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By TOR H. NILSEN and GEORGE W. MOORE

With a section on SEDIMENTARY PETROGRAPHY

By GARY R. WINKLER

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RECONNAISSANCE STUDY OF UPPER CRETACEOUS TO MIOCENE STRATIGRAPHIC UNITS AND SEDIMENTARY FACIES, KODIAK AND ADJACENT ISLANDS, ALASKA

By TOR H. NILSEN and GEORGE W. MOORE

ABSTRACT

The sedimentary structures and facies, paleocurrents, and stratigraphic relations of five formations exposed on Kodiak and adjacent islands were studied in reconnaissance fashion at several localities during the summer of 1976. The Upper Cretaceous Kodiak Formation, in fault contact with both younger and older formations, consists of turbidites deposited primarily in slope and basin-plain environments; paleocurrents indicate sediment transport to the southwest. The Paleocene and Eocene Ghost Rocks Formation, in fault contact with both younger and older formations, consists of at least in part syndepositionally deformed hemipelagic argillite and turbidites interbedded with pillow basalt; paleocurrents have an irregular orientation, possibly as a result of extensive post-depositional deformation that has disrupted the sedimentary characteristics of the formation.

The Eocene and Oligocene Sitkalidak Formation consists of middle- and outer-fan turbidites that locally include some basin-plain deposits; paleocurrents indicate general transport of sediments toward the south-southeast, although directions are variable, suggesting prominent southwestward transport southwest of Sitkalidak Island and northeastward transport northeast of Sitkalidak Island. The Oligocene Sitkinak Formation, where examined, consists of two distinctive facies: (1) on Sitkalidak Island, where it rests conformably on and interfingers in part with the Sitkalidak Formation, southward-transported turbidites deposited in inner-fan channel and slope environments; and (2) at its type locality on Sitkinak Island, where it essentially conformably underlies the Narrow Cape Formation and is in fault contact with the Sitkalidak Formation, eastward-transported marginal-marine strata deposited in fan-delta and lagoonal environments. The upper Oligocene? and Miocene Narrow Cape Formation consists of mollusk-rich, bioturbated siltstone and silty fine-grained sandstone deposited in shelf environments, probably derived from source areas to the northwest.

The Upper Cretaceous through Miocene sandstones on Kodiak and adjacent islands, which are primarily feldspatholithic, indicate a predominantly volcanic provenance. About 95 percent of the Kodiak and Ghost Rocks lithic detritus is composed of volcanic and plutonic rock fragments; in younger formations, the composition of rock fragments is more diverse. The sandstone modes indicate a general increase through geologic time in the total amount of quartzose grains (especially chert) and a decrease in the total amount of feldspar grains.

The Kodiak Formation forms part of the extensive Chugach terrane, thick Upper Cretaceous flyschlike strata in southern Alaska, apparently deposited in a major southwest-trending linear basin, possibly a southwest-sloping trench floor developed adjacent to the Alaskan continental margin. The highly deformed Ghost Rocks Formation, though possibly a distantly derived fragment rafted into southern Alaska along a convergent margin by sea-floor spreading processes, was most likely also deposited at the continental margin and derived from a southern Alaskan provenance, as indicated by its sedimentary petrography.

The Eocene to Miocene sequence—Sitkalidak, Sitkinak, and Narrow Cape Formations—represents a major first-order progradational cycle of shelf, slope, and deep-sea fan deposits that filled a northeast-trending sedimentary basin. These deposits filled either an inactive trench or major trench-slope basin developed during episodes of plate convergence.

INTRODUCTION

During the summer of 1976, we examined in reconnaissance fashion outcrops of the Kodiak, Ghost Rocks, Sitkalidak, Sitkinak, and Narrow Cape Formations of Kodiak and adjacent islands, which had earlier been mapped and named by Moore (1967, 1969). Moore had described the lithologies, type localities, approximate thicknesses, fossils, stratigraphic relations, and distribution of seven newly named Mesozoic and Cenozoic formations on Kodiak and adjacent islands. Earlier studies of the geology of Kodiak Island had been published by Martin (1912) and Capps (1937). In this report, we describe the outcrops, facies, sedimentology, petrography, and inferred paleogeography and depositional environments of the five formations, which range in age from Late Cretaceous to Miocene.

Strata on Kodiak Island are part of a widespread sequence of similar Mesozoic and Cenozoic rocks that form an arclike outcrop belt in southern Alaska extending from near Sitka in the southeast to the Shumagin and Sanak Islands in the southwest (fig. 1). This belt consists of five different terranes, separated by faults or unconformities. The interior terrane consists of metamorphic rocks of possible Paleozoic and Mesozoic age that crop out north of the Border Ranges fault (MacKevett and Plafker, 1974); these unnamed schists are present in northeastern Kodiak Island, from which they extend

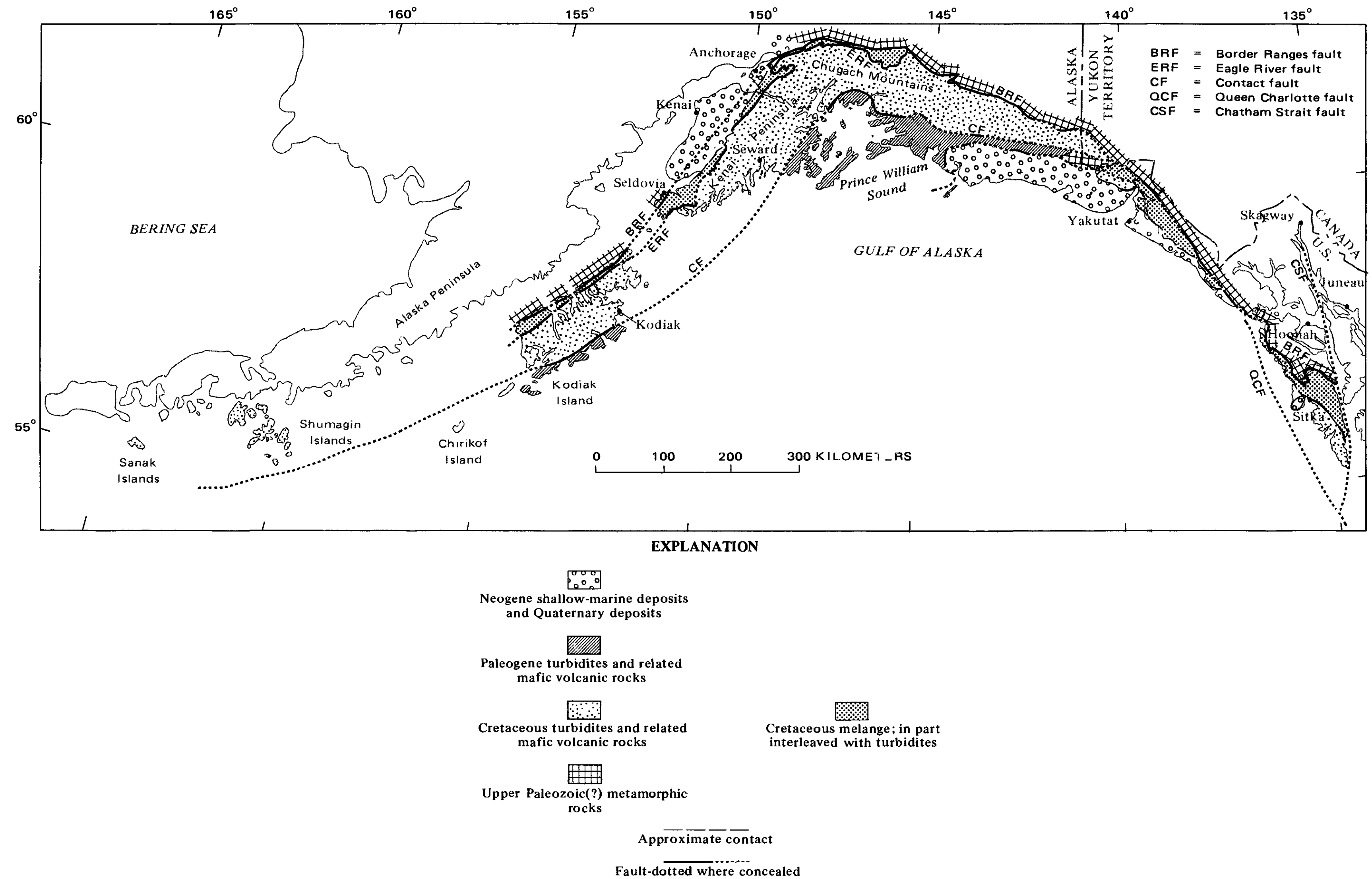


FIGURE 1.—Distribution of major geologic terranes and faults along the margins of the Gulf of Alaska. Geology modified from Beikman (1974a, b; 1975a, b) and Plafker, Jones, and Pessagno (1977b).

northeastward to the Kenai Peninsula, where similar schists crop out near Seldovia (fig. 1). The second terrane consists of melange that crops out between the Border Ranges fault and the Eagle River fault; this melange on Kodiak Island has been named the Uyak Formation by Moore (1969) and on the Kenai Peninsula to the northeast the McHugh Complex by Clark (1972, 1973). The third terrane, named the Chugach terrane by Berg, Jones, and Richter (1972), consists of Upper Cretaceous flyschlike strata that crop out between the Eagle River fault and the Contact fault (Plafker and others, 1977a, b). On Kodiak Island, this terrane is represented by the Kodiak Formation (fig. 2); on the Shumagin and Sanak Islands, by the Shumagin Formation (Moore, 1974b, c); on the Kenai Peninsula, by the Valdez Group (Clark, 1972, 1973); near Yakutat, by part of the Yakutat Group (Plafker and others, 1976); and near Sitka, by the Sitka Graywacke (Loney and others, 1975). The fourth terrane crops out south of the Contact fault and consists of folded and faulted Paleogene turbidites and related mafic volcanic rocks; on Kodiak and adjacent islands it consists of the Ghost Rocks, Sitkalidak, and Sitkinak Formations, which resemble in part the Orca Group of the Prince William Sound area (Winkler, 1976). The fifth and most oceanward terrane consists of less-deformed upper Paleogene and Neogene shallow-marine deposits, which on Kodiak and adjacent islands consist of the Narrow Cape and Tugidak Formations.

Kodiak Island lies in the western Gulf of Alaska and is about 100 km wide by 160 km long. Northeast-trending folded and faulted rocks underlie Kodiak and adjacent islands and extend southwestward from similarly trending rocks of the Kenai Peninsula (fig. 2). Metamorphic rocks that include quartz-mica schist, greenschist, blueschist, and epidote amphibolite form a northwesterly and older terrane on Kodiak Island (Carden and Forbes, 1976; Connelly and Moore, 1977). Potassium-argon dates from crossite and white mica in the schists yield ages of approximately 140-190 m.y. (Carden and others, 1977), the ages of metamorphism and possibly emplacement of the schist terrane. An age of 190 m.y. was determined from similar schist near Seldovia (Forbes and Lanphere, 1973). Less metamorphosed Upper Triassic volcaniclastic rocks crop out in small areas northwest of the schist along the coasts of Kodiak, Afognak, and Shuyak Islands (Connelly and Moore, 1977).

The Uyak Formation to the southeast of the schist terrane is at least in part a complexly deformed melange thought to be thrust southeastward over the Upper Cretaceous Kodiak Formation. It contains blocks or knockers of layered gabbro, clinopyroxenite, dunite, greenstone, chert, argillite, and wacke (Connelly and others, 1976, 1977). Various blocks contain Late Triassic fossils, and a distinctive unit of red chert underlain by pillow basalt contains radiolarians dated by E. A. Pessagno (written commun., 1976) as Early Cretaceous (Valanginian or Hauterivian). The Uyak Formation is thought to have been formed as part of a subduction complex of Mesozoic age (Connelly and Moore, 1975; Moore and Wheeler, 1975; Connelly and others, 1976, 1977; Connelly, 1976; Moore and Connelly, 1976, 1977). A subduction-slip vector of N. 38° W. ±11° was determined for this complex by Moore and Connelly (1976).

Granitic batholiths intrude the Upper Cretaceous Kodiak Formation and Paleocene and Eocene Ghost Rocks Formations at many localities on Kodiak and adjacent islands (Moore, 1967; fig. 2). The batholithic rocks on Kodiak Island have been dated by the potassium-argon method in part as 58±2.5 m.y. old (Karlstrom, 1969, p. 28); they form part of a belt of granitic intrusions in Cretaceous and Paleogene turbidites along the Gulf of Alaska margin (Kienle and Turner, 1976). The batholiths to the northeast in the Chugach Mountains have been dated by the potassium-argon method at 47-52 m.y. (Hudson and others 1977), to the southwest in the Shumagin Islands, at 56 to 64 m.y. (Burk, 1965; Moore, 1973b; Kienle and Turner, 1976), and in the Sanak Islands at 59.9 m.y. (Moore, 1973b; Kienle and Turner, 1976).

The Pliocene and Pleistocene Tugidak Formation consists of shallow-marine siltstone and sandstone containing ice-rafted dropstones. It crops out only on Tugidak Island, which is southwest of Kodiak Island (fig. 2), and at the north end of Chirikof Island (fig. 1). The schists, Uyak Formation, batholiths, and Tugidak Formation will not be further discussed herein.

The physical characteristics of all the Tertiary formations, in particular their porosity and permeability, are summarized by Lyle and others (1978). Additional fieldwork by us and other workers during the summer of 1977 focused in detail on the sedimentology of the Sitkalidak and Sitkinak Formations (Bouma and others, 1977); the results of this study will be reported in other publications.

TURBIDITE FACIES AND FACIES ASSOCIATIONS

The turbidite facies and facies associations described here in general follow the classification systems presented by Mutti and Ricci Lucchi (1972, 1975) and Nelson and Nilsen (1974), as summarized by Nilsen (1977). According to these systems, marine turbidites generally can be referred to three distinctive facies associations: slope, fan, and basin-plain (fig. 3).

The slope facies association is characterized by deposition of hemipelagic argillaceous mud and

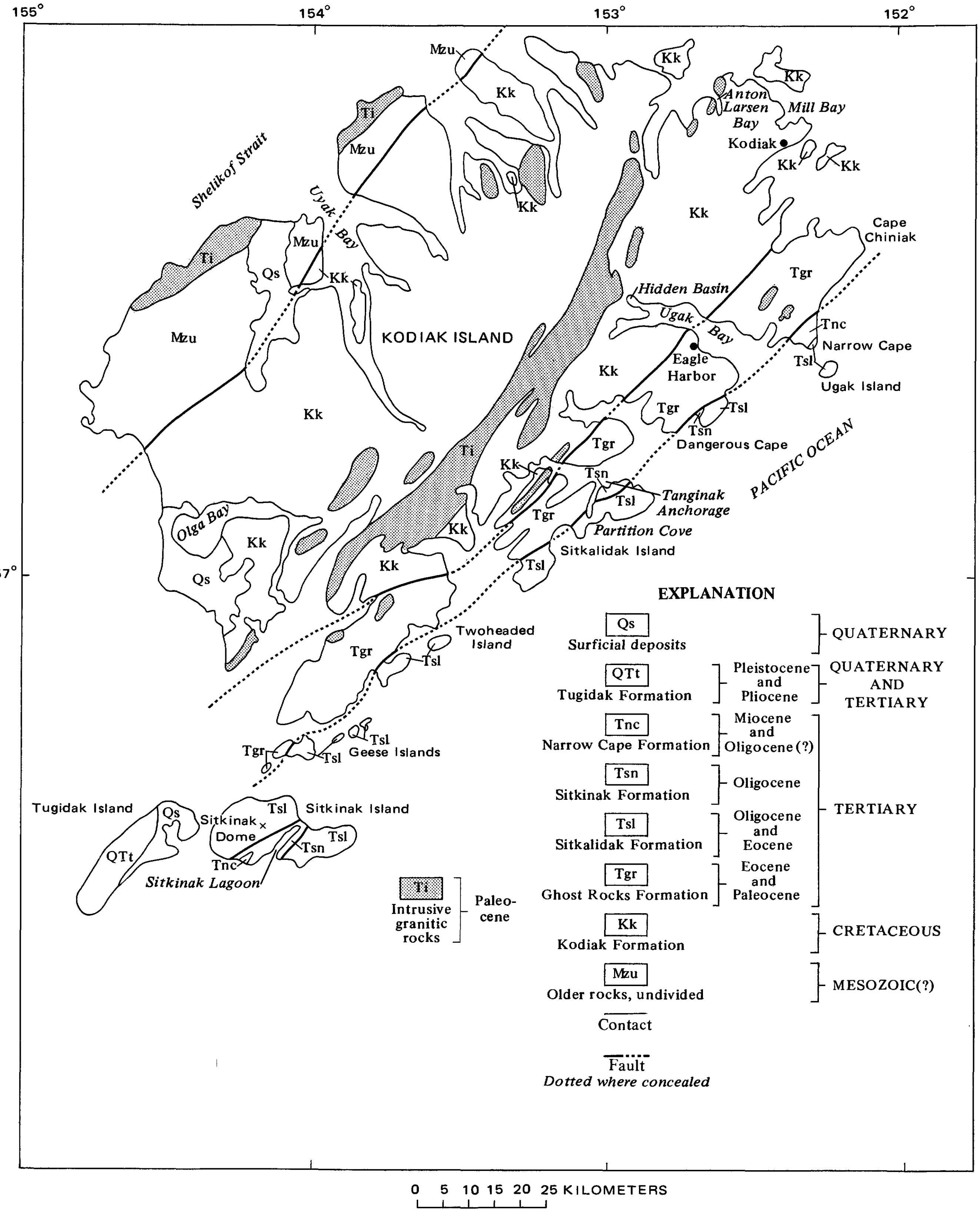


FIGURE 2.—Simplified geologic map of Kodiak and adjacent islands, Alaska. Geology modified from Moore (1967).

thinly interstratified fine-grained turbidites, cut in places by coarser grained submarine-canyon deposits. Upper-slope deposits typically slump and slide downslope, resulting in accumulation of imbricated slices

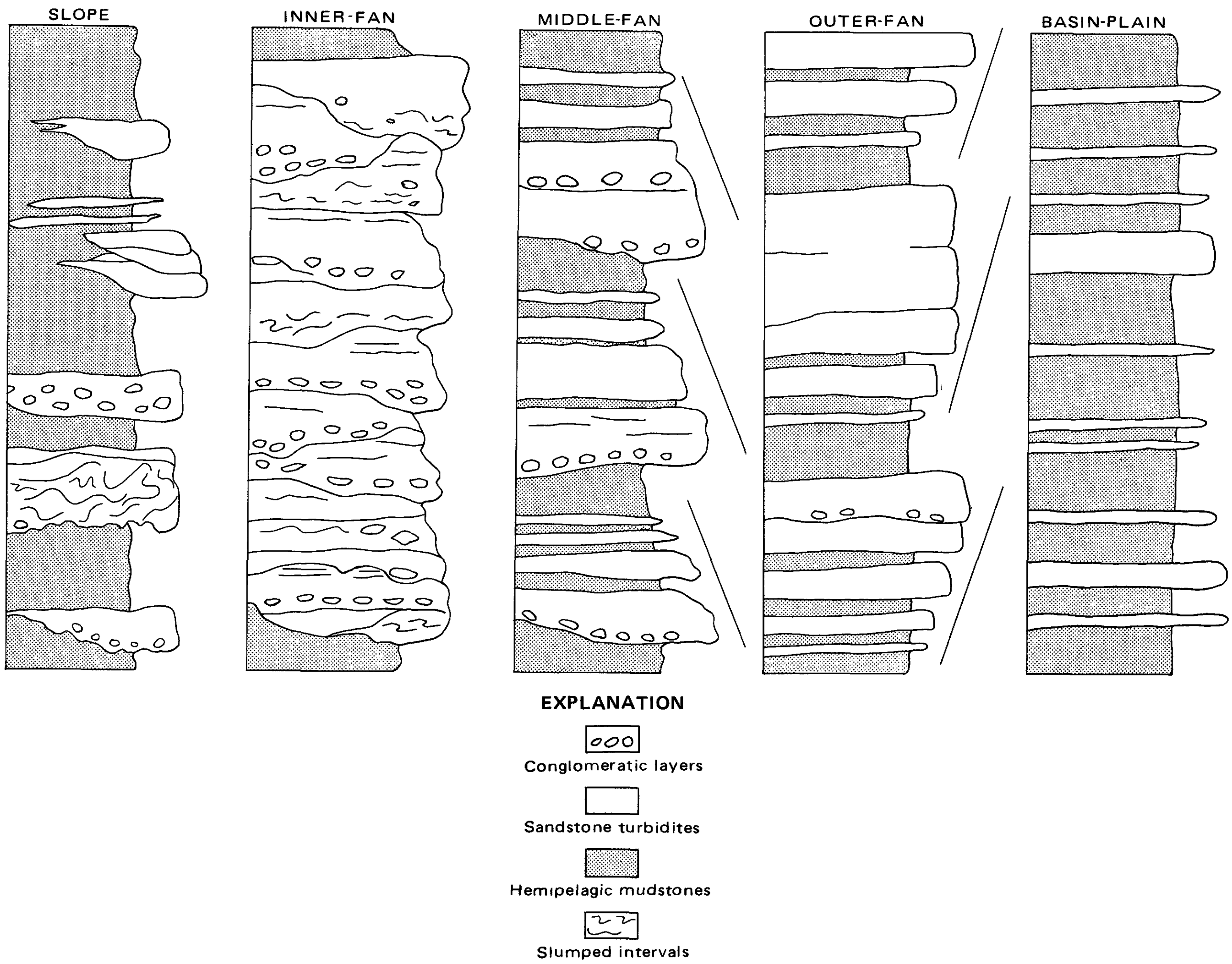


FIGURE 3.—Characteristic vertical cycles or megasequences of various deep-sea turbidite facies associations (modified from Mutti and Ricci Lucchi, 1972, fig. 14, and Nilsen, 1977, fig. 3-7). Larger cycles shown by bars to right of column.

of this material on the lower slope and base-of-slope.

The deep-sea fan facies association can be divided into: (1) inner-fan facies association, generally characterized by deposition of argillaceous channel-margin and interchannel mudstone and thick, noncyclically arranged beds of conglomerate and sandstone in one or several major channels; (2) middle-fan facies association, generally characterized by channelized, cyclically arranged thinning-upward and fining-upward megasequences of sandstone beds deposited in numerous distributary channels and channel-margin and interchannel mudstones with associated thinly bedded and fine-grained turbidites; and (3) outer-fan facies association, generally characterized by cyclically arranged thickening-upward and coarsening-upward megasequences of sandstone beds deposited as nonchannelized depositional lobes of considerable lateral extent downfan from the middle-fan distributaries. The thinning-upward middle-fan cycles generally result from gradual abandonment of channels, whereas the thickening-upward outer-fan cycles generally result from progradation, including progradation of feeding channel systems over depositional lobes.

The basin-plain facies association is generally characterized by noncyclically arranged, nonchannelized beds of sandstone and shale of wide lateral extent. This facies association in general has a lower sandstone:shale ratio than the deep-sea fan facies association and contains abundant hemipelagic shale. Bed thickness is nonsystematic because individual turbidites are derived randomly from numerous distributaries and multiple sources.

The classification of Mutti and Ricci Lucchi (1972, 1975) introduces a set of seven facies designated by letters—facies A to G—to refer to individual bedding types in turbidite sequences. Assemblages of beds of these lettered facies are characteristic of and comprise the slope, fan, and basin-plain facies associations. This system, ideally suited to reconnaissance study of turbidite sequences, will be used throughout this report. The facies, in brief, are: facies A—thick to massive, lenticular, graded and nongraded beds of conglomerate or sandstone generally lacking conspicuous sedimentary structures; facies B—thick to massively bedded, medium- to coarse-grained sandstone characterized by irregular plane-parallel, wavy, or inclined laminae and fluid-escape structures; facies C—graded beds of sandstone organized into Bouma (1962) sequences that start with the basal *a* division; facies D—thinner bedded and finer grained graded sandstone beds organized into Bouma sequences that lack the basal *a* division; facies E—thin- to medium-bedded, coarse- to fine grained sandstone characterized by dune-shaped tops, wedging of adjacent beds, and cross-stratification; facies F—chaotic deposits retransported by slumping and sliding; and facies G—hemipelagic pelites.

KODIAK FORMATION

BACKGROUND

The Kodiak Formation, of Late Cretaceous (Maestrichtian) age (Moore, 1969; Jones and Clark, 1973), crops out in a broad, general northwest-dipping faulted and folded tract over most of the central part of Kodiak Island. It is in fault contact with the probably older Uyak Formation to the northwest and the younger Ghost Rocks Formation to the southeast (Moore, 1967, 1969). The Kodiak Formation was examined in roadcuts and coastal outcrops along Ugak Bay and Uyak Bay (fig. 2). Originally considered to be about 30,000 m thick (Moore, 1969, 1975), the Kodiak Formation is now thought to be of the order of 5,000 m thick and to be repeated structurally by numerous folds and faults. Stratigraphic correlation is extremely difficult because of structural repetition of beds and recurrence of similar facies.

BASIN-PLAIN FACIES ASSOCIATION

Almost all the Kodiak Formation is of the basin-plain or slope facies associations. Deep-sea fan facies are only locally developed, probably where they fill relatively small intraslope basins.

The basin-plain facies association, structurally the lowest part of the formation, is characteristic of most of the Kodiak Formation on the southeast side of Kodiak Island. Here the basin-plain facies association consists of repetitively interstratified graded sandstone beds and hemipelagic shales, typically 30 cm thick, without any ordering or development of megasequences (fig. 4*A*, *B*). Some calcite-cemented turbidites are present. Sandstone:shale ratios range in general from 1:1 to 1:5. The interstratified hemipelagic shale is generally bioturbated; trace fossils typically are those of the surface-grazing deep-marine *Nereites* facies and include *Helminthoida* and *Helminthopsis* as well as larger trace fossils possibly formed by moving gastropods. The sandstone beds are plane-parallel, extend over long distances with out noticeable changes in thickness or grain size, are not channelized, and generally range in thickness from 1 to 35 cm, although single thicker beds are present in some areas. The beds are most commonly fine- to medium-grained facies D sandstone turbidites probably deposited by low-density turbidity currents of variable volume that have traveled long distances from source areas. Sedimentary structures include sole markings, parallel and wavy lamination, convolute lamination, current-ripple markings, and, rarely, ripple-drift lamination.

Thicker, coarser grained beds with rip-up clasts of siltstone or mudstone are occasionally found within the basin-plain facies association, generally along the northwest edge or stratigraphically upper part of the outcrops of the basin-plain facies association. These isolated beds, in places groups of beds that may possibly be locally tuffaceous, represent slumps or debris flows that traveled from marginal slopes out onto the basin-plain floor, forming thick, contorted wildflysch-like strata. Beds of this type were observed along the southeast shore of Hidden Basin in Ugak Bay (fig. 2).

Locally within the basin-plain facies, as at Mill Bay, Anton Larsen Bay and in quarries south of the city of Kodiak, thin lobelike outer-fan sequences are developed (fig. 4*C*). These occurrences are isolated, however; the preserved lobes are thin, generally only about 5 m thick. The strata consist primarily of facies C and D turbidites.

SLOPE FACIES ASSOCIATION

The slope facies association of the Kodiak Formation crops out on the northwest side of Kodiak Island; there it consists primarily of thick mudstone sequences that may form imbricate slices juxtaposed during multiple phases of synsedimentary slumping (fig. 4*D*). These rocks, which are primarily facies G and F deposits, contain chaotically oriented blocks, slabs, and disordered fragments of hemipelagic mudstone that probably slid from upper slope depositional sites to the lower slope or base of slope under the influence of gravity. The blocks are composed mainly of mudstone with thin interbeds of noncyclically arranged fine-grained sandstone, siltstone, and mudstone characterized by Bouma $T_{c\text{-}e}$, $T_{d\text{-}e}$, and T_e sequences. Sandstone:shale ratios are typically very low, ranging from 1:30 to 1:10. Large slump blocks containing complexly folded thicker beds of sandstone and shale are present within the finer grained slope deposits (fig. 4*E*), possibly representing downslope-transported blocks of outer-shelf facies. Some disrupted parts of the sequence consist of completely broken beds that contain isolated blocks of contorted and folded sandstone; locally only fold noses suspended in a fine-grained matrix of mudstone are preserved (fig. 4*E*).

Channelized thick beds of conglomerate and sandstone associated with thin beds of channel-margin turbidites crop out locally within the slope facies association, as in the Uyak Bay area (fig. 4*F*). These conglomerates, which have sandy matrices, represent the fill of canyons or channels cut into the slope that may have supplied some sediment to the more distal basin-plain depositional areas. The conglomeratic sequences exposed along the shores of Uyak Bay are of the order of 50 m thick; they consist of poorly developed thinning- and fining-upward cycles with channelized bases. Intermixed with the conglomerates are large fragments of slumped mudstone as long as several meters in longest dimension, derived from the channel or canyon walls, and some beds of pebbly mudstone (fig. 4*G*). Stratigraphically above and below the conglomeratic sequences are thin-bedded channel-margin overbank deposits composed of facies D turbidites (fig. 4*H*). These overbank turbidites form Bouma $T_{b\text{-}e}$ and $T_{c\text{-}e}$ sequences that most characteristically contain ripple-drift lamination thought to have been deposited by turbidity currents that overspilled channel margins and transported sediment away from the channel axes. Individual beds within the overbank turbidites thin and pitch out laterally and locally are arranged en echelon.

Present locally within the slope facies of the Kodiak Formation are thin fan facies apparently developed in depressions on the lower slope. Some of these small basins probably formed behind major slump blocks and slump masses. Alternatively, they may have developed tectonically as a result of slope deformation. Two sequences of fan facies of this type are exposed at Uyak Bay, where thickening-upward lobes are developed in sequences bounded above and below by slumped and imbricated hemipelagic slope facies. In the first sequence, one lobe is developed, in the second, four lobes; the lobes are 5-10 m thick and consist of facies C and D turbidites characterized by well-developed Bouma (1962) sequences. Sandstone:shale ratios are approximately 3:1 to 1.5:1.

PALEOCURRENT PATTERN

Paleocurrents obtained from the Kodiak Formation are relatively uniform in orientation, generally indicating southwestward transport of sediment by turbidity currents in both slope and basin-plain facies associations (fig. 5), although paleocurrents at the northwest end of Uyak Bay in the slope facies association indicate a more southerly direction of sediment transport. A total of 52 paleocurrents were measured, almost all from flute casts and groove casts; measurements were corrected by two-tilt stereonet rotation. The range of paleocurrent directions is 110° and 265°, that is, east-southeast to west-southwest, with a vector mean of 212° and a standard deviation of 34°. These data indicate that during deposition of the Kodiak Formation, turbidity currents mainly flowed toward the southwest.

GHOST ROCKS FORMATION

BACKGROUND

The Ghost Rocks Formation crops out in a long continuous belt southeast of the Kodiak Formation and appears to be separated from younger strata to the southeast by faults (fig. 2). It is isoclinally folded, faulted, and sheared; it may be as thick as 5,000 m, but structural complications preclude an accurate measurement of its thickness. Moore (1969) considered the Ghost Rocks Formation to be Paleocene and Eocene in age and recognizable by pillow basalt or greenstone, hard black claystone, thin limestone beds, and locally prominent zeolite-bearing tuffaceous sandstone beds. A limestone layer directly overlying pillow lava at 57°23.0'N., 152°36.1'W., contains planktonic foraminifers tentatively idenfied in thin section as *"Globigerina" pseudobulloides, Planorotalites* sp., and *Subbotina triangularis* or *S. triloculinoides,* a Paleocene assemblage (R. Z. Poore, written commun., 1976).

SEDIMENTARY FACIES

Because of the structural complications and because it was examined at only a few localities, understanding of the Ghost Rocks Formation in terms of turbidite facies and facies associations is uncertain. Most of the unit consists of sheared and highly deformed shale, argillite, and mudstone. Isolated and thin $T_{c\text{-}e}$ and $T_{d\text{-}e}$ sandy and silty facies D turbidites are present; they are characteristically

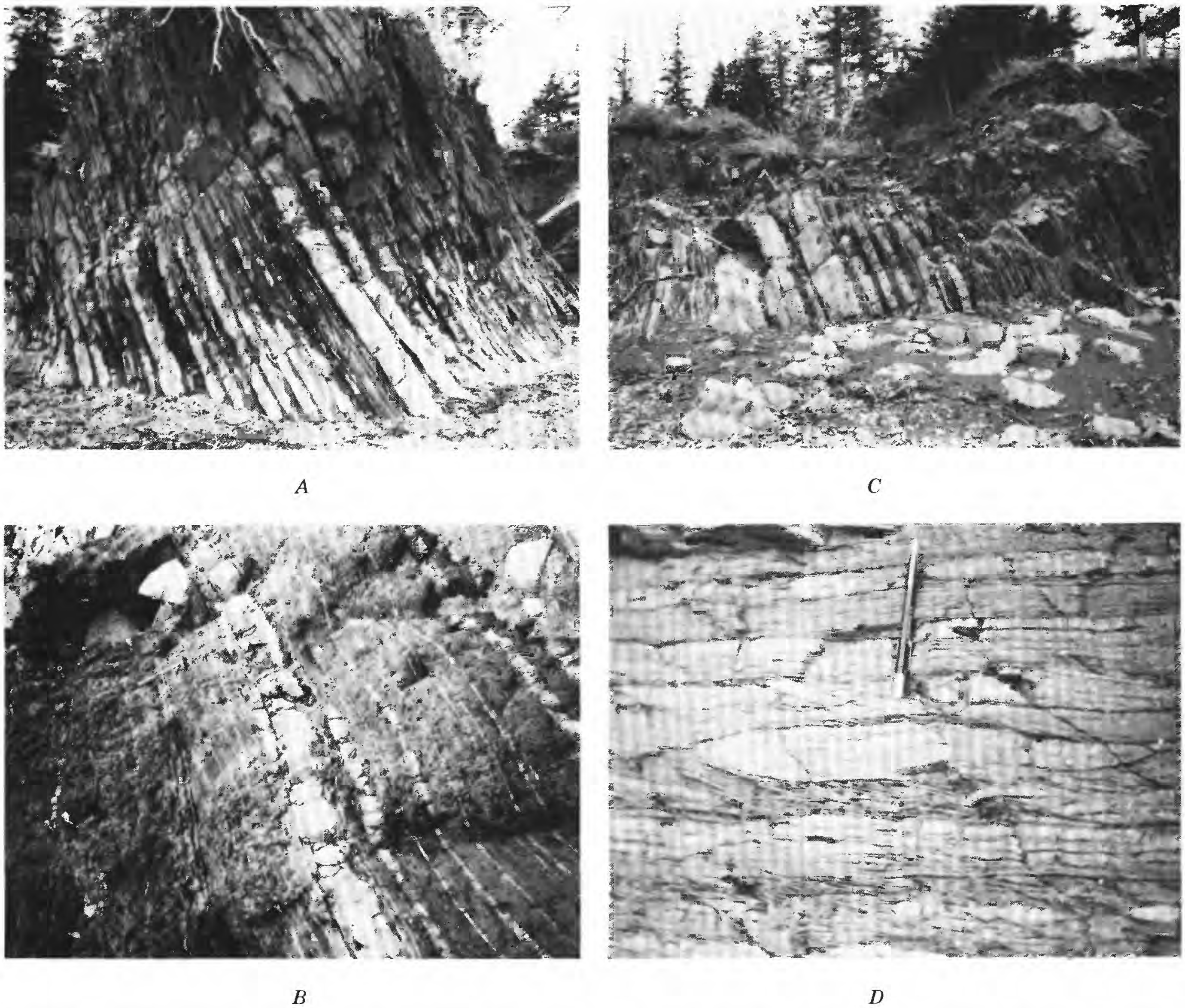
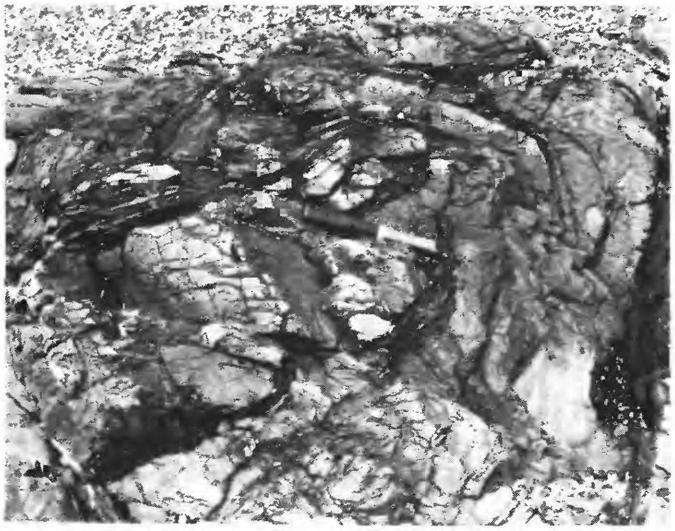


FIGURE 4.—Sedimentary facies, Kodiak Formation. *A*, Thinly bedded facies C and D basin-plain turbidites, Mill Bay; stratigraphic top to right. *B*, Thinly bedded facies D basin-plain to lobe-fringe turbidites, Uyak Bay; stratigraphic top to right. *C*, Basin-plain turbidites, Mill Bay, with irregular thinning-upward outer-fan sequence (center of photo); stratigraphic top to right. *D*. Synsedimentary recumbent fold in facies F slope turbidites, Uyak Bay; beds overturned.

folded and deformed such that only noses of folds are preserved and fold limbs are sheared out (figs. 6*A*, *B*, and *C*).

Some thicker facies C and D graded beds of turbiditic character are less deformed. These beds, characterized by convolute laminae, flame and load structures, and sandstone dikes and sills, are commonly contorted; they are typically greenish and tuffaceous and may form either thinning-upward or thickening-upward vertical megasequences (figs. 6*D*, *E*, and *F*). Very well developed thinning- and fining-upward middle-fan channel and interchannel megasequences are exposed east of Eagle Harbor on the south side of Ugak Bay (fig. 2). Levee deposits, locally slumped, are preserved at the tops of some of the channelized megasequences. The interval of megasequences is approximately 70 m thick and is bounded on the top and bottom by more sheared and deformed argillitic facies of the Ghost Rocks Formation. The relation of this preserved interval to other facies or facies associations within the Ghost Rocks is unclear.

Veins, fractures, minor faults, and melangelike features are characteristic of the Ghost Rocks For-



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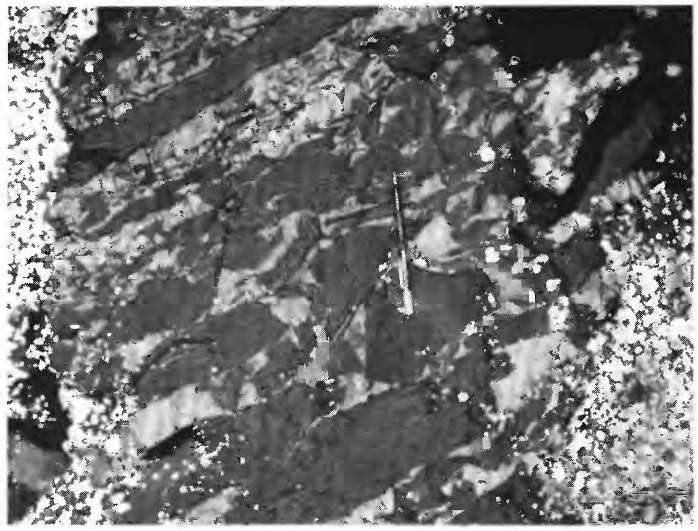


G

F

H

FIGURE 4.—Continued. *E*, Probable channel-margin facies F beds of slump-folded conglomerate, sandstone, and shale, Uyak Bay. *F*, Channelized facies A conglomerate and sandstone, Uyak Bay; stratigraphic top to left. *G*, Shale rip-up fragments in channel-fill facies A sandstone, Uyak Bay. *H*, Ripple-drift-laminated facies D levee and overbank deposits, Uyak Bay; sequence overturned, stratigraphic top to lower right.

mation. How many, if any, of the various structural complications are synsedimentary rather than tectonic in origin is difficult to determine on the basis of our brief reconnaissance.

PALEOCURRENT PATTERN

The few paleocurrents measured in the Ghost Rocks Formation are variable in orientation. Eleven measurements of cross-strata, flute casts, and groove casts along Ugak Bay yielded northwesterly, northeasterly, and southerly directions (fig. 5). Near Narrow Cape, three crossbed measurements yielded westerly paleocurrents. G. R. Winkler (written commun., July 1976) obtained southeasterly to southerly directions from two flute-cast measurements near Cape Chiniak.

The Ghost Rocks Formation may represent basin-plain or slope deposits that were severely deformed in a subduction zone. The direction of sedimentary transport for the clastics is not certain; the major facies associations are unclear because of extensive deformation; and the sedimentary and tectonic relations of the Ghost Rocks to younger and older formations are not well understood.

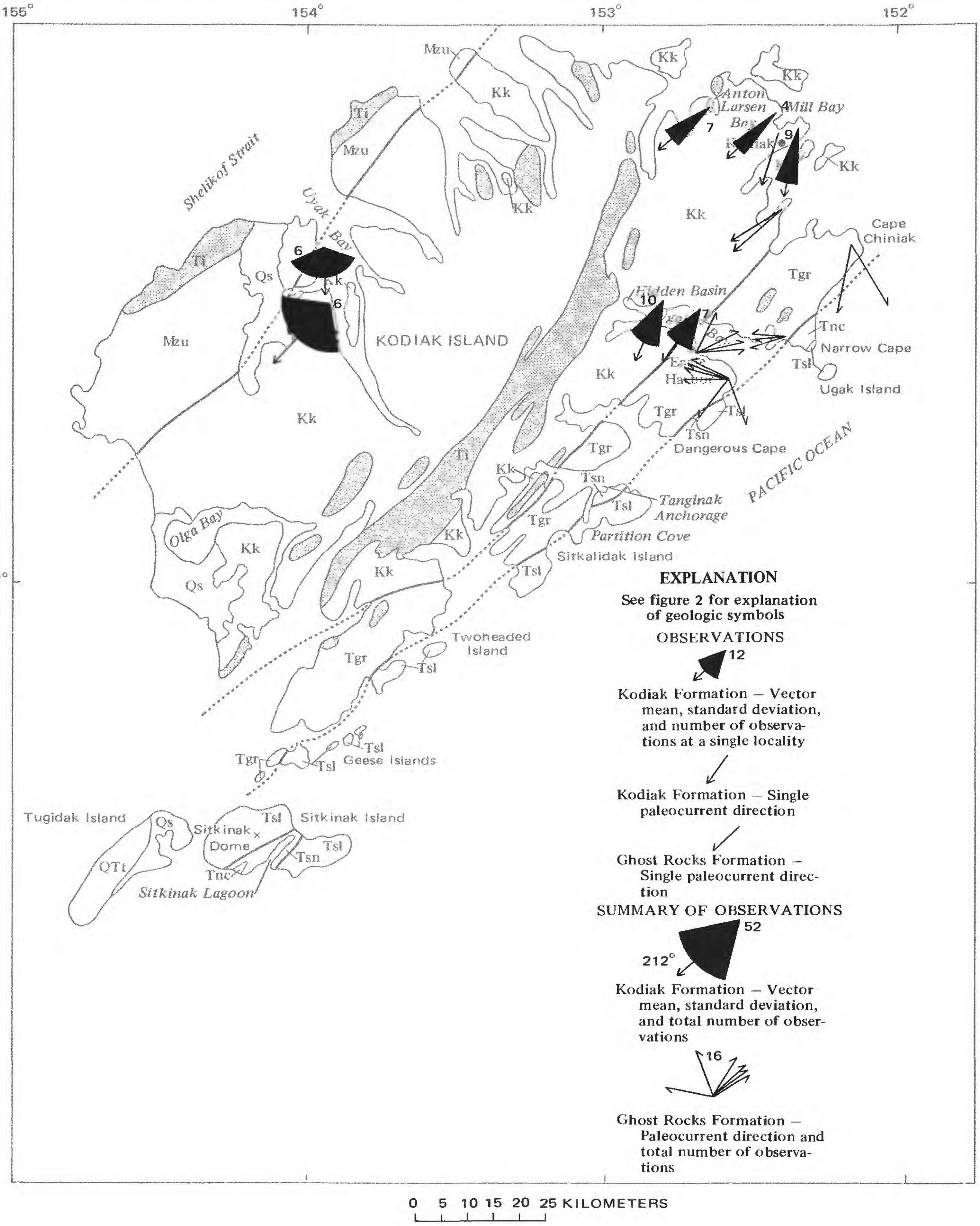


FIGURE 5.—Paleocurrent map for the Kodiak and Ghost Rocks Formations, Kodiak Island.

SITKALIDAK FORMATION

BACKGROUND

The Sitkalidak Formation, of Eocene and Oligocene age, crops out in separate areas along the southeastern parts of Kodiak, Sitkalidak, and Sitkinak Islands (Moore, 1967; fig. 2). It is separated from the older Ghost Rocks Formation to the northwest by faults; on Sitkalidak Island, it is conformably overlain by the Sitkinak Formation, whereas on Sitkinak Island it is separated from the Sitkinak Formation by faults (Moore, 1969). At Narrow Cape, it is overlain unconformably by the Narrow Cape Formation. Outcrops of the Sitkalidak Formation were examined at Narrow Cape and on Sitkalidak and Sitkinak Islands. On Sitkalidak Island, it was examined along the southeastern coast west of Partition Cove and along the northeastern coast east of Tanginak Anchorage (fig. 2). The formation everywhere consists of interbedded sandstone and shale that forms a thick series of turbidites, estimated by Moore (1969) to be about 3,000 m thick at the type section in eastern Sitkalidak Island.

NARROW CAPE

The Sitkalidak Formation at Narrow Cape is overturned toward the north and consists of coarsening- and thickening-upward megasequences formed primarily of facies C and D turbidites. The strata and megasequences are typical of outer-fan lobes. Three megasequences, about 10-40 m thick, are well exposed along the shoreline.

In the lower part of one megasequence, a prominent 90-cm-thick slurried bed contains scattered fragments of argillite in a sandstone matrix in the middle of the bed at the top of the Bouma *b* division and below the Bouma *c* division. Slurried beds of this type described from interlobe and lobe-fringe sequences by Mutti, Nilsen, and Ricci Lucchi (1978) and van Vliet (1978) seem to indicate erosion of the flanks or tops of lobes by turbidity currents.

At the tops of the megasequences are facies B beds as thick as 3 m. These beds are partly channelized into underlying strata (fig. 7*A*), probably a result of progradation in which the channel that fed the lobe eventually eroded part of the lobe constructed at its mouth. Alternatively, the erosive basal surfaces of these beds may simply represent erosion of the tops of lobes by turbidity currents, the same process that apparently yields slurried beds.

Nine paleocurrents from each of the three cycles were measured from flute casts, groove casts, and cross-strata. These paleocurrents indicate sediment transport toward the south with a vector mean of 171° and a standard deviation of 26° (fig. 8).

SITKALIDAK ISLAND

PARTITION COVE

On the west side of Partition Cove, the Sitkalidak Formation consists of a thick turbidite sequence that contains, in ascending order, lobe-fringe and distal-lobe deposits of the outer-fan facies association, some lobe deposits of the outer-fan facies association, channel and interchannel deposits of the middle-fan facies association, and possibly deposits of the inner-fan facies association. The sequence clearly indicates a prograding or outbuilding deep-sea fan sequence, presumably with inner-fan, slope, and shelf deposits present still higher stratigraphically in the formation, and basin-plain deposits lower in the formation.

The formation here consists almost entirely of sandstone and shale with no conglomerate present except for some granule-size detritus filling large flute casts at the bases of some thicker sandstone beds. Calcite-cemented turbidites and concretions are present locally, particularly in the lower part of the section. Coalified plant debris is abundant in most beds of sandstone, commonly concentrated in the Bouma *b* division or at the tops of thicker beds. Because of its low density, the plant debris probably was one of the last constituents to settle out of the depositing turbidity currents. Plant fragments are common in channel-margin and levee deposits, where they were deposited by overbank spilling of channelized larger turbidity currents. The abundant plant material may indicate the presence of a delta in more proximal marginal-marine areas.

The sequence shows no major development of outer-fan lobes; instead it is dominated by a large number of channelized thinning- and fining-upward megasequences in the upper two-thirds of the observed section. Possibly thick sequences of outer-fan lobes may be located either below the observed section or laterally to the northeast or southwest. The lobe-fringe sequences characteristically contain five or six laterally continuous beds of fine-grained facies D sandstone (fig. 7*B*) and some slurried beds 5-15 cm in thickness (fig. 7*C*). Sandstone:shale ratios are of the order of 1:1 to 1:2.

Only two outer-fan lobe megasequences were observed stratigraphically above the lobe-fringe deposits. These lobes are approximately 10 m thick and consist of 10-15 beds of facies B, C, and D sand-

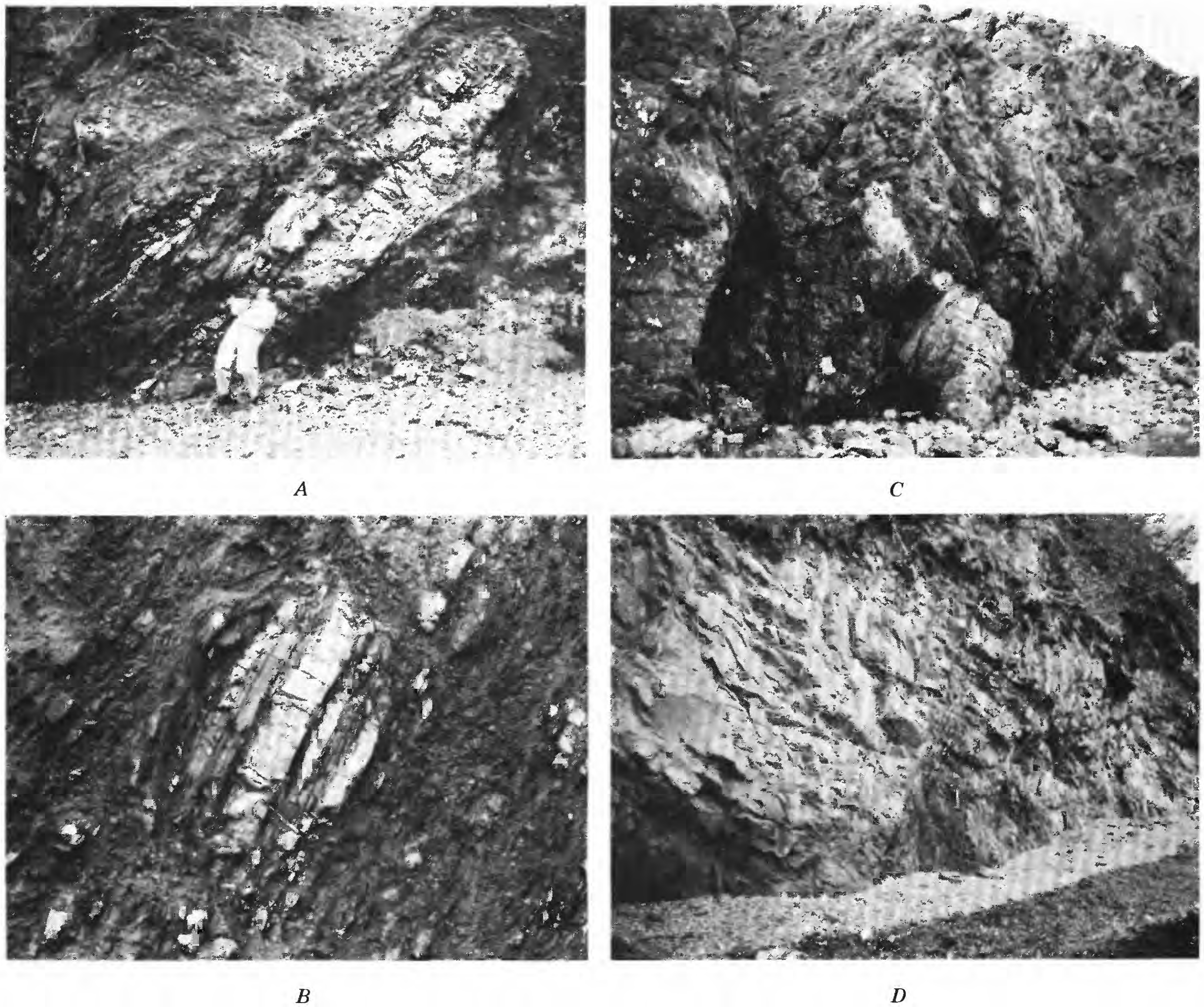


FIGURE 6.—Sedimentary facies, Ghost Rocks Formation. *A*, Broken beds of sandstone and shale, south shore of Ugak Bay; stratigraphic top not clear. *B*, Broken beds of sandstone and shale, west of Narrow Cape; stratigraphic top to left. *C*, Deformed greenstone and argillite, west of Narrow Cape; stratigraphic top uncertain. *D*, Massive facies A tuffaceous sandstone with interval of thin-bedded facies D sandstone and shale, south shore of Ugak Bay; stratigraphic top to left.

stone that have a sandstone:shale ratio of about 1:0.75. The thickest bed of sandstone is about 1.5 m thick. The stratigraphically highest lobe thins upward in its upper part and appears to contain an erosional surface in its middle part. A thick sequence of thinning-upward channel-fill cycles overlies this composite lobe; this relationship indicates relatively rapid progradation of the fan. Several slurried beds as thick as 150 cm are present in the lobe megasequences. Thin calcareous turbidites above the thickest lobe beds may represent sediment supply from a different source terrane.

The channelized middle-fan megasequences generally consist of thick beds of facies A sandstone and conglomerate at the base, thinner beds of facies A and B turbidites in the middle, and thinner facies C turbidites at the top (fig. 7*D*). The megasequences characteristically thin and fine upward and are separated from one another by shaly intervals. Dish structures are locally present, and minor channeling is very common. The megasequences, which range in thickness from 15 to 60 m, generally have sandstone:shale ratios of 2:1 to 5:1. The lower contact of the megasequence is generally channelized,

E

F

FIGURE 6.—Continued. *E*, Ripple-laminated facies D turbidites, south shore of Ugak Bay; stratigraphic top to left. *F*, Ripple-marked facies D turbidites, south shore of Ugak Bay; stratigraphic top to left.

cutting into underlying fine-grained interchannel and levee deposits that are locally as thick as 8 m. Ungraded debris-flow deposits that consist of sandstone and mudstone containing scattered and chaotically oriented rip-up clasts are present in some of the channelized megasequences.

The overbank and levee deposits consist of thin ripple-marked beds of siltstone, fine-grained sandstone, and mudstone. The siltstone and sandstone beds are discontinuous and characteristically vary in thickness laterally (fig. 7*E* and *F*). They typically consist of ripple-topped facies D turbidites that locally form thin, thinning-upward megasequences that presumably mimic the thinning-upward channel-fill cycles. Facies E beds present locally may represent reworking of channel-margin deposits by succeeding turbidity currents or overbanking of very large coarse-grained turbidity currents. Slump folds and synsedimentary faults in these overbank deposits are indicated by filling of topographic lows by turbidites of variable thickness (fig. 7*G*). In some deposits, outward migration of slumping away from the channel margin or growth slumping from prograding levee deposition is demonstrable.

Nonleveed interchannel deposits were seen at only one locality in this sequence, situated above slumped overbank deposits. Here they may be inner-fan interchannel deposits. These deposits consist of thinly interstratified siltstone and shale with numerous calcareous turbidite layers. The sandstone:shale ratio is about 1:3 to 1:6. Turbidite beds are about 3-7 cm thick; no cyclicity in bed thickness was noted within the sequence.

The uppermost part of the section west of Partition Cove contains very thick and almost continuous beds of amalgamated sandstone that may represent inner-fan channel deposits. Megasequences formed by variations in bedding thickness are not clearly defined. The sandstone:shale ratio in this part of the section is 10:1 or greater, and interbedded deposits of shale or mudstone are thin to nonexistent.

Nineteen paleocurrents from the Partition Cove sequence indicate sediment transport toward the southeast in the lower part of the sequence (lobe-fringe, outer-fan lobe, and lower part of the middle-fan channel deposits); the vector mean is 142°, standard deviation 36° (fig. 8). In the upper part of the sequence, paleocurrents are more variable and indicate flow in channels toward the northeast (vector mean of 48° from six measurements) and toward the southwest (vector mean of 226° from four measurements). Part of this variability in transport direction results from measurement of directions of both channel-axis flow and overbank spilling. The data in general suggest a source area to the north or northwest.

TANGINAK ANCHORAGE

East of Tanginak Anchorage on northeastern Sitkalidak Island, extensive thinning- and fining-upward channelized middle-fan megasequences—alternating channel, channel-margin and interchannel deposits—crop out stratigraphically below channelized inner-fan conglomerates of the Sitkinak Formation. The channel-fill sequence consists mainly

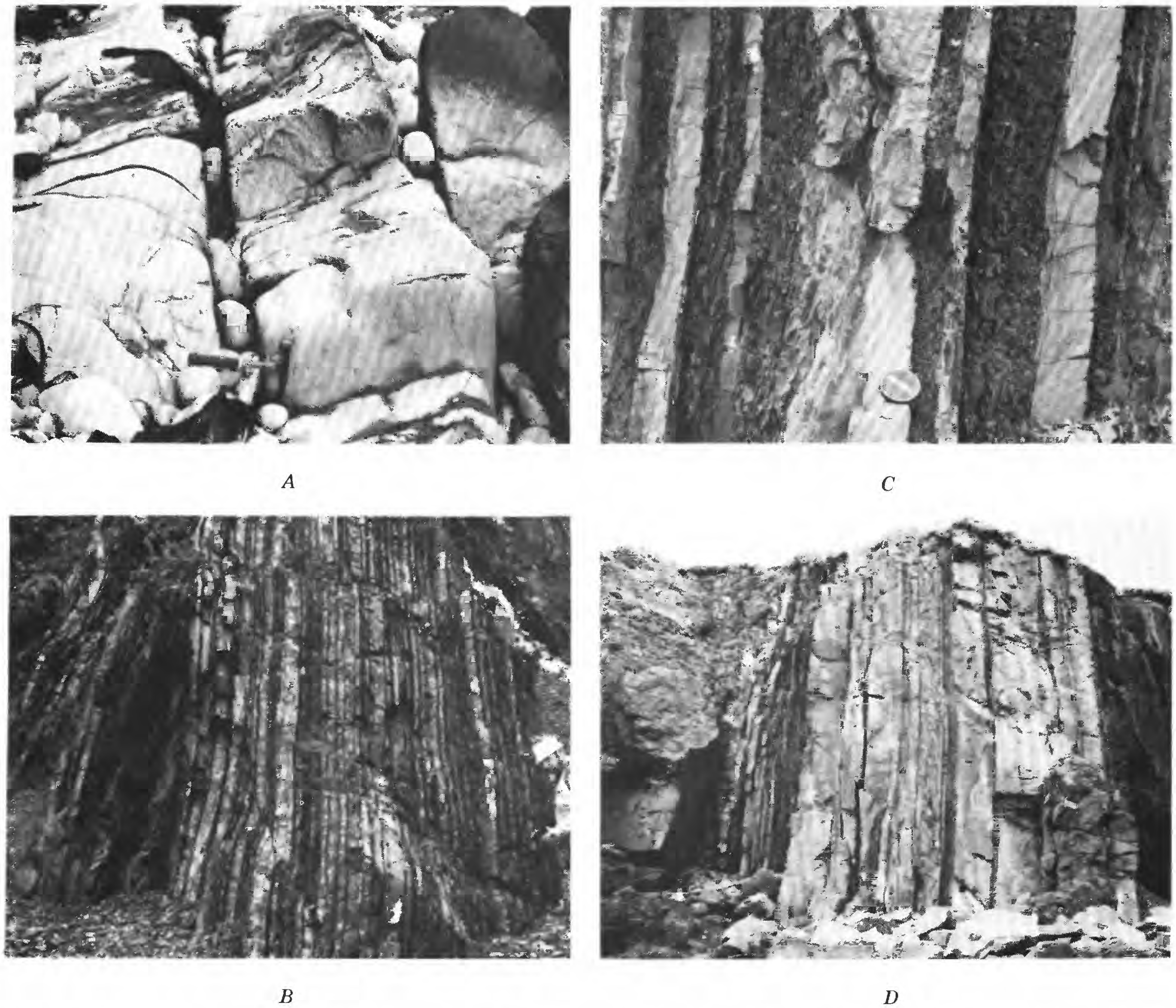


FIGURE 7.—Sedimentary facies, Sitkalidak Formation: *A*, Thickly bedded facies B turbidites at top of outer-fan lobe sequence, Narrow Cape; stratigraphic top to left. *B*, Thinly bedded facies D lobe-fringe turbidites, Partition Cove, Sitkalidak Island; stratigraphic top to left. *C*, Slurried bed of lobe-fringe turbidites, Partition Cove, Sitkalidak Island; stratigraphic top to left. *D*, Thinning-upward middle-fan channel deposit bounded by thin-bedded interchannel deposits, Partition Cove, Sitkalidak Island. Base of overlying thinning-upward cycle at left; stratigraphic top to left.

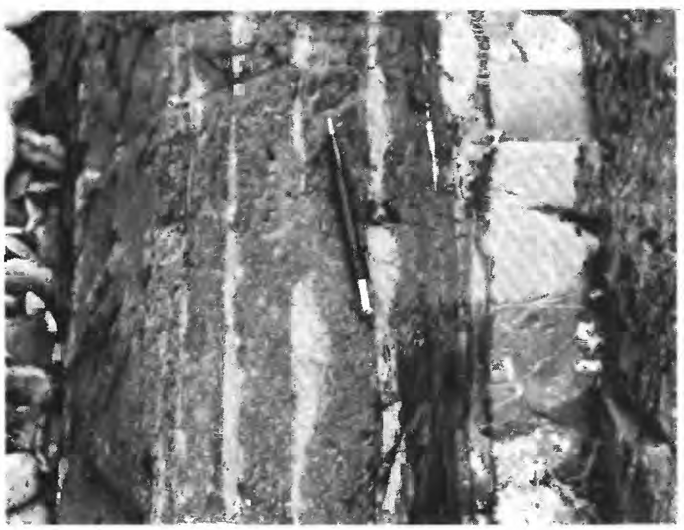
of facies B sandstone beds that are wedge-shaped, amalgamated, and commonly channeled into underlying beds. The sandstone beds form discrete thinning upward cycles 5-70 m thick. The upper parts of the cycles commonly contain more shale, thinner beds, and thin dune-shaped beds of facies E sandstone.

The channel-margin facies consists of thin- to medium-bedded, cross-stratified, and ripple-marked facies E sandstone and thin, isolated, and starved-ripple beds similar to those described by Nelson, Mutti, and Ricci Luchi (1975) for proximal thin-bedded turbidites. These beds wedge out abruptly away from the channels and have a relatively high sandstone:shale ratio.

The interchannel deposits consist primarily of bioturbated mudstone with thin facies D siltstone and fine-grained sandstone turbidites. These deposits form sequences 10-50 m thick between channel and channel-margin deposits. Moderately channelized facies B and C sandstone beds scattered within the fine-grained interchannel deposits probably are produced by random channel avulsions or channel

E

G



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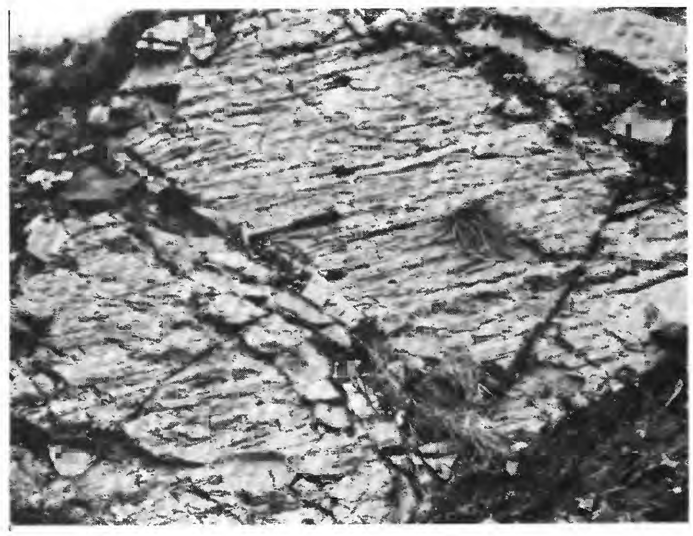


H

FIGURE 7.—Continued. *E*, Ripple-marked interchannel facies D turbidites, Partition Cove, Sitkalidak Island; stratigraphic top to right. *F*, Ripple-marked interchannel facies D turbidites, Partition Cove, Sitkalidak Island; stratigraphic top to right. *G*, Slumped channel-margin turbidites, Partition Cove, Sitkalidak Island; stratigraphic top to left. *H*, Flute and groove casts at base of facies C lobe-fringe turbidites, near Sitkinak Dome, Sitkinak Island; paleocurrents toward lower left.

overspilling by very large turbidity currents.

Paleocurrents in this channelized sequence have a bimodal distribution (fig. 8). About half are oriented toward the north (vector mean of 354° from seven measurements), half toward the south (vector mean of 191° from five measurements).

SITKINAK ISLAND

The Sitkalidak Formation crops out extensively in the eastern and western parts of Sitkinak Island peripheral to a central belt of younger rocks (fig. 2). It was examined in the Sitkinak Dome area and near Sitkinak Lagoon (fig. 2).

Near Sitkinak Dome, roadcuts expose facies C and D turbidites of the basin-plain, lobe-fringe, and outer-fan facies associations. Relative to the Sitkalidak Formation at Narrow Cape, the outer-fan lobe megasequences here are thinner, sandstone grain size is generally finer, beds are generally thinner, and more shale is present. Partially developed thickening- and coarsening-upward cycles are most prominent here and are more characteristic of lobe-fringe deposits than fully developed outer-fan

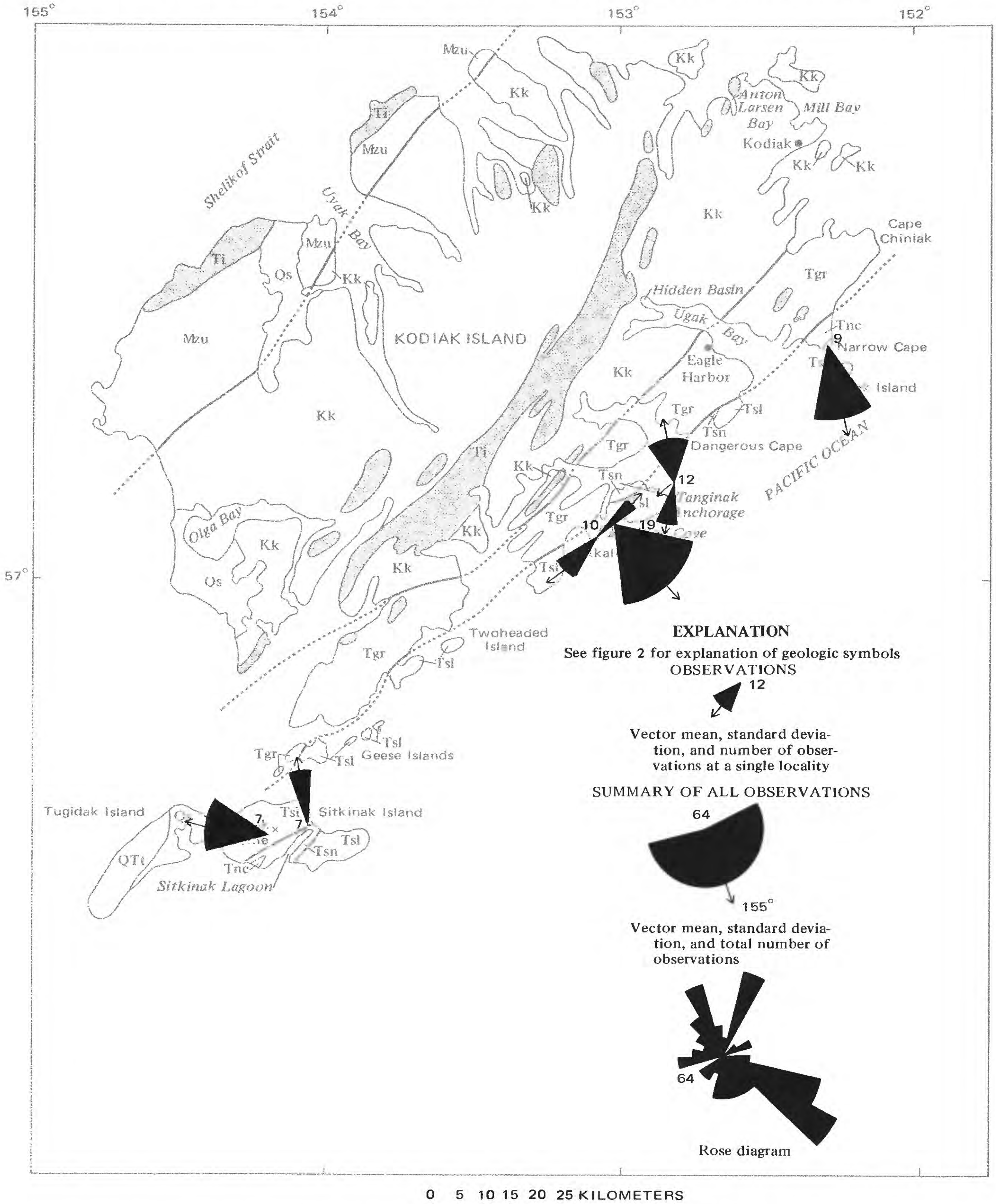


FIGURE 8.—Paleocurrent map for the Sitkalidak Formation, Kodiak Island and adjacent islands.

lobe deposits. No channels were observed in the upper parts of the megasequences. Sole markings are locally spectacularly developed, and thick and well-developed convolute laminae are common.

Seven paleocurrents measured near Sitkinak Dome yield a direction of sediment transport toward the west, with a vector mean of 280° and a standard deviation of 25° (fig. 8).

Basin-plain and lobe-fringe deposits are exposed along the northwest shore of the northern part of Sitkinak Lagoon. The sequence here consists typically of laterally extensive beds of facies C and D sandstone and siltstone interlayered with mudstone. Only a few thickening- and coarsening-upward cycles are present. Seven paleocurrents measured at this locality indicate sediment transport toward the north; a vector mean of 355° and a standard deviation of 15° are based on flute casts, groove casts, and single occurrences of small-scale cross-strata, prod marks, and primary current lineation (fig. 8). This direction of transport is opposite that of most paleocurrents measured in the Sitkalidak Formation, including directions measured near Sitkinak Dome.

SITKINAK FORMATION

BACKGROUND

The Sitkinak Formation crops out in small areas of southeastern Kodiak Island and adjacent islands from near Dangerous Cape to Chirikof Island, located southwest of Kodiak Island (figs. 1 and 2; Moore, 1967), a lateral distance of about 250 km. Its type section is along the south shore of Sitkinak Island, where it is 1,500 m thick; plant fossils indicate a middle or late Oligocene age (Moore, 1969). In this study, outcrops were examined both at the type section on Sitkinak Island and on Sitkalidak Island, where a different sedimentary facies is present. On Sitkalidak Island, it rests conformably on the Sitkalidak Formation and is in fault contact with the Ghost Rocks Formation. On Sitkinak Island, it is in fault contact with the Sitkalidak Formation and is overlain without angular discordance by the Narrow Cape Formation.

SITKALIDAK ISLAND

Coastal outcrops of conglomerate, sandstone, and shale of the Sitkinak Formation were examined at northeastern Sitkalidak Island about 3 km northeast of Tanginak Anchorage (fig. 2). Here the sequence rests on thinning- and fining-upward middle-fan megasequences of the Sitkalidak Formation.

Conglomerate that contains rounded clasts of volcanic rocks, graywacke, chert, and carbonate rocks as long as 50 cm forms most of the basal part of the sequence. The upper part of the sequence consists of turbidite sandstone and interbedded shale (fig. 9*A*). Above this part of the sequence is poorly exposed shale that underlies gently sloping, grass-covered areas inland from the coast and forms the core of a southwest-plunging syncline. In the part of the exposed sequence measured (fig. 10), the overall fining- and thinning-upward nature of the sequence is apparent, although cyclicity is not particularly well developed within the measured part of the sequence. The sequence represents a channel or canyon fill in an inner-fan or lower-slope environment. The overlying shale probably represents a slope facies, although it was not examined in detail.

The lower part of the sequence (lower 60 m of measured section, fig. 10) contains numerous erosional surfaces, typically at the base of graded beds of conglomerate. Such surfaces indicate channelization and erosion of underlying beds. Blocks of canyon- or channel-margin deposits as long as 1.5 m are irregularly distributed in the lower part of the conglomerate section. Consisting mostly of thinly interstratified ripple-marked sandstone and shale, probably originally deposited on levees or other areas adjacent to the main channel, these blocks slumped or slid into the channel and became incorporated in the channel conglomerates; many are folded and deformed, probably by the slumping.

Facies A, consisting here of organized and graded beds of conglomerate locally containing lenses of coarse-grained sandstone, makes up most of this sequence (fig. 9*B*). The beds of conglomerate are separated at some horizons by very thin shale partings that commonly pinch out laterally as a result of erosion or channelization, producing amalgamated beds of conglomerate. These shale partings probably represent facies G hemipelagic sediments deposited during intervals when coarser clastics were not in transit down the postulated canyon or inner-fan valley. Interbedded with the shale in some places are crossbedded, medium- to coarse-grained beds of facies E sandstone with ungraded and wavy or dune-shaped tops (fig. 9*C*). These facies E beds may represent either reworking of bed load in channels by subsequent turbidity currents or channel-margin levee deposits formed by overspilling either from the main channel or canyon or from subchannels within the larger channel. Other interbedded thinly laminated siltstone strata contain abundant mica and plant fragments indicative of overbank-spilling processes. Strata higher than 55 m above the base of the measured section contain slumped and contorted layers, discontinuous and en echelon thin strata of siltstone, and alternating facies E and D beds.

Finer grained, parallel-laminated, graded, and

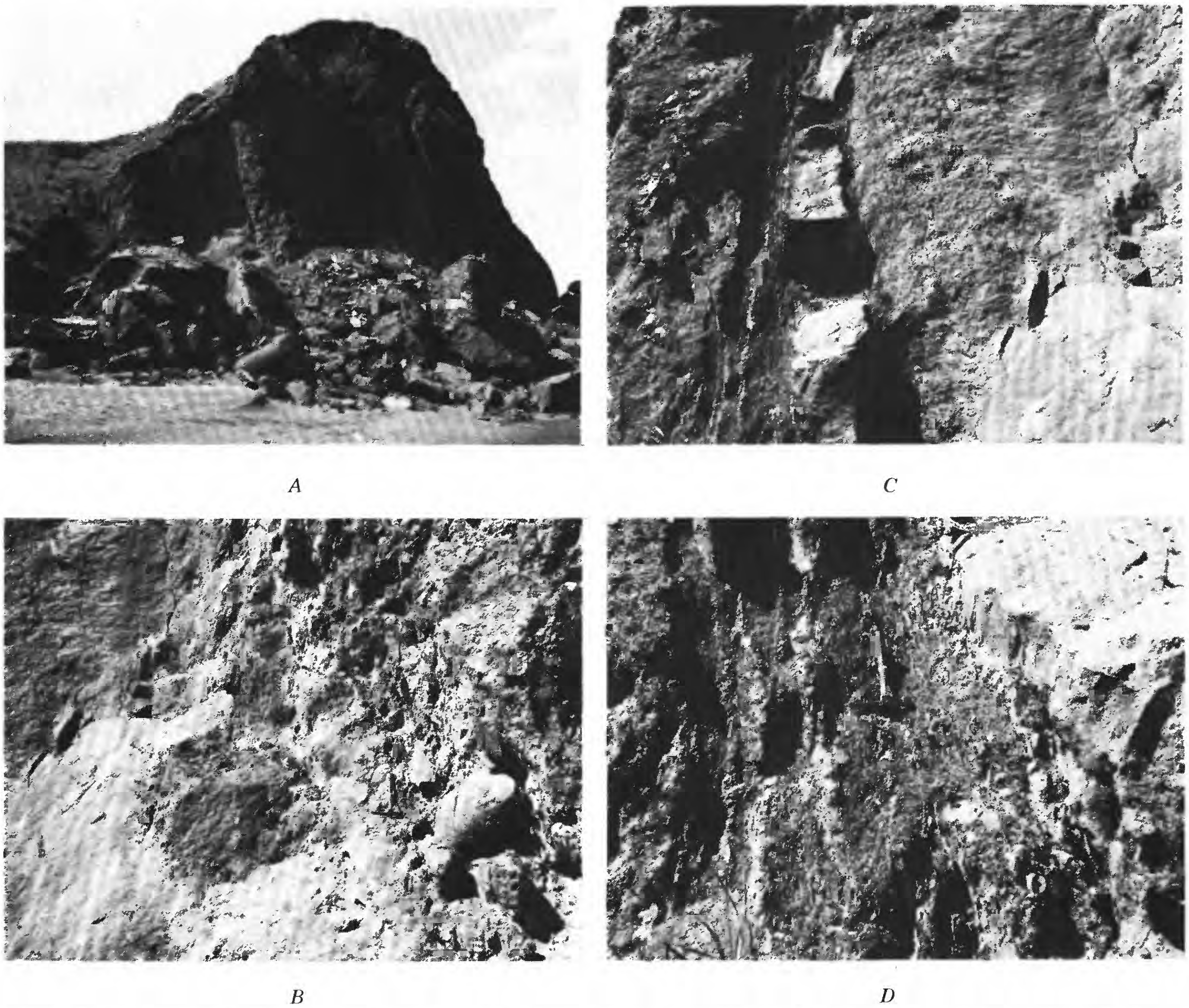
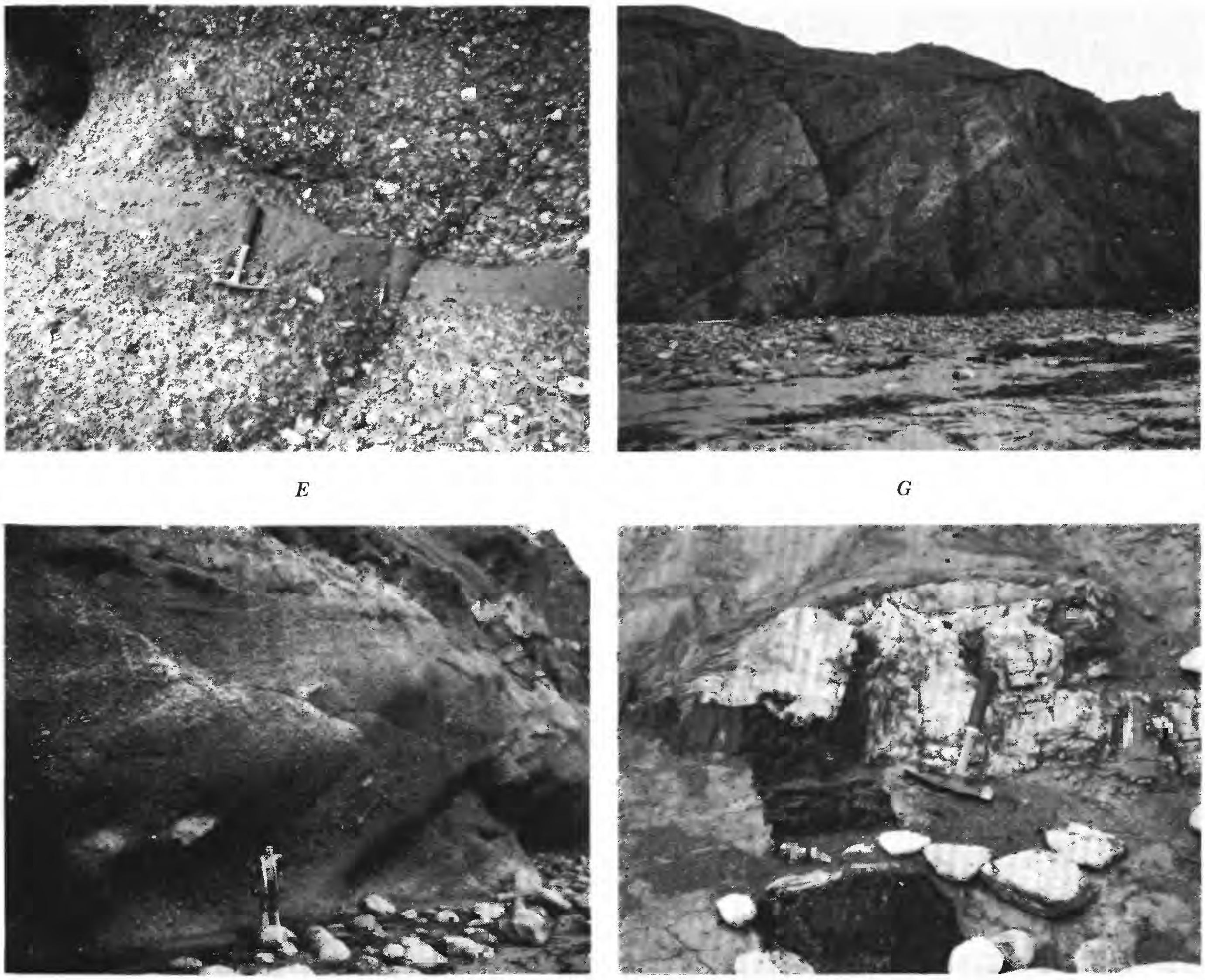


FIGURE 9.—Sedimentary facies, Sitkinak Formation. *A*, Outcrop of inner-fan channel facies near Tanginak Anchorage, Sitkalidak Island; stratigraphic top to left. See figure 10 for measured section. *B*, Graded facies A conglomerate and sandstone beds, Tanginak Anchorage, Sitkalidak Island; stratigraphic top to left. *C*, Wavy-topped, cross-stratified, coarse-grained facies E sandstone bed above fine conglomerate and below shale interval, Tanginak Anchorage, Sitkalidak Island; stratigraphic top to left. *D*, Thinly interbedded facies D sandstone turbidites and shale above coarse-grained facies E sandstone bed, Tanginak Anchorage, Sitkalidak Island; stratigraphic top to left.

locally ripple-marked sandstone beds are interbedded with shale at the top of the sequence (fig. 9*D*). These beds of sandstone are primarily facies B, but they include some facies D beds. At this level, the canyon or channel may have been nearly filled with sediment (to a depth of at least 80 m) and no longer very active, thus permitting some deposition of facies D turbidites that normally are more typical of outer-fan and basin-plain deposits.

In vertical sequence, an overall upward-fining and thinning can be observed within the 80-m-thick measured section. An attempt to subdivide this larger cycle into smaller thinning- and fining-upward cycles is shown on the measured section (fig. 10); the smaller cycles are not clearly developed and are marked more by the abrupt occurrence at 10- to 15-m intervals of thin shale partings with associated facies E turbidites than by sequences that gradually fine and thin upward. This relation suggests that the sequence represents an inner-fan channel or lower-slope canyon fill. The partly developed smaller cycles may represent deposition in subchannels



E *G* *F* *H*

FIGURE 9.—Continued. *E*, Cross-stratified lens of sandstone in conglomerate, south coast of Sitkinak Island. *F*, Outcrop of thickly bedded, imbricated conglomerate containing thin, generally parallel-stratified lenses of sandstone, south coast of Sitkinak Island. *G*, Alternating darker colored siltstone and coal intervals and lighter colored conglomerate and sandstone intervals, south coast of Sitkinak Island. *H*, Coalified piece of log oriented parallel to bedding in siltstone interval, south coast of Sitkinak Island.

10-15 m deep that formed within a much larger channel.

Ten paleocurrents measured near Tanginak Anchorage from flute casts, groove casts, pebble imbrications, preferred orientations of plant fragments, and facies-E cross-strata indicate transport of sediment toward the east-northeast, with a vector mean of 81° and a standard deviation of 20° (fig. 11). In summary, the formation in this locality probably represents an eastward-trending inner-fan to lower-slope valley fill, grading stratigraphically upward to upper-slope shale facies and downward to middle-fan sandstone facies.

SITKINAK ISLAND

Outcrops of the Sitkinak Formation were examined at several quarries and excavations in the central part of Sitkinak Island and along the southern coast of the island (fig. 2). The formation consists of alternating conglomerate-sandstone units and fine-grained sandstone and siltstone units with some coal and

I

J

FIGURE 9.—Continued. *I*, Cross-stratified sandstone tongue below and within siltstone-coal interval, south coast of Sitkinak Island. *J*, Interbedded coal (dark layers), siltstone (gray layers), and conglomerate at quarry adjacent to landing strip, Sitkinak Island.

carbonaceous shale strata. The alternating units are as thick as several hundred meters. The conglomerate-sandstone units make up about 70 percent of the formation, although the siltstone-coal intervals became relatively more numerous upward.

The conglomerate-sandstone units average 10-75 m in thickness and have a conglomerate:sandstone ratio greater than 5:2. Thin lenses of sandstone containing flat-stratification or very low angle cross-stratification and, at some localities, medium- to large-scale cross-stratification (fig. 9*E*), separate thick accumulations of well-imbricated conglomerate (fig. 9*F*). The conglomerate-sandstone units are typical of

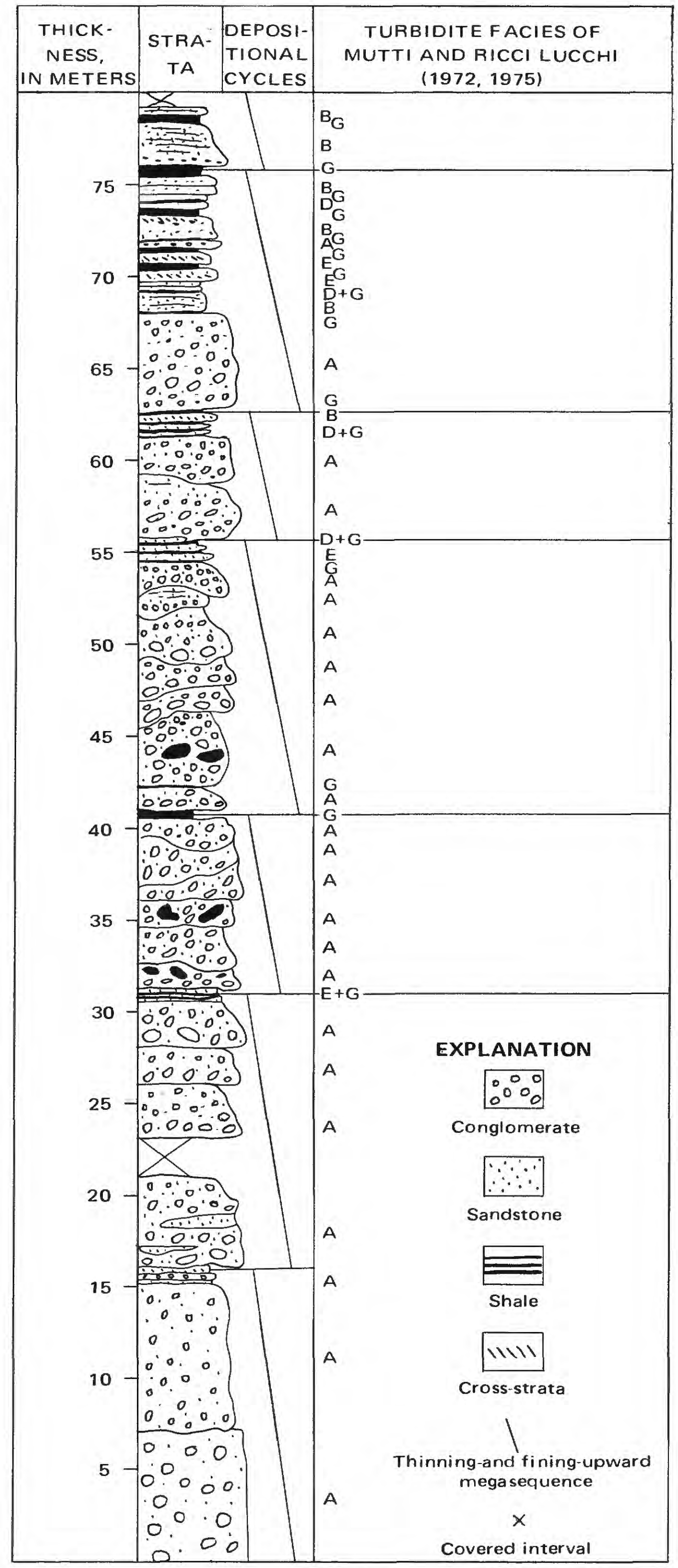


FIGURE 10.—Measured section of part of the Sitkinak Formation near Tanginak Anchorage, Sitkalidak Island. Larger cycles in bedding thickness shown to right of columnar section. Lettered symbols to right indicate type of turbidite facies for adjacent beds according to scheme of Mutti and Ricci Lucchi (1972, 1975), described in text in section on "Turbidite Facies and Facies Associations."

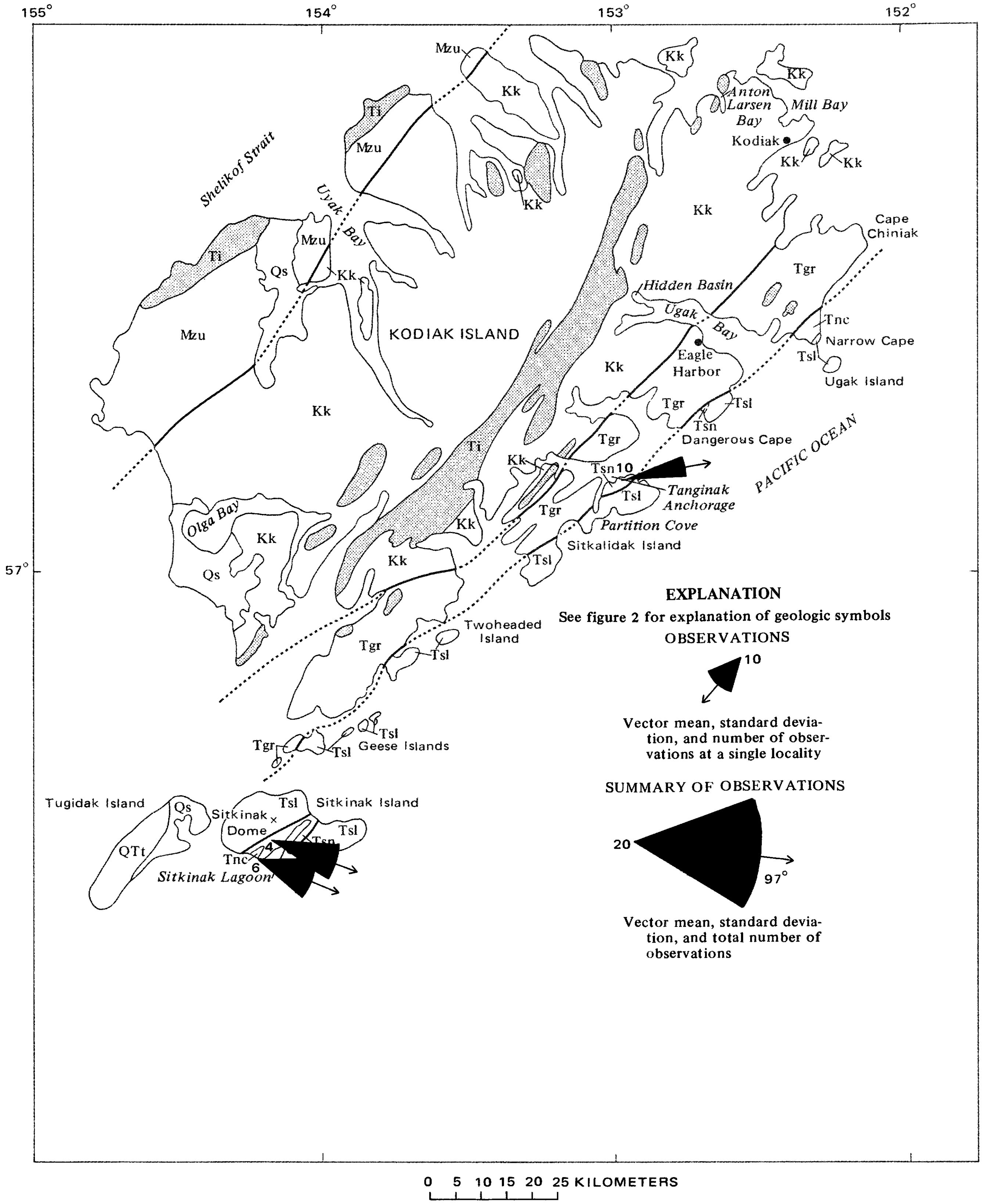


FIGURE 11.—Paleocurrent map for the Sitkinak Formation, Sitkalidak and Sitkinak Islands.

channelized fluvial braided-stream complexes. The conglomerates, which weather either reddish brown or gray, contain well-rounded clasts ot volcanic rocks, vein quartz, argillite, graywacke, red chert, and granite;

the clasts are locally as long as 40-50 cm, generally 5-10 cm. Paleocurrents measured from pebble or cobble imbrication and primary current lineation in flat-stratified sandstone indicate sediment transport toward the southeast, with a vector mean of 114° and a standard deviation of 23°.

The siltstone and coal units consist of irregularly stratified carbonaceous siltstone to fine-grained sandstone that is thoroughly bioturbated and very poorly sorted (fig. 9*G*). The coal forms impure layers 1-75 cm thick and locally contains coalified logs in vertical and horizontal positions (fig. 9*H*). The siltstone and fine-grained sandstone strata contain abundant plant fragments and fossil leaves. J. A. Wolfe (written commun., January 1977) identified specimens of *Metasequoia* cf. *M. glyptostroboides* Hu and Cheng and *Alnus evidens* (Holl.) Wolfe from collections taken in 1976. Well-stratified tongues of fine- to medium-grained sandstone, locally deformed by synsedimentary processes, extend into the siltstones (fig. 9*I*).

The siltstone-coal units probably represent interchannel, lagoonal, and interdistributary bay deposits that probably form lens-shaped bodies enclosed within the conglomerate-sandstone units. As the channelized conglomerate-sandstone units migrated laterally, they cut into and eroded the laterally equivalent siltstone intervals. There are no marine fossils in the type section of the Sitkinak Formation; however, the fact that the mollusk-bearing Narrow Cape Formation is essentially conformable on the Sitkinak may suggest marginal marine sedimentation. During the summer of 1977, fine-grained beds of sandstone with marine trace fossils were observed in the southeasternmost exposure of the Sitkinak Formation within its central outcrop belt on Sitkinak Island.

At the main quarry directly west of and adjacent to the landing strip on Sitkinak Island, a sequence is exposed that demonstrates the stratigraphic relations between the conglomerate-sandstone and siltstone-coal units (fig. 12). Here the section consists of thin vertical cycles of red-weathering conglomerate overlain by gray-weathering conglomerate and, at places in the section, carbonaceous siltstone (fig. 9*J*). The basal contacts of the conglomerate-sandstone units are erosional and indicate some channelization. The red-weathering conglomerate is imbricated (as is conglomerate on the south coast of the island) toward the southeast, with a vector mean of 111°, the presumed offshore direction. The gray-weathering conglomerate is imbricated toward the northwest, with a vector mean 278°, the presumed onshore direction. Within one thin sandstone bed, the long axes of scattered elongate pebbles are

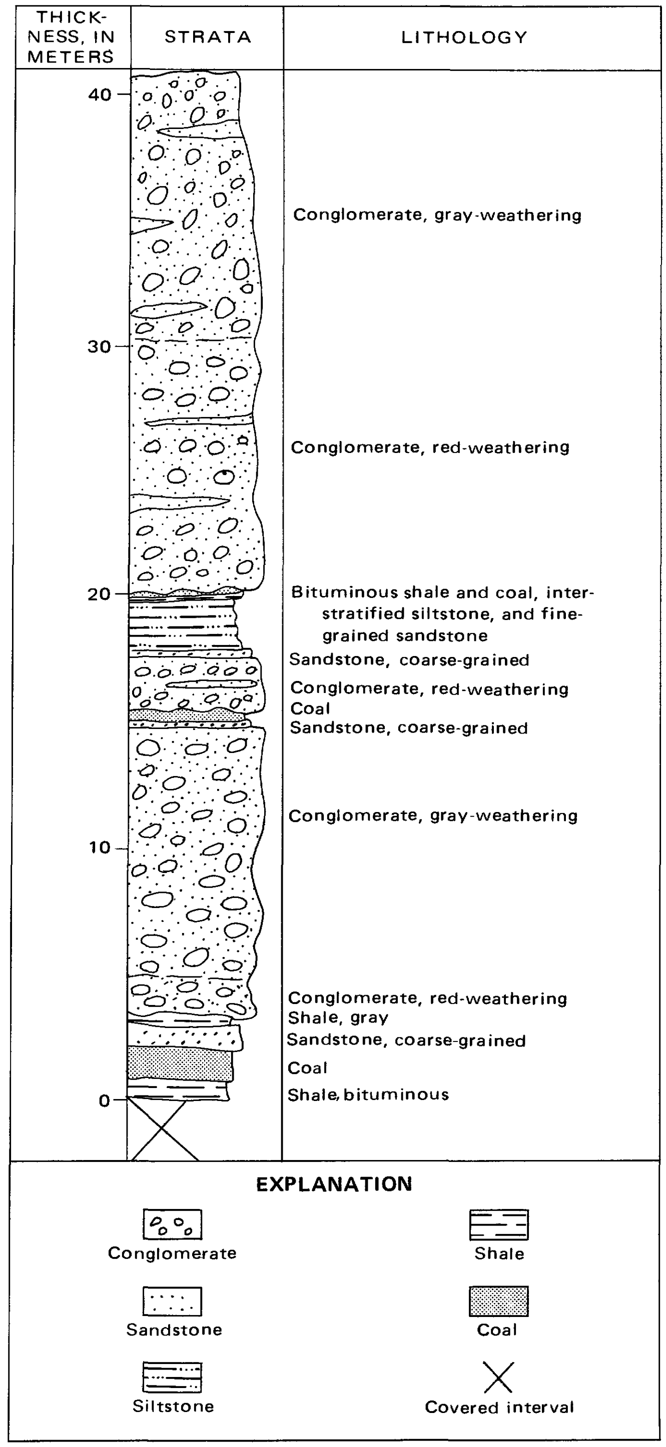


FIGURE 12.—Measured section of part of the Sitkinak Formation at quarry west of landing strip, Sitkinak Island.

orientated northeasterly (62°), a direction parallel to the approximate shoreline orientation. These fining-upward cycles suggest southeastward outbuilding of a major fan-delta complex in a marginal-marine setting, reworking by onshore currents, and subsidence yielding deposition of carbonaceous siltstone.

NARROW CAPE FORMATION

BACKGROUND

The Narrow Cape Formation crops out at Narrow Cape on eastern Kodiak Island, its type locality, and on southern Sitkinak Island (Moore, 1967, 1969; fig. 2). At Narrow Cape, its age is early and middle Miocene (Allison, 1976) and the formation rests with angular unconformity on the Sitkalidak and Ghost Rocks Formations. On Sitkinak Island, it is late Oligocene or early Miocene in age (Allison, 1976) and is exposed in two northeast-trending synclines; here it rests without angular unconformity on the Sitkinak Formation, and its top is not exposed. At both localities, it consists of shallow-marine sandstone containing abundant molluscan fossils. Because the outcrops differ in age and are geographically separate, it is possible that future offshore subsurface information will provide a lithogenetic basis for subdividing the unit.

NARROW CAPE

At Narrow Cape, the formation is gently dipping and about 700 m thick (Moore, 1969). A fossiliferous basal sedimentary breccia and conglomerate contains angular to subangular sandstone clasts as large as 40 cm derived from the underlying vertical to overturned Sitkalidak Formation (fig. 13*A*). The breccia, 1-3 m thick, contains mainly disarticulated and broken molluscan fragments. Overlying the breccia is highly bioturbated massive silty fine-grained sandstone and siltstone that constitutes more than 90 percent of the formation (fig. 13*B*). The largely unstratified but bioturbated sandstone (fig. 13*C*) contains gastropods, pelecypods, scaphopods, and echinoids; it also includes articulated mollusks in apparent growth position throughout.

Interlayered with the silty sandstone and siltstone at irregular intervals are coarser deposits as thick as 70 cm (fig. 13*D*) believed to have been deposited during storms. These layers contain well-rounded pebbles as large as 7 cm of granitic and volcanic rocks as well as clasts of the underlying Sitkalidak Formation and disarticulated, broken and partly rounded megafossil fragments. The conglomeratic or shelly layers are commonly graded, and their contact with the underlying bioturbated sandstone and siltstone is generally erosional. The upper part of the layers may consist of sandstone that contains parallel laminae or gently inclined medium-scale cross-strata (fig. 13*E*). The upper contact with bioturbated sandstone or siltstone is gradational. In one storm layer, an eastward (88°) paleocurrent direction was measured from a crossbed. No preserved ripple marks were seen anywhere in the sequence.

The Narrow Cape Formation at its type locality, Narrow Cape, appears to represent a transgressive inner-shelf sequence deposited in generally quiet water beyond the surf zone. Allison (1976) suggests deposition at subtidal to neritic water depths and in subtropical or warm-temperate water temperatures. The local offshore direction may have been to the east, as inferred from the transport direction of a storm-deposited layer.

SITKINAK ISLAND

The general lithology of the Narrow Cape Formation on Sitkinak Island is similar to that at Narrow Cape. It consists of highly bioturbated siltstone and very fine grained sandstone with sporadic coarse-grained layers thought to have been deposited during storms. Coal-bearing siltstone of the Sitkinak Formation (fig. 14) is disconformable with the Narrow Cape Formation, here 150 m thick (Moore, 1969). A 60-cm-thick pebble conglomerate with a siltstone matrix at the contact marks the disconformity. Small pebbles are scattered throughout the siltstone. The storm layers consist of well-rounded pebble conglomerate containing abundant clasts of sandstone derived from the Kodiak Formation and shelly layers of disarticulated and broken mollusk fragments (fig. 13*F*). Razor clams and other fossils in growth position are common in the bioturbated units (fig. 13*G* and *H*). Fossils are abundant, but species diversity is low: about 60 percent of the fossils are ribbed clams, 30 percent razor clams, 5 percent smooth-shelled gastropods, 5 percent turritellas, and less than 1 percent are ribbed gastropods. Allison (1976) concluded that the assemblage indicates middle or outer sublittoral (neritic) deposition probably in mild temperate waters, cooler conditions than for the somewhat younger assemblage in the Narrow Cape Formation at Narrow Cape.

SEDIMENTARY PETROGRAPHY

By G. R. Winkler

Modal analyses of 21 thin sections of Cretaceous and Tertiary sandstone samples from Kodiak and adjacent islands indicate that most samples are subquartzose; that is, the percentage of quartzose

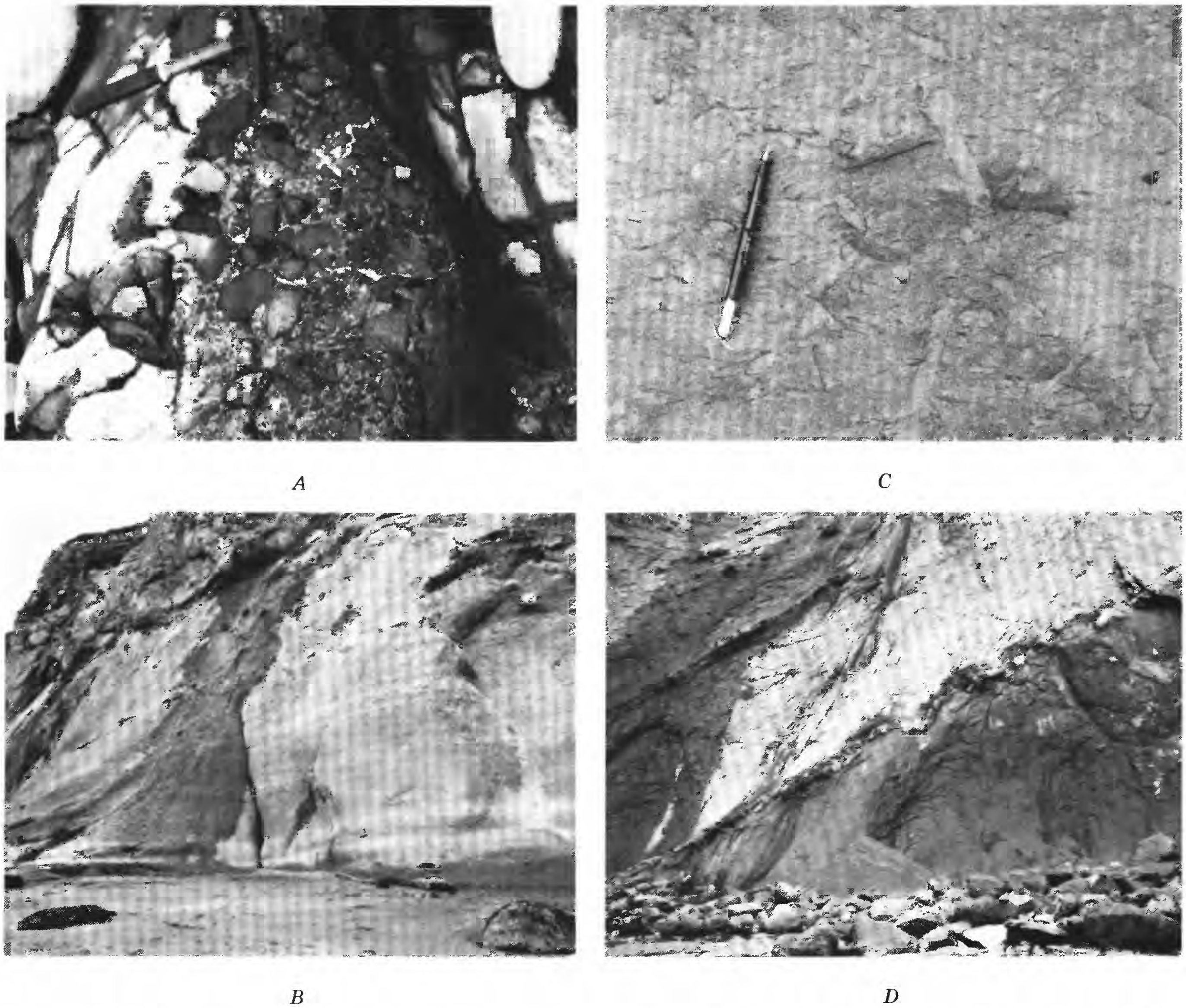
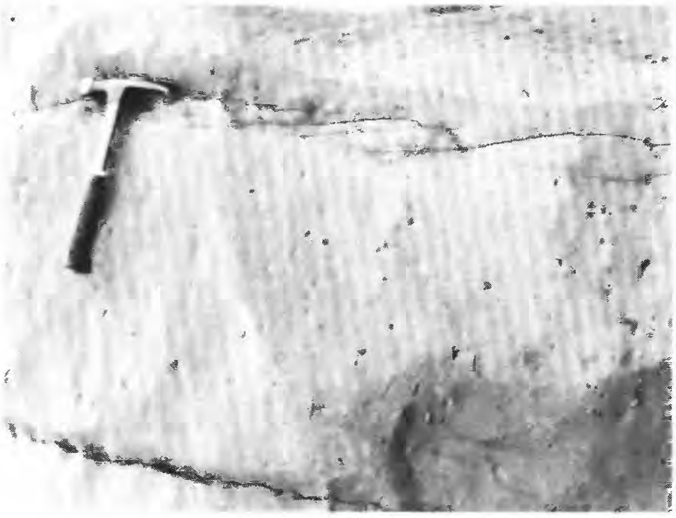


FIGURE 13.—Sedimentary facies, Narrow Cape Formation. *A*, Basal breccia-conglomerate resting unconformably on the Sitkalidak Formation, Narrow Cape. *B*, Massive bioturbated siltstone and fine-grained sandstone, Narrow Cape. *C*, Intensively bioturbated fine-grained sandstone, Narrow Cape. *D*, Thin storm layers in massive siltstone and fine-grained sandstone, Narrow Cape.

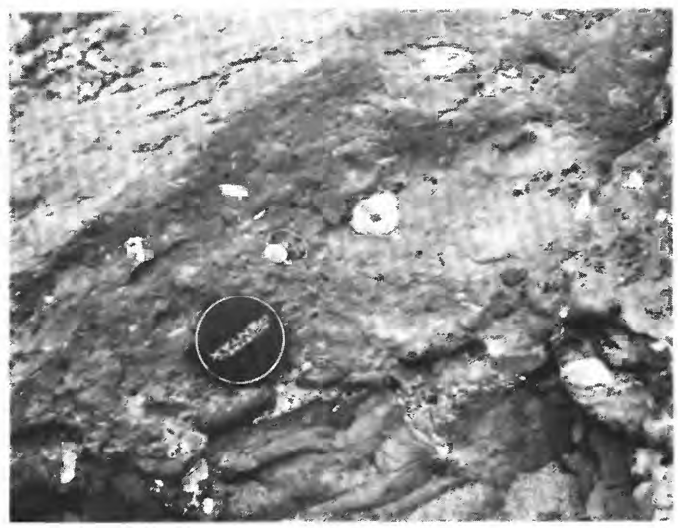
grains is generally less than 50 percent of all detrital constituents. Although plots of individual samples range widely on the quartzose-feldspar-lithic ternary diagram (fig. 15*A*), mean values for samples from the Kodiak (Upper Cretaceous), Ghost Rocks (Paleocene and Eocene), Sitkalidak (Eocene and Oligocene), and Sitkinak (Oligocene) Formations plot within the feldspatholithic field, and a mean value for the Narrow Cape (Oligocene? and Miocene) samples plots near the field boundary. A prominent trend through geologic time in the primary modes is an increase in total quartzose grains (Q) and a decrease in total feldspar grains (F) from the Kodiak Formation to the Narrow Cape Formation. Moreover, there is an increasing diversity in types of lithic fragments (L) from older to younger samples. Volcanic and plutonic lithic fragments (V) constitute more than 95 percent of Kodiak and Ghost Rocks lithic detritus (fig. 16*A* and *B*), about 75 percent of Sitkalidak and Sitkinak lithic detritus (fig. 16*C* and *D*), and 47 percent of Narrow Cape detritus. Most volcanic rock fragments have pilotaxitic, aphanitic, or porphyritic textures, and, though slightly altered, apparently were andesitic or basaltic; a smaller proportion are completely altered to silica, zeolite, prehnite, pumpellyite, or epidote. In the Sitkalidak and Sitkinak



E

G

F



H

FIGURE 13.—Continued. *E*, Low-angle cross-strata in fine-grained sandstone, Narrow Cape. *F*, Storm layers containing broken molluscan shells and fine pebbles, Sitkinak Island. *G*, Articulated molluscan fossils in living positions below shelly storm layer, Sitkinak Island. *H*, Articulated molluscan fossils in living positions, Sitkinak Island.

Formations (fig. 16*C* and *D*), lithic fragments also include intraformational and extraformational sedimentary rock fragments (S) and, in small amounts, weakly foliated metamorphic rock fragments (M). In the Narrow Cape Formation, sedimentary rock fragments are the most abundant lithic constituent (fig. 16*E*).

The change in proportions of lithic constituents is accompanied by a marked change in the amount of chert and other polycrystalline quartzose grains (C), which increases from about 10 percent of total quartzose grains in the Kodiak and Ghost Rocks sandstone samples to more than 25 percent in Sitkinak and Narrow Cape samples. A peculiar red-stained chert is particularly diagnostic of the younger formations. Much of the polycrystalline quartzose detritus probably was derived from strongly altered felsic volcanic rocks.

Texturally, a moderate contrast between the older and younger formations can be observed (fig. 15*B* and 16). Although all samples consist predominantly of framework grains, matrix is more abundant in some Kodiak and Ghost Rocks samples (fig. 16*A* and *B*), whereas carbonate or zeolite cement is more abundant in some Sitkalidak and Sitkinak samples. One sample from the Narrow Cape Formation is

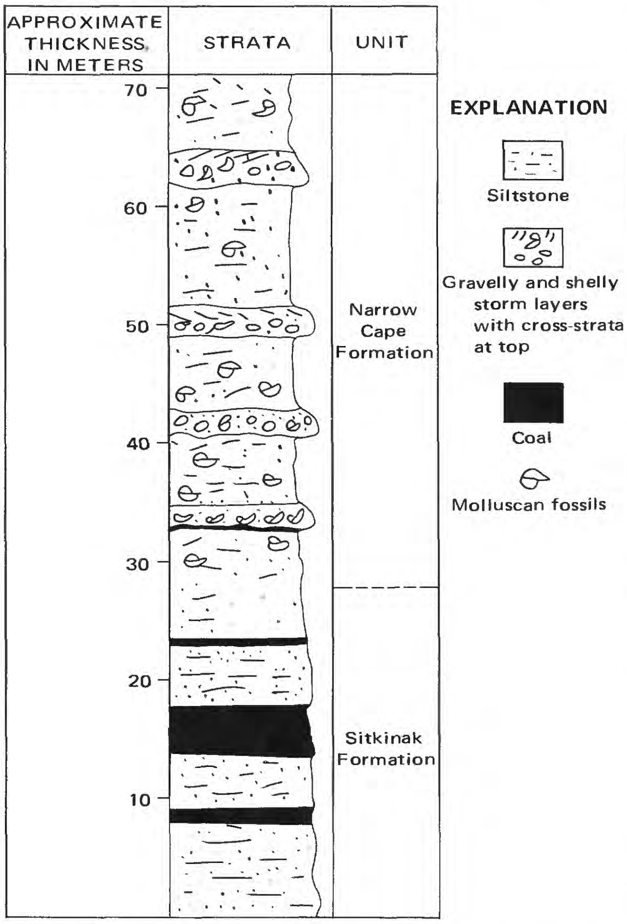


FIGURE 14.—Approximate section at contact of Narrow Cape and Sitkinak Formations, south coast of Sitkinak Island.

tightly cemented, whereas the other two have abundant matrix. Most matrix appears to be composed of deformed weak detrital grains that in many cases are mineralogically altered. Such problematic interstitial material has been called "pseudomatrix" by Dickinson (1970). Samples with abundant matrix are tightly compacted with many sutured grain boundaries, indicating nearly complete eradication of primary porosity. Tightly cemented samples also have been compacted and altered; probably cementation occurred late in the diagenetic histories of such samples.

Heavy minerals are not abundant in samples from any of the formations. In almost every sample, biotite, epidote, muscovite, garnet, amphibole, sphene, chlorite, and zircon are present in minor amounts. Biotite is much more abundant in Sitkinak and Narrow Cape samples, and glauconite is present only in Sitkinak and Narrow Cape samples, in particular those containing abundant carbonaceous and glass-rich volcanic detritus.

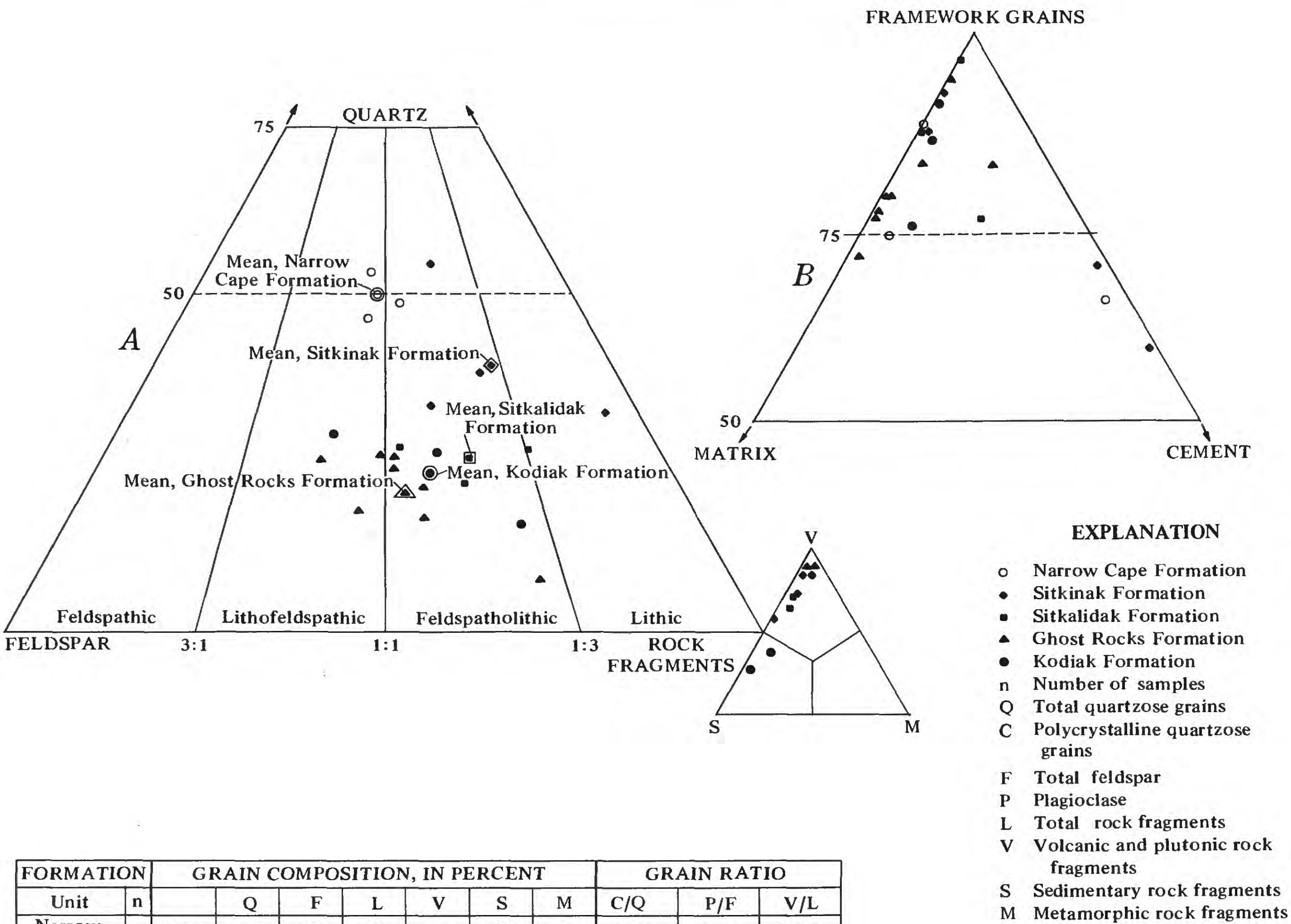
Cretaceous and Tertiary sandstones from Kodiak Island were derived from volcanic sources similar to that of coeval rocks of the Shumagin Islands (Moore, 1973a), Alaska Peninsula (Burk, 1965), and Bristol Basin (Galloway, 1974). Because of their abundant volcanic detritus, these sandstones are not likely to be proximal equivalents of coeval turbidites on the Aleutian Abyssal Plain, as tentatively suggested by Stewart (1976). Some of the volcanic detritus may be recycled from older volcanic terranes, as it consists partly of prehnite-pumpellyite facies metavolcanic rock fragments. The ubiquity of detrital epidote, garnet, and weakly foliated quartz-mica clasts certainly indicates partial derivation from metamorphic terranes.

The marked upsection increase in polycrystalline and monocrystalline quartzose detritus indicates greater contribution through time from a quartz-rich provenance. Traces of myrmekite and antiperthite in the younger rocks indicate minor input from exposed plutons. Multiple sources are necessary to yield the varied detritus in the Cretaceous and Tertiary sandstones of Kodiak and adjacent islands. The persistence of dominant volcanic sources of detritus for perhaps 50 million years indicates that the volcanoplutonic arc of the Alaska Peninsula and southern Alaska Range remained a major and long-lived source of sediments that accumulated in adjoining basins.

SUMMARY AND CONCLUSIONS

Some tentative conclusions can be drawn regarding sedimentary environments, facies, and paleogeography of Upper Cretaceous to Miocene turbidites and associated sedimentary strata of Kodiak and adjacent islands, despite the briefness of our reconnaissance. These tentative conclusions are of particular value at the present time because of the pressing need for specific stratigraphic data in the evaluation of the hydrocarbon potential of the adjacent outer continental shelf. Many of the offshore stratigraphic problems were summarized by von Huene and others (1976) in relation to regional geology, geologic hazards, and the technological constraints of offshore exploration.

The Kodiak Formation represents a combination of slope (northwestern Kodiak Island) and basin-plain (southeastern Kodiak Island) deposits. Within the slope deposits are thin basin-fill strata that form thin thickening-upward megasequences and sandstone-rich intervals. These deposits probably represent fillings of either local slope basins formed by downslope slumping and sliding or more extensive



FORMATION		GRAIN COMPOSITION, IN PERCENT							GRAIN RATIO		
Unit	n		Q	F	L	V	S	M	C/Q	P/F	V/L
Narrow Cape Formation	3	Mean	50	26	24	47	48	5	0.25	0.75	0.47
		Range	47-55	24-29	22-28	28-75	23-68	3-8	.20-.29	.65-.83	.28-.73
Sitkinak Formation	4	Mean	40	16	44	76	20	4	.34	.98	.75
		Range	33-55	4-26	29-63	58-84	8-39	2-8	.10-.76	.93-1.0	.57-.84
Sitkalidak Formation	3	Mean	26	26	48	75	21	3	.16	.91	.74
		Range	23-28	18-34	38-55	65-87	12-31	1-5	.04-.28	.83-.98	.63-.87
Ghost Rocks Formation	8	Mean	21	37	42	95	3	2	.08	.92	.95
		Range	8-26	26-45	27-66	89-100	0-7	0-8	.03-.15	.80-.97	.89-1.0
Kodiak Formation	3	Mean	24	32	44	96	3	1	.10	.95	.96
		Range	16-30	24-42	29-60	94-98	2-5	0-4	.05-.15	.90-.99	.94-.98
Shumagin Formation	61	Mean	17 -	31	52	96			.12	.97	.95

FIGURE 15.—Ternary diagrams showing sedimentary petrography of Upper Cretaceous to Miocene stratigraphic units, Kodiak and adjacent islands. *A*, Framework-grain compositions of 21 point-counted sandstone samples from Kodiak Island, following classification schemes of Crook (1960) and Dickinson (1970). For comparison, mean values are shown for the Shumagin Formation (Moore, 1973a), a stratigraphic unit correlative with the Kodiak Formation. *B*, Textural characteristics of 21 point-counted sandstone samples from Kodiak Island. Note that matrix forms a minor component except in some samples from the Kodiak and Ghost Rocks Formations and that cement is a minor component except in some samples from the Sitkinak and Narrow Cape Formations.

depressions formed by tectonic processes (fig. 17). Relatively small basins (see fig. 17) may develop (1) at the edge of the shelf as a result of rapid sedimentation and subsidence; (2) in slope depressions formed at the base of scarps formed by downslope sliding and slumping, (3) in slope depressions formed between imbricated slide blocks, and (4) in truncated or abandoned canyons on the slope. Kelling and Stanley (1976) reviewed the geometry and development of slope basins on slump blocks.

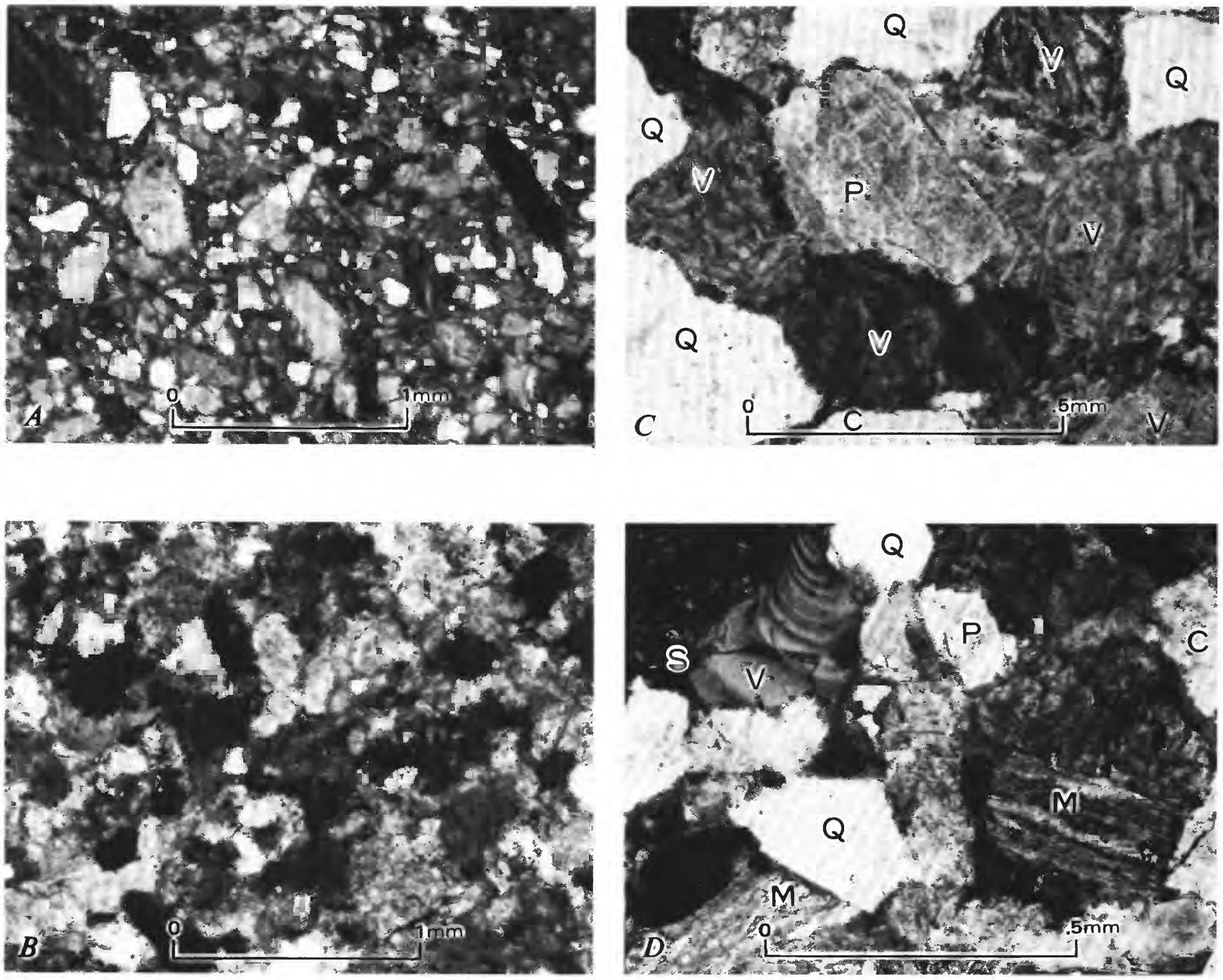


FIGURE 16.—Selected photomicrographs of sandstone samples from the Kodiak, Ghost Rocks, Sitkalidak, Sitkinak, and Narrow Cape Formations. Plane-polarized light. *A*, Kodiak Formation. Poorly sorted, poorly rounded, and tightly appressed sandstone with considerable amount of interstitial matrix. *B*, Ghost Rocks Formation. Tightly appressed and strongly altered sandstone with sutured or indistinct grain boundaries. *C*, Sitkalidak Formation. Tightly packed sandstone composed of volcanic rock fragments (V), plagioclase (P), quartz (Q), and chert (C). *D*, Sitkinak Formation. Sandstone composed of diverse foliated metamorphic (M) and glass-rich volcanic (V) rock fragments, mudstone (S), quartz (Q), plagioclase (P), and chert (C).

In tectonically active slopes that develop adjacent to trenches defined by subduction zones, a variety of other types of small to large intraslope basins can form as a result of tectonic imbrication of underthrusted slices, as shown by Moore and Karig (1976) on Nias Island, or by folding of base-of-slope strata into ridge-and-valley topography, as shown by Carson, Yuan, Myers, and Barnard (1974) for the continental slope west of the state of Washington. It is probable that some intraslope basins of these types developed within the slope deposits of the Kodiak Formation, but more detailed structural and sedimentological studies would be required to demonstrate this.

Other types of intraslope basins may form in response to other processes, but they have not been recognized within the slope facies association of the Kodiak Formation. Intraslope basins may develop on abandoned segments of submarine canyons as described by Bouma, Smith, Sidner, and McKee (1976). Development of slope basins by processes of salt diapirism has been recently summarized by Amery (1976) and by Watkins, Worzel, and Ladd (1976). Deposition of large debris flows in intraslope

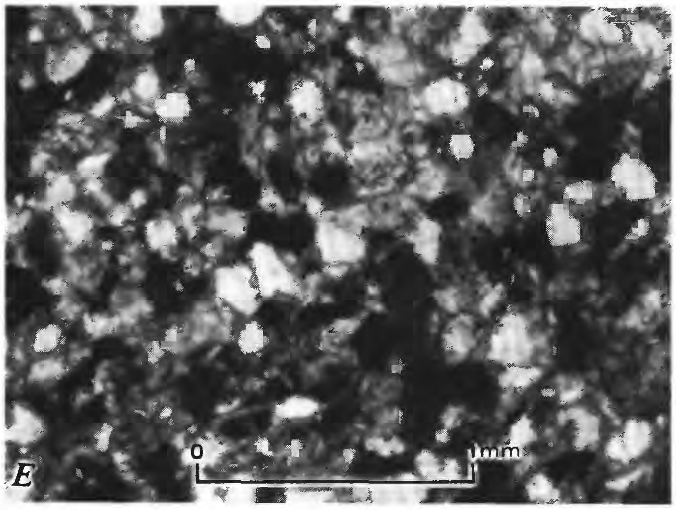


FIGURE 16.—Continued. *E*, Narrow Cape Formation. Tightly packed, poorly rounded sandstone with abundant dark, deformed mudstone fragments.

areas was most recently demonstrated by Embley (1976).

The mixture of slope and basin-plain facies to the exclusion of fan facies, as found within the Kodiak Formation, is not uncommon in deep-marine settings. Apparently not enough sediment was funneled through existing submarine canyons to feed or initiate the development of large deep-sea fans at the base of the slope. The canyons may not have extended all the way from shelf edge to base of slope owing to morphologic complications introduced by slumping or tectonic processes. Because consistent southwestward paleocurrents suggest sediment derivation from the northeast, deep-sea fan facies associations may be present to the northeast on the Kenai Peninsula or farther east in the Sitka area in rocks coeval with the basin-plain facies association of the Kodiak Formation (fig. 1).

The Kodiak Formation resembles other rocks of the structurally and stratigraphically similar Chugach terrane (Berg and others, 1972), which extends westward in an arc from near Sitka in southeastern Alaska across southern Alaska to Sanak Islands, 600 km southwest of Kodiak Island (fig. 1).

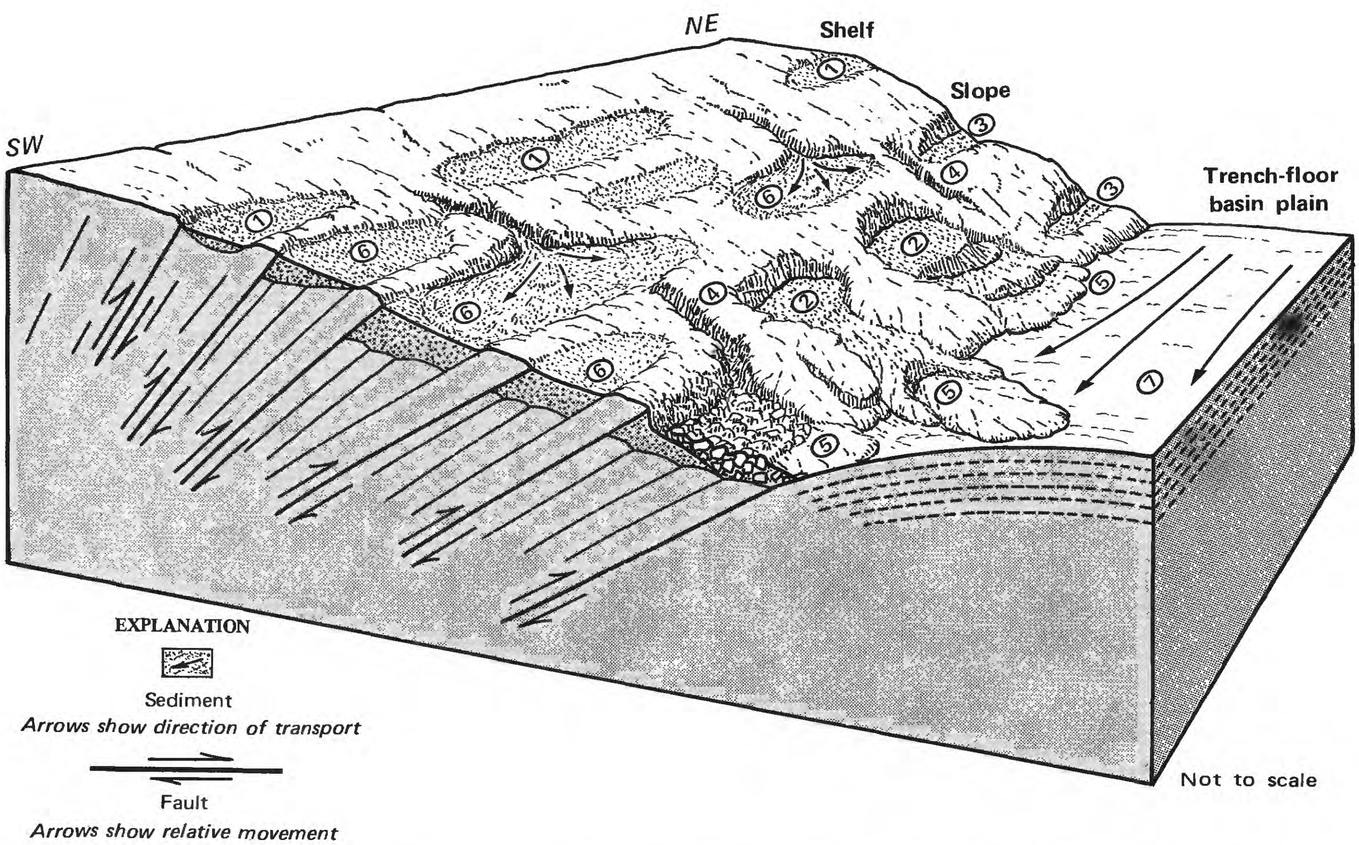


FIGURE 17.—Block diagram showing inferred paleogeography and depositional setting of the Kodiak Formation. (1) shelf-edge basin; (2) slide-scarp basin; (3) intraslide basin; (4) abandoned-canyon basin; (5) base-of-slope debris flow; (6) structurally produced basin; and (7) basin-plain turbidites. Arrows on the basin plain indicate direction of flow of turbidity currents.

Both J. C. Moore (1972, 1973a, b, 1974a) and Budnik (1974a, b) considered these rocks, on the Shumagin Islands and on the Kenai Peninsula respectively, to be Cretaceous trench sediments. Plafker, Jones and Pessagno (1977a, b) consider the Chugach terrane to represent turbidites accreted to the continental margin of southern Alaska by latest Cretaceous time. G. W. Moore and Bolm (1977) determined a subduction-slip azimuth from fold orientations of about N. 20° W. for the Kodiak Formation.

The origin of the extensive Chugach terrane and its relation to the associated melange terrane to its north and Paleogene turbidite terrane to its south remains the subject of extensive study. As more sedimentological data accumulate, constraints on the various proposed tectonic models become clearer. Progradation and outbuilding from the northwest of large deep-sea fans into the trench is not recorded by strata on Kodiak Island although it is possible that fans of this type may have subsequently been removed by subduction. If the basin-plain deposits did form in a trench from an upslope source, the consistent southwesterly paleocurrents suggest deflection into a trench whose axis sloped southwesterly.

Nilsen and Bouma (1977) concluded that the basin-plain facies association of the Kodiak Formation more likely represents distal deposition of a major deep-sea fan complex that prograded southwestward from a point source to the northeast; as such, it was deposited farther down the axis of a southwest-plunging trench floor than more proximal fan deposits. The presence of inner- and middle-fan turbidites in the correlative Upper Cretaceous Valdez Formation in the Anchorage-Seward area, as reported by Nilsen and Bouma (1977), supports this concept. Paleocurrents in the Valdez Formation in this area indicate sediment transport to the southwest toward Kodiak Island (Nilsen and Bouma, 1977). Reconnaissance examination of the coeval Sitka Graywacke in southeast Alaska by Nilsen and John Decker in 1978 indicated the presence of strata of the inner- to middle-fan facies associations in western or outboard outcrops and the slope facies association in eastern or inboard outcrops. This unit thus appears to represent the most proximal part of the axial trench fill, the coarsest and most thickly bedded part of the trench axis facies of the Chugach terrane. This scenario implies dominant filling of a trench floor by longitudinal transport from a major canyon and fan system developed northeast of Kodiak Island, probably traceable to southeast Alaska.

The basin-plain facies association of the Kodiak Formation is thought to represent trench-fill rather than trench-slope-basin fill for several reasons: (1) The very long and apparently continuous length of the Upper Cretaceous Chugach terrane (2,000 km) suggests the presence originally of a major tectonically controlled linear basin comparable to many modern continental-margin trenches, whereas trench-slope basins are more limited morphologic features; (2) paleocurrents in the Chugach terrane are remarkably persistent in orientation toward the southwest, from the Shumagin Islands (Moore, 1973a) to Kodiak Island (this report) to the Kenai Peninsula (Nilsen and Bouma, 1977); and (3) the general petrography of sandstones from the various components of the Chugach terrane is similarly dominated by volcanic lithic fragments (fig. 15; Moore, 1974a, b; Budnik, 1974a, b), implying a similar provenance for the terrane.

Part of the McHugh Complex (Clark, 1973) may represent the slope facies association of the Valdez Group, equivalent to the slope facies association of the Kodiak Formation (Nilsen and Bouma, 1977). Newly reported mapping in the McHugh Complex southeast of Anchorage by Tysdal and Case (1977) resulted in placement of strata previously mapped as McHugh Complex in the Valdez Group; these strata include mud-chip-bearing quartzofeldspathic sandstone, polymict conglomerate, and argillite—lithologies contained in the slope facies association of the Kodiak Formation. Nevertheless, the bulk of the McHugh Complex is certainly a melange terrane correlative with the Uyak Formation.

The Ghost Rocks Formation is sedimentologically difficult to interpret in terms of facies associations, mainly because of its extensive structural deformation. Paleocurrents are inconsistent in orientation; they have a slight preferential orientation toward the southwest. Because this formation is not clearly related stratigraphically to other units, it could represent a fragment of crust rafted in from a distant Pacific area during subduction. Yet the petrographic similarity of its sandstone turbidites to those of the Kodiak Formation suggests that it was derived from northwestern source terranes. The Ghost Rocks Formation may represent slope facies deformed by downslope gravitational movement as well as tectonic processes.

The Sitkalidak Formation appears to consist of middle- and outer-fan facies associations and some basin-plain deposits developed northeastward and southwestward of the major submarine canyon and inner-fan channel complex formed by the Sitkinak Formation in the vicinity of central Sitkalidak Island (fig. 18). Subsequent work during the summer

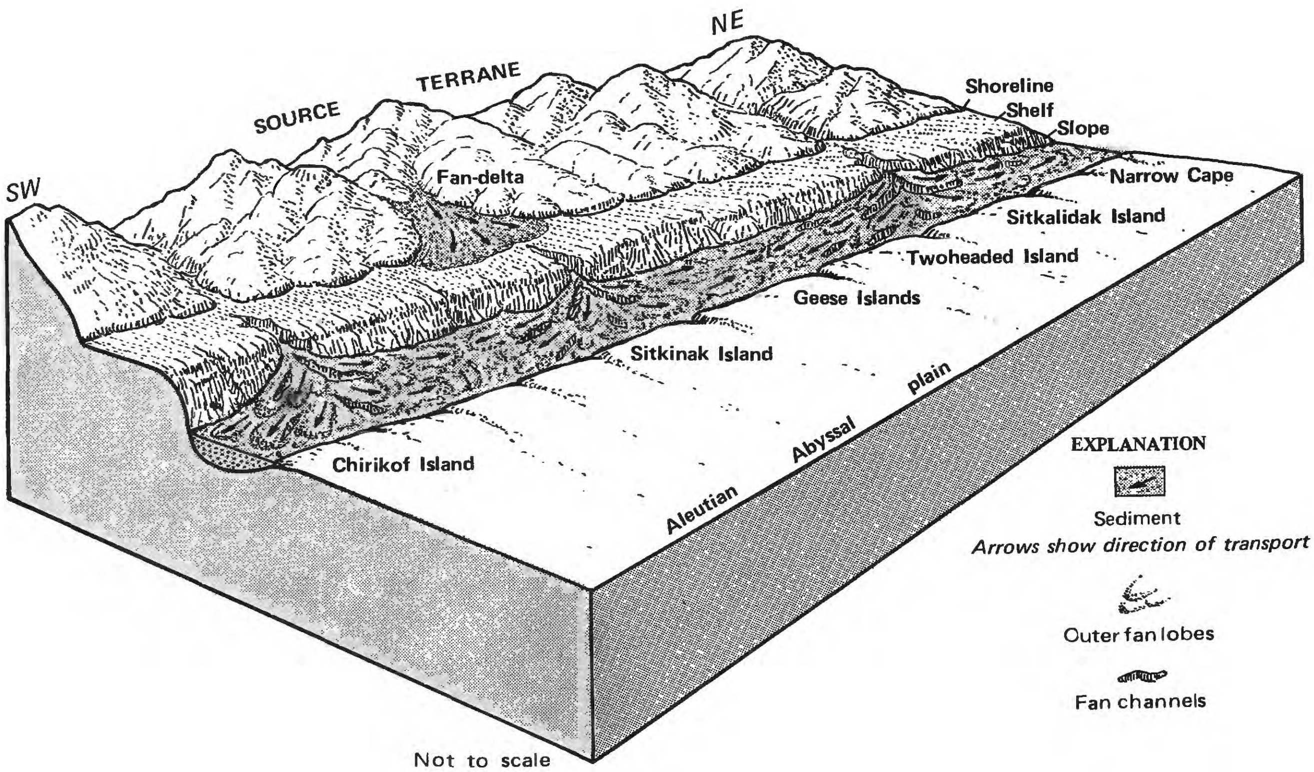


FIGURE 18.—Block diagram showing inferred paleogeography and depositional setting of the Sitkalidak and Sitkinak Formations.

of 1977 revealed the existence of two additional major submarine canyon and inner-fan channel complexes on western Sitkinak and Chirikof Islands (Bouma and others, 1977); these areas also supplied sediment to the dominantly middle- and outer-fan complexes of the Sitkalidak Formation. Paleocurrents in the middle-fan deposits of Sitkalidak Island are variable; this variability indicates sediment transport to the northeast, southeast, and southwest. This paleocurrent pattern, together with the distribution of facies associations, suggests that the major submarine canyon northwest of Sitkalidak Island bifurcated northeastward and southwestward into inner- and middle-fan channels upon reaching the basin floor. Some of these channels transported sediment northeastward to outer-fan lobe deposits such as those cropping out at Narrow Cape; other channels transported sediment southwestward toward Twoheaded Island and Geese Islands.

Because deep-sea fan deposits of the Sitkalidak Formation apparently prograded or grew to the northeast and southwest rather than southeastward toward the Pacific Ocean (fig. 18), the tectonic setting of the basin in which the Sitkalidak Formation was deposited must have partly confined the growing fan system. One possible configuration that would explain the distribution of paleocurrents and turbidite facies associations is a trench floor previously formed by a downgoing slab of oceanic crust that formed a northwest-sloping southeastern boundary to the trench (fig. 18). The general lack of subduction-related deformation in the Sitkalidak and Sitkinak turbidites suggests that if a trench floor formed the basin, active subduction was not taking place. A second possibility is deposition in an elongate trench-slope basin such as those described from Nias Island (Moore and Karig, 1976). Undoubtedly, other solutions that permit derivation of sediment from the northwest and outbuilding of fans toward the northeast and southwest are possible.

The Sitkinak Formation, defined by Moore (1969) for its numerous conglomerate beds, represents inner-fan channel or lower-slope canyon deposition on Sitkalidak Island (fig. 18). It probably represents fill of the same canyon and inner-fan channel system that fed the deep-sea fan deposits of the Sitkalidak Formation, and as such it is linked stratigraphically to the Sitkalidak. The lack of a more marked stratigraphic break between the two units on Sitkalidak Island supports this tentative conclusion, as does the regularity of the upward passage from outer-fan to middle-fan deposits within the Sitkalidak Formation directly beneath the Sitkinak Formation. Southeastward-directed paleocurrents within the Sitkinak Formation and the gradual upward increase in clast size through the sequence of the Sitkalidak and Sitkinak Formations here also suggest lateral continuity.

The Sitkinak Formation on Sitkinak Island represents a marginal-marine fan-delta complex of probably younger age than the deep-sea fan deposits of the Sitkalidak (fig. 18). The coalesced fan deltas of this sequence probably prograded to the east and may possibly represent younger very proximal top-of-slope deposition in the distributary system that fed the submarine canyon, fan, and basin-plain deposits of the Sitkalidak and Sitkinak Formations on Sitkinak Island. The fan-delta complex is probably preserved by downfaulting in the central graben on Sitkinak Island such that it is faulted against the older turbidite sequences (fig. 2). Part of the fan-delta distributary system may originally have traversed a narrow shelf cut by major southeast-trending submarine canyons. Funneling of sediment down the canyons then supplied material to the deep-sea fan deposits of the deep-marine part of the Sitkinak Formation and the Sitkalidak Formation.

The progressively more proximal environments represented by younger strata of the lower and middle Tertiary sequence of the southeastern flank of Kodiak Island suggest a major first-order offlapping or progradational depositional cycle similar to those described by Ricci Lucchi (1975). Such a cycle typically commences in vertical sequence with distal basin-plain turbidites, although on Kodiak Island the major cycle appears to commence with lobe-fringe and outer-fan lobe deposits of the lower part of the Sitkalidak Formation. During the summer of 1977, other basin-plain sequences were identified in the Sitkalidak Formation at various places. It is possible that deformed strata of the Ghost Rocks Formation might represent the most distal deposits of a major first-order cycle, but stratigraphic continuity between the Ghost Rocks and Sitkalidak Formations has not been demonstrated. Because the cycle includes marginal-marine to nonmarine deposits, it is even more inclusive than the turbidite cycles described by Ricci Lucchi.

The Narrow Cape Formation represents renewed transgression over the older Tertiary deposits following uplift and folding of the older rocks. On Sitkinak Island, the Narrow Cape Formation was deposited essentially conformably on the Sitkinak Formation, suggesting that the transgression took place across a low-relief marginal-marine area. At Narrow Cape, where the Narrow Cape Formation is younger than it is on Sitkinak Island, relief was greater and this younger sequence of Narrow Cape Formation was deposited on the erosional edge of the overturned Sitkalidak Formation.

The entire Cretaceous to Miocene sequence on Kodiak Island in general resembles other sequences of circum-Pacific subduction zones, where structural units closest to the continent are the oldest, most deformed, most metamorphosed, and most clearly oceanic, and structural units farthest from the continent are progressively younger, less deformed, less metamorphosed, and more continental. The northwestward dip of most faults and axial planes of folds supports the concept of northwesterly subduction of oceanic crust. Changes in rate of convergence and angle of subduction, as suggested by Moore (1977), certainly may have controlled the varying amounts of deformation found in the Mesozoic and Cenozoic rocks of Kodiak Island.

On the basis of paleocurrent data and turbidite facies analyses, most of the units discussed in this paper appear to have been derived from source terranes to the northwest or northeast. Although most units may have accreted to the continental margin of Alaska by subduction-related processes, there is no evidence from the facies associations, paleocurrent patterns, sedimentary petrography, or paleogeographic reconstructions to support the hypothesis for long-distance transport of these accreted units; they must have accumulated at or adjacent to the Alaskan continental margin. Only the highly deformed Ghost Rocks Formation, separated from younger and older units by faults and containing pillow basalt and basalt breccia, appears to possibly represent a sequence derived from more distant terranes and transported to Kodiak Island by sea-floor motion. Yet, the petrographic similarity of its sandstone to rocks of the adjacent Kodiak Formation argues for a local Alaskan source. Large-scale counterclockwise oroclinal bending or rotation of southern Alaska during Late Cretaceous or Paleogene time, as suggested by Plafker, Jones and Pessagno (1977a, b), would require revision of our concept of original geographic orientation of basin axes and paleocurrent orientations.

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