UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Summary geologic report for the Shumagin Outer Continental Shelf (OCS) Planning Area, Alaska

by

Terry R. Bruns[1], Roland von Huene[1], Raymond C. Culotta[1], and Steven D. Lewis[2]

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards or stratigraphic nomenclature. Any use of trade names is for purposes of identification only and does not imply endorsement by the U.S. Geological Survey.

[1]U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025

[2]Columbia University
Lamont-Doherty Geological Observatory
Palisades, NY 10964

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SUMMARY

The Shumagin Outer Continental Shelf planning area encompasses the continental margin segment and adjacent Pacific Ocean floor from Unimak Pass to the Semidi Islands (Fig. 1). No previous lease sales or exploratory drilling have occurred within this region.

The oldest rocks known to underlie the margin are highly deformed, deep-water turbidites of late Cretaceous age (Shumagin Formation). These turbidites were intruded by Paleocene and early Eocene granodiorites. Paleogene sedimentary rocks of the Kodiak region may extend southwest to and underlie at least parts of the Shumagin margin but are not known in outcrops on shelf islands. The Cretaceous and Paleogene (?) rocks form acoustic basement on multichannel seismic reflection data, and are overlain by a basin fill or probable late Miocene and younger age. Mesozoic rocks of the Alaska Peninsula extend seaward only to the inferred location of the Border Ranges Fault, and are unlikely to be present beneath most of the Shumagin margin. However, the dominantly non-marine and shallow marine Cenozoic rocks of the Alaska Peninsula may be up-slope equivalents of rocks which underlie the continental shelf and slope.

The geologic history of the Shumagin margin probably includes the late Cretaceous or early Tertiary truncation of the Mesozoic Alaska Peninsula margin at the Border Ranges fault, concurrent with or followed by accretion of the thick extensive Shumagin Formation. These events were likely followed by deposition of early Tertiary strata over the accreted Mesozoic rocks. During early to middle Miocene Time, a regional erosional event similar to that of the adjacent Kodiak shelf occurred in the Shumagin margin, and removed part or most of the early Tertiary strata deposited on the shelf. During the late Cenozoic, convergence between the Shumagin margin and the Pacific plate, and deposition of large amounts of glacially derived sediment on the Pacific plate, led to development of an accretionary complex on the lower continental slope.

The Shumagin margin is characterized by five major structural features or trends: (1) Shumagin basin, containing about 2.5 km of late Miocene and younger strata above acoustic basement; (2) Sanak basin, containing as much as 8 km of dominantly late Cenozoic strata in two sub-basins separated by a basement high; (3) Cenozoic shelf-edge and upper-slope sedimentary wedges that are 3 to 4 km thick, and possibly as thick as 6 km; (4) a mid-slope structural trend, Unimak ridge, which is characterized by numerous seafloor and subseafloor structural highs; and (5) an up to 30 km wide accretionary complex at the base of the slope. A thin sediment cover, less than 1 to 2 km thick, of late Miocene and younger age covers the continental shelf areas outside of Shumagin and Sanak basins.

Little information is available on source rock, reservoir rock, or thermal maturation characteristics of rocks underlying the Shumagin margin. Studies of six samples from three dredge hauls show that the sampled rocks have poor source and reservoir rock potential and are thermally immature for generation of hydrocarbons. However, Cenozoic rocks similar to those of the Alaska Peninsula, with good source and reservoir rock characteristics, could be present beneath the shelf and slope. The geothermal gradient of the Shumagin margin is likely about 30°C/km; if so, hydrocarbon generation could occur in rocks deeper than about 3 km.

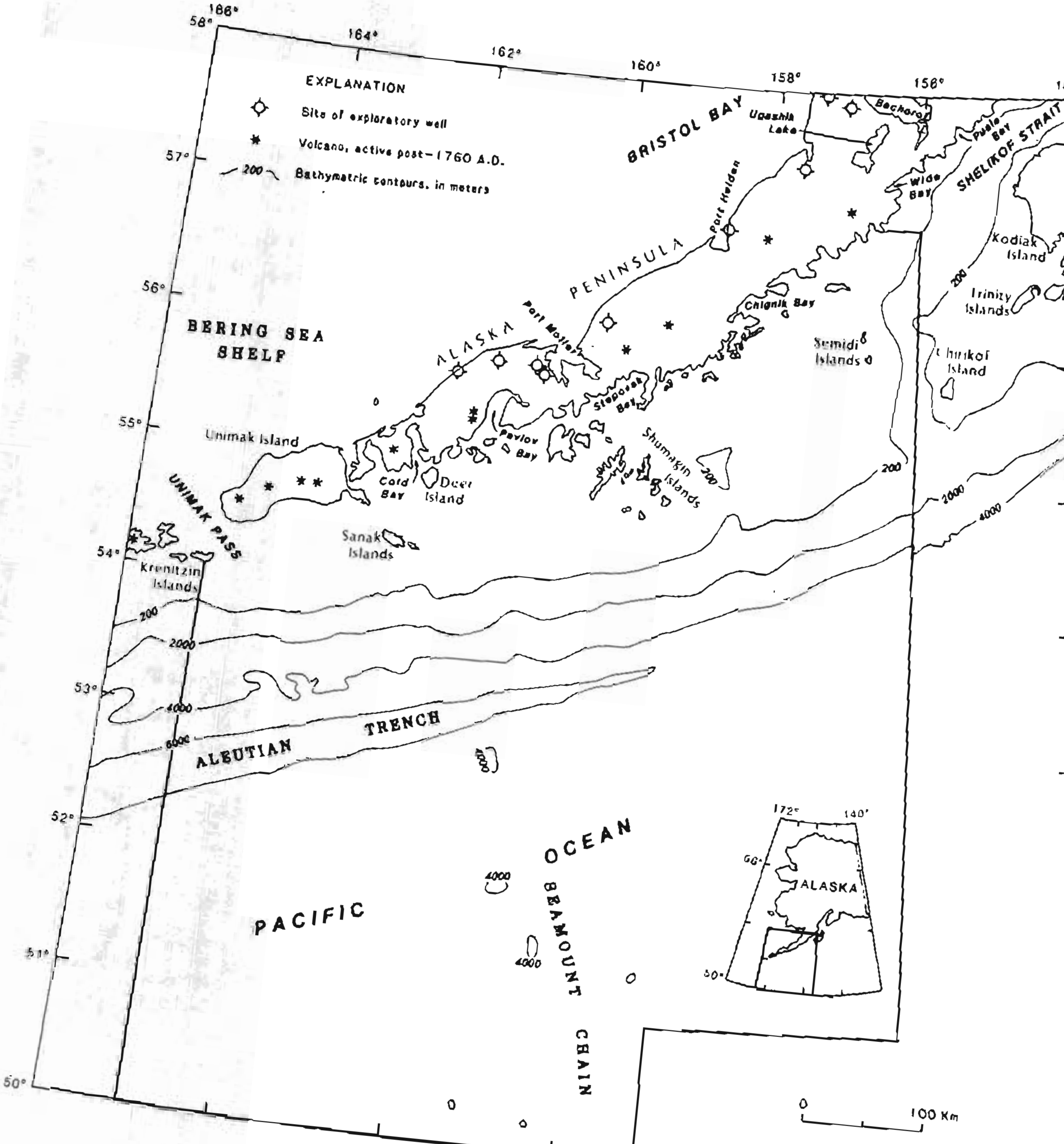


Figure 1. Index map of the Shumagin margin, western Gulf of Alaska, showing place names, bathymetry, and outline of Shumagin Outer Continental Shelf Planning Area.

Potential hydrocarbon traps of the Shumagin margin include gentle structural traps and stratigraphic traps formed by pinchouts or onlap onto acoustic basement. Such features are or may be present in Shumagin and Sanak basins, within the upper slope sedimentary sequence, and along the mid-slope structural trend. No large anticlinal traps have been defined on the shelf or upper slope similar to anticlines of the adjacent Kodiak region. If early Tertiary rocks are preserved beneath the margin, traps within these rocks may be present within the acoustic basement.

The most prospective area of the Shumagin region is the thick sedimentary sequence in Sanak basin; other prospective areas may lie beneath the outer shelf and slope. A major unknown is whether prospective rocks are limited to the Miocene and younger sedimentary sequence, or if early Tertiary rocks may be present beneath much of the shelf and slope as well. If such rocks are present, a much greater part of the region may have significant petroleum potential.

Known geologic hazards in the Shumagin region include (1) seismicity and tsunamis; (2) volcanic activity; (3) active faulting and submarine slumping; and (4) gas charged sediment and gas hydrates. Current and wave induced sediment transport, unstable sediment accumulations, and buried channels are possible additional hazards, and are known from areas adjacent to the Shumagin region, but have not yet been recognized or studied in the Shumagin region.

The seismicity and tsunami hazard of the Shumagin margin is extreme. The Shumagin region includes a seismic gap, the Shumagin gap, where a great earthquake is expected within the next 10 to 20 years, and is adjacent to a second seismic gap, the Unalaska gap, where a great earthquake could occur within the next few decades. A great earthquake in 1946 near Unalaska Island generated one of the most destructive tsunamis on record.

INTRODUCTION

This report summarizes the geology and resource potential of the Shumagin Outer Continental Shelf (OCS) Planning Area for lease sale area 86, Alaska. The study area consists of the Shumagin continental margin, the margin segment between the longitudes of 156° W. and 165° W. or roughly between Chirikof and the Semidi Islands and Unimak Pass; and the adjacent Pacific abyssal plain south to 51° N. to 50° N. latitude (Fig. 1). No lease sales or exploratory drilling have occurred within the study area. The major focus of this report is on describing new geophysical and geological data acquired by the U.S. Geological Survey in the Shumagin region in the last few years.

The geology of the islands, and of the Alaska Peninsula and Kodiak shelf adjacent to the Shumagin margin, is relatively well studied (Burk, 1965; Moore, 1972, 1973a,b, 1973b, 1974 1978; Moore and Connelley, 1977; Moore and others, 1983; Detterman and others, 1981a, b, 1983; Fisher, 1979, 1980, 1981; Fisher and Holmes, 1981; Fisher and von Huene, 1980, 1982, and in press; Fisher and others, 1981; McLean, 1977, 1979; McLean and others, 1978; von Huene, 1979; Von Huene and others, 1976, 1979a, b, 1983, and in press), but geophysical and geological studies of the submerged lands are in an early stage of investigation. Two sedimentary basins of the Shumagin margin segment were described by Bruns and Von Huene (1977), based on about 500 km of 24-fold multichannel seismic reflection data (Bruns and Beyer, 1977). These data were augmented in 1981 and 1982 by about 4000 km of 24-fold seismic reflection data, concurrently recorded gravity and magnetic data, and 49 sonobuoy refraction profiles acquired from the U.S. Geological Survey research vessel R/V S.P. Lee (Fig. 2). Geological information is almost nonexistent, and consists of rocks dredged at three sites along the continental margin during 1979. Most of these data are from the Shumagin continental margin; little data has been acquired over the adjacent deep ocean.

GEOLOGIC FRAMEWORK

The Alaska Peninsula and the adjacent shelf islands, from east to west, the Semidi Islands, Shumagin Islands, and Sanak Island, are composed of dominantly northeast-southwest striking lithologic units ranging in age from Permo-Triassic to Recent (Figs. 3 and 4; Burk, 1965). Exposed rocks of the Alaska Peninsula and the inner Shumagin Islands are island-arc related volcanic or plutonic rocks and shallow-marine and continental deposits rich in volcanic or plutonic detritus. In marked contrast, rocks of the Semidi, outer Shumagin, and Sanak Islands are thick, deep-water upper Cretaceous volcaniclastic flysch assemblages of the Shumagin Formation which are intruded by Paleocene to early Eocene granodiorites.

Although the contact between the Alaska Peninsula shallow-marine and continental rocks, and the deep water Shumagin Formation is nowhere exposed, regional geologic considerations suggest that the contact may be the southwest extension of the Border Ranges Fault (Fisher, 1981, and as discussed later). The critical element for petroleum potential of the Shumagin OCS is that pre-Cenozoic strata of the Alaska Peninsula are not known to be present beneath the continental shelf except near the Alaska Peninsula, although these pre-Cenozoic rocks were likely the source terrain for much of the Cenozoic strata of the continental shelf and slope. Also, Cenozoic rocks of the Peninsula are likely to be non-marine and shallow marine equivalents of sedimentary rocks that fill the offshore basins.

Alaska Peninsula

The oldest rocks on the Alaska Peninsula are Permo-Triassic interbedded volcanic rocks and limestones exposed near Puale Bay (Fig. 4, Burk, 1965). These rocks are conformably overlain by an early to middle Triassic sequence of volcanic flows, breccias, and tuffs, and minor limestone and chert. Intercalated exotic blocks of schist and ultramafic rocks have been radiometrically dated as 180-190 m.y. (late Triassic-early Jurassic; Forbes and Lanphere, 1973).

Lower and middle Jurassic rocks adjacent to the Shumagin shelf are exposed in areally limited outcrops near Wide Bay and Puale Bay, but are extensively exposed to the northeast around lower Cook Inlet. The lower Jurassic rocks (Talkeetna Formation) consist of volcanic breccias, flows, agglomerate, and argillites of andesitic or basaltic composition (Burk, 1965). The lower Jurassic strata are intruded by plutons approximately 176-154 m.y. old (Middle Jurassic; Reed and Lanphere, 1973). Middle Jurassic strata (Kialagvik Formation) consist of mainly shallow marine volcaniclastic sandstone, shale, and conglomerate. The abundance and thickness of the early and middle Jurassic rocks in Cook Inlet and near Paule and Wide Bays suggests that rocks of this age may be present in the subsurface of the Alaska

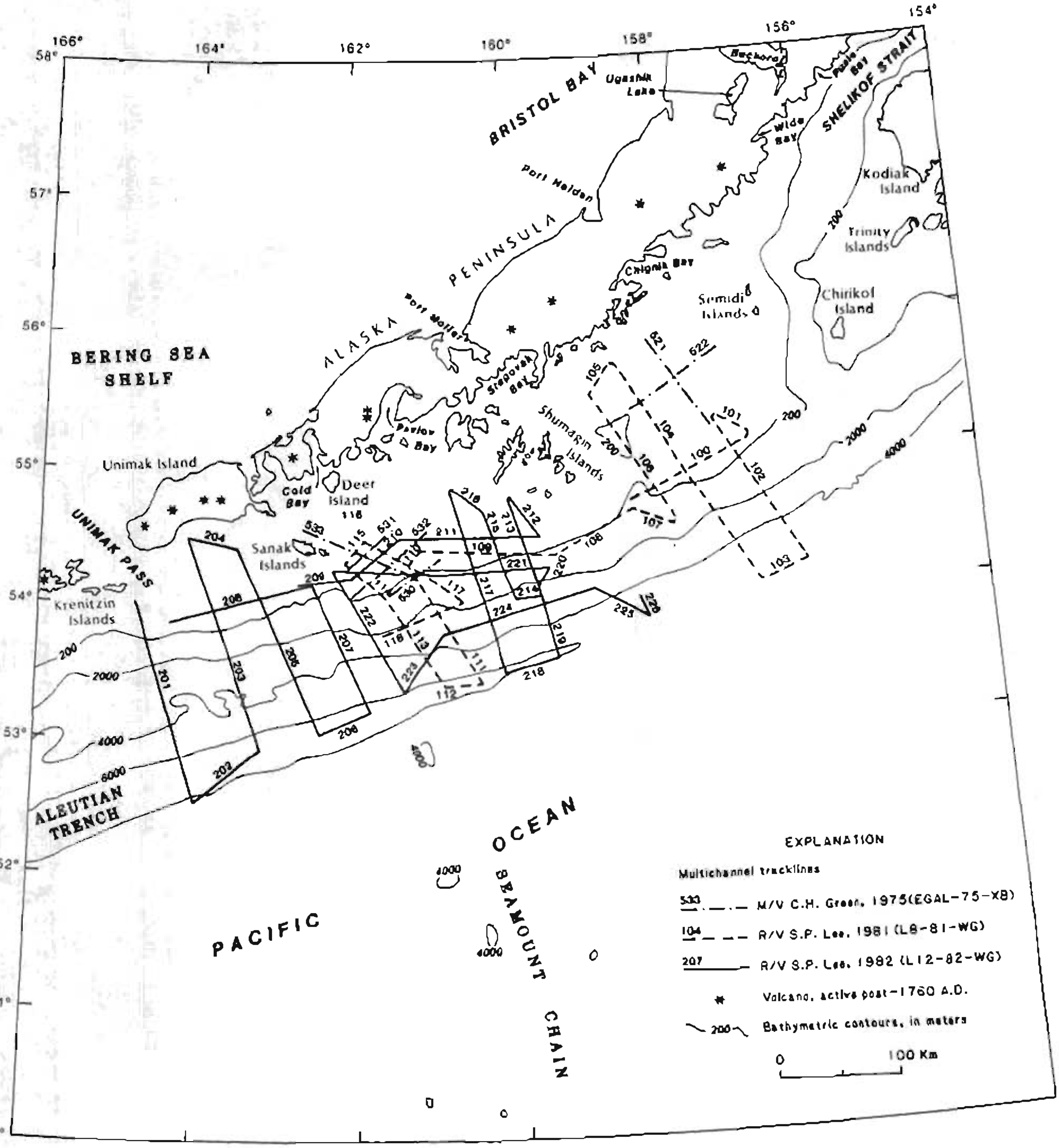


Figure 2. Tracklines of multichannel seismic data acquired by the U.S. Geological Survey in the Shumagin region, Alaska.

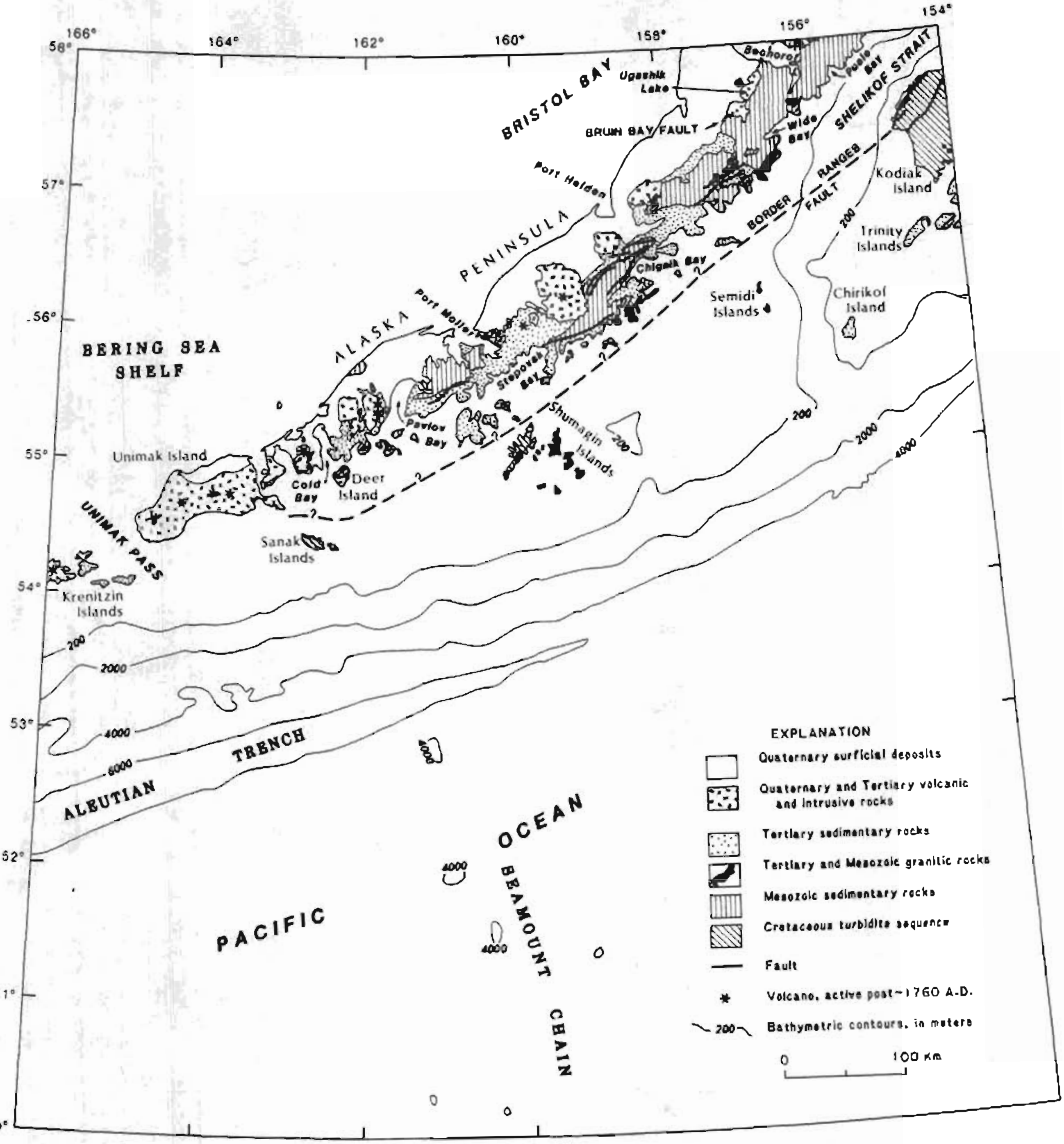


Figure 3. Simplified geology of the Shumagin region.

		ALASKA PENINSULA	SHUMAGIN MARGIN	KODIAK MARGIN
QUATERNARY	Recent and Pleistocene	Alluvial, glacial		
TERTIARY	Pliocene	Milky River Formation		Tugidak Formation
	Miocene	Bear Lake Formation		
	Miocene and Oligocene(?)			Narrow Cape Formation
	Oligocene			Sitkinak Formation
	Oligocene and Eocene	Meshik Formation		Sitkalidak Formation
	Eocene and Paleocene	Tolstoi Formation		Ghost Rocks Formation
CRETACEOUS	Upper Cretaceous	Hoodoo Formation Chignik Formation	Shumagin Formation	Kodiak Formation
	Lower Cretaceous	Herendeen Limestone		Uyak Formation
CRETACEOUS AND JURASSIC	Lower Cretaceous and Upper Jurassic	Staniukovich Formation		
JURASSIC	Upper Jurassic	Naknek Formation		
	Middle Jurassic	Shelikof Formation		
	Middle and Lower Jurassic	Kialagvik Formation		
	Lower Jurassic	Talkeetna Formation		
TRIASSIC	Upper Triassic			Shuyak Formation
PERMIAN	Upper Permian	Limestone		

Figure 4. Sedimentary formations of the Alaska Peninsula, Shumagin, and Kodiak regions, from Detterman and others (1981) and Burk (1965).

Peninsula (Burk, 1965), although they have not been sampled in exploratory wells southwest of Puale Bay.

Upper Jurassic and lower Cretaceous age rocks unconformably overlie the older rocks and constitute a thick (up to 2000 m), conformable, distinctive sequence throughout the Alaska Peninsula. These rocks include the extensively exposed Naknek Formation, the less extensively exposed, overlying Staniukovich Formation, and the Herendeen Limestone, mainly exposed in the vicinity of Port Moller and in limited areas elsewhere. The Naknek Formation includes a shallow-marine to fluvial non-marine lower member of thick-bedded to massive arkosic sandstones and conglomerates, and an upper member of shallow marine siltstone and shale. The conglomerate includes abundant granitic clasts. The Staniukovich Formation is mainly marine thin-bedded sandstone, siltstone, and shale. The Herendeen limestone consists of thin bedded calcarenite and thin limey sandstone (Burk, 1965; Detterman and others, 1981, 1983).

The source terrain for the upper Jurassic and lower Cretaceous age clastic rocks is of dominantly hornblende-biotite granitic composition (Burk, 1965). The sequence was probably deposited in a rapidly subsiding basin near a rapidly rising source. Burk (1965) suggests that the Bruin Bay Fault (Fig. 3) may have been a locus of much of this differential vertical movement. Mapping near lower Cook Inlet by Detterman and Hartsock (1966) indicates that at least 3 km of vertical movement has occurred on this fault.

Late Cretaceous rocks of the Alaska Peninsula include the Chignik and Hoodoo Formations, which unconformably overlie the Herendeen Limestone and Staniukovich Formations. The Chignik Formation is a cyclic, near-shore marine and non-marine sedimentary rock unit consisting of as much as 500 m of cross-bedded sandstones and siltstones with minor coal. The Hoodoo Formation conformably overlies the Chignik Formation and consists of as much as 500 m of rhythmically bedded dark-gray shale, siltstone, and thin sandstone, deposited as deep-water turbidites (Burk, 1965; Detterman and others, 1981, 1983).

Cenozoic rocks of the Peninsula consist of the Tolstoi (Eocene and Paleocene), Meshik and Stepovak (Oligocene and late Eocene), Bear Lake (late and middle(?) Miocene), and Milky River (Pliocene) Formations. The Stepovak Formation is as much as 4500 m thick, and the other formations as much 1500 m thick. All the formations are separated from each other by unconformities. The lithologies of the Tolstoi, Bear Lake, and Milky River Formations are similar, consisting of dominantly non-marine and subsidiary shallow marine volcaniclastic sandstone, conglomerate, siltstone, shale, and minor coal. The Meshik Formation consists mainly of coarse volcanic rubble, lahars, basalt and andesitic flows, tuffs, and minor volcanogenic sedimentary rocks. The Stepovak Formation is a finer grained and thicker equivalent of the Meshik, and consists of interbedded volcanic sandstone and conglomerate with much black siltstone and some lignite beds. The upper part of the Milky River Formation contains numerous andesitic flows, lahars and tuff beds interlayered with the sedimentary rocks; these volcanic rocks are thicker and more numerous upward. Volcanic and intrusive rocks of Cenozoic age are widespread on the Alaska Peninsula, and provided much of the volcaniclastic material found in the sedimentary rocks (Burk, 1965, Detterman and others, 1981, 1983).

The composition of the Mesozoic rocks on the Alaska Peninsula, with large amounts of volcaniclastic and plutonically derived rocks, indicates that a volcanic arc was active during middle Mesozoic time. Episodes of plutonic activity occurred in the middle Jurassic and late Cretaceous time. Rapid uplift and erosion of the middle Mesozoic plutons subsequently occurred during the late Mesozoic. Formations containing fossiliferous limestone and coal bearing units indicate deposition in a stable shelf environment during the Mesozoic (Burk, 1965).

The abundance of volcanic debris in the Cenozoic sedimentary sequences indicates that the Aleutian volcanic arc remained active throughout the Cenozoic. Volcanic and intrusive activity along the Cenozoic arc was episodic. A mid-Tertiary magnatic episode occurred from about 40 to 20 m.y., and is marked by exposures of mainly andesites and basaltic andesites. At about 22-25 m.y., a small series of andesitic volcanics and hypabyssal andesite intrusives were injected eastward of the older volcanics. A major pulse occurred in the 3 to 7 m.y. range, with emplacement of several large granodiorite batholiths and associated andesite to dacite volcanics along the Pacific coast side of the Alaska Peninsula. The currently active volcanic cycle started about 7 m.y. ago with initial basalt eruptions changing to andesite and culminating in dacite. The centers for this activity moved westward of the mid-Tertiary centers. Abundant late Tertiary to Recent volcanic flows and intrusive plugs, and numerous active or recently active volcanoes mark the location of the present-day Aleutian volcanic arc (Burk, 1965; Moore and others, 1983; Von Huene and others, in press).

Continental shelf

Rocks outcropping on islands of the continental shelf in the study area comprise the Shumagin Formation and Paleocene granodiorites. The Shumagin Formation, exposed on the Sanak, outer Shumagin, and Semidi islands within the study area, is part of an extensive belt of similar rocks that are exposed on Kodiak Island (Kodiak Formation), the Kenai Peninsula, and in the Chugach and Saint Elias Mountains of southern Alaska. The Shumagin and Kodiak Formations consist of complexly deformed deep-water turbidite sandstone, siltstone, and graywacke that probably accumulated as a trench and trench-slope deposit (Burk, 1965; Moore, 1974; Nilsen and Moore, 1979; Nilsen and Zuffa, 1982), and is dated as late Cretaceous (Maastrichtian) on the basis of sparse fossils (Burk, 1965; Jones and Clark, 1973). The formations are cut by Paleocene plutons, indicating deformation and emplacement in latest Cretaceous and early Paleocene time.

The composition of rocks within the Shumagin and Kodiak Formations is different from the rocks of the Alaska Peninsula. The Shumagin strata are characterized by a great abundance of angular fragments of felsic volcanic rocks and with abundant phenocrysts of plagioclase laths. Such material is rare in the upper Cretaceous of the Alaska Peninsula. Thus, the source of the Shumagin Formation is markedly different from the source of the Alaska Peninsula clastic sedimentary rocks (Burk, 1965). Deposition of the Shumagin Formation probably occurred in slope basins or a trench setting (Moore, 1974), and uplift and subsequent exposure of the formation is related to processes of subduction-accretion along a convergent margin.

Cenozoic rocks are not exposed on the shelf islands of the Shumagin shelf, but are extensively exposed on strike to the northeast along the seaward part of Kodiak Island, and have been sampled in an exploratory well near Middleton Island in the northern Gulf of Alaska (Keller and others, 1984). These Cenozoic rocks could extend southwest along strike and underlie the outer shelf and upper slope of the Shumagin segment. Cenozoic rocks on Kodiak Island include the deep-water turbidites and interbedded mid-ocean ridge basalts of the Paleocene Ghost Rocks Formation, late Eocene to Oligocene(?) turbidites of the Sitkalidak Formation, nonmarine to shallow marine rocks of the Oligocene Sitkinak and upper Miocene Narrow Cape Formations, and shallow water sedimentary rocks of the late Pliocene Tugidak Formation (Moore, 1969; Byrne, 1982; Moore and others, 1983; Nilsen and Moore, 1979; Moore and Alwardt, 1980, and Von Huene and others, in press). The Ghost Rocks and Sitkalidak Formations are complexly deformed and overlain with angular unconformity by the less deformed Sitkinak Formation. Rocks similar to those of the Narrow Cape and Tugidak Formation could comprise part or much of the basin filling rocks of the Shumagin segment. Based on seismic stratigraphic studies and well data, the basin fill of the Kodiak shelf is considered to be late Miocene and younger (Fisher and Von Huene, 1980; Keller and others, 1984).

Dredge Samples

During 1979, rocks were dredged at three sites on the Shumagin continental margin from the U.S. Geological Survey vessel R/V Sea Sounder (Figs. 5, 6, 7). These samples are the only dredge samples that have been acquired along a 600 km long continental margin segment, and are clearly insufficient to characterize the sedimentary rocks that underlie the margin.

A description of selected samples is given in Table 1, and seismic sections showing the locations of the dredge hauls are shown in figures 6 and 7. Obvious rounded or striated erratics were excluded from analysis, and the rocks described, with one possible exception discussed below, are representative of several samples from the dredge hauls. Thus, we believe these rocks are from outcrops and are indicative of the sedimentary section exposed on the continental slope at the dredge sites.

Sites 2 and 3 were on the north and south flanks respectively of Unimak Seamount, a prominent, mid-slope bathymetric high about 60 km south of Sanak Island (Fig. 6). About 70 percent of the rocks recovered from Site 2 were siltstones and mudstones, about 20 percent were sandstones or coarse-grained volcanoclastic rocks, and about 10 percent were erratics. Rocks recovered at Site 3 were 50 percent basalt, 10 percent mudstone, and 40 percent erratics.

Site 4 was on the west wall of a submarine canyon located south of the Shumagin Islands (Fig. 7). About 80 percent of the recovered samples were sedimentary rocks, 10 percent were igneous, and 10 percent were erratics.

Four rock units were sampled from Sites 2 and 3 on Unimak Seamount:

(1) A late Eocene (late Narizian) calcareous mudstone (sample 2-10; dated by foraminifera). This rock was unique in the dredge haul. It could be an erratic, as it was moderately rounded and well indurated. However, the rock was atypical of other erratics, which were hard, rounded metamorphic and igneous rocks, usually with glacial striations. Thus, we feel the rock could be an indication of a continental slope rock unit. Clearly, however, the occurrence of Eocene rocks at this location must be considered as questionable until confirmed by further sampling.

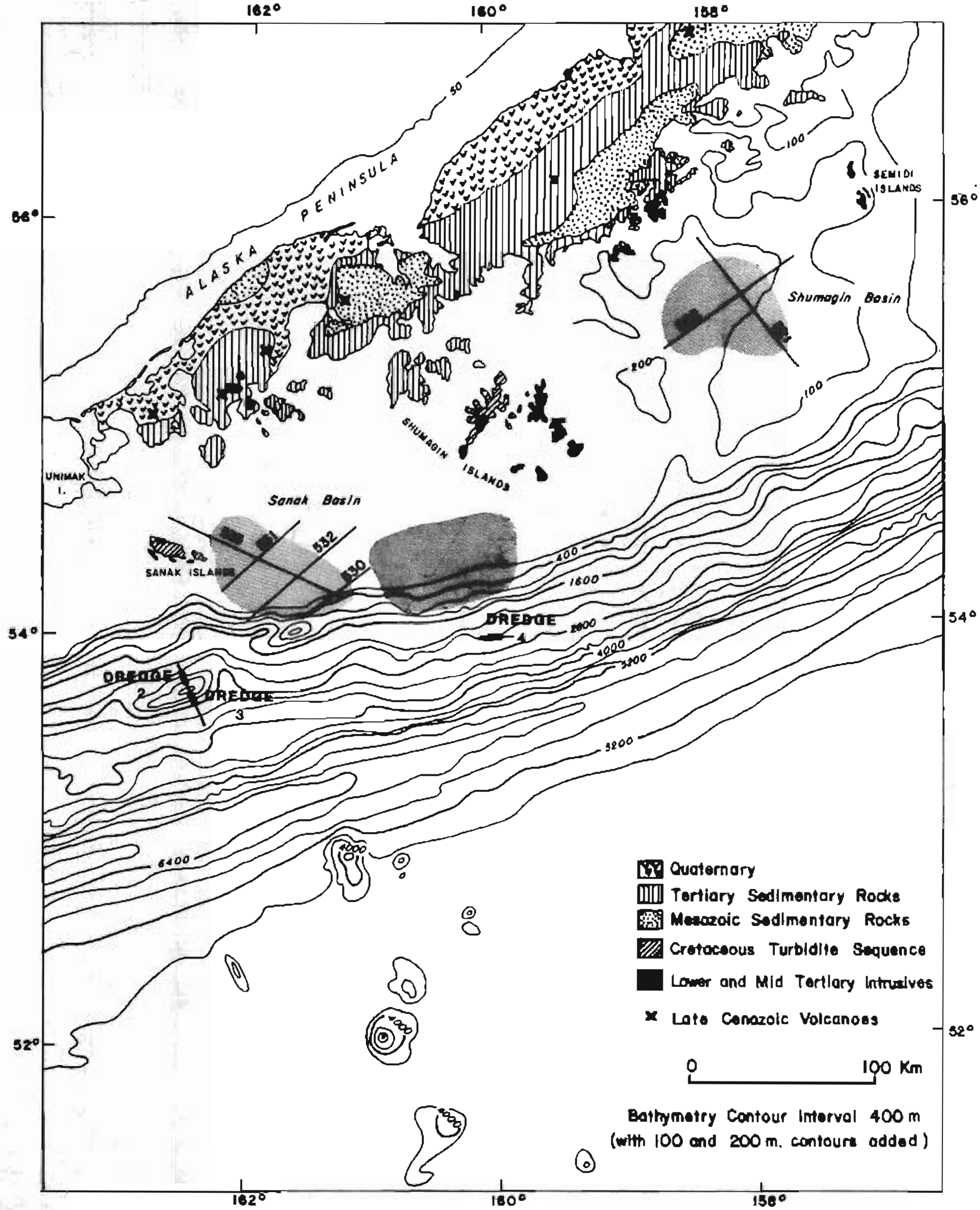


Figure 5. Locations of dredge hauls from the Shumagin margin.

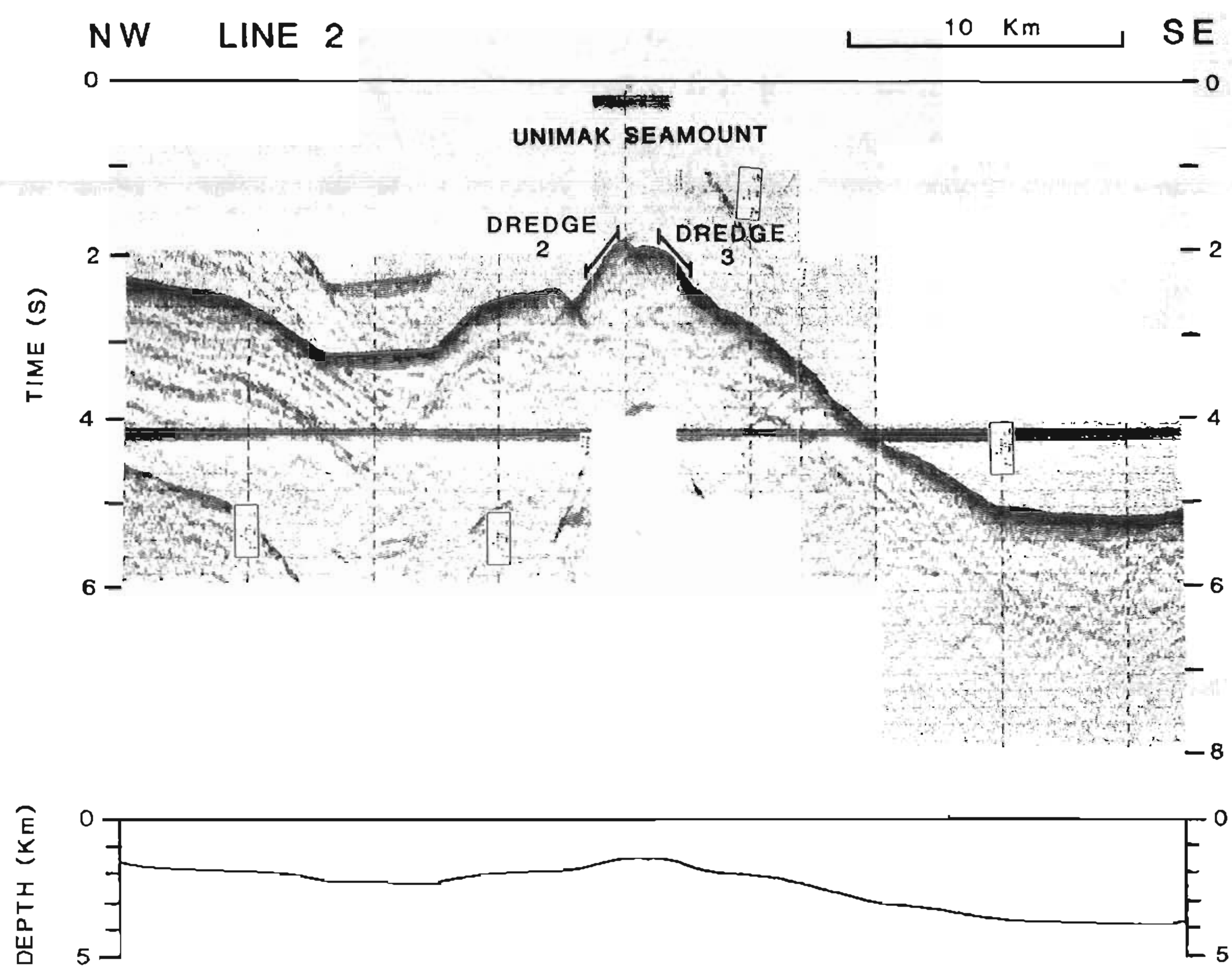


Figure 6. Single-channel seismic reflection line showing locations of dredges 2 and 3; line location shown in Fig. 5.

(2) An early to middle Miocene sequence of mudstone, siltstone (samples 2-6 and 2-8, dated by abundant diatoms), and volcaniclastic sandstone (samples 2-1, 2-2, and 2-4). Rocks of this unit all contain abundant pumice and glass shards, indicating proximity to an active volcanic chain during deposition. None of the coarse grained rocks included in this unit are dated. We feel that these coarse rocks are of early to middle Miocene age, based on their occurrence with the abundant, well-dated early to middle Miocene fine-grained rocks from Site 2. The coarse volcaniclastic sandstones have a probable quartz diorite or granodiorite source rock. Several samples were composed primarily of volcanic glass shards and pumice fragments (for example, sample 2-4).

(3) Upper Pliocene to Quaternary mudstone (sample 3-2). This unit is represented by two cobbles.

(4) Basalt (samples 3-1 and 3-3). The basalt is represented by two large (30x30x20 cm) pieces from Site 3, and, in thin section, is typical of an oceanic seamount basalt (D.A. Clague, written communication, 1983). The age of the basalt is unknown, but these rocks likely underlie the sedimentary rocks described above, since they are atypical of either island arc basalts, or the volcanic component observed in the sedimentary rocks. Age dating and geochemical analysis of these basalts is in progress.

Site 4 yielded rocks of two kinds:

(1) Hard, nodular limestone and calcareous siltstone (samples 4-1, 4-3, and 4-6). Based on diatom analysis, these rocks are of late Pliocene to early Pleistocene age.

(2) Dacite and basaltic andesite. The recovered igneous rocks include hornblend dacite porphyry (samples 4-4 and 4-11) and basaltic andesite (samples 4-8, 4-9, and 4-12). Both rock types are characteristic of an island arc setting. These rocks have undergone high temperature alteration, suggesting a hypabyssal origin (D.A. Clague, written communication, 1983). The ages of the rocks are unknown.

Multichannel seismic reflection data indicate that Unimak Seamount is part of a mid-slope bathymetric and structural high, herein Termed Unimak ridge, that stretches from Unimak Pass to the Shumagin Islands. North of the ridge, a thick (2 to 3 km or more), seaward-dipping sedimentary wedge onlaps and may be in part folded into the north side of the ridge. The large number of early to middle Miocene age rocks recovered from the seamount suggests that the sedimentary section on the seamount and adjacent continental slope includes rocks of that age. Seismic reflectors can be traced from the seamount towards the sedimentary strata of Sanak Basin, a graben-like basin northeast of Sanak Island with up to 8 km of section (discussed later, Bruns and von Huene, 1977), suggesting the basin may include strata of early and middle Miocene age. In contrast, basins of the Kodiak shelf, in a similar tectonic setting to the northeast, contain primarily late Miocene and younger strata unconformably overlying lower Eocene to lowermost Miocene strata (Fisher and von Huene, 1980).

TECTONIC SETTING

The Shumagin region can be divided into discrete, fault bounded tectonostratigraphic terranes (Fig. 8). Each terrane is characterized by a geologic history that is distinct from that of neighboring terranes. The basic terrane nomenclature is from Jones and others (1981). The terrane character and boundaries are best exposed in the Kodiak Island region, but certainly extend along strike into the Shumagin margin region. The following discussion is abstracted from a transect study across the Kodiak Island region (Von Huene and others, in press).

The Alaska Peninsula is part of the Peninsular terrane, and extends from a poorly defined boundary in the Bering Sea to the Border Ranges fault on Kodiak Island. The Peninsular terrane underlies the inner Shumagin shelf.

The Cretaceous Kodiak Formation of Kodiak Island and the Shumagin Formation are part of the Chugach terrane, while the Cenozoic rocks of Kodiak Island are part of the Prince William terrane. These terranes are separated by the Contact fault, although as noted by Von Huene and others (in press), this fault is an artificial subdivision because the Cretaceous Kodiak and early Tertiary Ghost Rock Formations were sequentially accreted, and both were intruded by the same suite of granodioritic plutons by 60 m.y. We herin consider these terranes as the Chugach-Prince William terrane. The seaward part of this terrane extends to the base of the continental slope and to the active accretionary zone.

The Pacific plate is a third terrane and is underthrusting the continental margin. The igneous ocean crust beneath the trench along the study area is late Paleocene to early Eocene in age, based on magnetic anomalies.

The Peninsular terrane is comprised of two distinct subterranes separated by the Bruin Bay fault. West of the fault is the Iliamna subterrane which consists of highly deformed rocks ranging in metamorphic grade from greenschist to amphibolite facies and including schist, gneiss, marble, greenstone, and metavolcanics all intruded by the Jurassic Alaska-Aleutian Range batholith. Late Cretaceous granitic rocks intrude the western edge of the Jurassic batholith and middle Tertiary plutons occur farther west. East of the Bruin Bay fault are slightly deformed clastic and carbonate rocks comprising the Chignik subterrane. The base of the Chignik subterrane stratigraphic sequence is the thin Permian and Triassic platform carbonates with interbedded basalt flows. This is overlain by more than 4 km of slightly deformed clastic rocks, dominantly non-marine to shallow marine, but including submarine fan and slope sediments of middle Jurassic and late Cretaceous age deposited on a southeast facing paleoslope and overlain by continental shelf and fluvial deposits. The Mesozoic volcanic arc was confined to the Iliamna subterrane, but tuffaceous sediments and basalt flows, probably derived from that arc, are included in the Chignik subterrane in rocks as old as Triassic. The two subterranes were then probably in close proximity to each other, but not definitely welded together until mid-Jurassic (Callovian) time when clasts of the volcanic arc and batholith became the main source of sediments for the Chignik subterrane.

The Iliamna subterrane was probably thrust southeastward over the Chignik subterrane (von Huene and others, in press). Early Tertiary (Paleocene-

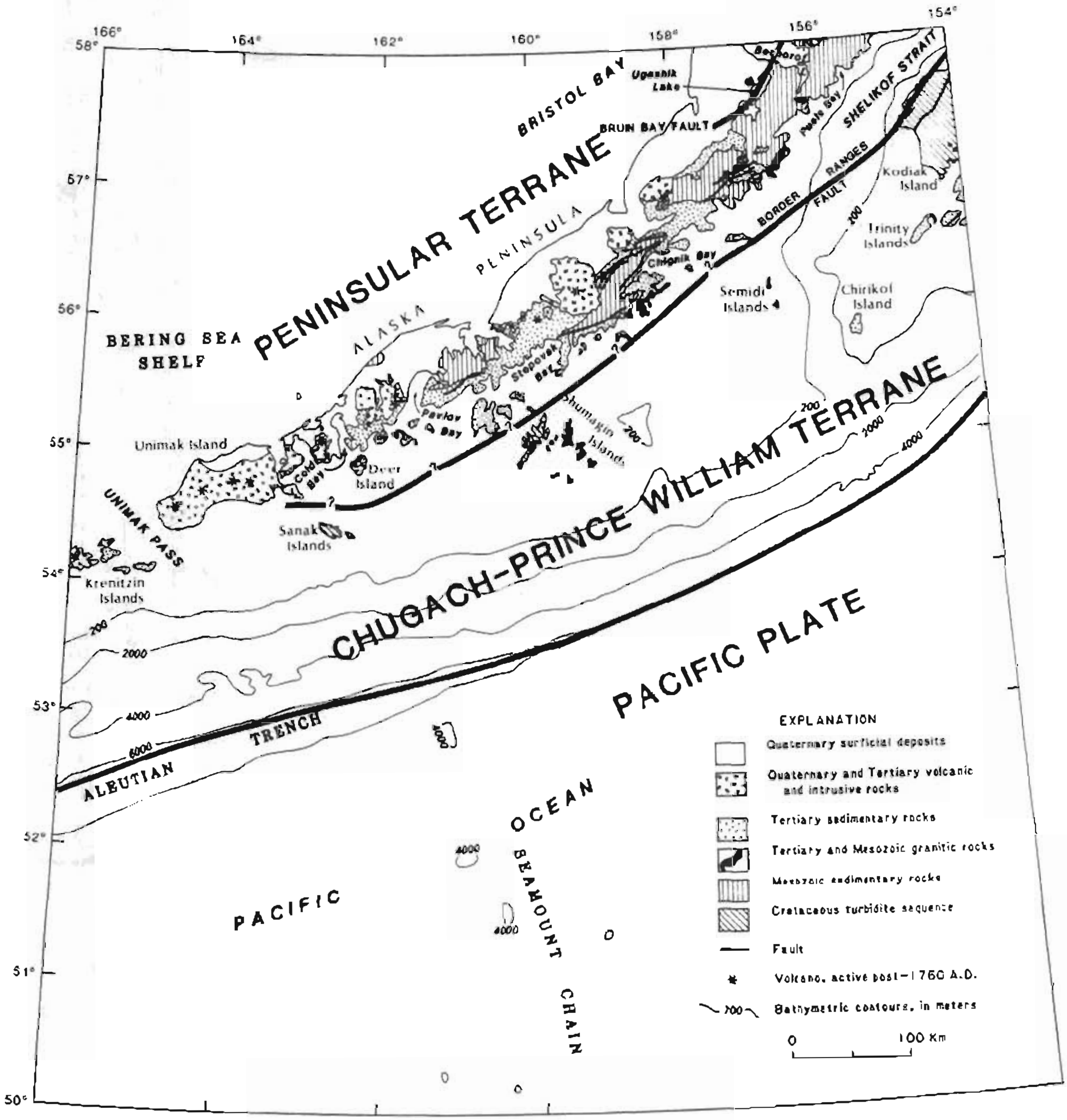


Figure 8. Tectonostratigraphic terranes of the Alaska Peninsula-Shumagin margin region.

Eocene) clastic rocks locally cover both terranes and indicate that at least by early Tertiary time, the two terranes were acting as one coherent unit.

The Peninsular terrane underlies the northwest side of Kodiak Island to the Border Ranges Fault, and includes late Triassic volcanic and volcaniclastic rocks, schist with early Jurassic metamorphic ages, and an early Jurassic diorite and quartz diorite plutonic unit that intrudes the schist and volcanic units. Along the northwest side of Shelikof Strait, a major fault apparently drops a part of the Chignik subterrane 5 km downward under the Strait. The terrane basement is then steeply tilted upwards onto the exposures of Kodiak Island (Fisher and von Huene, in press; Fisher and Detterman, in preperation).

The Chugach-Prince William terrane lies southeast of the Border Ranges fault and includes the early Cretaceous Uyak Complex, a melange formed during juxtaposition of the Chugach-Prince William terrane against the Peninsular terrane, the Kodiak Formation, and the Cenozoic rocks of Kodiak Island and the Kodiak shelf. The Border Ranges Fault thus separates the older non-marine and continental shelf rocks of the Peninsular terrane from the Cretaceous and younger accreted deep ocean turbidites and overlying shelf and slope rocks of the Chugach-Prince William terrane.

Border Ranges Fault tectonism could extend from early to late Cretaceous. In the Anchorage area Pavlis (1982) argues for tectonism on the fault between 120 and 135 m.y. ago. Border Ranges Fault tectonism may have steeply tilted a Jurassic and Cretaceous section in Cook Inlet during the Late Cretaceous (Fisher and von Huene, in press). The Uyak Complex structurally overlies the late Cretaceous Kodiak Formation in some areas (Connely and others, 1977). Deformation within the Uyak Complex suggests underthrusting orthogonal to the Border Ranges Fault. Whatever its age, Border Ranges Fault tectonism resulted in the truncation of the Alaska Peninsula Paleozoic and Mesozoic shelf sedimentary sequence. Pieces of the Mesozoic shelf sequence and oceanic crust were caught up in the Uyak melange zone, and the Kodiak Formation was thrust under the Paleozoic-Mesozoic platform sequence. Following accretion of the Kodiak Formation, and the equivalent Shumagin Formation to the southwest, the Ghost Rocks and Sitkalidak Formations were accreted outboard of the Kodiak Formation.

Within the Chugach-Prince William terrane, paleomagnetic and paleontological studies indicate deposition and emplacement of Paleocene to Oligocene rock at latitudes as much as 30° south of their present position (Plumley and others, 1982, 1983; Moore and others, 1983; Keller and others, 1984). However, paleomagnetic data northwest of the Peninsular terrane from Cretaceous rocks of the Togiak terrane (Fig. 8, Globerman and Coe, 1984) and from Paleocene rocks in the Illiamna subterrane of the Peninsular terrane (Hillhouse and Gromme, 1982) indicate that these rocks have experienced no significant latitudinal displacement. Other studies of Peninsular terrane paleomagnetism from the Togiak subterrane, (Stone and Packer, 1979; Stone and others, 1982) suggest that parts of the Peninsular terrane lower Tertiary section have experienced significant northward displacement. At present the data suggest that a zone of considerable Tertiary convergence is located somewhere between the Togiak and Chugach terranes, that is, along the boundaries of the Peninsular terrane.

The major faults bounding the terranes of the Kodiak margin (Border Ranges Fault and Contact Fault) have not been traced across the Shumagin margin, since these boundaries are concealed beneath the Alaska Peninsula or lie beneath the continental shelf, and may be affected by transverse tectonic boundaries which cut the margin (Fisher and others, 1981). However, the distribution of rocks on the Alaska Peninsula, Shumagin, and Sanak Islands indicates that the Border Ranges Fault certainly continues to the southwest at least to Sanak Island (Fisher, 1981). Thus, the major events of the Kodiak margin also occurred on the Shumagin margin.

The terrane and tectonic continuity is critical in evaluating the resource potential of the Shumagin margin in two main ways. First, the Mesozoic and older rocks of the Alaska Peninsula are probably not present beneath the Shumagin margin, and hence the resource potential of the Alaska Peninsula rocks is dissimilar from that of the pre-Cenozoic rocks of the Shumagin shelf. However, the Alaska Peninsula Mesozoic rocks were a source terrain for rocks filling offshore sedimentary basins. The Peninsula Cenozoic rocks were also likely source rocks for offshore strata, and are non-marine and shallow marine equivalents of the offshore rocks. Second, basement rocks of the Shumagin segment are likely to be similar to those exposed on Kodiak Island or lying beneath the Kodiak shelf and slope. Similarly, Neogene basin filling rocks of the Shumagin and Kodiak segments are likely to be similar. Thus, studies of the Kodiak shelf seismic stratigraphy and dredge samples such as Fisher (1979, 1980), Fisher and Holmes (1980), Fisher and von Huene (1980), McClellan and others (1982), and Keller and others (1984) have a direct correlation and application to the Shumagin segment.

GEOPHYSICAL DATA AND GEOLOGIC CORRELATIONS

Seismic reflection data from the Shumagin shelf typically show a strong, regionally extensive reflection event, horizon A-B, that separates a lower seismic sequence, unit A, characterized by discontinuous reflectors, from an upper, well-bedded seismic sequence, unit B, characterized by high amplitude, laterally continuous seismic reflectors. These units are annotated on seismic lines shown in this report. Rocks above horizon A-B have seismic refraction velocities less than about 4.4 km/s, whereas rocks below the horizon have velocities greater than about 4.6 km/s. Horizon A-B forms the deepest mappable horizon within the Shumagin segment, and is herein considered as acoustic basement.

The correlation of rock-types with the seismic units is best determined in the vicinity of the Shumagin and Sanak Islands. In these areas, the A-B horizon is shallow and rises towards the islands. The deformed and metamorphosed Shumagin Formation and its associated granitic intrusives exposed in these islands are not likely to be recorded as extensive layered reflective sequences on seismic reflection data. Also, a velocity greater than 4.6 km/s is reasonable for variably deformed flysch or graywacke. Therefore Unit A, comprising the rocks below horizon A-B, almost certainly includes offshore correlatives of the Cretaceous Shumagin Formation.

However, Unit A might also include mildly metamorphosed to unmetamorphosed, deformed lower Tertiary sedimentary rocks similar to those exposed on Kodiak Island. The absence of lower Tertiary rocks on the islands of the Shumagin shelf does not rule out this possibility, since the lower

Tertiary rocks on Kodiak Island are similar in general lithology to rocks of the Shumagin Formation and are sparsely fossiliferous (Moore, 1969). Lower Tertiary rocks may not yet have been recognized in the limited exposures of the Shumagin shelf. Therefore, the lack of these rocks on the islands does not rule out their presence beneath the Shumagin shelf.

A second method of inferring rock types beneath the Shumagin margin is by anology with the adjacent and geologically similar Kodiak shelf. In this region, a prominent seismic reflection horizon, horizon C of Fisher and von Huene (1980), is present; horizon A-B is similar in character to horizon C. Horizon C is considered to separate Oligocene and older rocks from basin fill of probable late Miocene and younger age and reflects one or more regional erosional events that occurred during early and middle Miocene time (Fisher and von Huene, 1980; Keller and others, 1984). Horizon A-B probably was caused by a similar geologic history.

The absence of recognizable early Tertiary exposures on the Shumagin shelf island suggests that during the Miocene, erosion of insular highs was deep enough to remove the lower Tertiary rocks (if such rocks were ever present), and that much of the basin fill above horizon A-B is late Miocene and younger. However, Eocene (?) and early and middle Miocene rocks were dredged off Unimak Seamount, and the seismic data suggests that these rocks are present beneath the slope and may extend into the deepest basin of the Shumagin margin, Sanak basin. Our preliminary correlation of the seismic units is, therefore, that horizon A-B represents a regional early to middle Miocene unconformity; that rocks below the horizon are largely equivalent to the onshore Shumagin Formation but could include deformed rocks as young as Oligocene; and that rocks in the basin-filling unit B are largely of late Miocene and younger age, but could include early and middle Miocene rocks in Sanak Basin and beneath the continental slope.

Time-to-depth conversion of seismic data

In this report, we present structure contour or sediment isopach maps for two basins on horizon A-B, and show the horizon on several seismic sections. To convert seismic reflection traveltime to depth, we converted stacking velocities from the multichannel seismic reflection data to interval velocities using the Dix Equation (Dix, 1955), and compared these data to the seismic refraction velocities. The resulting time-depth curve is shown in Fig. 9 (Bruns and von Huene, 1977).

STRUCTURE

The Shumagin margin is characterized by five major structural features: (1) Shumagin basin, (2) Sanak basin, (3) shelf edge and upper slope sedimentary wedges, (4) a mid-slope structural trend which includes Unimak ridge, and (5) a lower slope accretionary complex.

Outside of the two major basin areas, the shelf is covered by 1 to 2 km of relatively undeformed strata that thicken seaward to 3 to 6 km beneath the outer shelf and upper slope. Shelf areas covered by only a thin (1 to 2 km or less) sedimentary cover include much and perhaps most of the shelf region between Unimak Pass and Sanak Island and the shelf regions adjacent to the Alaska Peninsula, the Shumagin Islands, and the Semidi Islands. The submerged lands adjacent to the Alaska Peninsula may be underlain by the continuation of

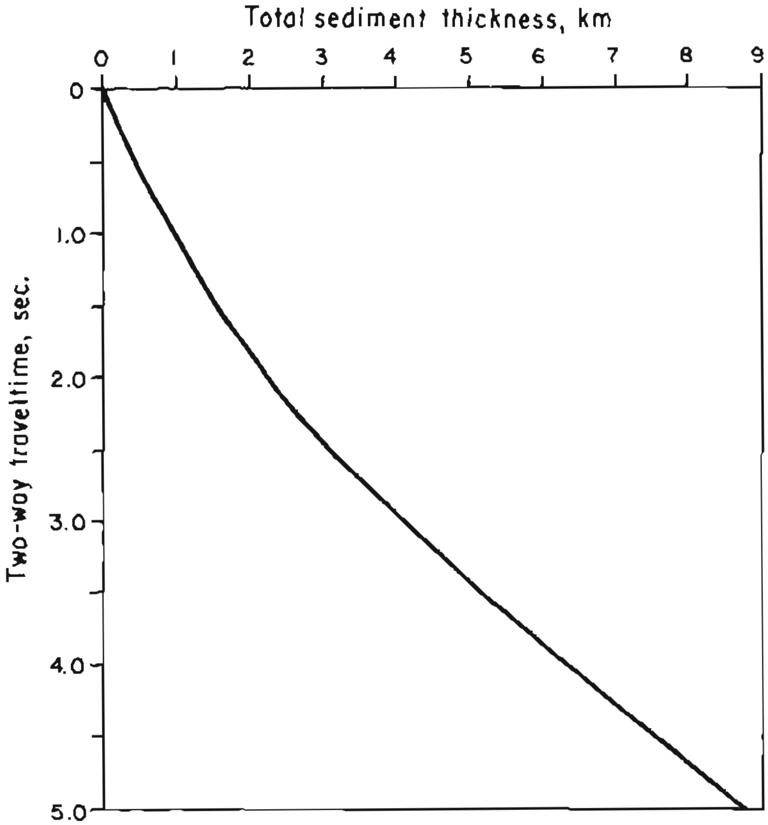


Figure 9. Time-to-depth conversion curve for converting two-way sub-seafloor traveltime on seismic sections to depth. Water-layer thickness must be added to obtain total depth.

rocks and structures observed on the Peninsula, but the seismic reflection data do not cover these nearshore areas.

Major anticlinal deformation of the shelf edge like that observed on the adjacent Kodiak shelf is notably absent along the Shumagin segment. The landwardmost major deformation of the margin occurs at bathymetric and structural highs of the midslope structural trend. Seaward of these structural highs, an accretionary complex as much as 30 km wide is present at the base of the slope.

Shumagin basin. Shumagin basin (Figs. 10, 11), an approximately 75-km-diameter roughly circular depression between the Shumagin and Semidi Islands, contains about 2.5 km of strata above horizon A-B, and is entirely in water less than 200 m deep. Strata thin towards the surrounding islands and towards the shelf edge; the seaward margin of the basin is a gentle structural high. Below horizon A-B, discontinuous reflectors and refraction data suggest a sedimentary section as much as 2 km thick is present, with interval velocities in the 4 to 4.4 km/s range lying above rocks with velocities of 4.8 to 6 km/s. The rocks with 4 to 4.4 km/s velocities (subunit A_T, Fig.11) may be of Oligocene and older age. The 4.8-6 km/s rocks are likely correlative to the Shumagin Formation (subunit A_K, Fig. 11). Unit A rocks beneath Shumagin basin are gently arched upward beneath the center of the basin, forming two separated depressions on the northwest and southeast flanks of the basin. Minor faults cut the unit A rocks, but do not generally extend into the overlying unit B section. Discontinuous reflections in the seismic reflection data suggest that the sedimentary section within the upper part of unit A (subunit A_T) is thickest beneath the depressions and may partially or entirely pinch out beneath the arch.

Unit B rocks beneath the basin are generally flat-lying except towards the outer shelf, where the sequence dips gently landward, and in the lower part of the sequence, where strata fill the depressions in the unit A rocks and gently onlap the flanks of the basin. Only minor faults cut the unit B strata. The maximum sediment thickness in the basin-fill strata above horizon A-B is about 2.5 km. Towards the surrounding islands and Alaska Peninsula, the basin strata thin to less than about 0.5 km.

Sanak basin. Sanak basin lies beneath the outer shelf and slope between the Sanak and Shumagin Islands (Fig. 12). The basin contains two major depositional centers separated by a faulted basement high. We refer to these two subbasins as West Sanak basin and East Sanak basin. Both subbasins contain as much as 8 km of probably Miocene and younger fill (unit B) above acoustic basement (horizon A-B).

West Sanak basin (Figs. 12,13) is an elongate half-graben between bounding faults on the northeast and southwest. Sanak Island and the Sandman reefs bound the northwest end of the basin; the southeast end continues beneath the upper continental slope. The southwest side is formed by a high-angle fault adjacent to Sanak Island, with as much as 5 km of separation on horizon A-B across the fault (line 531, Fig. 13). Strata within West Sanak basin dip towards and are truncated along the fault. Southwest of this fault, 1 to 2 km of gently seaward dipping strata overlies horizon A-B.

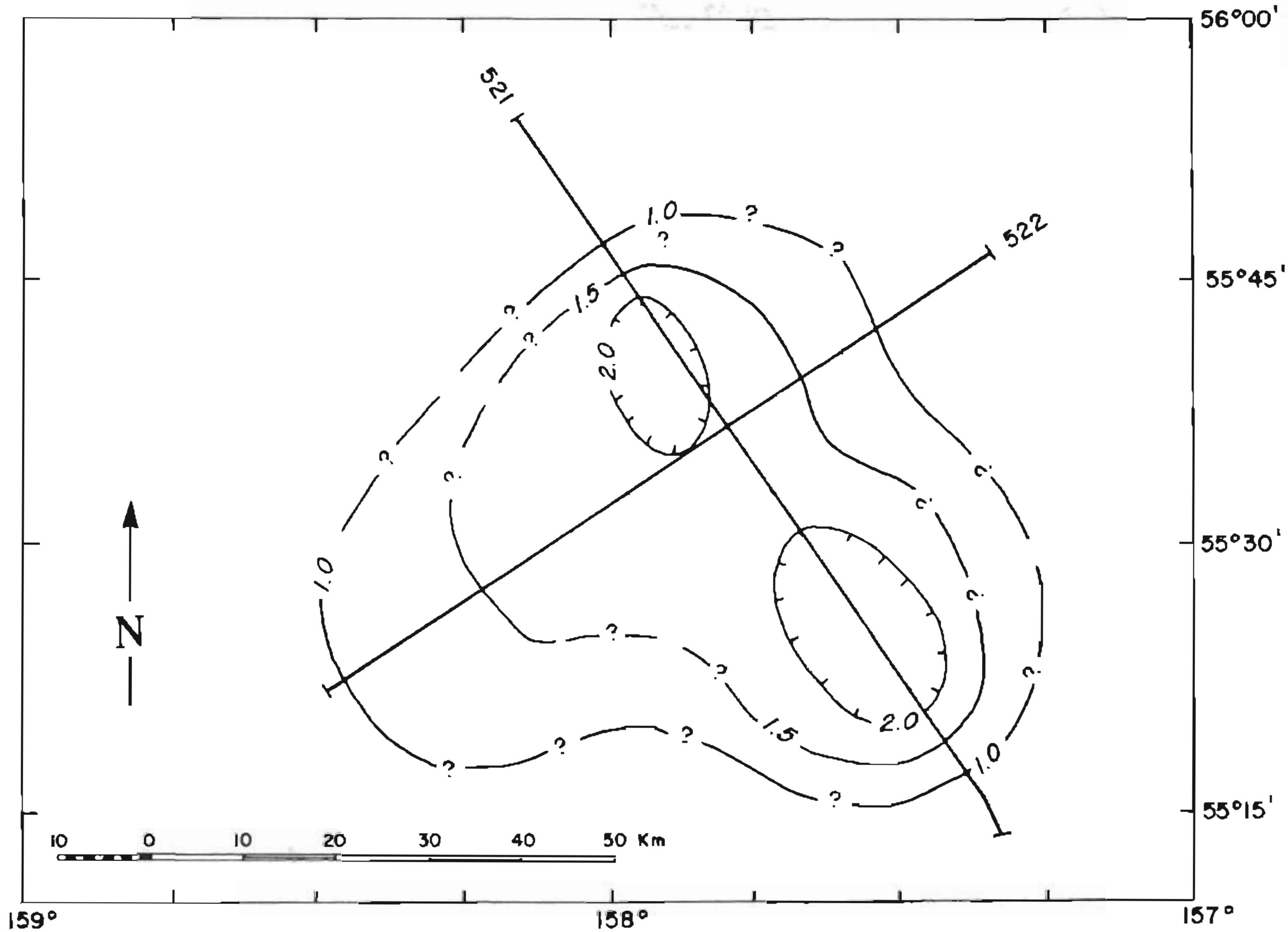


Figure 10. Preliminary structure contour map at base of Miocene and younger strata (horizon A-B), Shumagin basin.

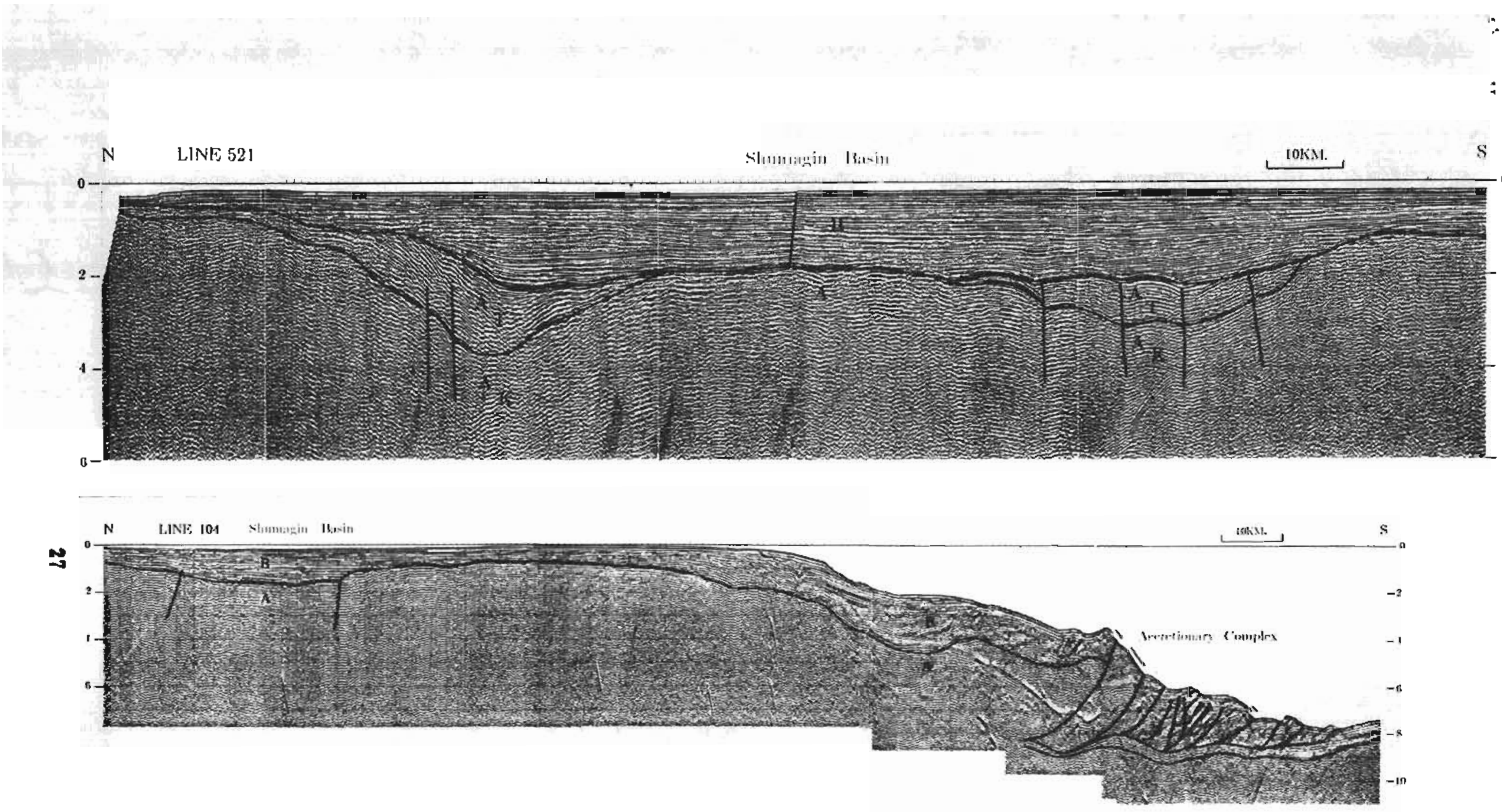


Figure 11. Seismic lines 521 and 104 across Shumagin basin and the adjacent continental shelf and slope. Line locations shown in Fig. 2.

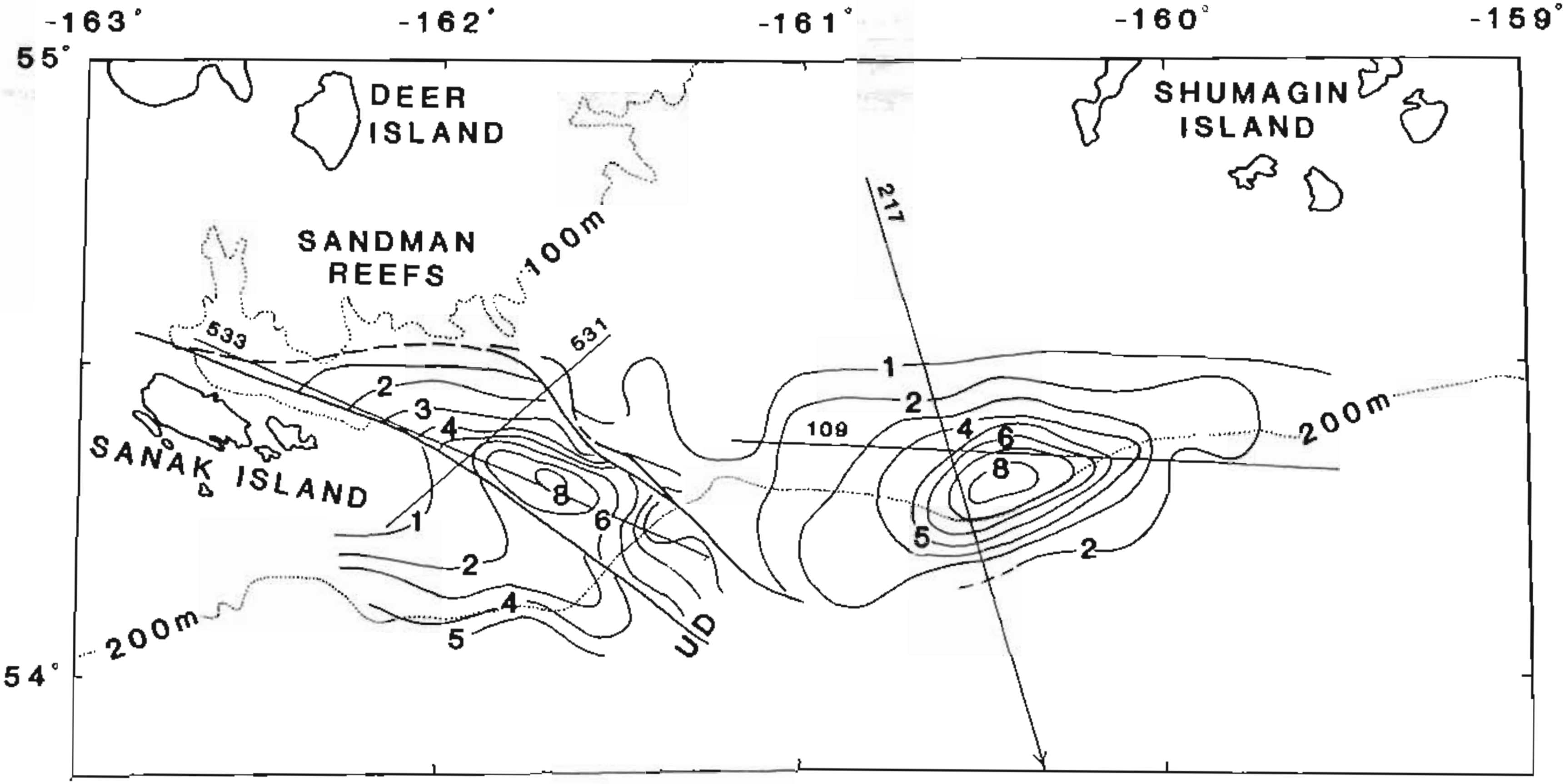


Figure 12. Preliminary isopach map of Miocene(?) and younger strata (unit B strata) in Sanak basin.

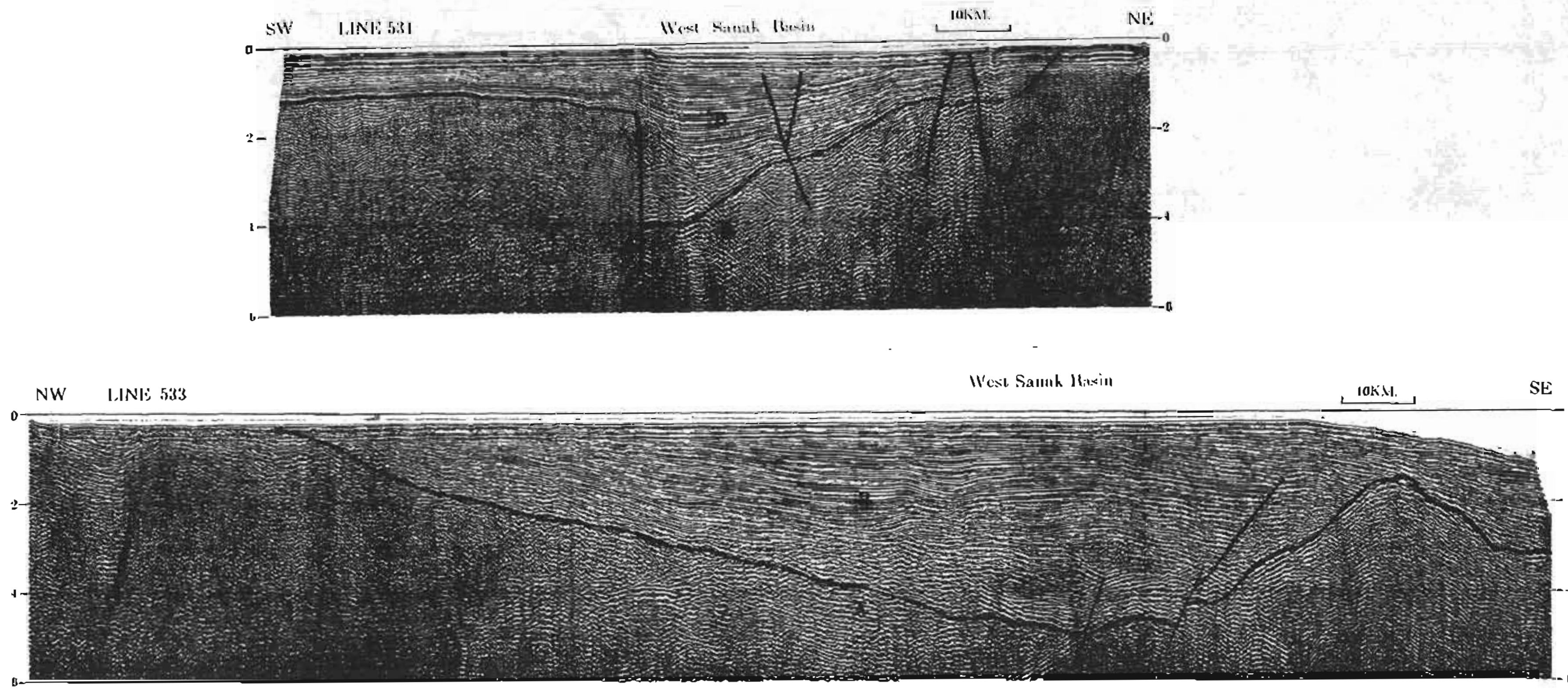


Figure 13. Seismic lines 531 and 533, west Sanak basin. Line location shown in Figs. 2 and 11.

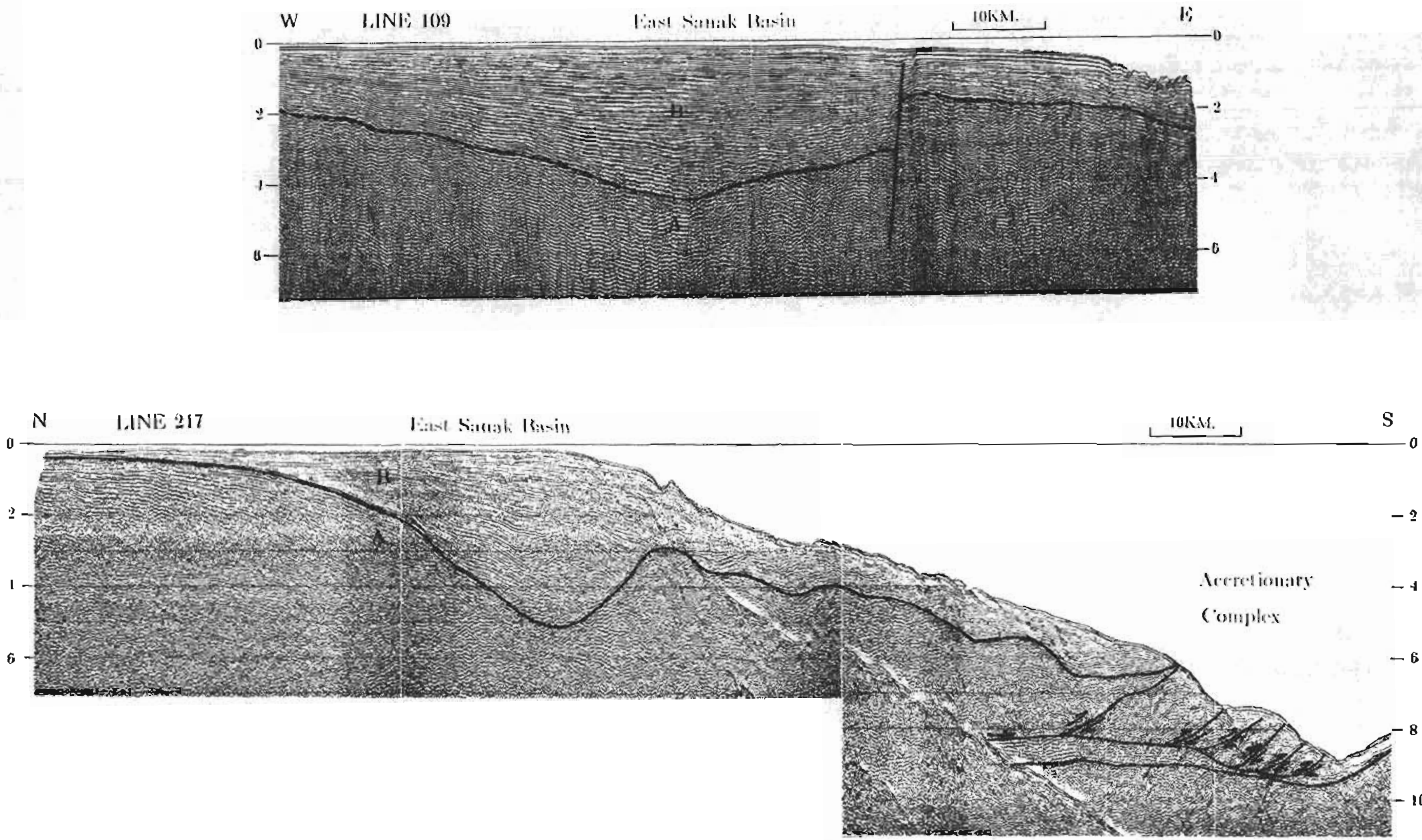


Figure 14. Seismic lines 109 and 217, east Sanak basin. Line locations shown in Figs. 2 and 11.

Along strike, basin strata thin to the northwest, and may be ponded behind a structural high to the southeast. Seismic line 533 (Fig. 13) is an axial line in West Sanak basin. At the northwest end of the line, the seismic record shows that horizon A-B crops out at the seafloor and dips southeast to form the floor of the basin. The horizon is not well defined in the deepest part of the basin, due to the depth to the horizon and to deformation within the lower part of the unit B strata. The maximum depth to the horizon is at least 8 km and could be greater. A basement high on the southeast end of the line rises to within 1.5 km of the surface. Seismic reflectors within unit B are not deformed over this high, and appear to onlap it. Therefore the high was likely in place prior to deposition of the unit B strata. This high could have been a barrier to seaward transport of sediment forming the lower part of the unit B sequence. This basement high is associated with a large magnetic anomaly (Bruns and von Huene, 1977) and is probably a basaltic body within the basement.

Deformation and faulting increase with depth in unit B. The deepest strata thicken markedly towards the southeast, suggesting more rapid subsidence and deposition at the seaward end of the basin than at the landward end. The intermediate beds are relatively uniform in thickness, although some pinch out landward. The uppermost beds show little deformation, uniform thickness, and some seaward progradation.

East Sanak basin (Figs. 12, 14) trends generally east-west, and is separated from West Sanak basin by a faulted basement high. The maximum sediment thickness in East Sanak basin is as much as 8 km and could be greater, since the position of horizon A-B is poorly controlled by available data in the area of thickest section (lines 109 and 217, Fig. 14). The basin is underlain on the south by a basement high (line 217, Fig. 14). As in West Sanak Basin, unit B strata onlap the high in the lower part of the unit, and are deposited seaward across the high in the upper part of the section. Little deformation is observed in the unit B strata, suggesting the basement relief, and hence basin architecture, was largely formed prior to deposition of the basin-filling unit B strata.

The position and development of West Sanak basin may in part be controlled by a major transverse tectonic boundary that segments the forearc. The position of West Sanak basin is coincident with the western limit of a seismic gap, the Shumagin seismic gap, defined by Sykes (1971), Sykes and others (1984), and Davies and others (1981). The transverse boundary is probably a major crustal feature expressed near the surface as the faults bounding Sanak basin. The origin of East Sanak basin is less clear. The basin may reflect massive subsidence in the Cretaceous and Paleogene rocks near the transverse boundary. Alternatively, the basin may have developed on an old continental slope. The seaward margin of the basin is formed by subsurface structural highs which may have formed on a paleo-continental slope, formed a barrier to sediment transport, and ponded the strata within the basin behind the highs.

Shelf edge and upper slope sedimentary sequences. Unit B extends seaward beneath the upper continental slope, with thicknesses of 2 to 4 km observed on seismic reflection data (line 104, Fig. 11, line 217, Fig. 14, and line 205, Fig. 15), and possibly as much as 6 km on seismic refraction data (based on refraction velocities less than 3.6 km/s). This section is either relatively

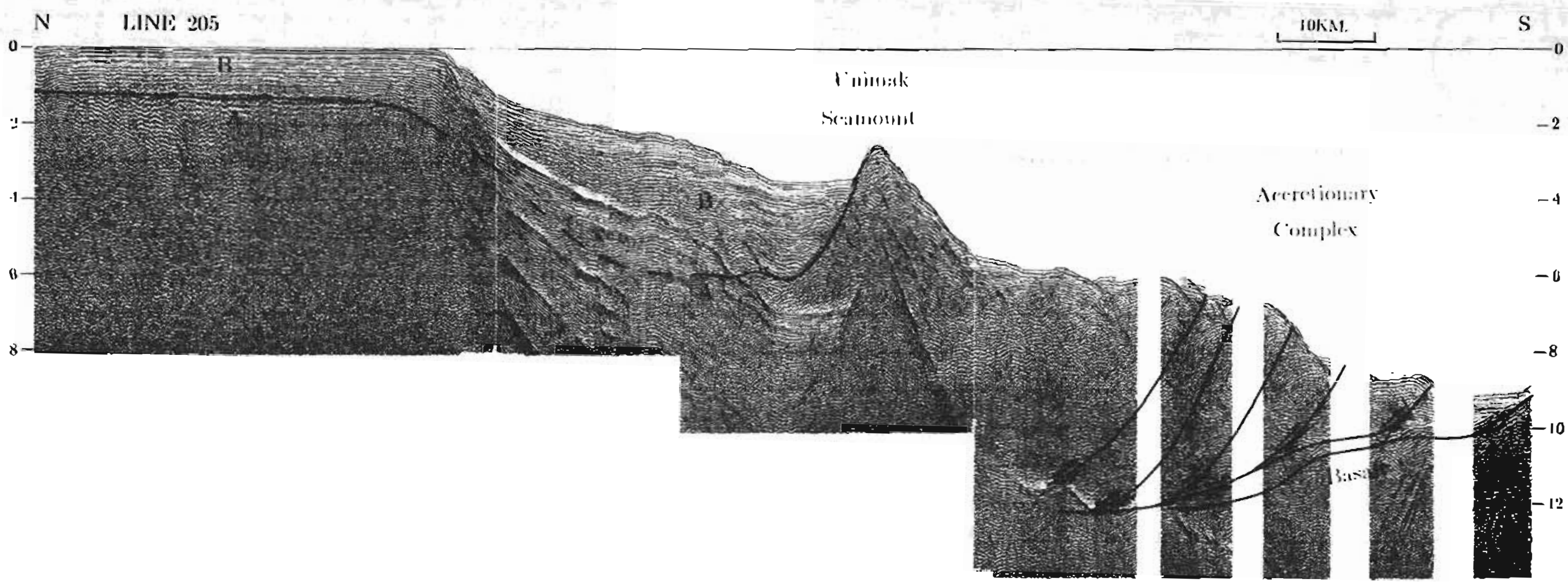


Figure 15. Seismic line 205 across the continental shelf and slope west of Sanak Island. Line location shown in Fig. 2.

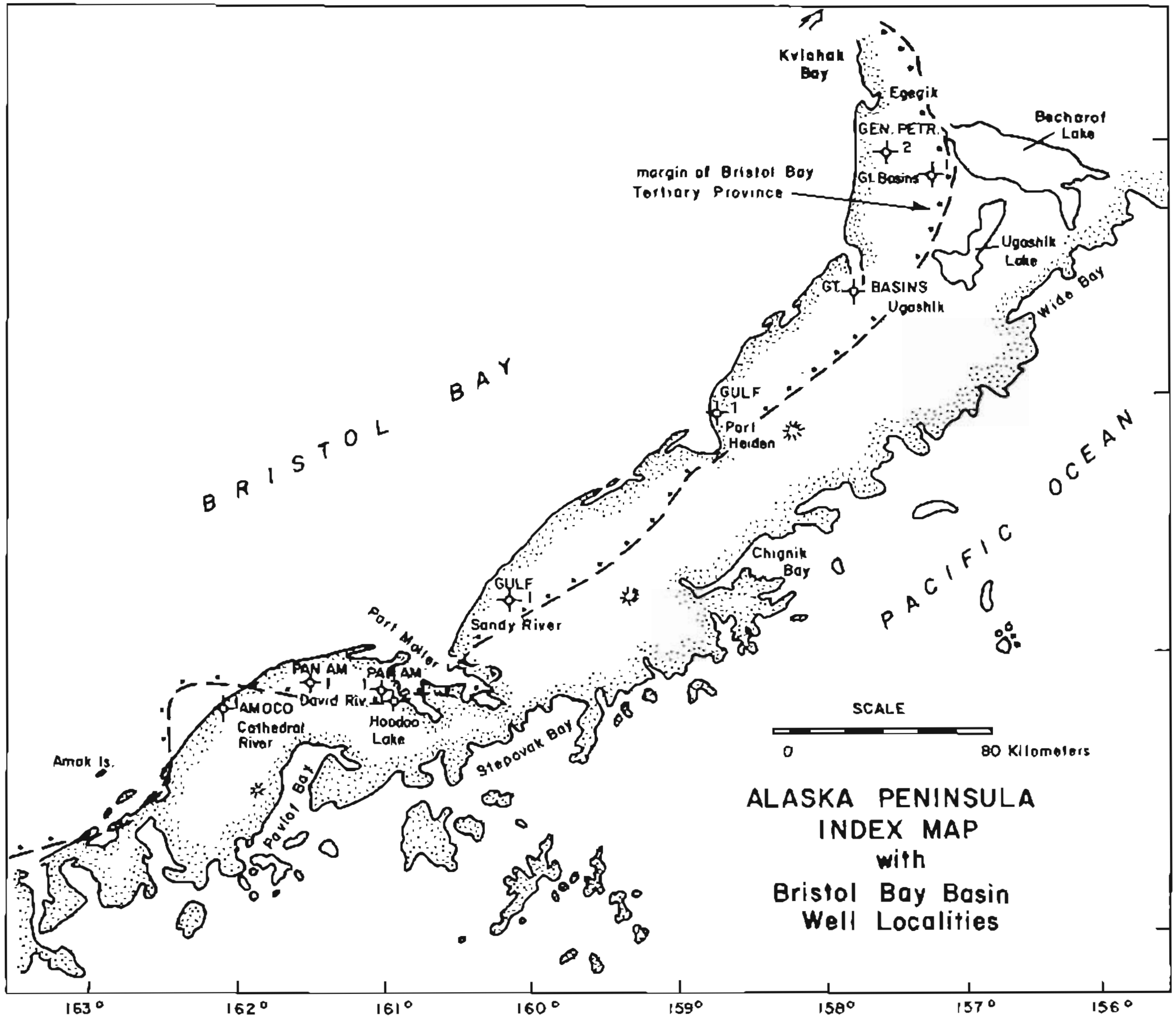


Figure 16. Index map of Alaska Peninsula showing sites of wells drilled on the peninsula.

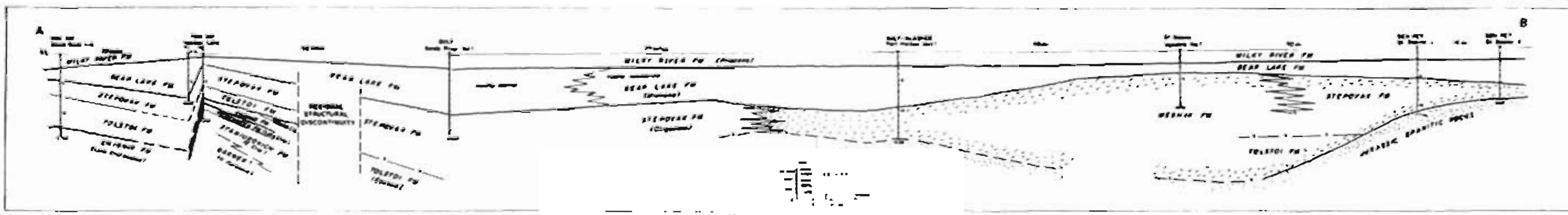


Figure 17. Generalized stratigraphic cross section along the Alaska Peninsula, modified from Brockway and others (1975). See Fig. 4 for columnar section of the Alaska Peninsula region.

the Bear Lake Formation may have been derived from source rocks within the underlying Stepovak Formation (late Eocene and Oligocene).

Source beds

The best source rocks in the Tertiary sequence appear to be the black marine siltstone and shale beds in the Stepovak Formation. On the Alaska Peninsula, the Stepovak Formation is locally at least 4500 m thick (Burk, 1965). Scattered shows of oil and gas in Stepovak rocks have been reported from three Alaska Peninsula wells, Gulf Sandy River, Pan American Hoodoo Lake No. 2, and Pan American David River 1-A (Fig. 17, Brockway and others, 1975). Potential source rocks may also occur in the Miocene Bear Lake Formation because locally the basal portion containing marine siltstone and shale may have been buried deep enough to generate hydrocarbons. Marine shales of Late Jurassic and Late Cretaceous age might also be considered as potential source rocks, but are probably not present beneath the Shumagin margin.

Core chips and drill cuttings from eight of the nine wells drilled along the Alaska Peninsula were subjected to lithologic and paleontologic analysis by McLean (1977). Results suggest that at least locally, sedimentary rocks of Tertiary age contain potential source and reservoir rocks capable of generating and accumulating hydrocarbons.

Paleogene strata on the Alaska Peninsula are rich in organic carbon but are immature. However, strata in offshore basins of the Shumagin margin may have been subjected to a higher thermal gradient. Total organic carbon content of fine-grained, Neogene strata appears to be significantly lower than in Paleogene rocks, possibly reflecting nonmarine or brackish water environments of deposition. Neogene sandstone beds locally yield high values of porosity and permeability to depths of about 2450 m (McLean, 1977). Below this depth, reservoir potential declines rapidly.

The General Petroleum, Great Basins No. 1 well, drilled along the shore of Bristol Bay, reached granitic rocks. Other wells drilled closer to the axis of the Aleutian volcanic arc indicate that both Tertiary and Mesozoic sedimentary rocks have been intruded by dikes and sills of andesite and basalt. Although the Alaska Peninsula has been the focus of igneous activity throughout much of Mesozoic and Tertiary time, thermal maturity indicators such as vitrinite reflectance and coal rank suggest, that on a regional scale, sedimentary rocks have not been subjected to abnormally high geothermal gradients.

Lyle and others (1979) studied 14 stratigraphic sections totaling 5000m along the Alaska Peninsula. They found that 63 percent of the total measured stratigraphic section contained potential Tertiary reservoir sandstone. However, the porosities and permeabilities for these sandstones were generally low in most areas because of pervasive pore-filling mineralization. The best preserved and most probable reservoir rocks are sandstone beds in the Bear Lake Formation. In studying potential Tertiary source rocks, Lyle and others (1979) found that the total organic carbon for their samples ranged from less than 0.2 percent to 8.0 percent, that the hydrocarbon C_{15+} extracts averaged 362 ppm, that the major organic constituents are herbaceous-spore debris, and that most samples have a thermal alteration index of 2- to 2+ (immature).

They concluded that dry gas is the most probable hydrocarbon to form in Tertiary source rocks on the Alaska Peninsula.

<u>Organic analysis of dredge samples</u>. Little is known about possible source rocks from the Shumagin margin. Six dredge samples were analyzed for organic carbon (Kvenvolden and von Huene, 1984 and in press). Five samples, including three mudstones and two dolomitic rocks, were used from site 2, and one sample, a limestone, was used from site 4 (Fig. 5). Total carbon was measured for each of these rocks and all were analyzed by a temperature programed pyrolysis technique (Thermal Evolution Analysis or TEA) in which the products of pyrolysis are measured by a flame ionization detector (FID), and the temperature of maximum pyrolysis yield is determined (Claypool and Reed, 1976). Pyrograms of the 6 samples are shown in Figure 18. In general, the patterns are rather non-descript and lacking distinctive peaks. The patterns signal that the organic matter in many samples is somewhat unstructured and likely immature.

This pyrolysis method provides information on total hydrocarbon yield (measured in percent of organic carbon), volatile hydrocarbons (measured in parts per million of the total hydrocarbon yield), and T_{max} in degrees C representing the temperature at which the maximum amount of organic matter is thermally decomposed. "Live carbon" is considered to be the carbon that will, upon thermal evolution, still yield additional hydrocarbon products such as methane gas. The results of these analysis are listed in Table 2. These results show that all of the samples analyzed contain low amounts (less than 1 percent) of organic carbon (OC). The total hydrocarbon yield and "live carbon" are also low and range between 0.03 and 0.06 percent and 7 to 15 percent respectively. The volatile hydrocarbon is always less than 100 ppm. T_{max} ranges from 429 to 456°C, but the pyrograms (Fig. 18) from which these data are taken are so indistinctive that the results are considered unreliable for interpretive purposes. All of these factors indicate that the sampled sediments are poor potential source rocks for petroleum, both oil and gas. The average amount of organic carbon is less than 0.6 percent, a value considered near the lower limit for potential sources of hydrocarbons (Hunt, 1979). The amount of "live hydrocarbon", ie, the carbon available for future hydrocarbon generation, is less than 30 percent which indicates, according to work by Magoon and Claypool (1981) that the organic matter is prone to gas generation rather than oil generation.

Two samples (2-13 and 2-16) were selected for detailed examination of organic matter type (Table 3). These samples were chosen because they appeared to be richest in organic carbon, and there was sufficient sample on which to carry out the analysis. These samples were subjected to a specialized pyrolytic technique called Rock-Eval (Tissot and Welte, 1978). In addition, the analysis included vitrinite reflectance measurements, visual kerogen analyses by both transmitted and incident light, and evaluation of the thermal alteration index (TAI).

Rock-Eval analysis provided an independant measurement of organic carbon and T_{max}. In both cases the Rock-Eval organic carbon value is larger than the value obtained by TEA (Table 2). The Rock-Eval T_{max} is lower than T_{max} from TEA for both dredge samples (Table 2). The Rock-Eval measurements for these two parameters are considered less reliable than TEA measurements and therefore are not considered further. Rock-Eval analysis yielded hydrogen indices (HI) and oxygen indices (OI) which can be plotted on a van Krevelen

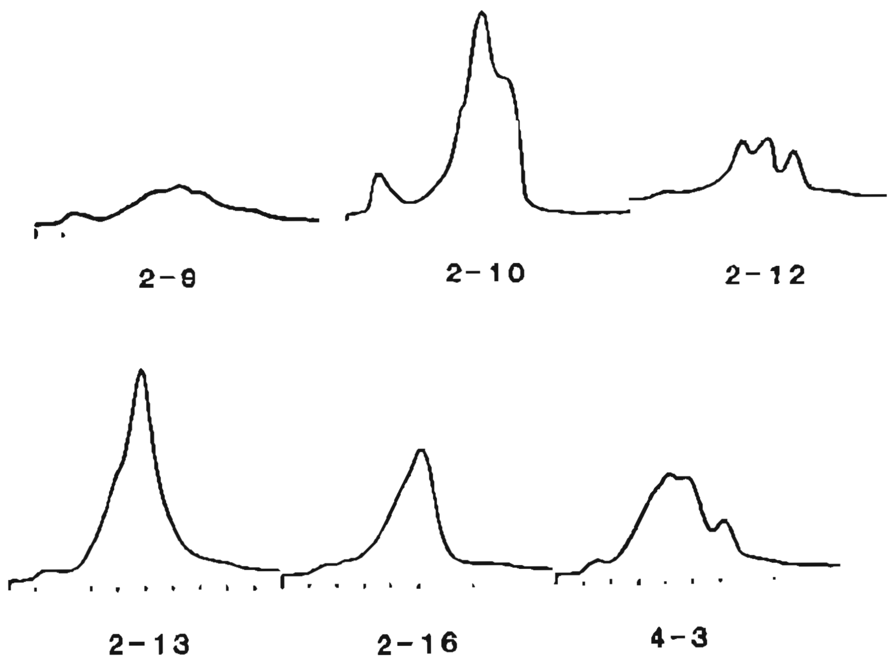


Figure 18. Pyrograms of dredge samples from the Shumagin margin, from Kvenvolden and von Huene (1984).

Table 2. Results of geochemical analysis of Shumagin dredge samples.

Sample	2-9	2-10	2-12	2-13	2-16	4-3	Average for site 2
Lithology	Mudstone	Dolomite	Clastic Dolomite	Mudstone	Mudstone	Nodular Limestone	
Age	Early to Middle Miocene	Middle to Late Eocene	Early to Middle Miocene	Eocene(?)	Early to Middle Miocene	Early Pleistocene	
Organic Carbon (%) TEA/Rock-Eval	0.45	0.33	0.24	0.66/1.1	0.80/0.92	0.30	0.50±0.23
Total Carbon(%)	0.43	9.4	9.0	0.67	0.77	6.6	
Carbonate Carbon(%)	0.0	9.1	8.8	0.01	0.0	6.3	
Total Hydrocarbon Yield	0.03	0.05	0.03	0.05	0.06	0.03	0.04±0.01
"Live Carbon" (%)	7	15	13	8	8	10	10±4
Volatile Hydrocarbon (ppm)	37	46	20	61	94	76	52±28
T_{Max} °C TEA/Rock-Eval	440	443	456	437/409	429/411	433	441±9

Table 3. Results of kerogen analysis of Shumagin dredge samples.

Sample	2-13	2-16
HI (mgHc/gOC)	160	122
OI ($mgCO_2/gOC$)	71	111
R_o (%)	0.50	0.38
TAI	2.0-2.4	2.3-2.5
Exinite (%)	5	7
Vitrinite (%)	20	15
Inertinite (%)	5	--
Recycled Vitrinite (%)	30	24
Recycled Sporinite (%)	10	16
Other Amorphous	30	40

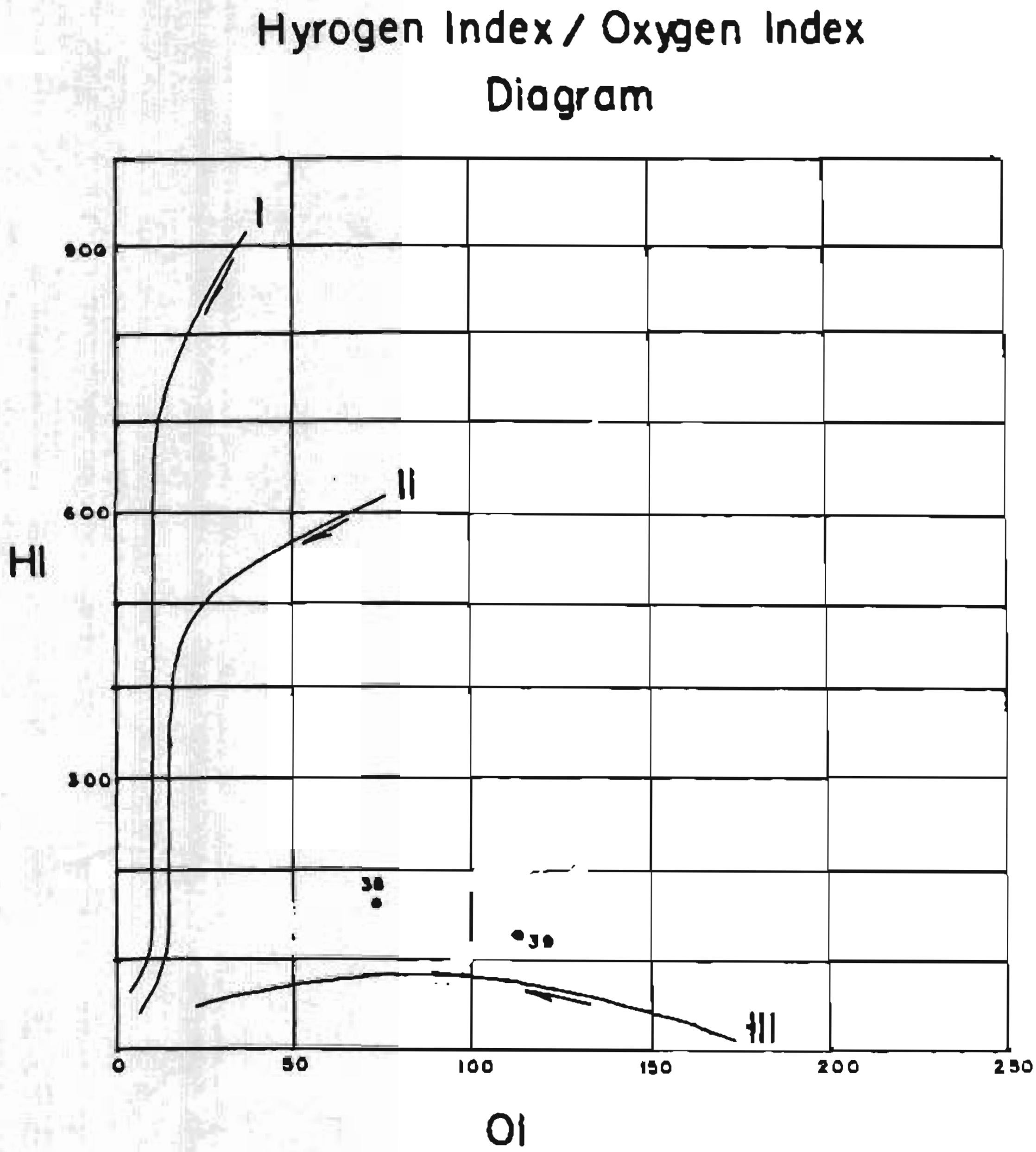
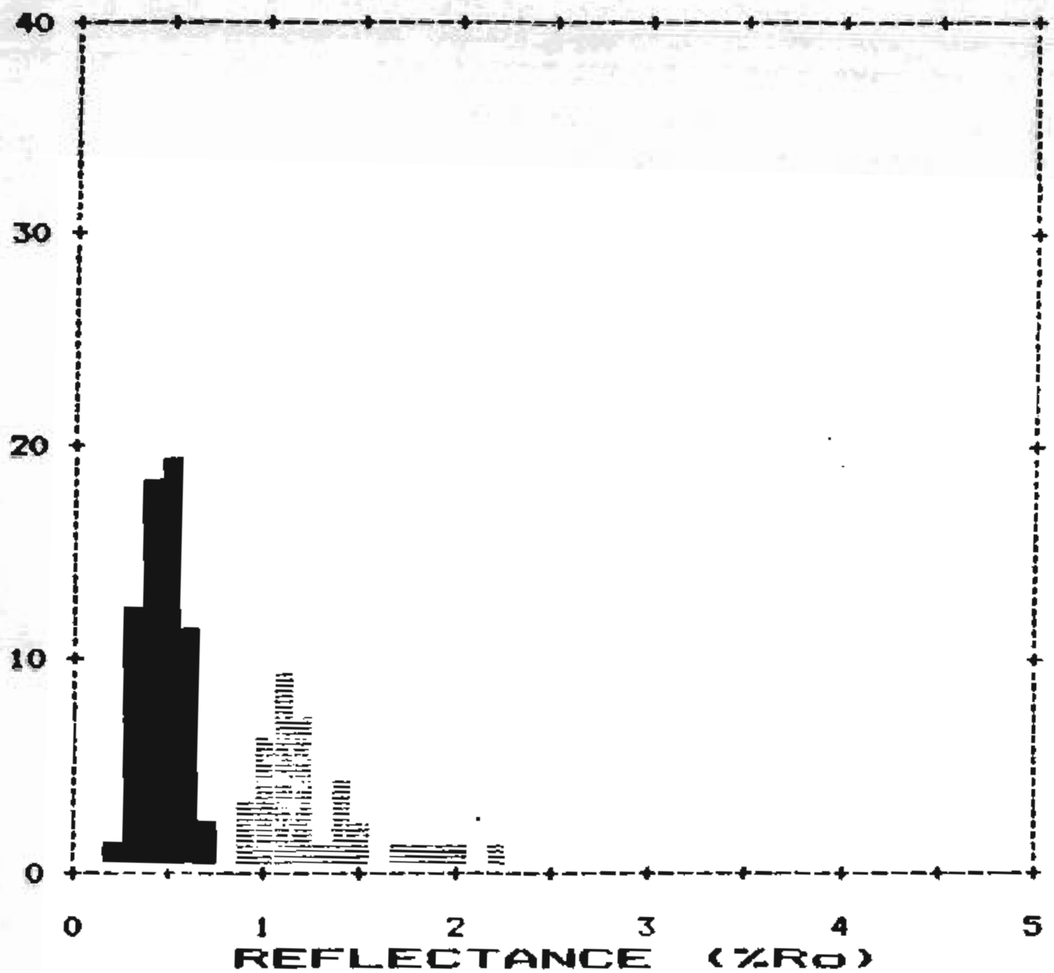


Figure 19. Van Krevelen diagram of dredge samples from the Shumagin margin, from Kvenvolden and von Huene (1984).

VITRINITE REFLECTANCE



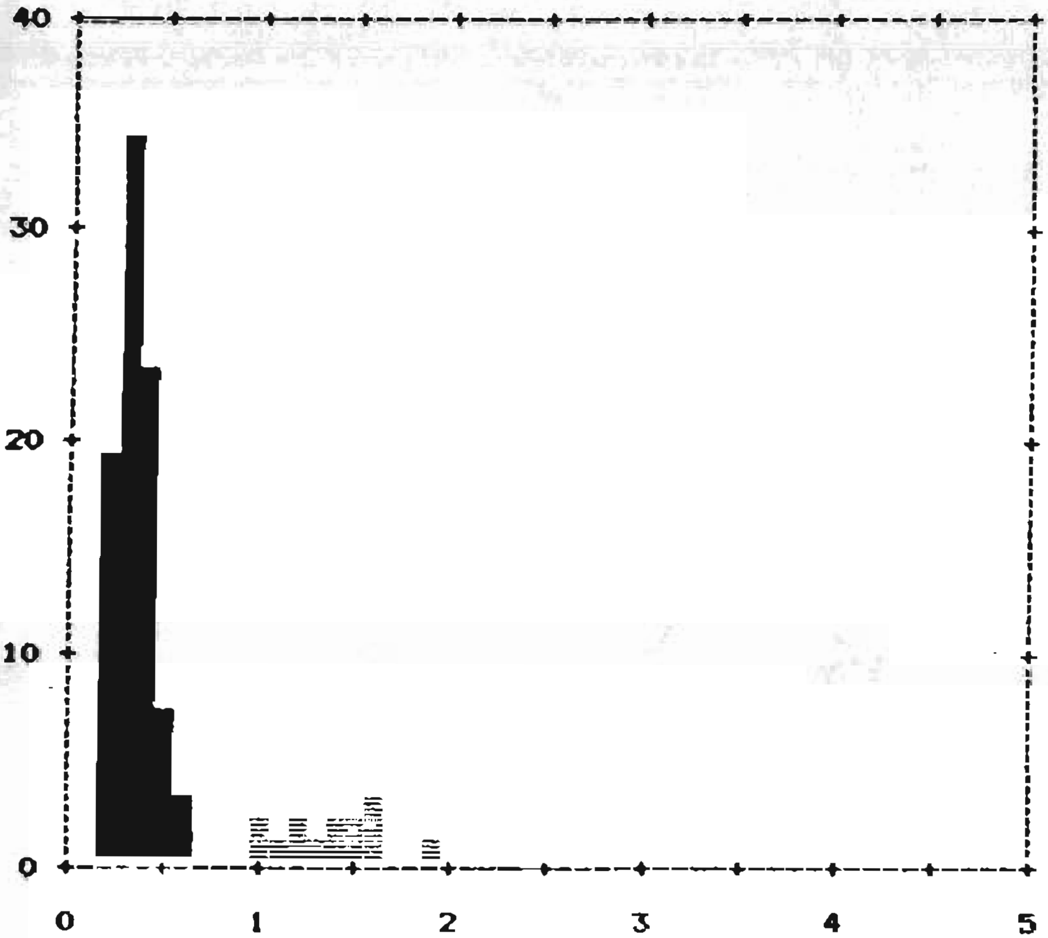
ORDERED READINGS

0.27	0.3	0.32	0.32	0.35
0.35	0.36	0.36	0.37	0.38
0.38	0.38	0.38	0.4	0.41
0.42	0.42	0.42	0.44	0.47
0.47	0.47	0.47	0.47	0.48
0.48	0.48	0.48	0.48	0.49
0.49	0.5	0.5	0.5	0.51
0.51	0.51	0.51	0.52	0.52
0.55	0.55	0.56	0.57	0.58
0.58	0.58	0.58	0.58	0.59
0.62	0.62	0.63	0.64	0.64
0.65	0.65	0.66	0.66	0.68
0.68	0.72	0.78	*0.9	*0.95
*0.95	*1	*1	*1.03	*1.04
*1.05	*1.07	*1.1	*1.12	*1.12
*1.15	*1.17	*1.17	*1.18	*1.18
*1.19	*1.2	*1.2	*1.2	*1.22
*1.25	*1.27	*1.27	*1.31	*1.4
*1.42	*1.44	*1.49	*1.52	*1.58
*1.78	*1.84	*1.9	*2.01	*2.24

MEAN: 0.5 STANDARD DEV.: 0.11
NUMBER: 63 MODE: 0.5
RANGE: 0.27-0.78
* Data not considered in statistical analysis.

Figure 20. Vitrinite analysis of dredge sample 2-13.

VITRINITE REFLECTANCE



ORDERED READINGS

0.23	0.24	0.25	0.25	0.25
0.25	0.26	0.26	0.27	0.27
0.28	0.28	0.28	0.28	0.28
0.28	0.29	0.29	0.29	0.3
0.3	0.3	0.3	0.3	0.31
0.31	0.31	0.31	0.31	0.31
0.32	0.32	0.33	0.33	0.35
0.35	0.35	0.36	0.36	0.36
0.36	0.36	0.37	0.38	0.38
0.38	0.38	0.38	0.38	0.38
0.38	0.38	0.39	0.4	0.4
0.4	0.4	0.4	0.41	0.41
0.42	0.42	0.42	0.42	0.43
0.44	0.44	0.45	0.45	0.45
0.45	0.46	0.47	0.47	0.47
0.49	0.5	0.51	0.52	0.54
0.55	0.58	0.58	0.6	0.62
0.64	*1.02	*1.07	*1.16	*1.22
*1.26	*1.32	*1.42	*1.42	*1.5
*1.58	*1.61	*1.62	*1.63	*1.93

MEAN: 0.38 STANDARD DEV.: 0.09
NUMBER: 86 MODE: 0.3
RANGE: 0.23-0.64
* Data not considered in statistical analysis.

Figure 21. Vitrinite analysis of dredge sample 2-16.

diagram (Fig. 19). The samples lie along the Type III pathway of this diagram; type III organic matter is generally considered to be of terrestrial origin and gas-prone (Tissot and Welte, 1978).

Vitrinite reflectance (R_o) values of primary vitrinite are 0.38 and 0.50 percent (Table 3 and Figs. 20, 21). Recycled vitrinite of greater R_o values is also present in the samples. TAI evaluations range from 2.0 to 2.5 (Table 3). Both vitrinite reflectance and TAI values indicate that the organic matter of these samples is immature with respect to oil or gas generation and shows strong indications of reworking. Visual kerogen analysis (Table 3) indicates that, in addition to vitrinite and recycled vitrinite, the samples also contain exinite, inertinite, recycled sporinite, and amorphous material. The distribution of these kerogen macerals suggests that most of the organic matter is terrestrial in origin.

Taken together, the geochemical analysis shows that the amount of organic carbon in the samples is small and approaches the lower limit as a potential source of hydrocarbons. The presence of inertinite further reduces the hydrocarbon potential of these samples. The organic matter is mainly from terrestrial sources, is gas prone, and is immature with respect to gas generation. Upon thermal evolution, the samples are expected to generate only small amounts of gas (Kvendvolden and von Huene, 1984 and in press).

While these results are discouraging for hydrocarbon potential of the Shumagin margin, they are from such a limited number of samples that they cannot be considered as representative of the thick strata within the basins or beneath the outer shelf and upper slope. Offsetting these results are the better source rock characteristics of onshore rocks which may have offshore correlatives. Also, somewhat greater source rock potential has been found from dredge samples in the adjacent Aleutians (Scholl and others, 1983; Cooper and Marlow, 1984). Thus, considerably more sampling of Shumagin margin rocks must be done before a reasonable estimate of source rock potential can be made.

Reservoir beds

The rocks that have the greatest reservoir potential for oil and gas in the Shumagin margin are probably sandstone units equivalent to those in the onshore Miocene Bear Lake Formation. Bear Lake sandstone beds are both marine and nonmarine and contain a combination of volcanic grains, dioritic grains, chert, and sedimentary lithic fragments. Most of the sandstones are classified as lithic subgraywackes and others as lithic arenites (Burk, 1965). Shows of oil and gas have been reported from the basal Bear Lake Formation sandstones in the Gulf Sandy River and Pan American David River wells. Sandstones in the older Tertiary formations, Tolstoi and Stepovak, have an abundance of unstable volcanic detritus as well as matrix clay. These rocks are dense and highly indurated, and thus are not considered good reservoir beds.

Offshore equivalents to the Bear Lake sandstones are likely to be dominantly marine. No potential reservoir sandstones were sampled in the dredge rocks from the Shumagin margin. The sampled sandstones are characterized by an abundance of unstable rock fragments and matrix clay. As with potential source rocks, however, the limited number of samples cannot be considered as representative of the Shumagin margin rocks, and more samples need to be obtained and analyzed for a comprehensive assessment of reservoir potential.

Traps

Most of the potential oil and gas traps on the Alaska Peninsula and the Kodiak margin are anticlinal structures. Such major anticlinal features are not present on the Shumagin margin except, possibly, along the mid-slope structural trend. However, within the major basins, structural and stratigraphic traps are likely to be present within the Miocene and younger section, formed by draping and differential compaction of strata over block faulted basement highs, by pinch-outs within the sedimentary sequence, or by onlap against the acoustic basement (against rocks below horizon A-B). Broad, gentle anticlinal features are present beneath and around Shumagin basin, and may be present within Sanak basin or beneath the slope, but not recognized so far in the widely spaced seismic data.

The rocks below horizon A-B may contain traps in Paleogene strata, if such strata are present offshore. Such rocks could be similar to the onshore early Eocene and Oligocene Stepovak Formation within which good source rocks are present. Also, if Paleogene strata have generated hydrocarbons, these hydrocarbons could migrate into sandstones in the overlying Miocene and younger strata, which could have good reservoir rocks equivalent to those in the onshore Miocene Bear Lake Formation.

Structures within the mid-slope structural trend could have trapping potential, either within the structures or in stratigraphic traps on the flanks of the structures. More detailed mapping is needed on these structures to determine the amount of faulting that may have occurred, the age and composition of rocks underlying the structures, and if closure and traps are present.

The numerous structural folds within the accretionary complex may have trap and reservoir potential. However, structures within the wedge may be ephemeral, quickly removed with continued subduction. Thus, the overall potential for trapping hydrocarbons generated in place or migrating through subducted sediment is probably low.

The thick sedimentary sequences in Sanak basin and beneath the continental slope hold the greatest potential for generating and trapping hydrocarbons generated in place or migrating upward from Paleogene strata beneath the basins. These are the areas where additional work needs to be done to determine if structural closure is present or if stratigraphic traps are large enough to be potentially commercial.

Geothermal gradient

The hydrocarbon potential of a sedimentary sequence is largely dependent upon burial at sufficient depths and temperatures to generate hydrocarbons. No heat flow measurements have been obtained within the Shumagin region. However, a geothermal gradient can be estimated based on the depth to gas hydrates beneath the Shumagin slope. MacLeod (1982), using this technique, obtained a geothermal gradient of about 30°C/km for the Shumagin region.

Using a similar technique, Kvenvolden and von Huene (1984) obtained geothermal gradients in the Kodiak region ranging from about 28 to 36°C/km, with a best estimate of about 30°C/km. A gradient of 28°C/km was measured from a well at Middleton Island, about 800 km northeast of the Shumagin region, but in the same convergent margin tectonic regime. Also, other convergent margins have similar geothermal gradients, such as an average gradient of 32°C/km along the Middle America Trench (von Huene and others, 1982) and a 24 to 32°C/km gradient for the Japan Trench (Langseth and Burch, 1980). Thus, a gradient of 30°C/km is probably a reasonable estimate for the frontal part of Shumagin margin.

With a gradient of 30°C/km, onset of hydrocarbon generation (about 100°C) could occur at a depth of about 3 km. Substantial thicknesses of strata, primarily in Sanak basin, but also below the outer shelf and upper slope, could then be within the hydrocarbon generation zone.

Substantially higher geothermal gradients may occur or have occurred locally near Tertiary plutons and adjacent to the active volcanic arc. Also, geothermal gradients as high as 50 to 82°C/km have been reported from the Unimak Plateau region, northwest of the Shumagin region and on the north side of the Aleutian ridge (Cooper and others, 1980). If such high gradients have occurred within the Shumagin region, even shallower strata could be mature. Clearly, further sampling and heat flow measurements are needed in the Shumagin region to evaluate the geothermal gradient and thermal maturity of the rocks.

Resource potential by area

We estimate that the most prospective area for resource potential within the Shumagin region is Sanak basin. Positive factors include a thick sedimentary sequence, the possibility of source and reservoir rocks within the basin fill that might be similar to onshore rocks, and the potential for thermal maturity and hydrocarbon generation at a relatively shallow depth (about 3 km). Traps are present, primarily stratigraphic traps in pinch-outs and in strata onlapping acoustic basement, and possibly including gentle anticlinal traps. Paleogene rocks may be present near or below the acoustic basement, perhaps remaining behind in a developed Paleogene basin rather than being removed during a Miocene erosional event that has likely affected most of the shelf area of the Shumagin margin. Unknown factors include the lack of known major anticlinal traps with extensive closure, and the extent of potential source and reservoir rocks.

The sedimentary sequence beneath the outer shelf and continental slope is the second most prospective area, for the same reasons noted above, and for the better potential for presence of Paleogene rocks. Traps may be present within or along the mid-slope structural trend. A major negative feature is the greater water depth over potential target areas, thus making exploration and exploitation more difficult.

The Shumagin basin has relatively low resource potential within the basin fill sequence, since the fill is relatively thin (less than 2.5 km) and therefore likely immature. However, early Tertiary rocks may be present below the basin and may be deformed into potential traps or allow migration of hydrocarbons into the overlying Miocene and younger basin fill.

Much of the shelf outside of Sanak and Shumagin basins likely has low resource potential since only thin (less than 1 to 2 km) of Miocene and younger strata are present, and much of the early Tertiary sequence, if it was ever present, may have been stripped off during the Miocene erosional event.

The accretionary wedge has low resource potential, although fluids or gas from the subducting sediment could migrate along the subduction zone into structures within the complex, or upwards into rocks overlying the subduction zone.

Much information needs to be obtained from the Shumagin margin to better constrain an estimate of resource potential. Major sampling and heat flow programs are needed to evaluate source and reservoir rock potential and thermal maturity of the sedimentary rocks. We do not know what similarities and differences there may be between Alaska Peninsula rocks and Shumagin margin rocks. Also, major unknowns are the extent, composition, and state of preservation of early Tertiary rocks beneath the margin. The resource potential of the Shumagin margin could be substantially greater than we would currently estimate if extensive early Tertiary strata have been preserved beneath the margin in areas otherwise deemed unprospective because the Miocene and younger strata are thin.

GEOLOGIC HAZARDS

The major potential geologic hazards in the Shumagin region are: (1) seismicity and tsunamis, (2) volcanic activity, (3) active faulting, (4) submarine slumping, (5) gas-charged sediment and gas hydrates, and (6) current and wave induced sediment transport, unstable sediment, and buried channels. Minor hazards such as shoreline effects by storm waves and landsliding could be locally important.

Seismicity and tsunamis

Earthquakes pose three distinct geohazards: (1) severe ground shaking caused by a great earthquake (magnitude greater than 7); (2) frequent earthquakes of low to moderate magnitude that may be associated with progressive rupturing of the sea floor, and (3) tsunamis or seismic sea waves.

The Shumagin margin falls within the Aleutian seismic zone, one of the most active seismic zones in the world. Great earthquakes, and their destructive potential in terms of violent ground motion and associated tsunamis, occur commonly in the vicinity of the Shumagin margin. At least 10 great earthquakes (magnitude greater than or equal to 7.4) and numerous smaller magnitude earthquakes have occurred along the Shumagin region (155^{o} W. to 165^{o} W.) since 1929 (Sykes, 1971; Sykes and others, 1981). One of these earthquakes, the 1946 shock seaward of Unimak Island, generated one of the most destructive tsunamis recorded in the Pacific (Sykes, 1971). Moreover, the Shumagin region lies within the Shumagin seismic gap, where a great earthquake is predicted to happen within the next 10 to 20 years (Sykes, 1971; Sykes and others, 1981; McCann and others, 1980; Davies and House, 1979; Davies and others, 1981), and is adjacent to a second seismic gap, the Unalaska Gap, with a similar potential for a great earthquake (House and others, 1981) (Fig. 22). The seismicity and tsunami hazard is therefore high; a potentially destructive and possibly tsunami-generating earthquake is likely to occur within the Shumagin region within the next few decades.

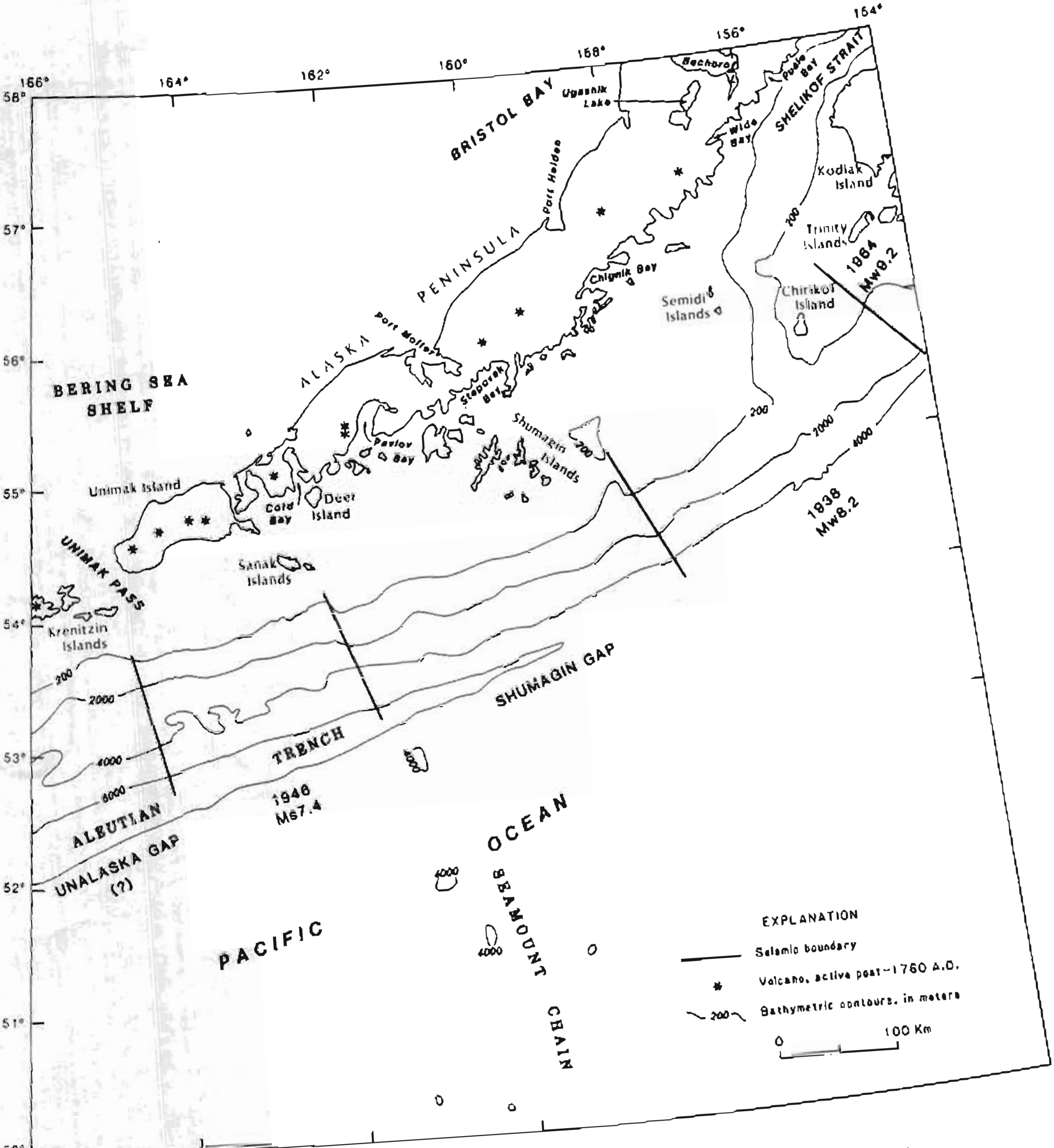


Figure 22. Seismic gaps in the Shumagin margin region. The dates and magnitudes of major earthquakes are shown in their respective aftershock regions. The seismic boundaries are taken from Davies and others, 1981.

Volcanic activity

The Shumagin margin is adjacent to the volcanically active Alaska Peninsula and Unimak Island where 10 volcanoes have been active since about 1760 (Figs. 1, 3; Beikman, 1980). Aleutian volcanoes are andesitic and can explode violently. Several Aleutian volcanoes have erupted explosively and catastrophically during the past 10,000 years (Miller and Smith, 1977). Hazards from volcanic activity are associated with eruption of lava and ash, and the attendant earthquakes and possibly tsunamis. Eruptions from the Aleutian Arc volcanoes could spread pyroclastic materials over large areas. Severe danger from lava flows, nuee ardentes, or lahars is probably restricted to land and coastline areas around the volcanoes, although in the event of a large eruption, major effects could be felt at sea. Abrasive and corrosive effects of ash falls from typical eruptions can extend regionally and be a danger to offshore operations.

The largest known, catastrophic eruption of an Aleutian volcano in historic times occurred at the Katmai volcano in 1912. Some 21 km^3 of ash was erupted and carried over distances of 2000 km or more. At a distance of 180 km from the volcano, ash was deposited with a density of about 45 g/cm (Lisitsyn, 1966). This event was also accompanied by major earthquakes.

Active faulting and submarine slumping

No systematic study of active faults or submarine slumps with high resolution seismic reflection data has so far been made in the Shumagin region. Both processes are present at least locally, as observed on the multichannel seismic data, and are likely to be as widespread as in the Kodiak region (Von Huene and others, 1976) and the Bering Sea, Unimak, and Aleutian regions (Cooper and others, 1984). One major active fault is on the southwest side of West Sanak basin, where a fault scarp is observed on seismic records. Faults cutting the near-surface sediment are also common on the continental slope and along the mid-slope structural trend. Similarly, areas of sediment slumping have been observed on the continental slope on the multichannel data. More definitive data on slope faults and slumps will be available within the next one to two years, as data from a recent Seabeam and single channel seismic cruise along the Shumagin slope are analyzed (Lamont Doherty and U.S.G.S. cooperative cruise in June-July, 1984). A high resolution seismic and sampling cruise is needed in the Shumagin region to better evaluate these potential hazards.

Gas charged sediment and gas hydrates

Gas charged sediment and gas hydrates can reduce the bearing capacity and strength of seafloor sediment, as well as creating operational problems in drilling through or siting over the gas or hydrate zone. Gas charged sediment has been reported from the Cook Inlet, the Kodiak region, and the Bering Sea (Von Huene and others, 1976; Cooper and others, 1980, 1984; Marlow and others, 1976, 1979c, 1980). No similar accumulations have so far been observed in the Shumagin region, but, as with faulting and slumping, no systematic and thorough study has been made.

Gas hydrates are known to occur on the continental slope (MacLeod, 1982) and have been observed, but not systematically mapped, on the multichannel data.

Current and wave induced sediment transport and other sediment hazards

Sediment transport and erosion due to currents or storm waves could cause erosion and undermining of structural foundations or pipelines. Similarly, unstable sediment or buried channels could be hazards to offshore structures. Swift (6-10 knots) tide-generated currents sweep through narrow passes between islands of the Shumagin region and along the Aleutians. These currents are fast enough to move coarse grained sediment and to generate moving bedforms. Wave erosion, wave transport, and longshore currents could also produce significant erosion and transport of sediment. Unconsolidated, unstable sediment and buried channels may also be present, as such features have been observed in adjacent study areas. However, none of these processes or features has been studied or evaluated in the Shumagin region.

HARD MINERALS GEOLOGY

Potential hard mineral resources in the Shumagin planning area are Manganese-Cobalt (Mn-Co) crusts, massive (Kuroko-type) sulfide deposits, and porphyry copper deposits. None of these have been investigated to determine their resource potential beneath the Shumagin margin.

Mn-Co crusts have been dredged from along the adjacent Aleutian ridge, but no source data are available. Preliminary investigations in other island arcs have identified hydrothermal sources for some of the crusts, which means that they should be evaluated in the Shumagin region. Such crusts may also occur on the numerous seamounts present on the Pacific ocean floor within the Shumagin planning area.

Kuroko-type base/precious metal deposits are related to island arc volcanism. The processes (e.g. source of metals, structural and geochemical controls for sulfide deposition, origin, and composition of ore fluids, and evolution of the source and depositional systems in time and space), however, are problematic and poorly understood. Hydrothermal activity has created metal deposits along the Aleutian arc in the past as shown by sulfide deposits on Unalaska Island and on the Soviet-held Komandorsky Islands. Hydrothermal activity has also occurred on Attu and Atka islands in the Aleutians. This implies that hydrothermal ore bodies could occur along the Aleutian arc adjacent to the Shumagin region.

Porphyry copper deposits and mineralized intrusives have been reported on the Alaska Peninsula (Wilson 1979; Detterman and others, 1981 and references contained therein). No study has been made to determine if these potential mineral deposits extend beneath the Shumagin shelf.

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