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Tectonic framework of petroliferous rocks in Alaska

By

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Tectonic Framework of Petroliferous Rocks in Alaska

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Abstract

Alaska, comprising 3.6 X 10^6 sq km (about 28 percent) of the land, shelf, and upper continental slope of the United States, has been estimated by the U.S. Geological Survey (1974) to contain about 25 percent of the Nation's petroleum resources. Some 11 billion barrels of petroleum liquids and 31 trillion cubic feet of natural gas have been announced as discovered to date.

In northern Alaska, Paleozoic and Mesozoic shelf and slope deposits of the Brooks Range orogen were thrust relatively northward over the depressed south margin of the Paleozoic and Mesozoic Arctic platform, upon which a foredeep (the Colville geosyncline) developed in earliest Cretaceous time. Detritus from the Brooks Range filled the foredeep and prograded northwest and northeast to fill the Cretaceous and Tertiary North Chukchi and Umiat-Camden basins and form the Beaufort shelf.

In southern Alaska, a series of arc-trench systems developed on oceanic rocks during the Jurassic and Cretaceous. Between the arcs and the metamorphic (continental) terranes of east-central and northern Alaska,

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large back-arc and arc-trench gap basins received thick volcanic and detrital deposits. These deposits were extensively deformed and disrupted by mid-Jurassic to Tertiary plutonism, Laramide oroclinal bending, wrench faulting, and arc-related compression.

The Laramide events 'continentalized' the late Mesozoic back-arc basin deposits and welded them to the older continental terranes to the north and east. Subsequent sedimentation was localized and nonmarine except in onshore and offshore coastal basins, where thick mixed marine and nonmarine sections were deposited. The Aleutian arc and associated Queen Charlotte transform fault system have dominated structural and depositional patterns in southern Alaska since the early Cenozoic.

The largest petroleum reserves in Alaska (the Prudhoe Bay and associated fields) and the best prospects for additional large discoveries are in northern Alaska, where an extensive terrane is underlain by Upper Paleozoic to Tertiary carbonate and shelf, slope and delta clastic deposits. The pre-Tertiary back-arc and arc-trench gap basins in southern and interior Alaska are too intensely deformed or too low in porosity (because of diagenetic mobilization of labile constituents) to offer more than modest local prospects. The Tertiary coastal basins do, however, offer large tracts of thick marine and nonmarine clastic rocks and in some areas many large folds to exploration. Such basins are known to be petroliferous on Bristol Bay and the Gulf of Alaska and to contain major accumulations of oil and gas at Cook Inlet, but they are relatively little explored.

Introduction

This paper relates the occurrence of petroleum in Alaska to its tectonic history. We consider that plate tectonic theory and the ideas of D. E. Karig and others on marginal ocean basins, migrating arcs and back-arc sedimentation provide the most fruitful available concepts for understanding Alaskan tectonics, and our discussion is colored by these ideas. We present an outline of the tectonics of Alaska to provide a conceptual basis for evaluating its petroleum resources, but because of limitations of time and space, the outline is necessarily sketchy and over-simplified. For the sake of brevity, we use an assertive style that may imply a greater confidence than we place in all the details of the tectonic history we outline, and we have not attempted to reconcile the many worthy, but often conflicting ideas on the subject that have been proposed recently. For our purposes, Alaska includes both its land areas and bordering continental terraces. These terraces constitute more than half of the total continental mass in and adjacent to Alaska and offer large tracts of ground that appear to be attractive to exploration.

This paper was initiated and presented at the Circum-Pacific Energy and Mineral Resources Conference, Honolulu, Hawaii, August 26-30, 1974, with C. E. Kirschner as senior author. However, because Kirschner was assigned to Amoseas Indonesia, Inc., Jakarta in the fall of 1973, the main burden of preparing the paper and illustrations fell to Arthur Grantz. The latter therefore has assumed the responsibility of senior author.

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Tectonic Setting

Alaska lies in the northwestern part of the late Mesozoic and Cenozoic North American crustal plate. Seafloor spreading in the North Atlantic has produced a continent to continent compressional boundary between the North American and Eurasian plates along the west front of the Cherskiy foldbelt of northeastern U.S.S.R. (Churkin, 1972), and extensive east-west megascale compression in western and northern Alaska. Similarly, spreading at the East Pacific rise has produced an oceanic crust to continent compressional boundary between the Pacific plate and its predecessors and the evolving North American plate along the Aleutian arc and the Gulf of Alaska. These two interplate collision zones have been the dominant determinants of the late Mesozoic and Cenozoic tectonic evolution of Alaska.

Viewed broadly (Fig. 1), Alaska is an isthmus connecting the Eurasian

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Figure 1 near here.

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and North American continents in which topography and structure are dominated by the Cordilleran foldbelt of western North America. As a result of collisions with the Eurasian continental and Pacific oceanic plates, this foldbelt in Alaska was deformed by megascale oroclinal deformation, (i.e., by rotation in plan). This deformation is postulated to have produced the genetically linked Alaska, Pribilof and Navarin oroclines in southern and central Alaska and the Bering shelf, and the Chukchi syntaxis, and Porcupine and Ogilvie oroclines in northern Alaska.

Physiography and Structural Setting

The major physiographic-structural provinces of Alaska and some of the major fault systems are shown in Figure 2. The Southern and Interior

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Figure 2 near here.

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provinces together with the Brooks Range of the Northern province make up the Cordilleran system in Alaska. The Northern province is dominated by a late Paleozoic and Mesozoic stable shelf and Cretaceous and Tertiary thrust fault system, whereas the Interior and Southern provinces are dominated, respectively, by deformed late Mesozoic back-arc basins and Mesozoic and Tertiary arc-trench systems.

Northern Province

The Northern province consists of the tectonically related Arctic coastal plain, Foothills, and Brooks Range subprovinces. The coastal plain and foothills are underlain by a stable shelf, the Arctic platform, containing Upper Devonian to lowest Cretaceous rocks of northern provenance. The shelf is apparently truncated on the north by the linear Beaufort scarp, which follows the Beaufort Sea continental slope, and it is disrupted on the south and southwest by Cretaceous and early Tertiary thrust fault systems in the Brooks Range and central Chukchi Sea. To the east it is partly uplifted in the northeastern Brooks Range and partly buried under Cretaceous and

Tertiary beds in the Arctic coastal plain, Beaufort shelf and MacKenzie delta. This delta was localized at the intersection of the Beaufort scarp and the Canadian platform subsequent to development of the Canada basin.

We speculate that the Beaufort scarp may be an extinct transform fault system, active only during the Jurassic and Early Cretaceous, that extended east from the Chukchi Sea end of the Alpha Ridge of the Arctic basin. This ridge is thought to have been an active spreading axis from 200 to 40 m.y.b.p. (Ostenso, 1973). However, the recent discovery of latest Cretaceous sediments on the Greenland end of the ridge (Ling and others, 1973) suggests that activity ended during Late Cretaceous time. At least a part of the oceanic Canada basin may thus have opened by relative southeast movement of the Canadian platform along the Beaufort scarp and away from the Alpha Ridge. Right slip on the postulated Beaufort transform fault might have been dissipated into oblique slip along the Jurassic or Early Cretaceous Cordilleran front via an ancestral Donna River right-slip fault, much as the present Donna River fault zone of northweasternmost Canada (Fig. 2) appears to have transferred its right-slip to right-oblique slip faults in the northwestern MacKenzie Mountains (see, for example, Geol. Survey Canada, 1970a, b). The present curvilinear trace of the postulated Beaufort-ancestral Donna River alinement resulted from oroclinal bending of the eastern Brooks Range by relative northeastward displacement of northern Alaska along the Kaltag-Porcupine and Tintina faults.

The Brooks Range is bordered along its northern foothills by earliest Cretaceous to Tertiary thrust faults on which Brooks Range rocks overrode and depressed the southern margin of the Arctic platform to form a foredeep, the Cretaceous Colville geosyncline. The foredeep deposits thin and buttress northward against the Arctic platform and coarsen southward toward the thrust belt and Brooks Range. The Brooks Range and foothills rocks and structures correspond in time and style to those of the Rocky Mountains province of Canada and have been tentatively traced into northeastern U.S.S.R. and Wrangel Island via the Seward Peninsula (Churkin, 1973, p. 47ff).

The Brooks Range is bounded on the south by the Kobuk fault zone (Patton, 1973) much as in most places the MacKenzie-Rocky Mountains system is bounded on the southwest by the Tintina and Rocky Mountain fault zones. In both areas, Upper Cretaceous nonmarine clastic sediments were deposited in and along the topographic trenches that are associated with these faults (Brabb, 1969; Patton, 1973). Accordingly, we postulate that the Kobuk may be a deformed and offset extension of a pre-Tertiary Tintina fault zone.

Interior Province

The Interior province lies between the Kobuk-Tintina fault system on the north and the Denali fault system, southern Alaska Range and Aleutian arc on the south. Its commonly metamorphozed Paleozoic rocks and infolded, complexly deformed Mesozoic geosynclinal clastic rocks extend southeastward into Canada and westward beneath patchy Tertiary basins on the Bering shelf.

The Interior province contains a mainly Late Cretaceous to middle Tertiary en echelon fracture system consisting of the Kaltag, Iditarod, Farewell, Mulchatna, and perhaps other right-slip faults. These faults may have formed in response to rotational stresses about vertical axes in the active western limb of the Alaska orocline (Grantz, 1966). Pre-existing structural features such as the Kobuk and Tintina fault zones (Roddick, 1967) and the strands of the Denali fault in the central Alaska Range are older structures, with a long history of movement, that were offset or bent by deformation in the west limb of the orocline. The northeast-trending Kaltag and Farewell faults appear in part to offset and in part to splay or trail into the older, northwest-trending Tintina and Denali faults. They do not appear to be folded segments of these older faults, although the Farewell and Denali faults have been regarded as parts of the Denali fault system (Grantz, 1966).

Southern Province

The Southern or Pacific province is a complex of arcuate mountain ranges, linear lowlands, and a narrow continental shelf whose structural trends reflect the influence of the Alaska orocline and subduction along the Cenozoic Aleutian arc. Most outcropping rocks in the province were formed in a system of Jurassic and Cretaceous arcs, trenches, arc-trench gap basins and back-arc basins in the sense of Dickinson (1974). The province is separated from the Pacific basin by the Aleutian Trench and the genetically related Queen Charlotte transform fault system.

The Aleutian volcanic arc enters the continent at Unimak Island and follows the Alaska Peninsula to the central Alaska Range. There, Tertiary igneous activity and historic earthquakes related to the associated Benioff zone terminate near the axis of the Alaska orocline. Subparallel to the volcanic arc is an outer, nonvolcanic or tectonic arc that is defined by

Kodiak Island and the Kenai-Chugach Mountains.

Summary

The Kaltag-Porcupine fault appears as an important break north and south of which deformation of the Alaskan intercontinental "isthmus" followed somewhat different geometries. To the north a box-fold of syntaxes and oroclines related to right slip along the Kaltag-Porcupine fault dominates the megastructure of the Northern province; to the south an S-fold pattern of complementary oroclines dominates the structure of the Interior and Southern provinces and their offshore extensions. On both sides of the fault, however, the causative stress was east-west shortening in response to relative westward drift of North America. The oroclinal deformations may have been localized in western and northern Alaska because here the isthmus between Eurasia and North America was narrowest.

Stratigraphy

Introduction

The stratigraphic record in Alaska is similar in many respects to that of the Canadian platform and the Pacific Cordillera. In general, Paleozoic to Early Cretaceous sedimentation was miogeosynclinal to the north and eugeosynclinal to the south. However, early Paleozoic eugeosynclinal rocks underlie much of northernmost Alaska. Large areas in western Interior and Southern Alaska remained oceanic until late Mesozoic time, when they were finally continentalized and accreted to North America.

Paleozoic and Triassic rocks

The Paleozoic rocks of Alaska have been summarized recently by Brosgé and Dutro (1973) and by Churkin (1973) and some data on these and the Triassic rocks can be found in King (1969). The late Paleozoic and Triassic rocks of northern Alaska are shelf deposits of northerly provenance that rest unconformably on both eugeosynclinal and miogeosynclinal rocks of early Paleozoic age (see Figs. 3 and 4). The unconformity marks a major Late Devonian orogenic event that consolidated the early Paleozoic geosynclinal rocks into a stable shelf, the Arctic platform, upon which the late Paleozoic and Triassic rocks were deposited.

The late Paleozoic and Triassic rocks of northern Alaska are cut off on the north by earliest Cretaceous and older erosion and by the Beaufort Scarp,

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Figures 3 and 4 near here.

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which we speculate was a late Mesozoic transform fault. If this interpretation is correct, the shelf deposits were derived from part of the Canadian platform, now displaced relatively southeastward along the Beaufort transform. Because the area of the stable shelf, the Arctic platform, was reduced sharply after the mid-Jurassic and because Cretaceous clastic rocks prograded across the Arctic platform and Barrow arch to thicken northward on the Beaufort shelf, dislocation along the transform was probably Late Jurassic and/or earliest Cretaceous.

Most of early Paleozoic to Triassic southern Alaska was oceanic and contained volcanic arcs, but the boundary between these rocks and the shelf deposits to the north was apparently mobile. Note that the western two-thirds of the Carboniferous to Triassic miogeosynclinal-eugeosynclinal boundary in Alaska (Fig. 4) must lie north of the present position of the early Paleozoic miogeosynclinal-eugeosynclinal boundary (Fig. 3). The specific position of the former boundary in Figure 4 is, however, an interpretation. These relations suggest that the southern margin of the early Paleozoic continental terrace was fragmented and rifted south, perhaps during the Late Devonian orogeny which strongly affected northern Alaska, or during the Carboniferous. We postulate that a late Paleozoic marginal ocean basin, with ensimatic sedimentation, then formed in the gap thus created in the earlier shelf. The distribution of ophiolitic rocks led Patton to postulate earlier (1970, p. E20, and personal commun., 1974) that the Yukon-Koyukuk province of Cretaceous volcanic and sedimentary rocks (Fig. 6) filled a Permian, Triassic, or Jurassic rift in this same gap. Rifting and marginal ocean basin expansion may thus have occurred from the Late Devonian or

Carboniferous to the Jurassic or Cretaceous in west-central Alaska. The episodes of expansion may have alternated with one or more periods of basin collapse, as suggested by Churkin (1974) for the Cordilleran foldbelt to the southeast, but the chronology of such events in the two areas may have differed.

Broad bands of pelitic schists, marble, serpentine, and greenstone lie along much of the boundary between the miogeosynclinal and eugeosynclinal rocks in central Alaska (Fig. 5). We speculate that where these schists

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Figure 5 near here.

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lie near the late Paleozoic facies boundary or along the raft of early Paleozoic miogeosynclinal rocks, they include metamorphosed continental rise deposits. The local presence of serpentines and blueschists (Forbes and others, 1971; Patton, 1973) suggests that in places these schists also mark ancient, but now disrupted and obducted, subduction zones along the Paleozoic boundaries.

Jurassic and Cretaceous rocks

The Jurassic Period brought changes to Alaskan depositional patterns and tectonics that were comparable in scope to those created by the Late Devonian orogeny. These changes heralded a period of crustal mobility and compression that, by Tertiary time, created a continent out of the back-arc terrains of western Interior and the arc-trench gap terrains of Southern Alaska. The Jurassic and Cretaceous sedimentary basins of Alaska are shown in Figure 6. Data for this figure and the text were drawn from Berg and others (1972), Brabb (1969), Brosgé and Tailleur (1971), J. M. Hoare,

Figure 6 near here.

personal commun. (1974), King (1969), Lerand (1973), Marlow and others (in press), Morgridge and Smith (1972), Patton (1973), Scholl and others (in press), Tailleur and Brosgé (1970), and our own studies.

In northern Alaska clastic rocks of northern provenance and platform facies were deposited through the Jurassic. Uplift and northward-directed thrust faulting in the Brooks Range began in the latest Jurassic and was yoked to creation of a foredeep, the Colville geosyncline, to the north. The rising thrust belt shed voluminous orogenic and postorogenic detritus northward that overfilled the foredeep during the Cretaceous and prograded northwest and northeast, across the Barrow arch, to form the North Chukchi and Umiat delta systems and basins. The Upper Cretaceous Umiat basin of the Colville geosyncline underlies the eastern part of the Arctic coastal plain and adjacent continental shelf.

Jurassic mafic rocks in the southern Brooks Range appear to mark the southern edge of the continent at that time and place, and a zone of northward-directed obduction as well. Late Paleozoic and early Mesozoic ophiolites in the southern Brooks Range, and at many localities in the Interior and Southern provinces, are presumed to represent deep seafloor igneous and bedded rocks formed in marginal ocean basins. Remanent arcs (Karig, 1972) of Paleozoic (particularly late Paleozoic) and Triassic age and at least one large ridge of rifted Precambrian and Paleozoic continental shelf were scattered across this marginal ocean basin terrane, which must have looked much like parts of the modern southwest Pacific. Upon this complex foundation between the southern Brooks Range and a frontal arc-trench system in and immediately north of the present Kodiak-Chugach-St. Elias Mountains (see Fig. 6), there developed an assemblage of Jurassic and Cretaceous volcanic arcs and back-arc basins. These basins, some apparently resting on oceanic crust, some on continentalized crust, filled with Jurassic and Cretaceous volcanic and clastic rocks of diverse facies. The earliest deposits were typically marine volcanic rocks and turbidites of local volcanic provenance, succeeded by shallow marine, then deltaic and lastly coal-bearing sequences of increasingly continental provenance.

The back-arc basins formed behind (north of) a Middle Jurassic to Late Cretaceous eugeosyncline that fronted the Pacific basin in the present Kodiak-Chugach Mountains and an arc-trench gap basin and a magmatic (volcanic) arc that were contiguous on the north and genetically related to the eugeosyncline. The eugeosyncline contains continental rise and trench turbidites and submarine basalts that have been tectonically disordered and collapsed to a fraction of their former extent by underflow of the Pacific basin. The arc-trench gap basin (the Matanuska geosyncline) consists of shelf and slope clastic rocks much like those of similar age in the Sacramento Valley of California.

Tertiary rocks

Tertiary deposition in interior Alaska was restricted to nonmarine, intermontane basins, a legacy of Cretaceous "continentalization" of the Interior and Southern provinces. Thick marine and nonmarine clastic wedges, however, occur semicontinuously around Alaska's continental margins and constitute some of the State's most prospective ground for petroleum exploration. The Tertiary basins are shown in Figure 7. Sources for this

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Figure 7 near here.

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figure and the text were Barnes (1969 and 1971), Grantz and others (1970), Hatten (1971), King (1969), Kirschner and Lyon (1973), Marlow and others (in press), Plafker (1971) and von Huene and others (1971), M. S. Marlow and D. W. Scholl, personal commun. (1974), and our own studies.

The Interior basins are filled with clastic sediments that generally contain coal. The section in most of the basins is of moderate thickness, and deformation is generally slight to moderate. Intermontane, half-graben basins form the principal sediment ~~tapes~~ traps.

The Tertiary coastal basins are larger and deeper than the Interior basins and in many places more strongly deformed. In addition to coal-bearing rocks they contain paralic, shallow marine shelf, and deltaic rocks, deep marine turbidites, and organic shale. All Tertiary epochs are represented. Deformation ranges from gentle to intense, even metamorphic.

The Aleutian volcanic arc and trench system, which formed in latest Cretaceous or earliest Tertiary time, and the tectonically linked Queen Charlotte transform system controlled or strongly influenced Cenozoic sedimentation in the St. Elias, Kodiak, Cook Inlet and Bristol Bay coastal basins.

The Cook Inlet and Kodiak basins are parts of a compound Tertiary arc-trench gap basin lying between the Aleutian volcanic arc and trench (Fig. 8). The Cook Inlet basin and its extensions into Susitna lowland

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Figure 8 near here.

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and Shelikof Strait occupy a tectonic trough between the Aleutian volcanic arc and the Kodiak-Chugach tectonic arc. This trough contains nonmarine clastic rocks and some first-cycle volcanic materials. Deformation is progressively stronger in older sediments and may result in part from the impressed rotational strains developed in the Alaska orocline. The Kodiak basin lies between the tectonic arc and the Aleutian trench and contains both marine and nonmarine rocks. Its eastern extension, the St. Elias basin, lies between the Chugach-St. Elias tectonic arc and a poorly developed trench in the Gulf of Alaska and is bounded by splays of the Queen Charlotte transform fault system.

The Tertiary basins along the outer Bering shelf are half-grabens formed as a result of slumping and collapse of a late Mesozoic continental margin. Their structural position and depth, as well as limited sampling, suggest that they include both marine and nonmarine facies. The Tertiary basins of the inner Bering shelf and the southern Chukchi Sea are thinner than those of the outer Bering shelf and may be predominantly nonmarine.

Tertiary beds in the North Chukchi and Camden basins and the Beaufort shelf in the Northern province probably consist chiefly of deltaic and progradational continental shelf sequences. They presumably contain marine as well as nonmarine beds offshore, as they do onshore in northeastern Alaska.

Clastic sediments that were swept across the Alaska continental shelves have formed thick Cretaceous and Cenozoic continental rise sedimentary prisms in the Beaufort and Bering Seas and contributed to thick sedimentary prisms overlying oceanic crust in the Canada and Aleutian basins. They have also partly filled the Cenozoic Aleutian trench. Each of these extensive deep ocean sedimentary prisms may eventually be prospective for oil and gas.

Petroleum Prospects

The sedimentary basins in Alaska and its continental terraces that, on the basis of published data, appear to have significant potential for oil and gas are shown and classified in Figure 9. The remainder of this paper relates the occurrence of oil and gas in these basins to Alaska's

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Figure 9 near here.

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stratigraphic and tectonic history.

In the extensive Northern province (Fig. 10), petroliferous late Paleozoic and early Mesozoic marine shelf sediments on the Arctic platform

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Figure 10 near here.

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contain broad structures that, near the crest of the Barrow arch at Prudhoe Bay, have stratigraphically and structurally trapped giant oil and gas reserves (Morgridge and Smith, 1972). Significant, but much smaller reserves have also been found in the overlying Cretaceous sediments of the Colville geosyncline. We anticipate that additional substantial accumulations will be found in both suites of rocks, which are virtually untested.

Significant prospects may also occur in the Cretaceous and Tertiary rocks of the coastal and offshore Umiat-Camden and North Chukchi basins and the Beaufort shelf, but older prospective rocks may be thin or absent north of the Barrow arch. Beds in the coastal Camden basin and Beaufort shelf are thrown into large folds from Camden Bay (146° W. long.) east. In the North Chukchi basin an extensive offshore wedge of Cretaceous and Tertiary deltaic and progradational shelf clastic rocks contains many diapirs, perhaps of Cretaceous shale.

The Foothills belt of the Northern province consists of overthrusts in Paleozoic shelf sediments on the south and detachment folds in thick late Mesozoic orogenic clastic wedges on the north. Many of the sedimentary units are petroliferous, but the structural definition of viable prospects will be difficult.

In the Interior province, excluding Bristol Bay, only three exploratory tests have been drilled, all barren. Two of these, near the Yukon River in western Alaska (Fig. 6), penetrated diagenetically compacted and strongly deformed clastic rocks typical of the Jurassic and Cretaceous back-arc basins of the Interior province. We conclude, therefore, that these basins have little potential.

The third well, in the Nenana basin (Fig. 7), penetrated Neogene non-marine conglomerate, sand, shale and coal and bottomed in Paleozoic schist. The sequence is probably typical of the small and relatively shallow Tertiary basins of the Interior province. Viable prospects in this setting, which would be for dry gas, may require greater thicknesses and volumes of sediment than are commonly present.

The Bristol Bay basin (Fig. 11) is a large back-arc, half-graben basin that rests on continental crust and contains a thick Tertiary section of moderately to gently folded marine and nonmarine clastic and volcanic rock. Shows of oil and gas, but no production, were logged in several onshore test wells. The basin becomes more marine and deeper toward the southwest. Broad structures on the northwest shelf may provide attractive exploratory prospects. Its southeastern margin overlies locally petroliferous late Mesozoic shelf and slope clastic rocks of the Matanuska geosyncline.

Figure 11 near here.

In the Southern province, thick Middle Jurassic to Late Cretaceous marine arc-trench gap shelf and slope clastic rocks, the Matanuska geosyncline, trend more than 1,600 km from Canada to the outer Bering shelf (Figs. 6 and 9). These rocks are generally moderately folded, but in places they are intensely deformed or intruded by dikes and small plutons. The Matanuska rocks contain large oil seepages, but exploratory tests, although commonly encountering oil or gas shows, have been discouraging owing to diagenetically diminished porosity. These rocks offer the only significant, albeit modest, prospects for Mesozoic oil and gas in Alaska south of the Colville geosyncline.

The best prospects for large oil or gas accumulations in the Southern province lie in the coastal Tertiary basins.

The Cook Inlet basin (Kirschner and Lyon, 1973) is an intermontane half-graben containing a thick section of Oligocene to Pliocene deltaic, estuarine, and continental clastic deposits, the Kenai Group of Calderwood and Fackler (1972) (see Fig. 12). These rocks overlie Paleocene sand,

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Figure 12 near here.

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shale and coal and Jurassic and Cretaceous marine sediment with oil shows. Estimated proved in-place reserves in the basin exceed 2.6 billion barrels of oil and 5 trillion cubic feet of gas (after Crick, 1971). The oil and gas fields are in the Kenai Group and cluster in the north-central area of the basin, apparently in an optimum stratigraphic position. Exploratory tests elsewhere, however, have been noncommercial, and the potential of the basin for additional large reserves is speculative.

The Kodiak and St. Elias basins (Figs. 13 and 14) lie largely beneath the

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Figures 13 and 14 near here.

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continental terrace outboard of the tectonic arc represented by the Kodiak-Chugach-St. Elias Mountains. The boundary between these stratigraphically and structurally related basins is the easternmost of the northeast-striking faults and folds related to subduction at the Aleutian trench.

The Kodiak basin overlies the Aleutian trench Benioff zone and is an arc-trench gap shelf basin. It contains a linear, gently continentward-dipping half-graben wedge of upper Tertiary clastics bounded by large faults along the outer coast of Kodiak Island and a semicontinuous arch at the continental shelf-break. Tertiary and Quaternary sediments in the arch and beneath the continental slope are being tectonically churned by slumping, folding, and imbricate thrusting due to underflow of the Pacific plate. No exploratory wells have been drilled in this mainly offshore basin, and little is known of its stratigraphy. On Kodiak and adjacent islands, Oligocene continental and paralic sediments and Miocene and Pliocene marine sand and silt overlie complexly deformed and mildly metamorphosed turbidites and mafic volcanic rocks of Paleocene and Eocene age. The Kodiak basin offers a large area of modest potential for exploration, but uncertainty about reservoir rocks and locally complex deformation suggest that the basin may not be as attractive as its sedimentary volume might suggest.

The St. Elias basin, which is bounded by splays of the active Queen Charlotte-Fairweather transform fault system, has been structurally telescoped by slip on the bordering right-reverse faults. These faults appear to have taken up much of the large relative northwestward translation that occurred along the Queen Charlotte fault system. This telescoping has given the basin a complex stratigraphic and tectonic history. In the west, where the basin is very deep, imbricate thrusting in the St. Elias thrust system is succeeded southward by tight east-west striking thrust-folds near the coast and broad asymmetric folds offshore. Eastward the basin is shallower, and the structure is dominated by a broad southeastward-striking syncline.

Paleocene and Eocene turbidites and mafic volcanic rocks at the base of the section are intensely deformed or mildly metamorphosed and offer no potential for petroleum. They are succeeded by Eocene to lower Miocene deltaic sand, coastal plain shale and coal, and thick transgressive Oligocene and Miocene petroliferous silt and oil shale. These are in turn overlain by thousands of feet of marine sand and tillite deposited under conditions much like those of the present along this heavily glaciated coast. The petroliferous rocks, oil seepages, large structures, and thick sedimentary section spurred the drilling of 25 onshore exploratory tests in the basin. These failed to develop production owing to complex structure and diagenetically diminished porosity. The offshore offers more attractive prospects in large, and perhaps less complex, structures, but the presence there of adequate reservoir rocks will be critical.

The recent discovery of several Tertiary sedimentary basins beneath the Bering and Chukchi shelves (Figs. 7 and 9) has greatly increased the areas of known prospective ground in the Alaskan offshore.

The inner basins of the Bering and southern Chukchi shelves--Norton, St. Matthew and Hope--are of moderate depth and are thought to have been formed by crustal extension and subsidence behind the large terrane in northern Alaska that was displaced relatively northeastward by Laramide right-slip on the Kaltag fault. Broad folding and faulting have provided possible structural traps in these basins, but the stratigraphy is almost unknown. Marginal outcrops, a few seafloor samples, and regional considerations suggest that both nonmarine and marine beds of Upper Cretaceous(?) and both Paleogene and Neogene age are present in one or another of these basins. Natural gas has been found in the partly analogous Anadyr basin in northeastern Siberia (Meyerhoff, 1972). The deeper parts of these basins appear to offer good prospects for natural gas, and perhaps for some oil as well.

The outer basins of the Bering shelf, which include the large and deep (6 and 8 km, respectively) Navarin and St. George Tertiary half-graben basins, formed by collapse of a continental margin that has been tectonically passive since formation of the Aleutian arc in Laramide time. These basins have thus been spared the intense tectonism that underflow of the Pacific plate produced in the Kodiak and St. Elias basins. Tilting, faulting, and subordinate folding in the outer basins may have provided structural traps, but the adequacy of source and reservoir rocks is not known. Seabed sampling by Hopkins and others (1969) has shown that Oligocene to Pliocene shallow marine clastic rocks are present at least locally. Their tectonic setting, and facies relations in the adjacent Anadyr and Bristol Bay basins, suggest that the outer basins are dominantly marine. The great extent and volume of potentially favorable rocks and the stable tectonic environment of the outer Bering basins combine to make them attractive for oil and gas exploration.

Alaska comprises about 28 percent of the land and continental terrace of the United States. The U.S. Geological Survey (1974) has estimated that Alaska could contain about 25 percent of the Nation's total petroleum liquids and natural gas resources. While this optimistic estimate is certainly speculative, it is obvious that Alaska offers a wide variety of gently to strongly deformed sedimentary basins of diverse ages and tectonic environments to exploration.

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Page

Figure 1. Broad patterns of Cordilleran belt in Alaska ---------- 4

2. Physiography and selected major faults of Alaska, after Wahrhaftig (1965), Grantz (1966) and King (1969). P.F.-Porcupine fault; I.F.-Iditarod fault; F.F.-Farewell fault; M.F.-Mulchatna fault; C.M.F.-Castle Mountain fault; F.W.F.-Fairweather fault; D.R.F.-Donna River fault zone ---------------------- 5

3. Present distribution of Cambrian to Middle Devonian facies, after Brosgé and Dutro (1973) and Churkin (1973) ------------------------------------ 10

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13. Generalized cross section, Kodiak basin -------------- 20

14. Generalized cross section, St. Elias basin ------------ 20

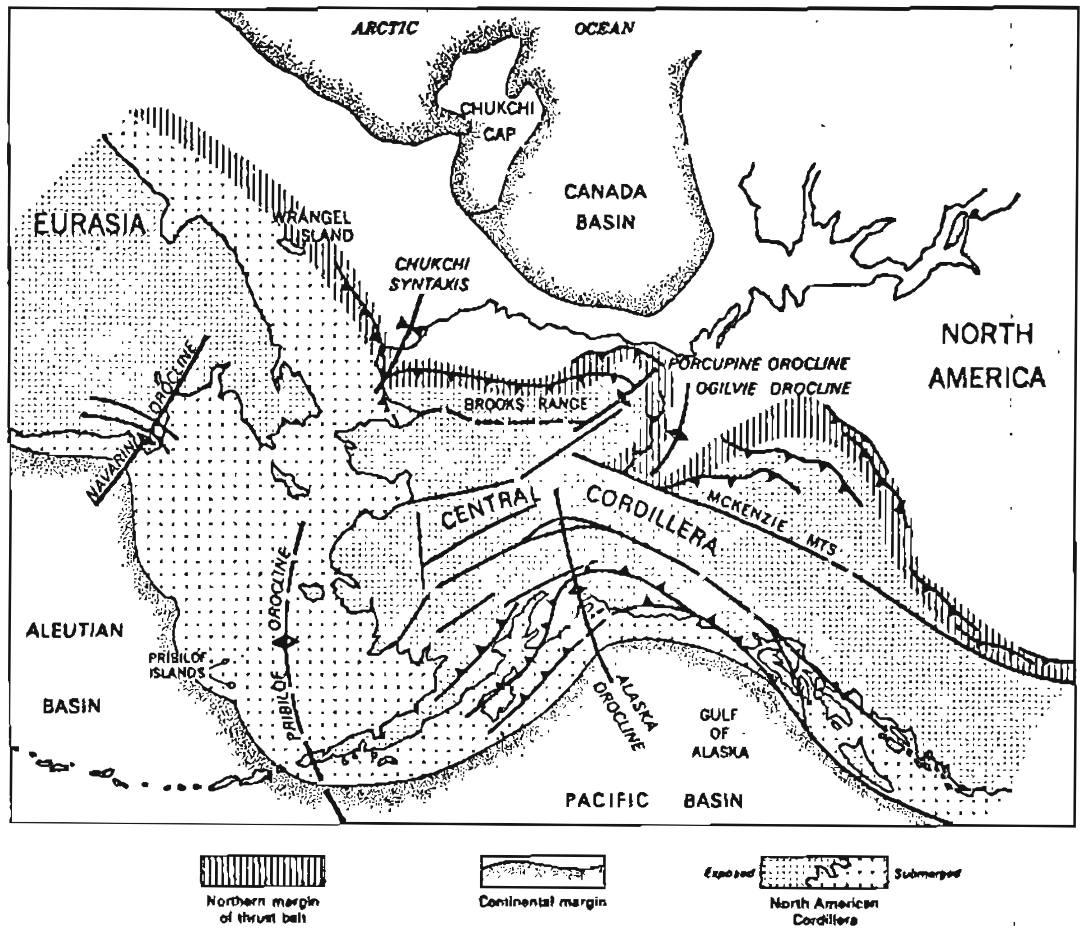
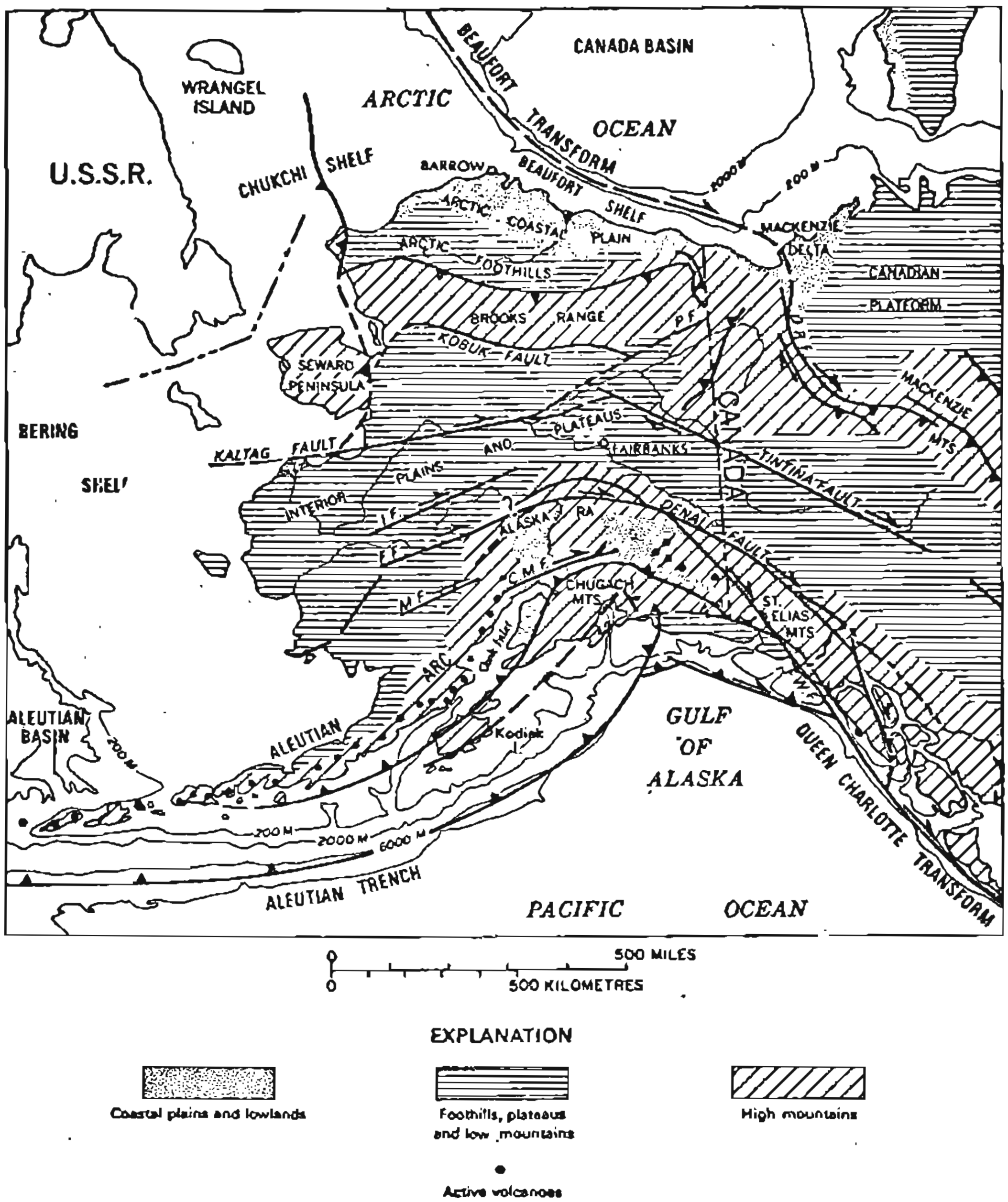

ARCTIC OCEAN
CHUKCHI CAP
CANADA BASIN
EURASIA
WRANGEL ISLAND
CHUKCHI SYNTAXIS
NORTH AMERICA
PORCUPINE OROCLINE
OGILVIE OROCLINE
BROOKS RANGE
NAVARIN OROCLINE
CENTRAL CORDILLERA
MCKENZIE MTS.
PRIBILOF OROCLINE
ALEUTIAN BASIN
PRIBILOF ISLANDS
ALASKA OROCLINE
GULF OF ALASKA
PACIFIC BASIN
Northern margin of thrust belt
Continental margin
Exposed
Submerged
North American Cordillera

FIG. 1.



NORTHERN PROVINCE	Arctic Coastal Plain Arctic Foothills Brooks Range Seward Peninsula
INTERIOR PROVINCE	Interior Plains and Plateaus
SOUTHERN PROVINCE	Alaska Range Kodiak—Chugach—St Elias Mountains Aleutian Arc

FIG. 2

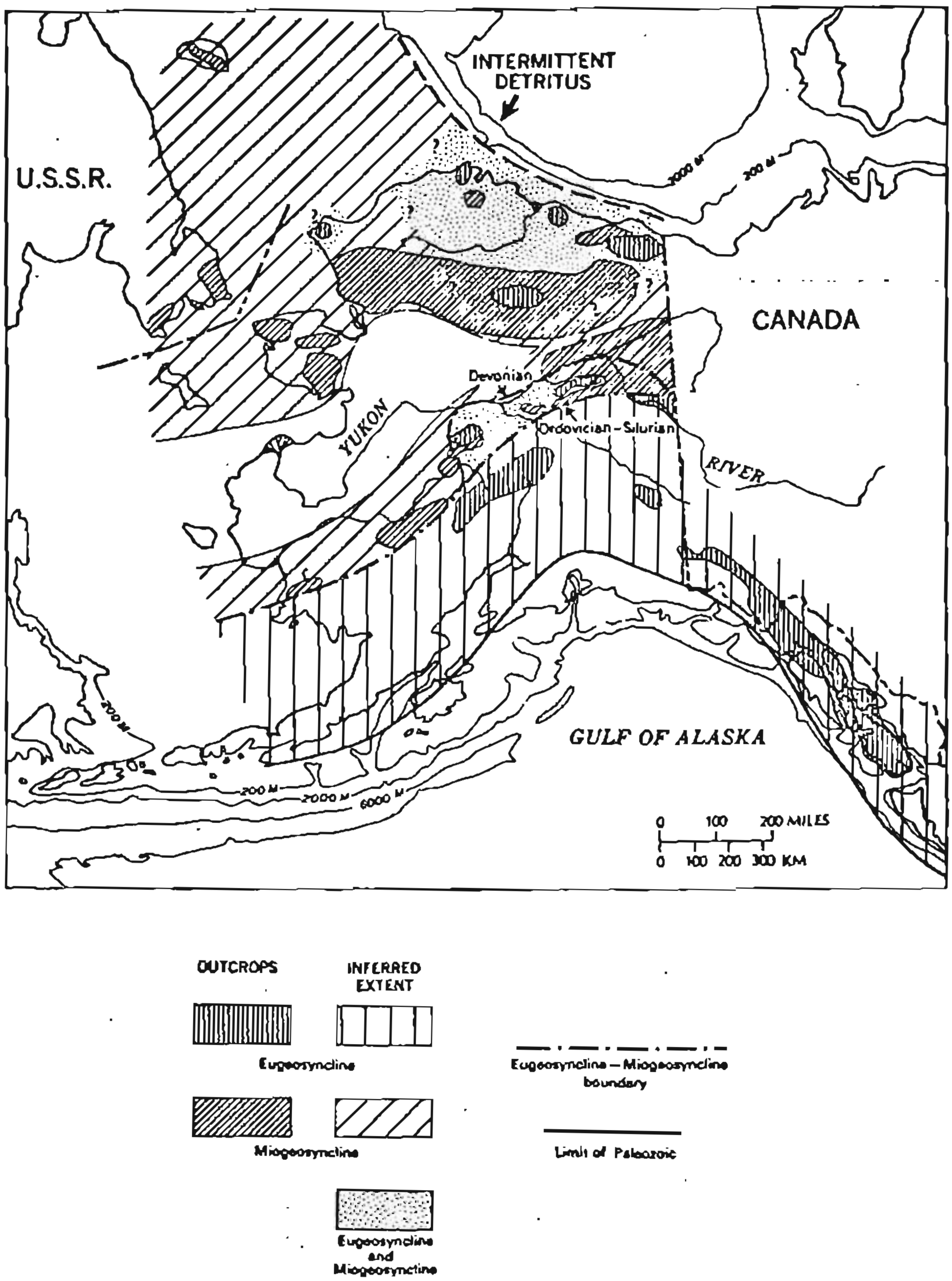
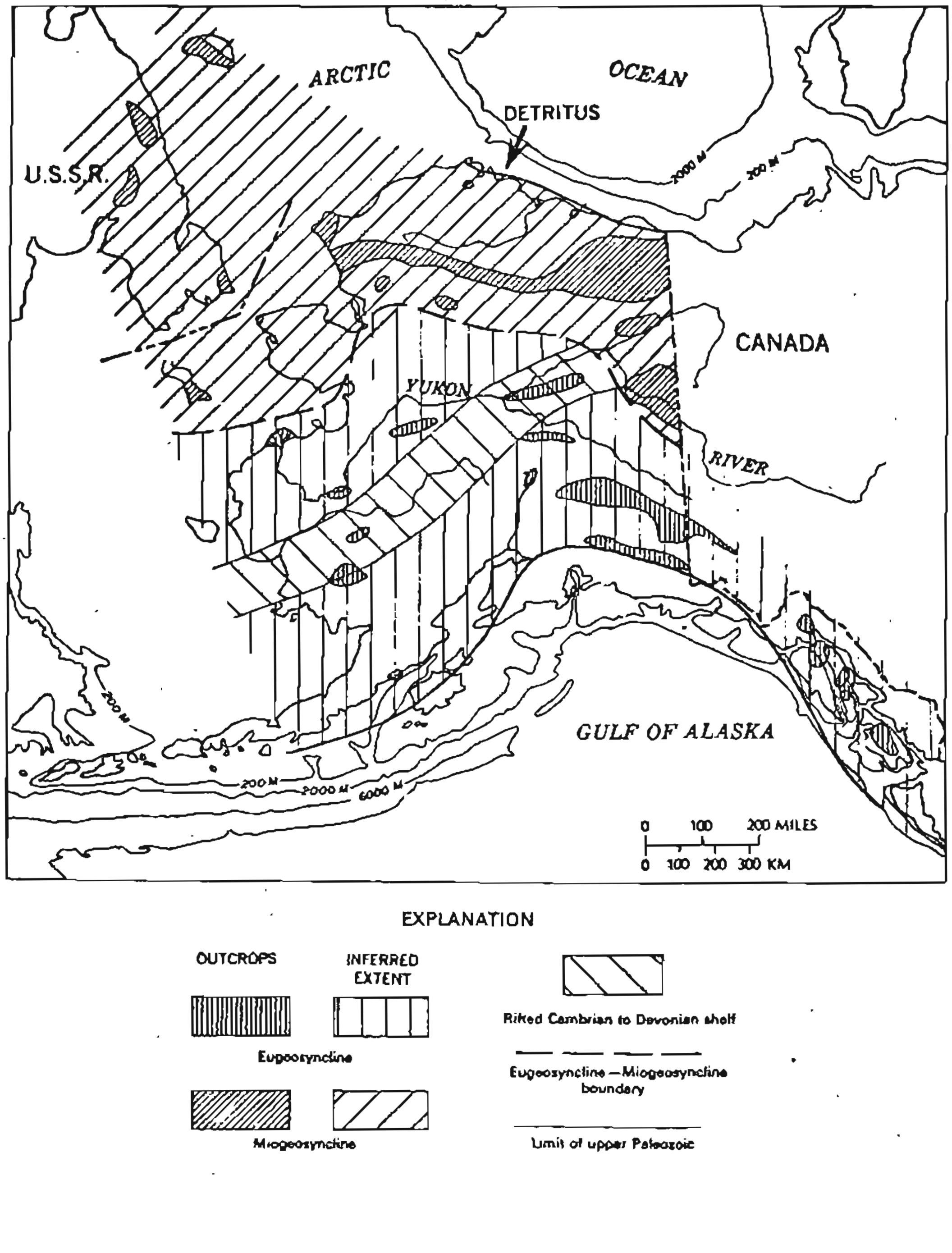

INTERMITTENT
DETRITUS
U.S.S.R.
CANADA
Devonian
Ordovician – Silurian
YUKON
RIVER
GULF OF ALASKA
200 M
2000 M
6000 M
0 100 200 MILES
0 100 200 300 KM
OUTCROPS
INFERRED
EXTENT
Eugeosyncline
Miogeosyncline
Eugeosyncline – Miogeosyncline
boundary
Limit of Paleozoic
Eugeosyncline
and
Miogeosyncline

FIG. 3



ARCTIC
OCEAN
DETRITUS
U.S.S.R.
CANADA
YUKON
RIVER
GULF OF ALASKA
200 M
2000 M
6000 M
0 100 200 MILES
0 100 200 300 KM
EXPLANATION
OUTCROPS
INFERRED EXTENT
Eugeosyncline
Miogeosyncline
Rifted Cambrian to Devonian shelf
Eugeosyncline — Miogeosyncline boundary
Limit of upper Paleozoic

FIG. 4.

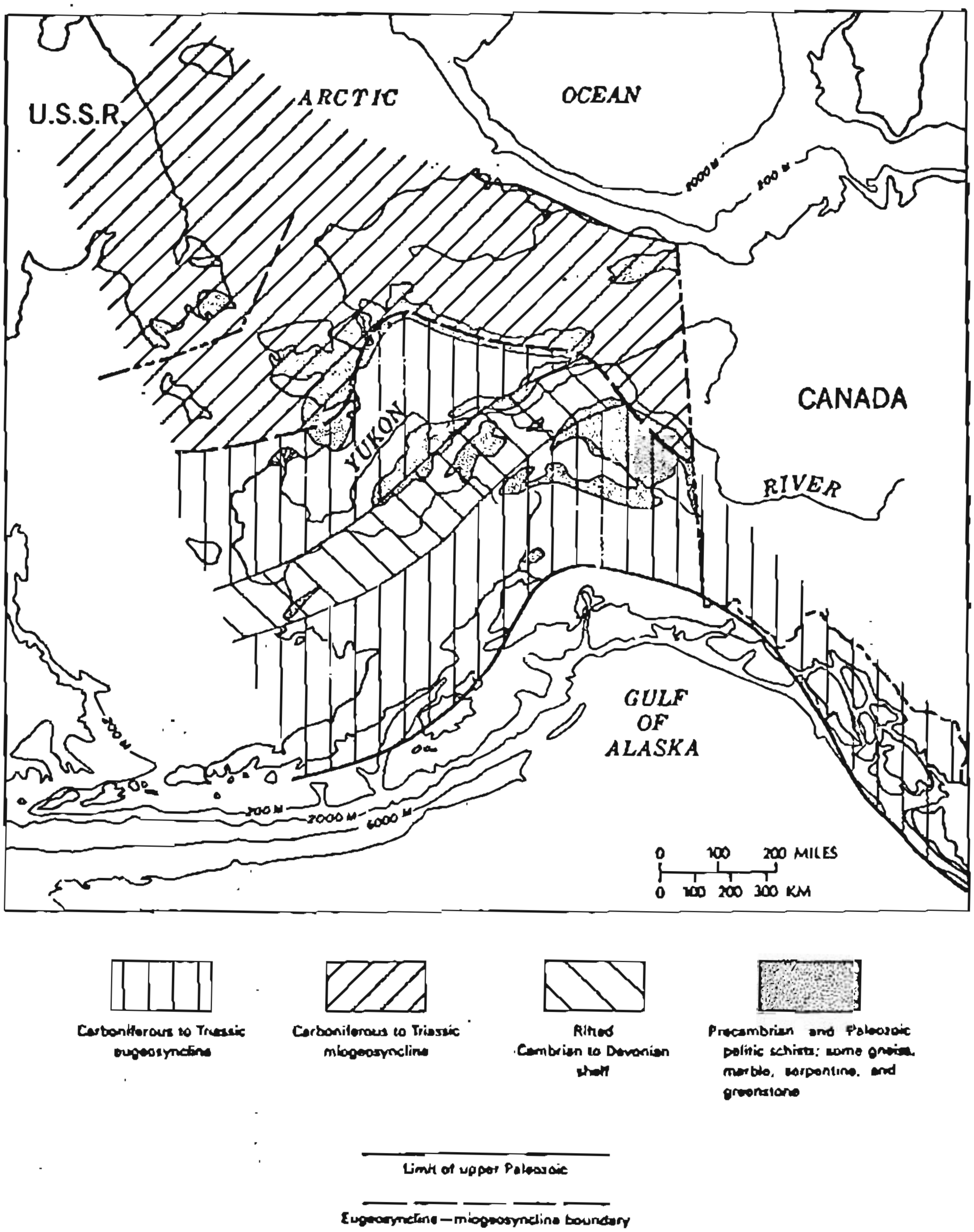

U.S.S.R.
ARCTIC
OCEAN
CANADA
YUKON
RIVER
GULF
OF
ALASKA
0 100 200 MILES
0 100 200 300 KM
Carboniferous to Triassic eugeosyncline
Carboniferous to Triassic miogeosyncline
Rifted Cambrian to Devonian shelf
Precambrian and Paleozoic pelitic schists; some gneiss, marble, serpentine, and greenstone
Limit of upper Paleozoic
Eugeosyncline—miogeosyncline boundary

FIG. 5.

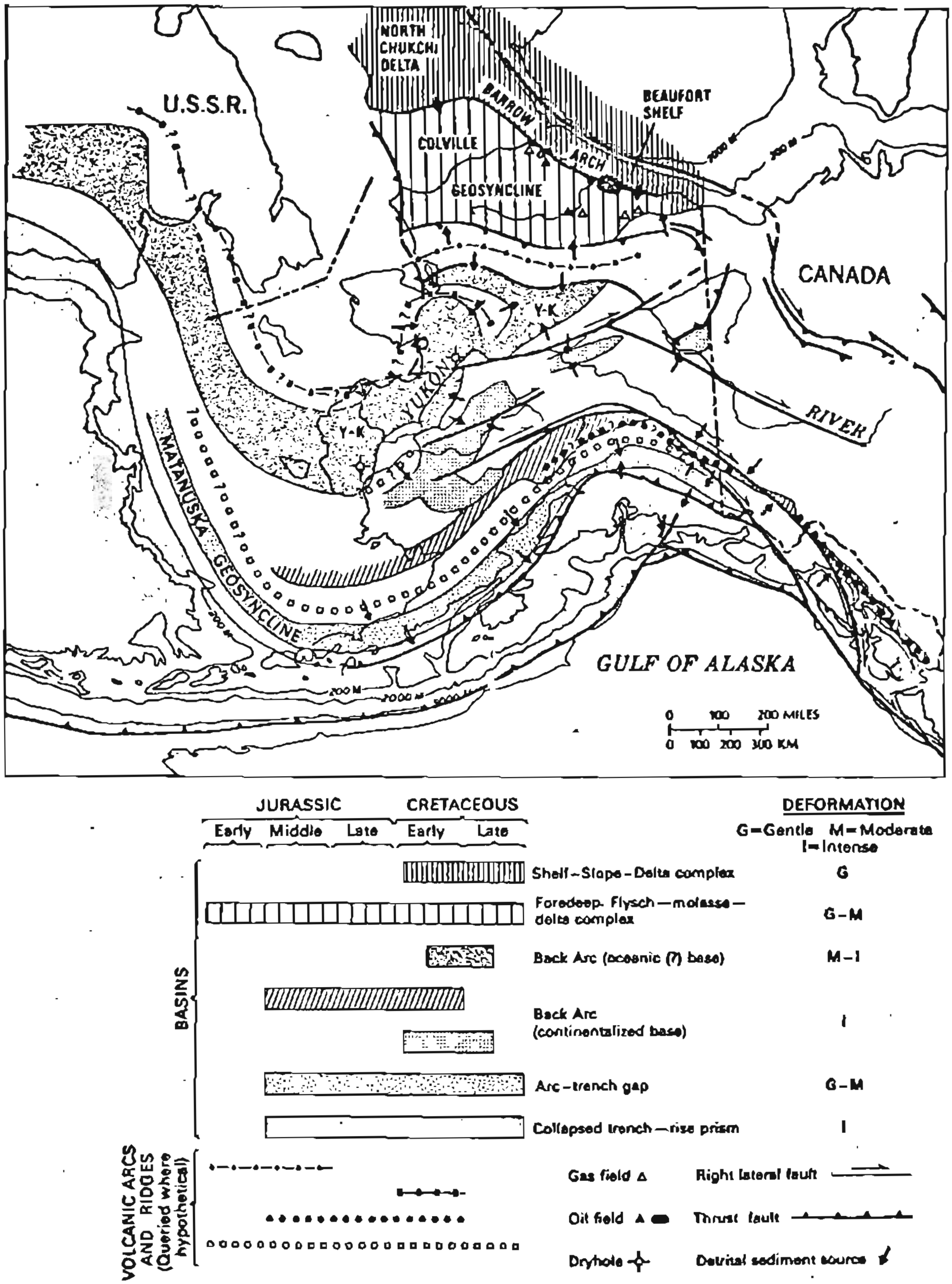
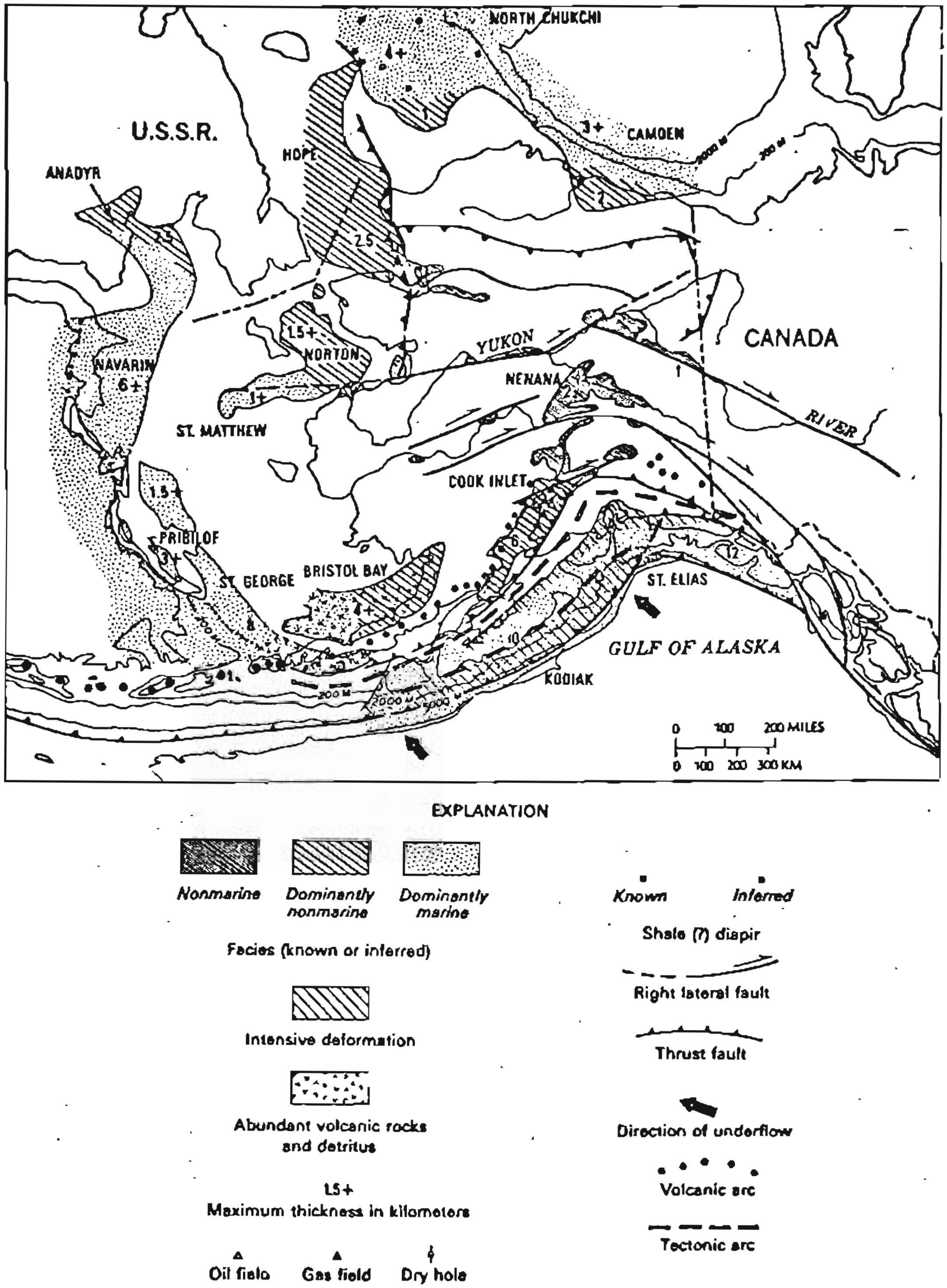
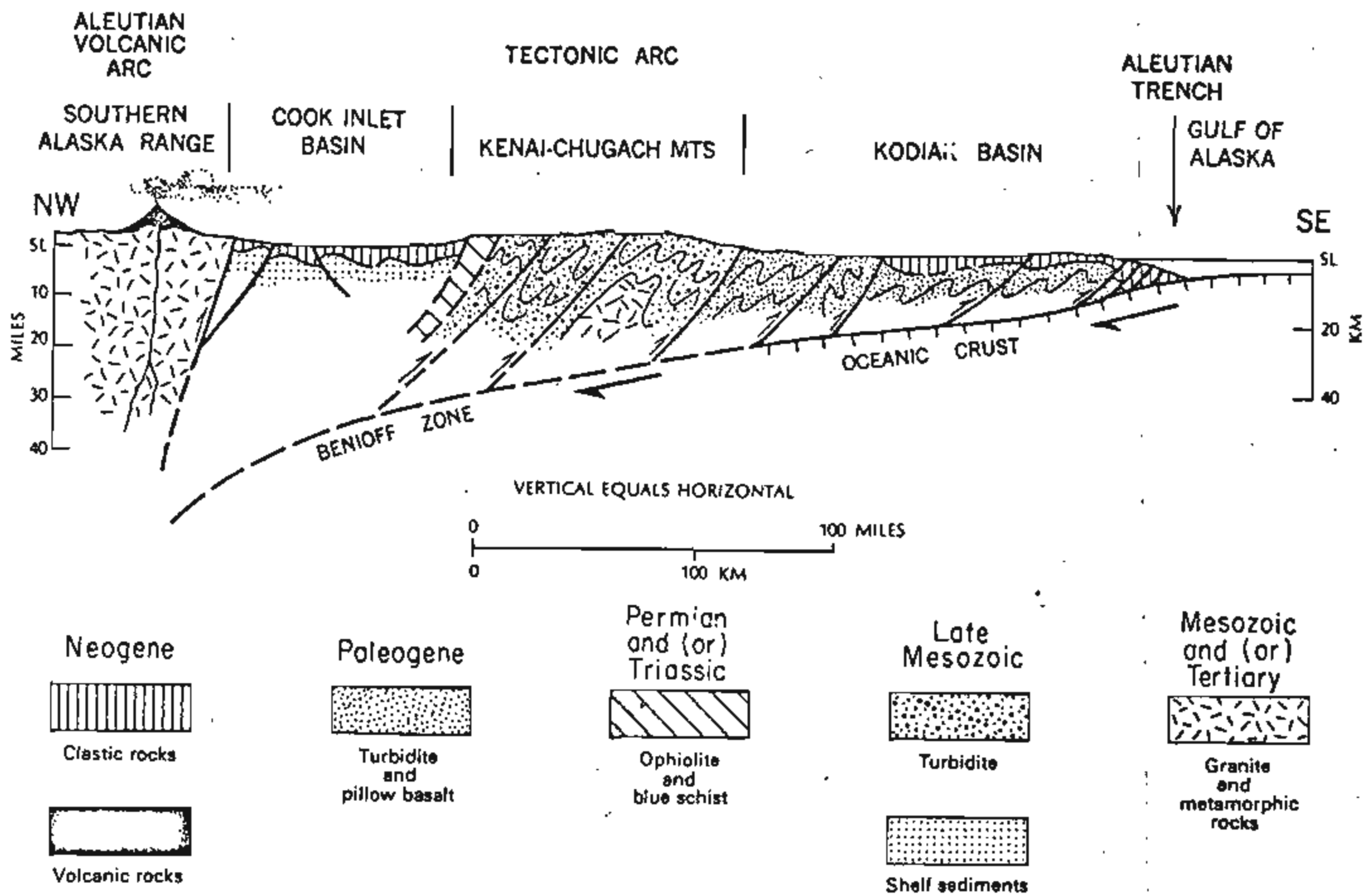

NORTH CHUKCHI DELTA
U.S.S.R.
BARROW ARCH
BEAUFORT SHELF
COLVILLE GEOSYNCLINE
CANADA
Y-K
YUKON
RIVER
MATANUSKA GEOSYNCLINE
GULF OF ALASKA
200 M
2000 M
5000 M
0 100 200 MILES
0 100 200 300 KM
JURASSIC
CRETACEOUS
Early Middle Late
Early Late
DEFORMATION
G=Gentle M=Moderate I=Intense
BASINS
Shelf-Slope-Delta complex G
Foredeep. Flysch—molasse—delta complex G-M
Back Arc (oceanic (?) base) M-I
Back Arc (continentalized base) I
Arc-trench gap G-M
Collapsed trench—rise prism I
VOLCANIC ARCS AND RIDGES (Queried where hypothetical)
Gas field
Oil field
Dryhole
Right lateral fault
Thrust fault
Detrital sediment source

FIG. 6.



NORTH CHUKCHI
U.S.S.R.
HOPE
CAMDEN
ANADYR
2.5
1.5+
NORTON
YUKON
CANADA
NAVARIN
6+
1+
NENANA
ST. MATTHEW
RIVER
COOK INLET
1.5+
PRIBILOF
3+
ST. GEORGE
BRISTOL BAY
4+
ST. ELIAS
GULF OF ALASKA
KODIAK
200 M
2000 M
5000
0 100 200 MILES
0 100 200 300 KM
EXPLANATION
Nonmarine
Dominantly nonmarine
Dominantly marine
Facies (known or inferred)
Intensive deformation
Abundant volcanic rocks and detritus
1.5+
Maximum thickness in kilometers
Oil field
Gas field
Dry hole
Known
Inferred
Shale (?) diapir
Right lateral fault
Thrust fault
Direction of underflow
Volcanic arc
Tectonic arc

FIG. 7



ALEUTIAN
VOLCANIC
ARC
TECTONIC ARC
ALEUTIAN
TRENCH
SOUTHERN
ALASKA RANGE
COOK INLET
BASIN
KENAI-CHUGACH MTS
KODIAK BASIN
GULF OF
ALASKA
NW
SE
SL
SL
10
20
30
40
MILES
20
40
KM
OCEANIC CRUST
BENIOFF ZONE
VERTICAL EQUALS HORIZONTAL
0
100 MILES
0
100 KM
Neogene
Clastic rocks
Volcanic rocks
Paleogene
Turbidite
and
pillow basalt
Permian
and (or)
Triassic
Ophiolite
and
blue schist
Late
Mesozoic
Turbidite
Shelf sediments
Mesozoic
and (or)
Tertiary
Granite
and
metamorphic
rocks

FIG. 8.

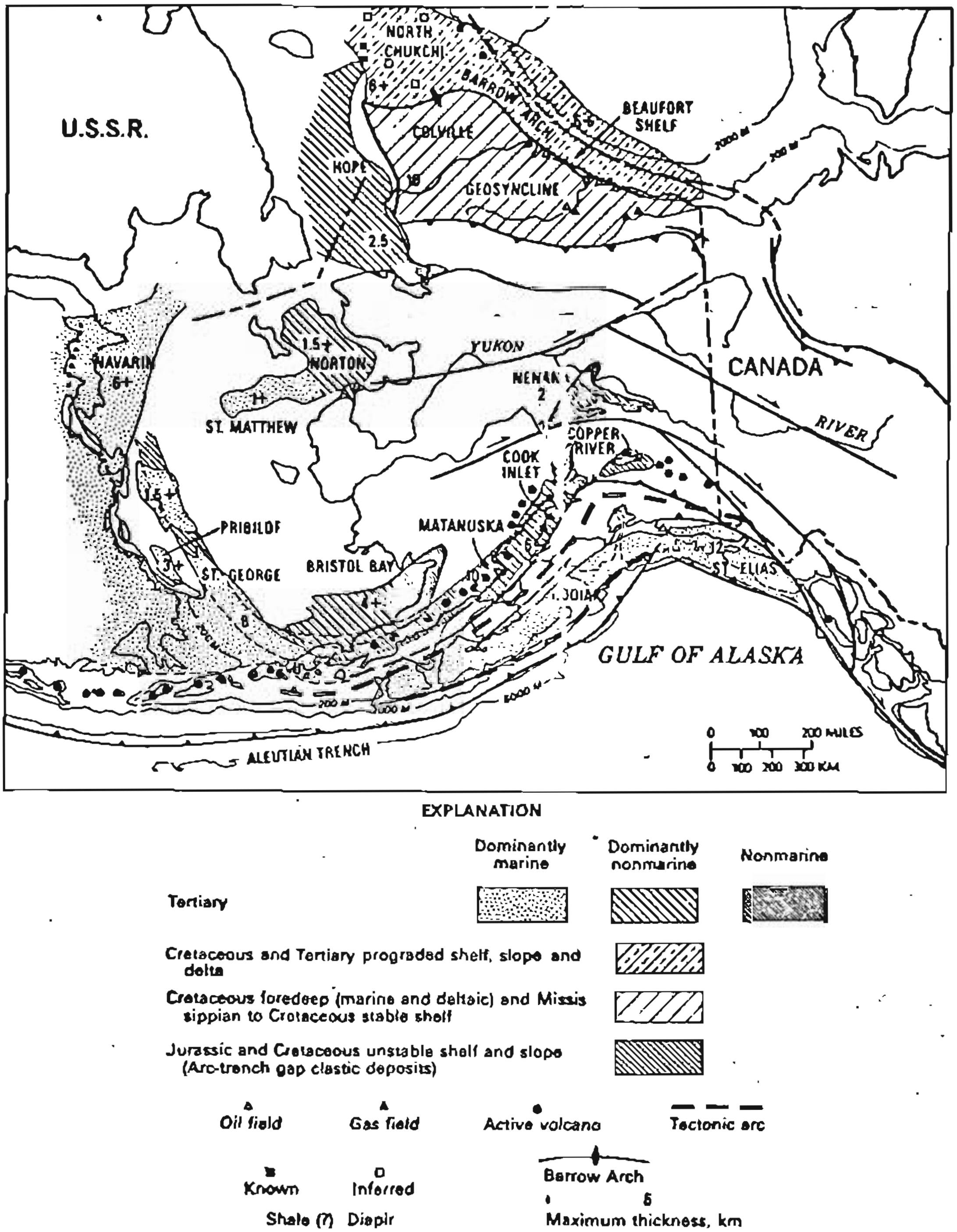

U.S.S.R.
NORTH CHUKCHI
BARROW ARCH
BEAUFORT SHELF
COLVILLE
GEOSYNCLINE
HOPE
2.5
1.5+
NORTON
YUKON
NAVARIN
6+
ST. MATTHEW
CANADA
RIVER
COPPER RIVER
COOK INLET
MATANUSKA
PRIBILOF
3+
ST. GEORGE
BRISTOL BAY
ST. ELIAS
GULF OF ALASKA
ALEUTIAN TRENCH
0 100 200 MILES
0 100 200 300 KM
EXPLANATION
Dominantly marine
Dominantly nonmarine
Nonmarine
Tertiary
Cretaceous and Tertiary prograded shelf, slope and delta
Cretaceous foredeep (marine and deltaic) and Mississippian to Cretaceous stable shelf
Jurassic and Cretaceous unstable shelf and slope (Arc-trench gap clastic deposits)
Oil field
Gas field
Active volcano
Tectonic arc
Known
Inferred
Shale (?) Diapir
Barrow Arch
5
Maximum thickness, km

FIG. 9

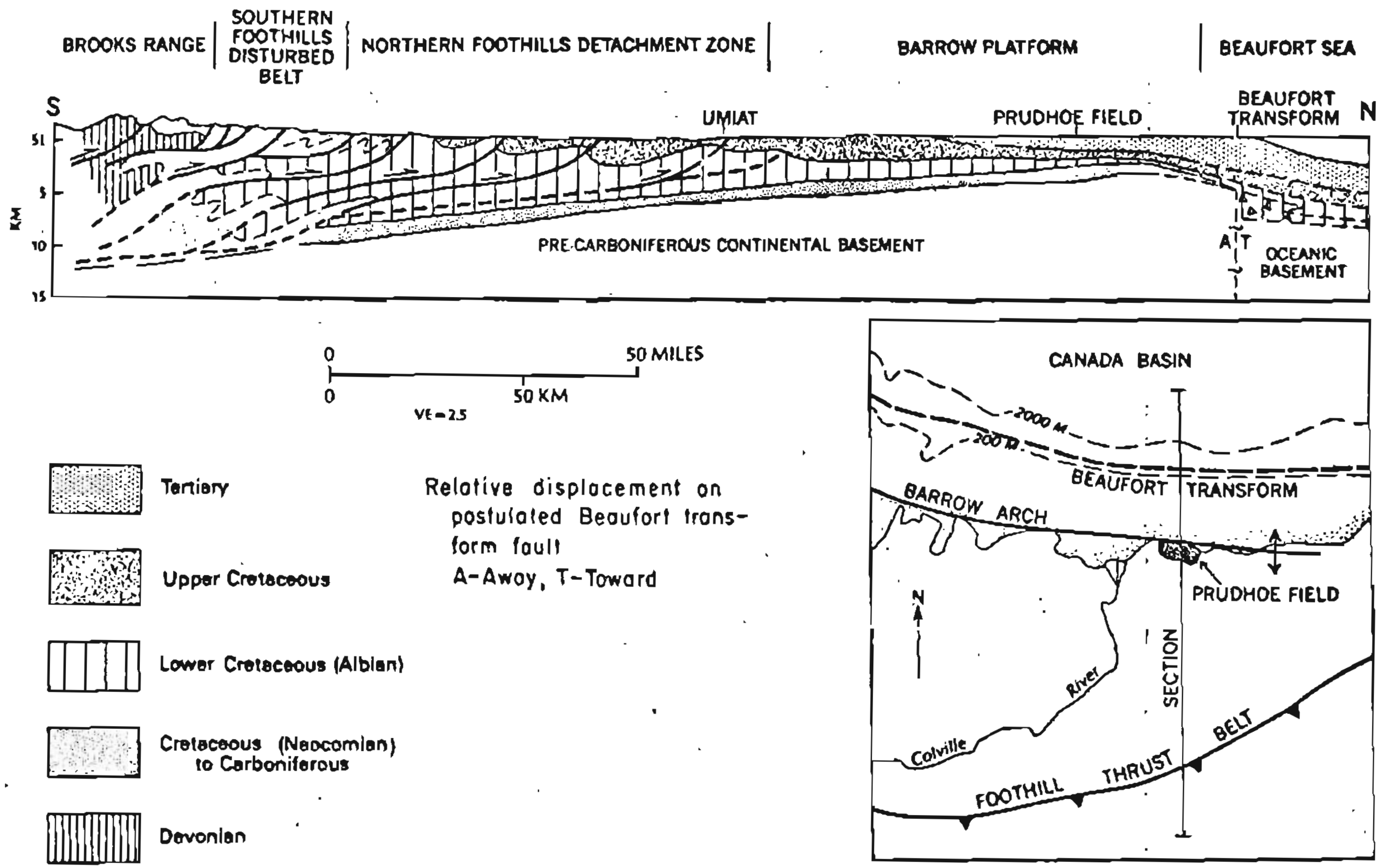

BROOKS RANGE
SOUTHERN FOOTHILLS DISTURBED BELT
NORTHERN FOOTHILLS DETACHMENT ZONE
BARROW PLATFORM
BEAUFORT SEA
S
N
UMIAT
PRUDHOE FIELD
BEAUFORT TRANSFORM
KM
5
10
15
PRE-CARBONIFEROUS CONTINENTAL BASEMENT
A T
OCEANIC BASEMENT
0
50 MILES
0
50 KM
VE=2.5
Tertiary
Upper Cretaceous
Lower Cretaceous (Albian)
Cretaceous (Neocomian) to Carboniferous
Devonian
Relative displacement on postulated Beaufort transform fault
A-Away, T-Toward
CANADA BASIN
2000 M
200 M
BEAUFORT TRANSFORM
BARROW ARCH
PRUDHOE FIELD
N
SECTION
Colville River
FOOTHILL THRUST BELT

FIG. 10

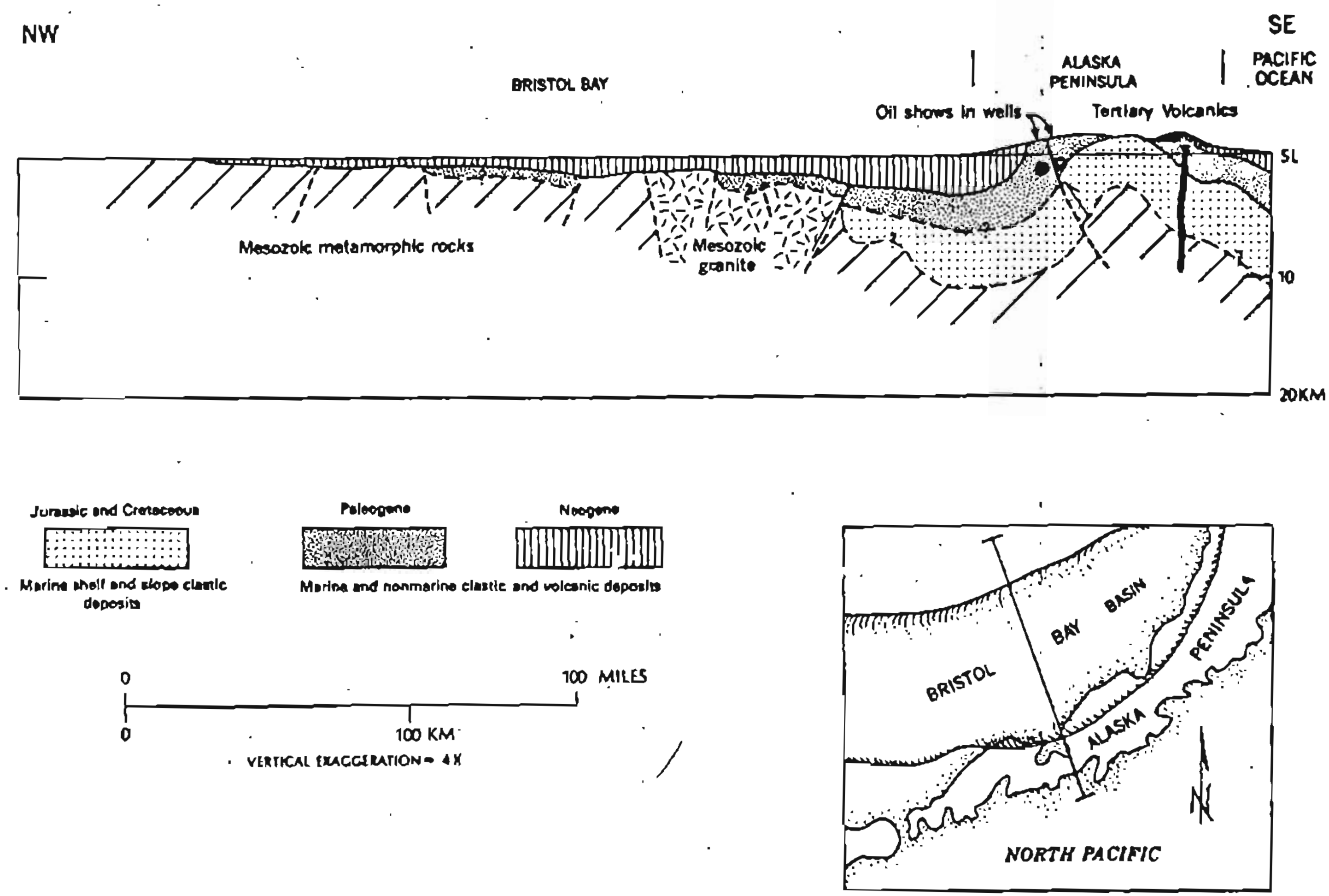
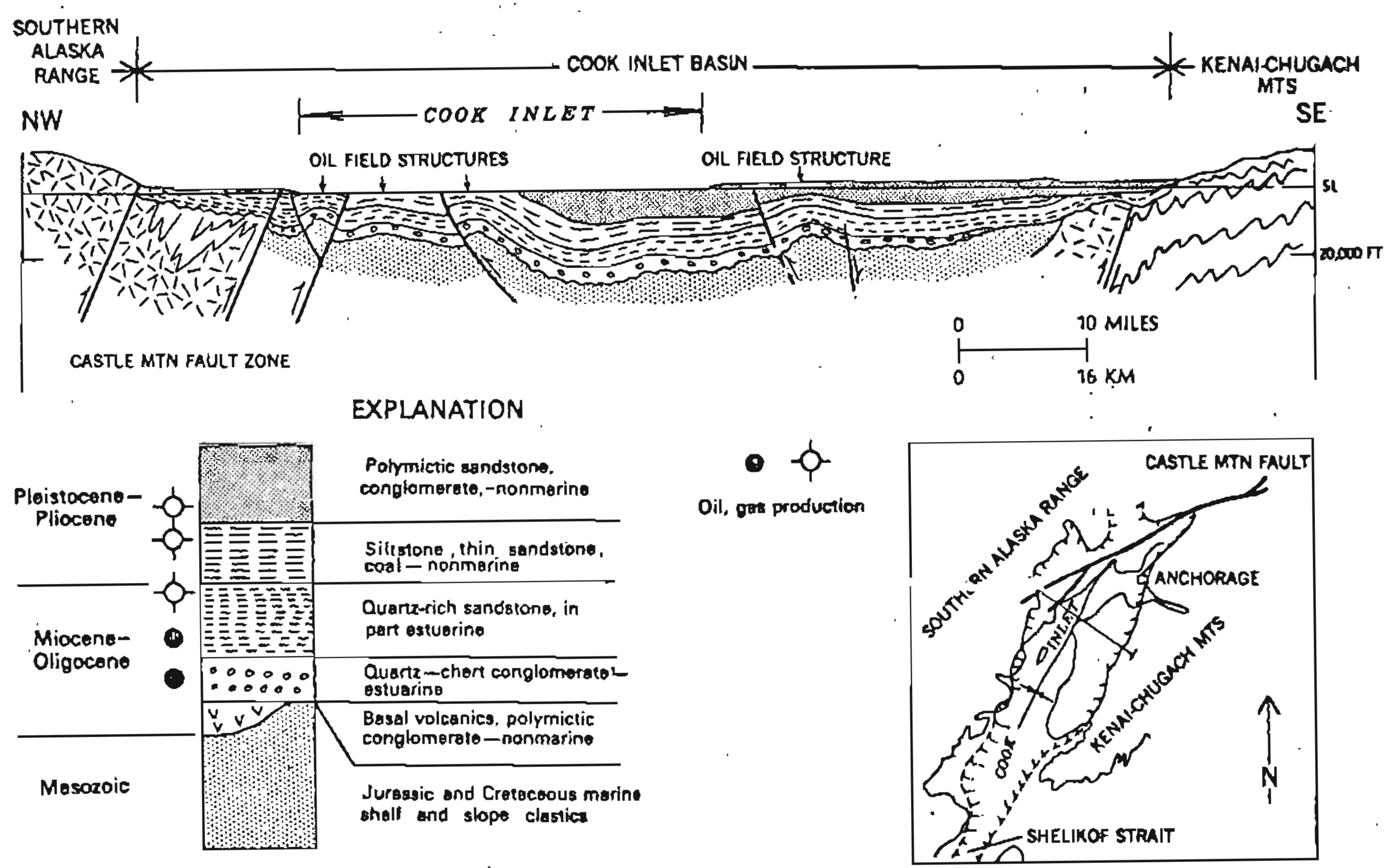

NW
SE
BRISTOL BAY
ALASKA PENINSULA
PACIFIC OCEAN
Oil shows in wells
Tertiary Volcanics
SL
10
20KM
Mesozoic metamorphic rocks
Mesozoic granite
Jurassic and Cretaceous
Marine shelf and slope clastic deposits
Paleogene
Neogene
Marine and nonmarine clastic and volcanic deposits
0
100 MILES
0
100 KM
VERTICAL EXAGGERATION = 4X
BRISTOL
BAY
BASIN
ALASKA
PENINSULA
NORTH PACIFIC
N

FIG. 11.



SOUTHERN ALASKA RANGE
COOK INLET BASIN
KENAI-CHUGACH MTS
NW
SE
COOK INLET
OIL FIELD STRUCTURES
OIL FIELD STRUCTURE
SL
20,000 FT
0
10 MILES
0
16 KM
CASTLE MTN FAULT ZONE
EXPLANATION
Pleistocene—Pliocene
Miocene—Oligocene
Mesozoic
Polymictic sandstone, conglomerate,—nonmarine
Siltstone, thin sandstone, coal — nonmarine
Quartz-rich sandstone, in part estuarine
Quartz—chert conglomerate—estuarine
Basal volcanics, polymictic conglomerate—nonmarine
Jurassic and Cretaceous marine shelf and slope clastics
Oil, gas production
CASTLE MTN FAULT
ANCHORAGE
KENAI-CHUGACH MTS
COOK
INLET
SHELIKOF STRAIT
N

FIG. 12.

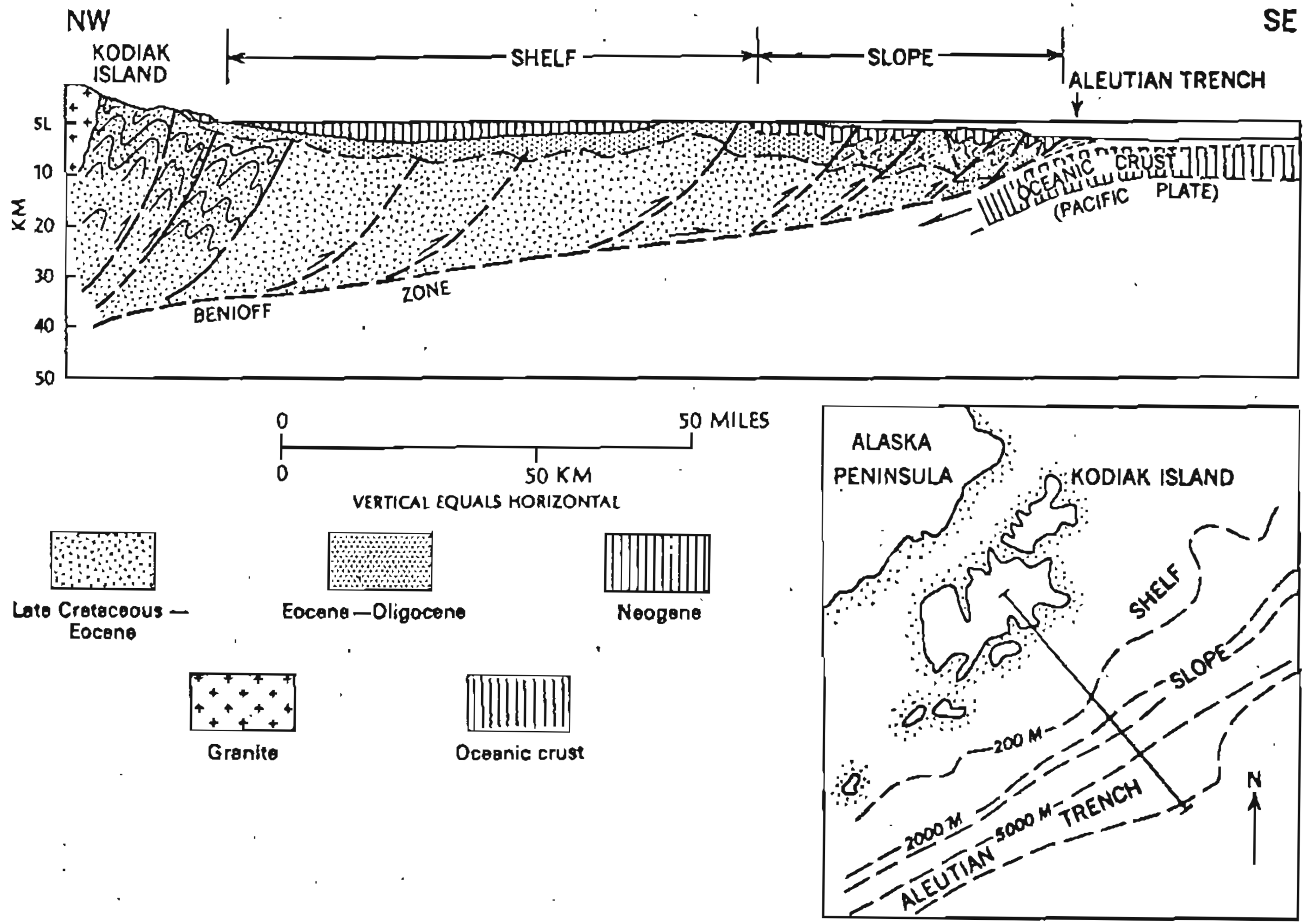

NW
SE
KODIAK ISLAND
SHELF
SLOPE
ALEUTIAN TRENCH
SL
10
20
30
40
50
KM
OCEANIC CRUST
(PACIFIC PLATE)
BENIOFF
ZONE
0
50 MILES
0
50 KM
VERTICAL EQUALS HORIZONTAL
Late Cretaceous — Eocene
Eocene—Oligocene
Neogene
Granite
Oceanic crust
ALASKA PENINSULA
KODIAK ISLAND
SHELF
SLOPE
200 M
2000 M
5000 M
ALEUTIAN TRENCH
N

FIG. 13.

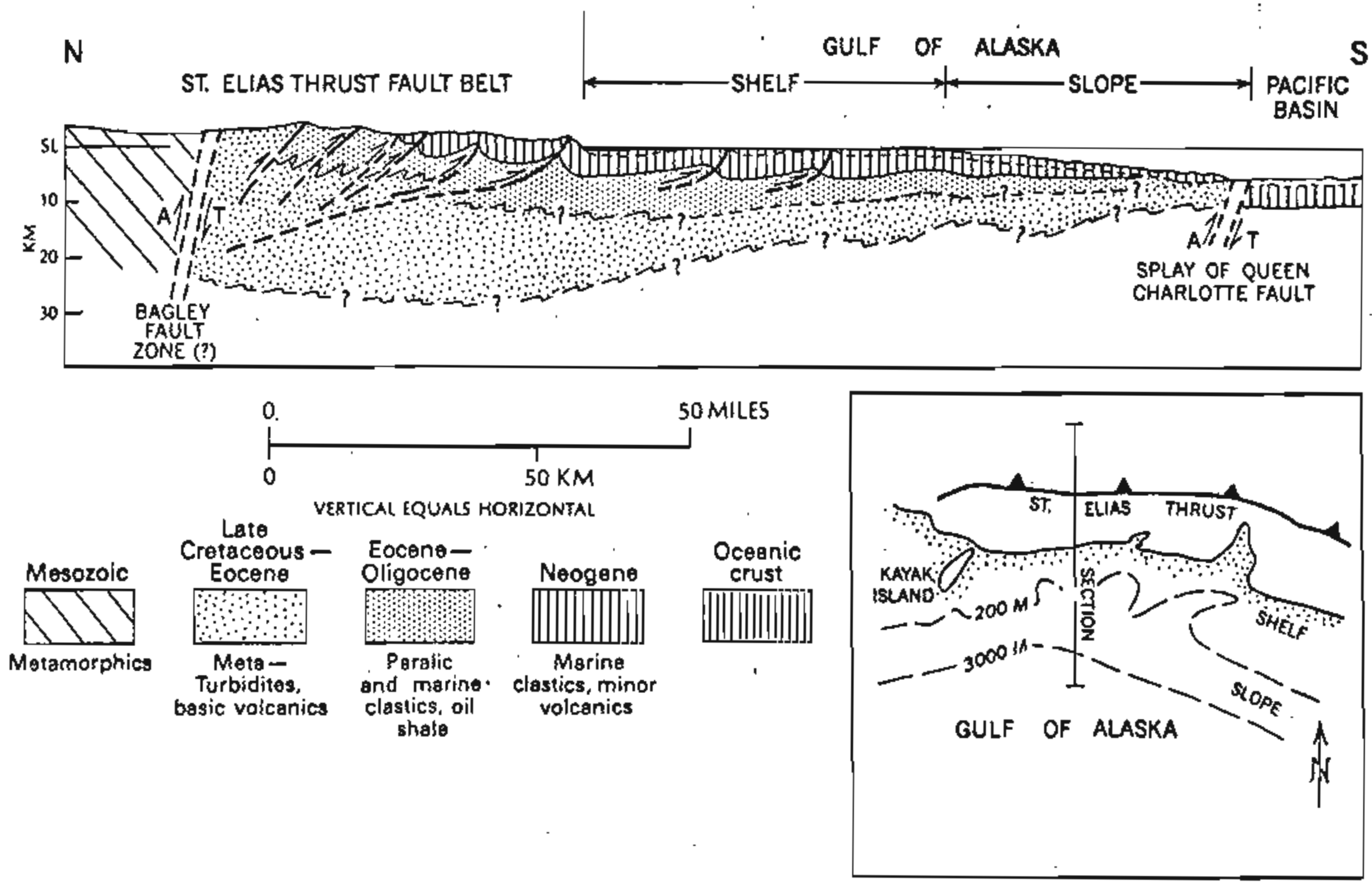

N
S
GULF OF ALASKA
ST. ELIAS THRUST FAULT BELT
SHELF
SLOPE
PACIFIC BASIN
SL
10
20
30
KM
A
T
BAGLEY FAULT ZONE (?)
SPLAY OF QUEEN CHARLOTTE FAULT
0
50 MILES
0
50 KM
VERTICAL EQUALS HORIZONTAL
Mesozoic
Metamorphics
Late Cretaceous — Eocene
Meta — Turbidites, basic volcanics
Eocene — Oligocene
Paralic and marine clastics, oil shale
Neogene
Marine clastics, minor volcanics
Oceanic crust
ST. ELIAS THRUST
KAYAK ISLAND
SECTION
200 M
3000 M
SHELF
SLOPE
GULF OF ALASKA
N

FIG. 14.