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LATE GLACIAL FORAMINIFERA FROM SOUTHEAST ALASKA AND BRITISH COLUMBIA AND A WORLD-WIDE HIGH NORTHERN LATITUDE SHALLOW-WATER FAUNAL PROVINCE

BY

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ABSTRACT

Glacio-marine deposits of probable late Pleistocene age were sampled at localities in the vicinity of Juneau, Alaska; at Lakelse, British Columbia; along the northeast coast of the Queen Charlotte Islands, British Columbia; and dispersed about the Lower Mainland (Vancouver area) of British Columbia. These deposits yielded a foraminiferal fauna of 105 species, dominated by *Elphidium clavatum*, with subdominants *Buccella frigida*, *B. tenerrima*, *Islandiella teretis*, *Cassidulina barbara*, *Cibicides lobatulus*, *Elphidium frigidum*, *sensu lato*, *Nonionella auricula*, *Epistominella vitrea*, *Fursenkoina fusiformis*, *Elphidium bartletti*, and *Nonionellina labradorica*. Analysis of the Juneau and Queen Charlotte Islands faunas indicates life in shallow (mainly 30 meters or less) normal marine possibly to slightly brackish (approximately 35 to 28‰), cold (0 to 15°C) water. Assemblages from the Vancouver area differ in representing a greater salinity range among themselves, from normal marine or slightly brackish down to 15‰. Those from Lakelse probably represent salinities of approximately 15 to 20‰, with considerable geographic restriction.

The overall fauna is representative of a striking world-wide Quaternary foraminiferal province extending around the borders of the Arctic and northern North Pacific and North Atlantic Oceans in shallow, cold, marine and brackish waters.

INTRODUCTION

The first extensive scientific study of southeastern Alaska was the Harriman Alaska Expedition of 1899. On this expedition, W. H. Dall (1904) collected fossils from glacio-marine deposits, including some from Douglas Island (in the present Juneau area of study). Fossiliferous marine sediments were reported at altitudes up to 600 feet locally throughout southeastern Alaska in the first quarter of this century (see Buddington, 1927, 1929; Buddington and Chapin, 1929). No further interest in these sediments was evidenced until the U.S. Geological Survey began to map southeastern Alaska (see Lathram and others, 1958).

Early studies of the geology and paleontology of the Vancouver area have been summarized by Wagner (1959). The Queen Charlotte Islands have recently been mapped in some detail by Sutherland Brown (1968, personal communication) who summarizes the history of studies in the area in a forthcoming publication. As with

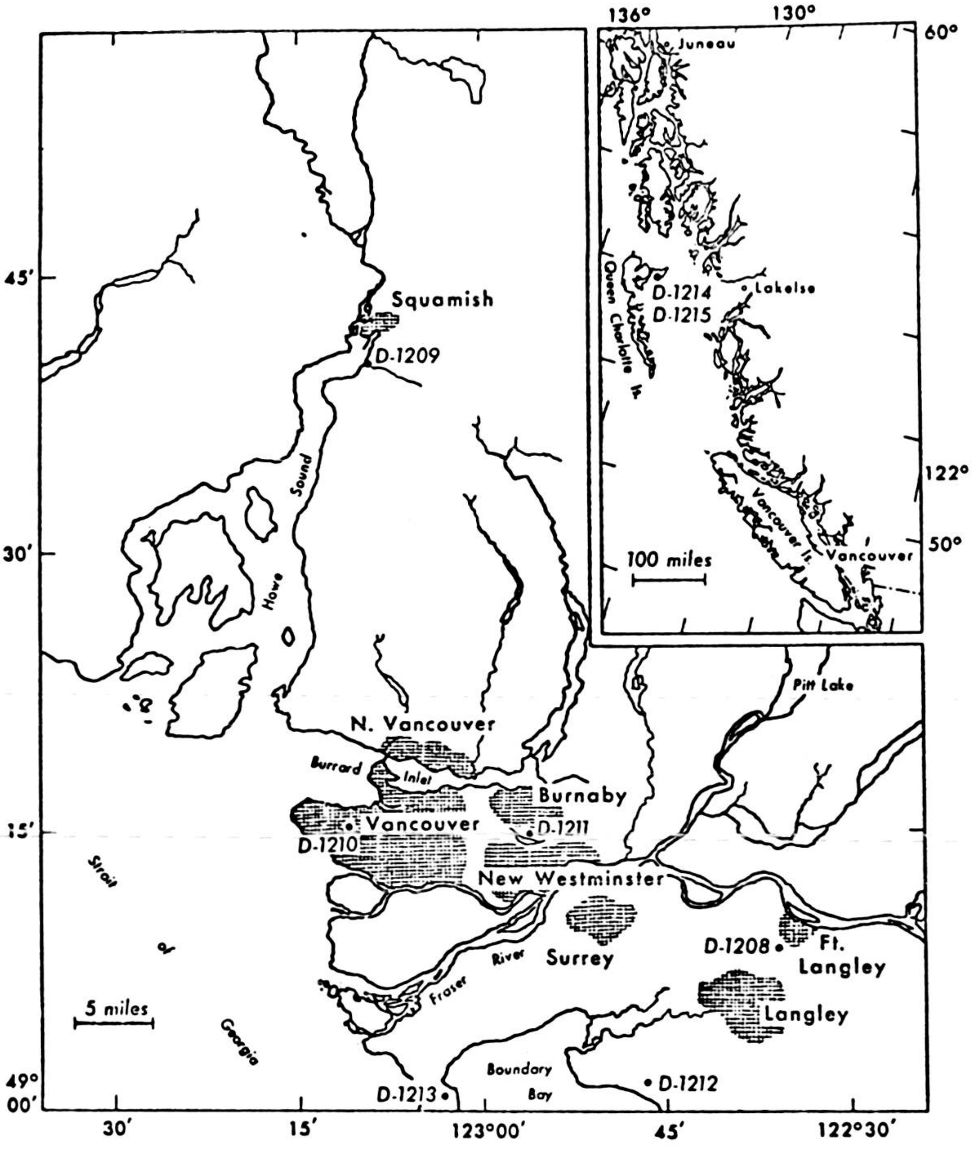

FIG. 1. — Pacific Northwest coastline sample areas and locality map for Vancouver area

much of the British Columbia coast, the third area sampled in this study, Lakelse, has not been closely studied. Text-figure 1 shows the coastline sampled, with the four localities of this study noted, and a detailed map of the Vancouver area. Text-figure 2 shows the Juneau area and the Lakelse area.

Throughout much of southeastern Alaska and coastal British Columbia, glaciomarine sediments rest unconformably on crystalline rocks and are thus easily separable from underlying formations. This is true of the present localities sampled, except the Queen Charlotte Islands, where Pleistocene sediments are thought to rest conformably on Pliocene locally. Where sedimentary beds underlie glacio-marine deposits, distinctive lithology will usually allow separation, however. Glacio-marine sediments generally are massive and of heterogeneous grain size (clay to

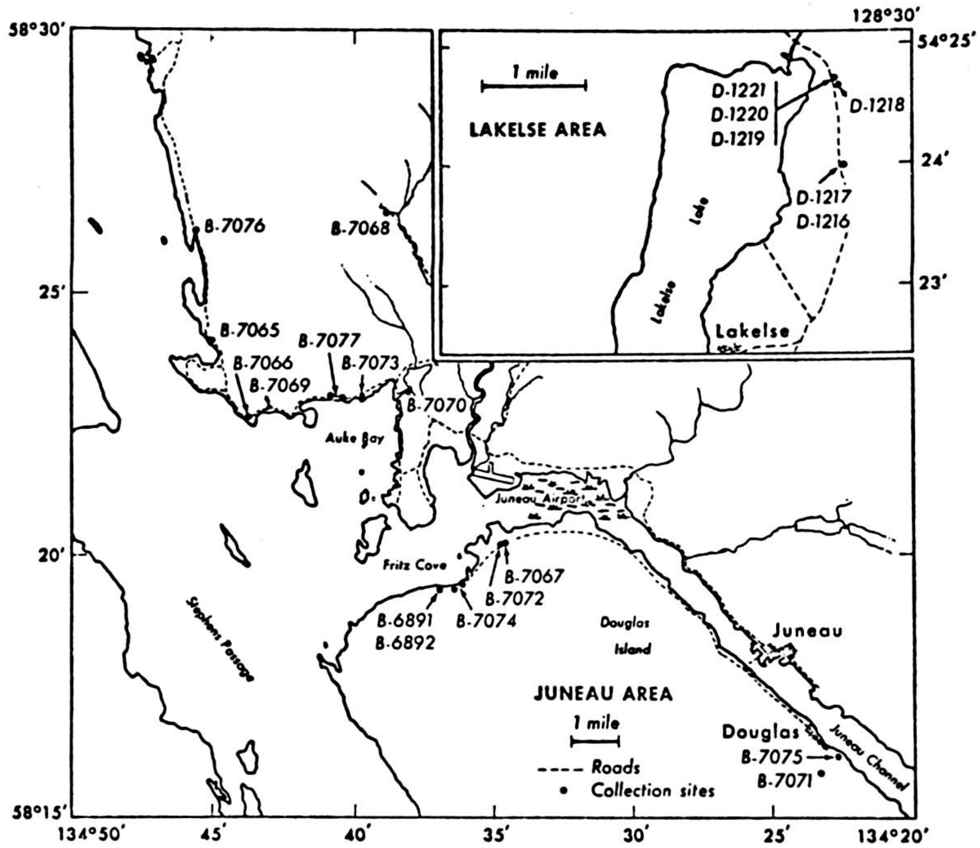

FIG. 2. — Locality maps for Juneau and Lakelse areas.

boulder) and, when fresh, blue grey in color and often with marine shells clearly visible. Locally, soil, peat, terrestrial clastics, and raised beach deposits overlie the glacio-marine material.

Where they have been found along the British Columbia and southeast Alaska coast, glacio-marine deposits range in elevation from present sea-level to as high as 1,000 feet locally. In the Juneau area, the elevations range from sea-level to approximately 500 feet, at Lakelse to approximately 300 feet, and in the Vancouver area to approximately 1,000 feet. Probably isostatic rebound and local faulting along the tectonically active coast have caused the uplift. If sea-stand was lower in late Pleistocene times than presently, some correlative deposits may still lie below sea level. Some could also have been downfaulted. In the Queen Charlotte Islands, glacio-marine deposits apparently do not range above 100 to 200 feet elevation (Sutherland Brown, 1968, personal communication). This area seems to have been relatively little affected by isostatic rebound or late Cenozoic large-scale faulting.

Almost all deposits sampled may be assigned to the Pleistocene Series if one includes in it all deposits formed during post-Pliocene glacial episodes through the last minor event approximately 10,000 to 12,000 years ago. Probably most sediments sampled were formed during this last minor glacial event. Close correlation between deposits in the same general areas often is not possible because almost all are characteristically glacio-marine, mainly massive, of very similar lithology and faunal content, and outcrops are very limited.

Foraminifera occur abundantly in the glacio-marine deposits along with larger marine invertebrates. The foraminiferal fauna is typical of glacio-marine sediments and some related cold, shallow-water sediments from all around the northern hemisphere. The study of these foraminifers is the basis of this work.

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SAMPLING AND PREPARATION METHODS

Exposures were examined and larger marine invertebrates collected from them. Separate sediment samples were taken from the same localities for study of foraminifera. From the Juneau area, samples were approximately 500 cm^3, exclusive of cobbles and boulders. From the Vancouver area, sample size varied from approximately 50 to 2,000 cm^3. The two Queen Charlotte Islands samples were relatively small, being about 25 cm^3 each. The samples from Lakelse each were two-foot-long sections of three-inch-diameter cores, from different levels in three test holes in the slide.

Locality descriptions are on file in the University of California (Berkeley) Museum of Paleontology. In the Juneau area, most samples came from road cuts on the mainland north of Juneau and across Gastineau (or Juneau) Channel on the northeast side of Douglas Island (see text-fig. 2). The two samples from the Queen Charlotte Islands were from a natural outcrop along the northeast coast of Graham Island. Those from Lakelse were from drill holes. Samples from the Vancouver area came mainly from man-made excavations also. Few natural exposures occur below tree line in the entire coastal area.

Samples were washed through 20 (841 micron) and 115 (125 micron) mesh Tyler Screen Scale Sieves. Washing some samples through 200 mesh (74 micron) sieves revealed almost no foraminifers so this procedure was abandoned. Samples were treated with CCl_4 to separate foraminifers from sand. All specimens from each concentrate were identified. Numerically and taxonomically representative assemblages were placed in slides, as were types of each taxon.

Woody fragments in glacio-marine sediment often seriously interfere with microscopic examination and picking. Ordinary flotation or ignition methods will not remove this debris. Therefore, following CCl_4 treatment, the method for removal of organic matter from plankton samples (see Sachs, Cifelli, and Bowen, 1964; Smith, 1967) by ignition at 500°C in a muffle furnace is advocated for use with such benthonic samples. With arenaceous forms, however, it should first be determined whether ignition will cause test breakdown. Some cements may not withstand the treatment.

STRATIGRAPHY, AGE AND CORRELATION

General

Stratigraphy and correlations of the glacio-marine deposits generally are difficult to interpret. The stratigraphic relations and local correlations of the particular areas discussed herein present some situations and problems unique to each area. These will be discussed below under the relavent headings. It is pertinent, however, to make some remarks here about age of all the glacio-marine deposits before going into the more local situations.

No attempt will be made here to go into Pleistocene boundary problems. Included here as occuring in the Pleistocene Epoch are all late Cenozoic glacial and interglacial events culminating with the last minor episode of approximately 10,000 to 12,000 years ago. Although the term Quaternary is perhaps more valid, avoiding the Pleistocene-Holocene boundary problem, most localities are assigned Pleistocene ages for the glacial connotation of the term. The sediments and faunas are characteristically glacio-marine. Biostratigraphically, one can restrict the age of the deposits only to Neogene on the known ranges of the most restricted foraminiferal species found. All species are living today and, although not characteristic pre-Pleistocene faunal elements in the well-known stratigraphic sections of the Pacific Coast, species common in the present fauna are found in sediments as old as Miocene elsewhere (see Gibson, 1967). The fauna does, however, characterize northern, cold, shallow-water Quaternary sediments deposited contemporaneously with distinctly different faunas further south along the Pacific Coast.

Juneau Area

The glacio-marine deposits rest directly on various metamorphic rocks everywhere where contacts are seen and no other rock types have been found in the area. True till also commonly overlies bedrock in the area. Terrestrial clastic sediments or peat or soil overlie the glacio-marine deposits, apparently conformably. Very locally, raised beach deposits unconformably overly glacio-marine deposits.

Thickness of most deposits cannot be measured because contacts cannot be seen. As the sediment mainly is massive, dips seldom are present, but larger marine invertebrate lenses locally show almost horizontal long axes. Glacio-marine deposits were found from a few feet to approximately 500 feet above sea level.

It is tentatively assumed here that all but one or two localities sampled represent the last minor glacial event, 10,000 to 12,000 years ago. The assumption is based mainly on the facts that 1) no stratigraphic succession—not biostratigraphic, "eco-stratigraphic," nor physical—can be observed and 2) in such terrane as around Juneau, it is likely that the last glacial event removed most evidences of its predecessors.

A 14C date of approximately 8,000 years was determined for peat overlying glacio-marine sediment sampled on Montana Creek (B-7068) (Loney, 1962, personal communication). Thus, that deposit at least clearly is older than 8,000 years and probably is 10,000 to 12,000 years old. The raised beach (B-6892) clearly postdates glacio-marine sediment immediately adjacent, being cut into it. B-7076 at Tee Harbor has distinct lithology which may not be glacio-marine and may postdate other deposits.

Nevertheless, it is not impossible that some other deposits sampled postdate the 10,000 to 12,000 year old glacial period, for the sort of glacio-marine deposition described here occurs today locally in southeastern Alaska. Glaciers still arise from ice fields and flow to the sea. For example, Taku Inlet, near Juneau, is a fjord with a large glacier at its upper end. The sediment being deposited in this fjord today probably would be indistinguishable either lithologically or faunally from that formed at least several thousand years earlier.

The history of deposition and subsequent vertical displacement of glacio-marine deposits around Juneau is very difficult to determine. Aside from the problems of age assignement, the physical phenomena of local and regional tectonism and probable variation of Pleistocene sea-stand make complications. Superposed on the problem of calculating amount of isostatic rebound with ice withdrawal is that of determining local movement on faults. The Juneau area today rests uneasily in a highly tectonically active area and no doubt has done so throughout Quaternary time. With respect to lowered glacial sea-stand, possibly some deposits were formed considerably below present sea level. Some of these may today rest below sea level, perhaps even having been subaerially exposed after some uplift but before rise of sea level. Thus, within the historical framework of Quaternary time, one can only conclude definitely that the glacio-marine sedimentation under consideration took place in shallow water (see pp. 691-693) and, subsequently, some deposits were uplifted probably as much as several hundred feet.

Correlation of localities sampled cannot be close because of lack of continuity of exposures and massive character of sediment. No observable stratigraphic sequence exists. Even the stratigraphy of vertical sections is enigmatic. One tends to assume deposition was on nearly horizontal surfaces even though sediments mainly lack bedding. This is not necessarily the case, however, nor are the topmost sediments in a vertical section necessarily the youngest. True vertical sections can be seen locally, as in road cuts where up to 100 feet of sediment are exposed. Elsewhere, small, separate exposures can be found in lines running approximately straight uphill for 200 or 300 feet. The first question, of original horizontality, arises out of the fact that local vertical extent for contemporaneous deposition of very similar sediment is at least from 30 to 60 meters (limits are based on observation of modern sedimentation and ecology of *Elphidium clavatum* Cushman). The second question, of stratigraphic sequence, arises out of lack of precise knowledge about uplift in the area. Possibly, where glacio-marine sediments are continuous for several hundred feet up a steep slope, the oldest occur at the top and continuing uplift allowed deposition of progressively younger marine deposits lower on the slopes. This seemingly peculiar stratigraphic situation may not be the rule in the Juneau area but it certainly is possible. Likely, more normal stratigraphic situations are represented also, with considerable thicknesses of sediment accumulated in the usual nearly horizontal sequences before uplift.

Lakelse Slide

The glacio-marine sediment of the Lakelse slide rests directly and unconformably on bedrock. It is partially overlain by soil. Again, the problem exists as to whether or to what degree the vertical extent of the slide represents a true stratigraphic section. Movement of the slide mass compounds the problem, particularly as it has not all been directly downhill as a coherent mass. Assuming original horizontality and no subsequent differential disturbance, 120 feet of section were sampled. Throughout this section (or whatever is represented), no age differences are detectable. Again, the age probably is late Pleistocene. The deposit may be equivalent to the last (Fraser) glaciation of the Vancouver area, during the last ice-withdrawal stage. It may, however, be younger, as Lakelse is further north and in a geographic position where a glacial lobe could have remained in the fjord after ice withdrawal was complete in the Fraser Lowland.

Queen Charlotte Islands Localities

The stratigraphic section from which the Queen Charlotte Islands samples came is the type section of the glacial succession, which succession overlies Pliocene sediments at least locally. The glacial deposits are divided into four main units. At the base is the "marine till" from which the two samples came. This is overlain by a central sand, then an upper till, and an uppermost sand. The surface is organic soil. The units of the glacial succession are not homogeneous throughout and both their lithologies and thicknesses change somewhat along strike.

Sutherland Brown (1968, personal communication) considers the Queen Charlotte Islands samples representative of Fraser ("=Wisconsin") Glaciation. He stated the following. "The age of the glaciation may be judged to be late Pleistocene by the freshness of the erosional features and the unweathered nature of the glacial deposits. This is confirmed by the one radiocarbon age on material that might closely date the end of glaciation [10,850 ± 800 years] and by the radiocarbon age of shells related to post glacial high sea level [8,620 ± 150 and 8,060 ± 140 years]." Nothing in the foraminiferal fauna disagrees with this.

Vancouver Area

In the Vancouver area (Fraser Lowland) the surficial sediments are known to rest unconformably on the Mesozoic Coast Range Batholith at their northernmost extension and on some Cenozoic volcanics locally. Some of these volcanics may even postdate much of the glacial succession. Very locally, Cretaceous and Tertiary sedimentary rocks crop out conformably beneath the surficial deposits. The base of the thick unconsolidated section has not been seen nor penetrated by boreholes throughout much of the area. Soil and, locally, peat overlie the glacial outwash and related deposits.

Armstrong and others (1965) have concluded that southwestern British Columbia and northwestern Washington State were subject to an interglaciation (Olympia) and a glaciation (Fraser) during the last 40,000 years, with evidence of prior glaciations too scanty to interpret. They stated that the Fraser Glaciation probably represents the same geologic-climate episode as the "classical" Wisconsin Glaciation of the Midwestern United States.

The stratigraphic section of unconsolidated deposits in the Fraser Lowland may be generalized under the following group names, beginning at the base: 1) Semiamu Drift, probably of glacial, and preglacial origin (exposed mainly in drill holes) and representing pre-Olympia "times"; 2) Quadra sediments of the Olympia Interglaciation; 3) Surrey Drift and Vashon Drift (lateral equivalents), whose deposition began during Olympia and concluded during Fraser "times"; 4) bodies of Fraser-glaciation sediments grouped as Capilano in British Columbia and including, in succession, Cloverdale sediments, Newton stony clay, and Whatcom glacio-marine deposits, and referred to different formational units in Washington; 5) Sumas Drift, of Fraser Glaciation, which occupies part of the Lowland in both British Columbia and Washington.

Within the unit Olympia Interglaciation—Fraser Glaciation, the Evans Creek Stade, the Vashon Stade, the Everson Interstade, and the Sumas Stade are recognized. The boundary between Interglaciation and Glaciation is time-transgressive from 25,000 to 15,000 years before present and crosses the Evans Creek and Vashon Stades. The last Cordilleran ice sheet to cover the area began its expansion into the lowlands in the Evans Creek Stade and reached a maximum in the Vashon Stade. Ice moved south and west out of the Coast Mountains of British Columbia to cover the Fraser Lowland, the Strait of Georgia, and the mountains of Vancouver Island up to altitudes of 5,500 feet. Retreat of the Vashon Cordilleran ice sheet marked the inception of the Everson Interstade. During this time the sea invaded the lowlands and floating ice (bergs and some shelf or sea ice) was present. (The samples of the present study come mainly from Everson Interstade sediments.) Following the Everson Interstade, the Sumas Stade featured a relatively minor ice advance from the east into the Lowland down the Fraser Valley. This advance probably ended before 9,000 years before present. These conclusions of Armstrong and others (1965) summarize and modify previous work in the area (see Armstrong, 1956, 1957).

Radiocarbon dates related to Vancouver-area samples include the following. Shells from the glacio-marine deposit and the overlying peat near Burnaby Lake (D-1211) give ages of about 12,000 and 9,000 years, respectively (Mathews, 1962, personal communication). Armstrong (1964, personal communication) cited ages, on marine shells, of $11{,}930 \pm 190$ years at Fort Langley (D-1208, and also given as dating unit 2, Everson Interstade in the Eastern Fraser Lowland, B. C. by Armstrong and others, 1965), $12{,}800 \pm 175$ years at Boundary Bay (presumed to be D-1213, and also given as the oldest date of six from "Newton stony clay" of the Everson Interstade in the western Fraser Lowland by Armstrong and others, 1965), and $12{,}625 \pm 450$ years several hundred yards away from and believed to be the same horizon as the King George Highway locality (D-1212). These ages indicate the Everson Interstade of the Fraser Glaciation, typified in the Fraser Lowland. The four localities D-1208, D-1211, D-1212, and D-1213 are in Capilano sediments.

Of the two remaining Vancouver area-localities, that from Howe Sound (D-1209) is too geographically separated from those of the Lowland to attempt a close correlation. Probably, however, it represents the same geologic-climate unit, the Everson

Interstade, or possibly the Sumas Stade. It likely postdates the Vashon Stade, during which ice cover would have been complete, scouring likely, and deposition of the type of glacio-marine sediment present possible but very unlikely. The subsequent ice-withdrawal environment is more likely.

A date on the Highbury Tunnel (D-1210) sample would be interesting because it is from the "base of the Pleistocene succession" as recognized by the excavators. Further, it is from 250 feet below the surface and only 3.7 miles from the Point Grey sea cliffs, which could place it in the "Point Grey formation" (of Armstrong and others, 1965, p. 325), with a date exceeding 35,000 years. Thus, this sample could represent pre-Olympia and Fraser Interglaciation and Glaciation. Certain infra-specific variations in *Elphidium clavatum* and *Cibicides lobatulus* (Walker and Jacob) from those from other localities of this study would be in keeping with this possibility.

NUMBER AND TAXONOMIC AFFINITIES OF FORAMINIFERA

A total of 105 taxa are represented in the Alaska and British Columbia assemblages. Ninety-five were found in the 15 Juneau-area samples, 11 in the six Lakelse samples, 34 in the two Queen Charlotte Island samples, and 47 in the six Vancouver-area samples. Taxa and their distribution are given in text-figure 3. At Juneau, the mean number per locality is 37, with a maximum of 46 and minimum of 17; only four samples contained fewer than 35 taxa. At Lakelse, the mean is four, maximum 10, and minimum one. The two Queen Charlotte Island samples contained 20 and 30 species. The relatively small sample size and particular species present suggest that larger samples would yield several more species. Vancouver samples show a mean of 16, maximum of 30, and minimum of six. In the six samples, 6, 9, 13, 15, 25, and 30 species are represented, showing important differences in diversity.

Almost all foraminifera are calcareous. Although members of the imperforate Miliolidae are fairly well represented taxonomically and numerically, they are not nearly so numerous nor diverse as perforate forms. Imperforate fischerinids are rare. Perforate elphidiids outnumber all other groups, either singly or combined. Members of the Islandiellidae, Cibicididae, Discorbidae, Cassidulinidae, Nonionidae, and Buliminacea occur in relatively large numbers. Unilocular Nodosariacea are represented by numerous taxa, but only two species are more than rarely present. A few uniserial nodosareaceans also are present. Members of the Polymorphinidae, multilocular Glandulinidae, Spirillinidae, Epistomariidae, Robertinidae, and Globigerinidae also occur. Occasional specimens representing the Ataxophragmiidae, Lituolidae, Trochamminidae, and Hormosinidae account for the arenaceous group. Observed specimen disintegration of *Eggerella advena* (Cushman) during sample preparation suggests that at least this species made arenaceous foraminifers more abundant in the living environment than after fossilization. (*Eggerella advena* commonly occurs with the important species of the present assemblages in modern faunas).

TAXONOMIC NOTES

The taxonomy used in this study follows, insofar as possible, current usage accepted as valid. Some designations, however, reflect systematic problems beyond the scope of this study. *Cassidulina barbara* Buzas of this study has been referred by Loeblich and Tappan (1953) and others to the species *islandica*, which has given its name for the genus *Islandiella*. Buzas (1965a) concluded that North American specimens referred to *Cassidulina islandica* Nørvang (or *Islandiella*) are members of *Cassidulina* and, therefore, erected the name *C. barbara*. "*Cassidulina teretis* Tappan" has an optically radial wall, placing it in *Islandiella*.

The specific identification of some *Elphidium* specimens presents problems. Numerous specimens could have been referred to *E. subarcticum* Cushman but were thought better retained in other species. The forms referred to *E. frigidum* Cushman, *E.* (?) sp. cf. *E. frigidum* Cushman, and (?) *Protelphidium pauciloculum* (Cushman) may be a quite variable group representing the same species, although they differ sufficiently to warrant a tentative taxonomic separation. The text designation *Elphidium frigidum*, *sensu lato*, includes all three, however. All have an optically radial wall. The wall surface of the group called *E.* (?) sp. cf. *E. frigidum* is so covered with minute nodes that the sutures and sutural pores seldom can be seen. One or two specimens appear to have double rows of pores, however, suggesting the genus *Elphidiella* rather than *Elphidium*.

Separation between *Buccella frigida* Cushman and *B. tenerrima* (Bandy) is very difficult in the present material. The form referred to *Pyrgo* (?) sp. cf. *P. lucernula* (Schwager) appears likely immature *P. lucernula*, but it has only a suggestion of a tooth and is slightly triloculine. *Angulogerina hughesi* (Galloway and Wissler) and *A. fluens* Todd appear a gradationally costate-noncostate group which probably represents one species. *Elphidiella hannai* (Cushman and Grant) and *E. nitida* Cushman also may be conspecific, but examination of present specimens and types did not allow a certain conclusion.

In the present material, two forms could be new subspecies. The first is an *Oolina collaris* (Cushman) which has several low, rounded costae extending part way up the test, the distance varying from near the base only to near the aperture. The species, *sensu stricto* is smooth, but the costate form appears completely gradational with the smooth form.

The second possible new subspecies has been included in *Fissurina* cf. *F. marginata* (Montagu). That designation includes two forms. Three small specimens from the

Vancouver area most closely resemble *F. marginata* and *F. circularis* Todd, but the material is inadequate for closer identification. The group in question, found at the Queen Charlotte Islands and Juneau localities, differs from the species, *sensu stricto* in having a slightly produced base, mucronate or with a small spine. It also differs from the original description of the species in lacking a keel.

Specimens of all taxa have been compared with types available in the U.S. National Museum of Natural History, Washington D.C., and with some at Stanford University, the University of Southern California, and the University of California at Los Angeles and at San Diego (La Jolla).

DOMINANT AND SUBDOMINANT SPECIES

General

In all but one of the Alaska and British Columbia samples *Elphidium clavatum* is dominant, and ranges from 35 to 100 per cent of assemblages. Subdominants are *Buccella frigida*, *B. tenerrima*, *Islandiella teretis*, *Cibicides lobatulus*, *Elphidium bartletti* Cushman, *E. frigidum*, *sensu lato*, *Nonionella auricula* Heron-Allen and Earland, *Cassidulina barbara*, *Fursenkoina fusiformis* (Williamson), *Epistominella vitrea* Parker, *Nonionellina labradorica* (Dawson), and *Quinqueloculina* spp. These subdominants are common and occur in several to most samples, though their relative abundance and distribution vary more than that of *Elphidium clavatum*.

Juneau Area

All samples from the Juneau area contain very similar foraminiferal assemblages (see text-fig. 3), although two of the 15 are slightly but noticeably different from the others. All but one are greatly dominated by *Elphidium clavatum*. Approximate percentages of *E. clavatum* in the 14 samples where it dominates range from 50 to 80. It constitutes about 5 per cent of the only sample where it is not dominant. Subdominants include all those listed above except *E. bartletti*, which is, however, present in all but two assemblages. Of the subdominants, *Buccella*, *Islandiella*, and *Nonionella auricula* are the most abundant and widespread.

The one sample (B-7076) not dominated by *Elphidium clavatum* is dominated by *E. frigidum*, *sensu lato* (about 60 per cent), with *Buccella tenerrima* constituting about 10 per cent and *Elphidium clavatum*, *Cibicides lobatulus*, and *Bolivina robusta* Brady being the only other species more than rarely represented. While dominated by *Elphidium clavatum*, the raised beach assemblage (B-6892) contains the greatest relative abundance of *Buliminella elegantissima* d'Orbigny, *Buccella frigida*, and *Epistominella vitrea* in the samples studied.

Lakelse Slide Samples

Elphidium clavatum dominates all 6 assemblages. Four samples contained species besides *E. clavatum*. *Islandella teratis*, *Bucella frigida*, and *Quinqueloculina stalkeri* Loeblich and Tappan each occurred in three (see text-fig. 3). Almost all specimens from the slide are relatively small and thin- walled.

Queen Charlotte Islands Samples

Elphidium clavatum dominates the two assemblages from Graham Island. *Cassidulina barbara* is common from the upper "more till-like" sample (D-1214). There are a few *Islandiella teretis*, *Fissurina lucida* (Williamson), and *Globigerina bulloides* d'Orbigny from D-1214 and *Buccella tenerrima* and *Cassidulina barbara* from D-1215. The other 28 species occur rarely.

Vancouver Area

Elphidium clavatum dominates all assemblages, and constitutes from approximately 35 to 75 per cent. *Islandiella teretis* and *Cibicides lobatulus* each are abundant in two assemblages, *Elphidium bartletti* is abundant in one, and all three are present in others. *Buccella frigida* is common in two assemblages and present in all. *B. tenerrima* is common in one and present in three others. *Cassidulina barbara* is common in one and present in all but one. *Oolina collaris* is common in one assemblage but not present elsewhere. All other taxa are represented in relatively small numbers.

To give an idea of the large numbers, absolutely and relatively, possible for *Elphidium clavatum* to attain, all specimens were picked from one washed sample (60 cm^3 unwashed), rather than the usual representative suite. The species and their numbers follow: *Elphidium clavatum*—1,514; *Buccella frigida*—630; *Elphidiella nitida*—3; *E. arctica* (Parker and Jones)—1; *Islandiella teretis*—1; *Cassidulina barbara*—1. Thus, for most purposes, the sample could be limited to *Elphidium clavatum* and *Buccella frigida*.

ECOLOGY

Environmental Data on Species Tolerences

For ecologic data on the species of the present fossil fauna, the works of Cushman and Todd (1947), Said (1951), Parker (1948; 1952a, b), Phleger (1951; 1952a, b), Loeblich and Tappan (1953), Beljaeva (1960), Anderson (1963), Cockbain (1963), Cooper (1964), Buzas (1965b), Adams and Frampton (1965), Ellison and others

(1965), and Todd and Low (1967) have been selected. Of these, Phleger (1952b), Loeblich and Tappan, Beljaeva, Anderson, Cooper, and Adams and Frampton consider Arctic faunas, while the others are primarily north temperate.

Studies of the ecology of cold, shallow-water Foraminifera were begun about 20 years ago. These show that in most cases dominance relationships between *Elphidium clavatum* and a few other species closely reflect changes in the very shallow-water environment. Environmental data for the more important Alaska-British Columbia species are summarized below.

Dominant Species, Elphidium clavatum

Elphidium clavatum thrives in salinities from normal marine (approximately 30 to 35‰) to approximately 15‰. (Likely, it can also live in hypersaline lagoonal waters.) Below 15‰ it is replaced mainly by a few arenaceous species which live in brackish but not fresh water. With respect to temperature, *E. clavatum* abounds where annual variation is 1) only a few degrees around 0°C, 2) between approximately 5 and 10°C, and 3) where winter minima are near 0°C but summer maxima reach 25°C. *E. clavatum* is abundant through a very limited depth range. It reaches maxima above 15 meters, decreases markedly in relative and numerical abundance at approximately 30 meters, and usually becomes negligible between 60 and 100 meters. Therefore, *E. clavatum* is eurythermal and euryhaline, but stenobathic. The causes for these tolerance limits are not known.

Salinity most probably has a direct effect on the organism within its geographic range, with true tolerance limits being reached, while temperature and depth involve other factors. Temperature itself no doubt is limiting under some circumstances. Likely, however, upper tolerance limits for *E. clavatum* are not reached throughout at least most of its geographic range. More probably, other associated factors, such as competition, cause it to disappear in warmer waters.

Depth of itself is not an ecological variable. With *E. clavatum*, temperature decrease with depth cannot be directly limiting. Although *E. clavatum* reaches its depth tolerance limits within its geographic range, attempts to correlate its depth zonation with any one of a host of environmental variables have not been successful. Most likely, many variables act in concert to control the depth distribution.

Subdominant Species

Buccella frigida and *B. tenerrima* (species difficult to differentiate) have ecological tolerences similar to *Elphidium clavatum* but their present distribution indicates that they cannot withstand salinities much below 20‰ and their maximum absolute and relative abundances occur in slightly deeper water (about 20 to 50 versus 15 or less to 30 meters). These buccellas and some associated quinqueloculinas and perhaps islandiellas live with *E. clavatum* at salinities around 20‰, below those tolerated by most of the other species of the present assemblages. The islandiellas and perhaps the quinqueloculinas also live in greater abundance in deeper water than does *E. clavatum*.

Islandiella teretis, rare to abundant in the present assemblages, is a common constituent of northern, high-latitude faunas. It probably lives in reduced as well as normal-marine-salinity waters and certainly at very shallow (less than 15 meters) depths, but also thrives at considerably greater depths than does *Elphidium clavatum*. Green (1960) found it dominating a "shelf" fauna in the Arctic Ocean at 433 and 510 meters. It appears to be restricted to quite high latitudes, at least in shallow water. The fact that it has not been recorded from the Straits of Georgia and Juan de Fuca (Cockbain, 1963) nor from around Cape Cod (Parker, 1952a) or Long Island Sound (Parker, 1952b, Buzas, 1965b) suggests this.

Cassidulina barbara, rare to common in the present assemblages, also is common in high northern latitudes at varying depths in "shallow" water. Uchio (1959) found a "shelf" fauna dominated by "*C. islandica*" and "*Trifarina fluens*" below 70 meters off Hokkaido. The shallower-water fauna was dominated by *Elphidium clavatum*, *Buccella frigida*, *Eggerella advena*, and *Nonionella japonica* (Asano).

Cibicides lobatulus is locally abundant in Vancouver-area samples and it and *Epistominella vitrea* are common in Juneau samples. They are recorded also from shallow-water Quaternary sediments in the Gulf of Alaska and southeastern Alaska (Todd and Low, 1967). Of the two, *Cibicides lobatulus* is more widely reported from shallow-water Quaternary deposits. For example, Adams and Frampton (1965) and Feyling-Hanssen (1965) reported *C. lobatulus* as a dominant from littoral sediment in Iceland and shallow-water sediments representing the "Post Glacial Warm Interval" in Spitsbergen, respectively. Phleger (1952a) found *C. lobatulus* representing 50 to 90 per cent of the fauna locally off Portsmouth, New Hampshire and (1952b) 61 per cent of a fauna at 124 meters in the Arctic. Cockbain (1963) found it occurring commonly from approximately 30 to 200 meters in Juan de Fuca Straits. Its type locality is shore sands in southern England.

Interestingly, Loeblich and Tappan (1953) reported neither *C. lobatulus* nor *Epistominella vitrea* nor *Buliminella elegantissima* as present in their study of Arctic Foraminifera and these species' geographic ranges extend further south than those of many of the other Alaska-British Columbia species. The type area for *Epistominella vitrea* is the Gulf Coast of the United States. It is also recorded (as "*E. exigua* Brady") from glacial sediments in southern Norway (Feyling-Hanssen, 1954a, 1964) and Denmark (Michelsen, 1967). *Buliminella elegantissima* is known commonly from shallow waters around England and the West and Gulf Coasts of the United States and Mexico.

Epistominella vitrea, as well as *E. pacifica* (Cushman), *Angulogerina fluens*, *A. hughesi*, and *Uvigerina cushmani*, found in relatively small numbers in the present fauna, have been questioned as being shallow-water forms at all. This writer has found all five living in four meters of water in southeastern Alaska, however. Further, the epistominellas were found abundantly in less than 20 meters of water off the north coast of the Queen Charlotte Islands by T. Rothwell (1968, personal communication). Nevertheless, all, and especially the last four species, may have deeper water optima.

Of the subdominant *Nonionella auricula*, little detail is known about ecologic tolerences. Loeblich and Tappan (1953) recorded it from all depths below 20 meters (21 to 223) from off Point Barrow. Other reported occurrences include the following: 1) Todd and Low (1967) reported it from 45 meters in Excursion Inlet, southeastern Alaska; 2) Cockbain (1963) found it living in small numbers in water less than 100 meters deep in straits near Vancouver, British Columbia; 3) Parker (1952a) recorded it living in shallow water off New England; 4) Buzas (1965b) recovered it in small numbers from glacio-marine sediments in Maine; 5) Feyling-Hanssen (1964, 1965) found it in shallow-water Quaternary sediments in Norway and Spitsbergen.

Both subdominants *Fursenkoina fusiformis* and *Nonionellina labradorica* are widely reported from shallow-water Quaternary sediments. They appear to have greater depth ranges than *Elphidium clavatum*, being common from very shallow (less than 30 meters) into deeper-water "shelf" faunas (Parker, 1948; Phleger, 1952a). *Nonionellina labradorica* here is common in two assemblages and is found more rarely in 15 others from British Columbia and Alaska. Perhaps this reflects a preference for deeper water than inferred for the living environment of these assemblages. In this regard, Loeblich and Tappan (1953) found the *Nonionellina* at most of their Point Barrow stations deeper than 20 meters but not from their three and nine meter stations. Todd and Low (1967) recorded *Nonionellina labradorica* as a major constituent of samples from 390 meters in Clarence Strait and from 90 meters in Kasaan Bay, both in southeastern Alaska. Parker (1952a) stated that the species is not found south of Cape Cod on the east coast of North America. The *Fursenkoina* is widely reported from cold, shallow water, though seldom as a dominant. It appears to have a more southerly range. In that regard, Loeblich and Tappan (1953) did not report it from Point Barrow.

Elphidium frigidum, sensu lato, with *Buccella tenerrima*, dominates the one Juneau assemblage not dominated by *Elphidium clavatum* and is common in one other (dominated by *E. clavatum* and *Buccella tenerrima*) and present in all but one. It is rare from British Columbia. Apparently, it has at least a slightly deeper-water optimum than does *Elphidium clavatum* and is more stenohaline and perhaps more stenothermal, being restricted to colder water. Loeblich and Tappan (1953) did not find *E. frigidum* at their three, nine and 21 meter stations, but it appeared at their 36 meter station and continued downward throughout the depth range they sampled. It was found from 18 and 45 meters, respectively, in Gambier Bay and Excursion Inlet, southeastern Alaska by Todd and Low (1967). The type locality for the species is from 45 meters in the center of Foxe Basin, Baffin Land.

Tolerences of *Elphidium bartletti* are not well known. It is numerous in two Vancouver samples and present in most of this study, except from Lakelse. Loeblich and Tappan (1953) recorded it from three meters downward along their traverse off Point Barrow (approximately −2°C, 3-223 meters, normal marine salinity). The type locality is off Labrador. As with several *Elphidium* species, it is possible that *E. bartletti* is recorded from other localities under another name.

Species Present in Smaller Numbers

For species found in smaller numbers, some ecological information is available. A comparison with the work of Loeblich and Tappan (1953) shows that between 35 and 40 species are common to their traverse off Point Barrow and the glacio-marine sediments studied from the Juneau area. The present dominant species, *Elphidium clavatum,* and most subdominants are found off Point Barrow.

Quinqueloculina is a genus with a fairly large number of specimens in the present fauna. Three of the four identified species are recorded from 21 meters downward at Point Barrow. The fourth species, *Q. akneriana bellatula* Bandy, appears to have a more southerly range. *Eggerella advena* and *Astrononion gallowayi* Loeblich and Tappan, rare among the present assemblages, are reported from three meters downward at Point Barrow. These two species are common in many deposits representing the same fauna as that treated in this study. Regarding the remaining species in common with Point Barrow, nine first appear at the 21 meter station, 11 at the 36 or 37 meter stations, one at 42 and one at 48 meters, and one (a questionable identification) at over 100 meters. Most of these remaining species are unilocular nodosariaceans.

PALEŒCOLOGICAL INTERPRETATIONS

General

The various assemblages from the four areas of this study all represent the same Quaternary world-wide high-northern-latitude foraminiferal faunal province. This province was and is developed in cold (variable, but with at least a seasonal period of quite low temperatures), very shallow (0 to 30 or, locally 60 meters), fully marine to brackish (35 to 15‰) waters. The four areas of this study show the following major differences among them: 1) the Juneau-area and Queen Charlotte Islands samples represent normal marine perhaps to slightly brackish (35-28‰) salinities and open seaways; 2) Lakelse samples represent brackish salinities from approximately 15 to 20‰ and a considerably geographically restricted seaway; 3) the Vancouver-area samples represent variable salinites from approximately 15‰ to normal marine or only slightly brackish but with little indication of geographic restriction. Tolerances and relative abundances of species present and species diversities indicate these differences; the present topography of the area supports the conclusion of geographic restriction at Lakelse. Details of the paleoecology of the four areas are discussed below.

JUNEAU AREA

To sum up the paleoecology of the fauna of the Juneau area, the conditions were shallow water, probably less than 30 meters deep, of normal marine salinity possibly to slightly brackish locally (35 to 27 or 29‰) and cold temperatures (probable seasonal range 0°C to 5 or 10°C). These limits are set by ecological data available for *Elphidium clavatum* and other species in combination with the presence of a relatively large number of species, most more stenohaline than *E. clavatum* and many also confined to cold, shallow, northern waters. In the Juneau area there are no truly taxonomically reduced faunas and no species with tolerences incompatible with cold, shallow, normal-marine conditions. The abundance of *E. clavatum* and absence of clearly deeper-water species contraindicates post-mortem downslope movement of sediments. The considerable species diversity indicates that approximately normal marine conditions in fairly open seaways prevailed. The probable temperature range is also based on comparison with temperatures in the Juneau area today and interpolations from them.

Little discussion of individual assemblages is required since, for the most part, they are very similar. The relatively low diversity at two localities, however, and the rather minor but notable faunal difference from the more characteristic faunas at two other localities will be discussed briefly. Only 17 species were found at B-7068. This locality is from an exposure several miles up Montana Creek from the present seaway. The topography suggests that it represents a restricted inlet when it was marine, and it also may have been very shallow and possibly slightly brackish. Only 20 species were found at B-7071. This locality was established near the Treadwell Ditch in a poor exposure of weathered sediment. The weathering may account for the relatively low species diversity; there is no indication that restricted or brackish conditions existed.

The assemblage from the raised beach (B-6892) suggests slightly warmer water than do the others, which is in keeping with that deposits' non-glacial character. It contains more specimens of *Buliminella elegantissima*, found in small numbers in only four samples, than any other sample (Natland, 1957, cited that species as characteristic of lagoonal environments further south.) It is also the only locality where *Epistominella vitrea* is common.

The locality at Tee Harbor (B-7076) is the only one not dominated by *Elphidium clavatum*. *E. frigidum, sensu lato*, and *Buccella tenerrima* dominate and *E. clavatum*, *Cibicides lobatulus*, and *Bolivina robusta* are the only other taxa represented more than rarely, though they are not common. *B. robusta* is common today in water deeper than that assumed for the rest of the present assemblages and *Elphidium frigidum* may have a deeper water optimum than *E. clavatum*. This suggests deposition in deeper water than that of the other assemblages. The picture is complicated, however, by the fact that the sediment at B-7076 is not typically glacio-marine. This could indicate deposition in a non-glacial period (interglacial or, more likely, post glacial) or simply a different environment which would support a somewhat different fauna.

Lakelse Slide Samples

All Lakelse slide samples (D-1216 to D-1221) show impoverished faunas, with from one to 10 species per sample and total of 11. *Elphidium clavatum* greatly predominates in all samples. Almost all specimens are relatively small and fragile, a condition which probably indicates some deficiency, but which cannot be explained further.

If one takes elevations of each sample and assumes that the slide has moved only slightly, something of a pattern emerges in the degree of impoverishment of the fauna and its implications. The stratigraphic section thus constructed with the number of species found at particular horizons is presented in text-figure 4. A 120 foot thickness of sediment is represented by samples. If this is a true stratigraphic section, the following conclusions are valid.

Low taxonomic diversity and the particular species present as well as the fjord-like topography indicate reduced salinity (around 15 to 25‰) and geographic restriction throughout the time of deposition. The restriction probably varied little (whatever the stratigraphic section), but salinity more likely varied some. The dominant species throughout, *E. clavatum*, thrives in salinities as low as 15‰, but no species present represent "marsh faunas" of even lower salinity. The few ostracods, barnacles, and mussels found tolerate reduced salinities also.

Apparently, salinities were around 20‰ during deposition of D-1221 and D-1218 decreased to approximately 15‰ for D-1220 and D-1219, and increased again to around 20‰ for D-1217 and 25‰ for D-1216. Probably the amount of meltwater varied during the time of deposition. Although D-1219 and D-1220 have the lowest diversity and the sediment showed signs of weathering, no reason exists to assume weathering destroyed specimens as those found were in perfect condition.

The depth represented is less certain than in more typical *Elphidium clavatum*-dominated assemblages. In less restricted seaways, *E. clavatum* reaches maxima in less than 30 meters of water, giving way to other species in deeper water. Where salinity is very low or geographic restriction great and diversity is very low, as with the Lakelse fjord, possibly *E. clavatum* thrives below its usual 0 to 60 meter range. Perhaps the usual deeper-water competitors are absent. Even in a relatively unrestricted environment, Cockbain (1963) found *E. clavatum* numerous in around 100 meters of water (though other species were more common and the specimens might have drifted downslope). Other studies show it thriving only in very shallow water. It is interesting that Feyling-Hanssen (1953) reported a fauna consisting solely of *E. clavatum* from "blue clay" in what likely represents a fjord at Romerike, Norway.

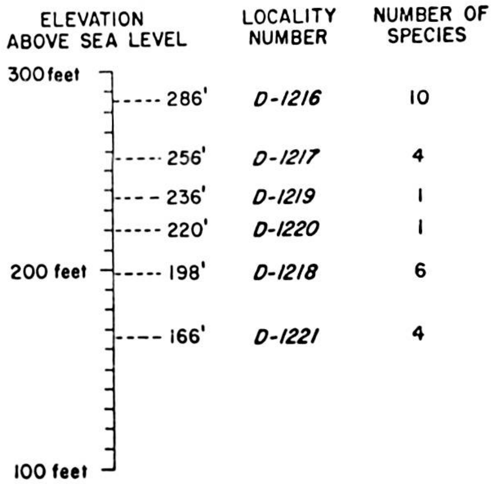

FIG. 4. — *Possible stratigraphic section at Lakelse with localities and their species diversities.*

For comparison with other areas, clearly the Lakelse fauna is from a restricted, reduced-salinity, cold-water environment. Two or three Vancouver area samples, notably D-1208, also show very few species. D-1208, however, probably simply represents low salinity and not also extreme geographic restriction. Although belonging to the same faunal province as the other samples of this study, the Lakelse samples are quite reduced and represent the most geographically restricted and brackish extremes of the province.

QUEEN CHARLOTTE ISLANDS SAMPLES

Samples D-1214 and D-1215 contain 20 and 30 species, respectively. Although these diversities are not as high as the average for the Juneau area, these Graham Island samples were relatively small. In view of sample size and particular species contained, little reason exists to assume reduced faunas. D-1214 may represent a condition where enough meltwater was present to reduce the salinity slightly (minimum 25‰) or make it slightly variable, in keeping with the "more till-like" character of the sediment. D-1215 most probably represents normal marine salinity (30-35‰). Both samples reflect cold temperatures (0 or 5°C to 10 or 15°C) and very shallow (probably less than 30 meters) water. The presence of several planktonic specimens in each sample reflects their relatively close proximity to the open ocean and lack of geographic restriction.

VANCOUVER AREA

A total of 47 species were found in the Vancouver-area samples. Species diversity (number of species present) ranges from six to 30 in the different samples. Species numbers are six (D-1208), nine (D-1212), 13 (D-1210), 15 (D-1209), 25 (D-1213), and 30 (D-1211). All except the last two may be considered relatively reduced faunas. Characteristically, very shallow, cold waters of normal marine salinity do not show relatively great species diversity, but 20 to 40 species may be considered average for a sample or small area in the indented waterways of the Pacific Northwest (see, for example, Todd and Low, 1967), although diversities may be lower in some other shallow, cold water areas (see Buzas and Gibson, 1969). The fossil assemblages from the Juneau area reflect the average diversities of the Pacific Northwest. Therefore, it is assumed here that numbers less than about 20 indicate some variation from a normal marine environment. In the case of the Vancouver area, relatively low species diversities apparently mainly indicate reduced salinities. This is because *Elphidium clavatum* dominates all samples and progressive decreases in diversity in combination with continued abundance of *E. clavatum* indicates progressive decrease in salinity from normal marine down to about 15‰. Minor differences in depth and geographic restriction may also be reflected among the Vancouver assemblages, but these cannot be documented with any certainty.

The six and nine species and their relative abundances found in D-1208 and D-1212 (see text-fig. 3) indicate very shallow, cold water with reduced salinities. *E. clavatum* dominates, but the presence of *Buccella* and other taxa tolerent of somewhat but not so reduced salinities as *Elphidium clavatum* contraindicates less than 20‰. The combination of *E. clavatum* and *Buccella* with no other taxa numerically important also suggests very shallow water, perhaps less than 15 meters. The very low diversities may also indicate some local geographic restriction.

Those samples with 13 and 15 taxa (D-1210 and D-1209) probably also represent reduced salinity, around 25‰ (and perhaps geographic restriction), but salinity tolerences of *Elphidium bartletti*, *Cibicides lobatulus* and *Islandiella teretis*, abundant along with *Elphidium clavatum*, are not certainly known. They and the other species present may live in somewhat reduced salinities. *Buccella* spp. are common at D-1210 and present at D-1209 and do live at reduced salinities. Between the two samples, D-1209 and D-1210, 1) the difference in abundance of *Buccella*, 2) abundance of *Islandiella teretis* in D-1209 and absence from D-1210, and 3) abundance of *Cibicides lobatulus* in D-1210 and absence from D-1209 probably indicate some difference in environment. Perhaps the *Islandiella-Cibicides* relationship means that D-1210 represents warmer water. This would be compatible with the postulated age difference, with D-1210 being older and perhaps from a warmer climate. Depths of less than 60 and probably less than 30 meters are indicated.

D-1213 and D-1211 contain 25 and 30 species, respectively. These are not reduced numbers of species. The salinity probably was normal marine with no significant geographic restriction. Water of less than 30 and certainly less than 60 meters depth is indicated by the abundance of *Elphidium clavatum*, with perhaps the greater relative abundance of *Islandiella* and *Cibicides* in D-1213 indicating slightly greater depth for that sample.

COMPARISON WITH SIMILAR QUATERNARY FOSSIL FAUNAS

Studies of a few shallow, cold-water, Quaternary fossil foraminiferal faunas from high northern latitudes are briefly described here for comparative purposes. Those of Mumby (in Schmidt, 1963), Feyling-Hanssen (1953, 1964, 1965), Michelsen (1967), and Buzas (1965a) are considered.

Mumby described a foraminiferal fauna from the Bootlegger Cove Clay near Anchorage, Alaska. The species listed are *Quinqueloculina seminula* (Linné), "*Guttulina lactea* (Walker and Jacob)", "*G.* sp.", "*Globulina* cf. *G. glacialis* Cushman and Ozawa", *Elphidium clavatum*, *E.* cf. *E. bartletti*, *Elphidiella groenlandica* (Cushman), and *Protelphidium orbiculare* (Brady). These species have been recorded from Quaternary sediments in the Arctic and North Atlantic and North Pacific. Ionium/Thorium dates on shells from the Clay ranged from 46,000 to 31,000 B.C. Although Schmidt believed shallow marine origin for the sediment, as described it differs from glacio-marine sediments. The fauna also differs enough to suggest deposition in water deeper or otherwise different from that of the present assemblages. The given species diversity is lower than might be expected, but cold temperatures and probably normal marine salinity are indicated. Interestingly, Mumby's species list also differs significantly from Todd and Low's (1967) for Pamplona Sea Ridge in the Gulf of Alaska and southeastern Alaska.

Feyling-Hanssen has studied fossil foraminiferal faunas from Quaternary deposits in Norway (1953; 1954a, b; 1957; 1964). In his extensive study of upper Pleistocene and Holocene deposits of the Oslofjord area (1964), he found an ecological or "eco-stratigraphic" succession of faunas dating from approximately 12,000 years ago to the present. All but the last one or two are believed to represent glacial periods. All but the last ecological "zones" were dominated by *Elphidium clavatum*, with various other species occurring with *E. clavatum* in the different "zones". Moving upward stratigraphically, six "zones" exist, with a seventh contemperaneous with the sixth. These "zones" with their dominant and characteristic species are tabulated below.

Species	*Zones* 1	2	3	4	5	6	7
Elphidium clavatum Cushman	D	D	D	D	D		
Nonionellina labradorica (Dawson)	C	C					
Cassidulina crassa d'Orbigny		C	C	C			
Fursenkoina loeblichi Feyling-Hanssen		C	C				
Cassidulina lævigata carinata Silvestri			C				
Quinqueloculina stalkeri Loeblich and Tappan				C			
Elphidium incertum (Williamson)					C		
Bulimina aculeata d'Orbigny						D	
Arenaceous species							D

Feyling-Hanssen assumed the fourth "zone" was deposited during the final, rapid retreat of the ice; the fifth and, especially, the sixth reflect "Post Glacial Warm Interval conditions"; and the seventh is contemporaneous with the sixth but represents a different environment. These last two represent the top of the succession.

Approximately 185 species were listed by Feyling-Hanssen; 140 are calcareous. Apparently, about 40 of these also occur in the present assemblages, but synonymous species names could raise the total to 50 or 60.

Feyling-Hanssen (1953) also described a fauna consisting solely of *Elphidium clavatum* from glacio-marine sediment at Romerike, Norway. According to the present interpretation, this indicates reduced salinity, probably around 15‰, cold water, and probably a shallow-water living site and a restricted seaway. No "marsh" forms, such as some *Trochammina*, nor reduced-salinity but somewhat warmer-water forms, such as *Ammonia beccarii* (Linné), are present.

From Spitsbergen, Feyling-Hanssen (1965) described four assemblages from sediments he interpreted as of the "Post Glacial Warm Interval". Of 57 species recorded, only about five arenaceous and five rarely occuring calcareous species do not occur also in the present assemblages. His dominant forms are *Elphidium clavatum*, *Astrononion gallowayi*, *Nonionellina labradorica*, *Cibicides lobatulus*, *Buccella tenerrima*, and *Cassidulina crassa* (which may be the same as at least some of the Arctic and Pacific forms referred to *C. islandica*). Between the four samples, however, dominance differences occur. *Elphidium clavatum* dominates one, constituting 31 per cent of the fauna, while in all the other three *Cibicides lobatulus*, *Astrononion gallowayi*, and *Nonionellina labradorica* dominate over *Elphidium clavatum*, and *Cassidulina crassa* does also in one. All other species remain relatively rare. Probably the *Elphidium*-dominated sample represents shallower water than the others, but no sample appears to reflect reduced salinity.

Feyling-Hanssen concluded temperatures were warmer than today by comparison with 12 Arctic bottom surface samples collected from off Spitsbergen and northeast Greenland. These samples contain fewer species and 80 per cent or more of most assemblages are *Elphidium clavatum* and *Cassidulina crassa.* According to Feyling-Hanssen, this frequency distribution characterizes "Recent" Arctic shallow-water faunas and late Pleistocene glacial clays in Norway.

Michelsen (1967) took samples from five bore holes on the island of Laesø, east of Jutland, Denmark. The section represents "late glacial Yoldia Clay" and post-glacial sand. Foraminifera recognized as 66 and 61 species came from these two units, respectively. There are 72 species altogether, with 55 common to both units. The faunas are very similar to that of the present study, especially that of the *Yoldia* Clay. *Elphidium clavatum* dominates, with *Cassidulina crassa* and *Cibicides lobatulus* subdominant, although the last is more abundant than *Elphidium clavatum* in three samples. Most of the species present in smaller numbers also occur in the Alaska-British Columbia assemblages.

The tops of four bore holes are essentially barren and their fossiliferous sequences begin with samples containing a few arenaceous specimens only. This may reflect quite brackish conditions or weathering of the sediment. The main differences between the Laesø and present Alaska-British Columbia faunas are the relatively small numbers of *Islandiella teretis* and *Buccella* and the presence of "*Ammonia batavus* (Hofker)", especially in the post-glacial sand, at Laesø.

Buzas (1965a) studied upper Pleistocene Foraminifera from the Presumpscot Formation near Waterville, Maine. He found 19 species representing 13 genera. Of these, only two or three rarely occurring forms are not found in the Alaska-British Columbia samples. *Elphidium clavatum* dominates, with *Protelphidium orbiculare, Elphidium incertum, Cassidulina barbara,* and *Buccella frigida* subdominant. In common also with the present assemblages, arenaceous species were nearly absent, being represented by two specimens of *Eggerella advena.*

As Buzas had a stratigraphic section, he was able to recreate the history of late glacial events in the Waterville area. The lithology and high per cent of *Elphidium clavatum* at the base indicate a shallow marine embayment into which glacial material washed. An increase in the per cent of *Cassidulina barbara* in two samples suggests a time of deeper water and maximum extension of the embayment. Subsequent shallowing is indicated by return to *Elphidium* dominance. Finally, conditions at the top of the section suggest transition to a fluvial environment.

THE WORLD-WIDE HIGH NORTHERN LATITUDE QUATERNARY SHALLOW-WATER FORAMINIFERAL PROVINCE

The late glacial Alaska and British Columbia foraminiferal assemblages studied are characteristic of the Quaternary foraminiferal fauna found in very shallow water at high northern latitudes all around the world. This fauna extends in time at least from the inception of the Pleistocene to the present. Geographically, a faunal province is represented, extending around the continental borders of North America and Eurasia. The southern boundaries today are gradational with more southerly shallow-water faunal provinces on both sides of the Atlantic and Pacific. These boundaries occur at about the latitudes of northern Washington and northern Japan and Korea in the Pacific and England and North Germany and between Cape Cod and Maryland in the Atlantic. The southern boundary probably oscillated north and south during Quaternary time with climatic changes, but the details have not been determined.

Depth limits are approximately from low tide to 100 meters, although the province is best developed above 60 or even 30 meters. Both to the south and in depth, the province gives way to various others locally. Some of the characteristic species are even also characteristic of other provinces. The shallowest water dominants, *Elphidium clavatum*, *Buccella frigida*, and *Eggerella advena* do not characterize deeper water provinces, however.

Salinities range from normal marine (30 to 35‰) down to 15‰, with a progressive decrease in species diversity with salinity decrease. Temperatures are quite variable within the province, with such extremes as yearly variations from —1°C to —2°C, nearly constant at or variable between 0 or 5°C and 10 or 15°C, and yearly variations from 0°C to 25°C; the only common factor appears to be a period of quite cold temperature. Substrate of itself probably is not a very important factor so long as at least a small amount of clay or silt is present, though other conditions related to substrate may be significant.

The characteristic dominant species for the faunal province as a whole is *Elphidium clavatum*. Subdominants (which may dominate locally) include *Buccella frigida*, *B. tenerrima*, *Islandiella teretis*, *I. islandica*, *Cassidulina algida* Cushman "*C. norcrossi*", *C. crassa*, *C. barbara*, *Elphidium frigidum*, *E. bartletti*, *E. incertum*, *E. tisburyense* (Butcher), "*E. subarcticum*", *Cibicides lobatulus*, *C. concentricus* (Cushman), *Nonionellina labradorica*, *Nonionella auricula*, *Protelphidium orbiculare*, "*P. pauciloculum*", *Astrononion gallowayi*, *Eggerella advena*, *Globobulimina auriculata* (Bailey), *Epistominella vitrea*, *Fursenkoina fusiformis*, *F. complanata* (Egger), *F. loeblichi*, *Buliminella elegantissima*, *Bulimina aculeata*, *Bolivina pseudoplicata* Heron-Allen and Earland, *B. pseudopunctata* Hogland, *B. pacifica* Cushman and McCulloch, *Ammonia beccarii*, "*A. batavus*", *Rosalina bertheloti* (d'Orbigny), *Quinqueloculina* spp., and some other miliolids. Usually not abundant, but characteristic are some unilocular nodosariaceans and some polymorphinids and multilocular glandulinids, *Elphidiella arctica*, *E. nitida*, *Angulogerina fluens*, and *A. hughesi*. As well as *Eggerella advena*, some other arenaceous species are important locally. These include some members of *Reophax*, *Trochammina*, *Textularia*, *Spiroplectammina*, *Recurvoides*, *Haplophragmoides*, *Labrospira*, *Alveolophragmium*, *Ammobaculites*, *Ammotium*, and *Ammoastuta*. Arenaceous specimens usually are very poorly represented in the fossil assemblages.

Most of the calcareous taxa characterizing the faunal province are represented in the present assemblages from British Columbia and Alaska, some commonly or abundantly. The arenaceous forms are not. Neither are the relatively-warm-water elements, *Ammonia*, *Rosalina bertheloti*, and *Bulimina aculeata*.

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CHECK LIST OF FORAMINIFERA

SPECIES	VANCOUVER						QC		LAKELSE						JUNEAU														
	D.1208	D.1209	D.1210	D.1211	D.1212	D.1213	D.1214	D.1215	D.1216	D.1217	D.1218	D.1219	D.1220	D.1221	B.6891	B.6892	B.7074	B.7067	B.7072	B.7075	B.7071	B.7068	B.7070	B.7073	B.7077	B.7069	B.7066	B.7065	B.7076
Angulogerina fluens (Todd)		○		○		○	○	○							○	○	○	○	○	○			○	○	○		○	○	○
Angulogerina hughesi (Galloway a. Wissler)				○		○									○	○	○		○	○			○	○			○	○	○
Astrononion gallowayi Loeblich a. Tappan									○						○	○		○	○	○			○	○		○	○	○	○
(?) Astrononion viragoense Cushman a. Edwards																			○										
Bolivina pacifica Cushman a. McCulloch																	○	○	○	○			○	○	○	○		○	○
Bolivina robusta Brady															○	○	○	○	○	○			○	○	○	○	×	○	×
Buccella frigida Cushman	●	×	×	×	●	○	○		○	○	○				×	●	×	○	○	×	○	○	×	×	×	○		?	○
Buccella frigida Cushman (?)				○												○		○	?	○			○				○		○
Buccella tenerrima (Bandy)			×	○	●	○	○	×							×	●	×	○	×	×	○	○	×	×	■	○	■	●	●
Buliminella elegantissima (d' Orbigny)																×	○	○									○		
Cassidulina barbara Buzas	○	○	×	●		○	●	×			○			○	×	○	○	○	○	○	○	○	●	○	●	○	×	○	○
Cassidulina barbara Buzas (?)		○						○							○														
Cibicides lobatulus (Walker a. Jacob)			■	×		■	○	○		○					×	×	○	○	×	●			○	○	○	○	●	×	×
Dentalina costai (Schwager)																○		○	○					○					
Dentalina ittai Loeblich a. Tappan		○													○						○				○			○	
Dentalina pauperata d' Orbigny																								○					
Discorbis spp.																		○	○				○	○	○		○	○	
Discorbis (?) spp.					○																				○		○	○	
Dyocibicides biserialis Cushman a. Valentine						○													○	○					?	○	○	○	?
Eggerella advena (Cushman)																○	○							○	○				
Elphidiella arctica (Parker a. Jones)	○		?					○								○	○	○											
Elphidiella nitida Cushman	○		?					○								○	○	○											
Elphidium bartletti Cushman		●	■	○		○	○	○							○		○	○	×	×	○	○	×	○	×	○	○	○	
Elphidium clavatum Cushman	■	■	■	■	■	■	■	■	■	■	■	■	●	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	×
Elphidium frigidum Cushman							○		○						○	○	○		○	○			○	○	○	○		×	●
Elphidium (?) sp. cf. E. frigidum Cushman															×	×	×	○	○	○	○		○		×	○	●	×	×
Elphidium oregonense Cushman a. Grant																				○				○	○				
Elphidium spp.			○		○	○		○							○				○		○					○	○	×	○
Epistomaroides cf. E. rimosa (Parker a. Jones)																○	○										○		
Epistominella pacifica (Cushman)								○								○	○	○	○								○		
Epistominella vitrea Parker		○		○		○	○	○							×	●	○	○	×	×		○	○	○	×	○	○	○	○
Fissurina cf. F. cucurbitasema Loeblich a. Tappan																○	○		○				○						
Fissurina lucida (Williamson)				○			×	○	○					○		○	○										○		
Fissurina cf. F. marginata (Montagu)			○	○				○								○	○	○		○			○	○	○			○	
Fissurina cf. F. quadrata (Williamson)																												○	○
Fissurina serrata (Schlumberger) (?)																				○				○					○
Fissurina sp.								○																					
Fursenkoina fusiformis (Williamson)		○				○									○	○	●	●	×	×	○	○	×	○	●	○	○	○	○
Globigerina bulloides d' Orbigny				○			×	○							○		○	○	○			○	○				○	○	
Globigerina pachyderma (Ehrenberg)							○	○															○	?			○		
Globobulimina auriculata (Bailey)																○	○	○											
Gordiospira cf. G. arctica Cushman																○									○	○	○	○	○
Haplophragmoides cf. H. subglobosum (G. O. Sars)																						○							
Haplophragmoides sp.																					○								
Islandiella (?) norcrossi (Cushman)								○																					
Islandiella teretis (Tappan)	○	■		●	○	■	×	○	●		○			○	●	●	×	○	×	●	○	×	●	■	■	×	×	○	○
Islandiella teretis (Tappan) (?)				×																									
Lagena cf. L. amphora Reuss																	○	○	○	○							○	○	
Lagena distoma Parker a. Jones				○												○			○	○									
Lagena flatulenta Loeblich a. Tappan																	○												
Lagena gracillima (Seguenza)		○		○		○	○	?								○			○	○	○	○	○	○					
Lagena laevis (Montagu)																				○									
Lagena mollis Cushman				○		○									○		○	○	○	○			○	○	○				
Lagena parri Loeblich a. Tappan				○																	○								
Lagena perlucida (Montagu) (?)				○											○	○	○	○	○	○				○				○	
Lagena semilineata Wright			○	○		○											○	○		○				○			○		
Lagena setigera Millett								?								○		○		○									
Lagena substriata Williamson				○																									
Lagena sulcata (Walker a. Jacob)															○	○		○									○	○	
Lagena spp.															○	○			○					○	○				
Laryngosigma hyalascidia Loeblich a. Tappan																			○				○						
Lenticulina sp.				○													○												
Miliolinella californica Rhumbler																													○
Miliolinella chukchiensis Loeblich a. Tappan																							○		○	○	○	○	○
Nonionella auricula Heron-Allen a. Earland						?									×	○	●	●	●	●			●	●	×	●	×	○	○
Nonionella cf. N. auricula Heron-Allen a. Earland																			○										
Nonionella turgida digitata Nørvang				○											○	○	○	○	○	○		○	○	○	○	○	○	○	
Nonionella (?) spp.				○												○			○										
Nonionellina labradorica (Dawson)		○		×		○		○	?						○	○	○	○	●	○		●	○	○	○	○			○
Oolina aff. O. alcocki (White)															○			○		○							○	○	
Oolina apiopleura (Loeblich a. Tappan)						○									○	○	○	○	○	○			○	○	○		○		
Oolina cf. O. apiopleura (Loeblich a. Tappan)																							?		○				
Oolina borealis Loeblich a. Tappan							?									○	○	○		○									
Oolina caudigera (Wiesner)																○	?		○	○			○						
Oolina collaris (Cushman)		●							?		○					○					○								
Oolina lineata (Williamson)																?	○		○					○	○			○	
Oolina melo d' Orbigny							○										○	○	○	○			○	○		○		○	
Oolina striatopunctata (Parker a. Jones)																○			○				○	○	○			○	
Patellina corrugata Williamson																		○	○	○								○	
Pateoris hauerinoides (Rhumbler)																									○	○	○	○	
Pateoris sp.															○														
Planularia californica (Galloway a. Wissler)																									○				
Polymorphina kincaidi Cushman a. Todd																													○
Protelphidium orbiculare (Brady)		?	×			○	○	○									○				○		○	○	○	○	○		○
(?) Protelphidium pauciloculum (Cushman)					○	○		?							○	○	×	○	○	○	○	○	○	○	○	○	○	○	
(?) Pseudopolymorphina charlottensis (Cushman)								○																					
Pyrgo lucernula (Schwager)				○											○					○					○		○	○	
Pyrgo (?) cf. P. lucernula (Schwager)				○		○									○													○	
Quinqueloculina agglutinata Cushman															○	○	○		○		○		○	○	○	○		○	
Quinqueloculina akneriana bellatula Bandy						○	○	○	?						?						○		○	○		○	○	○	
Quinqueloculina arctica Cushman															○		○		○	○			○		○	○	○	○	
Quinqueloculina stalkeri Loeblich a. Tappan		○		○		×	○	○	○	○	○				○	○	×	○	×	×	○	○	×	○	×	○	○	○	○
Quinqueloculina cf. Q. stalkeri Loeblich a. Tappan					○																								
Quinqueloculina spp.									○								○												
Rheophax longicollis (Wiesner)				○																									
Rheophax (?) sp.																										○			
Robertina charlottensis (Cushman)																				○									
Saccorhiza (?) sp.																			○										
Sigmoilina (?) sp.			○																										
Triloculina inornata d' Orbigny					○		○	○											○										
Triloculina trihedra Loeblich a. Tappan								○													○			○	?			○	
Trochammina (?) sp.																						○							
Uvigerina cushmani Todd				×		○												○				○							
Diatoms		+		+	+	+								+		+	+	+	+			+	+	+	+	+		+	+
Ostracoda		+		+	+	+	+	+			+				+	+	+	+	+	+	+		+		+	+	+	+	+
Echinoid spines	+		+		+											+	+	+		+					+		+		+
Mollusca					+											+	+		+	+									+
Serpula (?)																			+				+		+				
Sponge spicules						+												+		+				+		+	+	+	
Bryozoa								+									+	+	+	+			+	+		+	+	+	
Megafossil fragments		+	+	+			+	+	+			+				+										+	+		
Fish remains				+																									

■ ABUNDANT
● COMMON
× FEW
○ RARE
+ PRESENT
? QUEST. IDENT. (ALL RARE)
D., B. U. C. M. P. LOC. NO' S