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PETROLEUM GEOLOGY AND HYDROCARBON PLAYS OF THE GULF OF ALASKA ONSHORE PROVINCE: A REPORT FOR THE NATIONAL HYDROCARBON ASSESSMENT PROGRAM

by

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ABSTRACT

Thick Cenozoic sedimentary rocks are present in the Gulf of Alaska Onshore Province and contiguous offshore lying between Cross Sound and the Ragged Mountain Fault in the northern Gulf of Alaska. A small oil field at Katalla produced 154,000 barrels of oil from these rocks between 1902 and 1933. Yet, despite subsequent moderately extensive hydrocarbon exploration efforts onshore and in the adjacent offshore basin areas, no commercial hydrocarbon field has been discovered. The attributes necessary for a hydrocarbon province are present, including extensive onshore oil and gas seeps, numerous anticlinal traps, good organic-carbon content in potential source rocks, and at least some sections with potential reservoir rocks. Major reasons for lack of successful discoveries include the young age and complexity of the structures, the poor potential of a thick late Cenozoic covering sequence, the Yakataga Formation, and a lack of thermal maturity and reservoir rocks in the early Tertiary sections thus far tested by drilling. Although the resource potential of the area based on the unsuccessful drilling results must at present be considered as low, some unexplored targets remain to be tested.

INTRODUCTION

The purpose of this report is to describe the petroleum geology and hydrocarbon plays of the Gulf of Alaska Onshore Province, which includes the onshore and state offshore parts of the Cenozoic basin lying onshore between Cross Sound and Prince William Sound in the northern Gulf of Alaska (Figure 1). The province includes rocks underlying mainland Alaska and the contiguous islands. The onshore Cenozoic basin has been termed the Gulf of Alaska Tertiary Province (Miller and others, 1959; Stoneley, 1967; Plafker, 1967, 1971), and the term has been extended to include Cenozoic rocks underlying the entire continental margin between Cross Sound and Montague Island (Plafker, 1987). For resource assessment purposes, Dolton and others (1981) called the onshore regions the Gulf of Alaska Onshore Province, and that term is also used herein.

The onshore Cenozoic basin lies eastward of the Ragged Mountain fault and seaward of the Chugach-Saint Elias and Fairweather faults (Figures 1 and 2). The region consists of coastal lowlands from 0 to 40 km wide covered by alluvium and glaciers, and backed by coastal foothills, and the steep and high (to 5,000 m) Chugach and Saint Elias Mountains. Cenozoic rocks form a band up to 10 km wide band along the shoreline near Lituya Bay, have been sampled in exploratory wells near Yakutat Bay and beneath the adjacent coastal plain (the Yakutat Foreland), and outcrop in an up to 70 km wide area of the coastal plain and foothills from about Yakutat Bay to the Ragged Mountain fault (Figure 2). The area underlain by Cenozoic rocks onshore is about 18,750 km^2 of a total Cenozoic basin area (onshore plus offshore) of about 71,200 km^2 (Plafker, 1987). Oil and gas seeps have long been known in these Cenozoic rocks, and have fueled a long, but largely unsuccessful exploration effort. Pre-Cenozoic rocks have little or no petroleum potential and are discussed only briefly.

Middleton Island (Figures 1 and 2) is also included within the Gulf of Alaska Onshore Province. Middleton Island lies at the edge of the Middleton shelf about 100 km southwest of Kayak Island, the nearest outcropping section of the Yakutat terrane, and about 90 km from the entrance to Prince William Sound. The island is about 8 km long by 1.5 km wide, with maximum relief of about 38 m; shoal areas (water less than 10 m deep) make the island platform about 7.5 km long by 3.3 km wide. Rocks beneath the island were sampled in an exploratory well in 1969, but no commercial oil or gas was found. No hydrocarbon seeps are known on the island. Thus, the hydrocarbon potential of the small area around Middleton Island that would be included within the Gulf of Alaska Onshore Province must be considered as negligible at present. For this reason, the region around Middleton Island is considered only briefly herein.

TECTONIC SETTING

Paleozoic through Cenozoic age rocks underlie southern Alaska and form fault-bounded tectonostratigraphic terranes that assembled into their present positions in the Cretaceous and and Cenozoic (Figure 1; Jones and others, 1986). The terranes bordering the Gulf of Alaska are, from north to south, (1) the Peninsular, Wrangellia, and Alexander terranes, (2) the Chugach terrane, (3) the Prince William terrane, and (4) the Yakutat terrane. Plafker (1987) also defines a new terrane, the Ghost Rocks terrane, that forms a thin sliver between the Chugach and Prince William terranes, but which is here included with the Chugach terrane.

The Peninsular, Wrangellia, and Alexander terranes lie north of the Border Ranges Fault and are composed of Mesozoic and older, variably metamorphosed rocks intruded by a variety of plutonic rocks of Paleozoic and younger age. These terranes are comprised mainly of oceanic plateaus and arcs, were accreted to North America prior to the Cenozoic, and formed the backstop against which the seaward terranes have accreted.

The Chugach terrane lies between the Border Ranges Fault and the Contact fault system and is present in an arcuate belt throughout the Gulf of Alaska (Plafker and others, 1977). The terrane is an accretionary assemblage composed primarily of deformed and metamorphosed Late Cretaceous volcaniclastic flysch and oceanic basalt of the Valdez Group in the northern Gulf of Alaska, and the Ghost Rocks, Kodiak and Shumagin Formations along the Alaska Peninsula. These rocks were accreted to Alaska in the late Cretaceous and early Tertiary. An interpretation of paleomagnetic data suggests that the Chugach terrane originated well south of its present position and has migrated as much as 40^{0} northward (Plumley and others, 1983).

The Prince William terrane lies between the Contact fault system and the Aleutian Trench, and is bounded on its north end by the Ragged Mountain fault, the Chugach-Saint Elias fault system, and the Kayak zone. Onshore, the terrane forms an outcrop belt as much as 100 km wide consisting of rocks of the Orca Group, an accreted, deformed and metamorphosed late Paleocene and Eocene deep-sea-fan and oceanic rocks assemblage (Winkler, 1976; Winkler and Plafker, 1981b; Helwig and Emmett, 1981; Nelson and others, 1985; Dumoulin, 1987; 1988). The Orca Group is intruded by 50 m.y. old plutons in the western Prince William sound, indicating accretion by the middle Eocene; the eastern rocks of the group may be as young as late Eocene (Plafker and others, 1985) and may have accreted in the late Eocene (Dumoulin, 1987). Dumoulin (1987, 1988) interprets the rocks of the Valdez and Orca Groups as forming a continuous succession of strata which originated from the increasingly deep erosion and dissection of a volcanic arc sequence.

Offshore, rocks of the Orca Group presumably underlie an up to 4 km thick sequence of Cenozoic clastic sedimentary rocks beneath the Middleton segment of the continental margin (Bruns, 1985a). The youngest rocks of this sequence, part of the Yakataga Formation, outcrop on Middleton Island (Plafker, 1971, 1987), and rocks as old as Eocene were sampled beneath the island in a well on state lands near Middleton Island (Keller and others, 1984).

The terrane migration history of the Prince William terrane is unclear. Geologic data (Winkler and Plafker, 1981a; Plafker, 1987) and paleontologic data from the well at Middleton Island indicate no significant northward transport of Eocene strata (Keller and others, 1983, 1984; von Huene and others, 1985), but microfauna from the Orca Group have tropical affinities that suggest northward transport (Plafker and others, 1985). Paleomagnetic data are similarly inconclusive (Plumley and Plafker, 1985; Hillhouse and Gromme, 1977).

The Yakutat terrane lies eastward of the Kayak zone and the Ragged Mountain fault, and seaward of the Chugach-Saint Elias fault system and the Fairweather fault. The terrane is presently moving with the Pacific plate, and colliding with and subducting beneath southern Alaska along the Kayak zone and Ragged Mountain and Chugach-Saint Elias fault systems, with transform motion taken up along the Fairweather fault (Rogers, 1977; Plafker and others, 1978; Lahr and Plafker, 1980; von Huene and others, 1979; Plafker, 1983, 1987; Bruns, 1983a, b, 1985a; Stephens and others, 1984). A major fold and thrust fault belt onshore and offshore in the west and northwest parts of the terrane is a result of the collision process (Figure 2).

Basement rocks of the terrane consist of Paleocene(?) and early Eocene probable oceanic basalt west of the Dangerous River zone (Figures 1 and 2), and a Mesozoic flysch and melange sequence, the Yakutat Group, to the east. The basement is overlain by as much as 5 km of Paleogene strata that onlap older strata along the Dangerous River zone and are truncated at the Dangerous River zone and at the continental slope. The Dangerous River zone is probably a paleoslope, and possibly a paleo-subduction zone, that marks the Paleogene basin edge (Bruns, 1983b, 1985a). The Paleogene strata west of the Dangerous River zone and basement rocks to the east are in turn overlain by up to 5 km of late Miocene and younger strata of the glaciomarine Yakataga Formation (Bruns 1983a, b, 1985a; Bruns and Schwab, 1983). Except at Middleton Island, the potentially petroliferous onshore sedimentary rocks are entirely in the Eocene through Miocene strata of the Yakutat terrane.

The origin and movement history of the Yakutat terrane is at present controversial, with agreement only that the terrane is allochthonous, and that it is at present moving primarily or possibly entirely with the Pacific plate. Plafker (1983, 1987), primarily citing an igneous and high-grade metamorphic provenance for Paleogene sandstones of the Yakutat terrane, favors a model with about 5^{o} of northward transport, in which the terrane originated off British Columbia and southern Alaska, and has been in roughly its present position with respect to southern Alaska since the early Miocene. Limited paleomagnetic data from an offshore well in the terrane suggest an early middle Eocene location off the Oregon-Washington border and about 13^{o} of northward transport (Van Alstine and others, 1985). Keller and others (1983, 1984) and von Huene and others (1985) used microfaunal evidence to propose an origin for at least part of the terrane 30^{o} south of the present position. Bruns (1983a; 1985a), citing geophysical evidence plus the microfaunal evidence of Keller and others (1983, 1984), proposed that the terrane has been locked to and moving with the Pacific plate since the late Eocene or Oligocene. He speculates that the oceanic part of the terrane (the part southwest and west of the Dangerous River zone) originated 30^{o} south of the present position, and that a composite oceanic-continental terrane (adding the continental part east of the Dangerous River zone) developed off Oregon and Washington. The proposed origin models for the terrane have provoked considerable discussion (Plafker, 1984, 1987; Wolfe and McCoy, 1984; Chisolm, 1985; Bruns, 1984, 1985a, b; Bruns and Keller, 1984), and additional studies are necessary to derive a well-tested and documented solution.

With respect to the resource potential, the importance of the Yakutat terrane origin models is in determining the source terrane for the Paleogene strata, and in the timing of source rock maturation. Source terranes for sedimentary rocks of the terrane could range from Oregon and Washington to southern Alaska, making the basins of these areas possible analogs to the sedimentary rocks on the Yakutat terrane. Maturation of source rocks within the Paleogene strata may be largely dependant on burial by the Yakataga Formation, deposited as a result of uplift and erosion of the Chugach and Saint Elias mountains during collision of the Yakutat terrane with southern Alaska. If collision started in the early Miocene, then potential source rocks would have been buried earlier and would have had a significantly longer time to generate hydrocarbons than if the collision started in the late Miocene.

In the following description of the stratigraphy and structure of the Gulf of Alaska Onshore Province, the Yakutat and Prince William terranes are considered separately.

YAKUTAT TERRANE

Stratigraphy

Basement rocks of the Yakutat terrane consist of the Mesozoic Yakutat Group which forms basement east of the Dangerous River zone, and Eocene oceanic basalt to the west of the zone. The Yakutat Group outcrops southwest of and adjacent to the Fairweather fault. Cenozoic sedimentary rocks overlie the basement, and are broadly divisible into three subdivisions which correspond to changes in the depositional environment and tectonics of the basin. These are (1) upper Paleocene and Eocene continental to marine clastic coal-bearing strata, (2) Oligocene and Miocene marine clastic, glauconitic, and basaltic strata, and (3) Miocene through Quaternary marine and glaciomarine clastic strata (Figures 3, 4). Deep water equivalents of the onshore rocks have been sampled offshore (Plafker, 1987). The following brief descriptions concentrate on the onshore facies and are summarized primarily from Plafker (1971; 1987). Details are presented in Miller (1951, 1957, 1967a, b, c, d, e, 1971, 1975), Miller and others (1959), Stoneley (1967), Plafker (1967, 1971, 1974, 1987), Plafker and Miller (1957), Plafker and Addicott (1976), Addicott and others (1978), Winkler and Plafker (1981a, b), Helwig and Emmett, 1981; Rau and others (1983), Larson and others (1985a, b), and references contained therein.

Pre-Tertiary rocks

The Mesozoic Yakutat Group consists of highly deformed and locally metamorphosed flysch and melange, and is intruded by Eocene plutons. The Yakutat Group underlies the coastal mountains southwest of the Fairweather fault, is present at shallow depth beneath much of the Yakutat Foreland (the onshore coastal plain southeast of Yakutat Bay), and has been sampled offshore along Fairweather Ground (Plafker 1967; 1987, Plafker and others, 1977; Larson and others, 1985a, b). These rocks are not known to extend southwestward of the Dangerous River zone. The Yakutat Group rocks have no resource potential.

Paleocene through Oligocene basalt and sedimentary rocks

An early to middle Eocene basalt and marine sedimentary section is present in the Samavor Hills, a nunatak in the Malaspina Glacier northeast of Icy Bay (Figures 2-4). The basalt is apparently correlative with a thick offshore basalt unit that was extensively sampled by dredging on the continental slope (Plafker 1987).

The bulk of onshore early Tertiary strata consist of: (1) a siltstone and arkosic sandstone prodelta unit, the Stillwater Formation; (2) thick, interfingering coal-bearing, alluvial-plain, delta-plain, barrier-beach, and shallow marine deposits of the Kulthieth Formation; and (3) a deltaic marine equivalent, the Tokun Formation (Figures 3, 4). These units crop out from Yakutat Bay to the Ragged Mountain Fault. The units were deposited along an east-west trending shoreline, with the continental Kulthieth Formation intertonguing southward and westward with the marine Tokun Formation, and westward with the Stillwater Formation. Both the Stillwater and Tokun formations thin along strike to the east. The maximum thickness of the Stillwater, Kulthieth, and Tokun formations is about 3,000 m, 2,800 m, and 1,000 m respectively.

Oligocene through Miocene sedimentary rocks

These rocks include the the Poul Creek Formation, which is exposed between Icy Bay and the Ragged Mountains, and the Cenotaph Volcanics and Topsy Formation which are present in a small basin between Lituya Bay and Cross Sound (Figures 2-4). The Cenotaph Volcanics and Topsy Formation are an up to 750 m thick sequence of interfingering continental and marine volcaniclastic strata. The Poul Creek Formation is comprised of up to 1,860 m of shallow-to deep-water marine strata composed of predominantly shaley sediment, in part organic-carbon rich, characteristically glauconitic and intercalated with basaltic tuff, breccia, and pillow lavas. Glauconites were derived primarily by alteration of basalt fragments.

Rocks of the Poul Creek Formation were penetrated in wells drilled along the coast (Plafker, 1967; Rau and others, 1983; Larson and others, 1985a, b). Equivalent rocks were also sampled in dredge hauls from the continental slope (Plafker, 1987) and are present in wells drilled on the adjacent outer continental shelf (Herrera, 1978; Jones 1979; Lattanzi, 1981).

The youngest age of the Poul Creek Formation is variably defined. Plafker (1987) gives a youngest age of early Miocene. However, in one of the offshore wells, rocks identical to those of the Poul Creek Formation are of late Miocene and early Pliocene age (Lattanzi, 1981). Other workers note a middle Miocene hiatus within the Poul Creek Formation, and have found that the top of the formation at Cape Yakataga is of late Miocene age (Ariey, 1978; Lagoe, 1978, 1983; Armentrout and others, 1978; Armentrout, 1983; Larson and others, 1985a, b), although Plafker (1987) disagrees.

Miocene and younger sedimentary rocks

Rocks of Miocene and younger age comprise the Redwood and Yakataga Formations, and form thick sections overlying the older rocks (Figures 3, 4). The Redwood Formation, 1,130 m thick, consists of nonglacial clastic sediments with abundant conglomerate, and is found only in the Katalla area. The Yakataga Formation is widely distributed onshore and underlies much of the continental shelf and slope, with maximum thicknesses reaching about 5,500 m just offshore between Icy Bay and Yakutat Bay. The formation consists of interbedded siltstone, mudstone, and sandstone which predominates in the lower part of the section, and till-like diamictite which becomes the dominant rock type in the upper part of the formation. Conglomerate and dropstone clasts are present throughout the unit. The dropstones and diamictite are interpreted as indicating glaciomarine sedimentation and proximity to tidewater glaciers and ice rafting (Plafker and Addicott, 1976).

Plafker (1987) and Plafker and Addicott (1976) give an age range of late Oligocene(?) through Quaternary for the Yakataga Formation, based mainly on megafauna correlations. A diversity of opinion about the age of the Yakataga Formation exists however, and other studies using microfauna suggest a late Miocene age for the base of the formation and a Pliocene and younger age for the bulk of the formation (Ariey, 1978; Lagoe, 1978, 1983; Lattanzi, 1981; Armentrout, 1983; Armentrout and others, 1978; Keller and others, 1984; Larson and others, 1985a, b). The importance of the age for resource potential considerations is that the initial deposition of the Yakataga formation indicates the end of deposition of strata with good source and reservoir rock potential, and the beginning of burial by the Yakataga Formation of the Paleogene rocks, with possible concurrent maturation and migration of hydrocarbons.

Structure

For convenience of discussing resource potential, the Yakutat terrane Cenozoic basin Cenozoic basin is here divided into three structural provinces. These are: (1) the Lituya Bay region, from Cross Sound to Cape Fairweather, (2) the Yakutat foreland region, from Cape Fairweather to Icy Bay and (3) the Yakataga fold and thrust belt from about Icy Bay to the Ragged Mountain fault and the Kayak zone (Figures 1, 2). The structure of each of these provinces is discussed below, and is summarized from references previously given under the section on stratigraphy plus studies of offshore structure by Bruns (1979, 1983b, 1985a) and Bruns and Schwab (1983). A generalized cross-section across the continental margin shows the structural development of the fold and thrust belt (Figure 5), and cross-sections across onshore regions show details (Figure 6).

Lituya Bay region

The onshore Tertiary section southeast of Lituya Bay (Figure 6) lies seaward of the Mesozoic Yakutat Group rocks along the Fairweather fault, and is deformed into a broad syncline and a small, tightly folded, faulted anticline that lies near and trends subparallel to the coast (Figure 6; Miller, 1961e; Plafker, 1967, 1971, 1987; Stoneley, 1967). The north flank of the anticline is gently dipping, while the south flank is vertical to overturned. Just south of the crest of the anticline is a small thrust fault with limited displacement. Holocene uplift of marine terraces on the seaward side of the anticline indicates ongoing growth. Marked uplift and folding of the basin strata occur at or near the shoreline. Within 3 km of the coast, offshore seismic reflection data show flat-lying strata, and the late Cenozoic section (Yakataga Formation equivalent) reaches its maximum thickness of 4 km (Bruns, 1983b; 1985a), but at the shoreline, the Yakataga Formation crops out with almost vertical dip (Figure 6). Thus a major fault is inferred to lie just offshore of and parallel to the coast, and is associated with significant deformation and vertical displacement. This fault trends southeast into the active offshore segment of the Queen Charlotte-Fairweather fault (Carlson and others, 1979, 1985; Bruns, 1985a; Bruns and Carlson, 1987). The northwest extent of this fault is unknown; Plafker (1987) speculates that the fault extends to connect with active oblique thrust faults that occur on strike in the Yakutat area.

Yakutat foreland region

Tertiary rocks do not outcrop between Cape Fairweather and Yakutat Bay, and the Yakutat foreland, which lies between the outcropping Yakutat Group in the foothills and the coastline, is covered by Quaternary alluvium. The foreland is largely underlain by rocks of the Yakutat Group (Rau and others, 1983; Larson and others, 1985b). However, the Dangerous River zone, across which the Cenozoic basin thickens markedly to the south and southwest, trends onshore near Yakutat Bay, and continues beneath Yakutat Bay and the Malaspina Glacier (Figures 1, 2). Offshore seismic reflection data indicate that the thick Cenozoic section is truncated by faulting and by onlap onto basement rocks, probably of the Yakutat Group (Bruns, 1983b, 1985a). The nearshore area between Yakutat Bay and the Dangerous River is underlain by a rapidly seaward-thickening Cenozoic section, based on drill information (Rau and others, 1983; Larson and others, 1985b). As much as 9 km of Cenozoic strata are present offshore within a few kilometers of the shoreline, of which about 5 km are Yakataga Formation equivalents with the basin axis near the coast (Bruns, 1983b; 1985a). Thus, the nearshore area southeast of Yakutat Bay and the outer parts of both Yakutat Bay and the Malaspina Glacier both overlie the southward dipping and rapidly thickening north flank of the Cenozoic basin. Since the entire onshore segment of the Dangerous River zone is covered by alluvium, water, or ice, no folds or faults have been defined in the Cenozoic section across the zone.

Yakataga fold and thrust belt

The region between Icy Bay and the Ragged Mountain Fault-Kayak zone is characterized by moderately to intensely compressed folds, and by displacement along northward dipping thrust faults (Figures 2, 5, 6). The intensity of folding and the magnitude of displacement along faults increases from south to north. The observed structures consistently show uplift and overthrusting of older, landward formations over younger, seaward formations (Miller, 1957, 1961a-e, 1971; Miller and others, 1959; Plafker and Miller, 1957, Plafker, 1967, 1971, 1987; Stoneley, 1967). The fold and thrust belt has been mapped on seismic reflection data offshore, and extends southwest across the shelf and slope, joining with the Aleutian subduction zone southwest of Kayak Island (Figures 1, 2; Rogers, 1977; Bruns, 1979, 1985a; Bruns and Schwab, 1983). The deformation front marking the transition from relatively undeformed strata to the east to the deformed rocks of the fold belt is termed the Pamplona zone (Figures 1, 2; Rogers, 1977; Plafker and others, 1978b). The degree of deformation offshore is less than onshore and is dominated by broad synclines and anticlines that trend generally northeastward (Bruns and Schwab, 1983).

The structure of the onshore Cenozoic strata from Yakutat Bay to Kayak Island includes east-west trending synclines and thrust-faulted anticlines (Figures 2, 5, 6). The principle faults in the area expose increasingly older and more deformed rocks at the surface towards the Chugach-Saint Elias fault. In the coastal region, the structure is characterized by broad synclines and narrow, tightly compressed, asymmetrical, thrust-faulted anticlines. To the north, folds are of smaller, but are of more nearly equal amplitude, are relatively long, and become more intensely folded and faulted than to the south (Miller and others, 1959; Stoneley, 1967; Plafker, 1971, 1987). In the area of Kayak Island and the Ragged Mountain fault, structural trends are more northerly to northeasterly than to the east. Folds are typically of small amplitude, tightly compressed, and asymmetric or overturned to the southeast (Winkler and Plafker, 1981a). Kayak Island is cut into narrow, fault-bounded slices by displacement on at least five large up-to-the-northwest reverse faults (Plafker, 1974). In the Katalla region, folds are typically of small amplitude, tightly compressed, and asymmetric, with the axial plates inclined to the west or north. The amount of shortening onshore due to structural deformation is variously estimated as about 30 to 40 percent by Stoneley (1967), as 25 percent in Lathram and others (1974), and as 45 percent in the Paleogene strata and less than 25 percent in the late Cenozoic units by Plafker (1987).

PRINCE WILLIAM TERRANE (MIDDLETON ISLAND REGION)

Stratigraphy

The onshore, and much or possibly most of the offshore parts of the Middleton shelf part of the Prince William terrane are underlain by the Orca Group, which constitutes both acoustic basement for seismic reflection data and economic basement for petroleum exploration. Orca Group rocks are presumed to form the basement beneath Middleton Island, but have not been sampled by either the Tenneco Middleton Island well near Middleton Island or by dredging on the nearby slope. Sedimentary rocks overlying basement form a basin at least locally 5 km thick beneath the Middleton shelf and slope. The sequence is known only from Middleton Island and from the Middleton Island well. About 1,100 m of Quaternary strata of the Yakataga Formation are exposed on Middleton Island (Plafker, 1987), and are equivalent to strata exposed in the upper part of the Middleton Island well. The lower part of the drilled section, from 890 to 3,658 m, includes strata from late middle Eocene through latest

Oligocene or early Miocene age. Foraminifera indicate deposition of these strata occurred in lower to middle bathyal water depths (greater than 1,500 m). The upper part of the well, shallower than 700 m, consists of strata of late Miocene to Pleistocene age (undifferentiated) deposited in upper bathyal to neritic water depths (1,000 to 300 m). A hiatus is present between the early and late Miocene strata (Rau and others, 1983; Keller and others, 1984).

Dredging along the lower continental slope sampled indurated siltstones and sandstones with Paleogene palynomorphs and Eocene foraminifera; however these assemblages may be reworked. Pliocene and Quaternary strata were also sampled during dredging (Plafker, 1987).

Structure

Middleton Island lies on a faulted structural high at the edge of the shelf. The island has undergone Holocene northwestward tilting of as much as 28°, faulting, and earthquake-related Holocene tectonic uplift at a rate that averages close to 1 cm/yr and continues to the present time. However, dipmeter data from the well show moderate dips and suggest that a fault may lie between the island and the well (Plafker, 1987). Seismic reflection data around the island (Bruns, 1985a) show generally uncomplicated structure towards the continental slope, where gently seaward-dipping, late Cenozoic strata thicken to at least 3 km beneath the upper slope east and northeast of the island. Northwest of the island lies a complex, tightly folded and faulted northeast-trending anticline; Fountain Rock, an exposed reef about 7 km northwest of the island, lies at the crest of this anticline. To the west and southwest of the island lies a basin with at least 5 km of late Cenozoic fill.

PETROLEUM GEOLOGY

History

Abundant oil and gas seeps first directed attention to the petroleum possibilities of the onshore Cenozoic rocks in the northern Gulf of Alaska. A small field at Katalla (Figure 7) was developed in a fractured shale reservoir in the Poul Creek Formation, and about 154,000 barrels of oil were produced between 1902 and 1933. Twenty-five other wells and core holes were drilled and abandoned between 1954 and 1963 in onshore Cenozoic rocks, and one offshore well was drilled and abandoned in 1969 on state lands near Middleton Island. Information on the seeps and wells is summarized in Miller and others (1959; lists wells in Katalla region), Plafker (1971, lists onshore wells other than at Katalla), Plafker (1987, lists offshore wells), Plafker and others (1975, 1978a), Blasko (1976; describes seeps), Rau and others (1983), Keller and others (1984), and Larson and others (1985a, b). The only recent exploration activity onshore began in 1986 when the Alaskan Crude Corporation began activities to reactivate the Katalla field. As of early 1988, all activities were suspended on this operation.

Offshore, a stratigraphic test well was drilled on the continental shelf southwest of Cape Yakataga in 1975, but was terminated in Pleistocene strata at a depth of 1570 m (Bolm and others, 1976). After Federal oil and gas lease sale no. 39 in 1976, ten offshore wildcat wells were drilled and abandoned between Icy Bay and Kayak Island (Figure 7), with no discoveries of commercial oil or gas. A second lease sale, no. 55, was held for lands between Cross Sound and Icy Bay in 1980, and a reoffering sale was held in 1981. A test well was drilled on the largest structure in this region in 1983, and encountered no oil or gas in commercial quantities, although some oil and gas shows were reported. Most of the offshore wells failed to penetrate through the thick Yakataga Formation; however, at least 5 penetrated into the Paleogene rocks or the Poul Creek Formation (Plafker and others, 1978a; Lattanzi, 1981; Bruns and Plafker, 1982; Bruns, 1983b; Bruns and Schwab, 1983; Larson and others, 1985a; and Plafker, 1987). No offshore drilling has taken place on the continental margin since 1983, and most of the offshore leases have been allowed to expire. The petroleum industry exhibits little active interest in further exploration of the region at present.

Yakutat terrane

<u>Source rocks</u>

Rocks with favorable hydrocarbon source-rock characteristics are present in the Stillwater, Kulthieth, Tokun, and Poul Creek Formations onshore (Palmer, 1976; Plafker, 1987) and in Eocene and

Oligocene strata offshore (Plafker and Claypool, 1979; Plafker and others, 1980, Bruns and Plafker, 1982; Plafker, 1987). Organic matter in these rocks is predominantly herbaceous, with subordinate amounts of woody and amorphous kerogen. Total organic-carbon content ranged from 0.42 to 1.87 percent and was commonly greater than 1 percent in selected organic-rich samples from the Samovar Hills, Kayak and Wingham Islands, and Katalla, including as much as 6.6 percent organic carbon in Oligocene rocks from Kayak Island. The kerogen is of a type that can generate both liquid hydrocarbons and gas.

Two petroleum systems are present in the Gulf of Alaska Tertiary rocks, the Poul Creek system and the Stillwater-Kulthieth-Tokun system (Feux, in press; L.B. Magoon, oral communication, 1988). Based on oil-source rock correlations (Feux, in press), oil from the Katalla field was generated from source rocks in the Poul Creek Formation. However, petroleum from onshore seeps elsewhere, and extractable hydrocarbons in the dredge samples from the Yakutat slope are all similar in composition, are different from petroleum in the Poul Creek Formation, and are from source rocks in the Stillwater-Kulthieth-Tokun assemblage and its offshore correlative rocks (Plafker and Claypool, 1979; Plafker, 1987). Thus, source rocks are present throughout the thick Eocene and Oligocene strata of the Yakutat terrane, and these source rocks have generated the oils found onshore.

Samples from the late Cenozoic Yakataga Formation are low in organic carbon with values rarely greater than 0.5 percent and most in the range of 0.2 to 0.3 percent. These rocks therefore have unfavorable source rock characteristics (Plafker and others, 1980; Bruns and Plafker, 1982; Plafker, 1987).

Thermal maturity

Indicators of thermal maturity show that Eocene rocks are the only rocks, onshore or offshore, that are known to be mature or marginally mature. Onshore Eocene rocks are immature to marginally mature between Icy Bay and Yakutat Bay and can be mature or overmature west of Icy Bay (Mull and Nelson, 1986; Plafker, 1987). Most of the offshore dredge samples of Eocene age were immature to marginally mature (Plafker and Claypool, 1979; Plafker, 1987). The present heat flow regime is relatively cool, with the geothermal gradient estimated as lying between about 20^{o}C/km and 30^{o}C/km based on temperatures measured in wells (Bruns, 1983b; Bruns and Plafker, 1982). Paleogene rocks beneath the continental shelf are buried deeply enough that, based on these limits for the geothermal gradient, from 25 to 70 percent of these rocks could be mature enough to generate oil or gas which could then migrate updip into the onshore rocks (Bruns, 1983b). Plafker (1987) speculates that maturation of the sampled Eocene rocks may have occurred shortly after deposition, caused by a regionally high heat flow regime during the Eocene possibly related to subduction of the Kula spreading ridge. Evidence for a regional heating event is the widespread occurrence of the Eocene basalts offshore and of Eocene granitic plutons onshore within the rocks of the Yakutat Group.

The abundant seeps onshore may reflect migration of already generated oils, hydrocarbon generation within the deeply buried Paleogene rocks of the basin, or generation within Paleogene rocks being thrust deeply beneath southern Alaska as part of the Yakutat terrane collision process. Since the onshore rocks are all up-dip from the offshore basin, any hydrocarbons generated beneath the continental shelf could migrate up-dip into the onshore sections. Generation, expulsion, and migration of hydrocarbons from Paleogene strata could have occurred during burial of these rocks beneath the thick Yakataga Formation during the late Cenozoic. The Paleogene rocks are also being thrust beneath southern Alaska along the faults of the Kayak zone, the Ragged Mountain fault, and the Chugach-Saint Elias fault. Both generation of hydrocarbons and expulsion along fault planes could be occurring as a result of the underthrusting.

Identification of source rocks within the Paleogene section means that the entire onshore region adjacent to the thick Paleogene section along the Dangerous River zone, and between Icy Bay and the Ragged Mountain fault must be considered as prospective for hydrocarbons. Generated oil and gas could migrate updip into the onshore sections from the offshore basin.

Reservoir rocks

Samples from onshore wells and outcrops of Tertiary sandstones that might be reservoirs for petroleum have been studied by Winkler and others (1976) and Lyle and Palmer (1976) and are reviewed by Plafker (1987). In general, sandstones are fine to medium grained and range in composition from feldspathic to lithofeldspathic, with 21 to 26 percent lithic fragments, dominantly plutonic or volcanic. The sandstones are compositionally and texturally immature, with many unstable rock and mineral fragments. Sands with good porosity and permeability are present, but not abundant, and pore space has been considerably reduced by diagenetic affects.

For major units onshore, the approximate percentage of sandstone, thickness range, porosity range, and permeability range are as follows (Winkler and others, 1976; Lyle and Palmer, 1976):

Formation	*Percent Sandstone*	*Thickness Range (m)*	*Porosity Range (%)*	*Permeability Range (md)*
Kulthieth, Tokun	60	15-600	1.8-22.7	0-43
Poul Creek	1-30	15-350	2.2-19.2	0-12
Yakataga, Redwood	9-53	15-490	1.2-32.2	0-597

The Paleogene sands were apparently derived from nearby source areas, as the sands were well-washed when deposited and deposition was rapid. Induration and diagenesis are responsible for loss of good reservoir characteristics. Diagenetic alteration of framework grains throughout the section has produced widespread zeolite cement or phyllosilicate grain coatings and pseudomatrix. The sands have also been strongly deformed during burial and diagenesis, causing extensive grain alteration and interpenetration, and resulting in further reduction of porosity and permeability (Plafker, 1987).

The Yakataga Formation sands are more poorly sorted in general than the older sands, and unstable grains and primary matrix are more abundant. Unstable framework grains have undergone considerable alteration in even the youngest rocks, reducing porosity. The sandstones are commonly tightly encased in fine-grained strata, and thus largely inaccessible, except by faulting, for hydrocarbons migrating upwards from the buried Paleogene source rocks. The Yakataga Formation samples with good porosity and permeability are well above the base of the section, and thus well removed from the potential source rocks.

Traps

The primary traps for hydrocarbons are the large anticlinal structures of the fold and thrust belt of the western Yakutat terrane (Figure 7). Exploration wells drilled in the northern Gulf of Alaska, both onshore and offshore, have primarily tested these structures. In most of these wells, either the structure within the anticlines was complex, or the wells failed to penetrate through the thick late Cenozoic section. Especially onshore, folding and faulting within the anticlines probably prevented the structures from being an effective trap. Offshore, the wells which penetrated into the underlying, prospective Paleogene rocks, were unsuccessful at least in part because of immature source rocks and relatively poor reservoir quality. Paleogene rocks may only now be approaching maturity, and possibly few or no hydrocarbons have been generated that could migrate into the late Cenozoic structures either onshore or offshore. Also, the hydrocarbons observed in the onshore seeps may result from generation during underthrusting, with migration up the fault planes. In this case, offshore anticlines may be only poorly connected by a migration path to the regions where hydrocarbons are being generated.

Nonetheless, the large anticlines must still be regarded as potential traps. Traps may be found in parts of the anticlines that are untested, or structures may still be present which are untested. Especially onshore, if closed structural traps can be found, hydrocarbons are presumably present to fill them. Also, stratigraphic or fault traps may be present within the fold belt. None of these subtle kinds of traps have as yet been explored for or tested, except perhaps incidently during drilling of the major anticlines.

Another region with significant, but largely unexplored, trap potential is the Dangerous River zone. The onshore segment of this feature may have structural or fault traps, and stratigraphic traps could be present where the Paleogene section onlaps the underlying basement Mesozoic melange or early Tertiary basalt. This zone has been partially tested with wells on both sides of Yakutat Bay (Colorado Oil and Gas Yakutat Numbers 1, 2, and 3 near Yakutat, and the Colorado Oil and Gas Malaspina 1-A well on the west side of Yakutat Bay; Rau and others, 1983; Larson and others, 1985a, b). The Dangerous River zone may contain potential traps nearshore between the Dangerous River and and Yakutat Bay, beneath Yakutat Bay, and beneath the Malaspina Glacier between Yakutat Bay and Icy Bay.

The Lituya Bay region has at best only minor trap potential. The onshore anticline could have either structural or trap closure. Offshore traps could occur with fault closure or stratigraphic traps in the late Cenozoic section along the Icy Point-Lituya Bay fault. However, this area has limited potential for charging any existing traps because of an apparent lack of Paleogene source rocks onshore or in the adjacent offshore basin.

Prince William terrane (Middleton Island region)

Little is known of the hydrocarbon attributes of rocks underlying the Middleton Island region, despite the presence of the Middleton Island well. Direct evidence of lithology, organic carbon content, thermal maturity, and reservoir rock potential is not available from the well. Stratigraphic correlations in Larson and others (1985a) and Plafker (1987) correlate the stratigraphy of the Yakutat terrane into the Middleton Island well. In this case, the source and reservoir rock potential and thermal maturity would be similar to these characteristics as discussed for the Yakutat terrane. The Paleogene rocks beneath Middleton Island could contain good source rocks, but could be lacking thermal maturity and reservoir potential.

Alternatively, since the Middleton Island region lies on the Prince William terrane, the Eocene and Oligocene rocks beneath the shelf could have a very different source terrain and depositional environment from the Yakutat terrane rocks. Such a setting is in part implied by the findings of Keller and others (1984) who find that microfauna from the well indicate a high latitude position when similar age microfauna from the Yakutat terrane are at a much warmer, lower latitude position.

In this case, the source and reservoir rock potential might be more similar to that of the Kodiak shelf to the southwest, which also lies on the Prince William terrane. Studies of six stratigraphic test wells showed low organic carbon content in potential Paleogene source rocks, found that the organic carbon was mainly herbaceous, woody, and coaly, and found that the rocks were immature for petroleum generation (Turner and others, 1987).

Regardless of which model is used, the petroleum potential beneath Middleton Island must be considered as negligible at present, because hydrocarbons were not discovered in the Middleton Island well. Any further drilling in the island area would probably occur only if major discoveries were made on the adjacent lands of the Middleton or Kodiak shelves.

SUMMARY

Rocks are present within the Gulf of Alaska Onshore Province that have characteristics favorable for the generation and accumulation of hydrocarbons. Pre-Cenozoic rocks of the Yakutat terrane (Yakutat Group), and onshore early Tertiary rocks of the Prince William terrane (Orca group) have no resource potential. The Eocene through early Miocene rocks of the Yakutat terrane (Kulthieth, Tokun, Stillwater and Poul Creek Formations and offshore equivalents) are known to have favorable hydrocarbon characteristics including source and reservoir rock potential and thermal maturity. The late Cenozoic Yakataga Formation may have some reservoir potential, but no good source rocks are known within the formation. Hydrocarbons, if present, must migrate into traps in the Yakataga Formation from the underlying early Tertiary rocks. Structures with trapping potential are present throughout the onshore regions, but structural complexity and the young development age of of these structures have apparently prevented commercial accumulations of hydrocarbons in the structures that have so far been tested.

The Middleton Island region, which is considered as part of the Gulf of Alaska Onshore Province here, must be considered as having negligible resource potential. Eocene and younger rocks of the Middleton shelf were sampled by an exploratory well near Middleton Island with unfavorable results

(Keller and others, 1984; Larson and others, 1985a; Plafker, 1971; 1987). Thus, rocks immediately beneath the island and surrounding state lands have probably been adequately tested for petroleum. However, surrounding submarine regions of the Middleton shelf have not been tested.

The failure to discover commercial oil or gas onshore or offshore has dimmed what were once high hopes for petroleum discoveries in the northern Gulf of Alaska continental margin, both onshore and offshore. Major reasons for lack of successful discoveries include the young age and complexity of the structures, the poor potential of a thick late Cenozoic covering sequence (the Yakataga Formation), and a lack of thermal maturity and reservoir rocks in the early Tertiary sections thus far tested by drilling.

However, drilling has perhaps not exhausted either onshore or offshore hydrocarbon prospects. Onshore drilling occurred in the 1950's and 1960's, before modern exploration techniques were developed, and these modern techniques may reveal untested prospects. Offshore drilling has not thoroughly tested large segments of the continental margin. Most of the obvious offshore prospects, the large anticlines between Icy Bay and Kayak Island, were drilled during the 1970's. But only one well has been drilled in rocks between Cross Sound and Icy Bay and potential structural and stratigraphic traps along the Dangerous River zone are untested both onshore and offshore. Similarly, the only drilling that has occurred on the continental shelf between Kayak and Montague Islands is the well drilled on state lands at Middleton Island in 1969. The remainder of the Middleton shelf is unexplored.

Thus, further exploration both onshore and offshore is warrented. Within the basin, source rocks are certainly present, and at depths sufficient to generate hydrocarbons. Structures are present, and numerous faults should provide migration paths into these structures. The successful discovery of hydrocarbons in commercial quantities is largely dependant on finding reservoir rocks and suitable traps at drillable depths in the early Tertiary sedimentary rocks.

At present, the petroleum industry exhibits little active interest in further exploration of the region, and planned Federal offshore lease sales have been cancelled as a result. Although many favorable conditions for hydrocarbons accumulations are present in the Gulf of Alaska Onshore Province, unsuccessful drilling results both onshore and offshore require that, at the present time, the hydrocarbon resource potential of the region must be considered as low.

HYDROCARBON PLAY DESCRIPTION AND CHARACTERIZATION

The Gulf of Alaska onshore province can be broken into five hydrocarbon plays, four of which correspond to the structural provinces outlined above and the fifth of which is a highly speculative play based on underthrusting of the Yakutat terrane rocks beneath southern Alaska. The plays are: (1) Yakataga fold and thrust belt play; (2) Yakutat foreland play; (3) Lituya Bay play; (4) Middleton Island play; and (5) subducting plate play (Figure 7).

All plays have several properties in common. Source rocks lie within the Paleogene and Miocene strata, primarily on the Yakutat terrane (the Stillwater, Kulthieth, Tokun, and Poul Creek Formations and offshore equivalents). The late Cenozoic rocks of the Yakataga and Redwood Formations have little source rock potential. Generation of hydrocarbons could have occurred during a regional Eocene and Oligocene heating event, and could be occurring now with deep burial of the Paleogene rocks by the thick Yakataga Formation or by thrusting of the Paleogene rocks beneath the Chugach and Saint Elias mountains. Early migration of generated hydrocarbons would be into as yet undiscovered traps in the Paleogene rocks, and such traps would not necessarily have an expression in the overlying late Cenozoic rocks. Late Cenozoic generation and migration of hydrocarbons would be into the late Cenozoic structures and would be either up-dip through sands of the Paleogene rocks or along fault planes. Finally, seals for the traps could be fine-grained strata within the Yakataga Formation, or fault gouge clays along fault zones.

All plays also have some negative factors in common. Most of the potential source rocks are immature in onshore and offshore wells and samples. Most of the potential reservoir sands have relatively low porosity due to diagenetic affects such as compaction, post-depositional cementation, low-grade metamorphism, and alteration of unstable grains within the sands. And finally, most of the major structural traps have been tested, although these are primarily late Cenozoic structures. However, even an early Tertiary structure that was tested offshore did not have commercial hydrocarbons. Thus, discovery of commercial hydrocarbons depends on overcoming these generally widespread negative factors.

YAKATAGA FOLD AND THRUST BELT PLAY

Geological characterization

This play lies in the fold and thrust belt that extends from the Ragged Mountain fault-Kayak zone to the Pamplona zone at Icy Bay (Figure 7). Rocks prospective for petroleum exploration are the lower and middle Tertiary rocks; the overlying Yakataga Formation is considered unprospective. Areas west of the Ragged Mountain fault and north of the Chugach-Saint Elias fault are mainly complexly deformed, metamorphosed rocks of the Paleocene and Eocene Orca Group and Late Cretaceous Valdez Group, and have no petroleum potential. The lower Tertiary sedimentary rocks include as much as 4,000 m in the Stillwater (3,000 m maximum thickness), Kulthieth (2,800 m maximum), and Tokun (1,000 m maximum) Formations consisting of Eocene lagoon, barrier beach, and deltaic deposits, and about 1,600 m in the Oligocene and Miocene Poul Creek Formation, consisting of a transgressive sequence of dominantly shaly strata, in part organic rich.

Source rocks

Potential source rocks are present in the Paleogene sedimentary rocks and the Poul Creek Formation. These rocks are immature to mature in outcrop and well samples. Oils from onshore seeps are derived primarily from the Eocene rocks, based on a comparison of the hydrocarbon composition of the seep oils and the extractable hydrocarbons from potential source rocks. Oil in the Katalla region is derived from source rocks in the Poul Creek Formation. Samples from the Neogene and Quaternary Yakataga Formation are low in organic carbon and immature. The Yakataga Formation is therefore not considered a viable source rock.

Generation, migration, and timing

Development of the major onshore and offshore anticlinal traps occurred during Neogene and Quaternary time, and probably dominantly in Pliocene and younger time. Generation and migration of hydrocarbons from the Paleogene rocks is most likely to have occurred during the Neogene, concurrent with burial by the thick Yakataga Formation. Therefore, generated hydrocarbons could migrate into structural traps. Migration of hydrocarbons appears to be largely fault controlled, based on the location of onshore seeps dominantly along faults. Early generation of hydrocarbons in the Paleogene rocks could have occurred, based on evidence for a high local and possibly regional geothermal gradient in the Paleogene.

Reservoir type and quality

Potential sandstone reservoir rocks are present in all the Cenozoic sequences. The sandstones are characteristically poorly sorted, immature and mineralogically unstable. Diagenetic alteration of framework grains has produced widespread zeolite cement and pseudomatrix. Hence permeabilities and porosities in these rocks are generally poor. Production in the Katalla field was primarily at shallow depths and from fracture porosity in the Poul Creek Formation.

Traps and seals

The play area is part of a complexly deformed fold and thrust belt formed by deformation of the allochthonous Yakutat terrane during collision with southern Alaska. Numerous faulted anticlinal traps developed during the late Cenozoic. At least one anticline that developed in the Paleogene or early Neogene is present offshore eastward of the fold and thrust belt; similar traps could have been present in the fold and thrust belt region, and could have been overprinted by the late Cenozoic deformation. Traps could also be formed by structural or stratigraphic closure against faults. Structural complexity is so extreme as to make trap potential unfavorable on many, if not most onshore structures, and may increase with depth. Shales in both the Poul Creek and Yakataga Formations could provide seals for underlying reservoir rocks.

Depth range of objectives

Depth range of the Paleogene age major source and reservoir rocks is from 0 to at least 9 km (maximum observed thickness just offshore).

Exploration status

The play area is moderately explored. The Katalla field, which lies within the area, is the only field in the Gulf of Alaska which has produced commercial oil (about 154,000 barrels between 1902 and 1933). Forty-four wells were drilled on or near this field between 1901 and 1930, all to depths less than 716 m (Miller and others, 1959). Sixteen wells have been drilled elsewhere in the play area, mainly on the major anticlines, to depths as great as 4,480 m (Plafker, 1971). Thus, the most favorable accessible structures have been tested. The failure to find commercial hydrocarbons is a result of the complicated structure, poor reservoir quality, and immature or poor source rocks. Future exploration is justified on the basis of the known presence of oil. Prospects may be largely in hard-to-define traps lying below the surface structures and major thrust faults that cut the region.

YAKUTAT FORELAND PLAY

Geological characterization

The play lies between Icy Bay and Cape Fairweather, seaward of the Fairweather and Boundary faults (Figure 7). The play area includes the regions beneath the ice of the Malaspina Glacier and the waters of Yakutat Bay, and the Yakutat Foreland, the coastal plain between Yakutat Bay and Cape Fairweather. Since the area is covered by ice, water, or Quaternary alluvium, little is known of subsurface structure. That part of the region that lies north or northeast of the onshore continuation of the Dangerous River zone is underlain by rocks of the Yakutat Group; these rocks have been sampled in coreholes east of Yakutat Bay. Tertiary strata dip and thicken seaward along and south of the Dangerous River zone. Seaward of and along the Dangerous River zone continuation, thick sedimentary rocks are present, and are inferred to include equivalents of the Paleogene Stillwater, Kulthieth, and Tokun Formations, the Oligocene and Miocene Poul Creek Formation, and the Miocene and younger Yakataga Formation. Onshore, the Paleogene and Poul Creek Formation strata thin to the east; these strata are as much as 4 km and 1.6 km thick respectively west of Icy Bay, but are not known to be exposed in the Lituya Bay area. The Yakataga Formation is as thick as 4 km at Icy Bay, and also thins to the east. However, just offshore, Paleogene rocks are as thick as 4 km, and Yakataga Formation equivalents are as thick as 5 km. Thus, thick sequences of the Paleogene rocks are likely present beneath the Malaspina Glacier and Yakutat Bay, and have been sampled in wells near the shoreline in both Icy Bay and Yakutat Bay, and near the town of Yakutat.

Source rocks

Source rocks are the same is in the fold and thrust belt play, and would lie in the Paleogene sequence. Rocks of the Cretaceous Yakutat Group and the late Cenozoic Yakataga Formation have no source rock potential.

Generation, migration, and timing

Known or presumed potential traps lie along the Dangerous River zone. This feature developed in the early Tertiary, and traps could have formed either during the initial development or subsequently with deposition of strata against and over the zone. Generation and migration of hydrocarbons could have occurred anytime after deposition of the Paleogene strata, but may have occurred mostly during the late Cenozoic, concurrent with burial by the thick Yakataga Formation. The Dangerous River zone and the entire onshore region lie updip from the offshore basin axis. Thus, hydrocarbons generated in offshore Paleogene rocks during late Cenozoic burial could migrate updip into the onshore region. Some hydrocarbons have been generated; an exploratory well near Yakutat had oil and gas shows, and still leaks a small amount of gas to the surface.

Reservoir type and quality

Potential reservoir rocks are the same as in the fold and thrust belt play. Overall reservoir potential in any of the formations is most likely poor to fair at best.

Traps and seals

Few data are available onshore to determine subsurface structure. Based on prior exploratory drilling, three potential traps are inferred. Two of these are gentle closures in Icy Bay, inferred from the Standard Oil Co. of California Rioux Bay No. 1 well, and on the west side of Yakutat Bay, inferred from the Colorado Oil and Gas Corp. Malaspina 1A well. The third structure lies near the shoreline of the Yakutat Foreland, where seaward dipping rocks are truncated and may be folded into anticlines. This area has been partly tested by three wells (Colorado Oil and Gas Corp. Yakutat 1, 2, and 3 wells). Other structures could be present along the continuation of the Dangerous River zone onshore or beneath Yakutat Bay and the Malaspina Glacier.

Depth range of objectives

The depth range of lower Tertiary objectives ranges from about 0.5 km to perhaps 9 km. These estimates are based on well results for the minimum figure and on estimated depth to the base of Paleogene rocks immediately offshore for the maximum figure.

Exploration status

The play area is moderately explored. Ten wells and coreholes as deep as 4,200 m have been drilled within the region on structures defined on seismic reflection data. Further exploration depends on identifying subtle structural or stratigraphic traps, primarily along the Dangerous River zone, but also in the thick sedimentary rocks south and southwest of the Dangerous River zone.

LITUYA BAY PLAY

Geological characterization

The play lies between Icy Point and Cape Fairweather (Figure 7), and includes the Tertiary rocks between Cross Sound and Lituya Bay. Strata include about 750 m of the Cenotaph Volcanics and Topsy Formation, overlain by rocks of the Yakataga Formation. A thick (to almost 4 km) Cenozoic section, present immediately offshore, may have rocks equivalent to the Cenotaph Volcanics and Topsy Formation at the base, but is interpreted to consist mainly of rocks of the Yakataga Formation (Bruns, 1983b). The Cenozoic section overlies Cretaceous rocks of the Yakutat Group. The play region lies northeast of the Dangerous River zone, along which the thick onshore and offshore Paleogene sedimentary sequences are truncated. Thus, rocks equivalent to the thick Paleogene section in the Yakataga region (fold and thrust belt play) are not known to be present either onshore or in the offshore region adjacent to the play area. Hydrocarbons would therefore have to be generated entirely from the Cenotaph Volcanics and the Topsy and Yakataga Formations.

Source rocks

No source rocks are known in the strata underlying the Lituya Bay play area. Further, rocks similar to the Paleogene strata that are present west of the Dangerous River zone are not present in the Lituya Bay region or in the adjacent offshore. Thus, no source rock potential is known in the play region.

Generation, migration, and timing

If source rocks are present at the base of the late Cenozoic section offshore, generation could be beginning as a result of burial by the Yakataga Formation. Such hydrocarbons could migrate updip into the onshore Lituya Bay region, or into traps formed by a fault near the shoreline. No traces of oil or gas are known from the region however.

Reservoir type and quality

Sands may be present within either the Cenotaph volcanics or Topsy and Yakataga Formations that could serve as reservoir rocks.

Traps and seals

Rocks at the shoreline are vertical or near vertical and have little trapping potential, but a small anticline is present onshore. A fault near the shoreline could also create trap potential, either with structural or stratigraphic traps along the fault.

Depth range of objectives

Depth range of Cenozoic rocks ranges from 0 km onshore to about 4 km just offshore. Rocks deeper than about 4 km are probably part of the Yakutat Group.

Exploration status

No exploratory wells for hydrocarbons have been drilled in the Lituya Bay play area.

MIDDLETON ISLAND PLAY

Geological characterization

The play area includes Middleton Island and the contiguous state lands, thus encompassing an oval area about 19 km long by 12 km wide. An exploratory well was drilled into these rocks in 1969, with no commercial discovery of hydrocarbons. Economic basement to the region is presumed to be rocks of the Orca Group, and lies at an unknown depth. Overlying basement are at least 4 km of Cenozoic sedimentary rocks, with a late middle Eocene age from the oldest dated samples from the bottom of the Middleton Island well. At least the upper 1 km of this sequence is composed of late Cenozoic rocks of the Yakataga Formation. The play area lies on a broad, faulted high at the edge of the Middleton Shelf; rocks within the play area generally dip less than about 20° based on nearby marine seismic reflection data, but dip as much as 28° on Middleton Island. Hydrocarbons could be generated in the Paleogene rocks that underlie the area, or could migrate into the structural high from nearby basin areas.

Source rocks

No direct information is available on source rocks, but lack of hydrocarbons in the Middleton Island well suggests thermal immaturity or a decided lack of source rocks. Source rocks similar to those of the Yakutat terrane could be present in the Paleogene rocks beneath the island. If the Middleton region is similar to the Kodiak region, however, potential source rocks might have low organic carbon content, and contain mainly herbaceous, woody, or coaly kerogen which would generate mainly gas.

Generation, migration, and timing

The geothermal gradient in the Middleton Island well was about 21° to 28° C/km, or moderately cool. Generation of hydrocarbons would presumably begin at a depth of about 3.5 to 5 km. Generation could presently be occurring in the most deeply buried parts of the basin, and generated hydrocarbons could migrate into the late Cenozoic structures of the region. Both the generation of hydrocarbons and the development of the structures could be so recent that no significant accumulations have occurred.

Reservoir type and quality

No direct information is available on reservoir rocks. If rocks beneath the play area are similar to those of the Yakutat terrane, than the reservoir type and quality would be the same as for the Yakataga fold and thrust belt play.

Traps and seals

The Middleton Island play is at the crest of a large structural high which could form an effective trap. The high also appears to be faulted, possibly with significant offset on the fault, and such faulting could destroy trapping potential. The Yakataga Formation could form an effective seal over the Paleogene rocks.

Depth range of objectives

Depth range of the Paleogene age potential source and reservoir rocks is from about 1 km to over 4 km; the maximum depth to the base of these rocks is unknown.

Exploration status

The play area is small enough that the Middleton Island well could have effectively tested the entire play. The well was drilled on or near the crest of the structural high which underlies the play area. If the structure is faulted however, the well may have tested only part of the structure, and the possibility remains that closures with hydrocarbon accumulations could be present but untested. Future drilling would be difficult to justify unless significant hydrocarbon accumulations are found in nearby areas of the Middleton or Kodiak shelves. The region must be considered as well explored at present, and as having negligible hydrocarbon resource potential.

SUBDUCTING PLATE PLAY

Geological characterization

This play assumes that rocks of the Yakutat terrane are subducting beneath southern Alaska along the Kayak zone and the Chugach-Saint Elias fault system. The rocks entering this subduction zone include the thick Paleogene rocks that are present both onshore and offshore, and which have source rock potential. As these rocks are carried down, hydrocarbons could be generated and migrate up along fault zones into near surface rocks and traps. The oil and gas found in the onshore seeps may have originated in this way, formed in the deeply buried, subducting rocks and migrating upwards along the subduction zone faults to the surface. This play is a conceptual one, and no information is available to directly substantiate whether the play could lead to practical results or not. The subducting plate itself is probably a valid play only near the fault systems where the underthrust plate is shallow enough to be reached with a drill. Identification of potential traps on the underthrust plate could be difficult, however. The perhaps greater importance of the play and the subduction process is that substantial volumes of hydrocarbons could be generated in subducted rocks, and could migrate updip into available traps within rocks yet to enter the subduction zone or into traps in the overriding plate.

The play area is mainly the region of the fold and thrust belt play, but also includes areas north and west of the Kayak zone and Chugach-Saint Elias faults system where crystalline basement rocks outcrop at the surface, but which might be underlain by subducted sedimentary rocks. For example, oil seeps are present west of the Ragged Mountain Fault, indicating the presence of underthrust oil-prone rocks at least 6 km west of the fault (Plafker, 1987). Since the play is largely conceptual, practical northern and western limits cannot be defined until more information is available on the depths to the underthrust rocks.

Source rocks

Source rocks are the same as for the fold and thrust belt play, and lie in the Paleogene rocks and the Poul Creek Formation.

Generation, migration, and timing

Generation would begin when the rocks were buried 4 to 5 km deep, assuming a geothermal gradient of about 25^{0} C/km. Migration would presumably be contemporaneous with generation. Both processes could be ongoing, and could have begun during the Miocene, probably late Miocene, with initial subduction of the Yakutat terrane.

Reservoir type and quality

Reservoirs would be the same as for the fold and thrust belt play. Additional possible reservoirs would be in fracture porosity in the subducting rocks or the faulted overriding plate.

Traps and seals

Traps would be the same as for the fold and thrust belt play, plus any other kinds of traps that might be present in the overriding plate, or in fault wedges in the subducting plate.

Depth range of objectives

Depth range would be from 0 km to any practical drilling depth, with standard stratigraphic and structural traps as the objectives.

Exploration status

Exploration discussed under other plays may have inadvertently tested hydrocarbons developed in subducted rocks. The subducting plate concept itself is unexplored.

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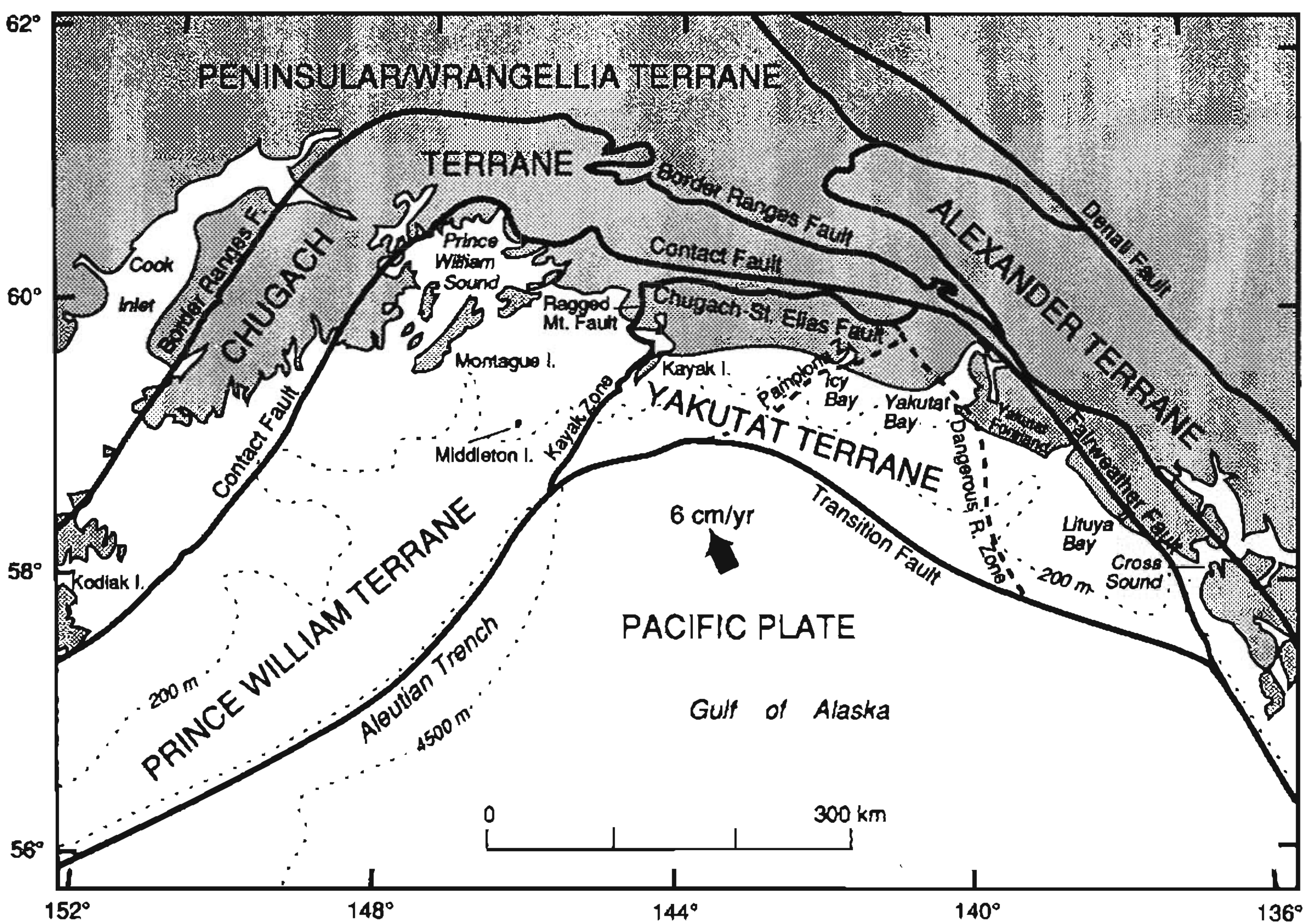


Figure 1. Index map and tectonostratigraphic terranes of the northern Gulf of Alaska region, from Jones and others (1986). Gulf of Alaska Onshore Province includes Middleton Island and the Yakutat terrane between Cross Sound and the Ragged Mountain Fault.

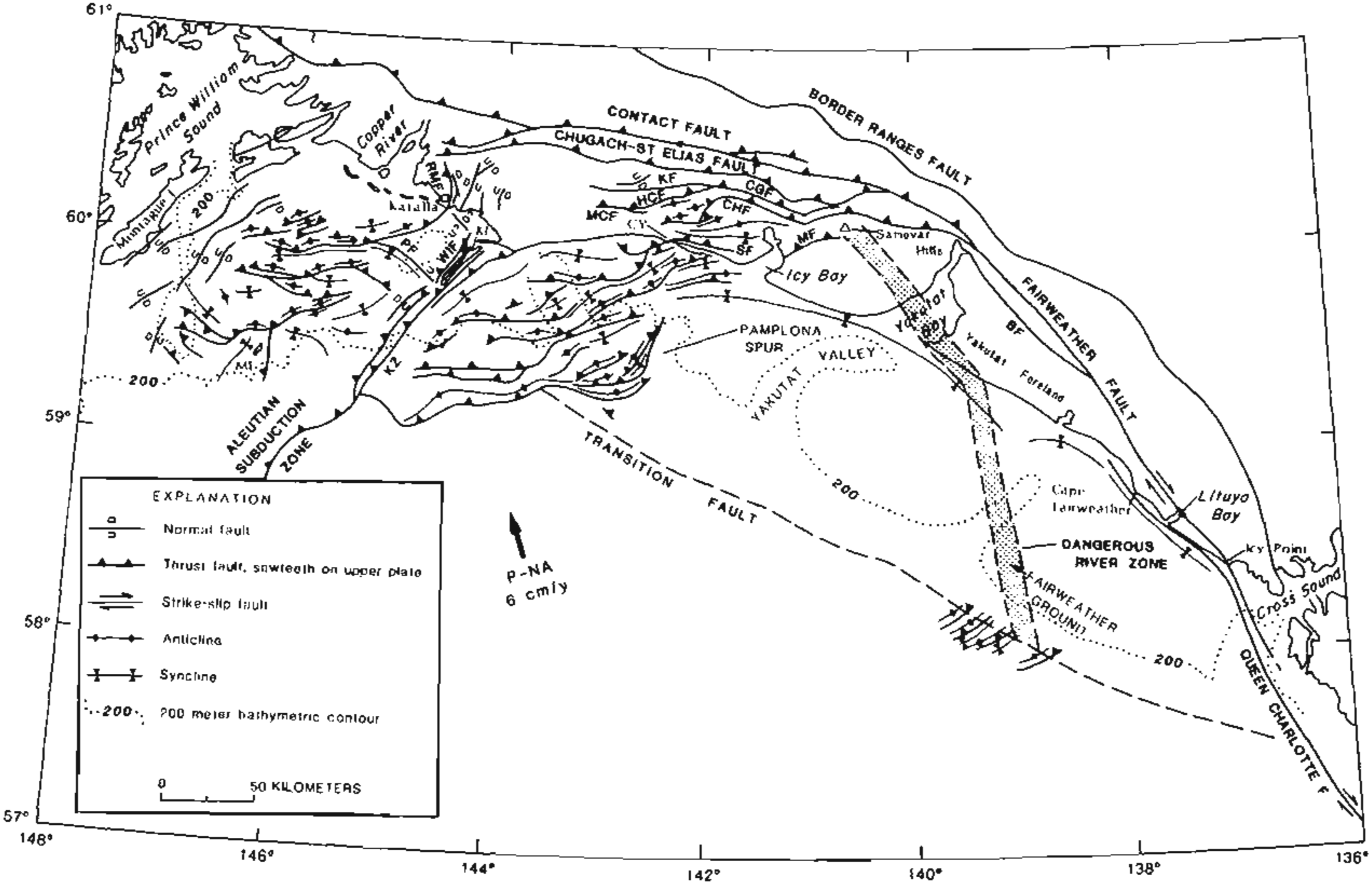
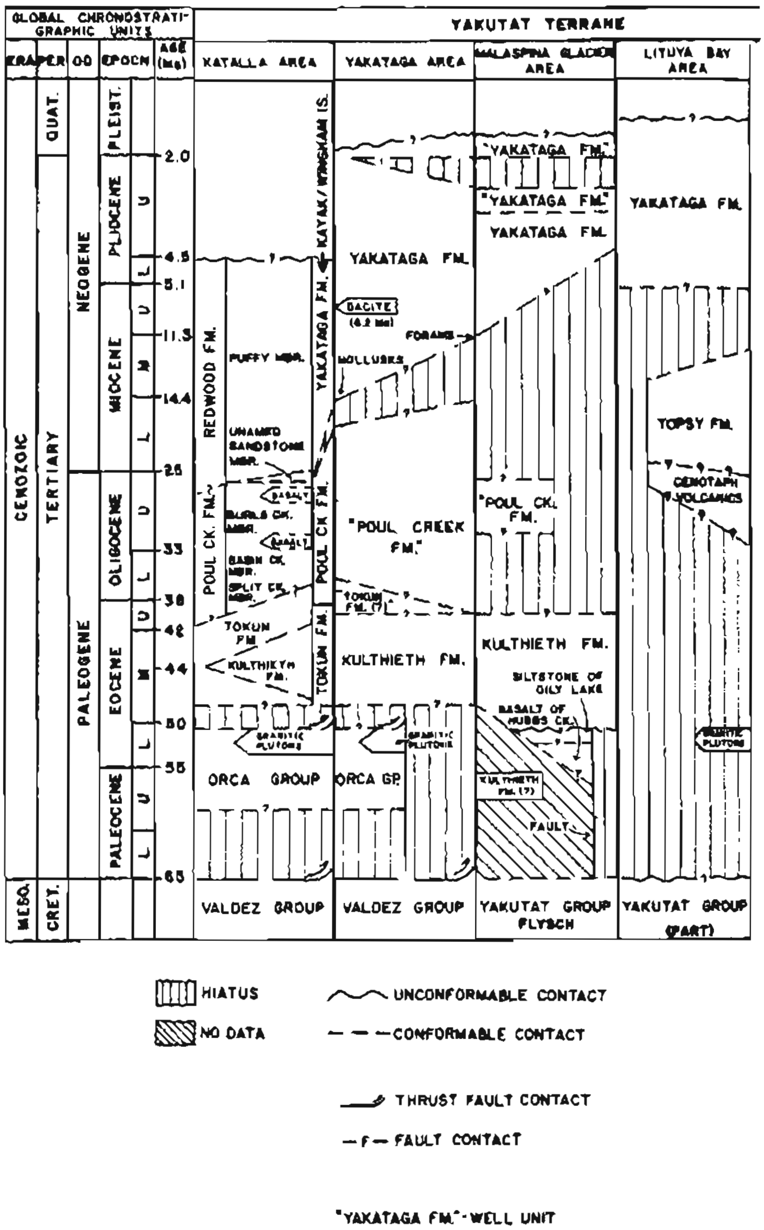
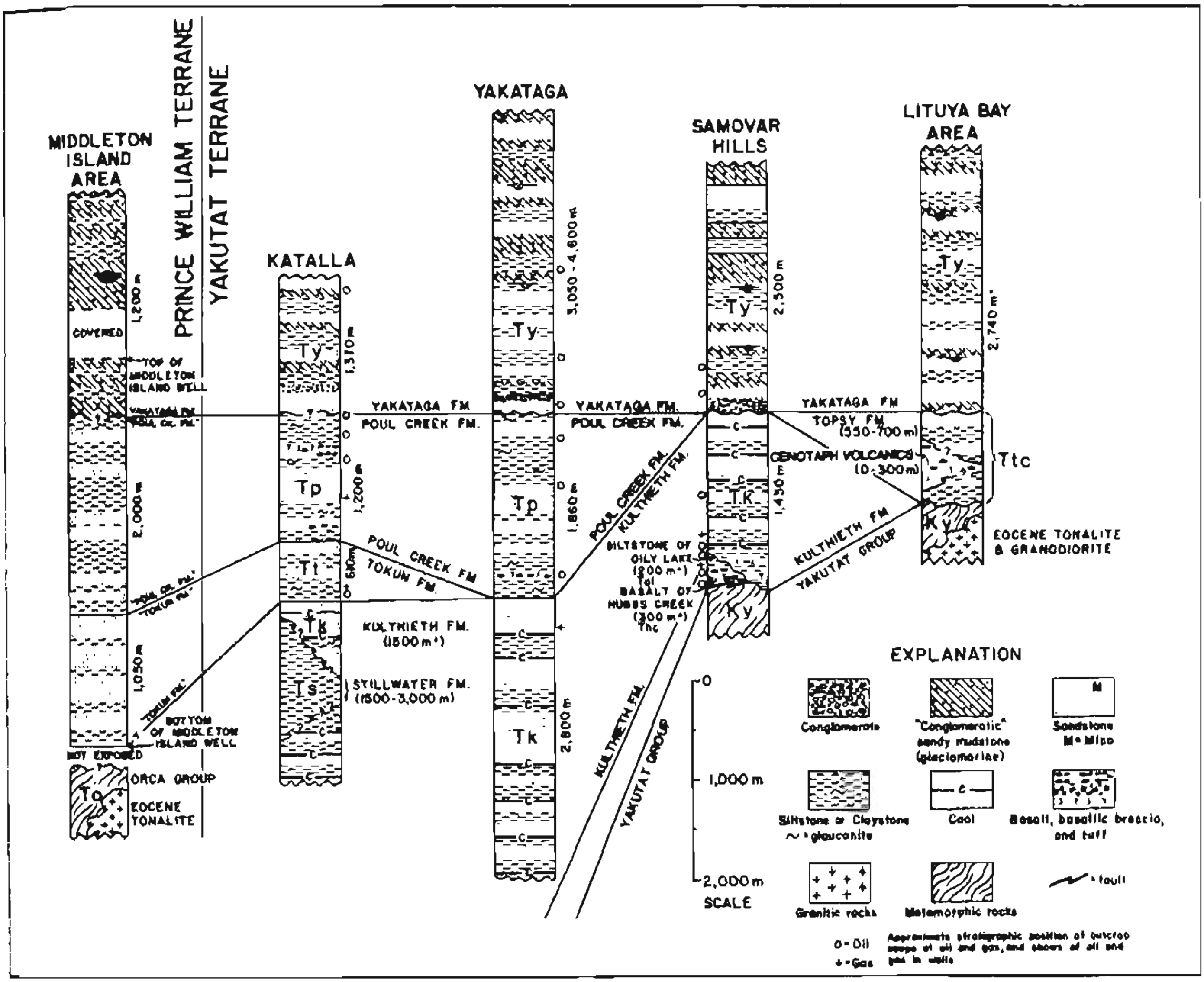


Figure 2. Structural features of the northern Gulf of Alaska continental margin. Onshore structure from Plafker (1967; 1971; 1987). Offshore structure from Bruns (1983b, 1985a) and Bruns and Schwab (1983). BF-Boundary Fault; CGF-Coal Glacier Fault; CHF-Chaix Hills Fault; CY-Cape Yakataga; HCF-Hope Creek Fault; IPF-Icy Point-Lituya Bay Fault; KI-Kayak Island; KF-Kosakuts Fault; KZ-Kayak zone; MCF-Miller Creek Fault; MF-Malaspina Fault; MI-Middleton Island; PF-Pinnacle Fault; RMF-Ragged Mountain Fault; SF-Sullivan Fault; WIF-Wingham Island Fault. Arrow shows Pacific plate-North America plate (P-NA) relative convergence direction.



3. Stratigraphic correlation chart for the Yakutat terrane, modified from Plafker (1987).



4. Generalized stratigraphic columns of onshore basinal strata along the northern Gulf of Alaska margin, modified from Plafker (1987).

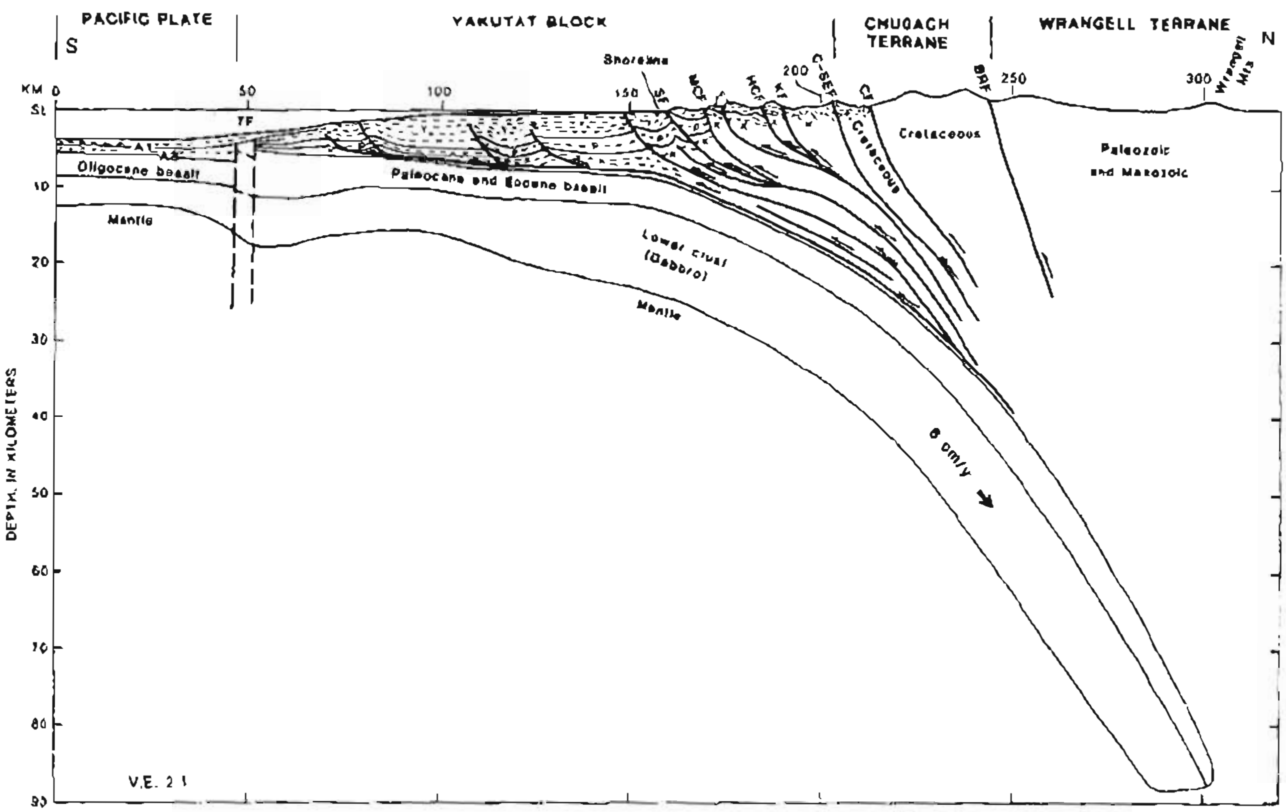
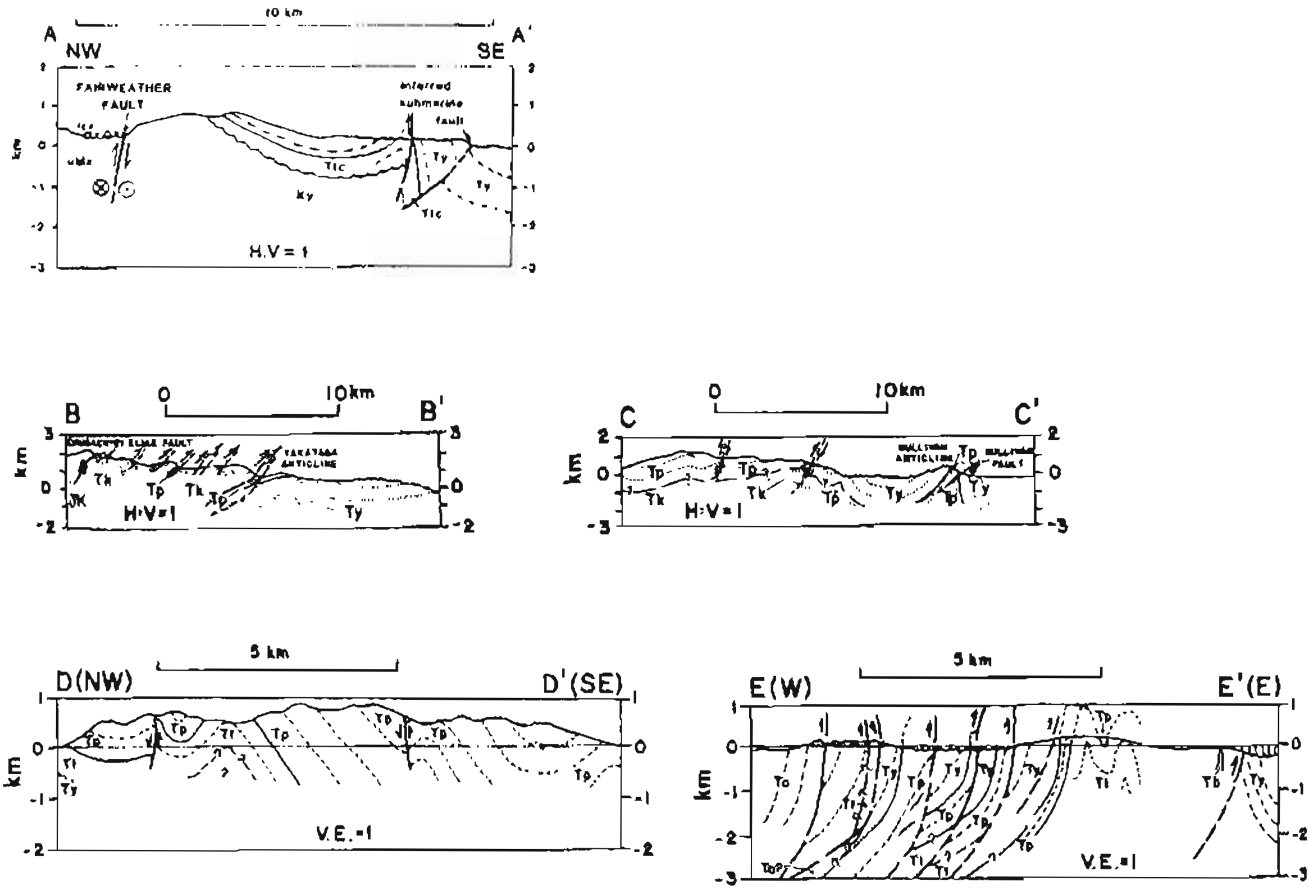


Figure 5. Schematic cross-section across the Yakataga fold and thrust belt of the Yakutat terrane, from Bruns (1985a). Deformation results from seaward propagating thrust faults as the Yakutat terrane moves towards and subducts beneath southern Alaska. The fold and thrust belt is likely underlain by a decollement surface within strata overlying Paleocene and Eocene oceanic basalt. The degree of faulting and deformation increases from south to north, reaching a maximum adjacent to the Chugach-Saint Elias fault. The earliest developed shelf anticlines are covered by undeformed strata of about Pleistocene age. Thickness of offshore sedimentary rocks, basalt, and lower crust are based on seismic reflection data, seismic refraction data, and gravity and magnetic modeling (Bruns, 1985a). Onshore structure and sediment thickness is based on cross-section of Miller (1971) which extends north from Cape Yakataga. Position of subducted slab is based on depth of Wrangell Benioff zone of Stephens and others (1984) and on position of active volcanoes of the Wrangell Mountains. Abbreviations as in Figure 2 plus Y-Yakataga Formation; P-Poul Creek Formation; K-Kulthieth, Stillwater, and Tokun Formations, C-CEF-Chugach Saint Elias Fault; CF-Contact Fault; BRF-Border Ranges Fault; TF-Transition Fault.



6. Structure sections: (A-A') Lituya Bay region just east of Lituya Bay; (B-B') Yakataga fold and thrust belt north of Icy Bay; (C-C') Yakataga fold and thrust belt midway between Icy Bay and Cape Yakataga; (D-D') Katalla region, and (E-E') center of Kayak Island, from Plafker (1971; 1974; 1987). Unit symbols are: JK, Jurassic and Cretaceous; uMz, Upper Mesozoic; Ky, Yakutat Group; To, Orca Group; Tk, Kulthieth Formation; Tt, Tokun Formation; Tp, Poul Creek Formation; Ttc, Topsy Formation and Cenotaph Volcanics; Ty, Yakataga Formation, Qo, Quaternary.

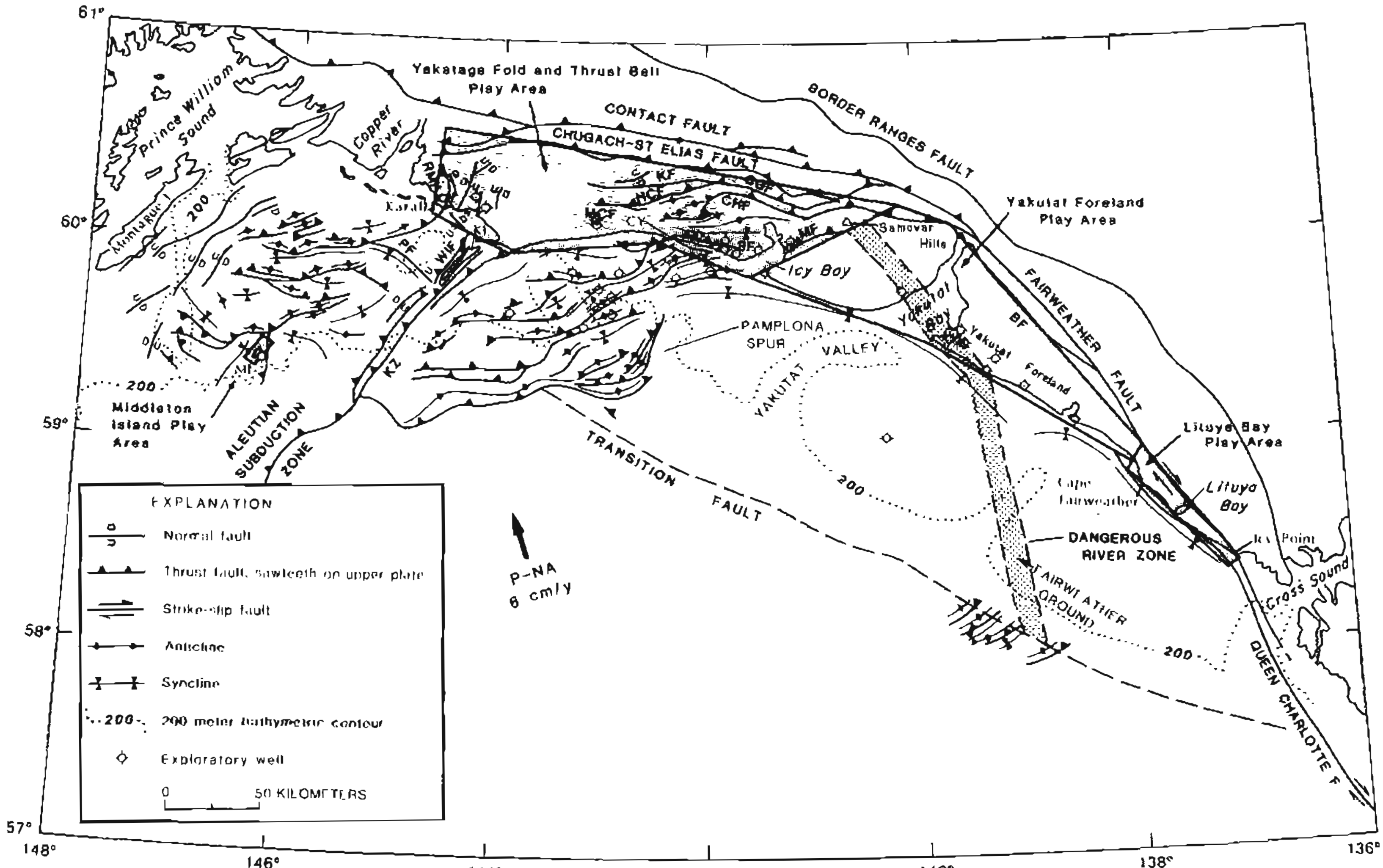


Figure 7. Hydrocarbon play areas of the Gulf of Alaska Onshore Province and locations of onshore and offshore exploratory wells, superposed on structural features of Figure 2. Abbreviations and explanation as in Figure 2.