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DEEP-SEA FAN DEPOSITION OF THE LOWER TERTIARY ORCA GROUP, EASTERN PRINCE WILLIAM SOUND, ALASKA

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DEEP-SEA FAN DEPOSITION OF THE LOWER TERTIARY ORCA GROUP, EASTERN PRINCE WILLIAM SOUND, ALASKA

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ABSTRACT

The Orca Group is a thick, complexly deformed, sparsely fossiliferous sequence of flysch-like sedimentary and tholeiitic volcanic rocks of middle or late Paleocene age that crops out over an area of roughly 21,000 km^2 in the Prince William Sound region and the adjacent Chugach Mountains. The Orca Group also probably underlies a large part of the Gulf of Alaska Tertiary province and the continental shelf south of the outcrop belt; coextensive rocks to the southwest on Kodiak Island are called the Ghost Rocks and Sitkalidak Formations.

The Orca Group was pervasively faulted, tightly folded, and metamorphosed regionally to laumontite and prehnite-pumpellyite facies prior to, and perhaps concurrently with, intrusion of early Eocene granodiorite and quartz monzonite plutons.

In eastern Prince William Sound, 95% of the Orca sedimentary rocks are interbedded feldspathic and lithofeldspathic sandstone, siltstone, and mudstone turbidites. Lithic components vary widely in abundance and composition, but labile sedimentary and volcanic grains dominate. A widespread yet minor amount of the mudstone is hemipelagic or pelagic, with scattered foraminifers. Pebbly sandstone with rounded clasts of exotic lithologies and locally conglomerate with angular blocks of deformed sandstone identical to the enclosing matrix are interbedded with the turbidites.

Thick and thin tabular bodies of altered tholeiitic basalt are locally and regionally conformable with the sedimentary rocks, and constitute 15-20% of Orca outcrops in eastern Prince William Sound. The basalt consists chiefly of pillowed and nonpillowed flows, but also includes minor pillow breccia, tuff, and intrusive rocks. Nonvolcanic turbidites are interbedded with the basalt; lenticular bioclastic limestone, red and green mudstone, chert, and conglomerate locally overlie the basalt, but are supplanted upward by turbidites. From west to east, basalts within the Orca Group become increasingly fragmental and amygdaloidal. Such textural changes probably indicate shallower water to the east.

A radial distribution of paleocurrents and distinctive associations of turbidite facies within the sedimentary rocks suggest that the Orca Group in eastern Prince William Sound was deposited on a westward-sloping, complex deep-sea fan. Detritus was derived primarily from "tectonized" sedimentary, volcanic, and plutonic rocks. Coeval submarine volcanism resulted in intercalation of basalt within prisms of terrigenous sediment.

INTRODUCTION

Sedimentary and volcanic rocks of the Orca Group originally were described by Schrader (1900), Grant and Higgins (1910), and Capps and Johnson (1912) from the islands and immediately adjacent mainland of Prince William Sound--an irregular embayment within the broad arc of the Chugach Mountains between the Copper River and the Kenai Peninsula. Recent work has shown that the Orca Group is more extensive than indicated in these pioneering studies; the Orca crops out over an area of roughly 21,000 km^2 from the vicinity of Barkley Ridge on the east to Blying Sound on the west (fig. 1). If rocks of equivalent lithology on Kodiak Island, the Ghost Rocks and Sitkalidak Formations (G. W. Moore, 1967, 1969), and probable extensions of the Orca on the continental shelf are included, the total area of outcrops on land and on the sea floor may be as much as 93,000 km^2. In addition, reconstruction of Orca basin limits suggests that much of the Gulf of Alaska Tertiary province west of the Canadian border, south of the Chugach-St. Elias fault, and east of the Ragged Mountain fault is underlain by the Orca Group.

Detailed stratigraphic and petrologic information on Orca sedimentary and volcanic rocks has been gathered since 1970 in conjunction with regional mapping in southern Alaska. Parts of this information have been published recently (Winkler, 1973; Winkler and Plafker, 1974; Plafker, 1974; Plafker and Lanphere, 1974); a geologic map of the Ragged Mountain area (scale, 1:63,360) will be available soon (Tysdal and others, 1975); and reconnaissance scale (1:250,000) geologic maps of the Cordova and Bering Glacier quadrangles which cover much of the Orca outcrop area are being compiled for publication.

The purposes of this paper are to assemble recently gathered information on the Orca Group (particularly the sedimentary rocks), to delineate a pattern of sedimentation and tectonism in eastern Prince William Sound during early Tertiary time, and to assess where additional information may be gained that will clarify the early Tertiary evolution of other areas of southern Alaska.

My field work on the Orca Group was carried out during 1971, 1972, and 1974, as one part of comprehensive U.S. Geological Survey studies of the Gulf of Alaska Tertiary province and the major fault systems of southern Alaska under the leadership of George Plafker. I am indebted to Plafker for generous advice and assistance, and to Plafker and Tor H. Nilsen for critical review of this manuscript. I gratefully acknowledge a grant-in-aid of research from The Society of The Sigma Xi, which defrayed part of the costs of the 1971 season.

LITHOLOGY

Sedimentary Rocks

The sedimentary rocks of the Orca Group are flysch-like: thick, well-bedded successions of alternating marine sandstone, siltstone, and mudstone (fig. 2) with primary sedimentary features similar to those thoroughly described by Dzulynski and Walton(1965). The Orca rocks also qualify as flysch under the recommendation of Hsu (1970) that the term be restricted to sequences that occur in alpine mountain chains.

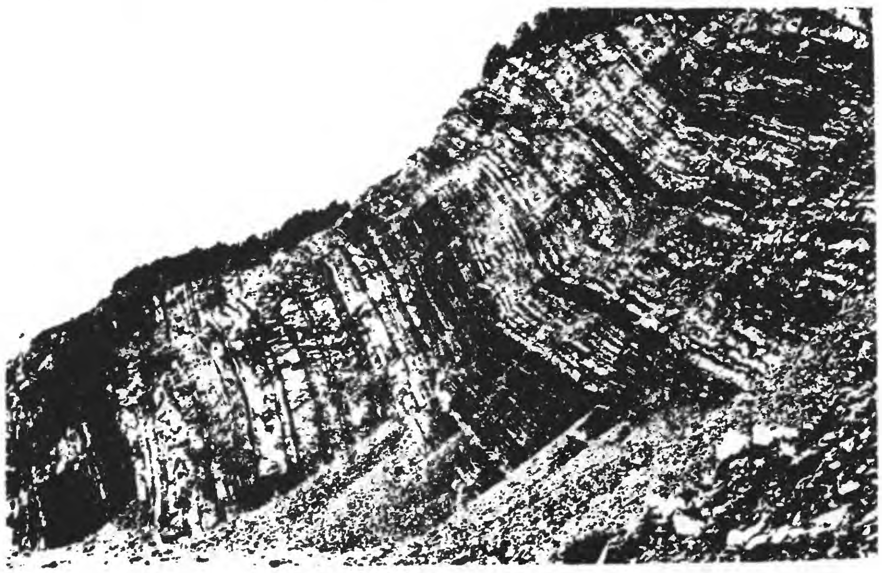


Figure 2. Alternating sandstone, siltstone, and mudstone, Hinchinbrook Island.

The Orca sandstones are subquartzose: although they vary widely in detrital modes, their average composition is feldspathic (fig. 3A). Subdivision of the ternary plot into secondary parameters (Dickinson, 1970) permits refined interpretation of provenances (fig. 3B). The ratio P/F characterizes inferred mafic to intermediate igneous sources for part of the Orca detritus better than Q-F relations. The ratio C/Q indicates some supracrustal derivation of stable quartzose grains. The standard deviation of V/L demonstrates a large compositional variability in the lithic detritus. Although labile sedimentary and volcanic grains dominate (fig. 4), more than half of the samples contain some weakly foliated grains. Other indications of mixed sources are (1) the subequal proportions of fresh and strongly altered plagioclase grains; (2) the moderate abundance of detrital mica, chiefly biotite (averaging ca. 1.6% of total grains); (3) the ubiquity of detrital epidote (ca. 1%); and (4) the common occurrence of trace amounts of detrital garnet. The intermediate percentages of quartz and the presence of polycrystalline quartzose grains, weakly foliated grains, epidote, and garnet are characteristics of a "tectonic" provenance (Dickinson, 1970, Table 4); whereas the high feldspar

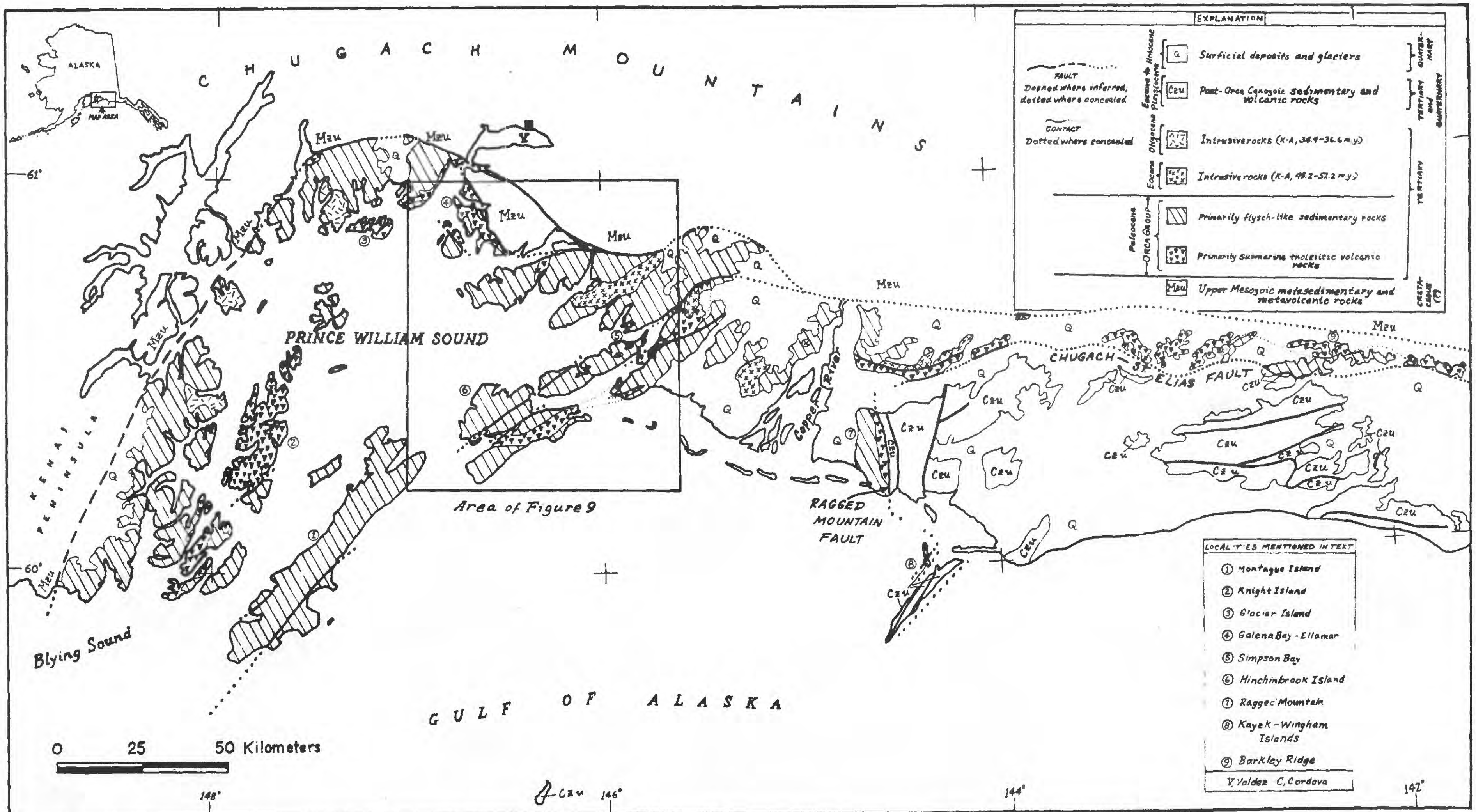
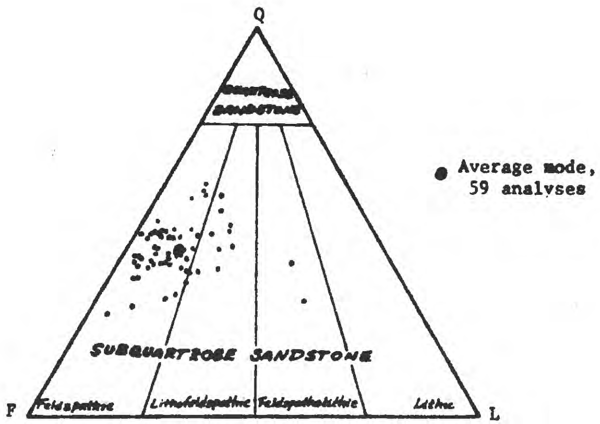


Figure 1. Distribution and structural relations of the Orca Group.



Q = total quartzose grains; F = total feldspar grains; L = total lithic grains

	% Q	% F	% L
MEAN	43.1	46.0	10.9
RANGE	26 - 60	22 - 70	1 - 44
STANDARD DEVIATION	7.2	9.5	7.9

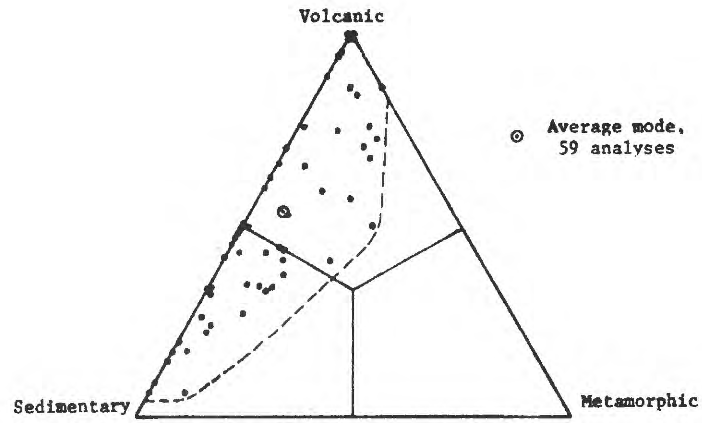
A. Primary parameters

C = total polycrystalline quartzose grains; P = total plagioclase feldspar grains; V = total volcanic lithic grains

	C/Q	P/F	V/L
MEAN	0.12	0.92	0.53
RANGE	0.01 - 0.32	0.80 - 1.00	0.17 - 1.00
STANDARD DEVIATION	0.08	0.05	0.27

B. Secondary parameters

Figure 3. Modal analyses of 59 sandstones, Orca Group.



	VOLCANIC	SEDIMENTARY	METAMORPHIC
MEAN	53.4	40.0	6.6
RANGE	6 - 100	0 - 94	0 - 30
STANDARD DEVIATION	27.3	27.6	7.2

Figure 4. Composition of lithic grains, 59 sandstones, Orca Group.

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and low lithic percentages and the presence of considerable mica suggest input from a plutonic provenance. The abundant altered feldspar probably indicates somes recycling of sediment.

Sediment for the Orca Group appears to have been derived by erosion of a composite sedimentary and volcanic terrane that had been tectonized and intruded. A possible source is the adjacent and lithologically similar Valdez terrane in the Chugach Mountains, which consists of low grade slate, graywacke, and greenstone west of the Copper River that is transitional into a high grade schist-gneiss-plutonic complex east of the Copper River.

Volcanic Rocks

In eastern Prince William Sound, altered tholeiitic basalt constitutes 15-20% of Orca outcrops. The most striking lithology is pillowed flows in which the maximum dimension of pillows is 10-12 m. Pillow breccia and massive or crudely columnar flows are almost as abundant. Gabbroic or diabasic intrusions and basaltic tuffs or tuff breccias are prominent at some places; generally they are subordinate in volume.

The basalt usually is holocrystalline, and plagioclase and clinopyroxene are the predominant minerals. Typical textures are aphyric or porphyritic, but the basalt may be amygdaloidal or glass-rich in the uppermost meter or so of pillows or pillow breccia immediately beneath an overlying unit.

On a structural cross section of central Knight Island in western Prince William Sound, Richter (1965) diagrammed the ratio of pillow vs. massive basalt as about 5:3. A measured section 510 m thick near Ellamar in northeastern Prince William Sound has 270 m (53%) of pillow basalt, 200 m (39%) of massive basalt, and 40 m (8%) of intercalated nonvolcanic mudstone, siltstone, and sandstone.

Sedimentary rocks within the volcanic sequences range from thin 1-10 m intervals near Ellamar to sequences 50 m or more thick on Hinchinbrook Island. In eastern Prince William Sound, the interbedded rocks are not (with minor exceptions) volcaniclastic or tuffaceous but are similar to Orca turbidites. Locally, chert, red and green mudstone, or conglomerate mantle upper surfaces of flows. These atypical Orca sedimentary rocks grade upward, at all localities, into normal, thick flysch-like turbidites.

East of Prince William Sound in the Ragged Mountain and Wingham Island area, greater proportions of the Orca volcanic sequences are glass-rich, amygdaloidal, or fragmental, and some of the intercalated sedimentary rocks are tuffaceous; the easternmost outcrops of Orca volcanic rocks near Barkley Ridge are almost entirely amygdaloidal or fragmental (George Plafker, R. G. Tysdal, and Travis Hudson, pers. commun., 1975). Because such rocks always are more strongly altered than holocrystalline basalts, their correlation with the Orca volcanic rocks of eastern Prince William Sound has been confirmed only recently. This eastward change in volcanic textures probably reflects decreasing water depths, which allowed greater vesiculation or fragmentation of extruding lava. Increasing abundances of shell coquina and related megafauna to the east in Orca sedimentary rocks that are associated with basalts also suggest shallowing (George Plafker, pers. commun., 1975).

At the loci of thickest or most rapid accumulation of basalt, edifices may have been constructed to sufficient heights to restrict access to parts of the Orca basin temporarily. At two places on Hinchinbrook Island, thin lenticular bioclastic limestone mantles upper surfaces of pillow basalt. Although they are displaced, fragmentary pelecypods, echinoids, bryozoans, coralline algae, diverse foraminiferal assemblages, and angular fragments of greenstone similar to the volcanic substrate suggest shallower environments than do foraminifers in the hemipelagic and pelagic turbidites. Furthermore, the limestones are overlain by a few meters of pure mudstone, suggesting that for a time perhaps the volcanic highs escaped overtopping by "normal" turbidites.

AGE AND STRUCTURAL RELATIONS

The evolution of thought regarding the age of the Orca Group was summarized by Moffit (1954) and by Plafker and MacNeil (1966). A collection of fossil crabs and mollusks from the lower part of the Orca Group in northeastern Prince William Sound originally was assigned a probable middle to late Eocene age by MacNeil. After reassessment of this collection, W. O. Addicott suggested that it most likely is of late Paleocene age, but may be as young as Eocene (Addicott and Plafker, 1971, p. B51). Poorly preserved pelagic foraminifers that were collected from the upper part of the Orca Group at scattered localities in southeastern Prince William Sound (Winkler, 1973) include a few tentatively identified forms suggestive of a middle to late Paleocene age (H. V. Kaska, written commun., 9/28/73). No other age-diagnostic fossils have been recovered from the Orca Group in Prince William Sound.

Samples from four granodiorite and quartz monzonite plutons that intrude the Orca Group give closely concordant early Eocene ages ranging from 49.2 to 52.2 m.y. (Plafker and Lanphere, 1974). Thus, only a relatively brief period of time ($\pm$ 5-10 m.y.) elapsed between deposition and intrusion of the Orca Group. During this time span, the Orca was pervasively folded and faulted, generally along trends parallel to the present continental margin. The Orca Group and coeval rocks on Kodiak Island are bounded on the north by a system of major faults along which the lower Tertiary rocks have been juxtaposed relatively beneath adjacent upper Mesozoic flysch terranes (Plafker, 1969; Winkler and Plafker, 1975). Deformation may have been in two distinct episodes. The first episode clearly preceded intrusion and was characterized by intense folding and faulting and development of poorly defined slaty cleavage--apparently while the Orca sediments were only semilithified and retained considerable pore water. A later, much less prominent episode of folding is suggested by local kink banding of slaty cleavage. The second episode may reflect regional adjustments associated with plutonism and metamorphism of the Orca Group to the laumontite and prehnite-pumpellyite facies.

Pervasive deformation of monotonous lithologies has precluded unraveling of detailed stratigraphic relations. In general, Orca sedimentary and volcanic sequences appear to be conformable, but the basalts--the key marker units--are lenticular, as though they were erupted from several specific centers. In addition, the basalts may have been erupted at different times as well as different locations. The Orca volcanic sequence that crops out in southeastern Prince William Sound on Hinchinbrook Island and the mainland near Cordova probably is different (younger?) from the more voluminous (older?) Knight Island-Glacier Island-Ellamar belt of Orca volcanic rocks in western and northern Prince William Sound. Additional analysis of regional structural trends, more paleontologic data, and perhaps geochemical characterization is needed before Orca terranes can be distinguished with certainty.

SEDIMENTARY FACIES

The preponderant Orca sedimentary rocks, from Barkley Ridge on the east to Blying Sound on the west, are repetitive sandstone-siltstone-mudstone turbidites. The Ghost Rocks and Sitkalidak Formations of Kodiak Island are analogous. In fact, for regional mapping it is this distinctive repetitive lithology that has been used to delineate the Orca Group. In eastern Prince William Sound, most Orca turbidites can be described by rhythmically alternating Bouma (1962) sequences. In the subdivision of turbidite types proposed by Mutti and Ricci Lucchi (1972), most Orca turbidites may be assigned either to facies D or facies C, the type of turbidites that Walker (1967) called "distal" or "proximal" (Table 1). These beds are fairly continuous laterally and have sharp, planar lower surfaces; many contain abundant fragmentary carbonaceous material.

Table 1. Turbidite facies of the Orca Group in eastern Prince William Sound.

	FACIES DESIGNATION (after Mutti & Ricci Lucchi, 1972)	OCCURRENCES
Bouma sequence not applicable	FACIES A Coarse grained conglomerate and sandstone	
	A1 Disorganized conglomerate	LOCAL, e. g., Simpson Bay
	A2 Organized conglomerate	LOCAL, e. g., Galena Bay
	A3 Disorganized pebbly sandstone A4 Organized pebbly sandstone	WIDESPREAD, mostly disorganized
	FACIES B Massive, medium-fine to coarse sandstone	
	B1 With dish structure	Not Identified
	B2 Without dish structure	WIDESPREAD, more abundant to E
Beds can be described by Bouma sequence	FACIES C Medium to fine sandstone--classical "proximal" turbidites beginning with Bouma division _a_	WIDESPREAD, more abundant to E
	FACIES D Fine to very fine sandstone and siltstone--classical "distal" turbidites beginning with Bouma division _b_ or _c_	WIDESPREAD, more abundant to W
	FACIES E Similar to D, but higher sand/shale ratio and thinner, more irregular beds	SCATTERED, mostly with facies C
Bouma sequence not applicable	FACIES F Chaotic deposits formed by downslope mass movement	LOCAL, e. g., N of Galena Bay
	FACIES G Pelagic and hemipelagic shale and marl--deposits of very dilute suspensions	WIDESPREAD in facies D and C

Facies D turbidites are distinguished by the absence of Bouma a and inconsistent presence of b intervals, by abundant bioturbation, and by much more abundant mudstone and siltstone than sandstone. Facies C turbidites are distinguished by incomplete Bouma a-e sequences--that is, by graded sandstone with an abrupt transition upward into minor mudstone. Some Orca sandstones are not graded and are in sharp contact with overlying pelitic beds; their upper surfaces commonly are rippled (fig. 5). Mutti and Ricci Lucchi (1972) assigned similar turbidites to facies E. On Hinchinbrook Island, the ripple-marked sandstones occur within sequences of facies C turbidites.

Figure 5. Complex pattern of probable linguoid ripples accentuated by loading on upper surface of sandstone bed, Hinchinbrook Island. Hammer = 38 cm.

Thin, lenticular, calcareous hemipelagic and pelagic layers are present in both facies D and C turbidites in eastern Prince William Sound. They usually occur near the tops of graded sequences--in some places as discrete beds, in others as concretionary horizons (fig. 6). Bioturbation of these layers is common, and many contain scattered tests of pelagic foraminifers.

A small but widespread portion of Orca turbidites consists of massive ungraded sandstone (fig. 7). Normally this type of turbidite (facies B, Table 1) consists of a series of amalgamated a intervals, infrequently with thin shale partings. It is well bedded, but is discontinuous laterally with numerous small channels. Many of the massive Orca sandstones contain a basal part that is rich in shale rip-up clasts.

A volumetrically minor portion of Orca turbidites in eastern Prince William Sound may be grouped with facies A--the coarse grained turbidites. Most prominent are the conglomerates and pebbly sandstones near Galena

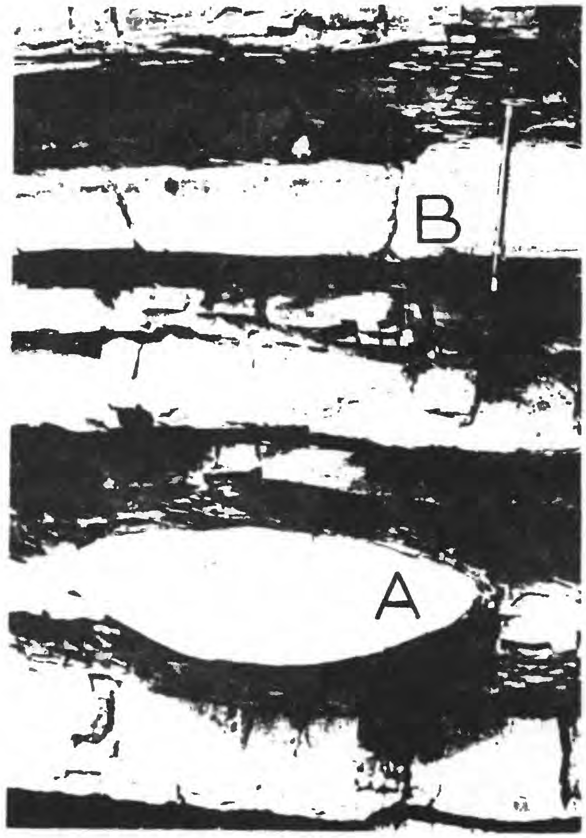

Figure 6. Two modes of occurrence of pelagic payers in Orca turbidites, Hinchinbrook Island: A = concretion, B = discrete bed, strongly bioturbated. Both have scattered foraminifers. Pencil = 15 cm.

Figure 7. Massive, amalgamated sandstone bed (facies B) with sharp, irregular bottom. Overlies facies C turbidites, Hawkins Island.

Bay (at least 800 m thick) and near Simpson Bay (at least 100 m thick) in northeastern and southeastern Prince William Sound, respectively. The coarse grained turbidites near Galena Bay predominantly are "organized"--that is, they are crudely to moderately well stratified, exhibit some preferred clast fabric (grading, alinement, or imbrication), and normally have a sandy matrix. Most clasts are subrounded to well rounded, and some are lithologies that are exotic to the Orca terrane, such as dacite and granodiorite. The fossiliferous conglomeratic argillite north of Galena Bay (Plafker and MacNeil, 1966) is exceptional; it is virtually unbedded and contains sporadically distributed, unsorted, angular to subangular clasts ranging in size from 8-foot blocks to granules (average size = 4 cm.) imbedded in a mud matrix. Diagenetic calcareous concretions that contain crabs and pelecypods are irregularly distributed throughout the matrix. These beds may have been resedimented by slumping. The conglomerates of Simpson Bay are both "organized" and "disorganized." The latter type has virtually no stratification or preferred clast orientation. Large angular blocks of sandstone are juxtaposed with well rounded pebbles in a sandy matrix (fig. 8). These sandstone blocks must have been only partly consolidated, for their margins are corraded, penetrated by pebbles, and--in a few places--resolved into the sandy matrix. They may have been derived by undercutting of channel walls.

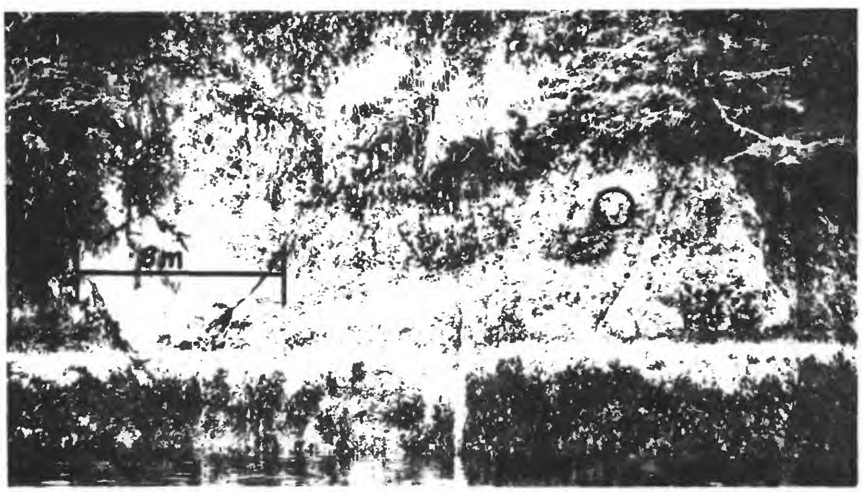

Figure 8. Large angular sandstone block embedded in conglomerate with generally well rounded pebbles (one is circled), Simpson Bay.

Thin, discontinuous, channeled pebbly sandstones that are not associated with conglomerates are widespread throughout eastern Prince William Sound. Generally the pebbles are dispersed only through the lower parts of beds, and these pebbly sandstones are transitional into the massive sandstones of facies B. Typically the pebbles are well rounded and frequently they are of exotic lithologies.

SEDIMENTARY STRUCTURES AND PALEOCURRENT ANALYSIS

Sedimentary rocks of the Orca Group contain a wide variety of primary structures that collectively are indicative of deposition by sediment gravity flow mechanisms, probably chiefly by turbidity currents and fluidized sediment flows (Middleton and Hampton, 1973). Sole markings (flute and groove casts, longitudinal furrows and ridges, transverse scour casts, prod and brush marks, load casts, and various feeding trails), upper bedding surface markings (chiefly transverse and linguoid ripples), and internal structures (graded bedding, ripple cross-lamination, convolute lamination, preferred clast fabrics, and bioturbation) all are present. Many of these primary structures provide directional data fundamental to reconstructing basin conditions.

Paleocurrent directions measured from sedimentary rocks of the Orca Group in eastern Prince William Sound are depicted on figure 9. Sole markings are the most abundant, widespread, and reliable indicators of paleocurrents. In many places flute casts occur in sufficient numbers that a mean direction of paleocurrent scour can be measured readily. Groove casts are nearly as abundant and, at many places, can be measured in conjunction with other sole markings that indicate an absolute direction of paleocurrent flow. Where groove casts are present alone, however, only a linear sense of current flow can be deduced.

Current ripple cross-laminations are rather common in Orca sedimentary rocks, but it seldom is possible to obtain adequate three-dimensional control on internal form in the field. Since sole markings usually are present at the same places, cross-laminations were not measured but merely were inspected to verify directions of associated sole markings.

At many places, upper bedding surfaces with asymmetrical ripple markings are well preserved. Wherever normals to ripple crests were measured, they were alined approximately parallel to sole markings from the same or adjacent beds. Thus, ripple markings were used as paleocurrent indicators, even where they occurred alone.

At two places within the bedded conglomerate of Galena Bay, clasts were determined to be imbricated parallel to paleocurrent flow; these measurements also are included as paleocurrent data.

On figure 9, individual paleocurrent vectors are shown for each locality. At some places there was a wide range in paleocurrent directions on a single bed or adjacent beds, particularly from sets of groove casts (fig. 10). Where angular differences were small (less than 30°, one class interval) and a dominant current direction could not be ascertained, the average paleocurrent is plotted. Where angular differences were greater than 30° and no direction dominated, two or more vectors are plotted. The map arbitrarily is divided into three sectors--N, W, and E--that are characterized by different paleocurrent regimes. The areas correspond roughly to Orca terranes of different aspect: the eastern sector has more abundant facies A and B turbidites, the western sector has more abundant facies C and D turbidites, and the northern sector (which is on a separate structural block) has more facies A turbidites than the other two sectors.

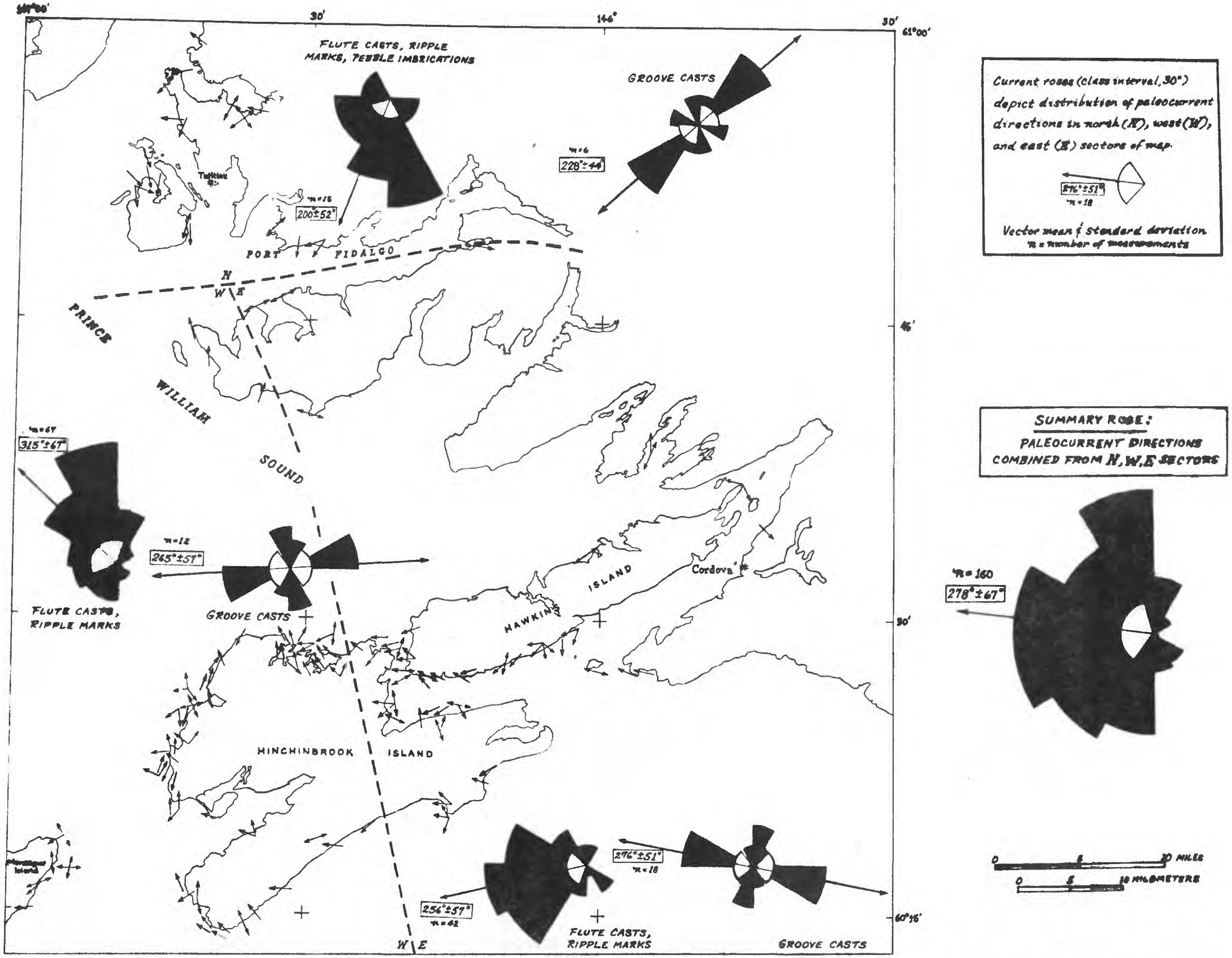

Figure 9. Paleocurrent directions of primary sedimentary structures in the Orca Group, eastern Prince William Sound.

Vectorial and linear data are summed separately for each sector on figure 9. Inasmuch as directions are dispersed more than 180°, vector means are calculated for grouped data by the geometrical method of Pincus (1956, Table 7). On the summary paleocurrent rose, the wide dispersion of directions is especially apparent; nonetheless there is a pronounced sense of westward flow of paleocurrents. The vector mean of 278° may correspond closely to the regional paleoslope.

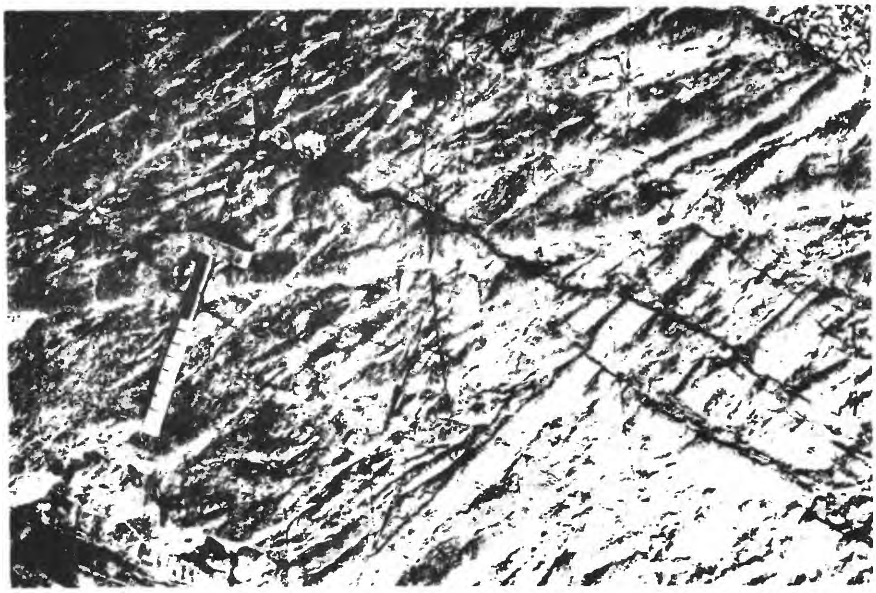

Figure 10. Bimodal groove casts, Hinchinbrook Island.

SEDIMENT-DISPERSAL MODEL FOR THE ORCA GROUP

Paleocurrent Patterns

What depositional setting for the Orca Group will yield an overall radial distribution of paleocurrents?

Most early studies of flysch-like rocks were confined to orogenic belts within continents where sediment had been delivered to laterally enclosed, elongate basins parallel to tectonic strike (e. g., Ten Haaf, 1959; Dzulynski and others, 1959; Hsu, 1960; McBride, 1962; Marshalko, 1964); paleocurrents were markedly uniform. Any divergent trends usually were attributed to lateral transport superimposed on dominant longitudinal transport. Subsequently Scott (1966), Ojakangas (1968), and J. C. Moore (1973) have described strongly alined paleocurrent configurations from turbidite sequences along active continental margins. Such patterns have been attributed to longitudinal deposition in fore-arc (or arc-trench gap) basins (Dickinson, 1971, p. 25) or in trenches (J. C. Moore, 1973, p. 609); both models require a bathymetric trough that is restricted on its seaward side. Scholl and Marlowe (1973) have presented theoretical objections to the trench depositional model, based primarily upon analysis of lithofacies.

Most recent studies of modern turbidite dispersal systems have been on submarine fans at continental margins (e.g., Shepard and others, 1969; Komar, 1969; Piper, 1970; Normark, 1970, 1973; Haner, 1971; Curray and Moore, 1971; Burke, 1972; Nelson and Kulm, 1973). These systems generally are unrestricted seaward and slope gradually toward an abyssal plain. There seem to be few modern analogues of laterally enclosed, elongate marine basins that are receiving thick accumulations of flysch-like sediments.

Directions of sediment dispersal on modern deep-sea fans are mostly inferred from the orientation and distribution of fan channels and interchannel areas (Nelson and Nilsen, 1973, p. 83). Fan channels radiate outward and downward from the fan apex; channel levees and interchannel areas slope laterally away from channels as well as down the fan. Migration of channels through time and inconsistent overspilling of turbidites away from channels presumably result in a very complex overall radial orientation of sediment dispersal patterns.

Nilsen and Simoni (1973) have demonstrated a radial distribution of paleocurrents from the Butano Sandstone in California that is analogous to the inferred dispersal pattern on modern deep-sea fans. The Orca pattern suggests that such a distribution of paleocurrents may be a distinguishing characteristic of ancient deep-sea fans in general.

Facies Associations

Recent studies by Mutti and Ricci Lucchi (1972), Mutti (1973), and Walker and Mutti (1973) have ascribed distinctive sequences and associations of turbidite facies to deep-sea fan depositional settings (fig. 11).

Most Orca Group sedimentary rocks in eastern Prince William Sound have facies associations that are characteristic of a middle fan (or suprafan) setting, although perhaps a small volume of Orca sedimentary rocks was deposited in an inner fan setting.

On modern deep-sea fans, the middle fan has two distinct environments (Normark, 1970): multiple distributary channels near the inner fan that are transitional down the fan into depositional lobes. In the channeled environment, mostly massive sandstone--perhaps with a pebbly base--is present, and it grades upward into thinner facies C and D turbidites. There is little lateral continuity of beds, with abrupt facies changes between channel, levee, and interchannel deposits. There may be considerable variability in paleocurrent directions, but basically the pattern will be down the fan laterally from the basin margin toward the basin axis. Although the total volume is small, these facies associations are widespread in Orca rocks, indicating some deposition in abundant distributary channels or in widely migrating channels. The great majority of Orca turbidites in eastern Prince William Sound, however, apparently were deposited in a depositional lobe environment, which is characterized by facies D and C turbidites. Individual beds tend to be more continuous laterally; there are only minor massive sandstone beds and channels. Paleocurrents are divergent on the depositional lobes, giving an overall radial pattern.

	FACIES ASSOCIATIONS	PALEOCURRENT TRENDS
INNER FAN	A Conglomerate & pebbly sandstone B Massive sandstone F Chaotic deposits (slumps)	Nearly uniform from margin across basin (lateral)
MIDDLE FAN	Channels C & D Mostly well bedded sandstone & siltstone A3, A4, & E Minor pebbly sandstone & levee sandstone	Fairly uniform, basically lateral but variable in interchannel areas
	Lobes D & C Mostly well bedded siltstone & sandstone B Minor massive sandstone	Wide variability but basically lateral
OUTER FAN	D Well bedded "distal" siltstone & sandstone G Hemipelagic & pelagic mudstone	? ? ? Perhaps wide variability

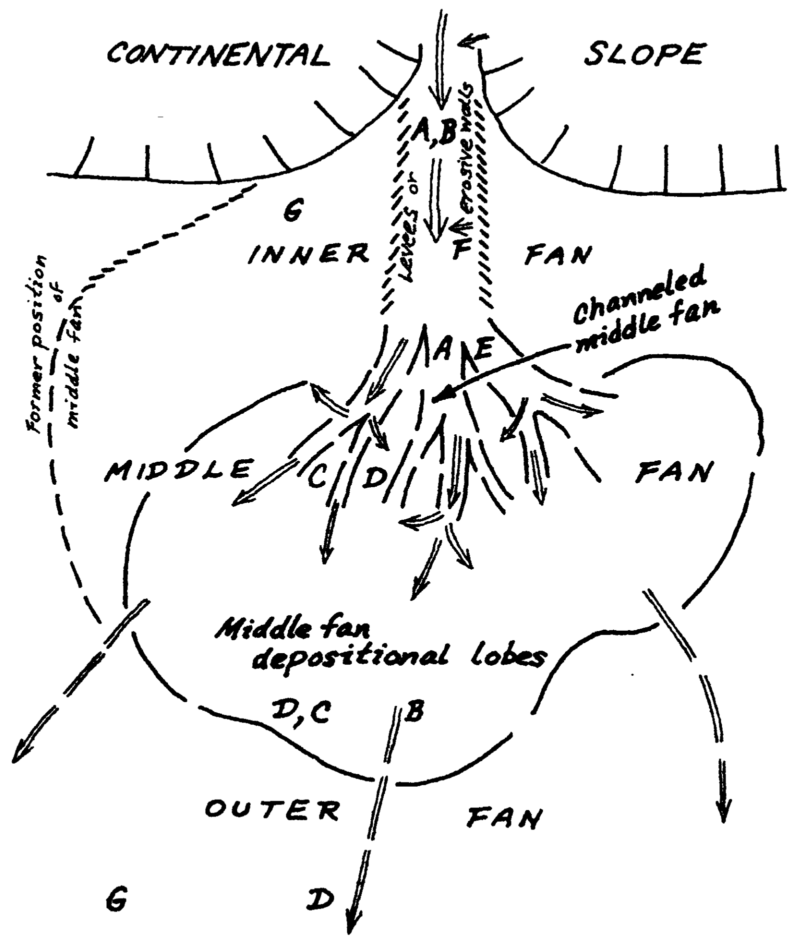

Figure 11. Deep-sea fan facies associations and paleocurrents (after Walker and Mutti, 1973, fig. 11).

The thick Orca conglomerates of Galena and Simpson Bays may represent two distinct inner fan channels--feeders of turbidites to the middle fan region. They indicate considerable erosive capability, since they include intraformational blocks and clasts that may have been derived from undercutting of the channel sides.

SUMMARY AND TECTONIC IMPLICATIONS

Uplift and emergence of the upper Mesozoic terrane of southern Alaska and its accretion to the continental margin in latest Cretaceous or earliest Tertiary time (Plafker, 1969; Jones and others, 1971) created a substantial source of partly tectonized sedimentary, volcanic, and plutonic sediment. Orca detritus is not sufficiently diagnostic to identify its sources with certainty. Most likely it was derived from the adjacent Valdez terrane in the Chugach Mountains. Right-lateral strike-slip translocation of the Orca Group from remote sources during Tertiary time is unlikely, but is not precluded.

Paleocurrent patterns and turbidite facies associations suggest that the lower Tertiary Orca Group was deposited on a complex deep-sea fan proximal to the continental margin. Submarine volcanism was active near enough to the continent for tholeiitic effusive rocks to be intercalated within the prism of terrigenous sediment. Age and structural relations suggest that accumulation of sediment was rapid and that initial deformation was nearly coeval.

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