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GENERALIZED STRATIGRAPHY AND PETROLEUM POTENTIAL OF THE HOLITNA REGION, SOUTHWEST ALASKA

By:
David L. LePain[1], Robert. B. Blodgett[2], James G. Clough[1], and Tim Ryherd[3]
[1]Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys,
794 University Avenue, Suite 200, Fairbanks, AK 99709
[2]Department of Zoology, Oregon State University, Corvallis, OR 97331
[3]Alaska Department of Natural Resources, Division of Oil and Gas, 550 West 7th Avenue, Suite 800,
Anchorage, AK 99501

Introduction

This report integrates data collected during the State's reconnaissance study in the mid-1980s and the 1998 reappraisal to summarize the petroleum potential of the Holitna region. The Holitna region is located in southwest Alaska, in a lowland setting between the Kuskokwim Mountains to the northwest and the Alaska Range to the southeast. Figure 1 shows the outline of the study area and a very generalized portrayal of the regional stratigraphy. Most of the region is tundra-covered lowland with only scattered, frost-shattered bedrock exposures in upland areas.

The report is organized in two sections. The first section includes a brief review of relevant aspects of the regional geology. The second section is a brief summary of the petroleum potential of the Holitna region based on available organic geochemical data. Most of the geological information summarized below was obtained by the second author (Blodgett) over the course of nearly two decades of work in the Holitna region; other data sources are cited in the text. Detailed geologic mapping of the Gagaryah River area (Lime Hills C-5 and C-6 1:63,360-scale quadrangles) by Bundtzen and others (1994) provided valuable information on the stratigraphy and structural geology of the northeastern part of the Holitna region.

The commercial petroleum potential of the Holitna region (fig. 1) was investigated by several oil companies (Sohio, Arco, and Unocal) in the early to mid 1980s, and by the State of Alaska during the same period and in 1998. The Alaska Department of Natural Resources, Division of Oil and Gas and Division of Geological & Geophysical Surveys (DGGS), working together, conducted a reconnaissance-level study of the oil and gas potential of Paleozoic and Mesozoic rocks in the region. The results of the industry and unpublished State studies suggested that Paleozoic and Mesozoic rocks of the Holitna region have poor potential to yield commercial quantities of oil, and poor to fair potential to yield commercial quantities of the gas. The oil potential was considered poor because indicators of thermal maturity suggested that most of the pre-Cenozoic rocks in the region were exposed to temperatures beyond the oil preservation limit, and rocks capable of generating commercial quantities of oil had not been found. The commercial gas potential of pre-Cenozoic rocks was considered fair to poor because rocks capable of generating commercial quantities of gas were not been observed in the area. The gas potential (including coal bed methane) of Tertiary non-marine strata in the Holitna area was not investigated. The gas potential of Tertiary non-marine strata is probably poor to fair owing to their distribution in relatively small fault-bounded slivers along the Denali-Farewell fault system and thermal immaturity. Apart from the generally high thermal maturity of Paleozoic and Mesozoic rocks in the region, the main reason for these negative assessments is the absence of potential source rocks at the surface.

The reconnaissance study conducted by the State of Alaska in the 1980s included sampling lower Paleozoic through Mesozoic strata for organic geochemistry to characterize source rock potential. Most samples were collected from obvious potential source rocks, including Ordovician to Silurian deep-water graptolitic shales and Cretaceous shales of the Kuskokwim Group. Consequently, sample locations are clustered along the Hoholitna River and in the southern Sleetmute and southwestern Lime Hills quadrangles (fig. 1), where the better exposures of Ordovician and Silurian deep-water strata are located, and outboard of the Paleozoic outcrop belt, where the better exposures of the Kuskokwim group are located. Thermal data collected from these locations up to the mid-1980s indicated that the rocks were post-mature and had little oil and gas potential.

Thermal data obtained since the mid-1980s have allowed identification of at least two areas where the Paleozoic rocks are within the oil window (Bundtzen and others, 1994; Blodgett, unpublished field data). One area extends at least from the Gagaryah River south to East Lime Lakes (Lime Hills C-5 Quadrangle), and corresponds to the footwall of a major thrust fault exposed in a tectonic window. The second area straddles the Sleetmute A-1, A-2, and A-3 quadrangles and corresponds to an east-west-trending anticlinorium. In this report, these areas are named the Gagaryah window and Sleetmute anticlinorium, respectively. Samples for organic geochemistry were not collected during the reconnaissance evaluation of the region in the 1980s. Consequently, a focused reappraisal of the petroleum potential of the region was conducted during the 1998 field season.

The primary aim of the 1998 reappraisal was to look for potential source rocks in the Gagaryah window and to collect additional data on the thermal maturity of rocks exposed in the Gagaryah window and in the Sleetmute anticlinorium. Secondary aims were to improve understanding of the general stratigraphic framework of the Holitna area as it relates to the area's petroleum potential, and to develop a basic model for the structural evolution of the Gagaryah window and the Sleetmute anticlinorium.

Regional Geology

Much of the western cordillera of North America, including the Holitna region and nearly all of Alaska, is comprised of a collage of accreted terranes (Coney and others, 1980; Jones and others, 1981 and 1987). The stratigraphy of the Holitna region is complex and includes elements of three previously recognized accreted terranes, including the Nixon Fork, Dillinger, and Mystic terranes. These terranes were recognized by Decker and others (1994) to be genetically related, and were reduced in rank as subterranes of a larger tectonostratigraphic entity termed the Farewell terrane. Owing to this stratigraphic complexity, it is difficult to express stratigraphic relations in a single generalized stratigraphic column. In order to simplify description of the regional stratigraphy, we divide the Holitna region into four areas with distinct stratigraphies (figs. 3-6) and describe each area separately. Stage terminology used in the text is listed in Figure 2.

Stratigraphy

Before discussing the stratigraphy of the Holitna region, a brief note is in order to avoid confusion for readers familiar with the older literature on the geology of southwestern

Alaska. The term Holitna Group was named by Cady and others (1955) for Paleozoic carbonates exposed in the western part of the Holitna Lowlands, specifically along the Holitna River and vicinity. Fossils of Silurian and Devonian age were reported. In addition, Ordovician strata were also inferred because of the presence of Ordovician fossils in similar rocks of the Medfra quadrangle to the northeast, as well as the fact that the Silurian and Devonian faunas were recovered only from the upper part of the Holitna Group. The thickness of the group was estimated "to be at least 5,000 and probably closer to 10,000 feet thick" (Cady and other, 1955, p. 24). Subsequent field investigations by the Alaska Division of Geological and Geophysical Surveys indicates that rocks assigned to this group are actually much greater in total thickness and includes strata as old as Cambrian (and probably even Neoproterozoic) and as young as Triassic. On this basis, Adrain and others (1995, p. 724) suggested that the term Holitna Group is too broadly defined, and that it should be abandoned in favor of more finely subdivided stratigraphic units.

Sheet 1 (in pocket) is a generalized 1:250,000-scale bedrock geologic map of the Holitna region. Proterozoic, lower Paleozoic, and Mesozoic sedimentary rocks are exposed in the hills around the perimeter of the lowland area; outcrops of Mesozoic strata are situated outboard of the Paleozoic rocks (away from the interior lowland) and, at many locations, contact relations with older rocks are uncertain (fault or unconformable contact). Outcrop locations discussed in the following paragraphs are numbered on Sheet 1.

North Side Sleetmute Anticlinorium

The generalized stratigraphy exposed on the north flank of the Sleetmute anticlinorium in the Sleetmute A-2 Quadrangle is illustrated in Figure 3. This stratigraphy is best described along a transect from the core of the anticlinorium (northern edge of the Taylor Mountains D-2 Quadrangle), across the north limb of the structure, to the northern edge of the Sleetmute A-2 Quadrangle. Proterozoic (?) through Middle Devonian rocks described in this section comprise the Nixon Fork terrane of Jones and others (1981 and 1987) and Decker and others (1994).

Low hills in the core of the anticlinorium are comprised of Proterozoic (?) through Middle Devonian rocks, with the oldest strata, bedded chert (or cherty argillite), situated in the core. Chert is not exposured, but is present as float in tundra and loose mineral soil (Location 1). Proterozoic dolostones with minor interbedded quartz siltstones and sandstones are discontinuously exposed on the north side of the anticlinorial core, stratigraphically above and geographically immediately north of the bedded chert. Contact relations between the chert and the dolostones are unknown. The dolostone succession includes at least four lithofacies: 1. Laminated dolostone consisting of millimeter-scale laminae of dolomite and quartzose silty/sandy dolomite; 2. trough cross bedded quartzose sandy dolomite; 3. siltstone; and 4. trough cross bedded quartzose sandstone. This association suggests deposition in a marginal-marine setting, possibly on a carbonate-dominated tidal flat.

Tundra cover separates the dolostone succession from overlying lower Middle Cambrian and upper Middle Cambrian lime mudstones and skeletal packstones (Location 2). Lime mudstones and skeletal packstones include an abundant open-marine fauna of well preserved trilobites (Location 2). Contact relations between the Cambrian limestones and the underlying dolostones, and between the lower Middle and upper Middle Cambrian successions, are unknown owing to tundra cover. Cambrian lithologies exposed in this area record deposition in a subtidal shallow platform setting.

Upper Cambrian-Lower Ordovician platy limestones with interbedded lenses of flat-pebble conglomerates (lime-clast conglomerates) are exposed discontinuously north of the Middle Cambrian limestones (Location 3). Again, poor exposures with intervening tundra cover obscure contact relations with underlying lithologies. Sharp, erosive basal bed contacts, graded beds, and lenses of flat pebble conglomerate suggest deposition from discrete flows, possibly in a slope setting.

Ordovician platy limestones are unconformably overlain, in ascending stratigraphic order, by Middle to Upper Ordovician grainstones, limestone breccias, and massive-bedded algal boundstones. The vertical sequence of lithologies suggests a prograding slope and platform-margin succession, complete with fringing algal reefs and forereef talus. Northward progradation of the margin across this area probably began in Late Cambrian time as evidenced by the interpreted Upper Cambian-Lower Ordovician slope facies exposed a few kilometers south of these exposures.

Probable Silurian ooid grainstones, Upper Silurian to Lower Devonian (?) sacchroidal to vuggy dolostone, and massive-bedded Lower Devonian algal boundstone are present in discontinuous exposures north of the Ordovician platy limestones (Location 4). Widespread tundra cover obscures contact relations with underlying Ordovician rocks and between the various Middle Silurian to Lower Devonian lithologies. The algal boundstone unit extends northwest into the Kulukbuk Hills (Sheet 1). Coeval laminated dolostones are present in poor exposures on the west side of the Kulukbuk Hills, in the Sleetmute A-5 and B-5 quadrangles (Decker and others, 1995). The algal boundstone unit contrasts sharply with the older lithologies nearby to the south in that it is highly fractured and cut by numerous calcite-filled veins. Fractures and veins are likely related to motion along a south-vergent thrust fault, named the Kulukbuk thrust by Decker and others (1995) (Sheet 1). The facies context of the ooid grainstone is unknown; they may record ooid shoals in a shallow water platform setting or ooid sands that were washed northward off the platform into adjacent deeper water settings. Lower Devonian algal boundstone and laminated dolostones record platform-margin and interior facies, respectively, along a north- and northeast-facing carbonate-dominated platform; algal boundstones record organic buildups along the seaward margin of a carbonate platform, whereas the coeval laminated dolostones record deposition in carbonate tidal flats on the landward side of the platform. Depending on the correct interpretation of the ooid grainstones, the overall succession is either transgressive (platform interior facies overlain by platform margin facies) or regressive (slope facies overlain by platform margin facies). An alternative interpretation is that the ooid grainstones record platform-margin sand shoals that pass laterally and vertically into platform-margin algal buildups and suggests that the entire succession records aggradation with sedimentation keeping pace with subsidence and relative sea level rise.

Gray weathering, platy limestones are exposed in an arcuate, northeast-trending belt approximately 25 km long, that extends from the eastern side of the Sleetmute A-2 Quadrangle, northeast to the north side of Tundra Lake in the Lime Hills B-7 Quadrangle (Location 13 in the lPzl unit on Sheet 1). These rocks were assigned to the Dillinger terrane by Jones and others (1981 and 1987). Lithologies include thin beds of graded sand- and silt-sized carbonate particles and thin beds of lime mudstone; siliciclastic shale and siltstone are absent along this trend. The coarser grained limestones resemble Bouma T_{ab}–$T_{bd?}$ sequences and are interpreted as distal turbidites. The lime mudstones resemble deep-water calcareous oozes. The age of this unit is poorly constrained as age diagnostic fossils have not been recovered to date, and the lPzl unit could as old as Ordovician or as young as Lower Devonian. The proximity of these rocks to Lower Devonian algal boundstones immediately east in the Lime Hills B-7 Quadrangle (Location 14) suggests that they may also be of Lower Devonian age. If our age assignment is correct, the platy limestone along this arcuate trend record deposition in deeper water outboard of the platform-margin algal boundstone. The lime mudstones and the thin bedded limestone turbidites suggest deposition in an outer fan to basinal setting; however, the presence of lime mudstone indicates deposition above the calcite compensation depth (typically between 4000 to 6000 m in modern oceans).

Southeast and north of the deformed Devonian boundstones, the northward-younging stratigraphic trend is disrupted by widely scattered exposures of Ordovician shale that were assigned to the Dillinger terrane by Jones and others (1981 and 1987) (OSls unit on Sheet 1). Discontinuous exposures of shale with a well-preserved Arenigian age graptolite fauna are scattered along approximately 35 km of the Hoholitna River in the northern Sleetmute A-2, B-2, and B-3 quadrangles, from approximately 61^{o} 3.8’ north latitude to VABM Diamond (Sleetmute B-3 Quadrangle). Exposures on the east and west banks of the Hoholitna River, near 61^{o} 3.8’ north latitude, consist of graptolitic shales with thin, laterally continuous interbeds of normally graded allodapic limestone (Location 5). Limestone beds dip toward the north, have sharp basal contacts with linear sole markings and commonly appear normally graded in the basal few centimeters. Graded intervals are overlain by plane-parallel lamination. These beds display partial

Bouma sequences ($T_{ab-d?}$ and $T_{b-d?}$) and are interpreted as turbidites. A few overturned folds with north-trending axes were observed at this locality; folds are overturned toward the east. Fold style and asymmetry suggest soft-sediment deformation on a sloping depositional surface, possibly as channel levee deposits in a slope setting, or as channel levee deposits in a submarine fan setting.

Exposures of graptolitic shale and thin-bedded limestone turbidites continue northward along the Hoholitna River to approximately 61^{o} 14.3’ north latitude (Location 6), north of which graptolitic shales with thin interbeds of siliciclastic turbidites are discontinuously exposed as far north as VABM Diamond (Location 7). Siliciclastic turbidites occur as thin interbeds within Arenigian shales, and include partial Bouma sequences similar to those observed in the limestone turbidites. The change from limestone to siliciclastic turbidites occurs over a distance of 1.5 km. Based on the approximate dips observed from the air, the limestone turbidites are slightly older as they appear to dip beneath the siliciclastic turbidites to the north. This suggests a significant change in the source area of sediment transported to the deep-water environment during Arenigian time, or progressive unroofing of the same source area through time.

South Side Sleetmute Anticlinorium

Lower Ordovician through Upper Triassic (and including possibly Lower Jurassic) strata comprise the Nixon Fork terrane of Jones and others (1981 and 1987). Lower Ordovician algal limestones (thrombolites), calcareous dolostones, and dolostones are exposed south of the core of the Sleetmute anticlinorium in northern Taylor Mountains D-1 and D-2 quadrangles (fig. 4 and Location 8 on Sheet 1). The limestones, which form the uppermost part of the succession, include an open-marine fauna of trilobites and conodonts indicative of Early Ordovician age.

A poorly exposed, recessive weathering, shale and chert unit of probable Middle Ordovician age separates fossiliferous limestones and dolostones below from an overlying Upper Ordovician (Ashgillian) platform lime mudstone and wackestone unit and a graptolite-bearing lower Lower Upper Silurian (Llandoverian-Wenlockian) allodapic platy limestone unit (Location 9). Platy limestones are thin- to very thin-bedded, have sharp lower contacts, are commonly normally graded, and pass upsection into interbedded platy limestone and clast- and matrix-supported limeclast-bearing debrites

The Silurian platy limestones and limeclast debrites are overlain by massive-bedded Upper Silurian to Lower Devonian algal boundstones. Dolostones locally occur within the algal boundstone unit. This succession is interpreted as a time-transgressive progradational platform-margin sequence with the algal boundstones representing platform-margin organic buildups flanked locally on their landward (south) sides by carbonate tidal flats. The algal boundstone unit is Late Silurian on the south and earliest Devonian on the north. These relations indicate that the unit is time-transgressive and prograded basinward (northward in present-day coordinates) over slope mudstone.

Middle Devonian through Middle Triassic rocks have not been recognized in the northern Taylor Mountains quadrangles. Upper Triassic (Norian) limestones with scleractinian corals, brachiopods, bivalves, and conodonts are present in a number of small exposures in the northern part of the Taylor Mountains D-3 Quadrangle (Location 10). Although no direct contact has been observed, this unit appears to rest unconfomably upon the Upper Silurian algal boundstones. The limestone unit appears to grade upward into bedded radiolarian cherts and siltstones and sandstones bearing numerous belemnites and rarer bivalves. These belemnite-rich beds have not been dates, but may be as young as Early Jurassic.

The Albian to Coniacian age Kuskokwim Group is exposed in south half of the Taylor Mountains D-1, D-2, and D-3 quadrangles, where it includes laminated shale and very fine-grained to coarse-grained lithic sandstone (K_k unit Sheet 1). Outcrop quality is generally poor and consists mostly of rubble. One exception is at VABM Holi in the Taylor Mountains D-1 quadrangle, where medium to coarse-grained lithic sandstone forms a north-northwest-trending exposure approximately 5 kms long (Location 11). Exposures along this trend range from poor to moderate and the rocks display a distinct structural fabric including a steeply dipping poorly developed cleavage to moderately developed schistose fabric. Bedding is obscure, but appears to dip at a low angle toward the south. The depositional setting of the Kuskokwim Group at this location is unknown.

Lime Hills-Why Lake

Thin-bedded lime mudstones and shales previously assigned to the Dillinger terrane by Jones and others (1981 and 1987) are exposed in low-lying hills around Why Lake, in the Lime Hills C-8 Quadrangle (fig. 5 and Location 12 on Sheet 1). Most limestone beds are thin (1 cm to 5 cm), and commonly exhibit normal size grading and plane-parallel lamination. Where graded beds were observed, they were commonly capped by thin plane-parallel laminated intervals, and both comprised Bouma $T_{ab-d?}$ sequences. More commonly, plane-parallel lamination, representing possible Bouma $T_{b-d?}$ intervals, is the most common sedimentary structure observed. These features suggest deposition as turbidites in a basinal setting, but shallower than the CCD. Nearby shales support a basinal interpretation. The age of these rocks is in part Middle Ordovician, based on the presence of graptolites in shaly intervals near Why Lake and along the banks of the Swift River.

Thin-bedded lime mudstones and calcisiltite are exposed at only a few outcrops east of Why Lake and immediately west of the Lime Hills (Location 13). As mentioned previously, the age of these rocks is uncertain, but they are probably latest Silurian to Early Devonian based on their present structural attitude and proximity to rocks of Early Devonian age in the Lime Hills. Lime mudstones and calcisiltite are interpreted as basinal ooze and turbidites, respectively. Siliciclastic turbidites similar to those noted near VABM Diamond (Location 7) have been observed.

Well exposed lower Lower Devonian algal boundstones and interbedded lime rudstones are exposed in the Lime Hills between Tundra Lake (northeastern corner of Lime Hills A-8 Quadrangle) and the Lime Lakes (Location 14 on Sheet 1). These rocks have been assigned to the Nixon Fork terrane by Jones and others (1981 and 1987). Algal boundstones are massively bedded, are comprised primarily of algal stromatolite and thrombolite mounds, and locally include karst features. Brachiopods in the boundstone indicate a Lochkovian (early Early Devonian) age. Rudstone and resedimented calcarenite and calcisiltite beds commonly separate algal boundstone packages. Rudstone, calcarenite, and calcisiltite beds increase in abundance toward the south (?) and southwest while, along the same trend, boundstone beds thin and become less common. Northeast of the Stony River, lower Lower Devonian skeletal wackestones, packstones, and grainstones are common, with only minor algal boundstones. As in the Sleetmute anticlinorium, algal boundstones here are interpreted as platform-margin algal buildups. Rudstones and finer-grained resedimented limestones were derived from the platform-margin algal buildups and deposited as forereef talus and debrites. Wackestones, packstones, and grainstones record deposition in back-reef, platform-interior settings. A detailed discussion of these lithofacies relations and their environmental significance is given by Clough and Blodgett (1988).

The Lime Hills trend was flown in a helicopter during the 1998 field season to observe large-scale stratal architecture. From the air, topset beds, including platform-margin algal boundstones, clearly pass southwestward into slope clinoforms. Contact relations between latest Silurian (?) resedimented limestones and the algal boundstones are uncertain due to tundra cover, but these observations suggest a southwest- or west-facing platform-margin. Both orientations are consistent with lithofacies relations observed on the ground and large-scale stratal architecture observed from the air.

Medium- to coarse-grained lithic sandstone and granule conglomerate of the Cretaceous Kuskokwim Group rest with angular discordance above Upper Silurian and Lower Devonian slope and platform carbonates in the Lime Hills quadrangle. West of the Lime Lakes (Location 15), the Kuskokwim includes coarse-grained sandstones and granule conglomerates that are covered with black lichen resembling large, charred corn flakes. Exposures are poor and largely rubble. Southwest of Tundra Lake, fine- to coarse-grained sandstones, granule conglomerates, and pebble conglomerates are poorly to moderately exposed around the flanks of a hill (Location 16). Conglomerate comprises the base of the exposure and grades upsection within a few meters of the base to interbedded conglomerate and sandstone which, in turn, grades upsection over a few meters to interbedded fine-grained sandstone and siltstone. Conglomerates are thick bedded (1 to 2 m), clast-supported, and locally exhibit normal size grading. Well-preserved plant impressions up to 5 cm long are present on parting planes of the fine-grained sandstones immediately above the interbedded sandstone and conglomerate succession. Moderately preserved casts of pelecypods were observed in sandstone float at the top of the hill. Collectively, these observations suggest deposition in a marginal- to shallow-marine setting, possibly associated with a drowned fan-delta lobe. A more refined interpretation is not possible given the limited lateral and vertical continuity of exposure at this location.

The hills east and southeast of the Lime Hills are comprised shale, sandstone, and conglomerate of the Kuskokwim Group. At Sparrevohn, in the Lime Hills A-7 Quadrangle (Location 17), Decker (1984) mapped 11 depositional units (facies associations) in the Kuskokwim Group, including eight that he interpreted as submarine fan deposits (inner fan, middle fan, outer fan, etc.) and three interpreted as fluvial deposits. Bedding in the Kuskokwim near Sparrevohn is steep and locally overturned. Decker (1984) mapped a series of south-dipping thrust faults involving the Kuskokwim Group in this area, including a fault that juxtaposes turbidites on top of fluvial deposits on the northwest side of the ridge immediately northwest of the airstrip at Sparrevohn. A large-scale concave-upward surface, probably marking the base of a submarine canyon-fill succession, was reported in the vicinity of Cairn Mountain (Location 18), northwest of Sparrevohn (W.K. Wallace, oral communication, 1996). These feature indicate that elements of alluvial plain, slope, and base-of-slope depositional systems are represented in the Kuskokwim Group in the Sparrevohn-Cairn Mountain area.

Gagaryah River-Lime Lakes

Thin- to thick-bedded lower Upper Devonian (Frasnian) to upper Upper Carboniferous (Kasimovian-Gshelian) limestones previously assigned to the Mystic terrane (Jones and others, 1981 and 1987) are discontinuously exposed along a narrow, northeast-trending belt that extends at least from the Lime Lakes area (Lime Hills B-6 and B-7 quadrangles) to the Gagaryah River (Lime Hills C-6 quadrangle; fig. 6). Thermally mature lime mudstones, wackestones, and packstones with open-marine faunas characterize these rocks (Bundtzen and others, 1994; Blodgett, unpublished data). Conodont color alteration indices range from 1.5 to 3.0 (Bundtzen and others, 1994; Blodgett, 1999).

Topography along this belt consists of low rolling hills that stand out in sharp contrast to the rugged hills and mountains that bound the belt to the northwest and southeast. In the Lime Lakes area, the rugged terrain to the northwest is underlain by thermally mature to overmature Lower Devonian algal boundstones and forereef debris (described above in the Lime Hills sections). The mountains to the southeast are underlain by the Cretaceous Kuskokwim Group. In the Gagaryah River area, thermally overmature Cambrian to Ordovician deep-water carbonates, shales, and siltstones are situated structurally above thermally mature Frasnian limestones (Location 19) described above (Bundtzen and others, 1994). These observations suggest that a major thrust fault bounds the northeast-trending belt, and that the Frasnian rocks represent footwall material exposed in a tectonic window that extends at least from the Lime Lakes area to the Gagaryah River, and possibly as far north as the Big River in the Lime Hills D-4 Quadrangle.

Scattered exposures of Triassic basalts (Trb on Sheet 1) straddle the Swift River northeast of the Lime Lakes. Lithologies include amygdaloidal pillow basalts and agglomerates. Minor conglomerates, sandstones, and siltstones are interbedded with the basalts. *Halobiid* bivalves of Norian (Late Jurassic) age have been recovered from the siltstones. No geochemical data are available for the basalts that could be used to evaluate their tectonic affinity. Triassic basalts in the area are overlain by Jurassic shales with thinly interbedded siltstone and very fine-grained sandstone turbidites. A radiolarian fauna of Pliensbachian age (Early Jurassic) has been recovered from these shales (Reed and others, 1985).

Kuskokwim Group

Mesozoic sedimentary rocks assigned to the Kuskokwim Group are exposed in the hills away from the lowland area of the outcrops of Paleozoic rocks. The contact relations with underlying Paleozoic rocks are obscured at most locations by poor exposure, but the contact appears to be faulted at some locations and depositional at others. Depositional contacts (unconformable contacts) have been observed at a few locations in the Holitna area, such as the north portion of the Lime Hills, north of the Stony River (Location 15). The Kuskokwim Group consists of variable proportions of interbedded shale, sandstone, and conglomerate interpreted to record deposition in a wide variety of settings from non-marine to deep-marine environments. Owing to its widespread distribution throughout southwest Alaska, where it rests above Paleozoic and older Mesozoic rocks, the Cretaceous Kuskokwim Group is viewed as an overlap assemblage deposited after amalgamation and accretion of the terranes comprising southwestern Alaska. Pacht and Wallace (1984) interpreted the source terranes for the Kuskokwim Group as the Togiak arc complex and terranes of continental affinity in southwest Alaska, and the depositional setting as one characterized by active tectonics in a post-collisional setting.

Tertiary Coal-Bearing Rocks Along the Farewell Fault

Tertiary non-marine coal-bearing clastic rocks have been mapped in fault slivers along the Farewell fault zone. Gravity data suggests up to 4,500 meters of Tertiary sedimentary rocks within a graben-like basin that straddles the Farewell fault zone in the Sleetmute 1:250,000-scale quadrangle. No exposures of Tertiary rocks have been recognized in the Sleetmute area. However, exposures of Tertiary clastic rocks have been mapped between the Big River and Windy Fork of the Kuskokwim River, in the southern part of the McGrath B-3 and B-4 1:63,360-scale quadrangles, northeast of the area shown in Sheet 1 (Dickey, 1984). The stratigraphy of the Tertiary clastic rocks is poorly known, but available data suggest that sandstone and conglomerate account for a significant percentage of these deposits, with mudrock (silt and clay-shale) and coal comprising a minor percentage of the total thickness. With the notable exception of the coal and carbonaceous mudrocks described by Dickey (1984), the organic content (source rock potential) of the interbedded mudrocks is unknown and the presence of effective reservoir top seals is unlikely. The steeply dipping beds typical of Tertiary strata along the Farewell fault zone diminishes their coalbed gas potential.

Paleogeography of the Holitna Region

Elements of three tectonostratigraphic terranes have been recognized in the Holitna region by previous workers (Jones and others, 1987). Pre-Frasnian rocks of shallow-water derivation in the Sleetmute, Lime Hills, and Taylor Mountains quadrangles were referred to as the Nixon Fork terrane, whereas, pre-Emsian rocks of deep-water derivation in the same area were referred to as the Dillinger terrane. Frasnian through Lower Cretaceous predominantly shallow-water rocks, in the region were assigned to the Mystic terrane (Jones and others, 1981). This nomenclature reflects the view that each terrane is a fault-bounded tectonostratigraphic entity with different stratigraphic successions and geologic histories. Elements of all three terranes have also been recognized in the McGrath and Medfra quandrangles located north and northeast of the Holitna region (Jones and others, 1981).

Several investigators (Bundtzen and Gilbert, 1983; Blodgett, 1983; Blodgett and Gilbert, 1983; Gilbert and Bundtzen, 1983) have suggested that the Dillinger and Nixon Fork terranes represent basinal and platformal facies, respectively, of the same depositional basin. The platform-to-basin facies transition was subsequently structurally modified, resulting in the distinct tectonostratigraphic units recognized today. As mentioned above, the Nixon Fork, Dillinger, and Mystic terranes of Jones and others (1981 and 1987) were interpreted by Decker and others (1994) as genetically-related subterranes of the larger Farewell terrane.

The following paleogeographic reconstruction is described in present-day coordinates. It is apparent that original lithologic trends have been significantly modified by post-Triassic to pre-Albian compressional deformation and deformation associated with right-lateral strike-slip motion on the Farewell fault during Late Cretaceous and Tertiary time.

The western half of the Holitna Lowland, including the north and south sides of the Sleetmute anticlinorium, is dominated by a Neoproterozoic to Triassic succession of predominantly shallow-water platform and slope carbonate rocks, corresponding in part to the Nixon Fork terrane of Jones and others (1981 and 1987) (figs. 3 and 4). The oldest strata of the platform are exposed in the core of the Sleetmute anticlinorium, just north of the southern border of the Sleetmute A-2 Quadrangle (Sheet 1). The platform was rimmed in Ordovician and Late Silurian-Early Devonian time by a northward-prograding algal reef margin that probably had the cross-sectional geometry of a distally steepened ramp (Read, 1985). Deeper-water, basinal equivalent rocks of Ordovician through Early Devonian age lay to the north and are represented by platy, thin-bedded allodapic carbonates, siltstones, and shales in exposures along the Hoholitna River and in the Door Mountains. The shelf and basin trend recognized in the southern part of the Sleetmute A-2 Quadrangle is part of a present-day arcuate trend that extends west-northwest to the Farewell fault, and northeast to the Stony River (Lime Hills Quadrangle).

Shelf strata of the western part of the study area represent a right-lateral fault-offset segment (along the Farewell fault) of equivalent shelf/platform deposits (Nixon Fork strata) exposed to the north near White Mountain (McGrath A-4 and A-5 quadrangles) and the Medfra Quadrangle. The Farewell terrane includes faunas exotic to North America, and most probably represents a rift block derived from the Siberian continent (Blodgett, 1998; Blodgett and Boucot, 1999)

The eastern half of the Holitna Lowland includes both slope and basin strata (Ordovician-Lower Devonian) and younger platform strata (uppermost Lower Devonian-Jurassic). Basinal rocks, as elsewhere, are composed of interbedded shales, siliciclastic turbidites, and allodapic limestones (limestone turbidites), and the platform rocks include a heterogeneous assemblage of rock types including fossiliferous limestones and shales. In the eastern half of the study area, shelf rocks include a thick succession of Frasnian (Late Devonian) age, a thin interval of Mississippian carbonates, and a thick succession of fossiliferous limestones of late Pennsylvanian age, all of which record deposition in a platform setting. A thick interval of Upper Triassic basaltic volcanics and minor interbedded shales with halobiid bivalves and Lower Jurassic siliciclastic turbidites overlie Pennsylvanian strata. Lower Mesozoic strata indicate a period of tectonic instability accompanied by, or immediately followed by, a rise in relative sea level resulting in deposition of the Lower Jurassic turbidites (Fig. 6). Basin and shelf polarities are not evident in rocks of the eastern half of the Holitna Lowland. Original paleogeographic trends have undoubtedly been modified by the compressional deformation evident in the southern Sleetmute Quadrangle, Lime Hills, Lime Lakes, and Gagaryah River areas.

Structural Framework of the Holitna Region

Deformation in the Farewell terrane varies from open, gentle folds with no megascopically recognizable penetrative fabrics to overturned isoclinal folds, thrust faults, and associated well-developed slaty to schistose fabrics. In a general sense, the shale-dominated deep-water successions of the Dillinger terrane of Jones and others (1981 and 1987), with their thin interbeds of limestone and siliciclastic turbidites, are characterized by a significantly greater degree of deformation (Dillinger terrane of former usage), whereas, the shallow-water platformal successions Nixon Fork and Mystic terranes are less deformed. In this section we briefly describe the major structural features of the Holitna region.

The lower Paleozoic succession exposed on the north side of the Sleetmute anticlinorium is characterized by gentle to moderate bedding dips and open folds with east-west- and northwest-trending axes. Ordovician through Lower Devonian deep-water limestones and shales north of the fractured Devonian algal boundstones have been folded into at least one arcuate, east-west- to northwest-trending anticline-syncline pair. These structures correspond to the pronounced linear northwest-trending aeromagnetic lows shown on Figure 7. The Lower Devonian algal boundstones exposed on the north side of the anticlinorium (Location 4), but southwest of the deep-water limestones are highly fractured, recrystallized, and rest structurally above younger Middle Devonian rocks. The structural attitude and condition of the algal boundstones and their structural position above younger rocks suggest south-vergence along a north-dipping thrust fault.

The structure of the Lime Hills and their relation to the Lime Lakes region immediately to the east is unknown. The aeromagnetic survey data shown in Figure 6 do not extend far enough to the northeast to include the Lime Hills and East Lime Lakes area. Algal boundstones and interbedded off-ramp deposits of Silurian to Lower Devonian age comprise most of the Lime Hills and deep-water allodapic limestones (limestone turbidites and pelagic sediment) of Ordovician to Lower Devonian age comprise the low northeast-trending hills immediately west of the Lime Hills. The low hills of deep-water limestone and the higher hills of algal boundstone and off-ramp debris of the Lime Hills rise in stair-step fashion from the low-lying muskeg farther west. Bedding in the limestone turbidites and algal boundstones generally strikes north-northeast and dips moderately toward the east and southeast; however, steep northeasterly dips are present west of Lime Village and outcrop-scale overturned folds are present on the southeast side of the Lime Hills, north of Stony River. The northeast-trending Lime Hills end abruptly between the Stony and Swift rivers, at their northeast end, and algal boundstones comprising the Lime Hills gradually disappear southwest of Tundra Lake, where the Lime Hills trend merges with the east end of east-west- to northeast-trending exposures and structures on the north side of the Sleetmute anticlinorium.

Immediately east of the Lime Hills, on the east side of East Lime Lake (at VABM Trunk), Frasnian age limestones with low southeasterly dips are overlain by Pennsylvanian age limestones with steep southeasterly dips (fig. 8). The contact relations between the Frasnian and Pennsylvanian limestones are obscured by vegetation. Steep, southeasterly dipping Frasnian age strata are exposed east of the southeast corner of East Lime Lake and, again, contact relations with strata in nearby exposures are obscured by cover. Given the southeasterly dipping beds in the Lime Hills and the structure at VABM Trunk (Location 17), we suggest that a thrust contact between the two locations. The vergence of this thrust is unknown, but is presumably related to the fault motion in the Gagaryah River area (Location 19), with the Frasnian through Pennsylvanian package at Trunk thrust northwestward, over the Devonian algal boundstones in the Lime Hills. An alternative explanation is that the Lime Hills were backthrust toward the southeast, over the late Paleozoic section in the Lime Lakes area., and subsequently eroded away. Both models require a decollment at depth.

Moderate to highly deformed rocks characterize the Gagaryah River area. The major structure in this area is a north-northeast-trending thrust fault that Bundtzen and others (1994) mapped from the Gagaryah River southward to the vicinity of VABM Gagaryah. Gilbert and others (1990) mapped the Gagaryah thrust as far north as the Big River in the Lime Hills D-4 Quadrangle. Erosion has breached the hangingwall and exposed footwall strata in a narrow north-northeast-trending tectonic window. The hangingwall is comprised of Ordovician through Triassic deep- and shallow-water strata and extrusive volcanics rocks. Paleozoic strata in the hangingwall have been isoclinally folded and typically display a penetrative fabric. Upper Devonian rocks in the footwall are generally less deformed than rocks in the haningwall, and footwall strata exposed southeast of VABM Gagaryah appear to be folded in broad southwest-plunging (?) anticline. Some exceptions to these generalizations regarding footwall structure have been observed. The geology of the Gagaryah River area has been mapped in detail by Bundtzen and others (1994), who interpreted the Gagaryah thrust fault as northwest-vergent.

Based on similarities in the ages, lithologies, and thermal maturity of rocks exposed in the Gagaryah window and in the Lime Lakes area, we believe that the structures in the two areas are related and associated with the same system of thrust faults. Some north-northeast-trending linear features visible on false color satellite imagery are continuous through both areas, supporting our interpretation that structures in both areas are related. However, the details of this relation are unclear. Specifically, we have not yet reconciled the presence of Frasnian and younger strata below a major thrust sheet in the Gagaryah River area with our suggestion that the Frasnian through Pennsylvanian package exposed at VABM Trunk has been thrust over the Lower Devonian platform-margin sediments in the Lime Hills. It is possible that the Lime Hills display greater structural relief than the Gagaryah River area and that the algal boundstones and interbedded off-ramp debris are present at depth in the latter area. This is significant as thermally mature strata may be present in the subsurface of this area. Clearly more work is needed to unravel these relations.

Structures in Paleozoic through early Mesozoic strata of the Holitna region are post-Triassic to pre-Cretaceous in age. Gilbert and others (1990) recognized multiple deformational events in correlative rocks exposed in the southwestern part of the Lime Hills D-4 Quadrangle, located north of the Gagaryah River area. The relation between the northwest-vergent structures in the Lime Hills-Lime Lakes-Gagaryah River area and south-vergent structures in the southern Sleetmute quadrangle is unknown, but the relative vergence in these areas suggests counterclockwise rotation of the Holitna Lowland block.

Rocks of the Kuskokwim Group are typically moderately to highly deformed. Structures include north- and northwest-vergent thrust faults, and open to isoclinal folds (Decker and others, 1984; LePain, unpublished field notes). Deformation of the Kuskokwim Group may be related to Late Cretaceous to Tertiary right-lateral motion on the Farewell fault, or may be related to an unrecognized deformation episode.

Petroleum Potential of the Holitna Region

The petroleum potential of an area depends on many factors. The more important factors controlling the accumulation of hydrocarbon in sedimentary basins include: 1. the presence of source rocks capable of generating and expelling hydrocarbons; 2. carrier beds in close proximity to source rocks that are capable of transmitting liquid and gaseous hydrocarbons; 3. reservoir rocks that are in hydraulic communication with carrier beds; 4. reservoir trap and seal couplets capable of forming effective barriers to hydrocarbon migration; and 5. the thermal history of the basin. Moreover, the relative timing of source rock deposition, source rock maturation, petroleum expulsion and secondary migration, deposition of reservoir and seal rocks, and trap formation must be such that hydrocarbons will be concentrated in reservoirs in exploitable quantities. The absence of any of any one of these factors will generally preclude formation of the hydrocarbon deposit.

In the Holitna region, potential reservoir rocks are not difficult to locate. It is conceivable that limestones and dolomites with sufficient primary porosity, secondary porosity, or fracture porosity are present at drillable depths to represent potential reservoirs. Ordovician, Silurian, and Devonian platform-margin algal boundstones may include significant primary porosity, and Lower Devonian dolomitic tidal flat facies, similar to rocks exposed in the Kulukbuk Hills, may include significant seconday porosity. Given the abundance of compressional structures in the region, it is also conceivable that potential reservoir rocks are present in trapping configurations and overlain by reservoir topseals. Finally, at least three areas within the region, the Sleetmute anticlinorium, Lime Lakes, and the Gagaryah window, include thermally mature rocks. However, the absence of source rocks at the surface throughout the region suggests that the petroleum potential is very low. The samples summarized in Tables 1 through 5 show that rocks of various ages and various thermal maturities from widely scattered locations have low to very low total organic carbon contents. The organic material that is present in these rocks is typically inert and incapable of generating liquid or gaseous hydrocarbons. It is important to note that inert kerogen is characteristic of both thermally mature and overmature rocks in the region.

Three samples listed in Table 1 are worth discussing in some detail. Sample 84-TNS-81, collected from the Ordovician shales at Location 5 (Sheet 1) contains 2.28 percent total organic carbon and amorphous sapropel is the dominant kerogen type. Sample 84-JC-62, collected from Ordovician shales exposed on the east side of the Hoholitna River near Location 6 (Sheet 1), contains 1.7 percent total organic carbon and the dominant kerogen type consists of a woody-structured material. The origin of the dominant kerogen type in this sample is unclear, but it may represent some form of marine vegetation that existed during Ordovician time. Sample 83-TNS-11, collected from Silurian-Ordovician deep-water strata exposed on the south side of the Cheeneetnuk River in the northeastern corner of the area shown on Sheet 1 (map unit OSls), contains 3.6 percent total organic carbon. The only kerogen type recognized in this sample is inertinite, which is incapable of generating hydrocarbons. The first two samples contain organic material that is near the oil preservation limit and the third sample contains organic material that is overmature.

Triassic age sedimentary rocks of unknown source rock potential are exposed in the northern Taylor Mountains, immediately south of the project area. The source rock potential of these rocks should be evaluated in the future.

According to the paleogeographic reconstruction outlined above, basinal strata should be present in the subsurface north of the Sleetmute anticlinorium and west of the Lime Hills. This area corresponds to an aeromagnetic high (Sheet 1 and Fig. 7) of unknown affinity. It is possible that the magnetic signature is associated with an isolated rift block. Given the size of the anomaly, it is unlikely to be associated with an intrusive body.

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Table 1. Organic geochemical data from Ordovician through Cretaceous rocks in the Holitna region.

Organic Richness

Station #	Sample Number	Quadrangle	Section, Township, and Range	Map Unit	Latitude and Longitude	Lithology	Total Organic Carbon (wgt. %)	C15+ Total Hic. (ppm)	Kerogen Type: C15+ Bitumen (ppm)	Kerogen Type: Visual Kerogen Assessment	Thermal Maturity: Kerogen Alteration Index (+-5 scale)	Thermal Maturity: Vitrinite Reflectance
1	83-TNS-57	LH A-8	13, 11N, 37W	Kk	61 03' 155 45'	Shale	0.82	*	99	W; H;-	3.3	2.99
2	84-JD-193	LH A-7	22, 11N, 35W	Kk	61 02' 155 28'	Shale	0.98	**	**	Am; I; -	4.3	
3	84-JD-169	LH A-7	24, 11N, 35W	Kk	61 02' 155 25'	Shale	0.67	**	**	Am; I; -	4.3	
4	84-JD-211	LH A-7	19, 11N, 35W	Kk	61 02' 155 23'	Shale	0.93	**	**	Am; I; -	4.3	
5	84-JD-220	LH A-7	34/35, 12N, 35W	Kk	61 05' 155 27'	Shale	0.92	**	**	W -I; -; Am	4.3	
6	84-JD-164	LH A-7	25, 12N, 36W	Kk	61 06' 155 35'	Shale	0.78	7.5e	55	W; - Am - H	3.4	
7	84-JD-263	LH A-7	19, 12N, 36W	Kk	61 07' 155 34'	Shale	0.73	5e	54	W; H; -	2.7	
8	84-JD-140	LH A-7	23, 12N, 36W	Kk	61 07' 155 36'	Shale	0.64	15e	89	H - W; -; -	2.2	
9	84-JD-262	LH A-7	15, 12N, 34W	Kk	61 08' 155 17'	Shale	0.61	3e	80	W; Am - H; -	2.7	
10	83-TNS-88	SM C-4	36, 19N, 44W	Kk	61 42' 157 11'	Shale	1.59	29.4	519	Am(Al); -; W	2.6	0.99
11	83-JD-382	SM B-5	27, 16N, 46W	Kk	61 27' 157 31'	Shale	1.06	**	**	W; H; -	2.3	
12	83-TNS-86	SM B-5	35, 14N, 47W	Kk	61 16' 157 38'	Shale	1.06	**	**	I; -; Am	4.5	
13	83-RR-429	SM A-5	19, 12N, 46W	Kk	61 07' 157 31'	Shale	1.11	**	**	W; H; -	2.4	
14	83-TNS-4	LH D-8	3, 19N, 36W	Udl	61 46' 155 47'	Shale	1.69	**	**	I; -; -	4.4	
15	83-TNS-67	SM B-4	24, 14N, 45W	DSdl	61 17' 157 15'	Dolomite	0.63	*	121	Am; -; -	2.8	
16	LIME-B-1000	LH B-7	33/34, 15N, 35W	Dsab	61 22' 155 33'	Limestone	0.42	*	108	Am; -; -	2.9	
17	83-TNS-11	LH D-7	35, 22N, 33W	OSls	62 58' 155 17'	Shale	3.6	**	**	I; -; -	4.4	
18	83-TNS-24	LH B-8	12,16N, 37W	OSls	61 29' 155 50'	Shale	0.67	*	101	W; H; Am	3.2	2.09
19	84-TNS-43	SM B-3	2, 14N, 42W	OSls	61 20' 156 45'	Shale	0.42	**	**	Am; -; W	2.9	
20	84-JC-64	SM B-2/B-3	2, 14N, 42W	OSls	61 20' 156 45'	Shale	0.98	11.5e	77	Am; W; H	2.8	
21	83-TNS-93	SM A-2	6, 13N, 41W	OSls	61 15' 156 42'	Shale	0.89	*	96	Am; -; -	3.1	
22	84-JC-63	SM A-2/B-2	6, 13N, 41W	OSls	61 15' 156 42'	Shale	0.62	5e	54	Am; W; H	2.8	
23	84-TNS-85	SM A-2	6, 13N, 41W	OSls	61 14' 156 42'	Shale	0.47	6e	53	Am(Al); W; H	2.8	
24	84-TNS-85A	SM A-2	6, 13N, 41W	OSls	61 14' 156 42'	Shale	0.41	**	**	Am - W; -; H	2.8	
25	84-TNS-85B	SM A-2	6, 13N, 41W	OSls	61 14' 156 42'	Shale	0.86	12e	81	W; Am(Al) - H; -	2.9	
26	84-JC-62	SM A-2	8, 13N, 41W	OSls	61 13' 156 40'	Shale	1.7	5.5e	58	W; Am - H; -	3.1	
27	84-TNS-81	SM A-2	18, 12N, 41W	OSls	61 08' 156 38'	Shale	2.28	40e	180	Am - H -: W; -; -	2.4	
28	83-TNS-95	SM A-2	18, 12N, 41W	OSls	61 07' 156 38'	Shale	0.54	*	83	Am; -; -	2.8	

*Too small to measure
**Not analyzed
All data from GeoChem Laboratories, Inc.

Kerogen
Al = Algal
Am = Amorphous-Sapropel
H = Herbaceous-membraneous

W = Woody-structured
I = Intertinite
\- = Not clearly defined population

LH = Lime Hills Quadrangle
SM = Sleetmute Quadrangle
Map unit abbreviations are defined on Sheet 1.

Table 2. Summary of C15+ Soxhlet Extraction, Deasphaltening, and Liquid Chromatography for Samples Collected in 1984

A. Weights of Extracts and Chromatographic Fractions

Sample Number	Weight of Rock Extracted (grams)	Total Extract (grams)	Precipitated Asphaltenes (grams)	N-C5 Soluble (grams)	Sulfur (grams)	Paraffins-Napthenes (grams)	Aromatics (grams)	Eluted NSOs (grams)	Noneluted NSOs (grams)
84-JC-62-G	100.0	0.0058	0.0047	0.0011	ND	ND	ND	ND	ND
84-JC-63-G	100.0	0.0054	0.0044	0.0010	ND	ND	ND	ND	ND
84-JC-64-G	100.0	0.0077	0.0054	0.0023	ND	ND	ND	ND	ND
84-JD-140-A	100.0	0.0089	0.0059	0.0030	ND	ND	ND	ND	ND
84-JD-164-A	100.0	0.0055	0.0040	0.0015	ND	ND	ND	ND	ND
84-JD-262-B	43.5	0.0035	0.0032	0.0003	ND	ND	ND	ND	ND
84-JD-263-A	100.0	0.0054	0.0044	0.0010	ND	ND	ND	ND	ND
84-TNS-81-G	100.0	0.0180	0.0100	0.0080	ND	ND	ND	ND	ND
84-TNS-85-G	100.0	0.0053	0.0041	0.0012	ND	ND	ND	ND	ND
84-TNS-85-G-B	100.0	0.0081	0.0056	0.0025	ND	ND	ND	ND	ND

B. Concentrations of Extracted Materials in Rock

		Hydrocabons				Nonhydrocarbons			
Sample Number	Total Extract (ppm)	Paraffin-Naphthene (ppm)	Aromatic (ppm)	Total (ppm)	Sulfur (ppm)	Precipitated Asphaltenes (ppm)	Eluted NSOs (ppm)	Noneluted NSOs (ppm)	Total (ppm)
84-JC-62-G	58.0			5.5e		47			
84-JC-63-G	54.0			5 e		44			
84-JC-64-G	77.0			11.5e		54			
84-JD-140-A	89.0			15 e		59			
84-JD-164-A	55.0			7.5e		40			
84-JD-262-B	80.00			3 e		74			
84-JD-263-A	54.00			5 e		44			
84-TNS-81-G	180.00			40 e		100			
84-TNS-85-G	53			6 e		41			
84-TNS-85-G-B	81			12 e		56			

C. Composition of Extracts

	Hydrocabons				**Nonhydrocarbons**				
Sample Number	Paraffin-Naphthene (percent)	Aromatic (percent)	PN/Aromatic	Sulfur (percent)	Eluted NSOs (percent)	Noneluted NSOs (percent)	Precipitated Asphaltenes (percent)	Asphaltene/NSO	HCs
84-JC-62-G							81		
84-JC-63-G							81.5		
84-JC-64-G							70.1		
84-JD-140-A							66.3		
84-JD-164-A							72.7		
84-JD-262-B							91.4		
84-JD-263-A							81.5		
84-TNS-81-G							55.6		
84-TNS-85-G							77.4		
84-TNS-85-G-B							69.1		

Sample locations are listed in Table 1.
All analyses by GeoChem Laboratories, Inc.

Table 3. Summary of C15+ Soxhlet Extraction, Deasphaltening, and Liquid Chromatography for Samples Collected in 1983

A. Weights of Extracts and Chromatographic Fractions

Sample Number	Weight of Rock Extracted (grams)	Total Extract (grams)	Precipitated Asphaltenes (grams)	N-C5 Soluble (grams)	Sulfur (grams)	Paraffins-Napthenes (grams)	Aromatics (grams)	Eluted NSOs (grams)	Noneluted NSOs (grams)
83-TNS-24G	100.0	0.0101	0.0079	0.0022	ND	ND	ND	ND	ND
83-TNS-57G	94.6	0.0094	0.0072	0.0022	ND	ND	ND	ND	ND
83-TNS-67G	100.0	0.0121	0.0095	0.0026	ND	ND	ND	ND	ND
83-TNS-88G	82.6	0.0429	0.0156	0.0273	ND	0.0154	0.0089	0.0020	0.0010
83-TNS-93G	100.0	0.0096	0.0069	0.0027	ND	ND	ND	ND	ND
83-TNS-95G	100.0	0.0083	0.0064	0.0019	ND	ND	ND	ND	ND
LIME HILLS LINE B 1000G	100.0	0.0108	0.0073	0.0035	ND	ND	ND	ND	ND

B. Concentrations of Extracted Materials in Rock

		Hydrocabons				Nonhydrocarbons			
Sample Number	Total Extract (ppm)	Paraffin-Naphthene (ppm)	Aromatic (ppm)	Total (ppm)	Sulfur (ppm)	Precipitated Asphaltenes (ppm)	Eluted NSOs (ppm)	Noneluted NSOs (ppm)	Total (ppm)
83-TNS-24G	101					79			
83-TNS-57G	99					76			
83-TNS-67G	121					95			
83-TNS-88G	519	186	108	294		189	24	12	225
83-TNS-93G	96					69			
83-TNS-95G	83					64			
LIME HILLS LINE B 1000G	108					73			

C. Composition of Extracts

	Hydrocabons				Nonhydrocarbons					
Sample Number	Paraffin-Naphthene (percent)	Aromatic (percent)	PN/Aromatic	Sulfur (percent)	Eluted NSOs (percent)	Noneluted NSOs (percent)	Precipitated Asphaltenes (percent)	Asphaltene/NSO	HCs	HC/Non HC
83-TNS-24G							78.2			
83-TNS-57G							76.6			
83-TNS-67G							78.5			
83-TNS-88G	35.9	20.7	1.73		4.7	2.3	36.4	5.2	56.6	1.31
83-TNS-93G							71.9			
83-TNS-95G							77.1			
LIME HILLS										
LINE B 1000G							67.6			

Sample locations are shown in Table 1.
All analyses by GeoChem Laboratories, Inc.

Table 4. C1-C7 Cuttings Analysis by Gas Chromatography.

Sample #	Quad.	Section, Township, Range	Methane	Ethane	Ethylene	Propane	Propylene	Isobutane	N Butane	C5-C7
84-JC-62-G			1017.44	9.08	0.00	1.62	0	0.38	0.43	0
84-JC-63-G			1508.48	9.43	0.00	1.45	0	0.23	0.23	0
84-JC-64-G			3003.71	19.86	0.00	1.37	0	0.11	0	0
84-JD-140--A			951.43	8.46	0.00	2.64	0	0.82	0.5	0
84-JD-164-A			1486.21	8.15	0.00	0.89	0	0.12	0	0
84-JD-263-A			1133	13.33	0.00	3.46	0	0.8	0.42	0
84-TNS-25-G	SM A-2	35, 12N, 42W	7534.25	2824.86	0.00	1126.17	1.05	262.06	356.14	902.08
84-TNS-30-G	SM A-2	26, 12N, 42W	5278.84	2736.87	0.00	1193.74	0.45	257.13	380.16	748.29
84-TNS-38-G	SM A-3	6, 11N, 42W	9702.42	913.59	0.00	215.06	1.18	24.27	57.13	79.74
84-TNS-76-G	SM A-2	13, 11N, 41W	3172.11	4.48	0.00	0.78	0	0.16	0.33	3.87
84-TNS-80-G	SM A-2	18, 12N, 41W	5708.5	61.91	0.00	7.48	0.11	1.5	1.8	10.55
84-TNS-81-G	SM A-2	18, 12N, 41W	1494.42	94.48	0.00	28.65	0.22	5.43	4.56	4.5
84-TNS-85-G			1992.32	15.45	0.00	1.86	0	0.25	0	0
84-TNS-85-G-B			802.7	3.94	0.00	0.65	0	0.08	0	0
84-TNS-91-G	SM A-4	14, 11N, 45W	1372.76	27.78	0.00	10.07	0.22	2.76	3.37	12.96
84-TNS-100-G	SM A-2	36, 13N, 42W	9073.33	172.47	0.00	55.54	0.53	20.06	25.99	82.53
84-TNS-101-G	LH B-6	32, 16N, 33W	59077.23	1656.26	0.00	483.27	0.83	292.47	201.77	910.94
84-TNS-82-G	SM A-2	4, 12N, 40W	5166.31	737.63	0.00	187.2	0.79	35.53	66.27	126.72
IL-78	SM A-4	29, 12N, 46W	32884.81	928.64	0	153.6	0	37.37	40.64	43.14

Location information not included in this table is listed in Table 1.
Analyses by GeoChem Laboratories, Inc.

Table 5. Organic carbon and Rock-Eval Pyrolysis Data for Samples Collected During 1998 Field Season.

Sample #	Quad.	Section, Township, Range	Map Unit	Sample Weight	Total Organic Carbon	S1	S2	S3	Tmax	S1/TOC	Hydrogen Index	Oxygen Index	S2/S3	PI
98DL64-2	SM A-3	7, 11N, 42W	CZls		0.09									
98DL73-1	TM D-1	3, 10N, 39W	OSls		0.24									
98DL81-3	LH B-6	32, 16N, 33W	UDl		0.09									
98DL94-1	LH B-6	33, 16N, 33W	UDl		0.17									
98DL97-4	LH B-6	12, 16N, 33W	JRsh	100.8	0.67	0.09	0.48	0.28	442	13	72	42	1.71	0.16
98DL97-5	LH B-6	12, 16N, 33W	JRsh	101.8	1.05	0.04	0.23	0.17	472	4	22	16	1.35	0.15
98DL98-1	LH B-7	5, 14N, 35W	DSdl		0.12									
98DL99-2	LH B-7	36, 16N, 34W	PMi	102.1	0.56	0	0.02	0.18	332	0	4	32	0.11	0
98DL100-4	LH B-7	25, 16N, 34W	UDl		0.35									
98DL101-1	LH B-6	9, 16N, 33W	PMi		0.04									
98DL102-1	LH C-6	31, 17N, 32W	TRb	107.6	1.36	0.06	0.89	0.72	440	4	65	53	1.24	0.06
98DL103-1	LH C-6	24, 17N, 33W	PMi		0.22									
98DL104-2	LH C-6	25, 17N, 33W	PMi		0.09									
98DL105-1	LH C-6	8, 17N, 32W	UDl		0.16									
98DL106-1	LH C-8	18, 17N, 35W	OSls		0.1									
98DL108-3	LH C-6	2, 17N, 32W	OSls		0.11									
98DL109-3	LH C-6	2, 17N, 32W	OSls		0.15									
98DL111-1	LH C-6	18, 17N, 32W	UDL		0.12									
98DL112-1	LH C-6	7, 17N,32W	UDl		0.21									
98DL112-2	LH C-6	7, 17N, 32W	UDl		0.13									
98DL113-1	LH C-6	4, 17N, 32W	UDl		0.06									
98DL114-1	LH C-6	17, 17N, 32W	UDl		0.07									
98JC202	SM A-2	28, 11N, 42W	CZls		0.05									
98JC206	SM A-3	6, 11N, 42W	OSls		0.2									
98JC207	TM D-1	3, 10N, 39W	OSls		0.17									
98JC208	SM A-1	5,11N, 39W	IPzl		0.09									
98RB26	LH B-7	35, 16N, 34W	UDl		0.17									
98RB51	LH B-6	32, 16N, 33W	PMi		0.1									
98RB63	LH B-7	36, 16N, 34W	PMi		0.3									
98TR6	SM A-3	7, 11N, 42W	OSld		0.08									
98TR9	TM D-1	3,10N, 39W	OSld	101.1	1.27	0	0.04	1.75	428	0	3	138	0.02	0

Map unit symbols defined on Sheet 1.
Geochemical analyses by DGSI, Inc., Houston, TX

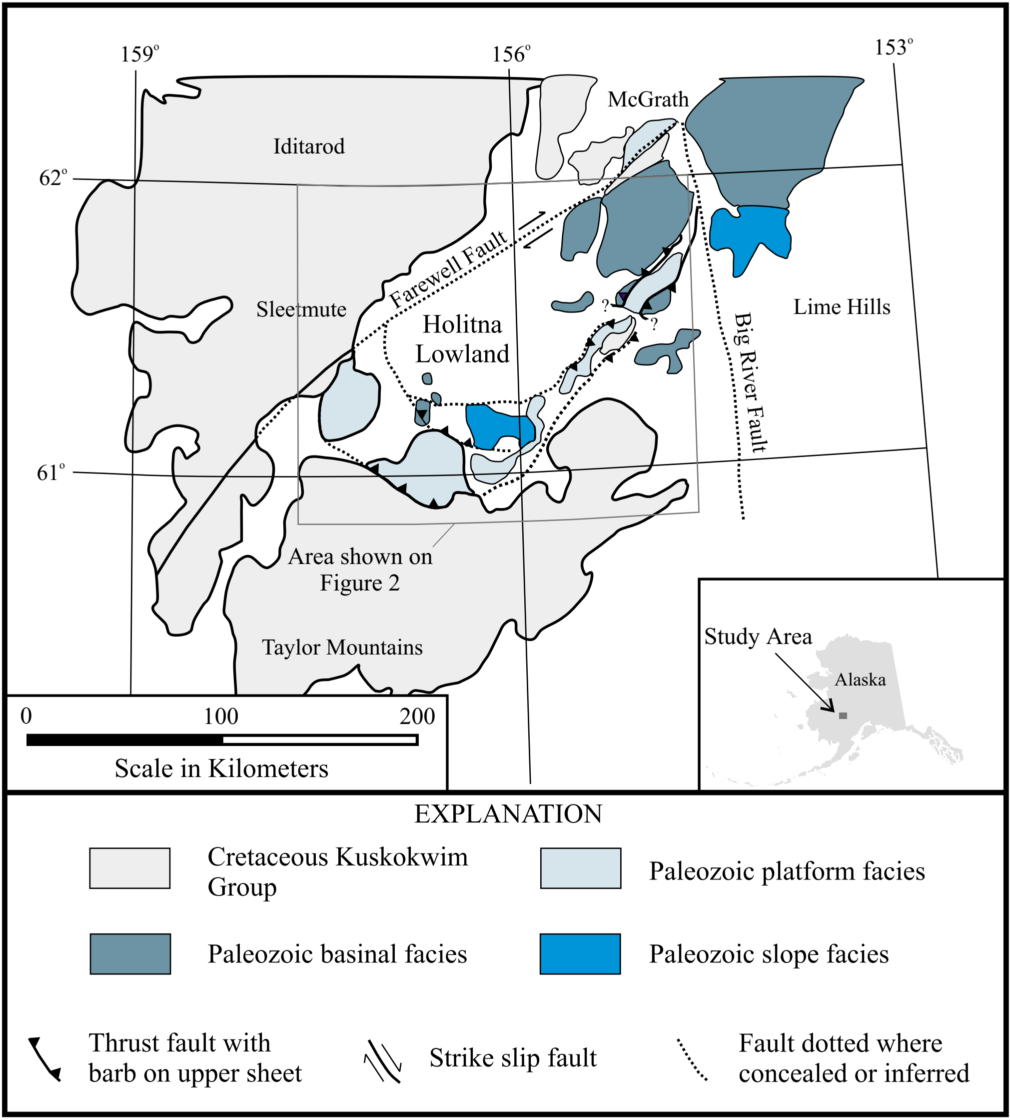


Figure 1. Map showing the location and generalized geology of the Holitna Lowland and surrounding hills discussed in this report. The study area straddles the Lime Hills, Sleetmute, and Taylor Mountains 1:250,000-scale quadrangles

PALEOZOIC			
Period/System	Epoch	Age / Stage	Series
Permian	Late	Tartarian	Upper
		Kazanian	
		Ufimian	
	Early	Kungurian	Lower
		Artinskian	
		Sakmarian	
		Asselian	
Pennsylvanian	Late	Gzelian	Upper
		Kasimovian	
	Middle	Moscovian	Middle
	Early	Bashkirian	Lower
Mississippian	Late	Serpukhovian	Upper
	Middle	Visean	Middle
	Early	Tournaisian	Lower
Devonian	Late	Famennian	Upper
		Frasnian	
	Middle	Givetian	Middle
		Eifelian	
	Early	Emsian	Lower
		Siegenian	
		Gedinnian	
Silurian	Late	Pridolian	Upper
		Ludlovian	
	Early	Wenlockian	Lower
		Llandoverian	
Ordovician	Late	Ashgillian	Upper
		Caradocian	
	Middle	Llandeilan	Middle
		Llanvirnian	
	Early	Arenigian	Lower
		Tremadocian	

MESOZOIC			
Period/System	Epoch	Age / Stage	Series
Cretaceous	Late	Maastrictian	Upper
		Campanian	
		Santonian	
		Coniacian	
		Turonian	
		Cenomanian	
	Early	Albian	Lower
		Aptian	
		Barremian	
		Hauterivian	
		Valanginian	
		Berriasian	
Jurassic	Late	Tithonian	Upper
		Kimmeridgian	
		Oxfordian	
	Middle	Callovian	Middle
		Bathonian	
		Bajocian	
		Aalenian	
	Early	Toarcian	Lower
		Pliensbachian	
		Sinemurian	
		Hettangian	
Triassic	Late	Norian	Upper
		Carnian	
	Middle	Ladinian	Middle
		Anisian	
	Early	Scythian	Lower

Figure 2. Age (time units) and stage (time-stratigraphic units) terms for the Paleozoic and Mesozoic. Cambrian stages are not referred to in the text and are not included in this figure.

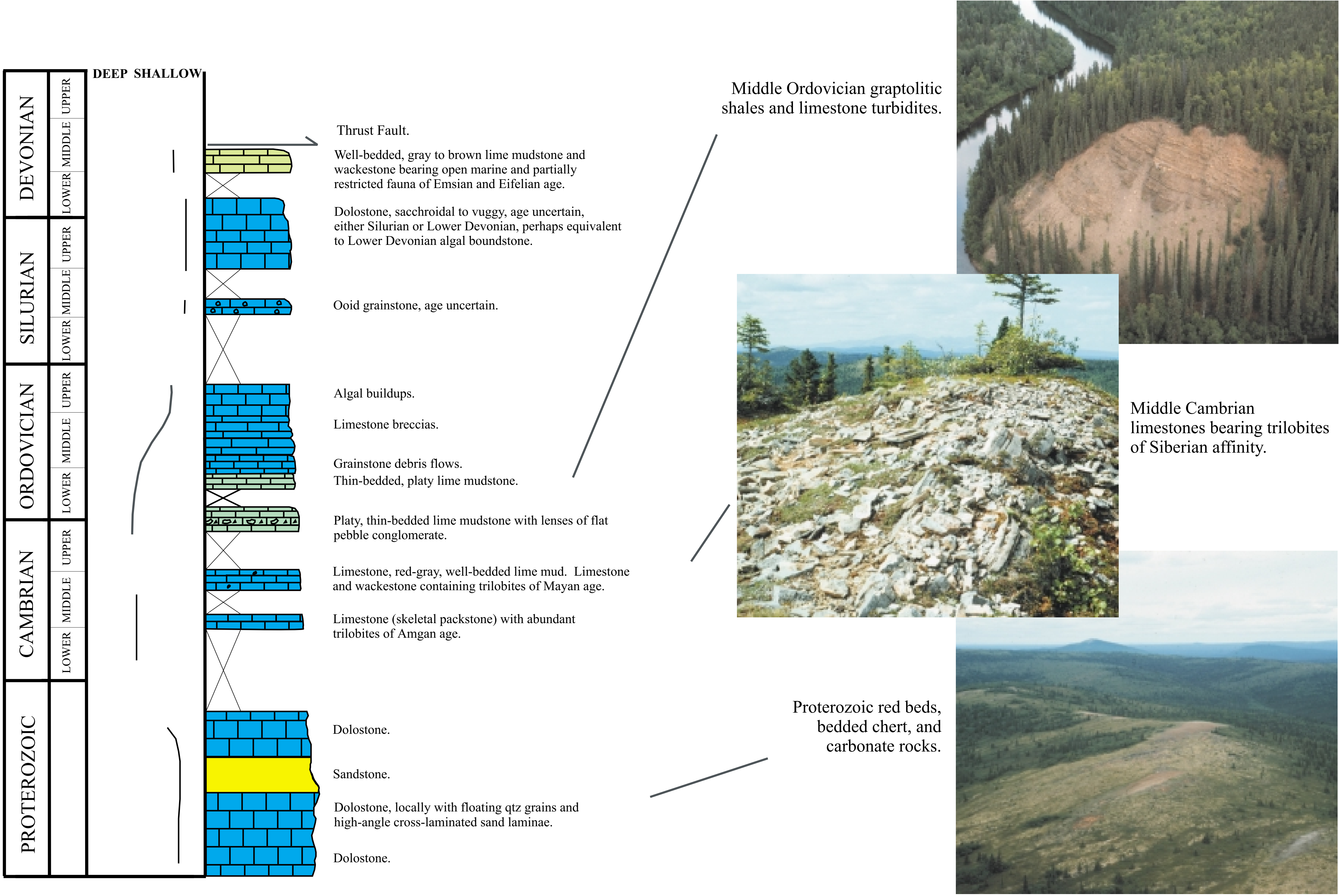
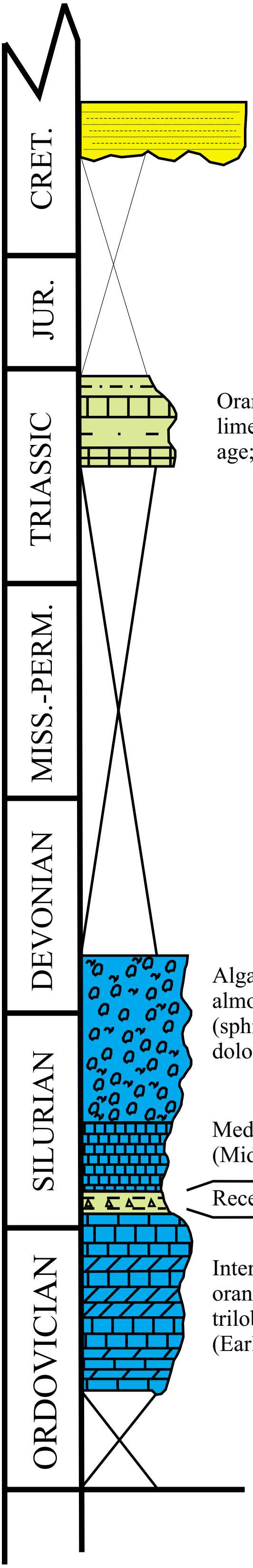


Figure 3. Generalized stratigraphic column for the north side of the Sleetmute anticlinorium.



Kuskokwim Group, interbedded graywacke sandstones and shale. Upper Cretaceous age.

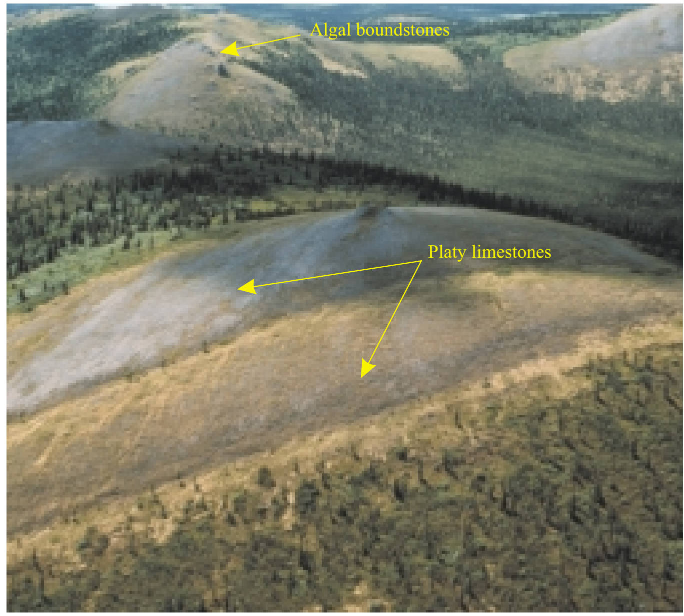
Orange-brown weathering, medium to thin bedded, platy calcareous siltstone and interbedded platy lime wackestone to mudstone; bears bivalves, brachiopods, belemnites, and conodonts of Late Triassic age; minimum thickness 20 - 30 meters.

Algal boundstone; light gray weathering, thick to massive bedded algal framestone/limestone; composed almost wholly of algal stromatolite and thrombolite limestone; contains brachiopods and Aphrosalpink (sphinctozoan sponge) in lower part indicative of Late Silurian age; minimum thickness 400 - 500 meters; dolostone present locally in upper part of unit.

Medium gray weathering; thin to medium bedded, platy limestones; contains graptolites of Wenlockian (Middle Silurian) thickness about 100 meters; contains abundant carbonate debris flows near top of unit.

Recessive unit (poorly exposed) of shale and chert; thickness about 50 - 100 meters

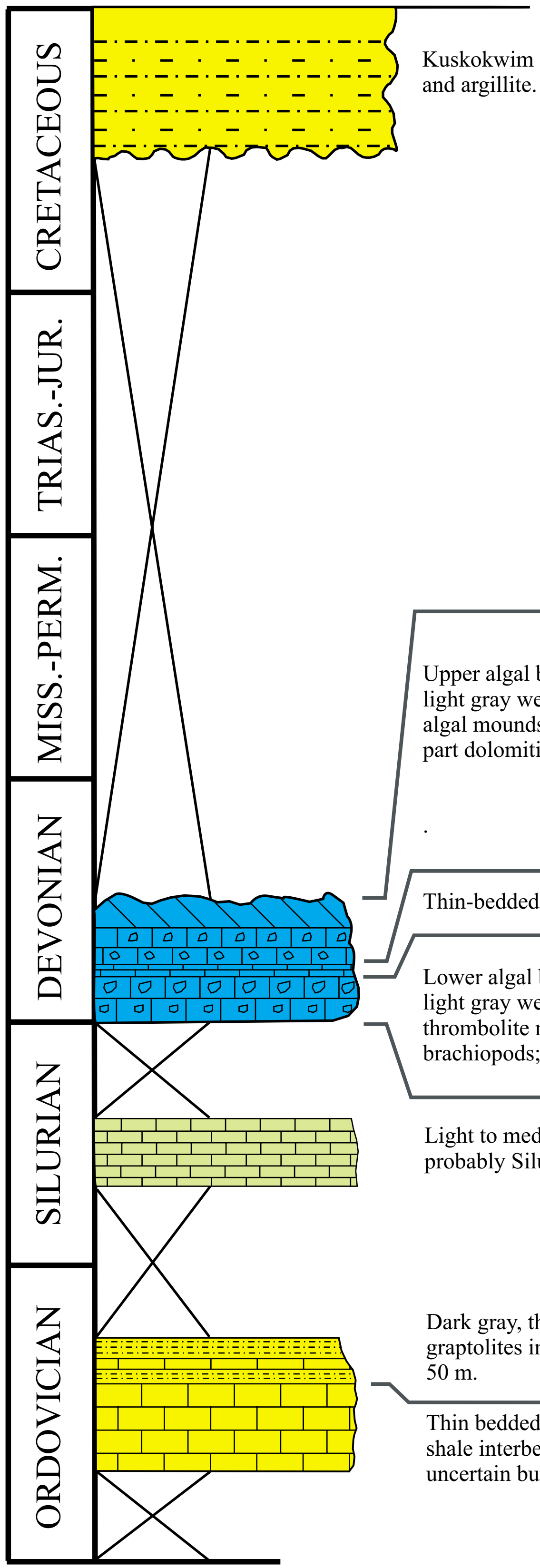
Interbedded limestone, limey dolostone, and dolostone. Limestone is light to med. gray weathering; dolostones are orange-gray weathering; med. to thick bedded; dolostone locally vuggy; contains fossil fauna (brachiopods, trilobites, gastropods, and conodonts) indicative of Middle and Late Ordovician age; as well as Llandoverian (Early Silurian) age. Minimum thickness 300 - 400 meters.



Upper Silurian platy limestones overlain by Upper Silurian algal boundstone in Taylor Mountains A-1. Quadrangle.

Middle and Upper Ordovician carbonate rocks exposed along ridge in Taylor Mountains Quadrangle.

Figure 4. Generalized stratigraphic column for the south side of the Sleetmute anticlinorium.



Kuskokwim Group, interbedded graywacke sandstones and argillite. Upper Cretaceous age.

Upper algal boundstone units; med. to massive bedded algal limestone; light gray weathering, composed primarily of stromatolitic-thrombolitic algal mounds; contains Lochkovian (Early Devonian) brachiopods; upper part dolomitic. Minimum thickness 500 m

.

Thin-bedded platy lime mudstone unit; thickness about 130 m.

Lower algal boundstone unit is med.- to thick- bedded algal limestone; light gray weathering; composed primarily of algal stromatolite and thrombolite mounds; contains Lochkovian (early Early Devonian) age brachiopods; minimum thickness 400 m.

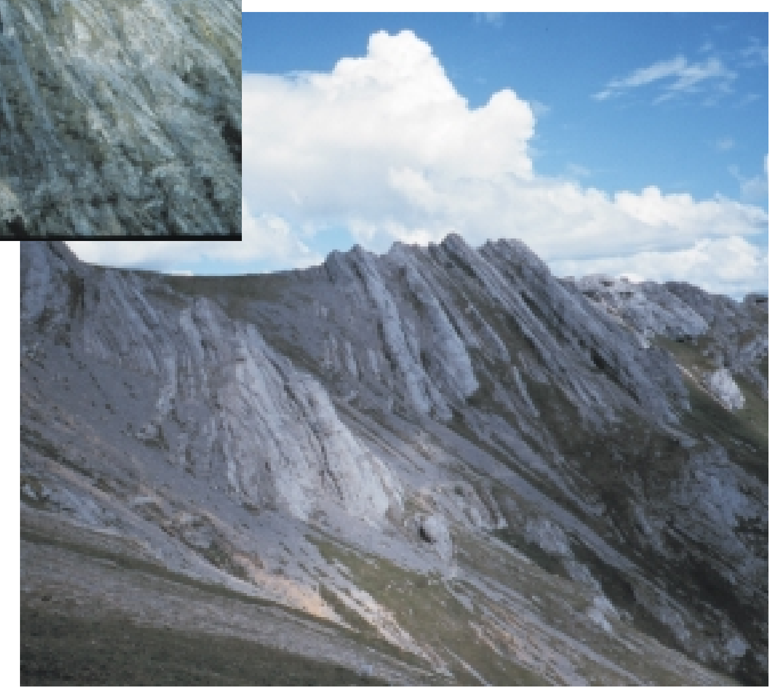
Light to med gray weathering, platy lime mudstone; age uncertain, probably Silurian; minimum thickness 100 m.

Dark gray, thin bedded silty shale, siltstone and sandstone; contains graptolites indicative of Middle Ordovician age, minimum thickness 50 m.

Thin bedded, platey lime mudstone, light gray weathering, contains shale interbeds in upper part of unit; minimum thickness 200 m.; Age uncertain but probably Ordovician.

Folded platy limestone. Fold overturned toward the northwest. Slope facies thrust over platform margin facies. Fold asymmetry suggests vergence toward northwest, opposite that shown on Panel 3. View toward the north-northwest.

Platform-margin algal boundstone near shelf edge. View toward the east-southeast.



Interbedded platform-margin algal boundstone and slope debris flow facies. View toward the north-northeast.

Figure 5. Generalized stratigraphic column of the Lime Hills-Why Lake area.

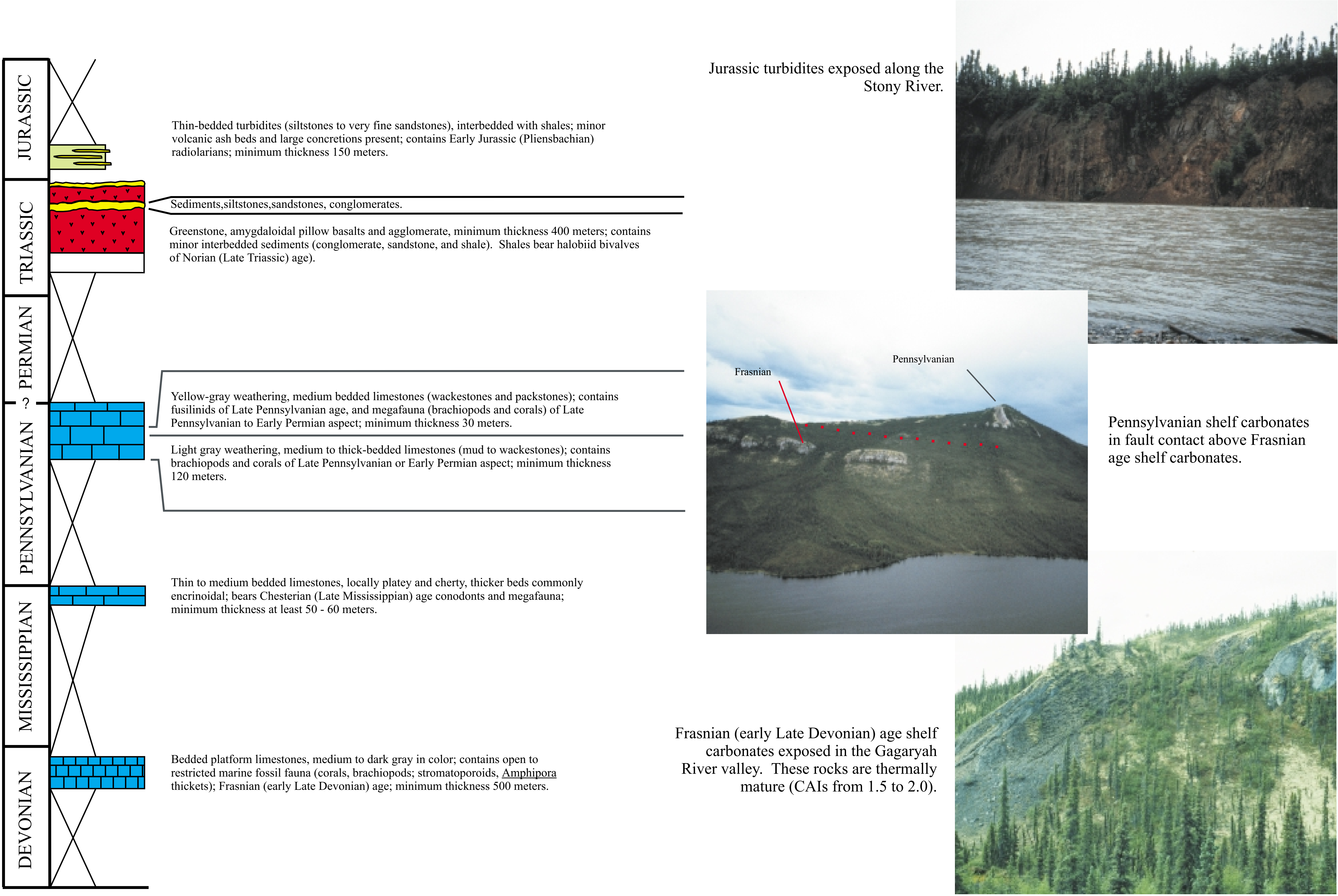


Figure 6. Generalized stratigraphic column of the Lime Lakes-Gagaryah River area.

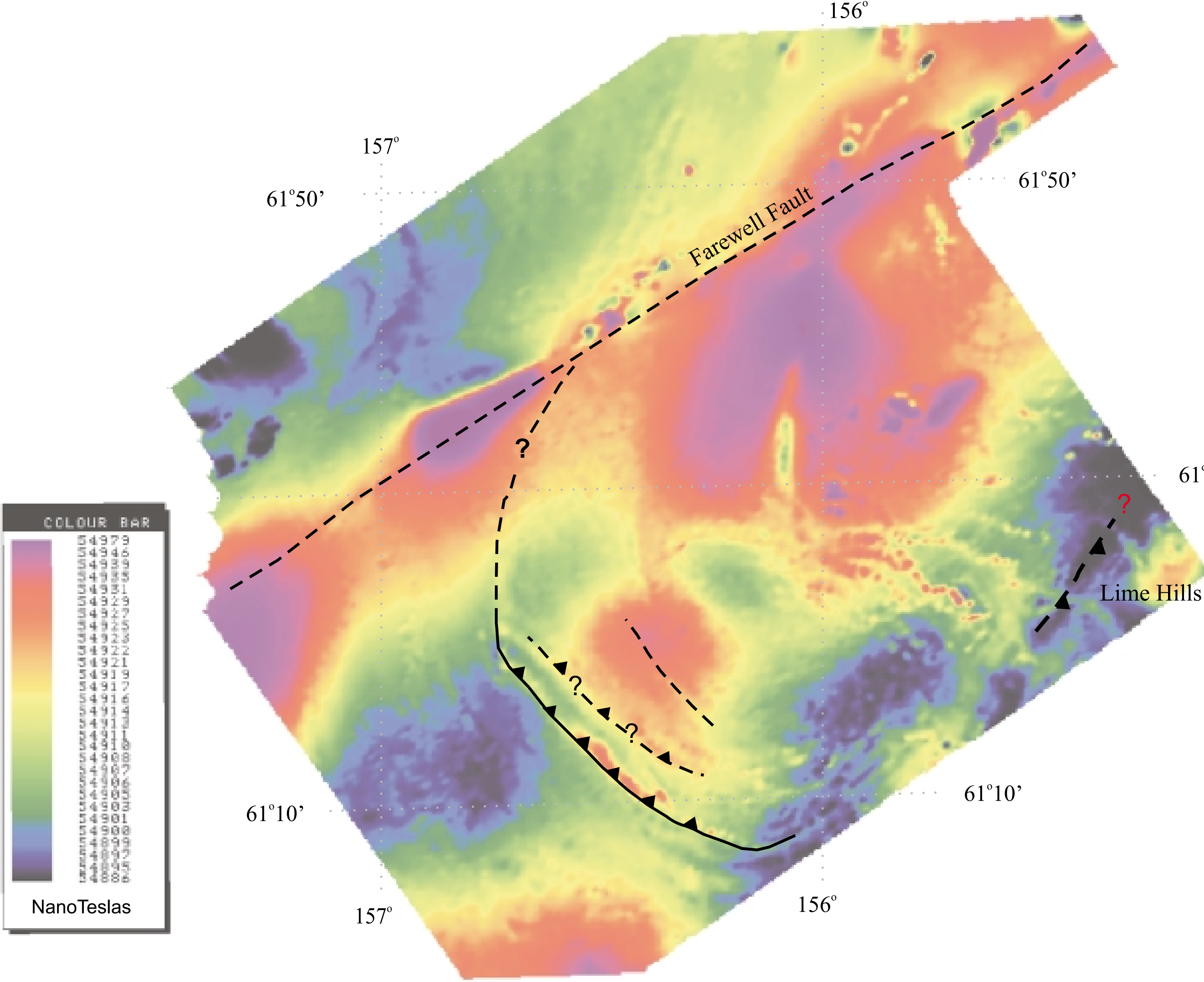


Figure 7. Aeromagnetic survey results for the Holitna region. Note the aeromagnetic high north of 61°10' north latitude and centered on 156° west longitude. The origin of this high is unknown. The linear trends visible in the sourthern part of the survey area correspond to south- and southwest-vergent fold and thrust structures shown in the DSL Dab units on Figure 2. Faults are dashed where concealed or inferred, and barbs are shown on upper sheet for thrust faults. The aeromagnetic survey results are available from DGGS as Public-Data File 98-29.