. dutertrei*. In this study, *N. dutertrei* is distinguished from *N. humerosa* by a tighter coiled test, a greater number of globular chambers with five to seven visible in the final whorl, slight distortion of the test, a slightly thicker test, a weakly rimmed aperture and a simpler umbilicus. These differences may be subtle in some specimens, reflecting environmental or chronologic changes (Stainforth et al., 1975). *Neogloboquadrina humerosa* is regarded as an intermediate form between *N. acostaensis* (Blow, 1969) and *N. dutertrei* (Bandy et al. 1967; Parker, 1967; Blow 1968; Lamb and Beard, 1972; Stainforth et al. 1975; Srinivasan and Kennett, 1976). Also, a close relationship is established with *N. pachyderma* (Jenkins, 1971; Srinivasan and Kennett, 1976). *N. dutertrei* occurs at the end of a bioseries, which includes precursor species such as *Neogloboquadrina pachyderma* (and *N. acostaensis* (Stainforth et al., 1975; Srinivasan and Kennett, 1976).

Age range and occurrence.—This species has been recorded from the *Globorotalia* (*G.*) *miotumida miotumida* Zone to the *G.* (*T.*) *inflata* Zone (Late Miocene to Pleistocene) in New Zealand (Jenkins, 1971). It commonly occurs in the Pleistocene to Holocene of Japan (Saito et al. 1981; Ujiie and Ujiie, 2000).

Neogloboquadrina incompta (Cifelli, 1961)

Plate 9, figures 32-35

Globigerina incompta CIFELLI, 1961, p. 83, pl. 4, figs. 1-7; 1973, p. 157, pl. 2, figs. 5-12; pl. 3, figs. 1,6,10; pl. 4, figs. 1,3.

Globigerina pachyderma incompta CIFELLI, 1965, p. 11, pl. 1 figs. 4-6.

Neogloboquadrina pachyderma incompta (Cifelli), RÖGL and BOLLI, 1973, p. 571, pl. 10.

Neogloboquadrina incompta (Cifelli); SAITO, THOMPSON and BREGER, 1981, p. 108, pl. 34, fig. 2; UJIIE and UJIIE, 2000, p. 352, pl. 1, fig. 5.

Neogloboquadrina pachyderma (Ehrenberg), FINGER, 1992, p. 76, pl. 11, figs. 1-3.

Remarks.—This species co-occurs with and is closely related to *N. pachyderma*. Both are similar in size, have four globular chambers in the final whorl and thick calcareous, granular (coarsely pitted) walls. It differs from *N. pachyderma*, by having distinct, more lobulate, inflated chambers that are tightly embraced, sutures that are deeply incised on the umbilical side and depressed on the spiral side. The final chamber slightly overhangs the umbilicus and the interomarginal, umbilical aperture is a low arch with a weak rim. The wall in *N. incompta* is more coarsely perforated and pustulate (tubercles), particularly on the final chamber.

Age range.—This species has been recorded from the late Pliocene to Holocene of Japan (Saito et al., 1981; Ujiie and Ujiie, 2000).

Neogloboquadrina pachyderma (Ehrenberg, 1861)

Plate 9, figures 36-38

Aristerospira pachyderma EHRENBERG, 1861, p. 276, 303; 1871, pl. 1, fig. 4

Globigerina pachyderma (Ehrenberg) BANDY, 1960, p. 671, text-fig. 1; PARKER, 1962, p. 224, pl. 1, figs. 26-35, pl. 2, fig. 1-6; TAKAYANAGI and SAITO, 1962, p. 89, pl. 26, fig. 4; OLSSON, 1976, p. 245-252, pl. 1, figs. 1-7; pl. 2, figs. 1-6; pl. 3, figs. 1-8; pl. 4, figs. 1-2; ODA, 1977, p. 51, pl. 2, figs. 1-4.

Globorotalia (*Turborotalia*) *pachyderma* (Ehrenberg), JENKINS, 1971, p. 128, pl. 12, figs. 345-347.

Neogloboquadrina pachyderma (Ehrenberg); SRINIVASAN and KENNETT, 1976, p. 346, pl. 5, figs. 1-4; SAITO, THOMPSON and BREGER, 1981, p. 106, pl. 34, fig. 1; HORNIBROOK, BRAZIER and STRONG, 1989, p. 136, fig. 28, 13; PATTERSON BLENKINSOP and CAVAZZA, 1995, p. 14, fig. 10-1, 2; UJIIE and UJIIE, 2000, p. 352, pl. 1, fig. 6.

Remarks.—This species is distinguished from other *Neogloboquadrina* species by its compact size and four to five tightly embracing chambers in the final whorl that increase rapidly in size as added, a low-arched interomarginal, umbilical aperture with a thickened rim, and thick granular walls. *Neogloboquadrina pachyderma* and *N. acostaensis* are regarded to have evolved from the late Miocene *N. continuosa* Blow (Srinivasan and Kennett, 1976). Close affinities with *N. dutertrei* and the *N. dutertrei* bioseries is discussed by Srinivasan and Kennett (1976). This genetic series concludes that dextral *N. pachyderma* is restricted to subtropical latitudes and grades into *N. dutertrei*.

It has been determined repeatedly that the coiling direction of chambers (dextral vs. sinistral) is a significant paleoclimate indicator (Olsson, 1976; Oda, 1977). Four chambered, sinistral (left) coiling forms commonly occur in cold-temperate and polar waters, at high latitudes in both hemispheres (Olsson, 1976) and represent minimum surface temperatures of 5°C (Ingle Jr., 1973). These forms are generally smaller with thicker test walls than dextrally-coiled forms from warm and/or temperate waters (Oda, 1977). Consequently, the oscillations between dextral and sinistral populations have been utilized as proxies for climatic oscillations (Hornibrook et al., 1989). These oscillations have been used to establish subzones for the Pliocene and Pleistocene strata in New Zealand and elsewhere (Jenkins, 1967; 1971).

Age range and occurrence.—This species is recorded from the *Globorotalia* (*Globorotalia*) *miotumida miotumida* Zone of the *Globorotalia* (*Turborotalia*) *pachyderma* D5 Subzone of the *G.* (*T.*) *inflata* Zone (late Miocene to late Pleistocene) of New Zealand (Jenkins, 1971). The earliest appearance of *N. pachyderma* is in the middle Miocene (N12-N15; Ingle Jr., 1973; *Globorotalia mayeri* Zone to Holocene in Japan; Saito, 1973).

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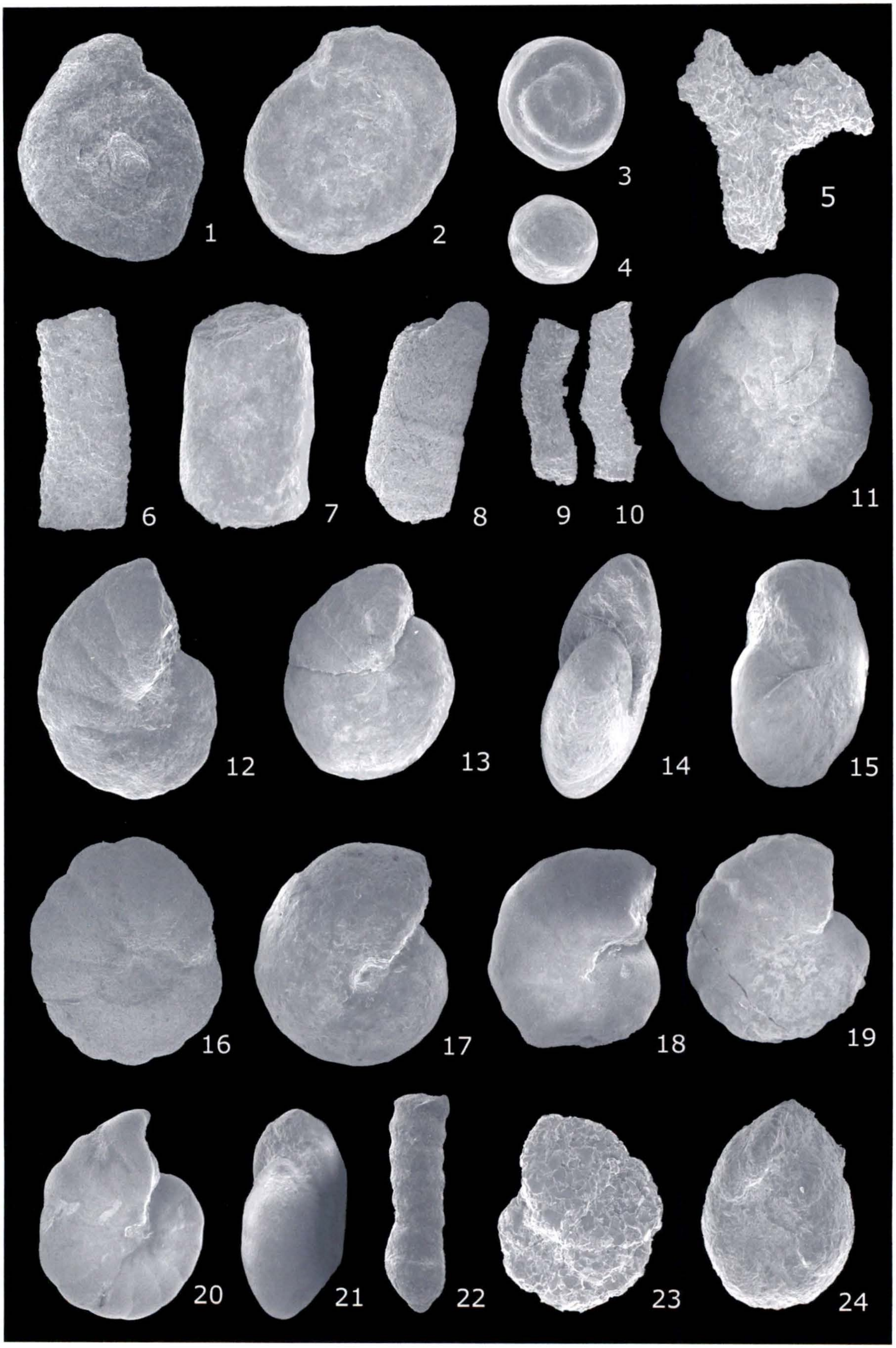

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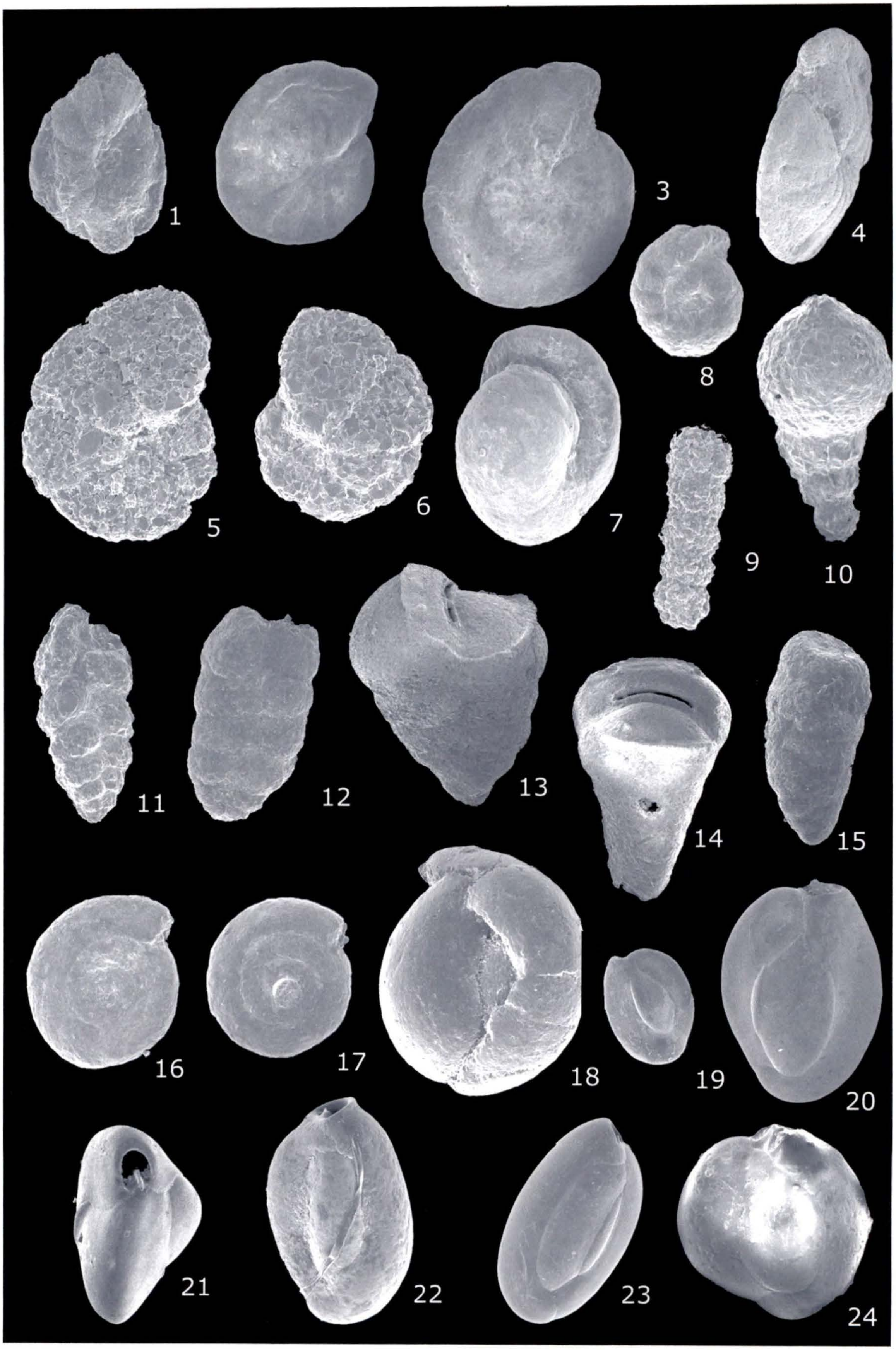

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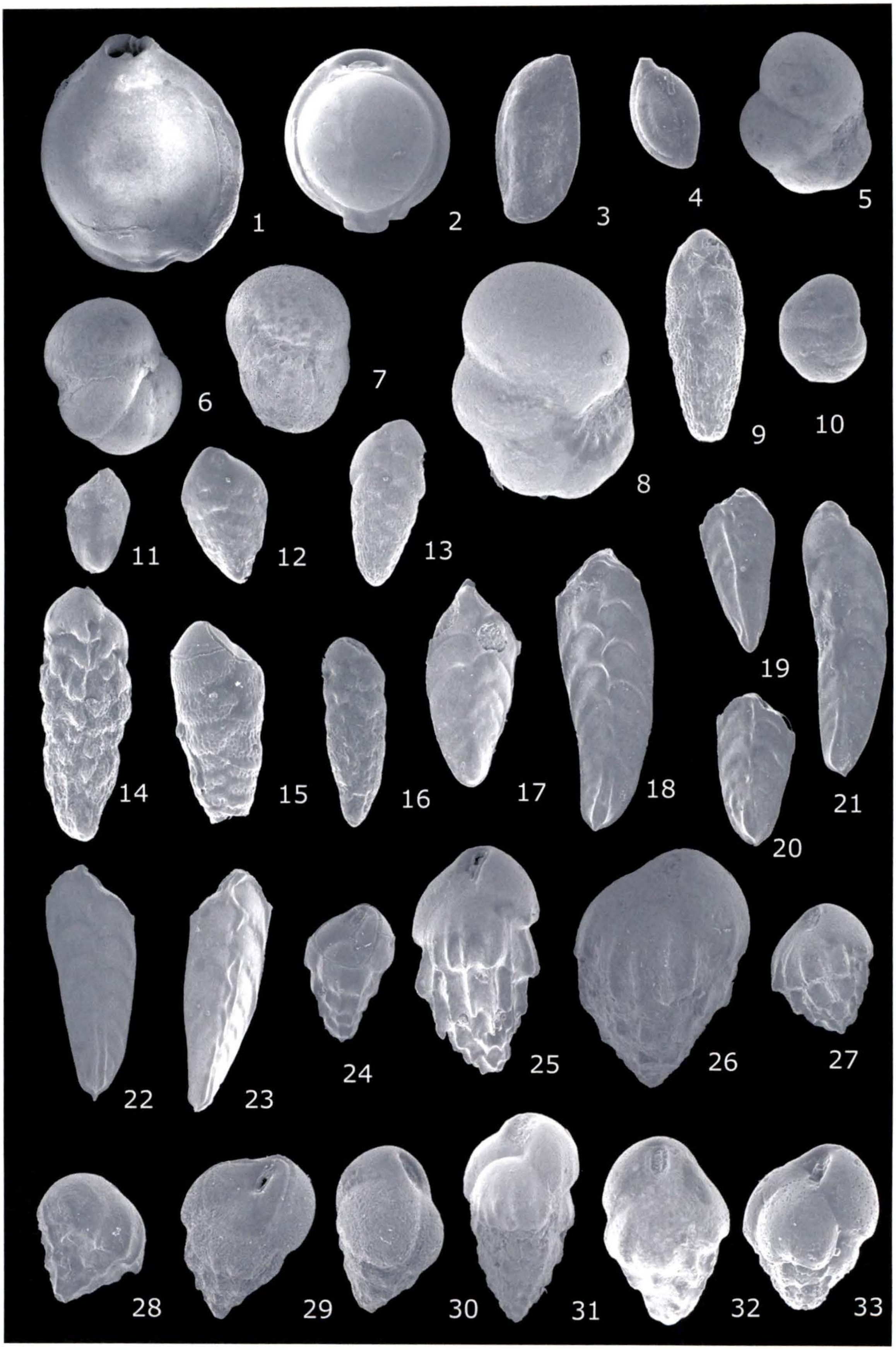
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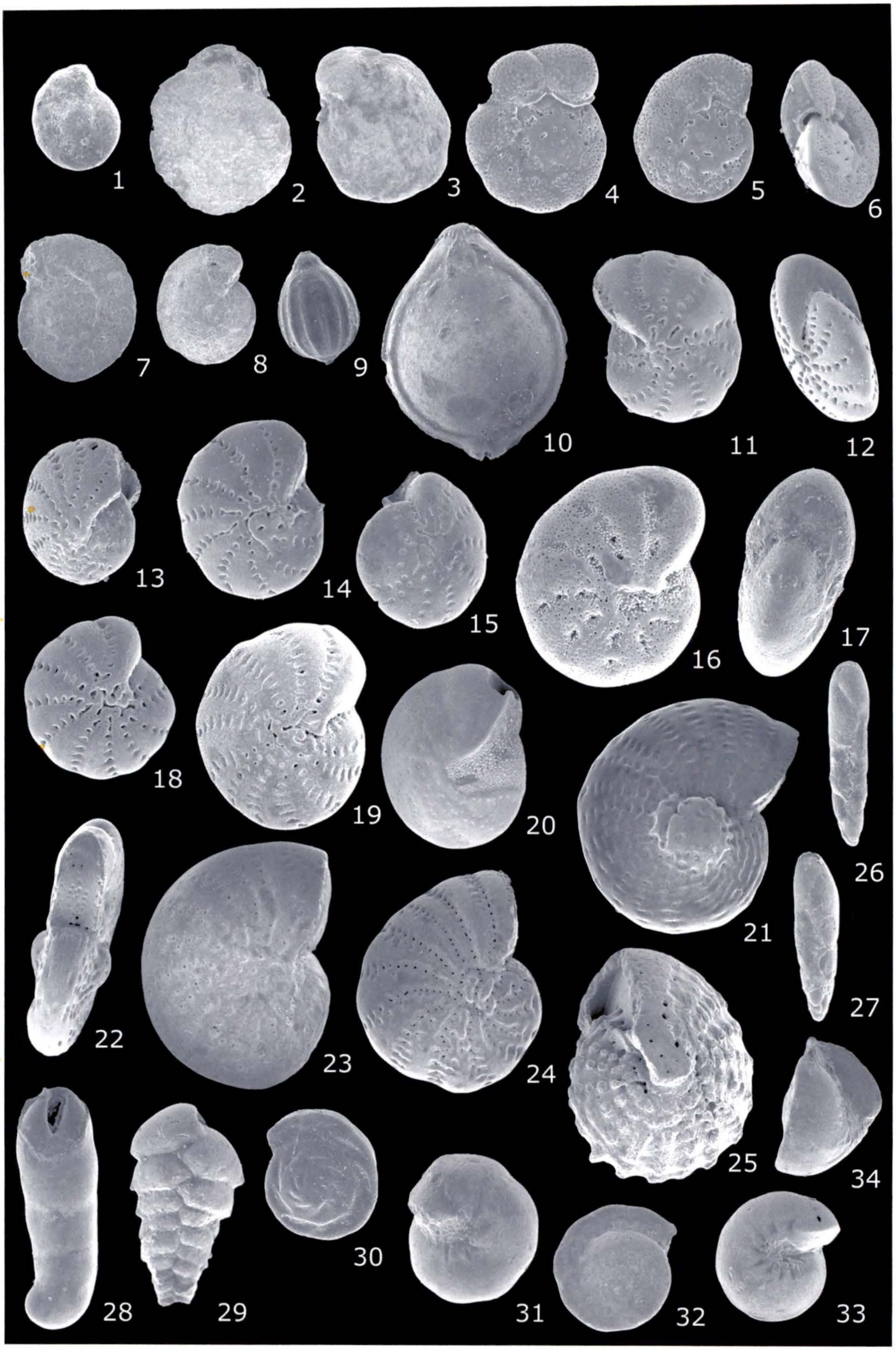
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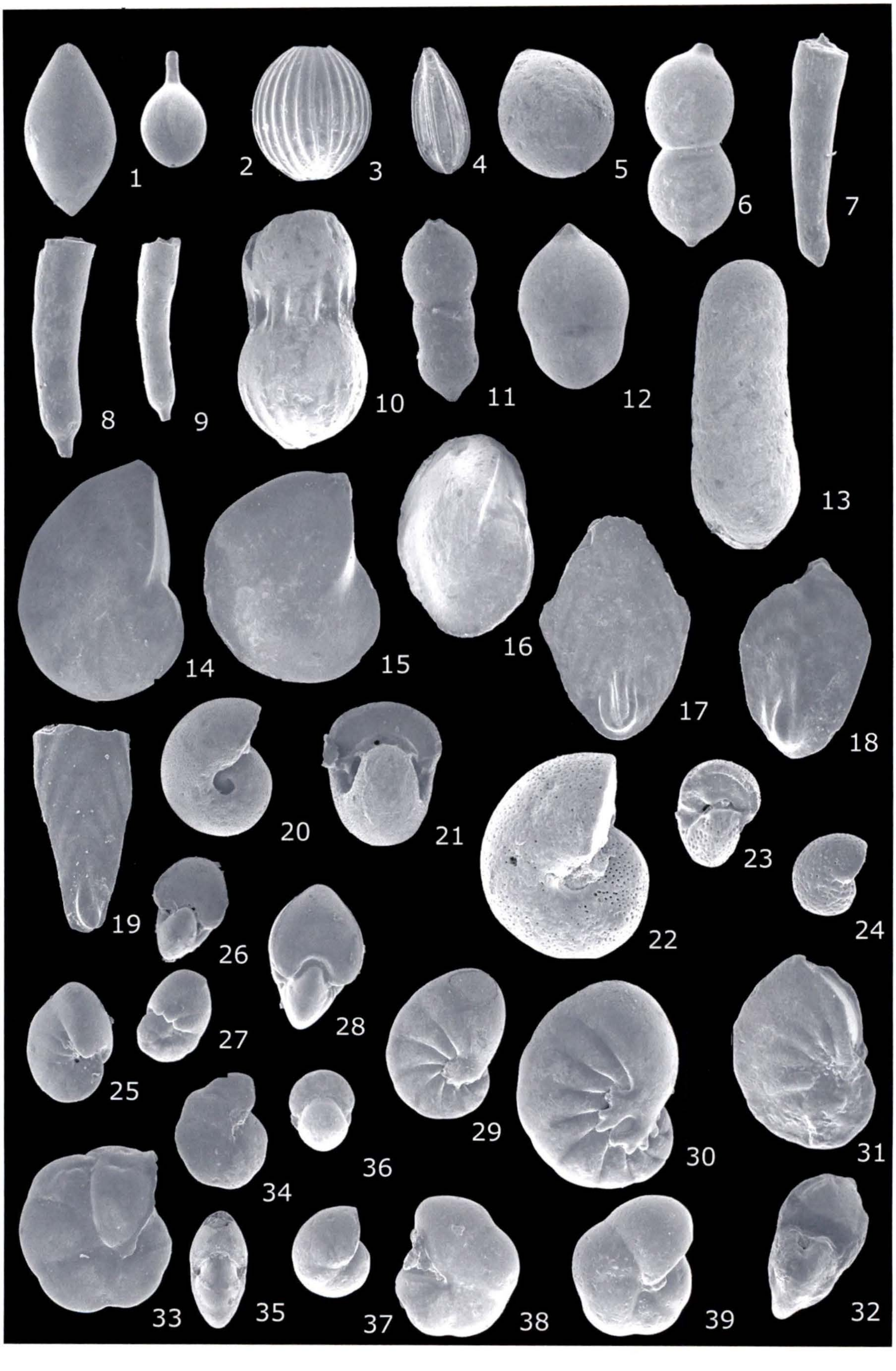
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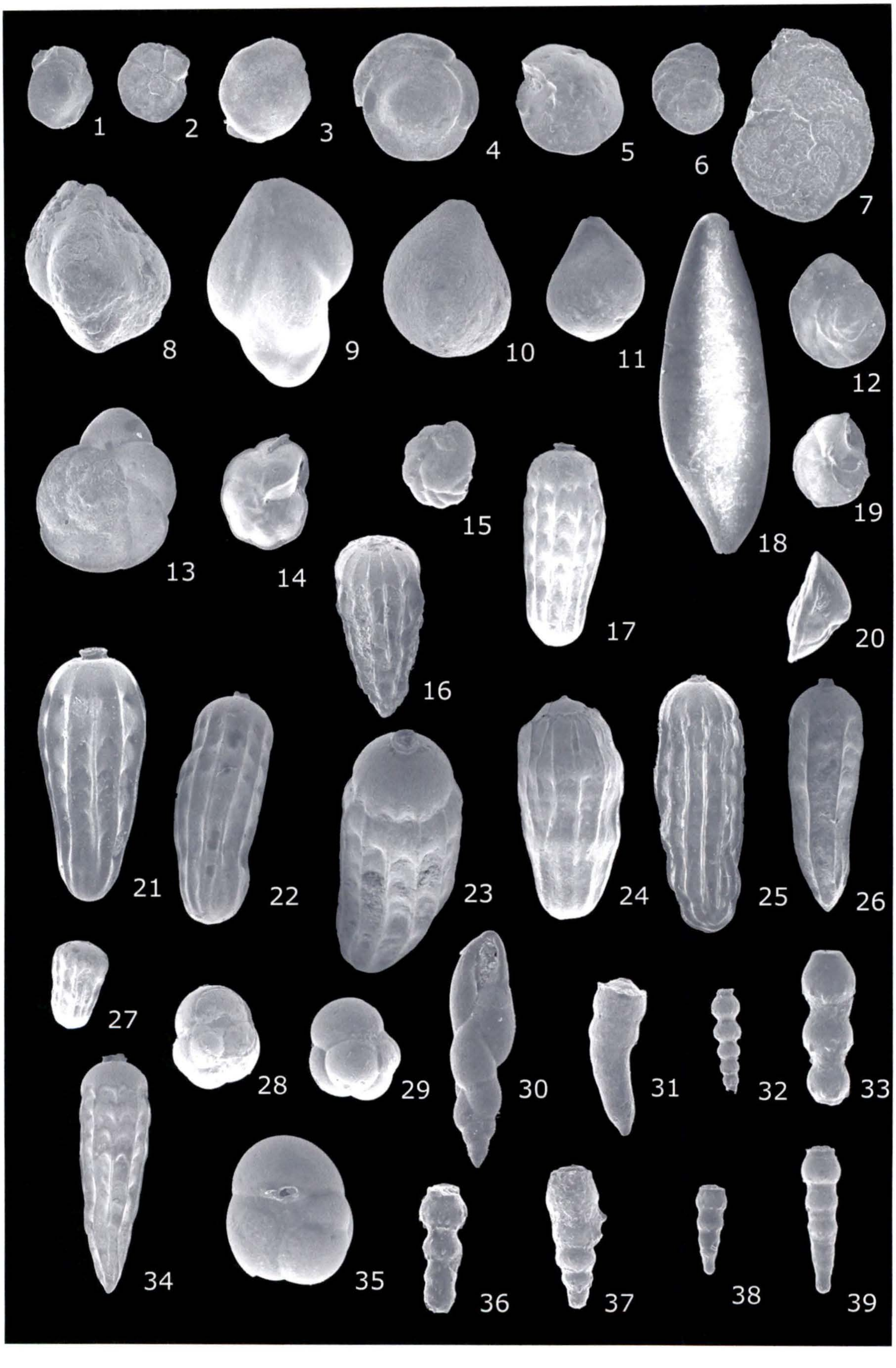
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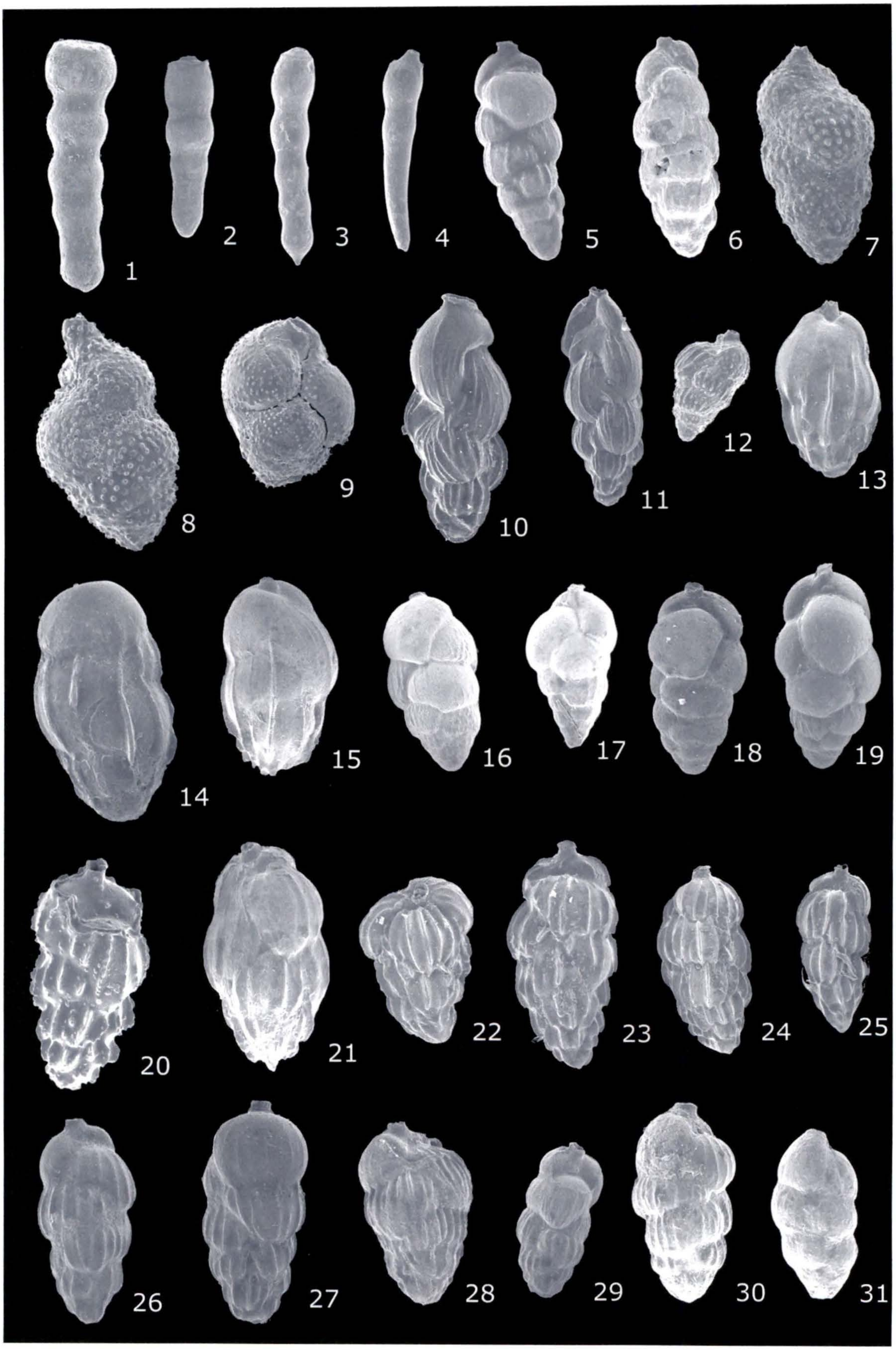
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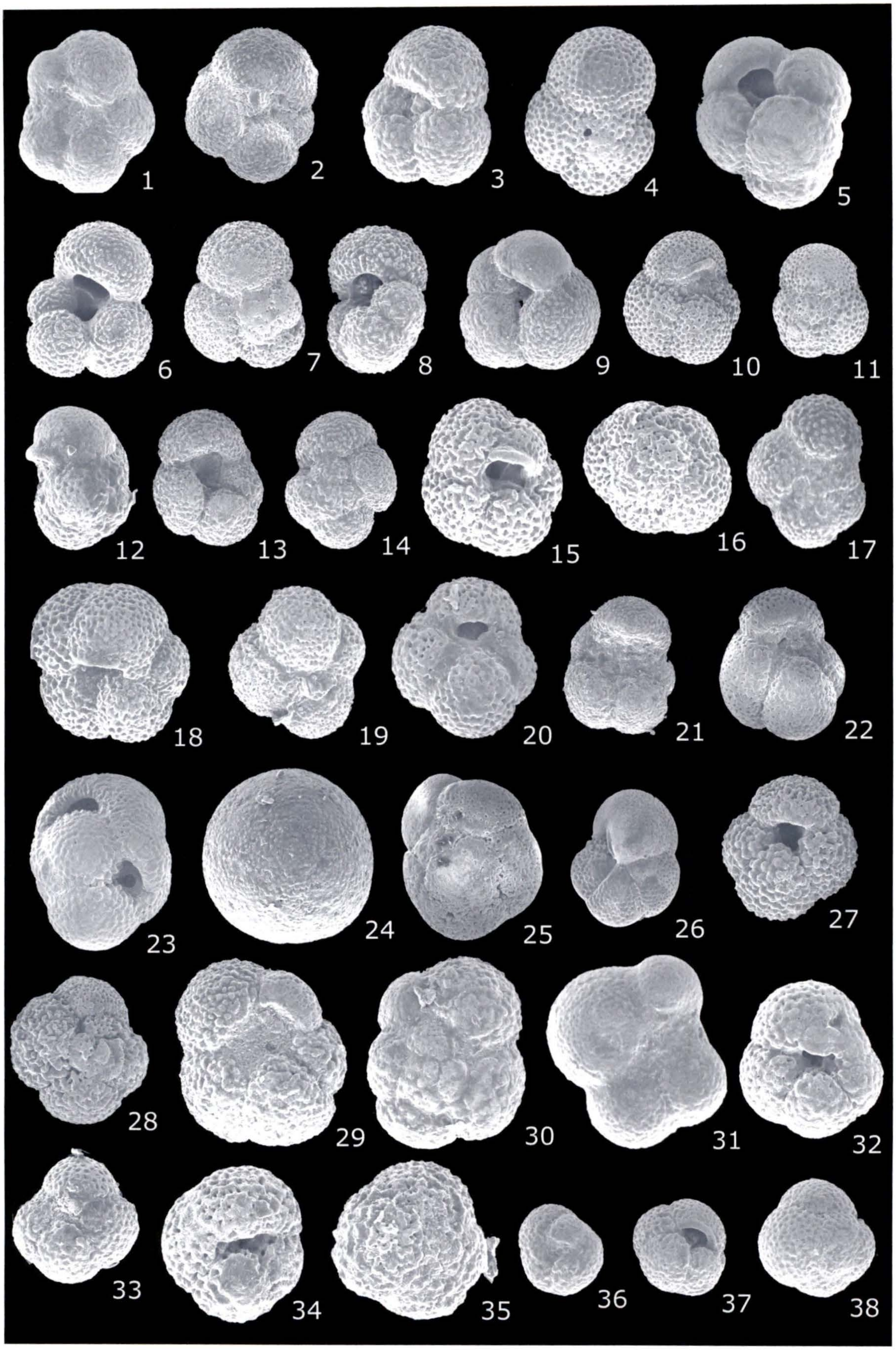
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APPENDIX A:

Table A.1. a) The results of 5 unsuccessful analyses, showing that not enough Sr was present in the samples (Trotter, CSIRO Petroleum); b)and c) results of the petrographic assessement of the host rock, in which samples that appeared to contain some sandstone was analyzed (Barclay, CSIRO Petroleum). Three of four (initially selected) offshore (b) and seven of eight (initially selected) onshore (c) samples were analyzed.

a.) Unsuccessful analyses:

Shell well	**Depth interval (ft)**	**Number of samples and taxa analaysed**	**Reasons for unsuccessful analyses/comments**
Zeus I-65	8530-9370	3 (large *Cyclammina*? sp.)	-sample aborted, no Sr -probably altered (dolomitized/silicified)
Cygnet J-100	2595-2626	8 (x7 *U.peregrina*, x1 *E. juncea*)	-sample aborted, too low in Sr(?)
BC-69-2	2860-2880	6 (*Siphonodosaria* sp.)	-sample aborted, too low in Sr -dark altered specimen -initial ratios indicate Late Jurassic
BC-69-2	3200-3220	5 (*Gyroidina, Siphonodosaria*, rotalids)	-too low in Sr -initial ratios indicate Pleistocene
BC-71-5	680 base	1 (bryozoan? fragment)	-too low in Sr -initial ratios indicate E. Pleistocene
BC-74-6	75-99	1 (small articulated bivalve)	-too low in Sr

b.) Petrographic assessment: Shell Canada wells, offshore samples:

Shell well	**Depth interval (ft)**	**Comments**
Zeus D-14	7310-7320	-shale-mudstone (no sandstone), not examined further
Zeus D-14	7370-7380	-mix of sandstone (medium grain size), shale-mudstone (50:50) -framework grains, coated by clay? grains -pore spaces and throats completely occluded by clay? -some dark-coloured mineral grains with platey morphology are visible (biotite?) -rare pale cream/white anhedral feldspar?, crystals visible, ragged, possibly indicates dissolution -much contamination (woody, straw-like material), possibly to prevent lost circulation during drilling?
Zeus I-65	4050-4060	-ss above without contamination -minor iron staining (possibly pyrite?)

Zeus I-65	9700-9710	-as above -mix of sandstone, shale-mudstone, and minor calcite (75:20:50) -minor iron staining (possibly pyrite?) -calcite in the form of white grains, vigorous reaction with 1mol HCl

c.) Petrographic assessment: Carmanah Group, onshore samples:

Outcrop section	**Depth interval (ft)**	**Comments**
BC-71-1	665-730	-very fine grained sandstone-mudstone; to fine to observe, therefore not examined further
BC-71-1	1002-1025	-1large piece of medium grained sandstone -framework grains (mainly quartz), coated by clay? grains -pore spaces and throats completely occluded by clay? -some dark-coloured mineral grains with platey morphology are visible (biotite?) -rare pale cream/white anhedral feldspar? crystals visible -ragged, possibly indicates dissolution
BC-71-1	1026.5-1032	-2 large pieces of fine-medium grained sandstone -as above
BC-74-12	251-286	-2 small pieces of fine grained sandstone -framework grains (mainly quartz) coated by clay? grains -pore spaces and throats completely occluded by clay? -no visible mica, possibly feldspar showing signs of dissolution
BC-74-12	788-823	-3 small pieces of fine-medium grained sandstone -framework grains (mainly quartz) coated by clay? grains -pore spaces and throats completely occluded by clay? - some dark-coloured mineral grains with platey morphology are visible (biotite?)
BC-74-8	248-279	-1 small piece of fine-medium grained sandstone - framework grains (mainly quartz) coated by clay? grains -pore spaces and throats completely occluded by clay? -two types of dark-coloured mineral grains visible: 1) biotite – platey morphology, ragged appearance 2) opaque minerals – subhedral crystal morphology, silicate or non-silicate
BC-74-8	279-310	-2 small pieces of fine-medium grained sandstone -framework grains (mainly quartz), coated by clay? grains -pore spaces and throats completely occluded by clay? -some dark-coloured mineral grains with platey morphology are visible (biotite?) -rare pale cream/white anhedral feldspar? crystals visible -ragged, possibly indicates dissolution
BC-74-17	460-480	-sample comprises 50% fine-medium grained sandstone -as above

APPENDIX B:

The common morphological descriptors used in the systematic taxonomy descriptions of the Tofino Basin foraminifers (modified from Loeblich and Tappan, 1964; Holburn and Henderson, 2002).

Test/Outline shape	Peripheral shape/modifications	Chamber shape (including proloculum)	Chamber arrangement	Chamber enlargement/inflation
Angled	Acute/subacute	Apiculate (apical spines)	Biserial	Compressed
Asymmetrical	Broadly rounded	Broad	Embracing	Gradually
Bifurcate/branching	Compressed/Flattened	Bulbous	Planispiral	Inflated (strongly/slightly)
Cylindrical/subcylindrical	Crenulated	Chevron (V)-shaped	Quinqueloculine	Rapidly
Discoidal	Imperforate	Elongate	Singular	
Elongate/Straight	Keeled/carinate	Globular/subglobular	Streptospiral	
Evolute	Lobulate	High/low	Triloculine	
Involute	Ovate	Lunate	Triserial	
Flaring	Rounded	Narrow	Trochospiral (low/high)	
Lobulate	Serrated	Ovate/subovate	Unilocular	
Globular/subglobular	Subrounded	Pyriform	Uniserial	
Planispiral	Truncate	Quadrate/subquadrate		
Slender		Recurved claw-shaped		
Tapered		Rhomboidal		
Triangular		Sigmoid		
Umbilicate (deeply)		Spherical/subspherical		
Unilocular		Stellate lobe		
Ovate		Stout		
Rotund/round/circular		Triangular		
Width nearly equal to length		Tubular		
Lanceolate		Wedge-shaped		
Pyriform				
Rectilinear				
Fusiform				
Lenticular				
Elliptical				
Parallel/subparallel				
Arcuate				

APPENDIX B: morphological descriptors continued.

Suture characteristic	Chamber wall	Chamber wall composition/ornamentation	Aperture position	Aperture shape and modifications
Angled	Coarsely agglutinated	Alveolar	Apex of final chamber	Apertural flap
Crenulated	Coarsely perforate	Annular constrictions	Areal/subareal	Bifid tooth
Curved (slightly/strongly)	Finely agglutinated	Bladed costae	Base of apertural face (final chamber face) or basal	Circular/semi-circular
Depressed (slightly/strongly)	Finely perforate	Calcareous hyaline	Equatorial	Comma-shaped
Distinct	Granular	Calcareous porcelaneous	Interomarginal	Crescentric-shaped opening
Flush with surface	Imperforate	Coarsely agglutinated	Interomarginal umbilical	Crista
Incised	Radial	Finely agglutinated	Interomarginal umbilical'extraumbilical	Denticulate
Indistinct		Glossy/shiny	Open end of tube	Elevated border or rim
Limbate		Hispid	Terminal	Entosolenian tube
Oblique		Jagged		High narrow arch
Sigmoid		Lobes		Loop
Straight		Longitudinal costae (ribs)		Low arch (recurved)
		Longitudinal striae		Neck (elongate/short)
		Papillate		Oval
		Pitted		Phialine lip (rim)
		Pores		Radiate
		Reticulate		Round
		Siliceous		Slit (elongate/narrow)
		Smooth		Supplementary pores on apertural face
		Spinose		Symmetrical/asymmetrical
		Translucent		Tooth-plate
		Umbonal boss		

APPENDIX B: continued

Glossary of some common morphological terms used in this study of Tofino Basin foraminifers (modified from Loeblich and Tappan, 1964, Treatise on Invertebrate Paleontology p. C58-C65).

Aboral: opposite to oral side.

Agglutinated: sediment particles bound together by cement.

Annular: cyclical or ring-like.

Aperture: opening or openings from chamber of test to exterior.

Areal aperture: aperture in face of final chamber.

Arenaceous: composed of sand grains or other foreign particles.

Argillaceous: composed of clay or mud (e.g. in some agglutinated tests).

Bioconvex: having both sides convex or more or less inflated.

Bifid: divided into two branches.

Biloculine: having a two-chambered exterior part of test (e.g. *Pyrgo*).

Biserial: having chambers arranged in two rows.

Biumbilicate: having central depression (umbilicus) on each side of test (e.g. planispiral forms).

Biumbonate: having 2 raised umbonal bosses (e.g. *Lenticulina*)

Boss: round and raised or knob-like ornamentation.

Bulla (pl. bullae): blister-like feature that partially or completely covers primary and secondary apertures; may be umbilical, sutural or areal in position (e.g. in planktic foraminifers).

Carina: keel or flange.

Carinate: having keel or flange.

Chamber: test cavity and its surrounding wall, formed at single short growth stage in multilocular forms; variously shaped inclosure within test, connected by pores/foramina to other inclosures and to the exterior.

Clavate: club-shaped.

Costa: raised ridge or rib.

Costate: having raised rib or costae.

Cribrate: perforated with round holes, sievelike.

Dimorphism: occurrence in single species of two distinct forms; megalospheric and microspheric tests.

Distal: direction away from proloculus.

Dorsal: spiral side of trochoid forms.

Entosolenian: having internal tubelike apertural extension (e.g. *Oolina*).

Equatorial: located in median plane normal to axis of coiling.

Evolute: tending to uncoil; chambers non-embracing.

Extraumbilical aperture: opening in final chamber of test not connecting with umbilicus, commonly sutural midway between umbilicus and periphery.

Extraumbilicul-umbilical aperture: opening in final chamber of test that extends along its forward margin from umbilicus toward periphery (outside umbilicus; e.g. *Globorotalia*).

Foramen (pl. foramina): opening between chambers located at base of septa or areal position.

Fusiform: spindle-shaped, tapering at each end.

Granular hyaline wall: perforate, lamellar part of test composed of minutely granular calcite, seen between crossed nicols as multitude of tiny flecks of color; granules equidimensional, variously oriented.

Hyaline: glassy clear, transparent.

Imperforate: without pores, sometimes common of porcelaneous tests (e.g. Miliolidae).

Interomarginal aperture: basal opening in test at margin of final chamber, along final suture.

Involute: strongly overlapping; in enrolled forms, later whorls completely enclosing earlier ones.

Lamellar: composed of thin plate-like layers of aragonite or calcite, one layer being formed with addition of each new chamber and covering whole previously formed test.

Lanceolate: flat, narrow and tapering to a point.

Lenticulate: lens-shaped (e.g. *Lenticulina)*.

Limbate: referring to a thickened border or edge of chamber, commonly at suture, may also be elevated.

Lip: elevated border of aperture, may be small and at one side of aperture or completely surrounds it.

Milioline: formed as in Miliolinidae, commonly with narrow elongate chambers, two to whorl, added in differing planes of coiling.

Oblique section: slice through test cut in direction neither parallel to axis of coiling nor normal to it.

Perforate: referring to walls of test pierced by numerous pores that are distinct from apertures, foramina and canals; characteristic of calcareous hyaline tests.

Phialine lip: having everted rim on apertural neck (e.g. as on neck of bottle).

Planispiral: coiled in single plane.

Porcelaneous: having calcareous, shiny and commonly imperforate wall resembling porcelain in surface appearance; shows low polarization tints between crossed nicols and has majority of crystals with c-axes tangential or more rarely arranged radially.

Primary aperture: main opening of test, may be only one or accompanied by secondary apertures.

Proloculus: Initial chamber of foraminiferal test.

Quinqueloculine: having five externally visible chambers as result of growth in varying planes about elongate axis (e.g. *Quinqueloculina*).

Radial microstructure: construction of calcareous tests consisting of calcite or aragonite crystals with c-axes perpendicular to surface; between crossed nicols shows black cross with concentric rings of color mimicking negative uniaxial interference figure.

Radiate aperture: opening associated with numerous diverging slits (e.g. *Nodosaria*)

Rectilinear: growing in a straight line.

Reniform: kidney-shaped.

Reticulate: referring to ornamental ridges at surface of test or inner meshwork (e.g. *Reticulophragmium*).

Retral processes: backward-pointing extensions of chamber cavity and enclosed protoplasm, located beneath external ridges on chamber wall (e.g. *Elphidium*).

Secondary apertures: additional or supplementary openings into main chamber cavity, may be areal, sutural or peripheral in position.

Septum: partition or wall between chambers.

Sigmoid: S-shaped.

Sigmoiline: sigmoid or with sigmoid axis (e.g. *Sigmoilina*).

Spinose: having fine elongate solid spines on surface of test.

Spiral side: part of test where all whorls are visible (e.g. trochospiral forms) also commonly called dorsal side.

Streptospiral: coiled like a ball of twine.

Striate: marked by parallel grooves.

Suture: line of union between two chambers or two whorls (spiral suture).

Tangential section: slice through part of test parallel to axis of coiling or growth, but not through proloculus.

Test: shell or skeletal covering, may be secreted, gelatinous, chitinous, calcareous, siliceous, composed of platelets, solid walls, agglutinated particles or a combination of two or more of these.

Tooth: projection in aperture of test, may be simple or complex, single or multiple.

Tooth plate: Internal, apertural modification commonly consisting of a plate that extends from aperture through chamber to previous septal foramen (e.g. *Bulimina*); one side may be attached to the chamber wall or base attached to proximal border of foramen.

Triloculine: having three externally visible chambers, resembling *Triloculina* in form and chamber plan.

Triserial: chambers arranged in three columns, high trochospiral with three chambers in each whorl.

Trochoid/Trochospiral: trochospiral, rotaloid, rotaliform; chambers coiled spirally, evolute on one side, involute on other.

Tuberculate: covered with tubercles or small rounded prominences.

Umbilical depression: closed, shallow, axial depressed area formed by curvature of overlapping chamber walls in involute spire; may be filled by thickenings or knob.

Umbilical side: involute side in trochospiral forms, with only one chamber visible around umbilicus; also called ventral side; commonly side with aperture.

Umbilical teeth: triangular modifications of apertural lip, giving characteristic serrate border to umbilicus (e.g. *Baggina*).

Umbilicate: having one or more umbilici.

Umbilicus: space formed between inner margins of umbilical walls of chambers belonging to same whorl.

Umbo: central round, elevated structure in discoidal forms; commonly due to lamellar thickening (e.g. *Lenticulina*), may occur on one or both sides of test.

Umbonate: having umbo on one or both sides (biumbonate).

Unilocular: Single-chambered.

Uniserial: having chambers arranged in a single row.

Ventral: pertaining to back side of test, commonly used for umbilical side; commonly apertural side.

Vitreous: hyaline, having appearance and luster of glass.

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Narayan, Y. R. and Barnes, C. R. 2001. Tertiary foraminifera from the Tofino Basin, offshore Vancouver Island, and their applications to biostratigraphic and paleoenvironmental studies. Fourth BC Paleontology Conference, Kamloops, May 10-14. Program with Abstracts, p. 19-20.

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