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STRATIGRAPHIC CORRELATION AND INTERPRETATION OF EXPLORATORY WELLS, ALASKA PENINSULA

by

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Introduction

The Alaska Peninsula has been the site of extensive oil and gas exploration since the early years of the twentieth century. This exploration includes both surface geologic studies and the drilling of exploratory wells. Attention was first directed to the area by the presence of oil seeps and the thick well-exposed sedimentary rock sequence. Twenty six exploratory wells have been drilled on the Alaska Peninsula, and one off-shore (North Aleutian Shelf-Cost #1) is included here (Fig. 1, Table 1). Most encountered a show of oil and/or gas, but to date none are considered commercial and all have been plugged and abandoned.

The U.S. Geological Survey started investigations of the exposed strata on the Alaska Peninsula about the same time as the exploratory drilling. These early investigations include reports by Atwood (1911); Dall (1896); Martin (1904, 1905); Smith (1925, 1926), and Smith and Baker (1924). The first modern study of the Alaska Peninsula, south of Wide Bay, was by Burk (1965). Burk's report was the foundation for the recent U.S. Geological Survey studies on the peninsula.

Between 1977 and 1988 the U.S. Geological Survey conducted a series of investigations on the Alaska Peninsula as part of the Alaska Mineral Resource Assessment Program (AMRAP). These investigations added considerable lithologic and paleontologic data for the peninsula, including detailed measurement and sampling of 40 stratigraphic sections, collection of 1,128 megafauna and 98 megaflora samples, and the addition of about 200 K-Ar dates for the intrusive and extrusive igneous rocks. As a result of this new data, a series of maps and reports have been published or are in the process of publication; these include Detterman and others 1981a, b, c, 1985, 1987a, b, 199_ (in preparation); Detterman and Miller, 1987; Riehle and others, 1987; Wilson and others, 199_ (in preparation).

The new data indicated that some major changes were needed in the published correlations for some of the wells (Brockway and others, 1975); atleast three wells (11, 19, and 21) have repetition of

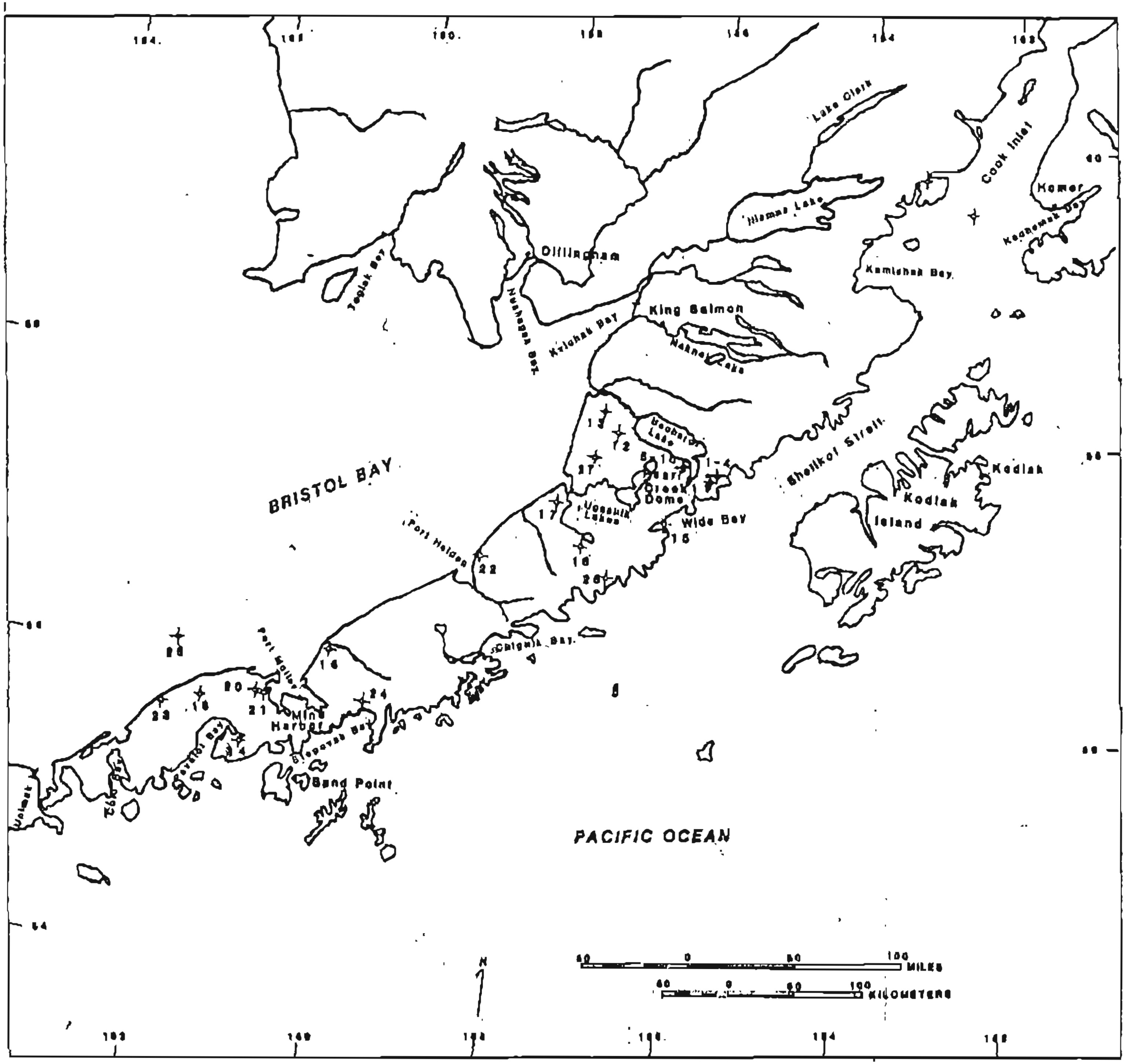


Figure 1. Exploratory wells drilled between 1903 and 1988

Table 1. Data on exploratory Wells drilled for petroleum on the Alaska Peninsula.

Number	Well	Company	Year	Location		Depth	Formation
1	Pacific Oil #1	Pacific Oil & Commercial	1903	NW 1/4 Sec.3, T.29S., R.40W.		1,421	Shelikof
2	Costello #1	J.H. Costello	1903	NW 1/4 Sec.10,	do.	728	Do.
3	Pacific Oil #2	Pacific Oil & Commercial	1904	SE 1/4 Sec.3,	do.	1,542	Do.
4	Costello #2	J.H. Costello	1904	SE 1/4 Sec.10,	do.	unknown	Unknown
5	Lathrop #1	Standard Oil of Calif.	1923	SE 1/4 Sec.17, T.29S., R.43W.		500	Naknek
6	Finnegan #1	Tidewater Associated	1923	NE 1/4 Sec.30,	do.	560	Do.
7	McNally	Standard Oil of Calif	1925	NW 1/4 Sec. 29,	do.,	510	Do.
8	Lee #1	do.	1926	SW 1/4 Sec.20,	do.	5,034	Unknown
9	Alaska #1	Tidewater Associated	1926	SW 1/4 Sec.20,	do.	3,033	Shelikof
10	Grammer #1	Standard Oil of Calif.	1940	SE 1/4 Sec.10, T.30S., R.43W.		7,596	Unknown
11	Bear Creek #1	Humble-Shell	1959	NE 1/4 Sec.36, T.29S., R.41W.		14,375	Kamishak
12	Great Basins #1	General Petroleum	1959	SW 1/4 Sec.2, T.27S., R.48W.		11,080	Batholith
13	Do.#2	do.	1959	SE 1/4 Sec.35, T.25S., R.50W.		8,865	Do.
14	Canoe Bay #1	Pure Oil	1963	NE 1/4 Sec.8, T.54S., R.78W.		6,642	Hoodoo
15	Wide Bay #1	Richfield et.al.	1963	NW 1/4 Sec.5, T.33S., R.44W.		12,568	Kamishak
16	Sandy River Federal #1	Gulf Oil	1963	SE 1/4 Sec.10, T.46S., R.70W.		13,068	Stepovak
17	Ugashik #1	Great Basins	1966	SE 1/4 Sec.8, T.32S., R.52W.		9,476	Meshik
18	Painter Creek #1	Cities Service	1967	NW 1/4 Sec.14, T.35S, R.51W.		7,912	Shelikof
19	David River #1 and 1A	Pan American	1969	SW 1/4 Sec.12, T.50S., R.80W.		13,769	Do.
20	Hoodoo Lake #1	Pan American-Standard of Calif.	1970	NE 1/4 Sec.21, T.50S., R.76W.		8,049	Do.
21	Do. #2	do.	1970	NE 1/4 Sec.35,	do.	11,243	Do.
22	Port Heiden #1,	Gulf Oil	1972	SE 1/4 Sec.20, T.37S., R.59W.		15,015	Batholith
23	Cathedral River #1	AMOCO Production	1974	SE 1/4 Sec.29, T.51S., R.83W.		14,301	Kamishak
24	Big River #1A	Phillips Petroleum	1977	SW 1/4 Sec.15, T.49S., R.68W.		11,371	Naknek
25	Koniag #1	Chevron USA	1981	SW 1/4 Sec.2, T.38S, R.49W.		10,900	Kamishak
26	North Aleutian Shelf	Consortium	1983	56°16'99"N., 161°58'34.37W.		17,155	Tolstoi
27	Becharof State #1	AMOCO Production	1985	NW 1/4 Sec.10, T.28S., R.48W.		9,023	Unknown

section due to thrust faulting. Also, stratigraphic contacts can now be made with greater confidence. This new information will be of value to any future investigation for organic fuels on the Alaska Peninsula and offshore areas. Data for 14 of the 17 wells drilled since 1959 are shown on the accompanying charts (plates 1 and 2). Three wells, Great Basins Ugashik #1, General Petroleum Great Basins #2, and AMOCO Production Becharof State #1, were not available.

Early Drilling

Exploratory drilling has been cyclic with the first cycle starting in 1903 and 1904 when the Pacific Oil and Commercial Company and J.H. Costello each drilled two wells along Bear Creek anticline (Figure 1) between Puale and Portage Bays (Martin, 1904, 1905). The wells were drilled near oil seeps on Oil Creek, and along the crest of the Bear Creek-Wide Bay anticline. Data on the rocks encountered is not available other than what was described by Martin (1904, 1905). The wells started in Shelikof Formation (Middle Jurassic) and probably were still in the formation at total depth (Figure 2). The deepest was only 1,542 feet (470 m). Drilling was done by cable-tool rig. Some rusting machinery is still present in the area, but the actual well sites are difficult to locate.

The second cycle of drilling started in 1923 when Standard Oil of California and Tidewater Associates started drilling on Pearl Creek Dome. Pearl Creek Dome is an uplifted segment of Ugashik anticline (Detterman and others, 1987a) about 3 miles southeast of Ugashik Crater. The doming was probably caused by the injection of magma at considerable depth. Six wells were drilled on this structure between 1923 and 1940, with most drilled between 1923 and 1926.

Bedrock on Pearl Creek Dome is all part of the Northeast Creek Sandstone Member and Chisik Conglomerate Member of the Naknek Formation (Detterman and others, 199_). Lava from Ugashik Crater and Mount Peluk overlies the sedimentary rocks on the northwest part of the structure. The Shelikof and Kialagvik Formations underlie the Naknek Formation, and were penetrated by some of the wells. The dome is cut by a number of small faults with maximum displacement of about 200 feet. Several oil seeps are present, most are along fault traces. All known seeps are discussed by Blasko (1976). The residue at most seeps is a black tar-like substance that would indicate the seeps

Stratigraphic Unit	23	26	19	21	20	14	24	16	22	17	18	25	15	11	4	3	1	2	5	6	8	7	9	10	12	13	27
Milky River Formation		X	X	X	X			X	X	X															X	X	X
Bear Lake Formation		X	X	X	X			X	X	X															X	X	X
Stepovak Formation		X	X2	X2	X		X	X																			
Meshik Volcanics							X		X	X	X																?
Tolstoi Formation		X	X	X			X				X														X	X	?
Hoodoo Formation						X																					
Chignik Formation			X	X			X				X																
Herendeen Formation				X			X																				
Staniukovich Formation				X			X																	?			
Naknek Formation																			X	X	X	X	X	X	X		
Indecision Creek Sandstone Mbr.																											
Snug Harbor Siltstone Mbr.	X						X					X															
Northeast Creek Sandstone Mbr.	X						X				X	X															
Chisik Conglomerate Mbr.											X																
Shelikof Formation	X										X	X		X	X	X	X	X			?		X	X			
Kialagvik Formation	X											X	X	X2	?									?			
Talkeetna Formation	X											X	X	X2													
Kamishak Formation	X											X	X	X													
Batholith									X																X	?	

X2-indicates unit repeated by faulting. ?-Stratigraphic unit probably present.

Figure 2. Stratigraphic units encountered in exploratory wells, Alaska Peninsula

were no longer active. Globs of bright green fresh oil were seen on Blue Creek. The actual seep was not located, but apparently at least one seep is still active. A more complete description of the geology of Pearl Creek Dome is contained in Smith (1926, p. 85-88), and Smith and Baker (1924).

Six wells were drilled on Pearl Creek Dome. The deepest, drilled by Standard Oil of California, reached a depth of 7,596 feet (2,315 meters). Unfortunately drilling records of the rocks encountered have not been made available. All wells were on the northwest flank of Mount Demian and started in the lower part of the Naknek Formation, and the deeper wells should have drilled through the underlying Shelikof Formation and probably into the Kialagvik Formation. Unfortunately, the best reservoir rocks are in the Naknek Formation that are exposed at the surface and within a few hundred meters of the surface. The underlying Shelikof Formation does contain thick units of sandstone and conglomerate locally, but these coarse grained rocks are volcaniclastic and diagenetic alteration has generally filled most pore space. Without well data it is impossible to determine the character of the rocks drilled, but all wells are plugged and abandoned so the results probably were not encouraging.

Recent Drilling

The main purpose of this discussion is to describe some of the results of the third cycle of exploratory drilling that started in 1959. Seventeen wells were drilled on the Alaska Peninsula and offshore in Bristol Bay between 1959, and 1985 (Fig. 1 Table 1). Lithologic details and stratigraphic breakdown are provided for 14 of the 17 wells competed. Lithologic data was obtained from the mud logs for each well, and a study of the available ditch samples and cores. Samples for most wells are stored at the Geologic Materials Center, Eagle River, Alaska. The amount and type of data on the logs was highly variable, and dependent on the ability of the person doing the logging to discriminate various rock types. Electric logs and stratigraphic correlations for some of the wells have been published (Brockway and others, 1975), and the organic geochemistry and paleontology for several of the wells were published by McLean (1977, 1979).

The wells on the Alaska Peninsula are numbered consecutively by completion date (Fig. 1, Table 1) and discussed from south to north. The only offshore well included is the Cost #1 well, number 26 on the index map showing exploratory wells.

AMOCO Production Company-Cathedral River #1

Cathedral River #1 (well 23, plate 1) exploratory well was spudded June 20, 1973, and completed August 13, 1974. The well is located 0.6 mile (1 km) from the Bristol Bay coast in Sec. 29, T.51S., R.83W., Cold Bay C-1 quadrangle, and is 14,301 feet (4,358.9 m) deep. The well, drilled on the northwest slope of Black Hill, starts in the Snug Harbor Siltstone Member of the Naknek Formation and penetrates a thick Mesozoic sequence.

The Black Hills area contains the southernmost exposures of Naknek Formation and may possibly be part of a fault black, but this cannot be proven by the well which starts in about the middle of the Snug Harbor Siltstone Member and continues through the Northeast Creek Sandstone Member. The lowermost Chisik Conglomerate Member is missing from this well probably due to erosion as the contact between the Naknek Formation and the underlying Shelikof Formation is considered to be unconformable. The upper part of the Snug Harbor Siltstone Member and the overlying Indecision Creek Sandstone Member are exposed at the surface in the vicinity so that a nearly complete section of Naknek Formation is present in the Black Hills area.

Depositionally the Naknek Formation at this locality represents a regressive, transgressive, regressive sequence. The exposed section of Indecision Creek Sandstone was deposited about middle shelf during a minor regression. This followed a transgression during the time the Snug Harbor Siltstone Member was deposited in a deeper outer shelf environment. The underlying Northeast Creek Sandstone Member represents a major regression and was deposited in a near shore to subaerial environment. Thick sandstone units are common and most are oil stained. Pebbles are common near the base which is considered to be unconformable on the underlying Shelikof Formation.

Siltstone and shale in the upper part of the Shelikof Formation were deposited during a minor transgression that had followed several minor fluctuations of sea level when the lower part of the formation was deposited. Oil staining is common in the sandstone . One unit of tuff indicates some nearby volcanic activity. A brown weathered zone at the top of the underlying Kialagvik Formation suggests a period of subaerial erosion between deposition of the Shelikof and Kialagvik.

The Kialagvik Formation is mainly a shelf deposit at this locality. Minor fluctuations of sea level are recorded, but the abundance of fossils recovered during drilling suggest mostly an inner shelf environment. Tuffaceous and bentonitic material are more abundant downward and represents the waning phase of volcanic activity that was present during Early Jurassic time when the Talkeetna Formation was deposited.

The Talkeetna Formation and the underlying Kamishak Formation (Upper Triassic) were deposited in moderately deep water at a considerable distance from land. Chert is abundant in the Triassic beds, but it is not known if this represents primary deposition or secondary replacement. Tuff and bentonite are abundant throughout the Talkeetna Formation, but the source was not nearby.

Sandstone in the upper 8,500 feet (2590 m) of the Cathedral River well is commonly oil-stained indicating the presence of oil. McLean (1977) collected cuttings from this interval for organic carbon content. He reports (1977, p. 9) that the organic carbon content is low, averaging 0.20 percent. Samples below 8,500 feet were contaminated with drilling mud, but did average slightly higher, 0.68 percent organic carbon. Diagenetic alteration of mineral grains has undoubtedly reduced pore space in sandstone beds, but none the less, the sandstone of the Northeast Creek Sandstone Member of the Naknek Formation has to be considered prospective for the production of oil as it contains thick, well-sorted, clean sandstone with only slight diagenetic alteration products. Also, oil staining indicates some porosity.

North Aleutian Shelf COST #1

Recently published data on the North Aleutian Shelf COST No. 1 well (Turner and others, 1988, well 26, plate 1) contains abundant data that has a direct bearing for the petroleum potential of the Alaska Peninsula, as well as the North Aleutian Shelf area. The COST No. 1 well is located approximately 33 miles (53 km) northwest of the Pan American-David river well on the Alaska Peninsula. The David River well penetrated the same stratigraphic sequence that was encountered in the COST No 1 and a direct correlation can be made between the two wells (Plate 1). Turner (1988) did not make a direct correlation with stratigraphic units on the Alaska Peninsula, as most of our recent data that makes the correlation possible was unpublished at the time of their compilation. There are facies changes between the two wells as would be expected over a distance of 33 miles. Most of the difference in facies is restricted to the Miocene and Pliocene sequence when the Alaska Peninsula was being established in essentially its present form and was the source for sediments. Sediments for this time interval on the Alaska Peninsula are mainly inner-neritic to nonmarine whereas at the COST No.1 site the strata were deposited in a middle- to outer-neritic environments. The lithology and depositional environment for the Oligocene to Eocene sequence in the COST well (Lynch, 1988) closely correlate with the Stepovak and Tolstoi Formations on the Alaska Peninsula (Detterman and others, 199_). A notable exception is the paucity of reported tuff in the COST well, which is surprising considering its proximity to the Alaska Peninsula.

The biostratigraphy and paleobathymetry for the COST well was obtained mainly from diatoms, foraminifera, calcareous nannofossils, and palynomorphs (Larson, 1988, p. 159). Megafauna and megaflora were of minor value for age determinations offshore, but onshore the megafauna and flora along with K-Ar dates represent the basis for age determinations. Nonetheless, the overall age range is in close agreement between onshore and offshore sequences, but the onshore stratigraphy cannot be as finely divided as is possible with the OCS stratigraphy.

Data on organic geochemistry of the OCS well (Flett, 1988), p. 184) is of primary importance not only to exploration on the outer continental shelf, but for the Alaska Peninsula as well, where data on amount and type of organic carbon is sparse. The total organic carbon (TOC) of the COST well is erratic (Flett, 1988) ranging from less than 0.1 percent to a high of 50 percent. Most is vitrinite and inertinite produced by the many coal layers encountered and is not considered productive for petroleum. Amorphous organic carbon of the type conducive for the formation of liquid hydrocarbons is present below 16,020 feet (Flett, 1988); this would be equivalent to the lower shaly part of the onshore Tolstoi Formation. The TOC for the interval below 16,020 ranges between 1 and 10 percent, which is well above the minimum of 0.5 percent generally considered necessary for the generation of petroleum (Tissot and Welte, 1984). Thermal maturation of the organic carbon is essential to the formation of petroleum, and this is dependent on the thermal gradient of the well site which in turn is dependent on depth of burial and on other heat sources such as nearby igneous bodies. A common method of determining the thermal maturity of the organic carbon is by vitrinite reflectance (Ro). Ro values between 0.6 and 1.3 are generally considered the range for the formation of liquid hydrocarbons (Tissot and Welte, 1984). Thermal maturity for the generation of liquid hydrocarbons, as based on the Ro values, was reached at a depth of 12,600 feet in the COST well (Flett, 1988); this is in rocks equivalent to the onshore Tolstoi Formation. The nearest exploratory well on the Alaska Peninsula for which data on Ro is available is the Pan American-Hoodoo Lake #2, about 57 miles (92 km) southeast of the COST well. The oil generating window in the Hoodoo Lake #2 starts about 6,300 feet (1,920 m) (McLean, 1977). This depth is one half of the depth determined for the COST well. Several factors may be responsible for the reduced depth to the oil generating point in the Hoodoo well; among them may be: 1) proximity of a buried igneous body; 2) greater depth of burial that was subsequently reduced by erosion, or 3) most likely heat generated by thrust faulting as the Hoodoo #2 well is in a thrust fault block. Regardless of the cause, the rocks at both well sites are of approximately the same geologic age (Middle Eocene Tolstoi Formation) and should be considered potential source beds.

The Pliocene Milky River Formation and the Late Miocene Bear Lake Formation at both the COST well and on shore Alaska Peninsula have little source bed potential. Organic carbon is mainly coaly vitrinite and inertinite with low potential for liquid hydrocarbons and in both onshore and offshore areas has not reached to oil generating point. The Oligocene and Eocene rocks (Stepovak and Tolstoi Formations) have both the organic carbon content and depth of burial for the formation of gaseous hydrocarbons; this is equally true for both onshore areas and the OCS area. Data for the underlying Cretaceous rocks is not available, but they should be considered to have potential as cursory surface observations indicates the organic carbon is present and the depth of burial would be sufficient. Jurassic rocks in most cases are probably over mature, but in the right structural setting could be reservoir rocks as they contain much less volcanic debris to be diagenetically altered with attendant reduction of porosity and permeability.

Pan American-David River #1 and #1A

The lithology shown is for David River 1A (well 19, plate 1) spudded November 6, 1968 and completed July 31, 1969, in Sec. 12, T.50S., R.80W., Port Moller D-5 quadrangle. The well is located on glacial moraine 5 miles (8 km) inland from the Bristol Bay coast, and 2.5 miles (4 km) north of David River, it was drilled to a depth of 13,769 feet (4,197 m).

Our interpretation of the stratigraphic sequence drilled in this well is considerably different than that in the original published data (Brockway and others, 1975), and also McLeans (1977). We differ not only in the placement of formational contacts, which we believe more closely represent the stratigraphic units as we now interpret them, but more importantly in picking a thrust fault at 12,575 feet (3,832 m) that partially repeats some of the uphole sequence. Major low-angle thrust faults have been mapped in the Port Moller area (Wilson and others, 199_), and this fault is the subsurface expression of another thrust fault, probably also low-angle. The vast amount of data collected during recent field work on the Alaska Peninsula permits this revision of the stratigraphic sequence in this well.

The David River #1A well is located on glacial moraine of the Brooks Lake glaciation (Detterman, 1986), and we interpret these deposits to extend to 680 feet (207 m) where they unconformably overlie Milky River Formation. The Milky River Formation in turn unconformably overlies the Bear Lake Formation at 1,870 feet (570 m). The Milky River Formation is easily discriminated from the underlying Bear Lake Formation by the preponderance of volcanic clasts and the general paucity of volcanic debris in the Bear Lake Formation (Detterman and others, 199_). Both Milky River and Bear Lake Formations are thin compared to exposures at Port Moller, about 25 miles (40 km) to the east. The lithology is similar to the basal part of the exposed sections for both units, suggesting the upper part of both formations was removed by erosion. The Milky River Formation is a fluvial deposit, and the Bear Lake is shallow marine. Both are poorly indurated and no oil residue was noted. The Bear Lake unconformably overlies the Stepovak Formation at 3,270 feet (996 m). The Stepovak Formation is mainly a subaerial deposit that includes several minor marine incursions. The sandstones are volcanogenic which is characteristic of the formation (Detterman and others, 199_). Coal and carbonaceous material are fairly common throughout, as are tuff and bentonite. The contact at 7,200 feet (2,195 m) with the underlying Tolstoi Formation is conformable. Coal and carbonaceous shale increase downward through the Tolstoi Formation along with thick shale and sandstone units suggesting a fluctuating shallow marine to nonmarine environment similar to exposures of the formation at Pavlof Bay. McLean (1977) reported early to middle Eocene palynomorphs from well cuttings through this interval in the David River #1A well; this corresponds to the age of rocks at Pavlof Bay based on mollusks (Marincovich, 1988).

A pronounced change in lithology at 11,640 feet (3,548 m) is considered the contact with the Chignik Formation. The calcareous gray sandstone with a few chert pebbles is characteristic of the Chignik Formation.

A radical change in lithology occurs at 12,575 feet (3,833 m) with the well penetrating a volcanoclastic sequence with abundant tuff and bentonite. A sticky clay at the contact is interpreted as a fault surface and the rocks below the surface are considered part of the Stepovak Formation. Another possibility exists, that is the underlying rocks are Talkeetna Formation. This would mean that nearly 12, 000 feet (3,658 m) of section (Naknek, Shelikof, and Kialagvik Formations were removed between the David River well site and the Cathedral River well, a distance of less than 30 miles (48 km) in low-dipping strata. Additionally, the volcanoclastic sediments are unlike the Talkeetna rocks in the Cathedral well.

The David River exploratory well contained very little evidence for the generation of petroleum. Slight staining in a few sandstone intervals was recorded on well log in the Stepovak and Tolstoi Formations. In general the rocks are probably immature and additionally they contain only scattered herbaceous material. Also, the well is cut off from mature source rocks by the thrust fault. A deep test might penetrate oil-saturated rocks in the block below the thrust fault.

Pan American-Standard of California-Hoodoo Lake #1

The Hoodoo Lake #1 (well 20, plate 1) exploratory well was spudded December 1969, in Sec. 21, T.50S., R.76W., in the Port Moller D-4 quadrangle, 3 miles (4.8 km) west of Herendeen Bay; it was abandoned in 1970 at a total depth of 8,049 feet (2,453 m).

The well is located on glacial moraine and the upper 235 feet were not logged and is presumably all surficial material. A thin sequence of conglomeratic sandstone, correlated with the Milky River Formation, unconformably overlies an abnormally thick section of Bear Lake Formation, but the well record does not give any indication of section duplication. Thick units of quartz-rich sandstone, in part conglomeratic, predominate. Siltstone, shale, carbonaceous shale, and coal are interbedded with the sandstone. Marine mollucks found sparsely throughout would indicate the Bear Lake Formation was deposited in a near shore to shore face and back-beach swamp environment.

A major lithologic change occurs in this well at 7,580 feet (2,310 m) when a volcanic-rich siltstone and shale are encountered. The contact is probably an unconformity, and the volcanic-rich sequence is considered Stepovak Formation.

Hoodoo Lake #1 contains no indication of oil generation or accumulation, and the rocks are considered immature. Also, the thrust fault present in the David River well, and in Hoodoo Lake #2, 3 miles (4.8 km) south of #1 was not encountered. If the well had been drilled deeper it should have cut the fault at about 9,500 feet (2,895 m) assuming the fault was low-angle similar to the one exposed at Herendeen Bay-Port Moller (Wilson and others, 199_).

Pan American-Standard of California-Hoodoo Lake #2

The Hoodoo Lake #2 (well 21, sheet 1) was drilled in 1970 in Sec. 35, T.50S., R.76W., Port Moller D-3 quadrangle 1 mile (0.6 km) from the shore of Herendeen Bay. Total depth was 11,243 feet (3,427 m). Our interpretation of the stratigraphic sequence differs from the published data (Brockway and others, 1975) mainly in that we infer a thrust fault at 10,020 feet (3,054 m) in this well that repeats part of the up-hole sequence. Also, we disagree on the placement of the contact between the Bear Lake and Stepovak Formations.

This well was drilled about 2.5 miles (4 km) northwest of the mountain front west of Herendeen Bay. These mountains are part of a major low-angle thrust fault block that is mapped at the surface (Wilson and others, 199_) which places at least 2,000 feet (610 m) of Naknek Formation (Upper Jurassic) overlying highly crumpled Bear Lake Formation (Upper Miocene). The exposed fault dips southward about 2 degrees. The dip on the subsurface fault is unknown, but is probably similar, so the two may be part of a duplex system. Other thrust faults have been mapped to the south across the Alaska Peninsula (Wilson and others, 199_). This strongly suggests that the structure at the south end of the Alaska Peninsula is considerably more complex than farther north along the peninsula where open folds are prevalent. The recognition of this complex structure has major implications for petroleum exploration both onshore and in offshore areas.

The Hoodoo #2 well site is on glacial moraine, and glacial drift along with silt and sand extend down to 350 feet (107 m). A thin, 700-foot (213 m) volcaniclastic sequence of Milky River Formation underlies the surficial deposits and unconformably overlies Bear Lake Formation. The brown to gray sandstone and siltstone of the Bear Lake is similar to the exposed section in the sea cliff about 1 mile to the east, and also similar to the Hoodoo Lake #1 sequence but is considerably thinner than Hoodoo Lake #1.

The volcanoclastic Stepovak Formation and the underlying Tolstoi formation are both thin and are bounded above and below by unconformities that apparently represent intervals of extensive erosion. The Tolstoi Formation is a subaerial coastal plain deposit that was occasionally inundated by the sea. Sea level continued to rise during deposition of the Stepovak Formation.

Nonmarine conglomeratic sandstone and siltstone of the Chignik Formation unconformably underlies the Tolstoi Formation. These rocks are very similar to the section exposed on the peninsula between Herendeen Bay and Port Moller, and include coal beds similar to those near Mine Harbor.

A nearly complete section of the distinctive Herendeen Formation unconformably underlies the Chignik Formation. The gray, bioclastic, limy sandstone of the Herendeen is readily identifiable in all wells where encountered; it is generally shown as limestone, and that is the way it is shown on sheet 1. *Inoceramus* prisms and shell fragments give these rocks the calcareous content and distinctive color.

Several hundred feet (107 m) of Staniukovich Formation underlies the Herendeen, but the full sequence is terminated by a thrust fault. This fault is probably the same one encountered in the David River well. Volcanoclastic rocks of the Stepovak Formation are present underlying the fault block. These rocks are unlike any Mesozoic sequence, but are similar to nearby exposures of Stepovak

Formation.

McLean (1977) has published a considerable amount of organic geochemistry data for the Hoodoo Lake #2 well. Some of that data on the amount and type of organic carbon and maturation index is included here with the graphic log. Most of the organic carbon is either woody(W) or carbonaceous(C) material that is more likely to produce gas rather than oil. Amorphous carbon(Am) and herbaceous material(H) account for a minor part of the material in this well. Amorphous carbon which is the main precursor for petroleum is not present in great quantity in the rocks of the Alaska Peninsula. The maturation index and vitrinite reflectance data indicate that only rocks of the Stepovak and older formations have reached the stage of oil generation.

Pure Oil Company-Canoe Bay #1

Canoe Bay #1 (well 14, plate 1) was spudded August 26, 1961 and abandoned October 26, 1963, at a total depth of 6,642 feet (2,024.5 m). The well is located in Sec. 8, T,54S., R.78W., Port Moller C-4 quadrangle, about 1 mile (0.6 km) south of Canoe Bay. This is the only well drilled entirely in one formation on the Alaska Peninsula. The lithology is unquestionably Hoodoo Formation, but the amount drilled can not be considered as an indication of the true thickness of the formation. We have mapped (Wilson and others, 199_) a thrust fault approximately through the well site based on structure and stratigraphic data.

The well probably was drilled in steeply dipping beds and may represent some repetition of section, but the duplicated section can not be picked with confidence. The graphic section indicates about 6 thick sand bodies. This is more than has been noted in nearby outcrops. This well was geologically mislocated and probably should not have been drilled. The excessive amount of time spent on this well would indicate major drilling problems, also, probably due to caving of highly fractured and steeply dipping siltstone.

Phillips Petroleum-Big River 1A

The Big River 1A (well 24, plate 1) well located in Sec. 15, T.49S., R.68W., was drilled along

Big River in Stepovak Bay D-6 quadrangle; it was spudded September 21, 1976, and completed at a depth of 11,371 feet (3,466 m) on March 25, 1977. The upper 390 feet (119 m) are in surficial materials mainly alluvium. A thick sequence of tuff, volcanic breccia, and flows underlie the alluvium. This is designated as Meshik Volcanics and Stepovak Formation undivided. The Big River is where the sedimentary rocks of the Stepovak Formation to the south interfinger with equivalent age volcanic rocks of the Meshik Volcanics from the north. The rocks encountered are mainly Meshik Volcanics, but two tongues of Stepovak sedimentary rocks are present. These include the upper 560 feet (170 m) and between 1900 and 2450 feet (168 m).

The Tolstoi Formation conformably underlies the Meshik-Stepovak sequence. Considerably more tuff is recorded on the well log than is customarily found in the Tolstoi Formation. Certainly much more than at the reference section at Ivanof Bay (Detterman and others, 199_) a few miles southeast. Many of the tuff units are associated with coal or carbonaceous shale beds suggesting these are underclay rather than tuff beds.

The Tolstoi unconformably overlies Chignik Formation at 7,135 feet (2,175 m). A basal conglomerate overlies a brownish erosion surface cut into sandstone of the Chignik Formation. The Chignik like the overlying Tolstoi is a subaerial deposit formed on a low lying broad alluvial plain probably close to sea level. Thin overbank shale and siltstone cap many of the sandstones. A basal conglomerate at 8,445 feet (2,574 m) cuts into the underlying Herendeen Formation.

The Herendeen is the typical light-gray calcarinite composed of *Inoceramus* prisms and quartz grains. Calcareous shale in the upper part would suggest a protected bay deposit, but most of the formation was deposited in a shallow high-energy environment. A thin sequence of Staniukovich Formation underlies the Herendeen Formation. The classification as Staniukovich Formation is based on little evidence and these beds may be actually part of the underlying Naknek Formation that continues to total depth of 11,371 feet (3,466 m).

Gulf Oil-Sandy River Federal #1

Sandy River Federal #1 well (well 16, plate 1) was spudded September 4, 1962 and completed

December 3, 1963, in Sec. 10, T.46S., R.70W., Chignik A-7 quadrangle. The well is 1.5 miles (2.5 km) south of the Sandy River, and 8 miles (12.8 km) inland from the Bristol Bay coast. The well is located on terminal moraine of the Kvichak advance of the Brooks Lake glaciation (Detterman and others, 1981a), and the upper 160 feet (49 m) are in glacial drift.

The Milky River Formation unconformably underlying the glacial drift has been designated a reference locality for the formation (Detterman and others, 199_). Volcanic breccia flows and tuff are interbedded with fluvial volcaniclastic sedimentary rocks. Volcanic debris is more abundant in the upper part and sediments in the lower part of the 3,380-foot (1,022 m) section.

Underlying the Milky River Formation is an abnormally thick (7,145 feet, 2,178 m) sequence of shallow marine to nonmarine clastic rocks of the Bear Lake Formation. If there is duplication of section by faulting it is extremely difficult to pick. A slight suggestion of a duplication exists between the upper coaly section starting about 4,450 feet (1,356 m) and the lower coaly sequence at 9,325 feet (2,842 m), but the evidence for duplication is not good and this has to be considered a normal but thick section. Steeply dipping beds probably can be ruled out as a cause as all indications from surface observations suggest the well should be drilled in low dipping strata. Nineteen sandstone samples were checked for porosity and permeability. Porosity ranged from 23.7 to 36.6 percent, unusually high for Alaska Peninsula rocks. Permeability varied from 0.1 to 1,268 millidarcys. Oil staining was noted at 10,000 feet.

The character of the rocks change below 10,625 feet (3,238 m) becoming more mature with a considerable amount of volcanic debris. We consider these rocks to be part of the Stepovak Formation as did Brockway and others (1975), but they postulate a fault cutting the sequence that we do not see.

Gulf Oil-Port Heiden #1

Port Heiden #1 (well 22, plate 2) was drilled on a beach ridge along Bristol Bay in Sec. 20, T.37S., R.59W., Chignik D-3 quadrangle. The well was spudded June 27, 1972 and completed September 14, 1972, at a total depth of 15,015 feet (4,576 m). The upper 335 feet (102 m) was not logged and is probably beach deposits and ash-flow tuff from Aniakchak crater.

Volcaniclastic sedimentary rocks of the Milky River Formation underlying the surficial materials contains mostly reworked volcanic debris rather than contemporaneous volcanic deposits that were abundant in wells drilled through the formation farther south on the peninsula. Also, some of these deposits are probably marine as shell fragments are reported at several levels. The Bear Lake Formation is thick 6,060 feet (1,847 m), but appears to be a normal sequence of shallow marine to nonmarine sandstone, siltstone, shale, and coal.

The section of Meshik Volcanics in Port Heiden #1 is designated the reference section for the formation (Detterman and others, 199_). The formation is almost entirely volcanic consisting mainly of tuff with minor amount of volcanic breccia and flows. The type locality along the Meshik River (Knappen, 1929) about 32 miles (52 km) east contains considerably more volcanic breccia, flows, and lahars than does the well section. These volcanic derived deposits cannot be considered a source or a potential reservoir for petroleum. The well bottomed in granitic rocks of the Alaska-Aleutian Range batholith. In as much as the late Tertiary sediments above the Meshik Volcanics are immature the entire section at this locality is nonproductive.

Cities Service-Painter Creek #1

Painter Creek #1 (well 18, plate 2), Sec. 14, T.35., R.51W., was drilled 3.5 miles (5.6 km) southwest of Mother Goose Lake in Ugashik A-5 quadrangle. The well was spudded April 2, 1967 and abandoned July 13, 1967, at a depth of 7,912 feet (2,4121 m). Our interpretation of the stratigraphic sequence is somewhat different than Brockway and others (1975). Rocks of the Meshik Volcanics are exposed at the well site and although the upper 225 feet (68 m) of the well are not logged we consider the Meshik to continue to 450 feet (135 m) where it unconformably overlies the Tolstoi Formation.

Sandstone, conglomerate, siltstone, shale, and coal, all of nonmarine origin, are common throughout the Tolstoi Formation. Yellow staining and gas was noted on several of the sand units, and palynomorphs from this sequence yield an Eocene or Paleocene age (McLean, 1977) similar to ages reported from nearby outcrop collections of megaflora (Detterman and others, 1985).

A thin calcareous sandstone and siltstone sequence of Chignik Formation unconformably underlies the Tolstoi Formation and unconformably overlies Northeast Creek Sandstone Member of the Naknek Formation. Both contacts are well-developed erosion surfaces. The well flowed gas and water cut mud from the contact with the Naknek Formation.

Naknek Formation continues down to 6,750 feet (2,057 m) where the Shelikof Formation underlies the Naknek. This contact is questionable; it may be Chisik Conglomerate Member of the Naknek Formation to the base of the well. This interval was called Shelikof on the basis of increased volcanic clasts in the conglomerate, but the lower part of the Chisik Conglomerate does contain some volcanic rocks in nearby outcrop sections. So the evidence for Shelikof Formation is poor.

Chevron USA-Koniag #1

Koniag #1 (well 25, plate 2) was drilled in Sec. 2, T.38S., R.49W., Sutwik Island D-4 quadrangle in 1981. The well is about 1.5 miles (2.4 km) inland from Shelikof Strait and was drilled to 10,900 feet (3,322 m). The well was spudded in bedrock of the Snug Harbor Siltstone Member, Naknek Formation, and penetrated 2,125 feet (647 m) of sandy siltstone before going into the thick quartz-biotite-rich arkosic sandstone of the Northeast Creek Sandstone Member. The interval between 4,500 and 4,560 feet (1,372 and 1,390 m) was not logged. The contact with the Shelikof Formation is considered to fall within that interval. The Chisik Conglomerate is missing in the well, but we do not know if this was due to nondeposition erosion, or faulting. Outcrop data from near the well site suggests this area was part of a quiet marine embayment with a low sedimentation rate, and therefore we believe the 4,560 feet (1,390 m) of Snug Harbor Siltstone and Northeast Creek Sandstone represents a complete Naknek Formation sequence. There are several of these basins or embayments in the Naknek Formation along the Alaska Peninsula. Sequences from several of them are shown on the lithofacies fence diagrams of the upper Mesozoic (Detterman and Miller (1987).

The interval drilled between 4,560 feet (1,390 m) and 7,350 feet (2,240 m) is divided about evenly on slight lithologic evidence into the Shelikof and Kialagvik Formations. The sequence is mainly dark-gray to dark-brown siltstone with a few sandstone interbeds. The sandstone is quartz-rich which suggests Kialagvik Formation, and occurs in the lower part of this sequence. Siltstone in the upper half of this sequence also tends to quartz-rich, so the entire unit may be Kialagvik Formation. These rocks were also deposited in a quiet basin with restricted input and circulation similar to the Naknek Formation.

The contact with the volcanic sequence of the Talkeetna Formation is sharp. Core #4 crosses the contact and the rocks below the contact are altered and much harder than above, so there is probably a considerable hiatus between the two units, but evidence of an erosional surface is missing. The Talkeetna consists entirely of tuff, flows, and volcanic breccia, all of which is slightly altered. Pyrite, talc, sericite, ziolites, and locally bornite occur in these rocks.

Limestone with fossils considered to be part of the Kamishak Formation (upper Triassic) was encountered at 9,575 feet (2,918 m) and continued to total depth. Chert, quartzite, and altered tuff form a considerable part of this moderately deep marine sequence. The abundant tuff here and in the overlying Talkeetna Formation indicates this area was close to a major early Mesozoic volcanic center.

Richfield et al-Wide Bay #1

The Wide Bay exploratory well (well 15, plate 2) was drilled several hundred yards offshore in Wide Bay at the mouth of Short Creek on the west side of Wide Bay in Sec. 5, T.35S., R.44W., Ugashik B-2 quadrangle. The well was spudded December 13, 1962, and abandoned October 17, 1963, at a total depth of 12,566 feet (3,827 m).

The upper 160 feet (48 m) are water and Quaternary sediments. Bedrock of the Kialagvik Formation was encountered at that depth, and is similar to rocks of that formation exposed onshore. Brown sandstone and siltstone, locally slightly tuffaceous, constitutes the bulk of the sequence. These rocks are highly fossiliferous and oil staining was noted on some of the sand intervals.

The contact with the Talkeetna Formation is tentatively placed at 3,270 feet (997 m) on the basis of a marked increase in bedded tuff and tuffaceous sediments along with a change in color and content of the rocks. The lower contact between the Talkeetna and Kamishak Formation at 9,630 feet (2,935 m) is also somewhat doubtful. These formational contacts seem reasonable, in which case the

Talkeetna is very thick. Alternately the sequence may be in part duplicated by faulting as the rocks in the lower part were considerably more fractured than the rocks higher up the hole. The Wide Bay-Bear Creek anticline is known to be thrust faulted locally, so a faulted sequence has to be considered. Another possibility is that the well went through steeply dipping strata near the axis of the anticline.

The underlying Kamishak Formation is mainly shale and limestone with thick units of bedded tuff similar to the Koniag well to the south. Fossil fragments were found throughout, and Triassic flat pelecypods are distinctive so the identification of these beds as Kamishak Formation should be correct.

Humble Oil-Shell Oil-Bear Creek #1

The Bear Creek well (well 11, plate 2) drilled in Sec. 36, T.29S., R.41W., Karluk C-6 quadrangle was spudded September 23, 1957 and completed February 21, 1959, at a total depth of 14,374 feet (4,381 m). The well started in bedrock of the Shelikof Formation on the ridge 0.6 mile (1 km) north of Bear Creek, and just east of the axis of the Bear Creek anticline. The upper 1,220 feet (372 m) were in siltstone and greenish-gray volcanogenic sandstone of the Shelikof formation.

A sequence of brownish-gray siltstone, shale, and thin sandstone 2,810 feet (856 m) thick of Kialagvik Formation underlies the Shelikof Formation. Three occurrences of oil staining was noted in the formation, particularly in the sandstone. These rocks may have been the source of the oil seeps that occur in this area. A 730-foot (223 m) sequence of tuff and tuffaceous siltstone underlies the Kialagvik Formation. We consider these rocks to be Talkeetna Formation, and that they are terminated at a thrust fault surface at 4,760 feet (1,450 m).

The entire upper part of the sequence in this well has apparently been thrust over the Kialagvik Formation and older strata. A fault was not mapped along the surface exposure of the anticline in this area, but thrust faults were mapped both north and south of this locality (Detterman and others, 1987a). About 1,320 feet (403 m) of the Kialagvik Formation are repeated below the fault. These rocks are similar to the lower part of the formation above the fault. A complete sequence of volcanic and volcaniclastic rocks of the Talkeetna Formation underlies the fault. Volcanic flow units and tuffs became thicker and more abundant downward. This locality apparently was close to the volcanic center as evidenced by the thick flow units.

The contact with the Kamishak Formation is arbitrarily placed at 10,918 feet (3,328 m). At this point the well enters a calcareous siltstone and shale sequence with only minor tuffaceous and flow units. Limestone is missing, but the marked change in lithology suggests a different stratigraphic unit is being drilled. The absence of limestone is troublesome, especially since limestone is present in exposures at Puale Bay just to the northeast and in the Wide Bay well to the southwest. The possibility has to be considered that these underlying rocks represent Kialagvik Formation again and that a second thrust fault is present in this well. The numerous references to fossil molds and the occurrence of hydrocarbons somewhat suggest Kialagvik Formation. The age of these rocks probably could have been determined by more precise information on the abundant fossil material. Fossils in the upper Triassic Kamishak Formation and the middle Jurassic Kialagvik Formation are very different and very distinctive.

General Petroleum-Great Basins #1

Great Basins #1 (well 12, plate 2) was spudded July 6, 1959 and completed September 13, 1959 in Sec. 2, T.27S., R.48W., Ugashik D-4 quadrangle. The drill-site is located on moraine of the Kvichak advance of the Brooks Lake Glaciation (Detterman and others, 1987b), 9 miles (14.5 km) southwest of Becharof Lake. The well encountered about 350 feet (106 m) of glacial drift before entering poorly consolidated bedrock of the Milky River Formation. The Milky River was mainly volcanogenic fine-grained sandstone with intervals of conglomerate, 1,860 feet (567 m) thick. These rocks were deposited in shallow marine waters and fossils were reported at several horizons. These rocks contain little organic material and are immature. Data shown here on organic carbon, maturation, and vitrinite reflectance are excerpted from McLean (1977).

The Bear Lake Formation underlying the Milky River Formation appears to be a normal sequence of shallow marine to nonmarine sandstone, siltstone, conglomerate, and coal about 3,400 feet (1,036 m) thick. The few samples with high organic carbon content were taken from coal or carbonaceous shale beds. Most of the organic material is herbaceous, but the rocks are immature. No oil shows were recorded.

We consider the rocks underlying the Bear Lake Formation to be Tolstoi Formation rather than Stepovak Formation as previously published (Brockway and others, 1975; McLean, 1977). The Tolstoi is exposed at the surface a few miles to the southeast (Detterman and others, 1987a). Alternately the rock sequence between 5,610 feet (1,710 m) and 10,516 feet (3,205 m) may be a part of the Hemlock Conglomerate. The Hemlock Conglomerate is exposed in the Katmai area northeast of the well site, and is of approximately the same age as the Stepovak and Meshik Volcanics (Detterman and others, 199_).

The 334 feet (102 m) of conglomerate near the bottom of Great Basins #1 is considered to be Naknek Formation, probably Chisik Conglomerate Member. It is hard, slickensided and the siltstone and sandstone associated with it are hornfelsed suggesting it was intruded by the batholith that forms the basement rock at total depth. The reported age of 177 Ma (Brockway and others, 1975) is somewhat too old for the Naknek Formation, but others age determinations (Reed and Lanphere, 1972) from nearby exposures of the batholith are about the same age as the Naknek Formation.

Regional Petrography

One hundred ninety one sandstone samples collected from Mesozoic and Tertiary Formations in the Alaska Peninsula were examined by the author in thin section to determine the rock characteristics, provenance, and reservoir potential. Point counts of individual mineral grains were made on each sample, and the samples were divided into arenites and wackes using the breakdowns of Williams, Turner, and Gilbert (1958) and Dott (1964). Ternary diagrams (Figures 3 and 4) were constructed for the formations with Q including monocrystalline and polycrystalline quartz, quartzite, and chert; F-plagioclase and orthoclase feldspar; and L-lithics rock fragments. This basic Q, F, L diagram was considered sufficiently to determine provenance and general rock characteristics for the Alaska Peninsula. Most of the rocks examined (65 percent) were arenites and of that number 47 percent were lithic arenites (Williams, Turner, and Gilbert, 1958). An equal number of the wackes (47 percent) can be classified as lithic wacke (Williams, Turner, and Gilbert, 1958, Dott, 1965). In gross aspect the

Tertiary and middle Jurassic rocks indicate a volcanic provenance while the late Jurassic and Cretaceous rocks suggest plutonic-metamorphic source terrane. Textural properties of the samples examined are shown in table 2.

The Kialagvik and Shelikof Formations were considered together for the ternary diagrams (Figures 3 and 4). The number of samples (9) were probably insufficient for a good analysis, but except for one sample in the Shelikof Formation, all were volcanic arenites or volcanic wackes. The provenance would be erosion of the lower Jurassic Talkeetna Formation. For a more detailed discussion of the Shelikof Formation petrography, see Allaway (1982).

Rocks of the Naknek Formation (Upper Jurassic) form the main sedimentary sequence on the Alaska Peninsula and were investigated in considerable detail. Twelve complete or partial sections of the Naknek Formation were measured, and the 63 samples used for the ternary diagrams were from measured sections. Details of the sections are shown in Detterman and Miller (1987). Arenites are nearly twice as abundant as wackes, but in both cases the rocks are mainly feldspathic to arkosic. Lithic fragments are mainly of plutonic and metamorphic rocks, however, some silicified volcanic rock fragments are present. Most of the volcanic fragments are reworked from older Jurassic rocks rather than contemporaneous volcanic activity, but some volcanic activity is recorded (Detterman and Miller, 1986, and Mullen, 1987). The provenance for the Naknek Formation is a plutonic-metamorphic terrane.

The more extensive outcrop areas of Naknek Formation on the Alaska Peninsula, and the greater amount of details obtained from these exposures during recent field investigations permit development of isopach and sand-shale ratio maps for the formation (Figures 5 and 6). The ration of coarse clastics to shale increases northward along the peninsula and reaches a maximum of 4:1 in the Katmai area. For the purpose of this map sand includes all sandstone and conglomerate, and shale includes all siltstone as well as shale. The sand-shale ratio map also shows several basins along the peninsula where the sequence is predominantly with shale. Areas of high sand-shale ratio indicate the presence of fluvial deltaic systems with abundant coarse sediment load. Shale and siltstone accumulated in the basins between the fluvial-deltaic systems. Along a major part of the area the Naknek Formation is cut

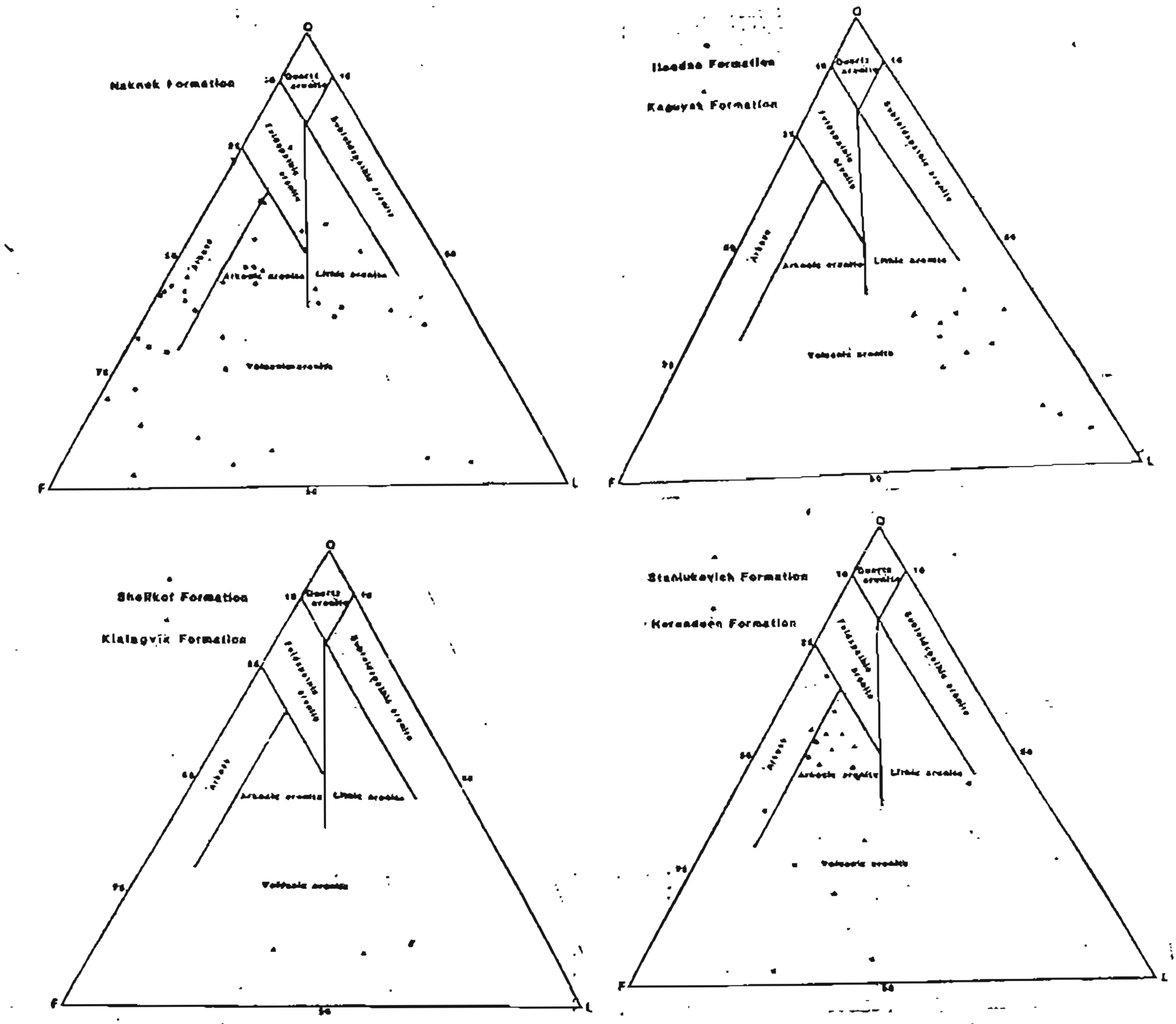


Figure 3. Ternary plots for arenites from surface exposures of Mesozoic and Tertiary rocks on the Alaska Peninsula. Classification system for arenites from Williams, Turner, and Gilbert (1958) Q- monocrystalline and polycrystalline quartz, and chert; F. feldspar; L- lithic grains.

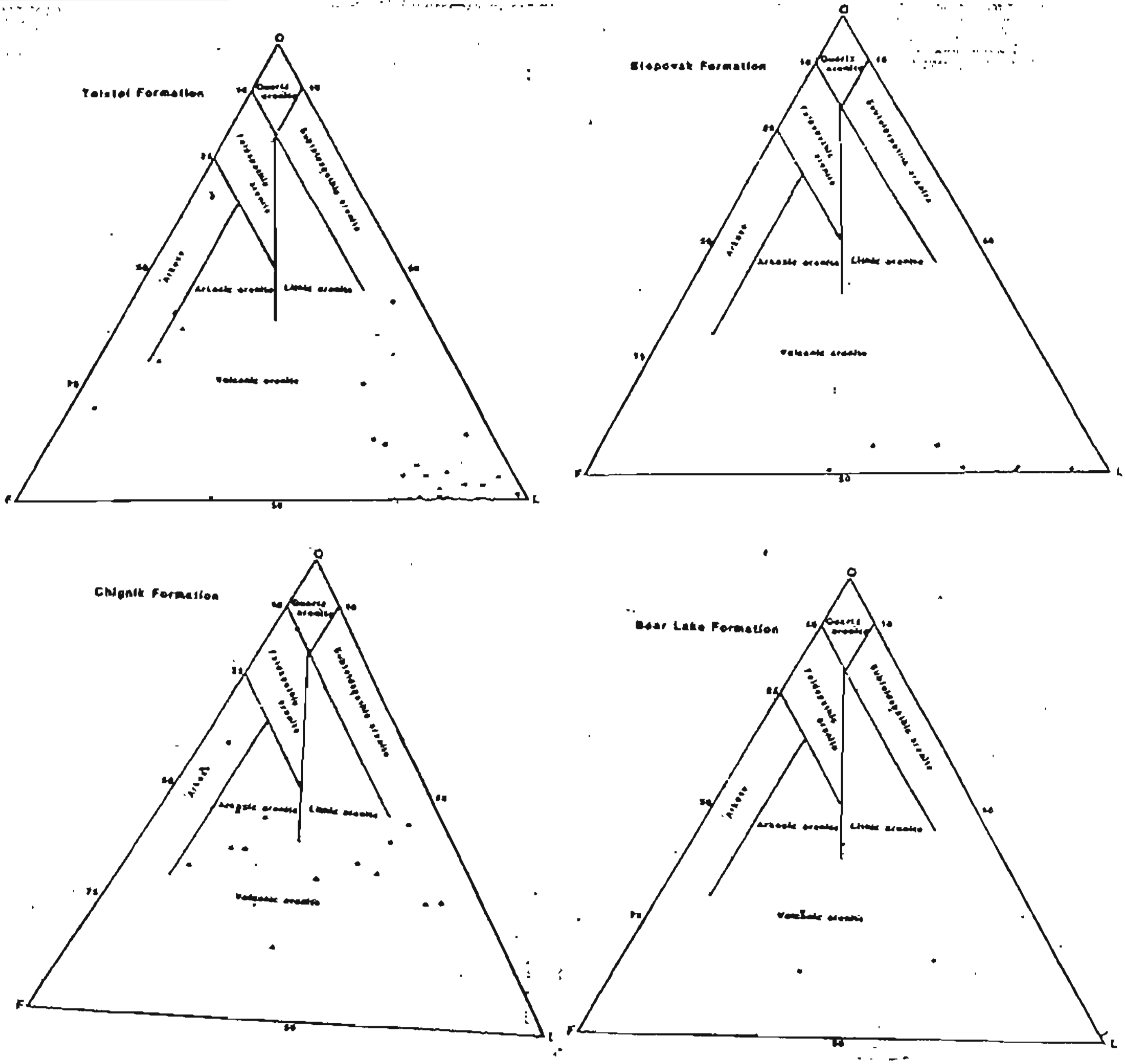


Figure 3. Continued

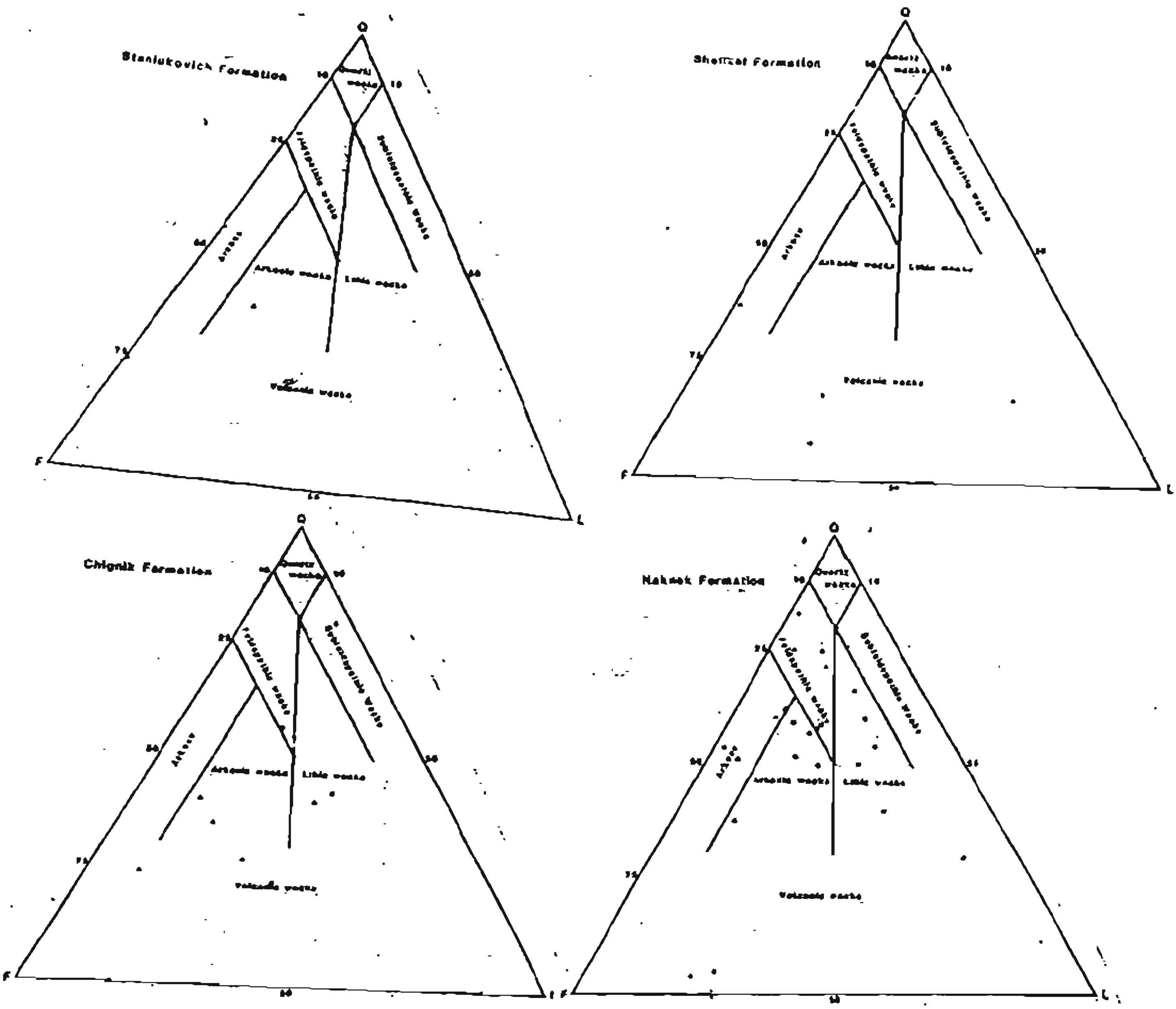
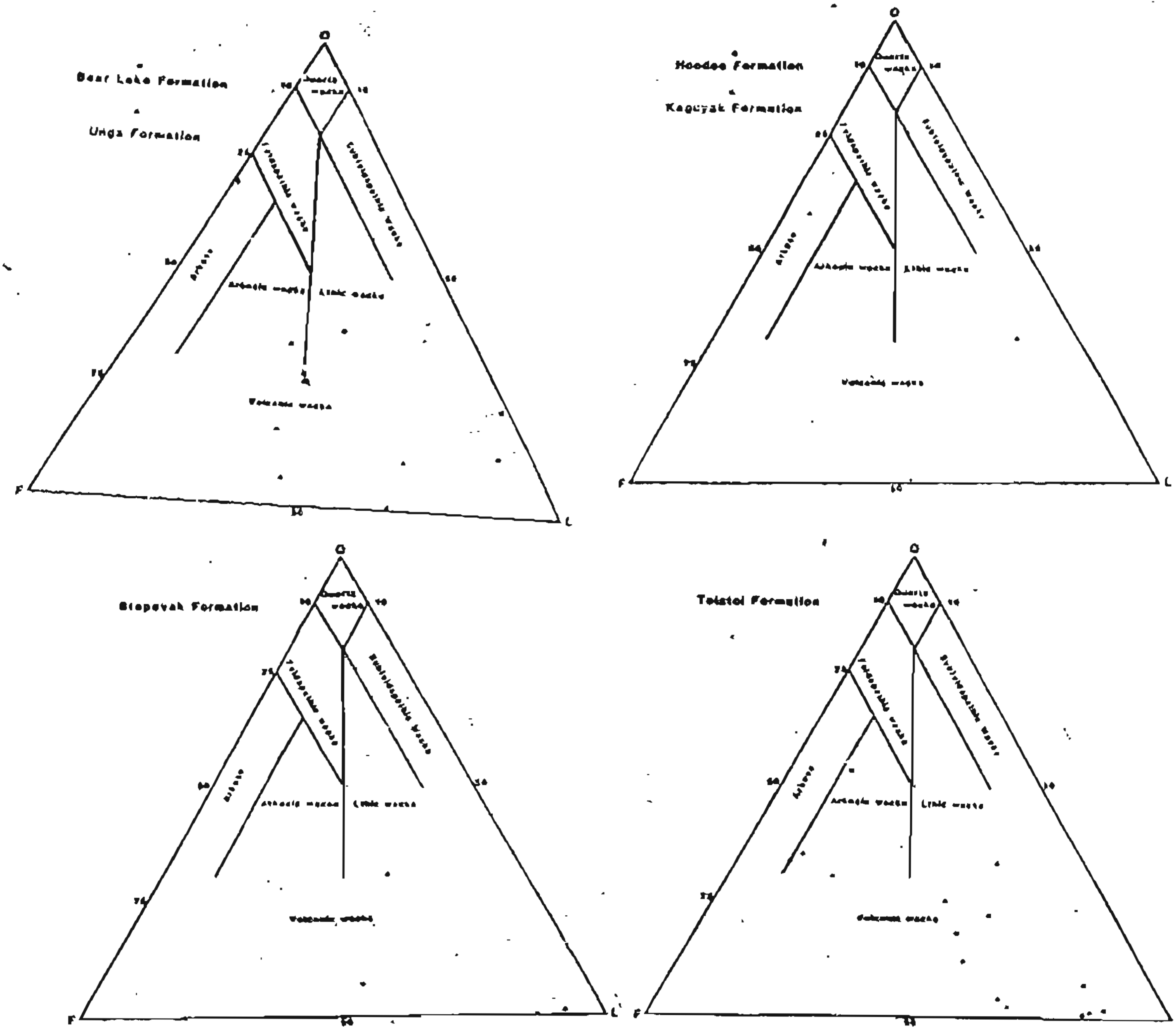


Figure 4. Ternary plots for wackes from surface exposures of Mesozoic and Tertiary rocks on the Alaska Peninsula. Classification system for wackes from Williams, Turner, and Gilbert(1958), and Dott(1964). Q- monocrystalline and polycrystalline quartz, quartzite, and chert; F- feldspar; L- lithic grains.



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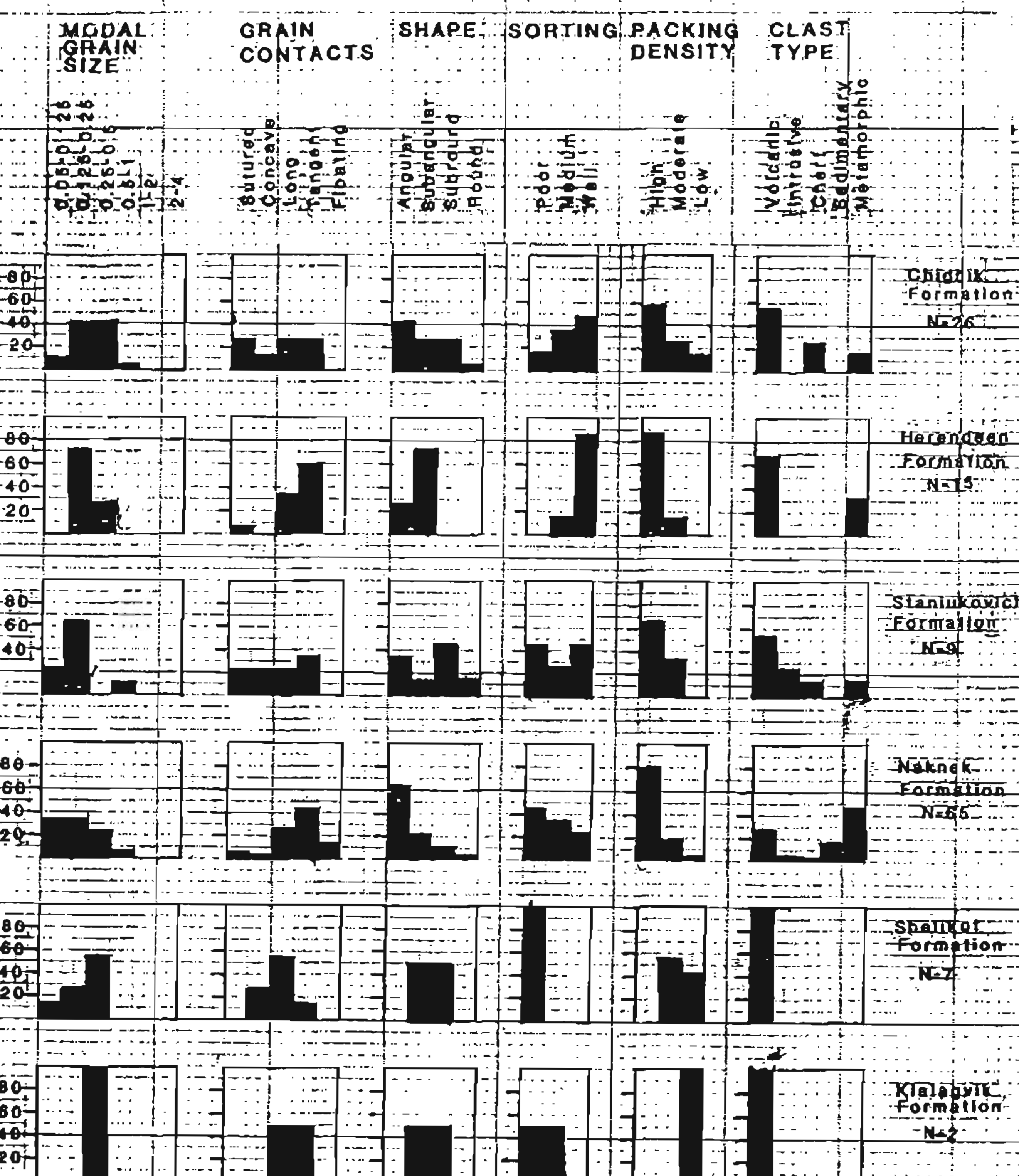

Table 2. Histograms showing textural properties of surface sandstones from selected formations on the Alaska Peninsula. The more favorable reservoir chacteristic for each textural category appears towards the right of each parameter shown. N, number of samples.

off on the west by the Bruin Bay Fault, so that lateral facies changes are restricted to the narrow width of the Alaska Peninsula east of the fault. Nonetheless, several fluvial-deltaic systems can be delineated.

The Early Cretaceous Staniukovich and Herendeen Formations are considered together, and the rocks are almost exclusively arenites of arkosic composition. Quartz forms more than 50 percent of the sandstone in both formations, and the Herendeen is unusual in that *Inoceramus* shell fragments form 30 to 40 percent of the rock throughout the formation. These rocks are clean and have visual porosity so that they should be considered potential reservoir rocks when they occur in the right structural setting.

Sandstone in the Chignik Formation continues to indicate a plutonic-metamorphic source terrane with some sediment from erosion of Jurassic sedimentary rocks, mostly Naknek Formation. The rocks are mainly arkosic to lithic arenites with minor wackes of similar types. The Hoodoo and Kaguyak Formations are mainly turbidite of approximately the same age as the Chignik Formation. Both formations are lithic-rich, but surprisingly are in the arenite classification rather than wackes as might be expected.

The 37 thin sections examined from the Tolstoi Formation exhibit a marked bias towards being lithic-rich. Most of the lithic fragments are volcanic, but many of the fragments are silicified volcanic rocks rather than fresh volcanic rock and suggest a source from the older volcanic-rich formations rather than contemporaneous eruptions. The thin sections are mainly from four measured sections along the peninsula and should be representative of the formation. The amount and type of volcanic debris is of prime importance in the Tolstoi Formation as this unit is considered a source for liquid hydrocarbons in both the COST #1 well and on the Alaska Peninsula. Fresh volcanic lithic clasts formed contemporaneously with the time of deposition are much more susceptible to diagenetic alteration than are silicified volcanic clasts. Diagenetic alteration can significantly lower the porosity and permeability of the enclosing rocks.

Samples from the Stepovak Formation are almost entirely from the upper sandy part of the type locality (Detterman and others, 199_) and are volcanic lithic-rich. The rocks are fresh and easily

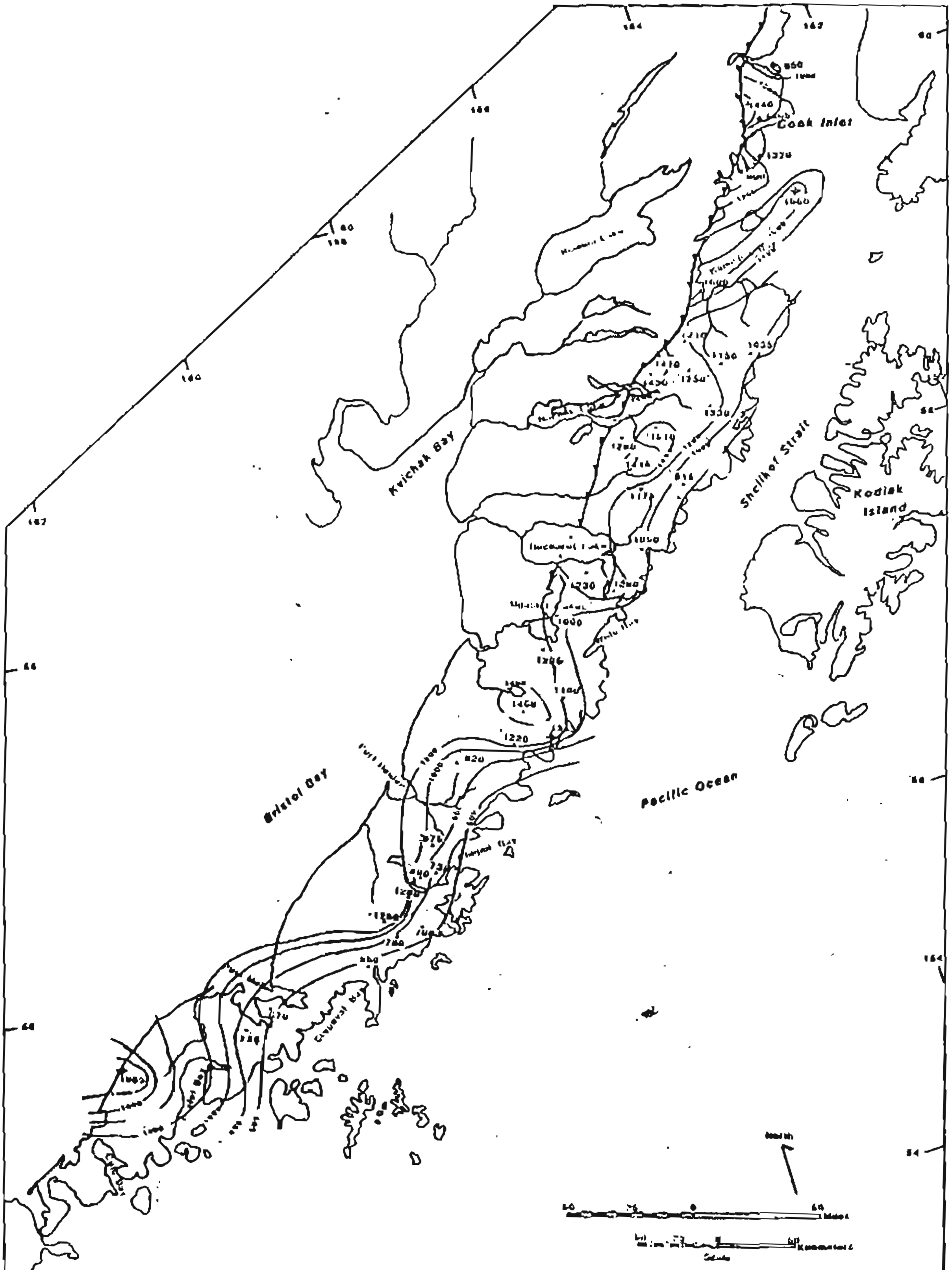

Figure 5.--Isopach map of the Naknek Formation on the Alaska Peninsula and Cook Inlet

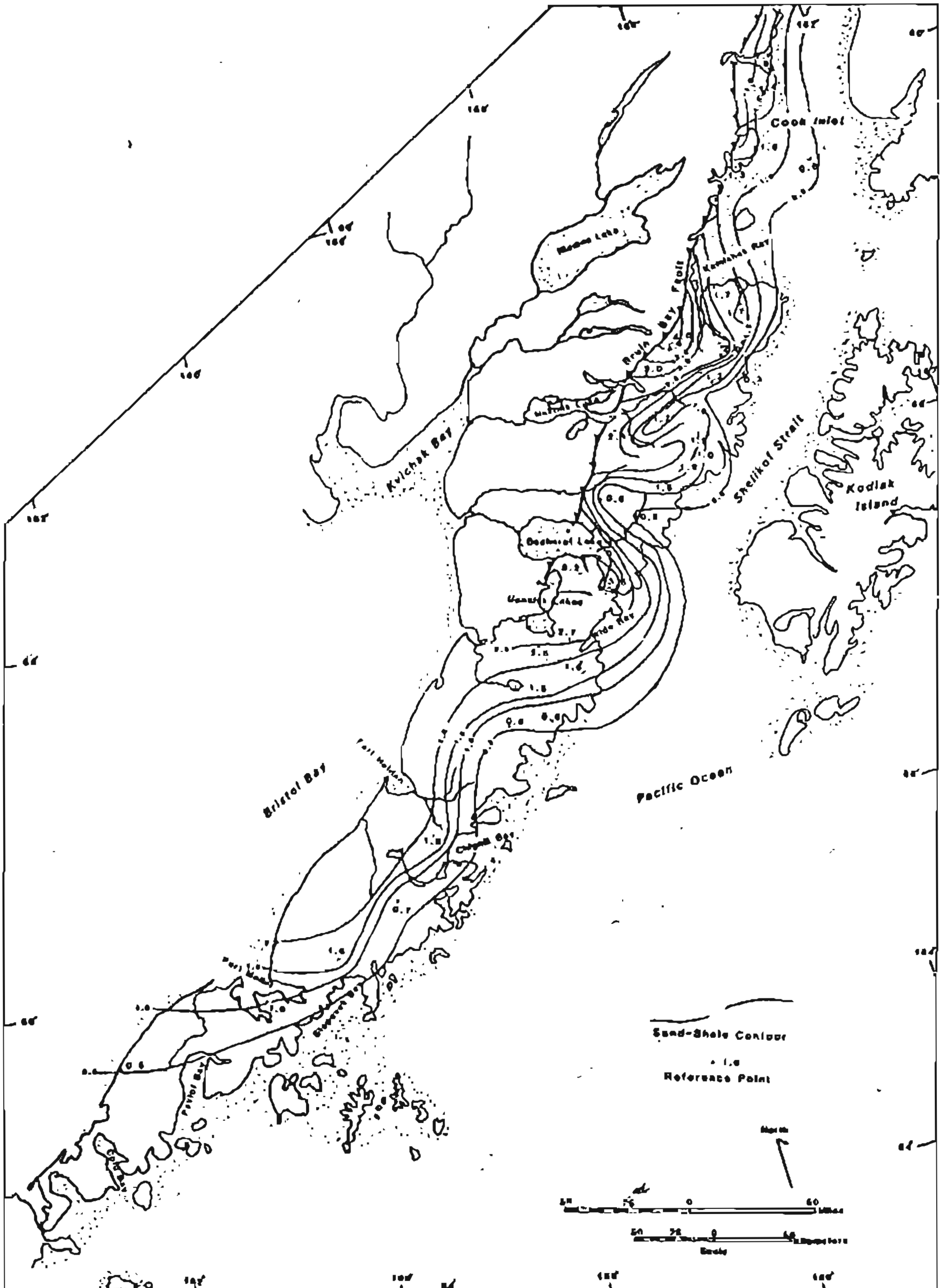

Figure 6. Sand-shale ratio map of the Naknek Formation on the Alaska Peninsula and Cook Inlet

altered clasts from contemporaneous Meshik arc (Wilson, 1985). The weathering products will greatly reduce the porosity and permeability of these rocks.

The Bear Lake and Unga Formations are not well represented, but are suggestive of a volcanic source terrane; this is particularly true of the Unga Formation. Outcrop data from the Bear Lake Formation indicate a considerable contribution from a nonvolcanic source.

Lithofacies Maps

A series of 8 lithofacies maps (Figures 7-14) show the rocks that we believe are present on the Alaska Peninsula and adjoining areas. The maps cover discrete blocks of geologic time that have similar lithologic and depositional characteristics, and include Upper Triassic, Lower Jurassic, Middle Jurassic, Upper Jurassic, Lower Cretaceous (Neocomian), Lower Cretaceous (Albian) and Upper Cretaceous, Paleogene, and Neogene. The data for the maps is based on recent field studies on the Alaska Peninsula, available information from exploratory wells (location of wells shown on maps), and published reports by Bouma and Nilsen, 1978; Burk, 1965; Connelly and Moore, 1979; Detterman and others, 1987 and 199_; Hoare and Coonrad, 1978, 1983; McLean and others, 1978; Moore, G.W., 1967; 1969; Moore, J.C., 1974a, b; and Nilsen and Moore, 1970. The maps show the main lithologies present, but thickness estimates should be considered as approximate. Only gross lithologic details are shown on these maps. Blank areas indicate either a lack of data, or that strata for that age are missing by nondeposition or erosion.

Upper Triassic

Upper Triassic rocks (Figure 7) are exposed at only two localities on the Alaska Peninsula, Puale Bay and just north of Becharof Lake, but are present locally along both sides of Cook Inlet. Four exploratory wells, Cathedral River #1, Koniag #1, Wide Bay #1, and Bear Creek #1 (plates 1 and 2) encountered Upper Triassic strata.

The rocks are of marine origin, mainly limestone, chert, siltstone, and shale with locally well-developed reef structures. The limestone with reef structures supported an abundant megafauna which indicates deposition in a warm tropical sea at low latitude. An Early Mesozoic volcanic arc contributed significantly to this sequence, particularly in the Cook Inlet area. Volcanic ash in the form of thick tuff beds and tuffaceous sedimentary rocks is present throughout the Alaska Peninsula.

The Upper Triassic sequence on the Alaska Peninsula indicates a shallow water depositional site for the northern part of the area, becoming a progressively deeper water deposit southward. This is accompanied by a decrease in limestone and an increase in chert, shale, and siltstone. These marine strata with abundant faunal remains have to be considered as potential source beds for hydrocarbons. The sequence throughout the area will probably be about 800 to 1,000 meters thick. Local variations are possible, but in all occurrences there are no strong indications of a major erosional surface between these rocks and the overlying Talkeetna Formation.

Lower Jurassic

Lower Jurassic strata (Figure 8) are exposed on the Alaska Peninsula at the same localities as the Upper Triassic, and were encountered in the same exploratory wells. A thick, well-exposed sequence is present along the west side of Cook Inlet, and continues into southwestern Alaska north of Bristol Bay.

A major facies change occurs during this time interval, with the early Mesozoic volcanic arc contributing most of the sequence in the Cook Inlet area while the Alaska Peninsula sequence was formed by marine deposition. Volcanic ash is present in all occurrences on the Alaska Peninsula, but other volcanic rocks are rare.

Shale and siltstone increase southward along the Alaska Peninsula indicating a progressively deeper water depositional site similar to the Upper Triassic sequence. The thickness of the Lower Jurassic sequence ranges between about 1,000 to 2,000 meters, generally decreasing southward. Minor erosion may have occurred locally, but there are no major unconformities between the Talkeetna Formation and the overlying Kialagvik Formation.

Middle Jurassic

Middle Jurassic strata (Figure 9) are well-exposed between Wide Bay and Puale Bay, on the Alaska Peninsula, but the main exposures for this time interval area along the west side of Cook Inlet (Detterman and Hartsock, 1966). The Alaska-Aleutian Range batholith of similar age (Reed and

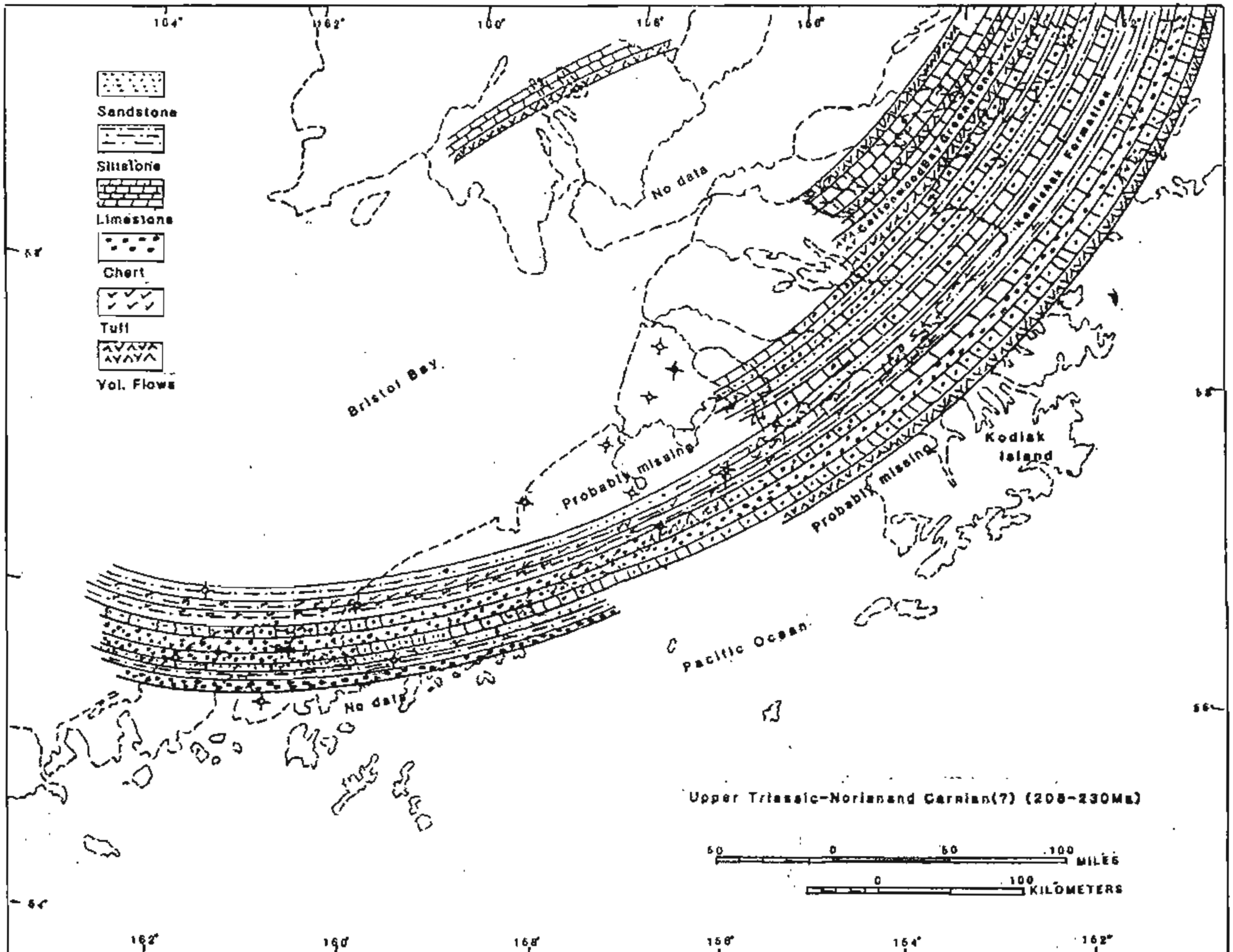

Figure 7.Extrapolation of Upper Triassic rocks in southwestern Alaska from outcrop data and exploratory wells.

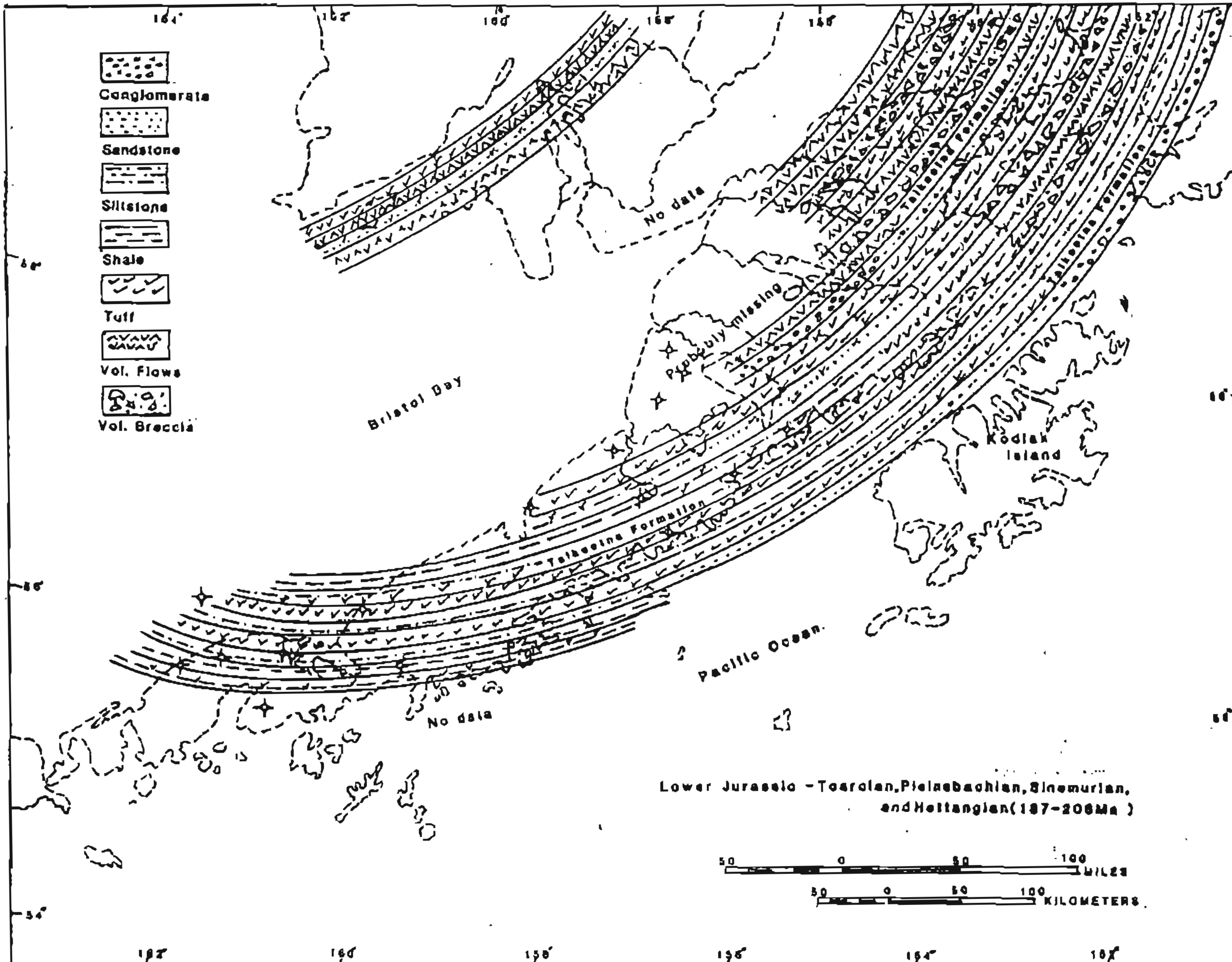

Figure 8. Extrapolation of Lower Jurassic rocks in southwestern Alaska from outcrop data and exploratory wells.

Lanphere, 1972) lies west of the sedimentary sequence and is separated from the sedimentary rocks by the Bruin Bay fault. The juxtaposition of these rock sequences along the Bruin Bay fault is the result of a later, probably early Tertiary, tectonic event. The two diverse rock sequences were probably in close proximity to each other as the batholith is believed to be the roots of the early Mesozoic volcanic arc that produce the detritus for the Middle Jurassic sedimentary sequence.

The Middle Jurassic rocks on the Alaska Peninsula and along Cook Inlet are mainly a fore arc basin and shelf sequence of volcanogenic sandstone, graywacke, siltstone and shale; it is thicker and the constituents are coarser-grained in the Cook Inlet area than on the Alaska Peninsula where the sequence becomes mainly siltstone and shale. The Cook Inlet sequence is as much as 2,500 meters thick, whereas on the Alaska Peninsula the sequence is more variable ranging between about 800 and 2,000 meters. The Middle Jurassic rocks north of Bristol Bay area mainly graywacke deposited as deep water turbidites (Hoare and Coonrad, 1978).

Upper Jurassic

Upper Jurassic rocks (Figure 10) form the backbone of the Alaska Peninsula, and are well-exposed almost the entire length as well as along Cook Inlet, and in southwestern Alaska, north of Bristol Bay. Throughout the Alaska Peninsula and Cook Inlet the Upper Jurassic sequence is mapped as the Naknek Formation, which is an inner shelf to nonmarine fine to coarse clastic unit (sheets 1 and 2; figures 5 and 6).

The Alaska-Aleutian Range batholith, of approximately the same age (Reed and Lanphere, 1972) was the provenance for the sediments comprising the Naknek Formation. Rapid facies changes are characteristic of the Naknek Formation, and superimposed on the local facies is an overall change to a finer-grained sequence in a southward direction. Part of the rapid facies changes were due to the major fluvial-deltaic build-ups in the northern Alaska Peninsula, with intervening basins containing only fine-grained rocks. Marine megafauna, mainly pelecypods, are common in all but the fluvial-deltaic deposits. Local unconformities are present within the Naknek Formation, and the upper surface of the formation has been eroded locally by both the pre-Upper Cretaceous and pre-Tertiary unconformities.

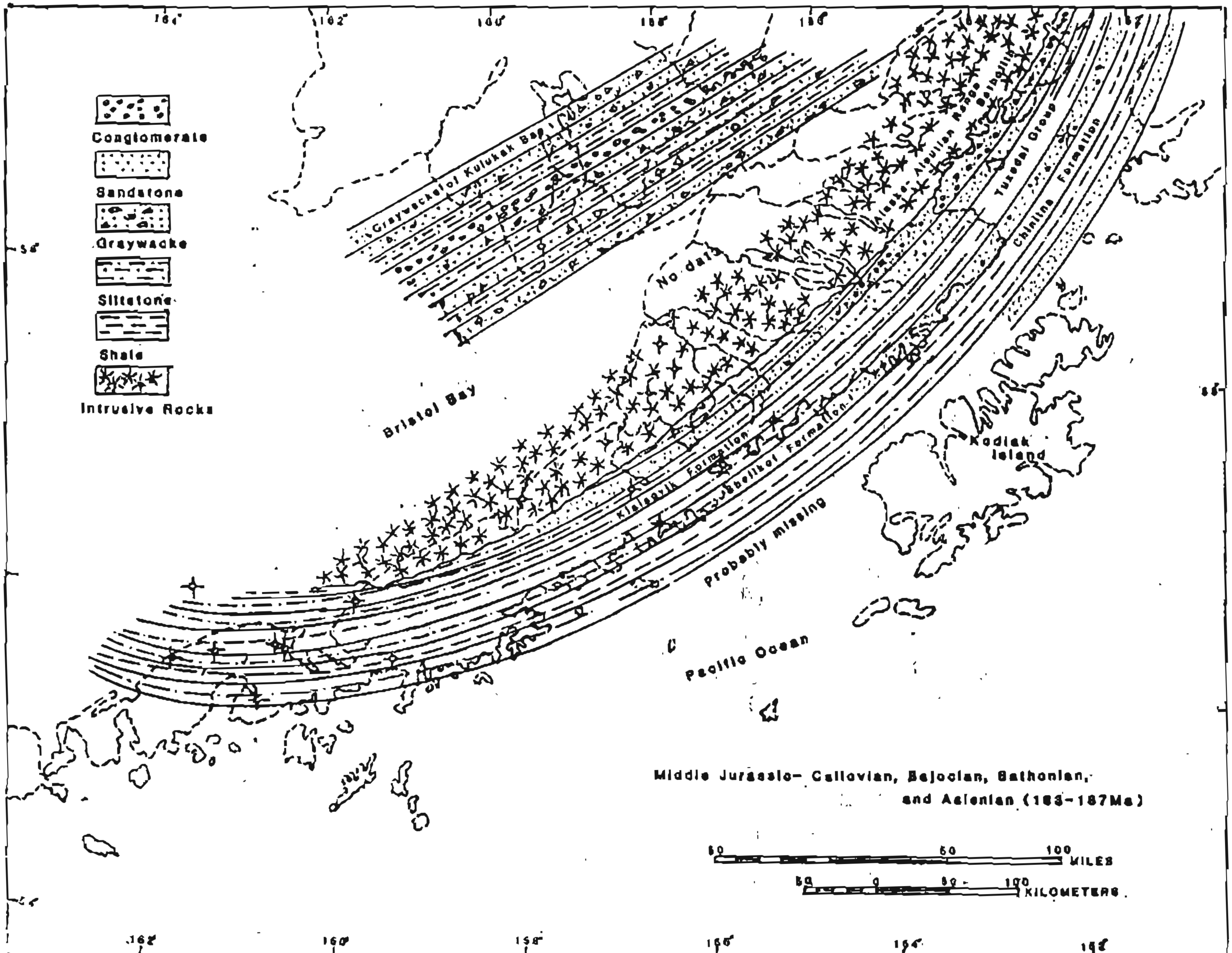

Figure 9: Extrapolation of the Middle Jurassic rocks in southwestern Alaska from outcrop data and exploratory wells.

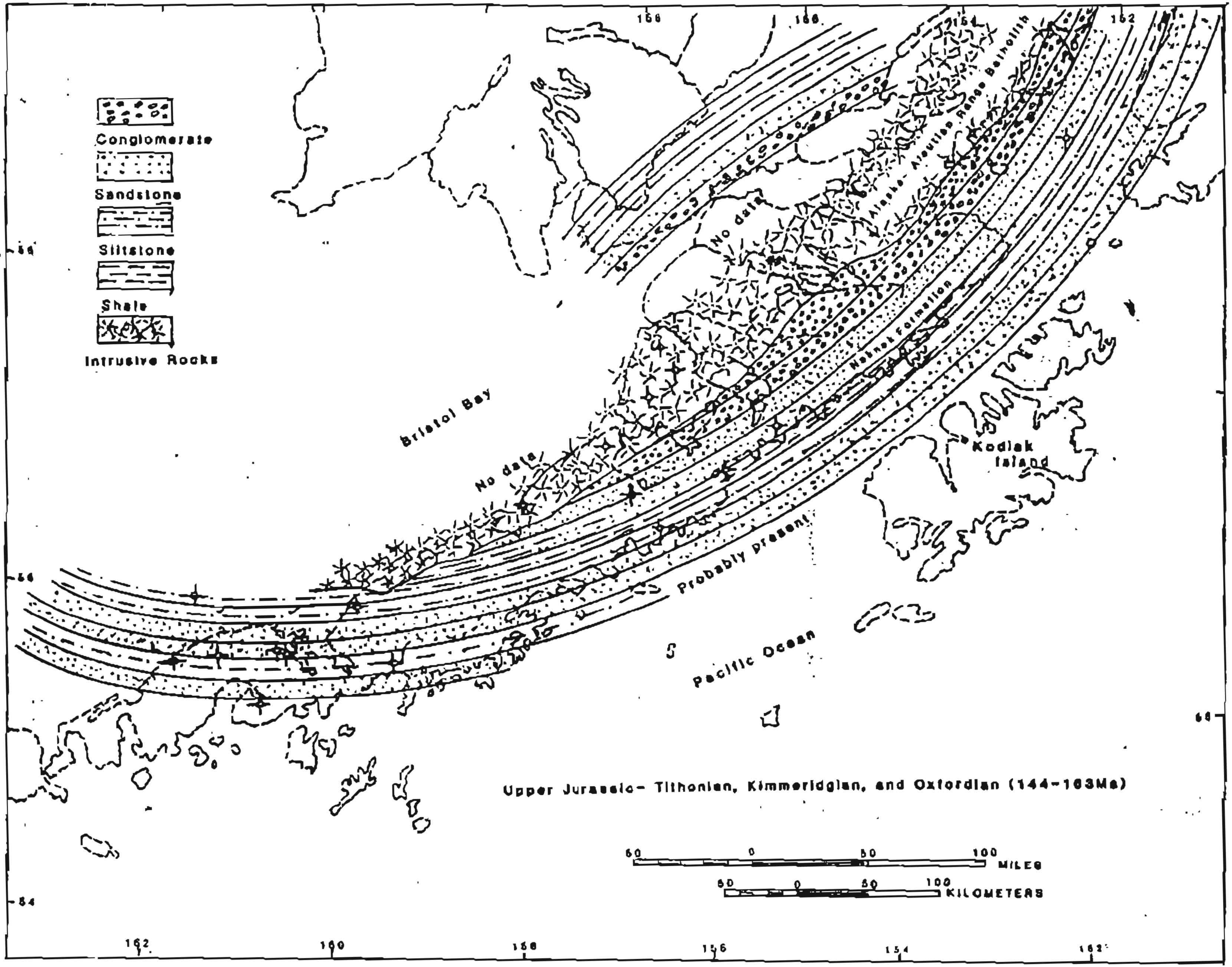

Figure 10.Extrapolation of the Upper Jurassic rocks in southwestern Alaska from outcrop data and exploratory wells.

Lower Cretaceous (Neocomian)

Neocomian strata (Figure 11), divided into the Staniukovich and Herendeen Formations, are exposed only in the Port Moller area and near the north end of the Alaska Peninsula. Exploratory wells at the south end of the peninsula have also encountered the formations at depth.

Deposition was essentially continuous across the Jura-Cretaceous boundary, but the Alaska Peninsula was becoming tectonically active and the associated uplift removed most of the Neocomian rocks and produced unconformities within the remaining sequence. The initiation of uplift can be dated as Hauterivian to Barremian during deposition of the Herendeen Formation. These rocks were deposited in a shallow-water, high-energy environment as the area was being uplifted. The Herendeen rocks consist of clean, well-sorted quartz-rich sandstone with a high percentage of broken *Inoceramus* shell material. The broken shell material make these rocks highly calcareous, but there has been little or no formation of secondary calcite so that the sandstones retain porosity and can be regarded as potential reservoir beds.

Both the Staniukovich and Herendeen are thin, with no more than 200 to 250 meters in each formation. Unconformities and other structural features commonly reduce this to less than 100 meters, and over much of the Alaska Peninsula one or both formations are missing.

Lower Cretaceous (Albian) and Upper Cretaceous

Albian strata (Figure 12) have been identified at only two localities near the north end of the Alaska Peninsula, where 50 to 80 meters of sandstone and siltstone are exposed. Elsewhere the formation, along with some of the older formations, has been removed by a major pre-upper Cretaceous unconformity.

Upper Cretaceous rocks overlying this unconformity are wide-spread along the Pacific Ocean side of the Alaska Peninsula. Most are deep-water turbidites 1000 to 3000 meters thick. The southern Half of the peninsula contains an inner neritic to nonmarine sequence of sandstone, siltstone, shale, and coal about 300 to 500 meters thick that is in part coeval with the turbidite sequence.

Paleogene

Paleogene strata (Figure 13) including sedimentary, volcanic, and intrusive rocks are widespread

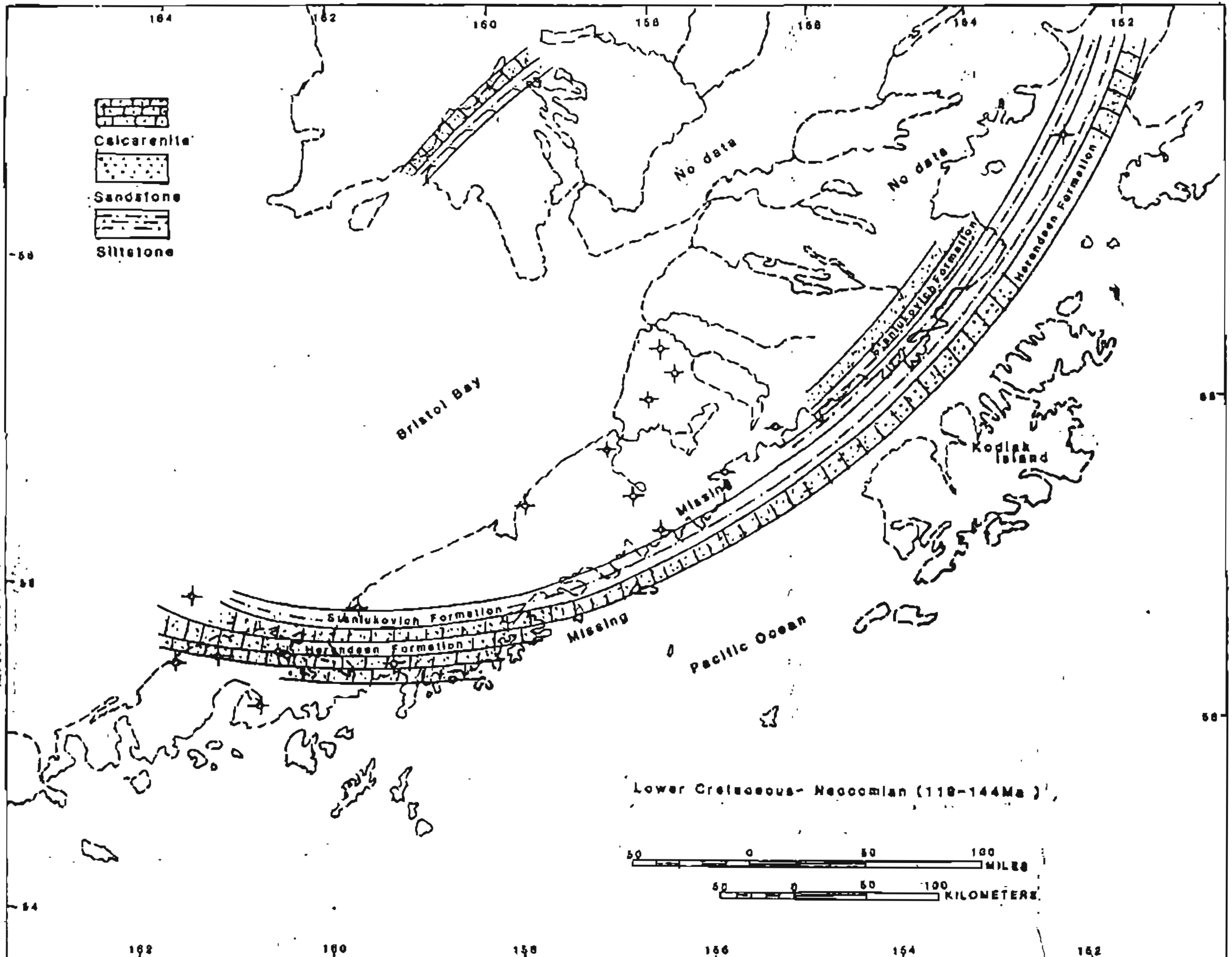

Figure 11.Extrapolation of the Neocomian rocks in southwestern Alaska from outcrop data and exploratory wells.

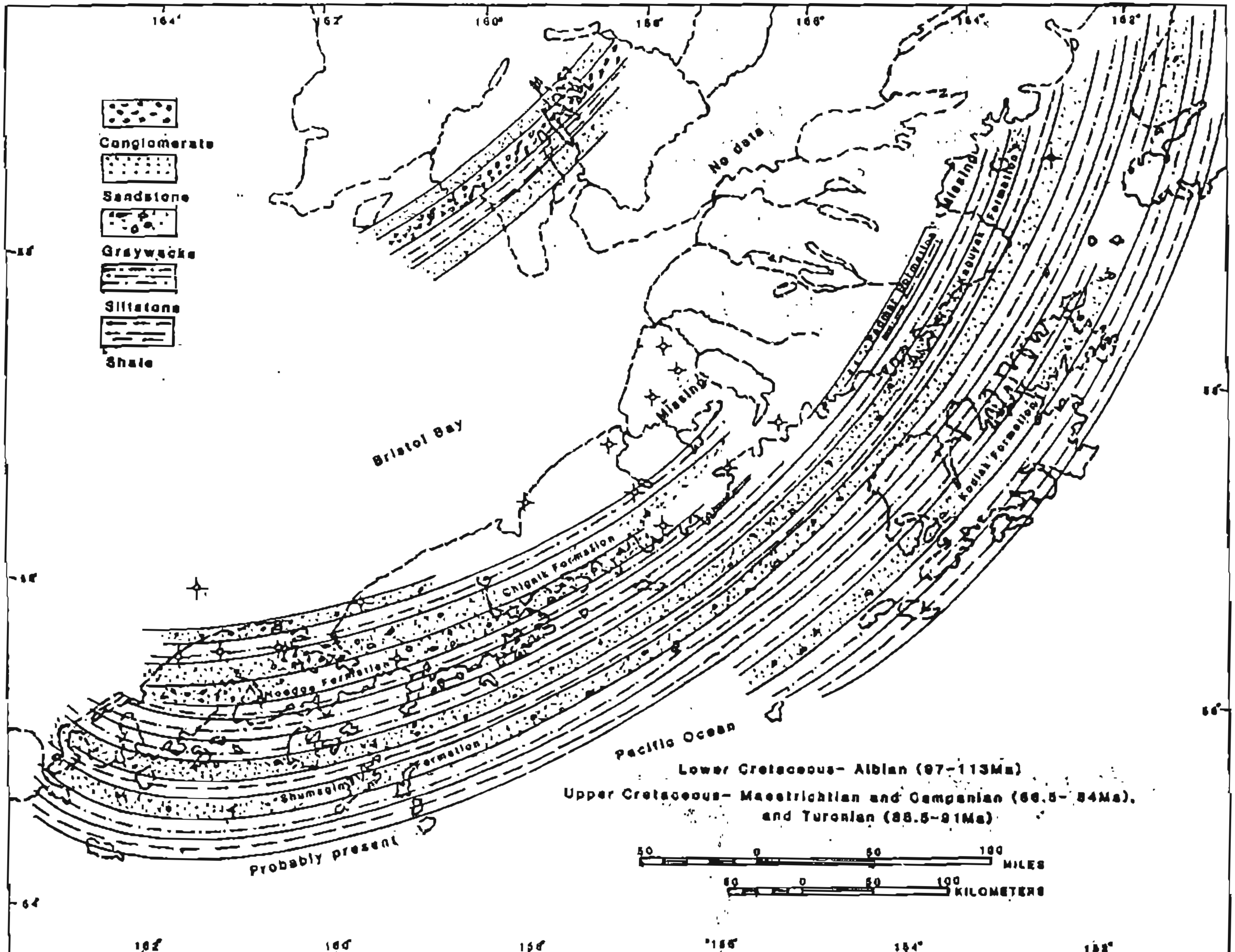

Figure 12. Extrapolation of the Albian and Upper Cretaceous rocks in southwestern Alaska from outcrop data and exploratory wells.

on the Alaska Peninsula, where they overlie a second major unconformity. This unconformity roughly corresponds to the Cretaceous-Tertiary boundary, but cannot be placed any closer than late Maestrichtian to early Paleocene time.

Sedimentary rocks of late Paleocene to middle Eocene age are present at both ends of the Alaska Peninsula; these are mainly fluvial to fluvial deltaic with minor interbedded marine strata at the south end of the peninsula. Volcanism was starting during the last part of this interval and some tuffaceous sediments are included.

A major volcanic episode (Meshik arc; Wilson, 1985) started in late Eocene time during deposition of the coeval Stepovak Formation and Meshik Volcanics. The volcanoclastic sediments of the Stepovak are confined to the southern Alaska Peninsula, and the Meshik Volcanics occur to the north. The two units interfinger throughout the middle portion.

The Paleogene sequence is about 2,000 to 3,000-meters thick except over the central part of the peninsula where it rarely exceeds 1,500 meters, and is predominately a volcanic sequence.

Neogene

By Neogene time the Alaska Peninsula was assuming its present configuration so that deposition was mainly along the east and west sides and not along the backbone of the peninsula (Figure 14). Approximately 2,000 to 3,000 meters of sedimentary rock with interbedded volcanic rocks (Bear Lake and Milky River Formations) were deposited along the west side of the Alaska Peninsula, and extend out under Bristol Bay. The Bear Lake Formation is mainly a moderately clean, well-sorted inner neritic sandstone and siltstone unit, whereas the Milky River is a volcaniclastic fluvial deposit.

Along the east side of the Alaska Peninsula the Neogene rocks are all volcanic and volcanoclastic, and range between 500 and 1,000 meters thick. These rocks are dirty, poorly sorted, and have little or no petroleum potential.

DISCUSSION

The Alaska Peninsula has been the site of considerable exploratory drilling during the past 80 years, and to date no commercial deposits of petroleum have been found. Both Tertiary and Mesozoic

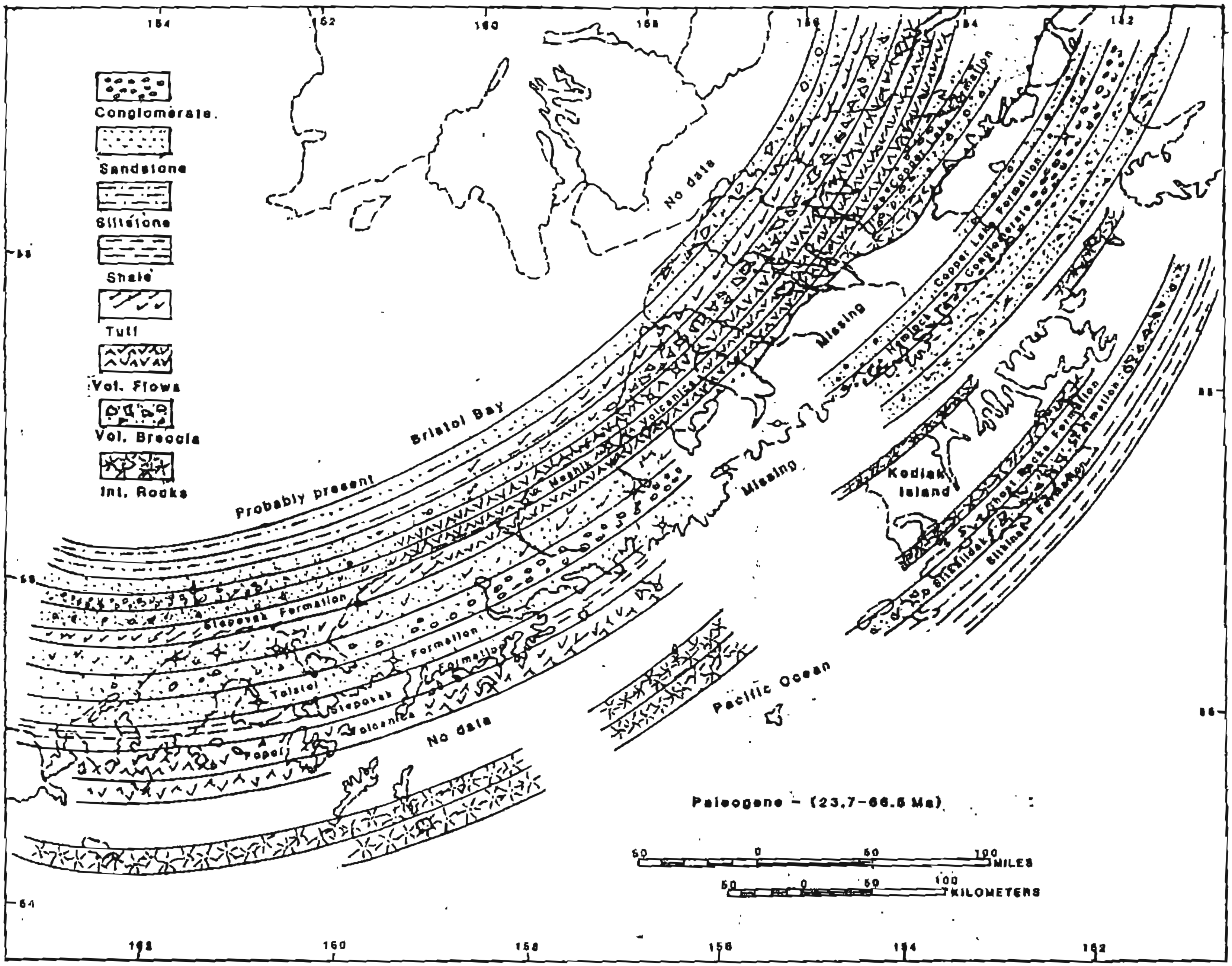

Figure 13 Extrapolation of the Paleogene rocks in southwestern Alaska from outcrop data and exploratory wells.

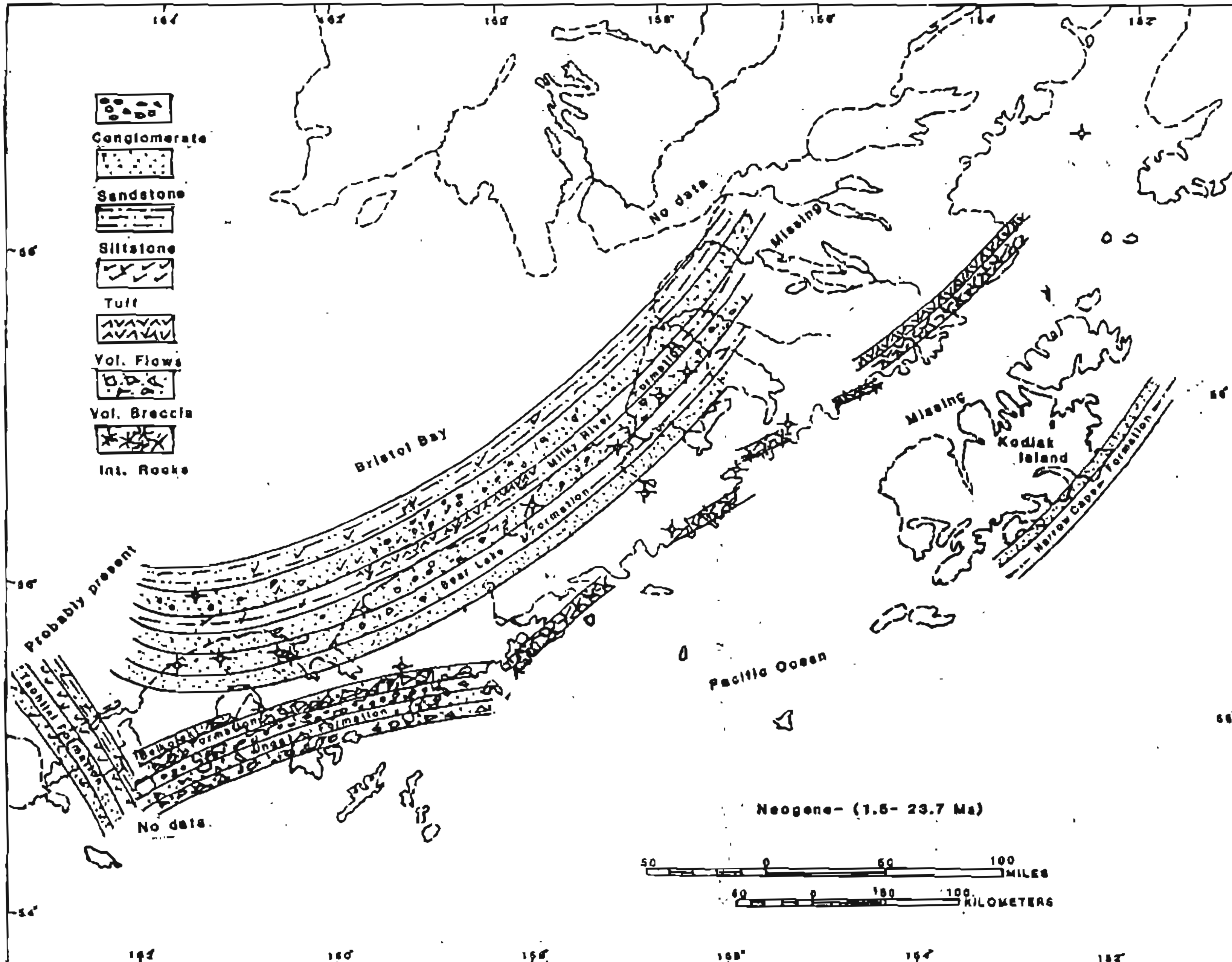

Figure 14. Extrapolation of the Neogene rocks in southwestern Alaska from outcrop data and exploratory wells..

rocks have been tested, and oil shows are almost invariably confined to Mesozoic rocks or early Tertiary rocks immediately overlying the Mesozoic sequence. All oil seeps are associated with Mesozoic strata. Probably the main reason for this is the type of organic carbon in the Tertiary rocks; it is almost entirely coaly and herbaceous material. Also, most of the Tertiary rocks are not old enough or buried deeply enough to reach maturity for the generation of petroleum.

Another reason for the poor potential for petroleum on the Alaska Peninsula is the character of the sediments. The Alaska Peninsula has been the site of repeated magmatic arcs from early Mesozoic time to the present. Consequently, the derived sedimentary rocks contain much volcanic debris. Some formations are almost exclusively volcaniclastic, and subsequent alteration of the volcanic material has drastically reduced porosity and permeability. A few formations, notably the Naknek, Herendeen, and Chignik, and to a lesser extent Tolstoi and Bear Lake, contain little volcanic material. Their sediments were derived mainly from the Alaska-Aleutian Range batholith and older sedimentary rocks and consequently these rocks have better porosity and permeability.

The numerous volcanoes and associated intrusive rocks in the form of stocks, plugs, and batholiths occupy atleast one third of the Alaska Peninsula. Heat from these sources would help generate petroleum, but at the same time greatly restrict the accumulation area. Additionally, the injection of these bodies into the sedimentary sequence forms many small local structures.

In conclusion the Alaska Peninsula has to be considered as having a low potential for the formation of major petroleum producing province. Small fields may be found and the most likely areas to prospect are near the southern end of the peninsula, and offshore to the west in this area. The stratigraphic sequence, as exposed and in the wells, generally contains less volcanic debris south of Herendeen Bay-Port Moller area in both the Tertiary and Mesozoic section. These rocks undoubtedly exist to the west under Bristol Bay, and the structures should be more open and favorable for the accumulation of petroleum. Offshore areas east of the Alaska Peninsula, particularly the southern half of the peninsula, hold little prospect as the thrusting came from the southeast and the rocks involved would include a highly deformed sequence of the Shumagin-Hoodoo Formation turbidites and a higher concentration of volcanic debris in the Tertiary sequence derived from the volcanic center forming the inner Shumagin Islands.

Samples of oil from the Alaska Peninsula compares favorably with hydrocarbons extracted from the Upper Triassic (Kamishak Formation) marine shales and Middle Jurassic (Kialagvik Formation) sandstone and shale (Magoon and Anders, 1989). The timing and method of oil generation are uncertain, but a magmatic heat source is suspected rather than overburden because of the proximity and timing of intrusion (Hudson, 1986).

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