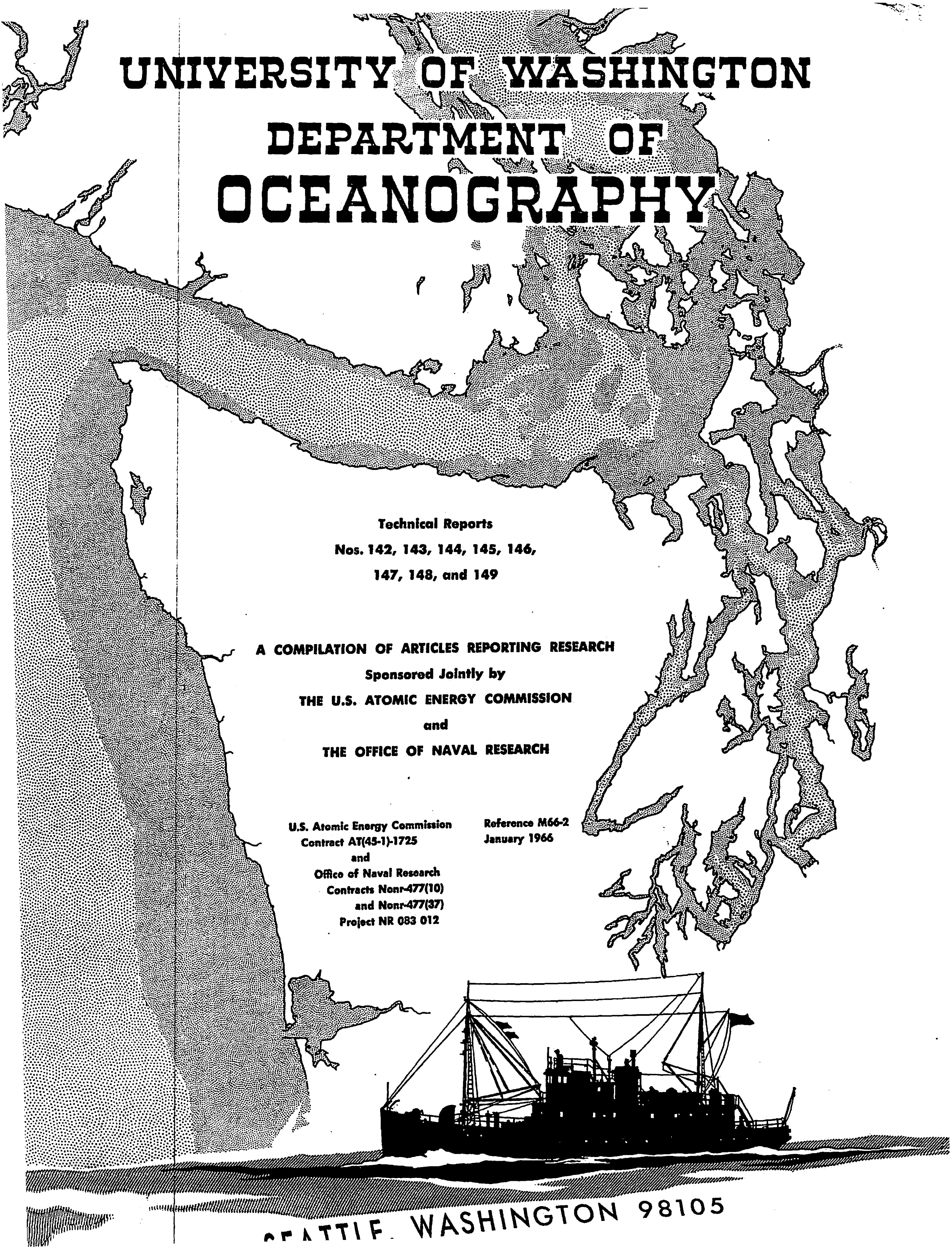

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RH Fleming
RICHARD H. FLEMING
Chairman

Clifford A. Barnes
CLIFFORD A. BARNES
Principal Investigator

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Technical Report No. 142

BIO-LITHOLOGY OF NORTHEAST PACIFIC SURFACE SEDIMENTS, by Y. R. Nayudu and B. J. Enbysk. Marine Geology, 2(4):310-342. 1964. (AEC: RLO-1725-42)

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THE TINTINNID PARAFAVELLA GIGANTEA (BRANDT), KOFOID & CAMPBELL, 1929, IN THE NORTH PACIFIC OCEAN, by Hsin-Yi Ling. Journal of Paleontology, 39(4): 72[illegible]-723. 1965. (AEC: RLO-1725-43)

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THE CARBONATE CONTENT OF SURFACE SEDIMENTS FROM THE NORTHEAST PACIFIC OCEAN, by M. Grant Gross. Northwest Science, 39(3):85-92. 1965. (AEC: RLO-1725-44)

Technical Report No. 145

RADIOACTIVITY OF THE COLUMBIA RIVER EFFLUENT, by M. Grant Gross, Clifford A. [illegible]rnes, and Gordon K. Riel. Science, 149(3688):1088-1090. 1965. (AEC: RLO-1725-45)

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FRACTIONATION OF PHYTOPLANKTON COMMUNITIES OFF THE WASHINGTON AND OREGON COASTS, by George C. Anderson. Limnology and Oceanography, 10(3):477-48[illegible]. 1965. (AEC: RLO-1725-46)

Technical Report No. 147

CHLOROPHYLLS IN MARINE PHYTOPLANKTON: CORRELATION WITH CARBON UPTAKE, by [illegible]. C Anderson and K. Banse. Deep-Sea Research, 12(4):531-533. 1965. (AEC: RLO-1725-47)

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GRAPHIC REPRESENTATION OF THE SALINITY DISTRIBUTION NEAR THE COLUMBIA RIVER MOUTH, by Betty-Ann Morse and Noel McGary. Pp. 923-942 in Ocean Science and Ocean Engineering 1965, vol. 2. Marine Technology Society, Washington, D. C. 1965. (AEC: RLO-1725-3)

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THE UNION OF THE COLUMBIA RIVER AND THE PACIFIC OCEAN -- GENERAL FEATURES, by [illegible]lyn C. Duxbury. Pp. 914-922 in Ocean Science and Ocean Engineering 19[illegible]. vol. 2. Marine Technology Society, Washington D. C. 1965. (AEC: RLO-1725-5)

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BIO-LITHOLOGY OF NORTHEAST PACIFIC SURFACE SEDIMENTS[1]

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(Resubmitted July 13, 1964)

SUMMARY

Seven bio-lithologic areas based on the relative abundances of diatoms, radiolarians, planktonic Foraminifera and lithic elements are defined for northeast Pacific surface sediments from the study of more than 200 gravity cores. These areas are: (*1*) northern terrigenous sediments with $< 20\%$ diatoms; (*2*) diatom-rich sediments with $> 20\%$ diatoms; (*3*) glacial marine remnant with diatoms; (*4*) Katmai volcanic ash; (*5*) Radiolaria-rich or biologically barren sediments; (*6*) *Globigerina*-rich sediments; (*7*) terrigenous sediments of outer shelf, slope and Great Trough, southern region. Color and benthonic foraminiferal characteristics are included in descriptions of the areas. Interrelated factors of terrigenous sediment supply, abundance of benthonic organisms, preservation of biogenous elements and plankton supply are evaluated. Topography and the major ocean currents of the region seem most responsible for the sedimentation patterns observed.

INTRODUCTION

Since early reconnaissance surveys off the northwest American coast, by "Tuscarora" (1874) and "Carnegie" cruise VII (1928–1929) (REVELLE, 1944), it has been generally accepted that fine clastic sediments cover the continental shelf, slope and parts of deep-sea areas. MENARD (1953) treated the entire area (40°–60° N) in its broad aspects based on his study of nine cores and seven dredge hauls. Recent detailed surveys by R. V. "Brown Bear", University of Washington (1954–1962), have revealed an interesting variety of arealy restricted bio-lithologic units (NAYUDU, 1958, 1959a, b). A description and discussion of the possible origin of these units is presented.

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[1] The major part of the research was done at the University of Washington and the paper was completed after additional study of cores at Scripps Institution of Oceanography.
Contribution no.282 from Department of Oceanography, University of Washington, Seattle, Wash. (U.S.A.)

Marine Geol., 2 (1964) 310–342

Of the more than 200 gravity cores which have been examined, 133 have been chosen to delineate the areas. Bathymetric and geographic positions of these cores are listed in Table I and Fig.6 and 9. The bathymetric range emphasized is 1,800–4,900 m. Only the topmost sections of the cores are considered here in an attempt to relate the present sediment surface with present climatic, sedimentation and oceanographic conditions. It is recognized that conditions of sampling make it likely that the "top" sample may not always reflect present conditions. Rose bengal stain for protein was used on many frozen surface samples in an effort to determine the living fauna and true bathymetric ranges of Foraminifera. Variations in this living record and preliminary geochemical studies (M. Grant Gross, 1964, personal communication) suggest that the 0–2 cm or 1–3 cm intervals examined vary significantly in contemporaneity from place to place. This is particularly noticeable in the Cascadia Abyssal Plain (Great Trough) sediments bordering the continental slope along the coast of Oregon and Washington. These discrepancies will be noted in the discussion below.

The interesting changes at depth in the cores of each bio-lithologic area and paleoclimatic history represented in these cores form the subject of a paper now in preparation by Nayudu. Biogenic elements in northeast Pacific cores will be discussed in a separate paper by Enbysk now in preparation.

BOTTOM TOPOGRAPHY

The effect of topography on sedimentation is great. The main features which influence the sediment types found are briefly described. Bathymetry of the area is shown in Fig.1 and 2 based on the published charts of HURLEY (1960), GIBSON (1960), and on sounding data obtained from "Brown Bear" cruises.

(*1*) The shelf off Alaska is quite wide. A steep slope forms the north, steeper side of the Aleutian Trench. The Trench has an average width of 80 miles and length of 2,000 miles. The axis lies at approximately 4,000 fathoms at its maximum depth and is 200–1,600 fathoms below the adjacent floor of the Pacific Ocean on the south.

(*2*) The Gulf of Alaska sea floor is a smooth gentle slope deepening to the southwest and locally warped downward in the northwest where it joins the eastern part of the Aleutian Trench. The surface is interrupted by several deep-sea channels. Three roughly parallel chains of seamounts trend in a northwesterly direction, with relief of 3,000–12,000 ft. HURLEY (1960) has defined three broad abyssal plains in the region: the Alaskan, Aleutian and Tufts.

(*3*) The continental shelf north of the Mendocino Escarpment broadens along the coasts of Oregon and Washington reaching a maximum width of about 30 miles. The continental slope is defined by a series of rugged elongate ridges and troughs at the outer edge of the slope. Farther north the slope narrows and steepens to form the Queen Charlotte Trough.

(*4*) Cascadia Abyssal Plain (HURLEY, 1960) or the Great Trough (MENARD,

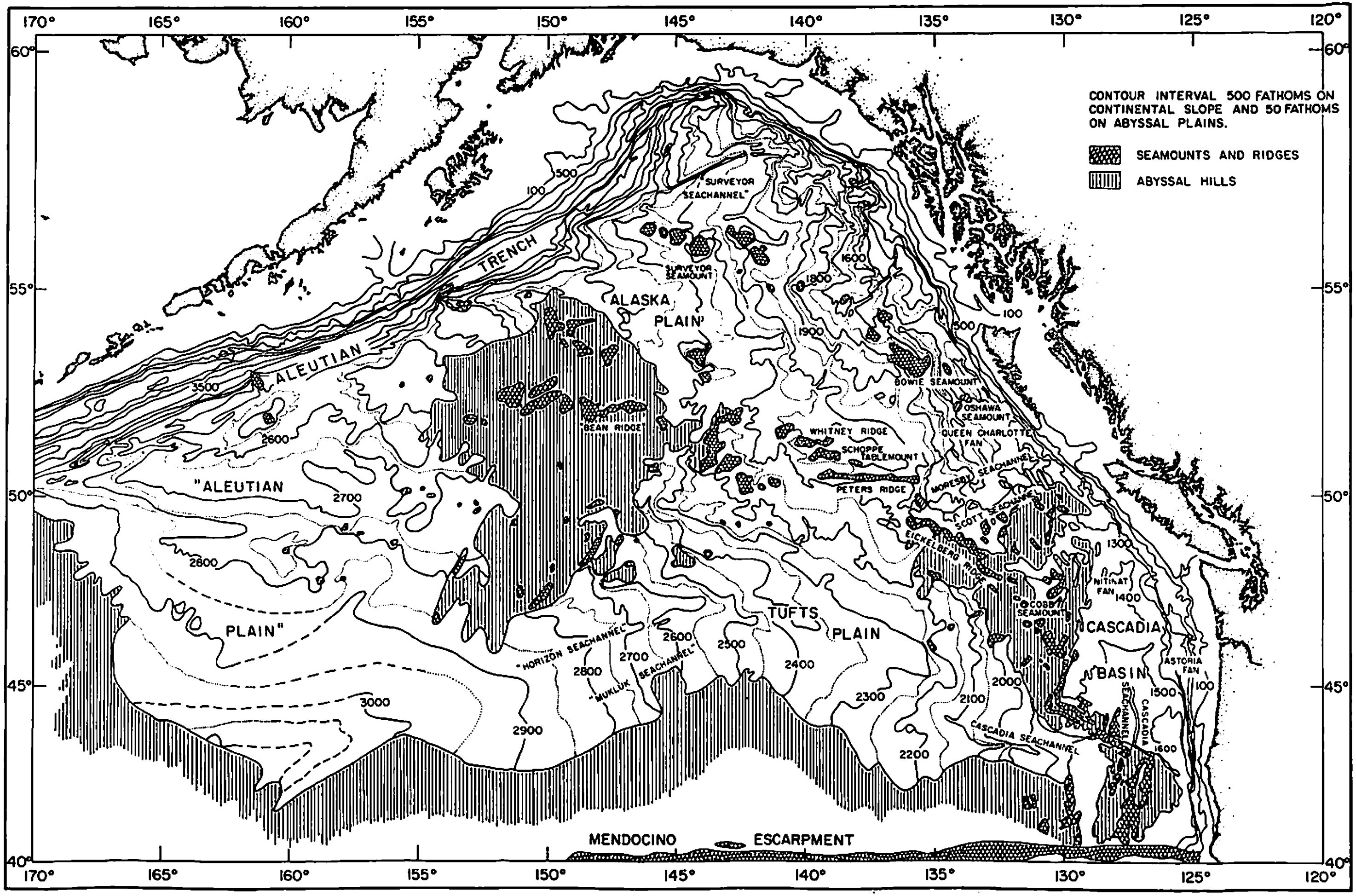


Fig.1. Bathymetry of northeast Pacific. (After HURLEY, 1960.)

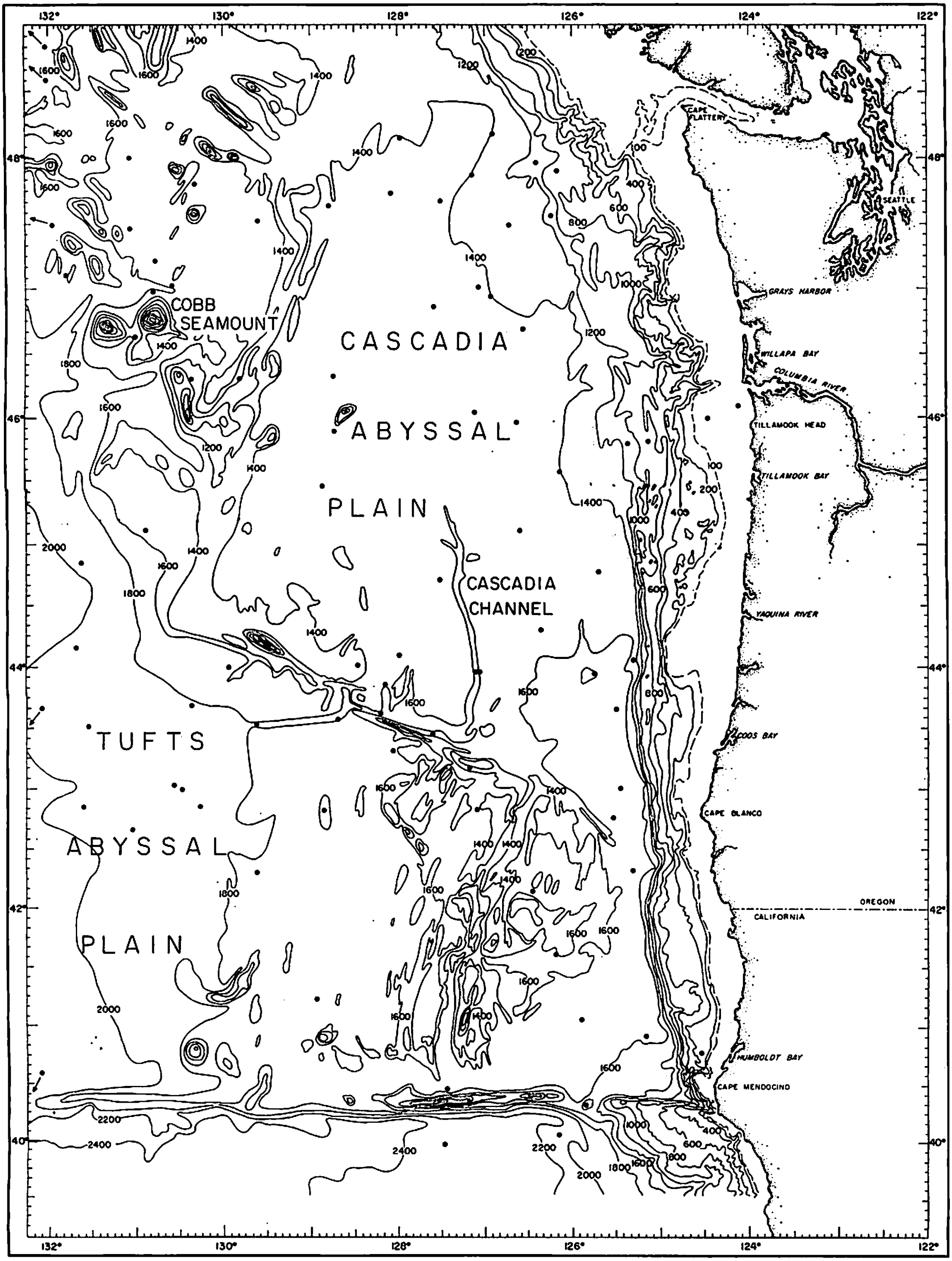


Fig.2. Bathymetry of southeast area. ● = core locations. Contours based on HURLEY (1960) and U.S. Naval Oceanographic Office charts.

1955; GIBSON, 1960) adjacent to the continental slope is remarkably smooth, suggesting an area of heavy sedimentation (Fig.2). The floor of the trough shows a uniform southward slope, roughly parallel with the continental margin. It is crossed by Cascadia and Astoria Channels (HURLEY, 1960). Cascadia Channel trends south to a narrow transverse ridge where it turns west into a pass from which it emerges on the Tufts Abyssal Plain. Astoria Channel runs south on a slightly sloping plain.

(*5*) A series of submarine mountain ridges rise along the western and southern edges of Cascadia Abyssal Plain (Fig.2). From the foot of the continental slope off Cape Blanco, Oregon (42° 5′N), a large ridge trends northwest to about 130° W. South of this ridge is a complex area of rough topography which smooths out to the southwest, north of the rise to the Mendocino Escarpment. North of Cascadia Channel another group of mountains trends almost north. This group includes several prominent circular seamounts, the major one of which is Cobb Seamount (BUDINGER and ENBYSK, 1960). Narrow elongate ridges are more common than the circular type and the mountain range merges into a series of ridges and rough topography between 48°N and 51°N. (Ridge and Trough Province of MENARD and DIETZ, 1951.)

(*6*) West and south of the mountain chain is the relatively smooth surface of Tufts Abyssal Plain which slopes slightly south of west at the edge of the study area to approximately 2,700 fathoms.

The entire area between 40° and 60°N may be divided into two regions latitudinally. The area between 60° and 50°N is referred to as the northern region and the area between 50° and 40°N as the southern region.

BIO-LITHOLOGY OF SURFACE SEDIMENTS

Color distribution

Color is one of the most obvious physical characteristics of Recent sediments. REVELLE (1944) gave a historical survey of the problem of colors in Recent sediments. It is generally agreed by the majority of workers in the field that the colors of deep-sea sediments are related to the relative rate of sedimentation and overall conditions under which they were formed. Color is affected by the state of oxidation of iron compounds, organic content and detrital source material.

It is possible to broadly delineate the region studied into three areas based on sediment color characteristics of the upper 5 – 10 cm of the surface layer as follows: (*1*) greenish-gray mud; (*2*) pale brown mud; (*3*) red clay. (The color designations of sediments are based on the rock-color chart distributed by the National Research Council.) The distribution of these colors is shown in Fig.3.

Greenish-gray mud. Various shades of greenish gray, including greenish gray (5GY6/1), greenish gray (5G6/1) and dark greenish gray (5GY4/1) are grouped. Sediments of this color were found by the writers to be restricted to continental

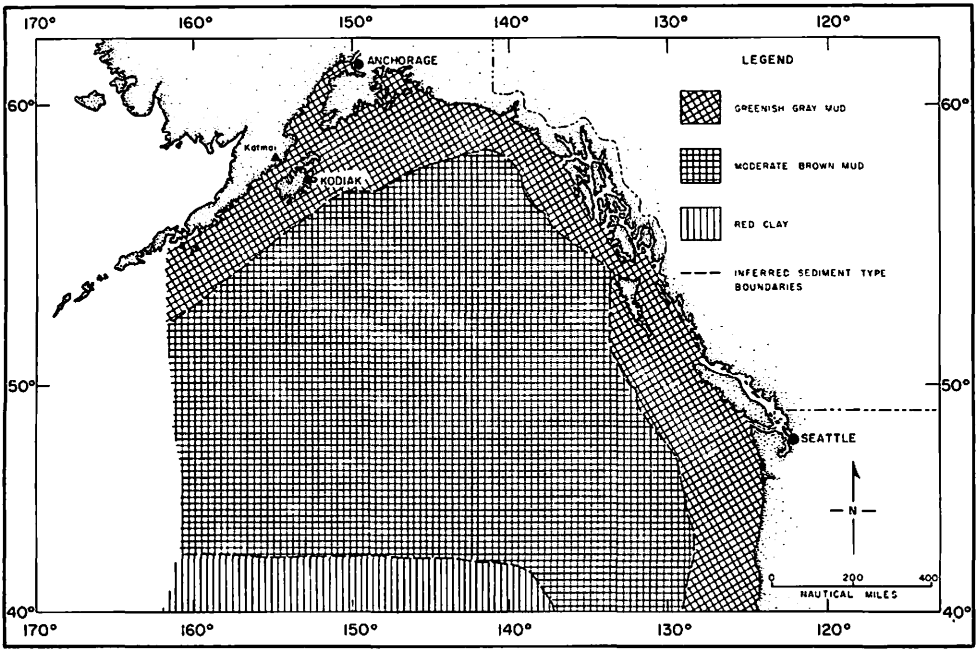


Fig.3. Color of northeast Pacific sediment surface samples.

borders, covering the continental shelf, slope and a moderate distance out beyond the slope in certain places.

Pale brown mud. The predominant color of the surface sediment layer in the area under investigation is pale moderate brown. Which includes grayish brown (5YR3/2), dark yellowish brown (10YR4/2) and occasionally moderate brown (5YR3/4). Sediments of this color cover part of the area that has been considered "red clay" area (MENARD, 1953). The present investigation shows that the "red clay" is more restricted than previously believed and the pale brown is more widespread. This is based on the fact that cores taken close to 140° and 146°W did not penetrate clays which could be classed as red clays (Table I). The upper few centimeters show pale to moderate brown color grading into light olive gray or moderate gray colors. Hence it is concluded that the previous designation of this area as "red clay" is no longer valid and that it should be classified under pale brown mud.

The color of the upper 10 cm of cores 144-8 and 199-27, which are located about 300 miles from the coast, is darker than that of core 144-6 which is almost 250 miles farther west than the two cores described above, i.e., approximately 600 miles from land. Similar observations were made by REVELLE (1944) for "Carnegie" sample 61 which is located in the vicinity of core 144-6. He states: "The color of this sample indicates terrigenous influence even though the distance from shore is great and nitrogen content is not larger than the other north Pacific clays". His sample 62 is described as red clay. Core 199-27 was taken at the same location. It is 80 cm long

TABLE I

CORE LOCATIONS

Sample number	*Depth (m)*	*Latitude (north)*	*Longitude (west)*
64- 5	3,072	52°02.0	134°30.3
64- 6	3,420	51°42.1	135°25.2
64- 9	2,968	54°12.0	137°06.0
64-11	3,658	54°08.3	141°14.8
64-14	3,695	51°57.7	143°14.8
64-17	4,005	54°32.0	145°28.0
64-20	4,389	53°16.0	149°28.5
64-22	4,389	52°05.0	151°29.5
64-24	4,297	53°18.0	153°27.0
64-27	3,658	55°43.3	153°14.2
64-41	2,195	59°18.4	145°32.5
64-44	3,786	57°24.6	145°11.8
64-45	3,823	56°04.5	145°14.5
64-46	3,749	57°24.3	143°42.9
64-53	3,420	58°24.2	141°11.8
64-55	3,640	56°11.0	141°12.9
108-50	2,734	42°51.7	127°04.2
108-51	3,292	42°49.2	128°50.8
108-56	1,829	48°35.9	126°53.2
108-57	1,445	48°35.9	126°47.4
110- 1	3,131	55°00.8	139°09.8
110- 2	3,775	57°12.8	144°10.7
110- 3	3,563	58°15.4	142°58.2
110-14	549	58°13.0	148°38.0
110-15	1,463	58°57.5	148°28.3
110-16	1,829	57°55.0	148°24.0
110-17	2,615	57°48.7	148°22.5
110-18	3,091	57°43.5	148°19.5
110-19	3,977	57°29.3	148°14.0
110-20	3,837	56°33.6	147°38.1
110-23	2,743	54°59.1	155°11.5
110-34	1,829	53°56.3	161°21.5
110-35	2,780	53°51.4	161°23.4
110-36	3,164	53°49.3	161°24.1
110-37	3,977	53°47.0	161°25.0
139- 5	2,889	47°00.0	130°48.7
139- 6	2,844	47°14.0	130°47.8
139-10	2,404	46°37.8	131°62.3
139-15	2,651	47°01.8	130°35.9
144- 1	3,832	49°56.2	136°59.2
144- 2	4,005	48°38.0	139°58.0
144- 3	4,261	47°18.5	139°56.8
144- 4	4,334	46°02.6	139°57.9
144- 5	4,334	44°06.0	140°05.0
144- 6	4,142	44°00.5	137°45.2
144- 7	3,968	44°59.0	134°57.0
144- 8	3,557	44°00.9	131°42.1
144- 9	2,554	44°01.7	128°29.3
144-10	3,394	49°04.3	133°00.0
188- 2	2,560	46°58.7	126°54.9
188- 3	2,560	48°13.2	126°51.5
188- 4	2,578	48°11.2	127°59.2
199- 3	3,191	48°59.0	132°56.0
199- 4	3,804	49°11.0	135°34.0
199- 5	3,950	49°16.0	138°08.0
199- 8	4,285	49°48.0	145°55.0
199- 9	4,480	47°54.0	146°22.0
199-10	4,700	46°04.0	146°26.0
199-11	4,901	44°00.0	146°26.0
199-27	3,823	40°35.0	132°31.0
202- 1	3,355	50°01.9	132°21.7
202- 2	3,383	49°44.9	133°57.9
202- 3	3,676	49°54.2	135°40.2
202- 4	3,731	47°57.3	134°00.1

TABLE I *(continued)*

Sample number	*Depth (m)*	*Latitude (north)*	*Longitude (west)*
202- 5	2,889	48°00.0	131°02.1
291- 5	2,600	47°42.2	127°31.7
291- 6	2,437	47°29.0	126°39.0
291- 7	2,250	47°32.3	126°12.4
291-14	2,597	46°59.0	127°04.1
291-15	2,670	46°52.0	127°38.5
291-16	2,597	46°40.0	126°32.6
291-37	3,072	42°43.4	125°32.0
291-38	2,975	43°34.6	125°31.6
291-39	2,926	43°53.4	125°49.2
291-40	2,889	44°13.0	126°27.5
291-41	2,798	44°42.6	127°36.0
291-42	2,780	45°00.5	126°42.5
291-48	2,706	45°57.4	126°40.2
291-49	2,725	46°03.0	127°12.0
311- 4	81	46°06.0	124°09.0
311- 5	143	46°01.8	124°29.0
311- 6	1,646	45°50.5	125°10.2
311- 7	2,012	45°48.0	125°24.0
311- 8	2,560	45°36.0	126°09.0
311- 9	2,789	44°48.2	125°44.5
311-10	2,743	44°04.0	125°19.0
311-12	3,156	43°58.5	127°09.0
311-13	2,926	43°57.3	127°05.8
311-14	2,834	44°07.0	127°59.0
311-15	2,926	43°50.5	128°11.0
311-16	3,146	43°34.0	128°10.8
311-17	3,347	43°33.3	128°45.0
311-18	3,072	43°19.0	128°08.0
311-19	2,834	43°26	127°30.0
311-20	3,127	43°10.0	127°11.0
311-21	3,036	43°00.0	125°26.0
311-22	3,072	42°20.0	125°18.4
311-23	2,670	42°10.0	126°26.0
311-24	2,889	41°36.0	126°12.8
311-25	3,109	41°04.0	126°00.0
311-26	530	40°48.5	124°33.0
311-27	2,981	40°55.5	125°10.0
311-28	2,450	40°22.5	125°53.0
311-29	3,840	40°06.0	126°10.5
311-30	4,334	40°00.0	127°30.0
311-31	3,200	40°29.0	127°27.0
311-34	3,237	41°13.0	128°58.0
311-36	3,156	42°17.2	129°37.0
311-37	3,402	42°52.0	130°19.0
311-38	3,521	43°60	130°30.0
311-39	3,475	42°59.0	130°24.5
311-40	3,530	42°39.5	131°07.0
311-41	3,548	42°50.0	131°39.0
311-42	3,566	43°32.6	132°26
311-43	3,475	43°31.5	131°34.0
311-44	3,329	43°40.0	130°25.0
311-45	3,383	43°28.5	129°36
311-46	3,146	44°00.5	129°57.0
311-49	3,603	44°53.0	131°40.0
311-50	2,853	45°07.2	130°55.5
311-53	2,798	45°28.5	128°54.0
311-54	2,743	45°55.0	128°45.0
311-56	2,761	46°20.5	128°44.5
311-57	2,450	46°19.3	129°50.0
311-58	1,957	46°19.2	130°24.2
311-60	3,255	47°07.0	131°48.0
311-61	2,889	47°29.2	131°03.2
311-62	2,889	47°49.0	130°19.0
311-63	2,761	47°32.0	129°36.0
311-64	2,633	47°38.0	128°48.0
311-65	2,633	47°44.0	128°05.3
311-66	2,560	47°51.0	127°09.0
311-67	1,884	47°57.0	126°19.0
311-68	1,737	47°58.5	126°10.4

and shows dark moderate brown color which in turn passes into dusky brown. Because of this sequence, this core is also grouped under brown color area.

The brown surface unit may represent partially oxidized sediments because most of the cores having moderate brown color grade downward into bluish green or moderate gray colors. In the offshore cores the striking difference in biologic content between the brown and lower sediments suggests that the brown material is an important sedimentary unit reflecting "recent" sedimentation and climatic conditions. Biologic, particle size and geochemical analyses now undertaken may show the real nature of this unit. Nearshore (eastern Cascadia Abyssal Plain) cores with high sedimentation rates do not exhibit a change in biologic content at the interval of color change.

Red clay. The extent of red clay as shown in Fig.3 is based on MENARD (1953) and the examination of two cores which are grayish red (5R4/2) and medium dusky red (10R3/2), taken south of the area under consideration in this report.

It is assumed from the color distribution that greenish-gray mud represents an area of rapid deposition; pale brown mud represents relatively slow deposition or hemipelagic environment; and red clay is typical for very slow rates of sedimentation or pelagic environment. These assumptions following REVELLE (1944) seem to agree with the inferred rates of sedimentation for this area. However, a possible volcanic source for the red clays is not precluded.

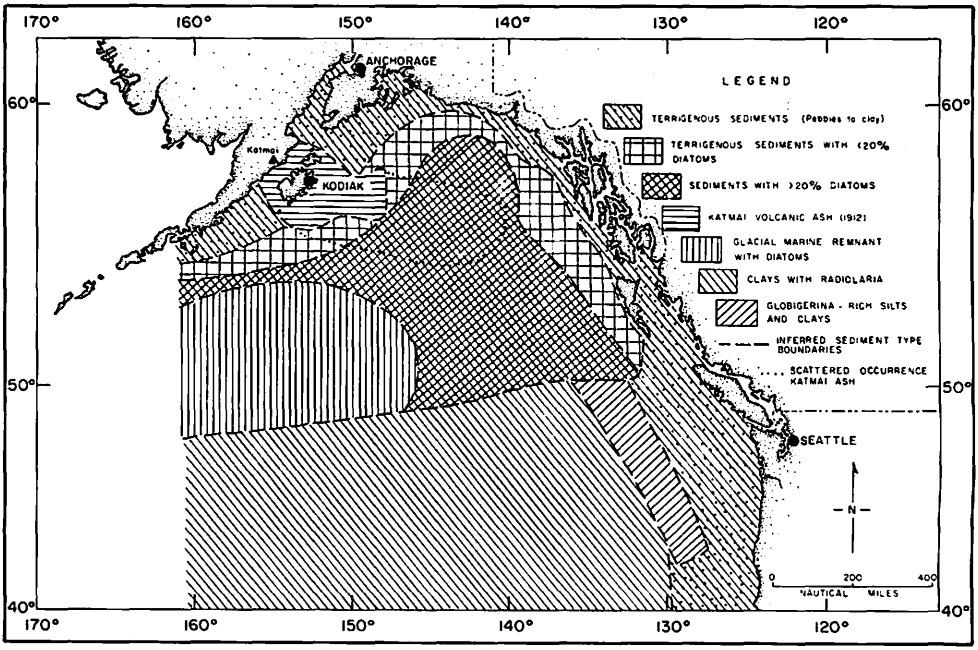


Fig.4. Bio-lithology of northeast Pacific sediment surface samples.

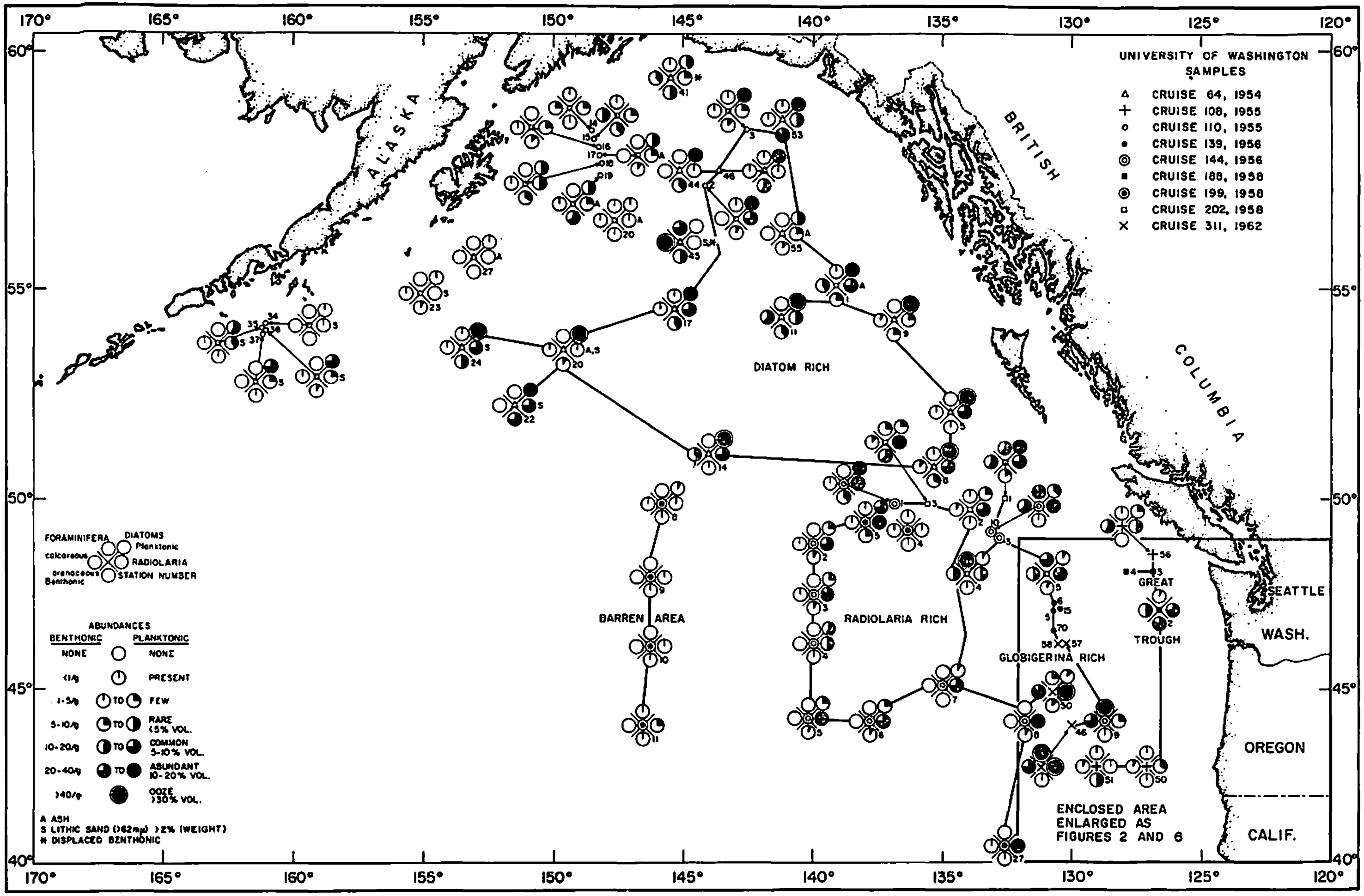
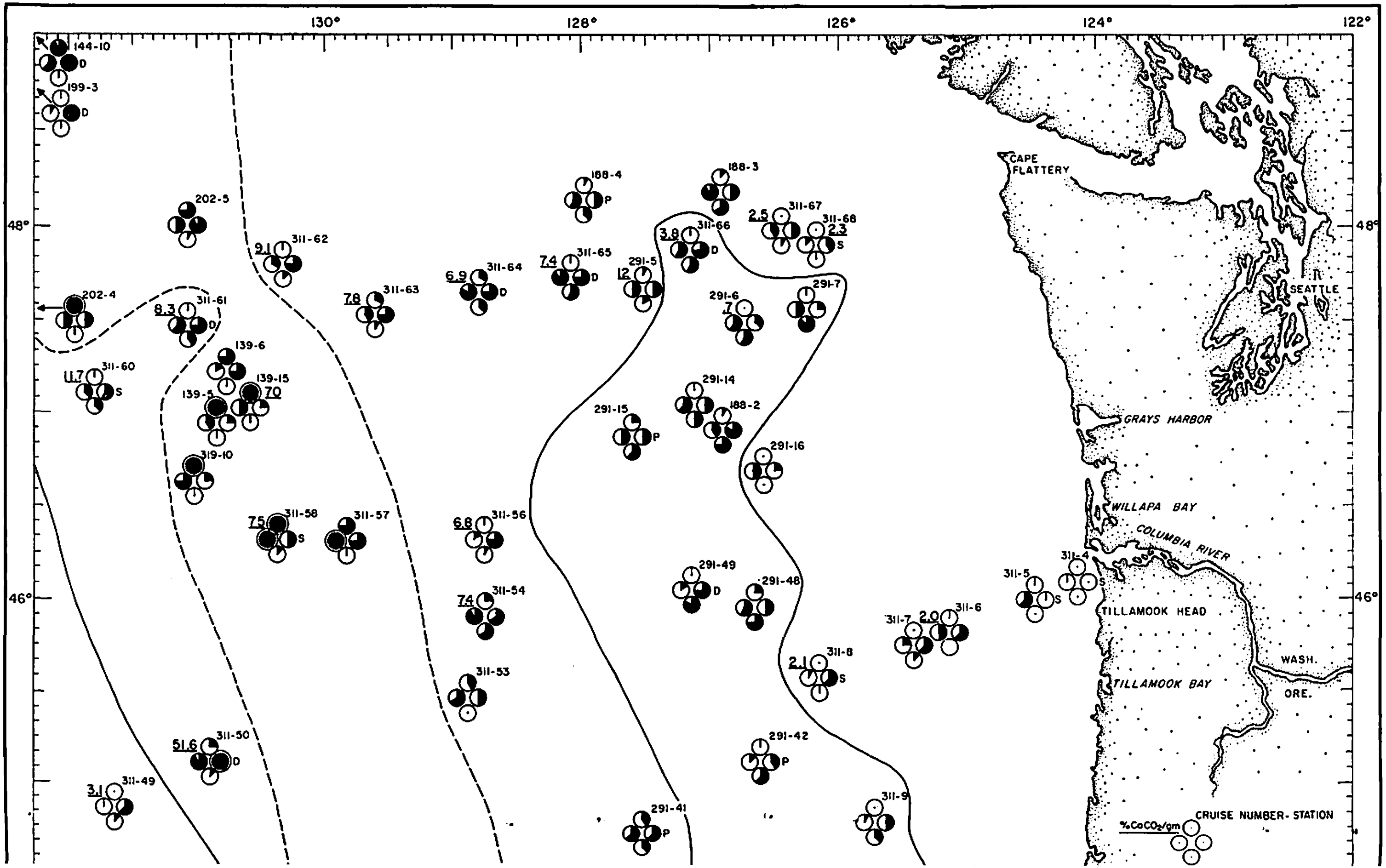


Fig.5. Bio-lithologic areas and sample characteristics.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202-5
202-4
8.3 311-61 D
11.7 311-60 S
9.1 311-62
139-6
139-15 7.0
139-5
319-10
7.5 311-58 S
311-57
7.8 311-63
6.9 311-64 D
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3.8 311-66 D
2.5 311-67
311-68 2.3 S
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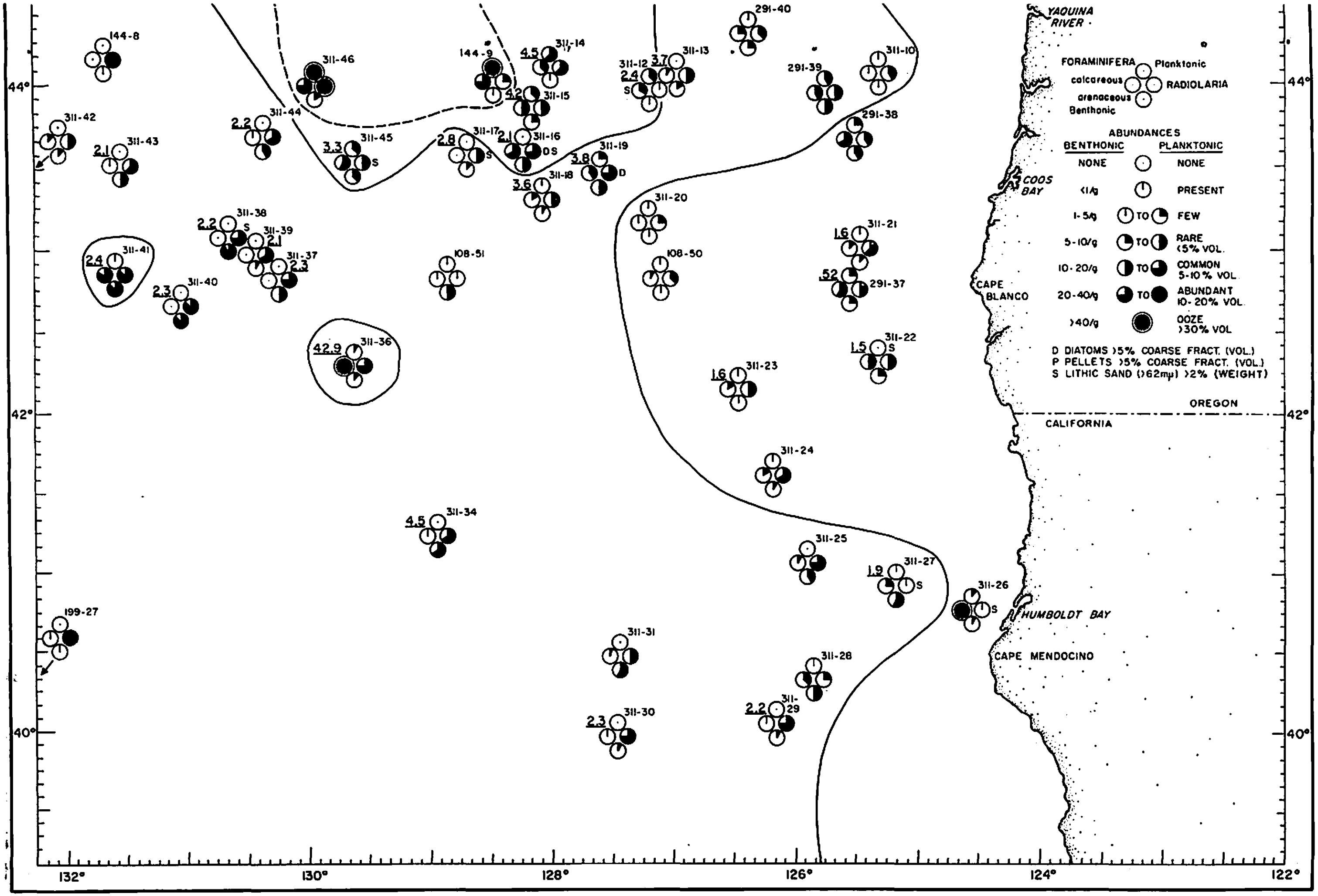

Fig.6. Bio-lithologic characteristics of southeast area. Solid line separates calcareous from arenaceous dominance; dashed line gives limit of *Globigerina*-rich area boundary.

Definition of bio-lithologic areas

As surface sediment data were being compiled it was noticed that samples characterized by the same relative proportions of planktonic Foraminifera, Radiolaria, diatoms and lithic sediment were arealy restricted. Bio-lithologic areas based on these four elements were defined by NAYUDU (1959a, b) and their biologic content evaluated by ENBYSK (1960). Areal distribution of the sediment types is shown in Fig.4 and biologic characteristics are summarized in Fig.5 and 6. The following areas have been defined: (*1*) Terrigenous sediments < 20% diatoms; (*2*) diatom-rich sediments with > 20% diatoms; (*3*) glacial marine remnant sediments with diatoms; (*4*) Katmai volcanic ash; (*5*) Radiolaria-rich or biologically barren clays; (*6*) *Globigerina*-rich silt and clays; (*7*) terrigenous sediments (pebbles to clay).

Terrigenous sediments with < 20% diatoms

In the northern region, seaward of shelf and upper slope terrigenous sediments is a narrow border area of sand to clay size terrigenous sediments containing 5–10% (by volume) diatoms but always less than 20%. This unit covers the major part of the continental slope, eastern Aleutian Trench and deep-sea floor.

Diatom-rich sediments with > 20% diatoms

Very fine textured terrigenous sediments with remains of siliceous organisms, mainly diatoms with lesser numbers of Radiolaria, cover the larger part of the northern region

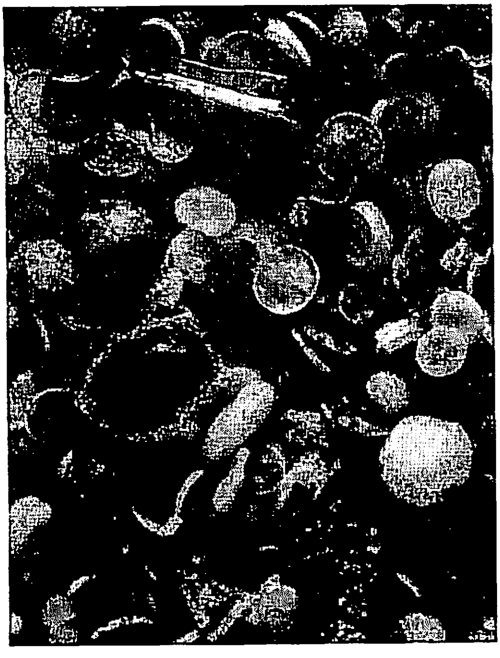

Fig.7. Photomicrograph of diatom-rich sediment in the northern area. (× 65)

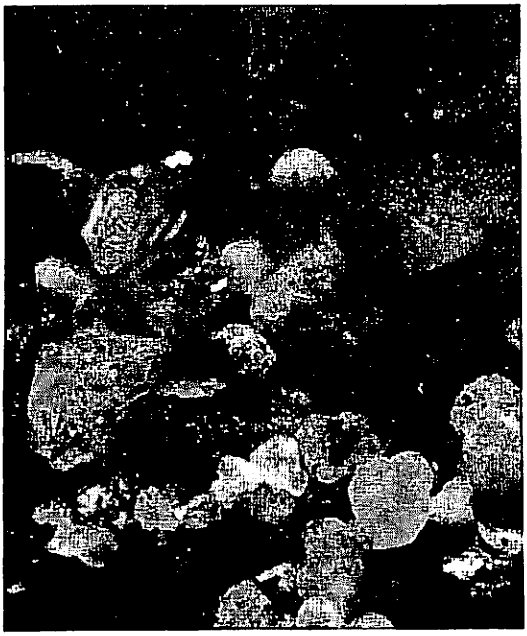

Fig.8. Photomicrograph of glacial marine sediments with diatoms showing quartz and lithic fragments with interstitial diatoms. (× 65)

as shown in Fig.4. Well-preserved diatoms are abundant (Fig.7). It is estimated that over 20 % of the sediment is composed of whole and fragmented diatoms. Large arenaceous Foraminifera are common and take up more sample space than would be surmised from the Foraminifera numbers presented in Fig.5. The present investigation has revealed that diatom-rich sediments are much more extensive than previously suggested by REVELLE (1944) and MENARD (1953).

Glacial marine remnant sediments with diatoms

In some cores of the west central Gulf of Alaska the sediment consists of lithic fragments of varied lithology and size, ranging from pebble to clay and is marked particularly by a great amount of very coarse sand (Fig.8). The lithic fragments represent a wide variety of rock types including sandstone, granite, metamorphics (phyllite and schist) and large pebbles of basalt. Different varieties of quartz are the most abundant coarse size particles constituting nearly 60 % of the sediment. Feldspar and mafic mineral grains are also present. Poor sorting and wide range of rounding are as a rule characteristic of this sediment. If consolidated, it would closely resemble lithic wacke.

The presence of rock fragments of varied lithologic type and abundant quartz suggests that the sediment is derived from the continent rather than local volcanic islands. The sediments are poorly sorted and occur in deeper parts of the ocean at least

300 nautical miles from the nearest land. Consideration of the various possibilities for such occurrences leads the writers to believe that these sediments were transported to their present position by Pleistocene icebergs. The southern limit extented to approximately 50° N. Hence they are Pleistocene glacial drift. There is essentially no deposition of terrigenous material today and diatoms act as interstitial filling in the coarse sediments of the 0–10 cm core intervals. The distribution of the sediments designated as "glacial marine remnant with diatoms" is shown in Fig.4. As this unit is essentially a relict, further discussion and description is not included in this report.

Katmai volcanic ash

Distribution of the uppermost volcanic ash of the northern region is shown in Fig.4. In a few cores it occurs in greatest concentration as a surface layer, e.g., core 110–20 (0–7 cm) and in other cores it is mixed with a greater proportion of terrigenous sediments of silt and clay. In the majority of occurrences, the base of the ash zone is well-defined. The concentration of glass shards is erratic with a general tendency to decrease toward the top of the core. The average estimated glass content in the ash layers is over 95%. A further discussion including the detailed petrography of Katmai ash and other older ash deposits of the area has been presented by NAYUDU (1964).

Radiolaria-rich or biologically barren clays

South of the diatomaceous sediments is a well-defined sedimentary province of clays

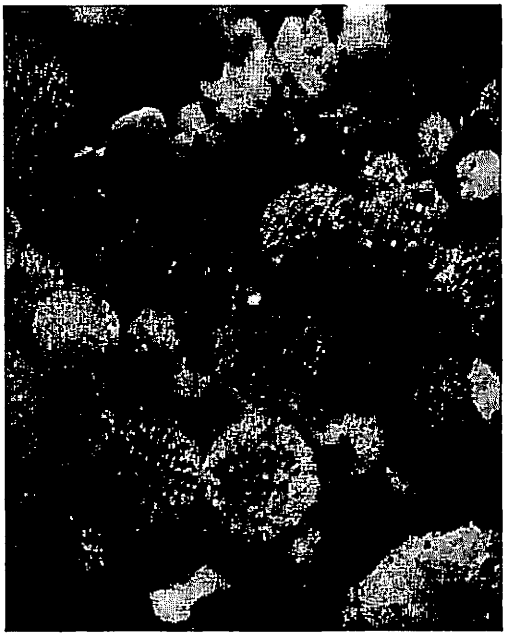

Fig.9. Photomicrograph of Radiolaria from Radiolaria-rich clays from the southern region. (× 65)

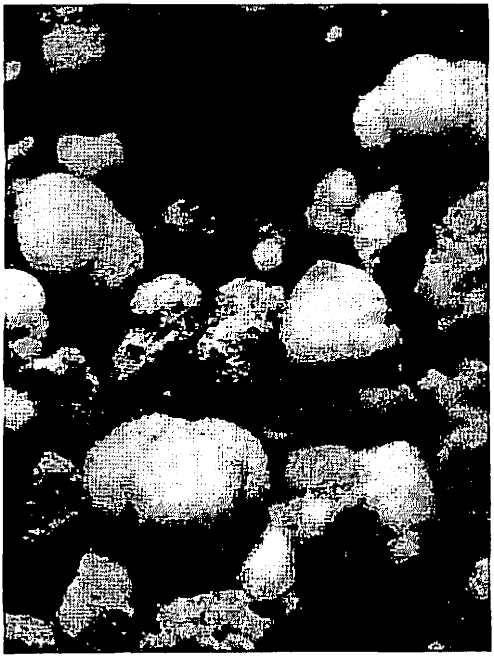

Fig.10. Photomicrograph of *Globigerina*-rich sediments. (× 65)

with or without Radiolaria. A few diatoms occur at the northern boundary. Due to lack of samples, the distribution of these clays was not mapped beyond 150°W. Radiolaria-rich samples are illustrated by Fig.9.

Globigerina-rich silts and clays

East of the area of radiolarian clays and west of the terrigenous sediments of the Great Trough is a narrow band of *Globigerina*-rich silts and clays. Carbonate values as high as 75% result from the great numbers of planktonic and calcareous benthonic Foraminifera tests (Fig.10).

Terrigenous sediments (pebbles to clay)

Deposits of sediments varying in grain size from pebbles to clay are found on the continental shelf and parts of the slope of the northern region, and reach the deep-sea floor in the Great Trough. Lithic fragments of many kinds occur with quartz (the predominant sand size mineral), clay and varying numbers of pellets, spines, shells and tests (Fig.11, 12).

Conclusions

Further sampling (1960–1962) has not changed the pattern of these major groups. Few stations show appreciable mixing of the biogenous elements and these are at

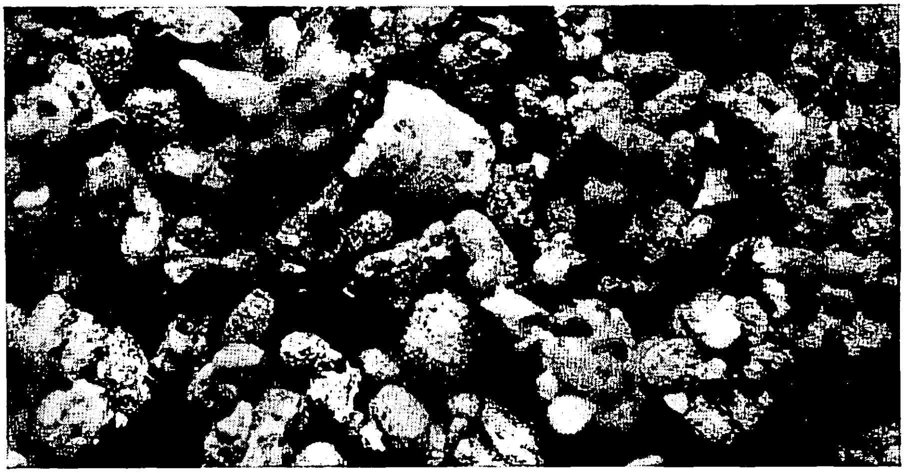

Fig.11. Photomicrograph of sediments with numerous pellets from Cascadia Abyssal Plain. (× 40)

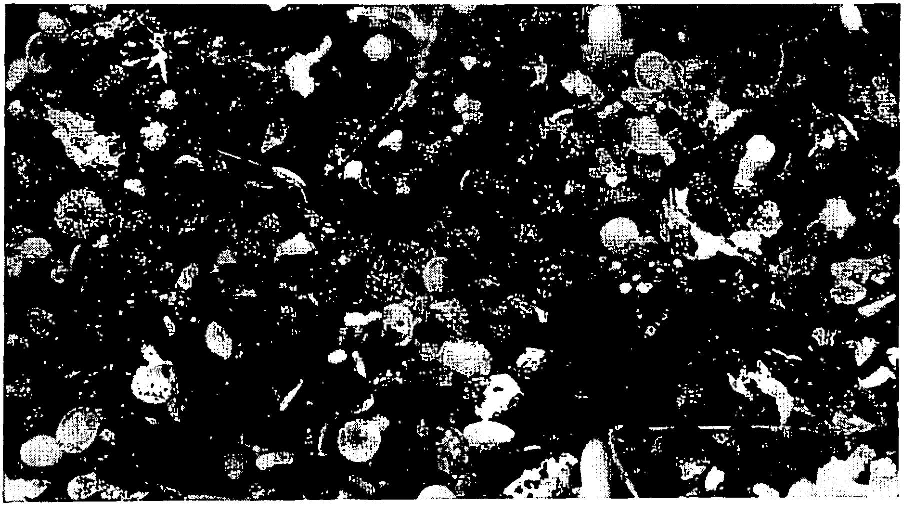

Fig.12. Photomicrograph of terrigenous sediments containing: diatoms, Radiolaria, spines, pellets. (× 40)

the common boundary of the biologically rich areas (Fig.5). Cores 202-1 and 144-10 included in the *Globigerina*-rich area have more diatoms and Radiolaria than the more southerly samples of this group. Cores 144-1, 199-5, 202-2 and 202-3 of the Radiolaria-rich area have rather abundant diatoms and a few *Globigerina*. Descriptions of the five areas and the nature of the boundaries are given below.

Although the bio-lithologic areas are based on the values of four general elements (planktonic Foraminifera, Radiolaria, diatoms and lithic content), they also differ consistently in benthonic Foraminifera content. These differences can be brought out by comparing the numbers of species designated in the various sample

TABLE II

COMPARISON OF SPECIES AMONG THREE BIO-LITHOLOGIC AREAS

	Diatom-rich area 82 species 24 restricted[1] (29% restricted)	
35 in common	ARENACEOUS SPECIES 16 species common to all	26 in common
Radiolaria-rich area 60 species 13 restricted (21% restricted)	19 in common	*Globigerina-rich area* 44 species 15 restricted (34% restricted)
	Diatom-rich area 40 species 7 restricted (18% restricted)	
10 in common	CALCAREOUS SPECIES 10 species common to all	30 in common
Radiolaria-rich area 18 species 3 restricted (16% restricted)	14 in common	*Globigerina-rich area* 140 species 95 restricted (67% restricted)
	Diatom-rich area 6 species	
2 in common	PLANKTONIC SPECIES 2 common to all	6 in common
Radiolaria-rich area 2 species	2 in common	*Globigerina-rich area* 14 species

[1] Not found in other two areas.

groups. Table II is a diagrammatic presentation based on thirteen diatom-rich, thirteen Radiolaria-rich and nine *Globigerina*-rich samples from similar bathymetric levels.

A somewhat generalized pattern of abundant calcareous and arenaceous benthonic Foraminifera was produced by SAIDOVA (1961). Portions of fig.1 and 3 of her paper are reproduced here as Fig.13. The present study would, perhaps because of differences in sampling gear and availability of samples, change some details of this figure.[1] The

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[1] Differences between SAIDOVA (1961) and this paper (Fig.5, 6, 15) in numbers of tests per gram of sample will be noted. Sample methods and calculations were different. Saidova examined 50 g of wet sediment of size coarser than 100 μ. Enbysk counted tests in material coarser than 62 μ and presents benthonic foraminiferal numbers; i.e., number of tests per gram total dry sample. Approximate comparisons may be made by considering Saidova's sample as 25 g dry weight. Water content of deep-sea samples of the region ranges from 45 to 65%.

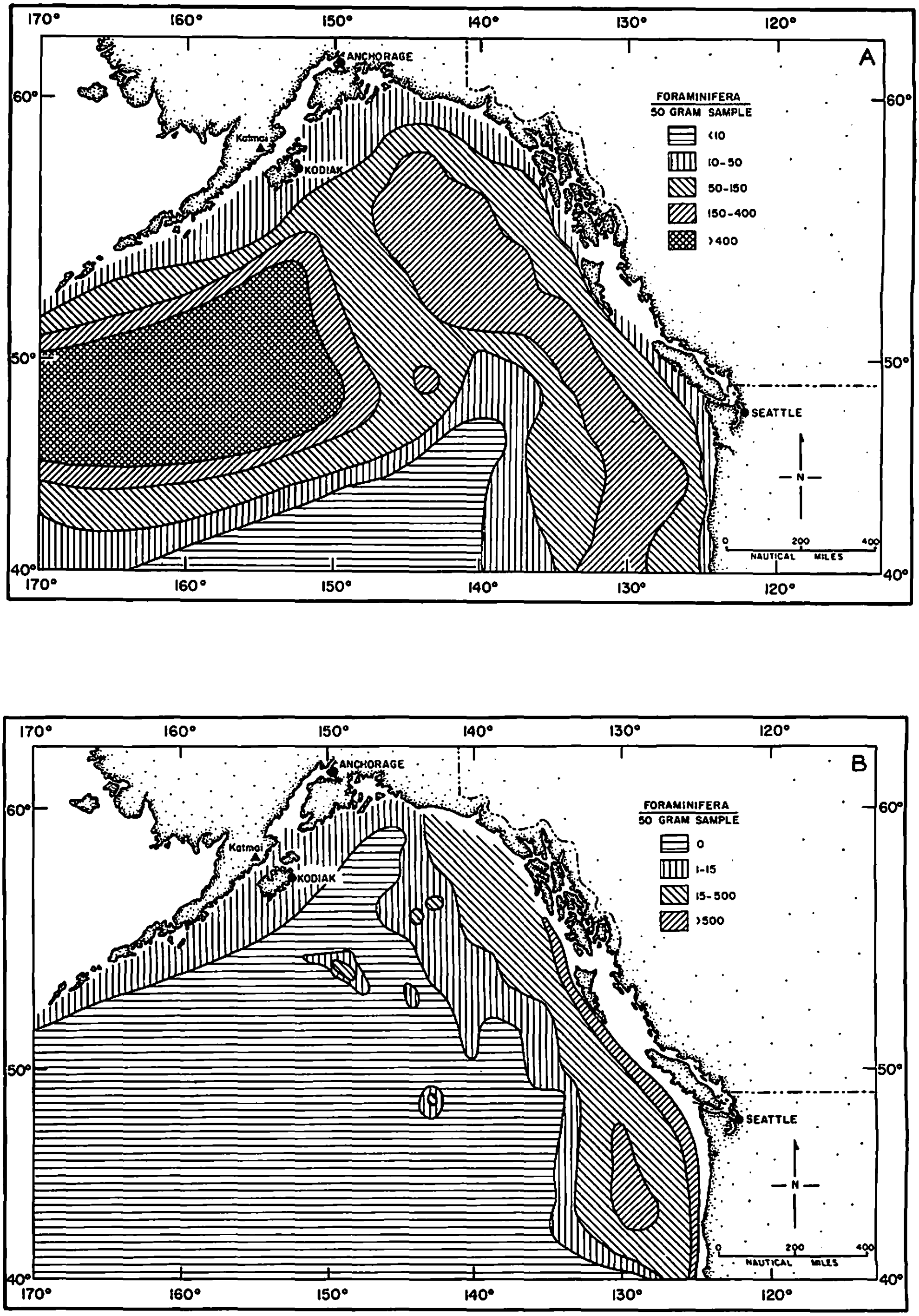


Fig.13. A. Arenaceous benthonic Foraminifera abundances. B. Calcareous benthonic Foraminifera abundances. (After SAIDOVA, 1961.)

most abundant category of the calcareous chart should probably extend around the Alaska shelf. The general coincidence of benthonic distributions and the biolithologic patterns based on planktonic and lithic elements (Fig.4) will be considered in the discussion below.

Descriptions of bio-lithologic areas

Terrigenous sediments with < 20% diatoms

The nature of the samples of this area (Fig.5) is dependent on bathymetric position for the type of Foraminifera found and on topography and surface currents for the degree of terrigenous material diluting the diatom content. The presence of Katmai ash within the area is affected by the presence or absence of burrowing animals, sediment slumping or current winnowing. Mud-feeding organisms are probable also responsible for the condition of the diatom tests preserved. In seaward traverses across this area, calcareous Foraminifera became less abundant than arenaceous below 1,000 fathoms. Below this level, arenaceous-calcareous ratios were higher than those of comparable depth in southern traverses. Many arenaceous species are stenobathic. Lagenids were mainly confined to the shelf as were miliolids and polymorphinids. Foraminifera were most abundant at shelf edge and on upper slope.

Diatom-rich area

The samples included contain over 20% diatom frustules. The area is the central northern part of the Gulf of Alaska (Fig.4, 5) which is effectively protected from terrigenous supply by the Aleutian Trench. In addition to the abundant diatoms, the sediments have the following foraminiferal faunal characteristics in common: very few *Globigerina*; absence of other planktonic genera; rare calcareous benthonic species; great numbers of arenaceous species, occasionally with great number of individuals. Radiolaria are common to rare in all samples. There is a tendency for Radiolaria to increase in numbers to the south. Certain calcareous Foraminifera groups with abyssal representatives in the other areas are absent in this area: miliolids, *Cassidulina*, polymorphinids, *Sphaeroidina* and *Chilostomella*. Many other genera are present only as one or two specimens in very few stations. Three cores have more calcareous than arenaceous individuals. Two of these (64-11, 64-14) are in the south central region and the third (64-45) lies below a seamount and has a displaced fauna. Calcareous species in greatest number of individuals are: *Pseudoeponides umbonatus*, *Epistominella exigua* and *Uvigerina auberiana*. Arenaceous species of abundant specimens are: *Ammobaculites catenulatus*, *Cyclammina cancellata*, *Haplophragmoides rotulatum*, *Reophax* cf. *Reophax gracilis*, *Saccorhiza ramosa* and *Adercotryma glomerata*. Only two planktonic species are present: *Globigerina pachyderma* and *Globigerina bulloides* (small, square-chambered form dominant).

Radiolaria-rich area

This area lies south of the diatom-rich area and west and south of the *Globigerina*-rich band 300 miles off the Washington–Oregon coast on Tufts Abyssal Plain (Fig.4, 5, 6). General paucity of all biologic groups except Radiolaria characterizes the area. Immediately south and west, the surface sediment is biologically barren.

Arenaceous Foraminifera are few but except in the southernmost samples are always more abundant than calcareous species. The most southern sample of the Radiolaria-rich group, "Carnegie" sample 62 at 2,000 fathoms, has more calcareous than arenaceous species (REVELLE, 1944). Planktonic numbers also increase. Two southern plankton not found elsewhere in the study area were reported: *Globoquadrina conglomerata* and *Pulleniatina obliquiloculata.* Sample 199-27, near the "Carnegie" sample 62, is practically barren but has more calcareous than arenaceous specimens. It is possible that although the study area was arbitrarily cut off at 40°N, a real boundary may exist related to sedimentation factors influenced by the Mendocino Escarpment and the influx of a "southern" plankton fauna.

Spinose and hispid *Uvigerina* comprise most of the meager calcareous benthonic fauna. *Cyclammina cancellata, Ammobaculites catenulatus* and *Labrospira arctica* are the most abundant arenaceous species. *Globigerina bulloides* and *Globigerina pachyderma* are the only common plankton except for those of the "Carnegie" sample mentioned above. Foraminifera are more abundant in the northern tier of samples. Radiolaria are universal.

Globigerina-rich area

The *Globigerina*-rich area is a 100-mile wide, 350-mile long band paralleling the Washington–Oregon coast some 300 miles offshore (Fig.4, 5, 6). The area includes and is wider than the north–south trending seamount chain (Fig.2). The northern boundary is based on a rather abrupt increase of diatoms in the sediments. The southern boundary is Cascadia Channel, south of the seamount chain, through which terrigenous sediments debouch on to Tufts Abyssal Plain. The eastern boundary is determined by the coast parallel depression (Great Trough) and its plankton masking terrigenous sediments. If based on planktonic Foraminifera, the 1,400 fathom line forms this boundary. It may be seen from Fig.6, that calcareous benthonic Foraminifera contribute to high carbonate content beyond the *Globigerina*-rich area. Thus the carbonate-rich band is wider than the *Globigerina*-rich band. Samples 311-50 and 199-3 on the southwest and northwest edges are somewhat anomalous in that the very topmost sections of the cores (0–2 cm) are Radiolaria-rich and immediately below are *Globigerina*-rich (the sample interval taken for the carbonate determination of sample 311-50 included this lower unit). The nature of the western and southern boundaries is particularly puzzling. Some factors involved are considered in the discussion section below.

The *Globigerina*-rich area samples are strikingly rich in plankton, as compared with the other deep-sea samples. Seven could be classified as *Globigerina* ooze as the plankton content is over 30%. All fourteen planktonic Foraminifera species recognized in this study are present in the area. Large, heavy *Globoquadrina dutertrei* are restricted to this group. The large spherical-chambered *Globigerina bulloides* is more common than the small square-chambered form. *Globorotalia hirsuta* and *Globorotalia scitula* in its larger flatter form are destricted. Radiolaria are abundant and of more varied types than in the Radiolaria-rich area. Diatoms are rare.

Calcareous benthonic forms are also more abundant here than in other deep-sea area of the northeast Pacific. As was seen in the diagram of species number comparisons (Table II) many forms are restricted to this area. Miliolids are few in number but persistent and large. *Pyrgo* is common only in this area. Many lagenid species are present but only a few specimens of each have been found. A great share of these are restricted. The most abundant genera are *Uvigerina*, *Pseudoeponides*, *Gyroidina*, *Nonion* (*Nonion affine* variants), *Bulimina*, *Planulina*, *Höglundina*, *Chilostomella* and *Sphaeroidina*. The large *Gyroidina* and *Pyrgo* are particularly noticeable in the core sections. The genus *Laticarinina* is rare in the northeast Pacific and all but one occurrence is in this area.

The number of individuals of each arenaceous species is few. The most persistent species is *Eggerella bradyi*. Many species of *Reophax* are present.

The peculiar nature of the calcareous benthonic fauna of this area with its great numbers and high degree of restrictions might suggest either an isolated or relic environment. That the living benthonic fauna is actually more abundant in the *Globigerina*-rich area could be demonstrated by comparing number of living to dead Foraminifera tests using rose bengal staining method. Unfortunately, most of the samples from the diatom-rich area were not treated for this examination, but comparison of the areas from the limited number available suggests that the living benthonic fauna is really more abundant and varied in the *Globigerina*-rich area. This is certainly true for the calcareous members. The great number of arenaceous species and individuals in the diatom-rich area may indicate a more favorable environment for that group or may reflect less masking by planktonic and calcareous forms. The Radiolaria-rich area seems to be a poor environment for all benthonic forms and may be considered as an extension of the north central Pacific barren area. The calcareous benthonic fauna of the Great Trough is quite abundant in certain samples (Fig.6) but is different in specific composition and made up of fewer species. It would seem that the *Globigerina*-rich area is actually the most favorable deep-sea living environment. Most of the species have a wide range outside the study area (Atlantic, Arctic, California coast). Genetic isolation is thus not involved in the apparent endemism.

Terrigenous sediments of Alaska coast and Cascadia Abyssal Plain

The characteristics of the Alaska coast terrigenous sediments were listed above. Extraordinarily high counts of calcareous benthonic Foraminifera (> 1500/g) were found in shelf samples. Living to dead ratios were also high suggesting both rapid lithic deposition and very favorable living sites. Other biogenic elements such as echinoid spines, mollusca fragments, ostracods and mysid statoliths are important fractions in many samples.

The Great Trough deep-sea area (Fig.6) is characterized by few planktonic Foraminifera, some of which are typically more southern forms (*Globoquadrina* *hexagona, Globigerinoides ruber)*: varying abundances of benthonics; common Radiolaria; and few readily discernible diatoms (> 62/μ). There is generally an excess supply of lithic elements over biogenic. Plankton and benthonics are usually both more abundant in the same samples, suggesting less lithic dilution rather than particularly favorable biologic environments.

Calcareous benthonic Foraminifera dominate arenaceous on eastern and western sides of the Cascadia Abyssal Plain. Only in the central area and in some channels do arenaceous become abundant. The west side benthonic fauna more closely resembles that of the *Globigerina*-rich area rather than the continental slope of comparable bathymetric position. The 1,400 fathom contour defines the *Globigerina*-rich Great Trough boundary. The line of "Trough" stations 311-60, 61, 62, seemingly bisects the *Globigerina*-rich area. At present no bathymetric evidence for an east–west channel across the seamount range exists but it is suggested by the sediments. Immediately below the surface samples (0–20 cm) the sediments have the characteristics of the *Globigerina*-rich area. Surface carbonate values remain higher than those of the central trough or continental slope.

Very few samples are available from the area of rough topography south of the Cascadia Abyssal Plain and the smoother area to the southwest. Sample 311-36 appears anomalous with its high carbonate and calcareous benthonic values. Other samples of the area fit the Radiolaria-rich category. That the southern limit of the *Globigerina*-rich area is defined by Cascadia Channel is also puzzling. In the region south of the channel one might expect a continuation of *Globigerina*-rich sediment as bathymetry, hydrographic condition and distance from shore are similar to those of the *Globigerina*-rich area.

DISCUSSION OF OBSERVED RELATIONSHIPS

The fact that recognizable areal groups are maintained within a relatively uniform geographic province was thought to be of sufficient interest to warrant attention. However, the exact combination of sedimentation and ecologic factors in operation are not yet clear. Abundances of biogenous elements which define the deep-sea bio-lithologic areas are affected by: (*1*) bottom conditions, such as sediment supply and stability, abundance and preservation of benthonic and planktonic contributions and (*2*) by the planktonic contribution available from overlying waters.

Bottom conditions

Topography

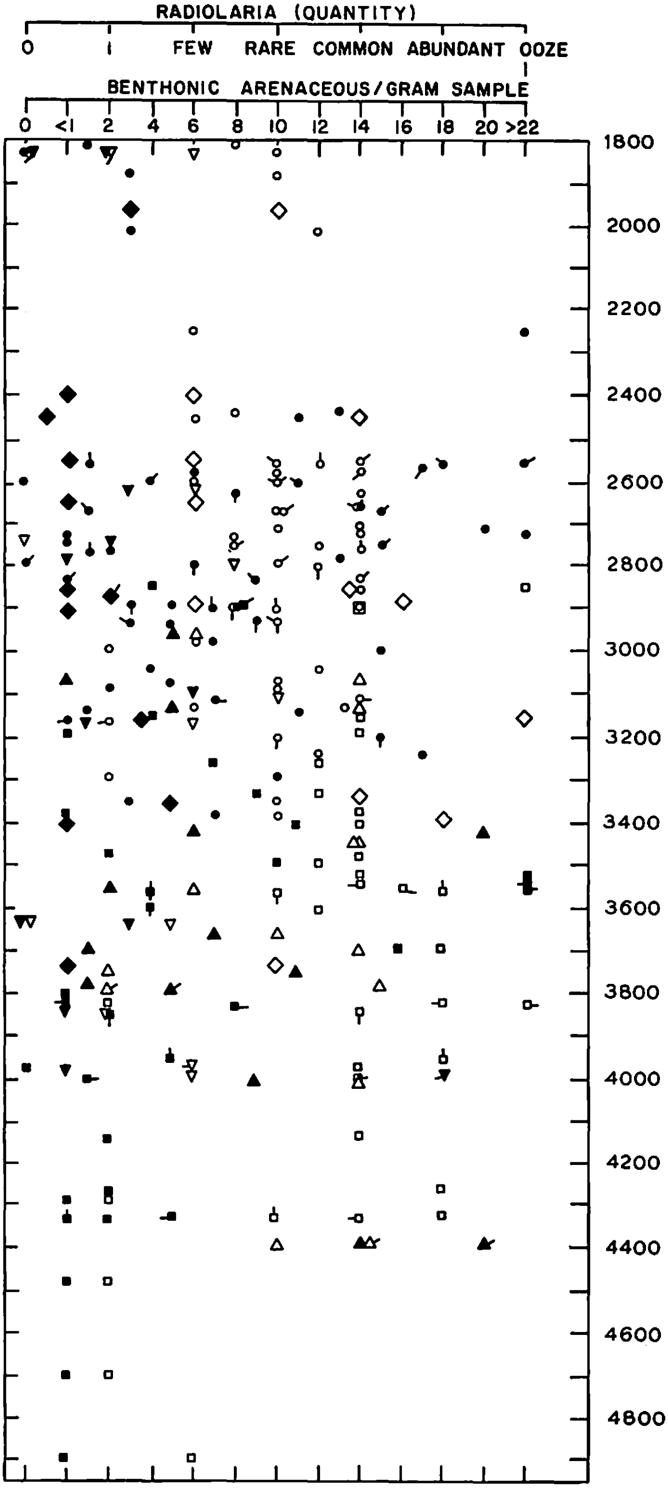
In general, the only samples containing planktonic Foraminifera in abundance are from areas effectively isolated from continental sediment deposition or from topographic highs. As was discussed above, each biologically rich area is generally protected from dilution by terrigenous elements. This is indicated by the course of the landward shape of the boundaries of the diatom-rich and *Globigerina*-rich areas (Fig.4, 6). The absence of diluting continental material in the northeastern region (cores 64-5, 6, 9, 110-1) would seem to illustrate the transporting ability of deep-sea channels and the relatively low amount of material reaching inter-channel areas. Topographic position does not explain the abundant planktonic fauna preserved in core 114-10 north of Eickelberg Ridge, and in core 202-4 on Tufts Abyssal Plain or the lack of biogenous elements south of Cascadia Channel on topographic highs. Winnowing by bottom currents would presumably remove fines with a resulting lag concentration of planktonic tests on topographic highs. Variations in trasksorting coefficient (S° 3- 10) within the *Globigerina*-rich area suggest that winnowing is not an important consideration. Bottom current measurements on the slope of Cobb Seamount had maximum velocity of 0.5 knots (E. Linger, 1963, personal communication). Downslope displacement of biologic lags from higher elevations was ruled out due to absence of displaced benthonics.

Sedimentation rates

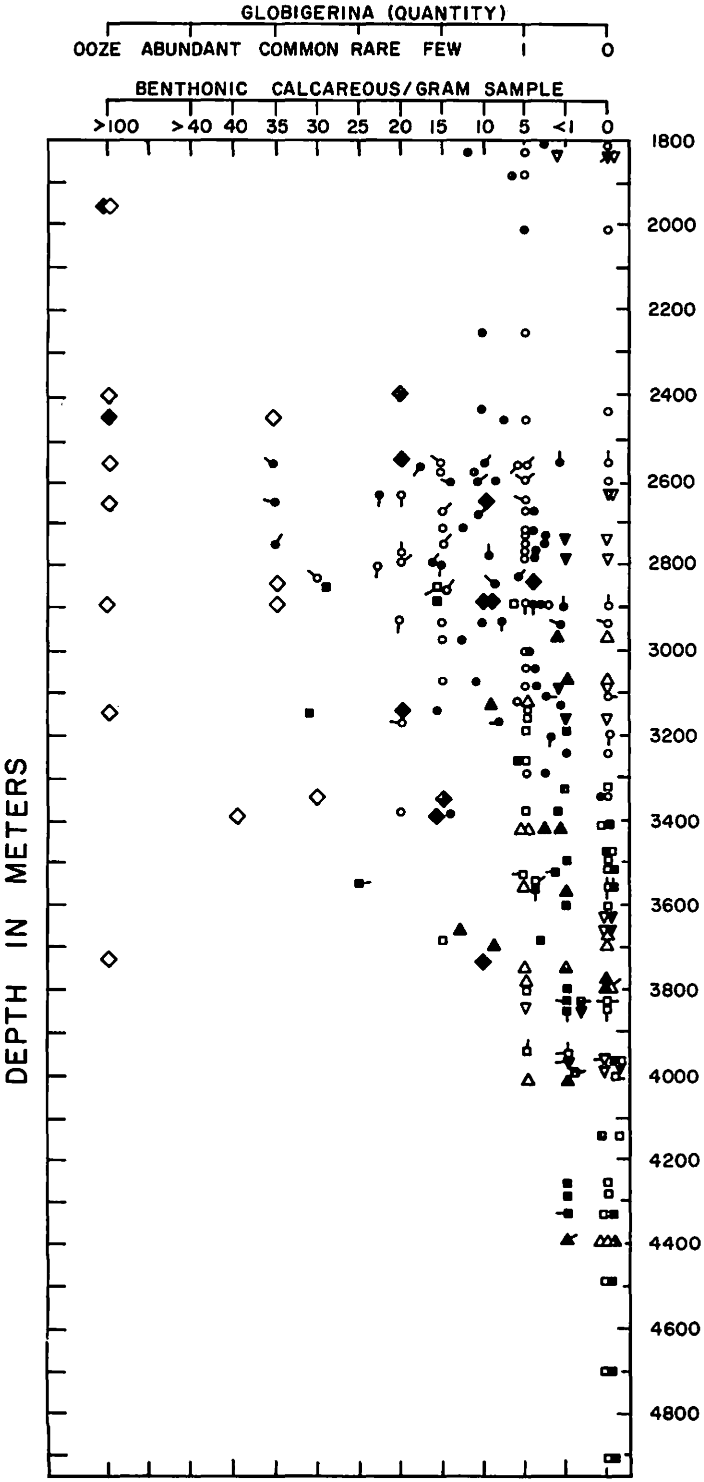
Theoretically, rapid sedimentation rates with resulting rapid burial should limit the effect of surface detritus and mud feeders in breaking up tests. In several samples from the Cascadia Abyssal Plain and the upper continental slopes of the study area, only pellets and crushed diatom tests were found. However, core 291–49 in the Great Trough with a rather high sedimentation rate (approximately 10 cm/1,000 years) contains numerous pellets associated with abundant arenaceous Foraminifera, well-preserved calcareous forms, and a high living to dead ratio. Pellets containing well-preserved calcareous Foraminifera show that passage through the animal gut is not necessarily destructive. The exact mechanism of sediment supply to a particular sample area would determine whether macrofauna destruction would be decreased or if increased food values would instead increase the possibilities of destruction by increasing the macrofauna numbers. The effect on the microfauna of rapid sediment influx would be deleterious, not only due to masking but actually from damaging of the bottom community. Precise knowledge of sedimentation rates by radio-carbon dating of various habitats, an understanding of sediment transport and an adequate record of bottom micro-topography should be necessary for a meaningful evaluation of these factors.

Fig.14. (pp.334, 335). Abundances of biogenous elements relative to depth of water.
Legend:

▼	▽	NORTHERN TERRIGENOUS AFFECTED AREA
▲	△	DIATOM-RICH AREA
●	○	GREAT TROUGH AREA
■	□	RADIOLARIA-RICH OR BARREN AREA
◆	◇	GLOBIGERINA-RICH AREA
BENTHONIC	PLANKTONIC	(124 SAMPLES FROM DEPTHS OVER 1800 METERS)



Legend see p.333.



Legend see p.333.

Sedimentation rates of the Radiolaria-rich area have not been determined. Based on color relationships discussed above, they are considered to be slow. However, movement of terrigenous sediment through the channels north and south of the seamount chain to Tufts Abyssal Plain, perhaps spasmodically, might result in masking of biogenous by lithic elements. The low benthonic fauna numbers are more probably the result of low food supply associated with distance from shore and hydrographic conditions (see below).

The deposition rate of surface unit type sediment of the *Globigerina*-rich area is approximately 2 cm/1,000 years. This is considerably slower than the rate established for the older more plankton-rich unit immediately below, but higher than the rate in the diatom-rich area (0.5 cm/1,000 years). The possibility that the *Globigerina*-rich area is a relict surface and thus not a product of present conditions is contradicted by the rather high numbers of living benthonic specimens and evident participation of the area in recent climatic change. The diatom-rich area might be considered a relict in that very little or no terrigenous material has reached the area since the deposition of large quantities of diatoms or since an ameliorated climate reduced iceberg penetration. The great diatom numbers may not result from immediate conditions, but may be due rather to slow, decelerating accumulation since the last stage of the Wisconsin, representing the last 15,000 years.

Bathymetric position

Bathymetric position is usually considered an important factor in type of benthonics present and preservation of planktonic elements. SAIDOVA (1961) found a decrease in calcareous benthonics in this region below 3,200–3,500 m, which is below the level of decrease in the northwest Pacific. A summary of the biologic character of 124 samples of the present study from below 1,800 m (Fig.14) suggests that no consistent relationship exists between bathymetric position in itself and calcareous-arenaceous ratios. Below 3,800 m, calcareous forms greatly decrease and were not found below 4,400 m. Rather more important would seem to be the bio-lithologic areal group to which the sample belongs. Although the Radiolaria-rich and diatom-rich stations were somewhat deeper than those of the *Globigerina*-rich group, all but one are in the lower abyssal range below 2,000 m (a boundary noted by many authors as significant, ZOBELL and JOHNSON, 1949; PHLEGER, 1960). Only two samples were obtained below the 4,500 m depth that is suggested as a possible limit for calcite tests preservation. There are no apparent barriers between the areas related to depth; also bottom temperatures are approximately the same. Yet there are rather striking differences in benthonic faunal composition as was indicated in Table II and in numbers of individuals (Fig.14).

Preservation of plankton relative to bathymetric position is also a factor affecting the observed patterns. The deepest sample not showing solution of *Globigerina* was 3,394 m. Below 4,005 m globigerinids were not found. Slight solution pitting was observed in two samples from the *Globigerina*-rich area at 2,844 and 3,731 m. A few tests were preserved at 3,950 m in the Radiolaria-rich area and at 4,005 m in the diatom-rich area. Selective solution of species was not detected in the comparison of bottom samples with plankton tow material. In the north Atlantic core samples, solution was most evident below 4,750 m although some striking exceptions were noted (PHLEGER et al., 1953). Constant and plentiful supply of tests to the bottom may also be an important preservation factor. Diatoms and Radiolaria would seem to be resistent within the limits of the area. The breakdown of diatom tests to clay has been suggested by several authors. Clay studies, only beginning in this region, may relate such a product to the bio-lithologic patterns established here.

It should be apparent from the above discussion that no single or evident combination of bottom conditions explains the observed patterns.

Planktonic contribution from overlying watermass

The water-mass plankton distribution determines the raw material on which the sedimentation factors can act to produce the observed bottom sediment patterns. Very few studies of zooplankton distribution have been made (BRADSHAW, 1959; SMITH, 1963). Phytoplankton and macrozooplankton have received somewhat more attention (ARON, 1962). All the observations suggest that the plankton distribution was patchy. The time involved in appreciable accumulation of tests or frustules at the bottom should cancel out such surface variations. But perhaps rather than "plankton rain" to the bottom sediments, cloudburst and drought would be better terms. Some samples have extraordinarily high numbers of young growth forms not evidently due to sorting. Patchiness might be preserved by chance over considerable lengths of time. The complications involved in this northern area due to the various times and number of plankton reproductions (or failure to reproduce by those groups living at the edge of their ranges) should produce a motley collection of skeleta for the bottom sediments. Indeed it was a source of some amazement and gratification that the broad bio-lithologic units set up for this study on the basis of fewer cores (NAYUDU, 1958, 1959a) have remained intact after further sampling.

The waters of the northeast Pacific are generally characterized as high in Radiolaria and diatoms and low in planktonic Foraminifera. SMITH (1963) studied *Sarcodina* distributions from plankton tow samples, between 40°–52°N, east of 140°W. Almost all 155 stations had Radiolaria in varying abundances and only 52 had Foraminifera. The ratio of Radiolaria to *Globigerina* available to the bottom sediments is even higher than would be indicated from the tow samples as various Radiolaria live at great depth or just above the bottom (the Radiolaria in the bottom samples have not been identified so their former position in the water column is unknown). Diatoms were relatively rare in these tow samples. G. Anderson (1963, personal communication) found extremely low productivity values in waters overlying the western portion of the Cascadia Abyssal Plain and in the *Globigerina*-rich area. SMITH (1963), however, found that the area of greater numbers of *Globigerina* in tow samples coincided with the *Globigerina*-rich area. A traverse northwest off Washington across the Gulf of Alaska (SMITH, 1964) showed a more abundant fauna north of 50°N decreasing again toward the central Gulf.

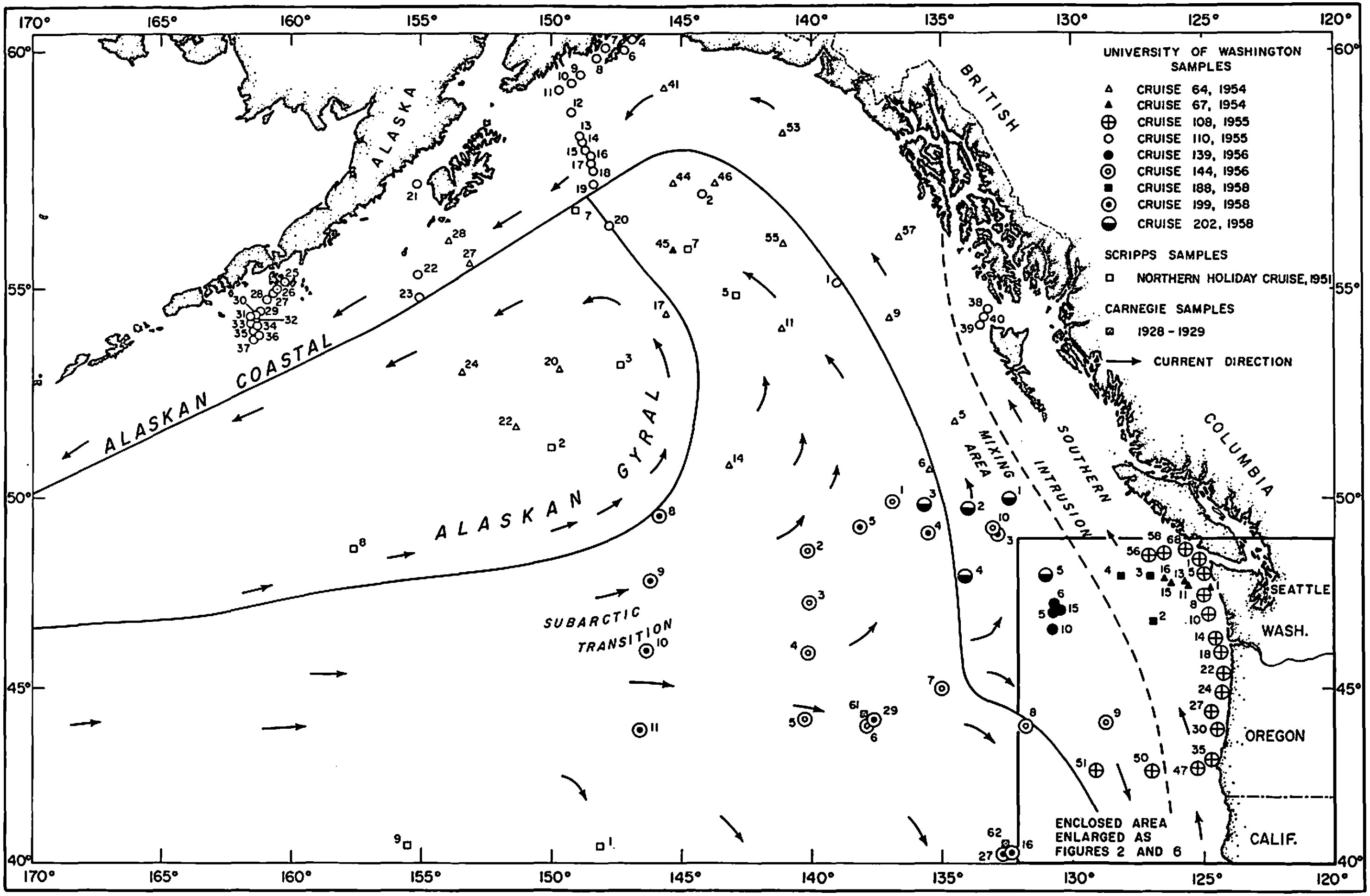
Within the temperate area of the study, the usual combination of cold water, few species, and many specimens is not always evident. Sea surface temperatures are effective in limiting certain species but seemingly do not explain the difference in number of specimens. The highest numbers of planktonic Foraminifera of the BRADSHAW study (1959) were found between the 10°–20°C isotherms in the northwest Pacific between 160°W and 150°E. Within this same thermal range in the northeast Pacific, Foraminifera are much less abundant. Plankton tow samples from the eastern Gulf of Alaska north of 52°N were not taken by Bradshaw, but from the few plankton observations mentioned above it is evident that *Globigerina* are not as abundant either in number or kinds in the central Gulf of Alaska and Cascadia Abyssal Plain. Radiolaria show less decrease and they generally prefer temperate mid-latitudes. Diatoms are a common element. Also within this same 10°–20° temperature range the number of planktonic Foraminifera species increases in Bradshaw's "transition zone" (south of 48°N).

Bradshaw also related the abundance of planktonic Foraminifera to phosphate supply. This is not a wholly satisfactory explanation as abundances do not exactly follow phosphate concentration. The previously mentioned high Foraminifera production in the northwest Pacific coincides with high phosphate values (1.5 µg-at/l) but the lower Foraminifera production and high diatom numbers in the Gulf of Alaska are still within a high range (1.0 µg-at/l) of concentration. This same phosphate value is found farther south in an area which has somewhat more abundant Foraminifera and fewer diatoms. Both complex biologic and historical factors must be considered in seeking an explanation. The close relationship of observed distribution patterns with current patterns contrasted with the generally poor matching with specific temperature, salinity and phosphate boundaries suggests that the individual water masses of the area constitute ecologic units in themselves.

The most important feature of the present study is the significant parallelism between the distribution of bio-lithologic elements on the ocean floor and major surface currents. The Subarctic Current centered about 40°N flows west–east. As it approaches the American coast, it splits into the northward deflected Alaskan Gyral and a southward deflected (California) Current. The latitude at which this apparent split occurs is approximately 50°N in summer and about 45°N in winter (FLEMING, 1955). In addition, there is some seasonal influence of the north-setting Davidson current, near the U. S. coast (Southern Intrusion of Fig.15).

The coincidence of current pattern (Fig.15) with distribution pattern of diatoms, Radiolaria, and *Globigerina*-rich sediments (Fig.4, 5) suggests that the type of plankton supplied to the bottom is related to the major currents of the area. The outer edge of the Alaskan Gyral overlies the diatom-rich area and the inner portion defines the

Fig.15. Core positions and natural oceanographic areas. (After FLEMING, 1955, 1958.)


UNIVERSITY OF WASHINGTON SAMPLES
△ CRUISE 64, 1954
▲ CRUISE 67, 1954
⊕ CRUISE 108, 1955
○ CRUISE 110, 1955
● CRUISE 139, 1956
◎ CRUISE 144, 1956
■ CRUISE 188, 1958
⊙ CRUISE 199, 1958
◒ CRUISE 202, 1958
SCRIPPS SAMPLES
□ NORTHERN HOLIDAY CRUISE, 1951
CARNEGIE SAMPLES
⊡ 1928 - 1929
→ CURRENT DIRECTION
ALASKA
BRITISH COLUMBIA
ALASKAN COASTAL
ALASKAN GYRAL
SUBARCTIC TRANSITION
MIXING AREA
SOUTHERN INTRUSION
SEATTLE
WASH.
OREGON
CALIF.
ENCLOSED AREA ENLARGED AS FIGURES 2 AND 6
170°
165°
160°
155°
150°
145°
140°
135°
130°
125°
120°
60°
55°
50°
45°
40°

glacial marine remnant area. Highest productivity values in surface waters were obtained south of the Aleutian chain (50°–53°N; 155°–165°W). It is possible that the diatom tests might be swept around to the east to the diatom-rich area where, due to lack of terrigenous sediment, they would form the major contribution to the bottom deposits.

The Radiolaria-rich area underlies the southern branch of the Subarctic Current and the region which in winter is the apparent division of north and south branches. The southern extension of this current coincides with the sharp southern boundary of the *Globigerina*-rich area which had no basis in topographic considerations. The mixing area (Fig.15) coincides with the *Globigerina*-rich area and the Cascadia Abyssal Plain underlies the southern intrusion.

Data gathering for the discrimination of currents and water masses by their biologic content is only beginning in the northeast Pacific. ARON (1962) gives a summary of previous work and relates macroplankton of his study to the major oceanographic divisions of the region. Foraminifera have been used in the south Atlantic for this purpose with considerable success (BOLTOVSKOY, 1959). Certain species or groups characterize water masses previously distinguished by hydrographic data. Such persistent associations would allow each recognizable water mass to be considered as an isolated three-dimensional environment with an individual biologic history. Thus the abundance or absence of a biologic group could not be totally explained by its relation to a specific ecologic factor or group of factors such as salinity, temperature, etc., or geographic position, but rather as the result of its historical development within a water mass. An initial chance advantage provided to a group in the past may be perpetuated under less than ideal ecologic conditions.

No single ecologic factor or combination seems to explain the observed patterns. An admonition in applying the surface sediment data to core interpretation in this area is offered. Changes in biologic types in various core intervals at depth need not necessarily imply great widespread changes in salinity, temperature, etc. The change may be either greater or less than is reflected in bottom sediments; i.e., the group survives beyond its normal limits having become established in the water mass, or slight current changes may give immense advantage to a fringe area group. These possibilities are particularly troublesome in this temperate or transition area.

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