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**SEDIMENTOLOGY AND HYDROCARBON SOURCE ROCK
POTENTIAL OF MIOCENE-OLIGOCENE STRATA,
McGRATH QUADRANGLE: AN OUTCROP ANALOG FOR THE
HOLITNA BASIN**

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INTRODUCTION

This report summarizes the Alaska Division of Geological & Geophysical Survey's (DGGS) Holitna Basin Shallow Gas project. The Holitna basin is located in southwestern Alaska, in the northeastern and northwestern quarters of the Sleetmute and Lime Hills quadrangles, respectively (Figure 1). The goal of the project was to evaluate the shallow gas potential of the Holitna basin to the extent possible given the absence of exposures of basin-filling strata and subsurface data (i.e. seismic reflection and test well data). A small gas resource in the basin could represent a significant source of energy for local use, particularly as a fuel for mine operations at the Donlin Creek prospect in the southern Iditarod Quadrangle (Fig. 1). This report does not address the economics of developing shallow gas in the Holitna basin.

With this goal in mind, DGGS developed a basin analysis approach that utilized outcrops of Tertiary strata in the southern McGrath Quadrangle that are presumed to be similar to the subsurface fill of the Holitna basin, and two potential field geophysical datasets (airborne magnetic data and a regional gravity survey). The Holitna basin is entirely a subsurface feature – its presence is inferred from regional gravity data that show an elongate northeast-trending, tear drop-shaped gravity low astride the Farewell fault zone (Kirschner, 1994; Meyer and Krouskop, 1984; Fig. 1). The relation, if any, between the Tertiary section in outcrop and the subsurface section in the Holitna basin is unknown. This poses a significant challenge in trying to assess the relevance of outcrop data to the stratigraphy of the Holitna basin and its shallow gas potential.

The objectives of this study include:

1. Utilize available geophysical datasets to evaluate the deep structure and sedimentary fill of the Holitna basin.
2. Conduct detailed stratigraphic studies of the Tertiary section exposed along the northwestern side of the Alaska Range [front] in southern and central McGrath Quadrangle to help evaluate the petroleum reservoir and source rock potential of the Tertiary section. This is based on the assumption that exposures of Tertiary strata represent an outcrop analog for the fill of the Holitna basin.
3. Attempt to relate the outcrop section in the McGrath Quadrangle to the subsurface Holitna basin.

4. Use the above data to make inferences regarding the shallow gas potential of the Holitna basin (conventional gas and coalbed methane).

The following sections summarize the regional geology of both the Holitna basin and outcrop belt to the northeast, the stratigraphy and sedimentology of the Tertiary section in outcrop, reservoir potential of conglomerates and sandstones, organic geochemical data, and the petroleum potential of the Holitna basin inferred from outcrop studies.

REGIONAL GEOLOGY AND PREVIOUS WORK

The existence of the Holitna basin is inferred from regional gravity data that show a pronounced Bouguer gravity low in excess of -40 mGals (Meyer and Krouskop, 1984) (Fig. 1). This gravity low is situated astride the Farewell fault zone (Kirschner, 1994), the western continuation of the Denali fault system (DFS) in southwestern Alaska. Gravity modeling suggests a thickness of up to 4,600 m of Tertiary age sedimentary rocks in the basin (Smith and others, 1985; Cady, written communication, 2001). The magnitude of the gravity low decreases toward the northeast, suggesting a corresponding decrease in the thickness of the Tertiary strata. The basin is bounded to the north and west by outcropping Cretaceous strata of the Kuskokwim Group, and to the southwest, south, and east by outcropping Paleozoic strata of the Nixon Fork and Dillinger sequences (Farewell terrane of Decker and others, 1994) (Bundtzen and others, 1994; Decker and others, 1995; and Gilbert, 1981) (Fig. 1). No exposures of the basin fill are known from the interior of the basin or along the basin margin, and no subsurface data (e.g. well or seismic) are available. The character and age of the basin fill are thought to be similar to Tertiary strata exposed along the northwestern flank of the Alaska Range [front] in the McGrath Quadrangle northeast of the basin (Fig. 1).

Discontinuous exposures of Tertiary sedimentary rocks are present northeast of the Holitna basin from the upper Cheeneetnuk River, southwest of White Mountain, to the Little Tonzona River (Fig. 1). Geologic mapping by Bundtzen and others (1997), Dickey (1982), and Gilbert (1981) show Tertiary strata along this trend in fault-bounded slivers associated with the Farewell fault zone. Near the southwest end of the outcrop belt, Priestley (cited in Brooks, 1911) reported considerable quantities of lignitic coal in the valley of the Big River from his trip through the region in 1909. Sainsbury (1965) and Sainsbury and MacKevett (1965), working in the White Mountain–Cheeneetnuk

River headwaters area a few kilometers west of the Big River, described at least 2,500 m (8,100 feet) of Cretaceous (?) conglomerate that they interpreted as down-faulted against older Paleozoic strata. These workers made no mention of coal or carbonaceous mudstone. Gilbert (1981) subsequently mapped these rocks (his map unit Tcg) and assigned a Tertiary age based on similarities with the Usibelli Group, a late Eocene to Miocene coal-bearing succession exposed in the foothills north of the central Alaska Range (Wahrhaftig and others, 1969; Wahrhaftig, 1987). Analysis of pollen samples recently collected from siltstones interbedded with the conglomerates suggest the Tertiary section near White Mountain is late Oligocene to possibly earliest Miocene (Ridgway and others, 2000). Our station 00DL56 corresponds to the exposure studied by Ridgway and others (2000).

W.H. Condon (cited in Barnes, 1967) reported a 2-m-wide exposure of bright, brittle coal along the bank of the Cheeneetnuk River, southwest of White Mountain, and stated that exposures of coal continue for several miles along the river. Gilbert (1981) mapped these exposures (his map unit uTs), located 17 to 25 km (10 to 15 miles) southwest of White Mountain, and considered them late Miocene in age based on plant megafossils (identified by the late Dr. Daniel Axelrod). Our station 00DL57 is located along a low, overgrown riverbank exposure on the north side of the Cheeneetnuk River, in Gilbert's (1981) unit uTs.

Herreid (1968) described exposures of pebble conglomerate on the west bank of the Windy Fork (Fig. 1) that he interpreted as Tertiary, but did not provide details on their stratigraphy (Fig. 1). Sloan and others (1979) subsequently measured and described the upper 268 m of the Windy Fork section (our station 00DL34), which includes thick intervals of claystone with numerous thin interbeds of bone (high ash content), bony coal (very high ash content), and coal, and several interbeds of sandstone.

Player (1976) conducted a helicopter reconnaissance of the Tertiary outcrop belt from the Cheeneetnuk River to the Little Tonzona River in 1970. Player (1976) provided the first description of the coal-bearing section in the Little Tonzona–Deepbank Creek area. According to Player, an isolated exposure with a total stratigraphic thickness of 60 m is present on the west bank of the Little Tonzona River, 30 m of which is clean subbituminous coal (our station 00DL28). Player described another exposure located 7 km west-southwest of the Little Tonzona River exposure, along an unnamed creek (tributary of Deepbank Creek, McGrath C-1 Quadrangle; our station 00DL43). Sloan and

others (1979) measured and described the coal-bearing sections at both locations and provided coal quality data (proximate and ultimate analyses).

Dickey (1982, 1984) and Ridgway and others (2000) provided the first detailed sedimentologic descriptions of the Tertiary section in outcrop. Dickey (1982) recognized three distinct Tertiary units between the Windy and Middle Forks of the Kuskokwim River (Fig. 1), including from oldest to youngest: a conglomerate, sandstone, siltstone, shale, and coal unit (unit Tqa); a limestone conglomerate (unit Tcl); and a felsite conglomerate (unit uTcf). The relative age of these units is inferred from field relations as no continuous section through the three units is known. Along the Windy and Middle forks Dickey (1982, 1984) measured 1,700 m and 650 m, respectively, of conglomerate, sandstone, siltstone, shale, carbonaceous shale, and coal in map unit Tqa. The ages of Dickey's three map units are poorly constrained. Dickey (1982, 1984) cited an ARCO in-house palynologic report that assigned an Oligocene age to Tertiary strata within his unit Tqa (location information is not provided). Solie and others (1991) reported a K-Ar date of 45.5 Ma (middle Eocene) from a dike that intruded coal-bearing mudstones between Windy and Middle forks. These mudstones occur in a fault-bounded mass approximately 1.5 km south of Dickey's unit Tqa (Solie and others, 1991). Dickey (1982 and 1984) did not provide information on the stratigraphy and sedimentology of units Tcl and uTcf.

High-angle faults mark the base of unit Tqa at both locations studied by Dickey, and the Tertiary strata at both places are overlain by a veneer of Quaternary outwash and Recent alluvium. At both locations Tertiary strata generally dip northward, with the exception that a southwest-trending synclinal axis is present near the north end of the Windy Fork exposure. There the northernmost ¼ mile of outcrop consists of south-dipping strata. Dickey (1984) noted that the succession at both locations fines-upward and is capped by thick shale, carbonaceous shale, and coal sequences. Dickey (1984) interpreted the clastic succession as the product of south-flowing braided streams that were separated by low-lying swamp and lacustrine settings. High-angle faults bound units Tcl and uTcf (Dickey 1982).

Ridgway and others (2000) measured nearly 500 m of conglomerate, sandstone, and mudstone exposed along ridgetops immediately south of the Farewell fault near the White Mountain mine (part of the Cretaceous (?) section described by Sainsbury and MacKevett, 1965) (Fig. 1). These exposures are part of the fill of what Ridgway and others (2000) refer to as the White Mountain basin. Three lithofacies were recognized,

including granule and pebble conglomerate; massive and trough cross-stratified sandstone; and mudstone. These lithofacies represent the product of low-sinuosity streams and adjacent overbank areas (Ridgway and others, 2000). Paleocurrent data suggest streams entered the basin from the east and flowed westward along the basin axis (Ridgway and others, 2000).

Regional Tectonic Setting

The Holitna basin and exposures of coal-bearing Tertiary rocks along the Alaska Range front to the northeast are intimately related to the DFS. The DFS is one of the most conspicuous geologic features in southern Alaska, where it extends in a broad arc for nearly 1,600 km from the Bristol Bay region on the west to the Alaska-Yukon border on the east (Plafker and others, 1977). Grantz (1966) divided the Denali fault system into three segments based, in part, on the contrasting orientation of fault structures. The eastern segment, referred to as the Shakwak valley segment, trends northwest; the western segment, referred to as the Farewell segment, trends northeast and cuts through the Holitna basin and exposures of Tertiary strata to the northeast (described below). The eastern and western segments are connected by a central segment that consists of two northward convex faults – the Hines Creek and Denali faults. Richter and Jones (1973) suggested that the Denali fault system formed along a late Paleozoic continental suture that was transformed to a strike-slip fault system in Tertiary time as a consequence of a change in plate motions. Most workers agree that the DFS is a major crustal scale tectonic feature that was significant in the tectonic evolution of southern Alaska (Grantz, 1966; Lanphere, 1978; Nokleberg and others, 1985; Plafker and others, 1977; Plafker and others, 1989; see Csejtey and others, 1996, for an opposing view).

The Farewell segment (synonymous with Farewell fault zone) is the least known stretch of the DFS (Lanphere, 1978). Grantz (1966) noted the segment is a complex feature characterized by many fault strands. Grantz (1966) also noted a dip-slip component along the fault segment (up on the south) and right-lateral separation based on offset Cretaceous rocks along the western end of the segment and regional drag features in rocks south of the fault. Offset Paleozoic facies trends along the west end of the segment suggest over 100 km (60 miles) of right-lateral offset (Decker and others, 1994). Although the sense of motion appears well established, not all workers agree. Redfield

and Fitzgerald (1993) question right-lateral motion along the western part of the DFS and argue for left-lateral motion on kinematic grounds.

The present distribution of Tertiary strata in outcrop is controlled by movement along the Farewell segment of the DFS. Similarly, the origin of the Tertiary section is most likely tied to the history of the Farewell fault zone. Discontinuous exposures of Tertiary strata have been described in close proximity to the Denali fault system along much of its length (Hickman, 1974; Hickman and others, 1977, 1978; Hickman and others, 1990; Reed and Nelson, 1980; Ridgway, 1992; Ridgway and others, 1997; Stout, cited in the DGGs 1973 Annual Report; Wahrhaftig and others, 1969; Wahrhaftig, 1987), presumably reflecting deposition in areally restricted strike-slip basins. Most other major strike-slip fault systems around the world have associated sedimentary basins (Reading, 1980; Christie-Blick and Biddle, 1985).

BASIN ANALYSIS APPROACH

The goal of this project is to evaluate the shallow gas potential of the Holitna basin. At least three theoretical plays exist in the basin. Carbonaceous mudstones and coal represent potential source rocks for all three plays. The first play involves gas stored in sandstone and conglomerate reservoirs and is referred to as the conventional gas play. The second play involves gas stored in carbonaceous mudstone and coal beds and is referred to as the coalbed methane play. The third play involves liquid hydrocarbons stored in sandstone and conglomerate reservoirs and is referred to as the conventional oil play.

Our basin analysis approach involves utilization of potential field geophysics and studies of Tertiary strata exposed in the southern and central McGrath Quadrangle northeast of the Holitna basin (Fig. 1). DGGs contracted Dr. John Cady to reprocess and interpret a high-resolution aeromagnetic survey of the Holitna lowland region flown in 1997. In addition, DGGs purchased a regional gravity survey of the Holitna lowland region that was acquired in 1982 by Edcon, Inc. of Denver, Colorado. Dr. Cady is interpreting the gravity data and integrating both datasets for a comprehensive geophysical interpretation of the Holitna basin. Exposures of Tertiary strata in the McGrath Quadrangle are critical as they represent the closest exposures of rocks thought to be similar to the sedimentary fill of the Holitna basin. Our studies of Tertiary strata in outcrop in the McGrath and northeastern Talkeetna quadrangles focused on 1) evaluating

the stratigraphy (including biostratigraphy) and depositional environments; 2) evaluating the reservoir potential of sandstones and conglomerates; and 3) evaluating the source rock potential of coals and carbonaceous shales.

STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS

The descriptions and interpretations that follow are based on 10 days of helicopter-supported field work on exposures of Tertiary coal-bearing strata from the lower Cheeneetnuk River (Lime Hills D-6 and D-7 quadrangles) to the Little Tonzona River (Talkeetna C-6 quadrangle) in late July 2000. Our work builds on published mapping and stratigraphic studies of the Tertiary section in outcrop. The purpose of our work was to better understand the stratigraphy and sedimentology of the Tertiary section, with particular emphasis on the nature of potential reservoir and source rocks.

Stratigraphic sections were examined in detail at White Mountain, Middle Fork of the Kuskokwim River, Khuchaynik Creek, Windy Fork of the Kuskokwim River, and Little Tonzona River; measured sections through selected intervals were obtained at all locations except White Mountain (see Ridgway and others, 2000, for a measured section). Extremely limited exposures of the Tertiary section along the lower Cheeneetnuk River did not warrant measurement. Preliminary descriptions of each location are presented below, along with brief interpretations of the depositional environments. The White Mountain section is summarized in Ridgway (2000) and is not discussed in detail in this report. Correlation of the Tertiary section in the McGrath Quadrangle with other Tertiary exposures in central and southern Alaska are summarized in Fig. 3.

In the discussion that follows, all plant megafossil identifications were done by the second author (Blodgett), with the exception of a single collection from the Cheeneetnuk River, identified by the late Dr. Daniel Axelrod (formerly at the University of California, Davis). All plant microfossils were identified, and abundance data quantified, by Dr. Robert Ravn (consultant under contract to DGGS, Aeon LLC., Anchorage, Alaska). Age calls and climatological analysis based on Ravn's data were performed by Dr. Pierre Zippi (consultant under contract to DGGS, biostratigraphy.com, Garland, Texas). Reports from these contractors will be released to the public as DGGS interpretive reports.

Cheeneetnuk River

Gilbert (1981) mapped two small exposures of Tertiary strata (unit uTs) along the Cheeneetnuk River between 155°15' and 155°11' west longitude (Fig. 4). Exposure quality and continuity are extremely poor and stratigraphic sections could not be measured at either location.

Biostratigraphy

Small broken broadleaf plant fossils were common in the float. Plant megafossils collected from this outcrop were analyzed by the late Dr. Daniel Axelrod (University of California, Davis), who assigned a tentative late Miocene age to the collection based the presence of poorly preserved *Salix*, *Platanus*, and *Alnus* specimens and comparison with a similar age flora from western Oregon (written comm. to Blodgett, 1980). Palynologic samples yielded two age diagnostic taxa, *Diervilla echinata* and *Tsuga heterophylla* (Ravn, written comm., 2001), indicative of a rather broad age range from middle Miocene to late Eocene (Zippi, written comm., 2001). However, Zippi (written comm., 2001) considered these rocks to be equivalent to the Homeric stage based on the nearly equal abundance of cold and temperate climate taxa and the near absence of taxa that prefer warm climates. Zippi's Homeric correlation is in agreement with Axelrod's late Miocene age assignment.

Stratigraphy and Lithofacies

The northeasternmost location (station 00DL30) consists of a 2-m-high bluff with small, discontinuous exposures of orange-brown weathering siltstones that appear to be in place. The southernmost location (station 00DL57) consists of siltstone float and small fragments of bright coal scattered among the riverbank vegetation. Float was scarce at this location and uncertainties regarding the source of the material precluded collecting samples.

Bundtzen and Kline (1986) reported coal-bearing Tertiary rocks overlying Devonian limestone in the vicinity of 00DL30 and reported "brittle coal beds up to 0.5 m known thickness." They also reported high sulfur contents in two samples (as much as 8.19 weight percent).

Interpretation

Little can be said about these exposures, other than the siltstone and poorly preserved plant megafossils suggest periodic incursions of silt laden waters in a flood basin setting distal to active stream channels. Bright coal at location 00DL30 indicates at least local accumulation and preservation of terrestrial vegetation. This interpretation agrees with Zippi (written comm., 2001), who stated "The presence of dinoflagellates and green algae along with abundant conifer pollen indicate deposition in a fluvial system with standing water, such as a swamp, slough, or small lake. The pollen flora is dominated by mixed conifer forest taxa *Picea*, *Pinus* and *Tsuga* with very low proportions of spores and angiosperm trees, shrubs, and grasses."

White Mountain

Tertiary strata south of White Mountain (Gilbert's map unit Tcg; station 00DL56 on Fig. 5) are situated in a down-dropped fault block bounded on the north side by the Farewell fault (Sainsbury and MacKevett, 1965) and an unnamed fault on the south side (Gilbert, 1981). Bedding dips toward the east and southeast at moderate angles. These bounding high-angle faults juxtapose the Tertiary section against Paleozoic shallow-water strata of the Nixon Fork terrane (north of Farewell fault) and Paleozoic deep-water strata of the Dillinger terrane (south of unnamed fault). Owing to poor exposure quality and the presence of only small, very poorly preserved plant megafossils, paleontologic samples were not collected during our study.

Several north-trending resistant units with intervening recessive weathering intervals are clearly visible from the air (Fig. 6). The resistant units range from 10 m to over 50 m thick; intervening mudstones range from a few meters thick to nearly 40 m thick (Ridgway, 2000). In general, the organization is similar to the lower two-thirds of the sections exposed on the Middle and Windy forks of the Kuskokwim River, which are described below. Intervening mudrocks at White Mountain, although poorly exposed, appear to include much less organic material and little or no coal. Ridgway's (2000) section represents less than a quarter of the thickness that Sainsbury and MacKevett estimate is present in the area. We agree with Ridgway's (2000) interpretation of the succession as the product of low-sinuosity braided streams with associated overbank deposits. Alternating resistant and non-resistant units (coarse-grained and fine-grained

lithologies, respectively), manifested in outcrop by alternating ridges and swales (Fig. 6), may be the result of episodic faulting along the Farewell fault zone.

Middle Fork and Windy Fork

East of White Mountain, the Tertiary section disappears under a veneer of Pleistocene glacial outwash and Holocene alluvium and does not reappear until a few kilometers east of the Big River, where rubble of Tertiary strata covers hilltop areas. Relatively good exposures of Tertiary strata are present along the Middle and Windy forks of the Kuskokwim River (Figs. 1, 7a, and 7b). These exposures were mapped by Dickey (1982; his unit Tqa). The succession in both exposures (Dickey's (1982) unit Tqa) is similar, consequently, they are discussed together in this section. Measured sections through portions of both exposures are shown in Figures 8 and 9.

Exposures continue for nearly 2.5 km along the east and west banks of the Middle Fork and for a comparable distance along the west bank of the Windy Fork. Dickey (1982) measured nearly 650 m and 1,850 m of Tertiary strata along the Middle and Windy forks, respectively, but was unable to measure complete thicknesses along both drainages due to structural complications and limited accessibility. High-angle faults of unknown displacement truncate the base of both exposures and numerous smaller scale high-angle faults are present within the Tertiary section along both drainages. Further complicating estimates of stratigraphic thickness is the presence of a map-scale syncline near the north end of the Windy Fork exposure. The amount of section removed by faulting at both locations is unknown.

Biostratigraphy

Plant megafossils and microfossils obtained from the Middle Fork and Windy Fork sections help constrain their age. Plant megafossils from the middle Fork section include indeterminate betulaceans and *Alnus* sp., indicating a broad Oligocene to Recent age range. Megafossils from the Windy Fork section include *Metasequoia* cf. *glyptostrobooides* Hu and Cheng, *Alnus* sp., *Carpinus seldoviana* Wolfe, *Salix cappsensis* Wolfe, and *Ulmus knowtoni* Tanai and Wolfe. This flora suggests correlation with the Seldovian stage from the Cook Inlet region and an early to middle Miocene age. Similarities in the stratigraphic organization of both sections suggest a middle Miocene age for the Middle Fork section.

Palynologic samples from the Middle Fork section yielded *Corsinipollenites oculusnoctis*, *Diervilla echinata*, and *Tsuga heterophylla* (Ravn, written comm., 2001), which indicate a middle Miocene to late-middle Eocene age (Zippi, written comm., 2001). The Windy Fork palynoflora includes *Diervilla echinata*, *Tilia crassipites*, and *Tsuga heterophylla* (Ravn, written comm., 2001), which suggest a middle Miocene to late Eocene age (Zippi, written comm., 2001).

Taken together, the megafossil and microfossil taxa suggest an early to middle Miocene age and correlation with the Seldovian floristic stage of Wolfe and others (1966) and Wolfe and Tanai (1980). We consider the strata exposed along Middle Fork and the west bank of Windy Fork to be roughly correlative.

A sample collected from the east bank of Windy Fork (station 00DL58 on Fig.7b, located roughly along strike from the northernmost exposures on the west bank (station 00DL34 on Fig.7b), included two specimens of the spore *Aquilapollenites*, which occurred from Late Cretaceous through Oligocene. While it is possible these spores were reworked from older rocks (Ravn, 2001), it is equally possible that they are in situ (Zippi, 2001). If the latter is correct, the age of this part of the exposure is restricted to Oligocene to late Eocene. If correct, a fault likely separates exposures on the east and west banks.

Stratigraphy and Lithofacies

Description - Assuming no major faults within the Tertiary sections at Middle Fork and along the west bank of Windy Fork, both sections are characterized by an overall fining-upward trend from pebble and cobble conglomerates near the base to interbedded siltstone, silty claystone, and coal near the top. The fine-grained lithologies are commonly carbonaceous and coals are typically high in ash content. The basal (southern) two-thirds to three-quarters of both exposures consists of numerous resistant weathering bodies of conglomerate, pebbly sandstone, sandstone, and minor mudstone from 3 m to 25 m thick, separated by recessive weathering mudstone intervals from a few meters to over 80 m thick (Fig. 10a).

Massive pebble and cobble conglomerates account for over 50 percent of the coarse-grained bodies at both locations (Figs. 8a, 9a, and 9b). Sandstone comprises approximately 35 percent. Conglomerate beds are a few decimeters to over 3 m thick and are commonly amalgamated to form thicker composite bodies (Fig. 10b). Conglomerate

beds are typically lenticular (Fig. 10c), but many outcrops have insufficient lateral extent to evaluate bedding geometry. Concave-upward erosional surfaces with up to 2 m of relief are common and may separate individual channel and bar macroforms (Fig. 10c).

Conglomerates are clast-supported, polymictic, and characterized by coarse-grained sandstone to granule conglomerate matrix. The matrix material creates a distinctive bimodal to polymodal texture. Most conglomerate beds display massive internal fabrics or poorly defined horizontal stratification; clast imbrication is well-developed locally, particularly where conglomerates include a high proportion of disc-shaped clasts. Clasts of vein quartz, black chert to dark gray chert, and black to dark gray argillite are abundant, and clasts of felsite are common. Coal clasts are present in conglomerates in both section, but are not abundant.

Dickey (1982, 1984) reported paleocurrent data from conglomerates that suggested south-flowing currents. We measured both south and north paleoflow indicators (from clast imbrication), suggesting a more complicated sediment dispersal pattern.

Laterally continuous pebbly sandstone and sandstone beds cap conglomerate beds locally (Fig. 9a). Sandstones form bedsets up to 2 m thick that are commonly transitional into overlying mudstone successions (Fig. 10d). Sandstone lenses up to 1 m thick within conglomerate bodies are common (Figs. 10f and 10g). Where mudstone overlies sandstone, the latter lithology becomes progressively muddier upsection and includes abundant variably preserved plant megafossils on bed parting surfaces. Casts of tree trunks and logs are relatively common in both conglomerates and sandstones (Fig. 10h). Minor mudstones up to 2 m thick are present as lenses within these coarser-grained bodies. Plant leaf impressions and coalified plant material are common in mudstone lenses.

Siltstone and silty shale successions up to 25 m thick separate conglomerate and sandstone bodies in the lower two-thirds to three-quarters of both the Middle Fork and Windy Fork successions (Figs. 8a, 9b, 10a, and 10i). These finer-grained lithologies are typically recessive weathering and exposures are poor to absent. Where exposed, the succession consists of silty shale, siltstone, bituminous coal, and minor sandstone and conglomerate (Fig. 10j). Silty shale and siltstone are locally carbonaceous and the latter lithology commonly includes abundant well-preserved plant megafossils (broadleaf impressions). Coals range from a few millimeters to several centimeters thick and many

are laterally continuous in outcrop. Coals are characterized by low sulfur content and some are more appropriately classified as carbonaceous shales or carbonaceous mudstones (Table 1). Coals with lower ash contents have alternating bright and dull bands up to two millimeters thick. Small non-descript gastropods and unornamented bivalves were noted in one mudstone succession on the Middle Fork (Fig. 8a).

Sandstone bodies up to 2 m thick are present in some mudstone successions (Fig. 10k). Conglomerates are present only locally in these bodies, are less than 40 cm thick, and are usually situated at the base of sandstone bedsets. Most conglomerates are massive, but some fine-upward and grade into overlying sandstones. Sandstones are medium- to coarse-grained, pebbly, and medium-bedded. Many sandstone beds are massive, but trough cross bedding is present locally. The basal contacts between these lithologies and the underlying mudstones are sharp; upper contacts are typically gradational and characterized by thinly interbedded sandstone and mudstone, with the proportion of mudstone increasing steadily upsection. Mudstone ripups are present locally near basal contacts with mudstones.

The upper one-third to one-quarter of the Tertiary section along both drainages consists of up to several hundred meters of silty shale, carbonaceous silty shale, coal, and minor sandstone and conglomerate (Figs. 8b, 9c, and 10l). Of these lithologies, silty shale and carbonaceous silty shale account for approximately 70 percent of the stratigraphic thickness. Silty shales typically weather into small chips and irregular shaped small blocks, but locally display a fissile weathering character. Coal is common (up to 5 percent of the total succession) throughout this part of the succession and is present in millimeter-thick stringers and, less commonly, as seams up to 0.5 m thick. Most coals have alternating bright and dark bands, and have low sulfur and moderate to high ash contents (Table 1). Sandstone and conglomerate beds are present in fining-upward (Fig. 10m) and coarsening-upward (Fig. 10n) successions up to 3 m thick. In fining-upward successions, sandstones and conglomerates are situated above sharp, erosional basal contacts with mudstone and are gradationally overlain by siltstone. Fining-upward successions are similar to those noted in the lower two-thirds of both exposures. Coarsening-upward successions start with silty claystones and grade upsection to siltstones and sandstones. Coarsening-upward successions like these were not observed in the lower two-thirds to three-quarters of the Tertiary section at both locations.

Interpretation - Massive clast-supported conglomerates with poorly sorted sandstone as matrix and tree stump and log casts, suggest deposition from flood events in a non-marine setting - possibly from hyperconcentrated flows (Pierson and Costa, 1987). Conglomerates with imbricate clast fabrics suggest transport and deposition from traction currents in confined channels, possibly during the early waning stages of fluvial flood events. Sandstone lenses record deposition during the later waning stages of flood events, or in the lee gravel macroforms under normal flow conditions. Sandstone bedsets transitional between conglomerate below and mudstone successions above record gradual abandonment of fluvial channel tracts, whereas conglomerate packages abruptly overlain by mudstones likely record major channel avulsion events. Mudstone successions between conglomerate bodies record deposition in perennial flood basins adjacent to active fluvial channel tracts. Sandstone and conglomerate bedsets within these mudstones record episodic major fluvial flood events and deposition as crevasse splays derived from nearby active channel tracts.

The thick mudstone successions at the north end of both sections probably record deposition in a long-lived lacustrine or perennial swamp setting. The abundance of terrestrial plant material indicates thickly vegetated areas within the swamp setting. Thin coal seams may have originated as allochthonous peat mats or in areally restricted, relatively short-lived mires scattered along the perimeter of a lake or throughout a swamp setting. Abundant ash in most coal seams indicates deposition near active fluvial channel tracts. High ash coals are consistent with deposition in relative proximity to active fluvial channel tracts. Fining-upward successions of sandstone and conglomerate are similar to those present in the lower parts of both sections and likely have a similar origin as crevasse splay deposits or high-sinuosity channel-point bar successions. Alternatively, some fining-upward successions, such as the one shown in Fig. 10m, may represent point bar sequences deposited by high-sinuosity streams. Coarsening-upward successions probably represent small lacustrine deltas.

Khuchaynik Creek

Two distinctly different successions are exposed in separate fault blocks on the west side of the Khuchaynik Creek (Fig. 7b). Dickey (1982) mapped a southern fault block (his Tc1 unit) dominated by limestone conglomerates and a northern fault block (his Tqa unit) containing a heterolithic succession of conglomerate, sandstone, siltstone, and

shale (Fig. 11). Conglomerates in unit Tqa include a variety of clast compositions, of which limestone is a minor component.

Biostratigraphy

Poorly preserved specimens of the plant megafossil *Metasequoia* cf. *glyptostrobooides* Hu and Cheng suggest an undifferentiated Miocene age for unit Tcl. The palynoflora recovered from unit Tcl includes *Diervilla echinata* and *Tsuga heterophylla* (Ravn, written comm., 2001), which suggests a middle Miocene to late Eocene age (Zippi, written comm., 2001). Plant megafossils recovered from siltstones of unit Tqa include *Metasequoia* cf. *glyptostrobooides* Hu and Cheng, *Salix cappsensis* Wolf, *Salix?* spp., *Carpinus?* n sp., and *Acer ezoanum* Oishi and Huzioka, which suggest an early to middle Miocene age. The palynoflora recovered from unit Tqa include *Diervilla echinata* and *Tsuga heterophylla* (Ravn, written comm., 2001), which suggest a middle Miocene to late Eocene age (Zippi, written comm., 2001). Collectively, the macrofossil and microfossil taxa collected from unit Tqa suggest correlation with the Seldovian floral stage (late Oligocene to middle Miocene) of Wolfe and others (1966) and Wolfe and Tanai (1980).

Stratigraphy and Lithofacies

Description - Unit Tcl consists largely of steeply dipping (near vertical) green weathering, clast-supported conglomerate (Fig. 12a). Bed thickness ranges from 0.5 m to approximately 1.5 m. As stated above, gray limestone clasts are most abundant, but chert, vein quartz, and volcanic rock fragments are also represented. Limestone clasts look similar to lithologies recognized in the Dillinger sequence. Equant and disc-shaped clasts are common, but the latter appear to be more common. Equant clasts tend to be larger (up to 22 cm) and segregated into beds where they represent the dominant clast morphology (Fig. 12b). Where disc-shaped clasts are abundant, a pronounced low-angle imbricate fabric is present (Fig. 12b). Matrix material fills most void spaces between clasts in conglomerate beds, is greenish colored, and consists of poorly sorted sandstone and granule conglomerate. Minor lenses of sandstone and siltstone up to a 0.5 m thick are present between some conglomerate beds. Siltstones include scrappy plant leaf impressions (*Metasequoia*).

Unit Tqa is very similar to the southern two-thirds to three-quarters of the Middle Fork and Windy Fork sections. The thick mudstone succession capping both the Middle and Windy fork successions is either not present or not exposed along the Khuchaynik River. The succession consists of composite conglomerate and sandstone bodies up to 15 m thick separated by poorly exposed mudstone intervals up to 22 m thick. Conglomerates are clast-supported, polymictic, and include both pebble- and cobble-sized clasts. Conglomerates are commonly internally massive, but poorly developed horizontal stratification is also common; bed thickness ranges from one meter to 11 m. Some of the thicker conglomerate beds may contain cryptic amalgamation surfaces (Fig. 12d). Sandstones are commonly medium- to very coarse-grained and pebbly. Bedding ranges from a few decimeters to over 0.5 m thick and is usually devoid of visible sedimentary structures. Trough cross bedded sandstone is rare. Sandstones are present as thin lenses between conglomerate beds and as laterally continuous beds, at least at outcrop scale, capping conglomerate bodies. Most conglomerates have a sheet-like geometry at outcrop scale, but high-angle channel margins (or scour margins) are present locally. Mudstones in unit Tqa are very poorly exposed and appear to consist of siltstones. One notable difference between the Khuchaynik River and Windy/Middle Fork sections is the apparent absence of coal and carbonaceous mudstones in the former section.

Interpretation - Unit Tcl was derived from a source terrane dominated by carbonate rocks. Many limestone clasts examined in the field appear similar to carbonate lithologies present nearby in the Dillinger sequence. The abundance of spore pollen and presence of plant megafossils indicated deposition in a non-marine setting. Imbrication of platy clasts and segregation of larger equant clast shapes suggest conglomerates in unit Tcl record transport and deposition from traction currents during flood events. Lateral continuity of exposure in unit Tcl is extremely limited and inferences regarding conglomerate body geometry cannot be made. Minor siltstone and sandstone lenses likely record deposition during the waning stages of flood events.

Unit Tqa is similar to the Tertiary successions exposed along the Middle and Windy forks of the Kuskokwim River and is similarly interpreted. The apparent absence of coal and carbonaceous mudstone may be due to non-deposition or structural removal (faulted out).

Little Tonzona River

Approximately 50 m of coal-bearing Tertiary strata are exposed on the west bank of the Little Tonzona River in the northwestern corner of the Talkeetna Quadrangle (Player, 1977) (Figs. 13 and 14a). The lateral continuity of these exposures is extremely limited and no exposures of Tertiary sedimentary rocks have been recognized on the east side of the Little Tonzona River.

Biostratigraphy

No plant megafossils worth collecting were encountered at the Little Tonzona exposure, however, four palynologic samples were collected from silty claystones between coal seams. Palynoflora include *Boisduvalia clavatites*, *Tilia crassipites*, *Diervilla echinata*, *Tsuga diversifolia*, and *Tsuga heterophylla* (Ravn, written comm., 2001). According to Zippi (written comm., 2001), the age of these rocks “is restricted to the Oligocene (probably early Oligocene) by the presence of *Boisduvalia clavatites*. The occurrence of *Tilia crassipites* also suggests an Oligocene age.....”

Stratigraphy and Lithofacies

Description - The succession exposed at the Little Tonzona River is unlike anything else in the outcrop belt (Figs. 13 and 14). Coals are dark brown lignite and resemble delaminated plywood. Seams dip 60° to 70° toward the north-northwest, and account for over 60 percent (31 m) of the exposed thickness (Fig. 15). Individual seams are up to 9 m thick. Silty claystones up to 4 m thick split the exposure into at least eight discrete coal seams. The ash content is low and sulfur content ranges from 1.04 to 2.25 weight percent (mean 1.79; Table 1). Bundtzen and Kline (1986) reported that sulfur content varies considerably from bed to bed in the Little Tonzona River coals. Plant fragments in the mudrocks are small, poorly preserved, and not abundant. Amber is abundant in most coal seams as fractured masses up to 1.5 cm in diameter. At least two tephra beds nearly completely altered to bentonite are present. The lower tephra, at least 1 m thick, was sampled for Ar/Ar dating, but no datable material was recovered. These are the only ash beds recognized in the Tertiary section between the lower Cheeneetnuk and Little Tonzona rivers.

Interpretation – Thick low-ash coals at the Little Tonzona River location indicate deposition in a long-lived swamp setting removed from sources of siliciclastic sediment

input – probably in a raised mire environment (McCabe, 1984). The abundance of amber indicates conifer trees were abundant, which is consistent with a palynoflora dominated by *Picea*, *Pinus*, and *Tsuga* (Zippi, written comm., 2001). Thick altered tephra deposits indicate volcanic activity somewhere in the region, presumably to the south. Interbedded silty mudstones suggest periodic inundation of the mire environment, possibly due to episodic tectonic activity (fault-related subsidence?). The absence of siliciclastic interbeds coarser than silty claystone indicates this part of the mire environment was removed from active fluvial channel tracts throughout its depositional history. The lateral extent of the mire is unknown (see interpretation of Deepbank Creek location below). Our interpretation is consistent with Zippi's, who stated "The presence of dinoflagellates and green algae along with abundant forest tree pollen indicate deposition in forested fluvial system with standing water, such as a swamp, slough, or small lakes."

The sulfur content of the Little Tonzona coals is two to five times higher than coal exposed at Deepbank Creek 7 km southwest the Little Tonzona locality (Fig. 13).

Deepbank Creek

A small exposure of coal is present in the bank of a tributary to Deepbank Creek, approximately 7 km west-southwest of the Little Tonzona River exposure (Figs. 13, location 00DL43, and 15b).

Description - The coals here are virtually identical to the Little Tonzona coals in appearance. An extremely limited sample suite (two samples) suggests ash contents between 8 and 20 percent and sulfur contents between 0.4 and 0.8 weight percent. Notably, the sulfur is lower than in the Little Tonzona River coals. No other lithologies are exposed at this location. No biostratigraphic data are available for this exposure.

Rubblecrops (loose blocks and chips of rock, essentially in place and in correct stratigraphic position, but detached from solid outcrops) of bright orange-red weathering baked siltstone (clinker), minor altered tephra, and sandstone are present along a low northeast-trending ridge situated mid-way between the Little Tonzona and Deepbank locations (Figs. 13 and 15c). The bright orange-red coloration is due to prolonged heating, most likely from burning coal at depth. The presence of these beds suggest that coal extends continuously from the Little Tonzona River at least as far west as Deepbank Creek. No exposures of Tertiary strata were observed between Deepbank Creek and the Windy Fork. The presence of the plant megafossil *Carpinus seldoviana* Wolfe in baked

siltstones suggests an early to middle Miocene age for the clinker beds and correlation with the Seldovian floristic stage in the Cook Inlet area (Wolfe and others, 1966; Wolfe and Tanai, 1980).

Interpretation – Coal at Deepbank Creek is virtually identical to the Little Tonzona River coal in appearance but not sulfur content (Table 2). In spite of differing sulfur contents, we tentatively correlate the Deepbank Creek coal with the Little Tonzona River coal and interpret the depositional setting similarly as the product of deposition in a raised mire.

STRATIGRAPHIC TRENDS

The relation between the Tertiary section in outcrop and the fill of the Holitna basin remains speculative. Detailed regional gravity data (DGGS Geophysical Report 2001-1) show a northeast-elongate low that extends from approximately 157°27' west longitude (a few kilometers west of the village of Sleetmute) to approximately 155°30' west longitude (lower reaches of the Cheeneetnuk River) in the northwestern Lime Hills Quadrangle. The magnitude of the gravity low decreases progressively toward the northeast, indicating the presence of a pre-Tertiary basement high (or sill) separating the outcrop belt from the Holitna basin.

Smith and others (1985) interpret up to 4,500 m (nearly 14,600 feet) of Tertiary strata in the Holitna basin based on a coarse grid of gravity data, and at least 1,800 m of Oligocene to Miocene age section is present in outcrop northeast of the basin. As stated previously, the section in outcrop is broken into several fault-bounded slivers; each sliver is bounded by high-angle faults precluding estimations of the original depositional thickness of the Tertiary section.

The thickest coal section is present at the Little Tonzona River and the thickest carbonaceous mudstones are present along the Middle and Windy forks of the Kuskokwim River. Coal and carbonaceous mudstone are absent in exposures near White Mountain and only small exposures of mudstone with thin coaly stringers are present farther to the southwest, along the Cheeneetnuk River.

The relation, if any, between coal-bearing strata on the Little Tonzona River and the latter locations is unknown. Biostratigraphic data suggest that strata on the Little Tonzona River are older (early Oligocene) and were probably deposited in a depositional system unrelated to those responsible for the Windy Fork and Middle Fork successions.

Biostratigraphic data also suggest that Tertiary strata become progressively younger toward the southwest as indicated by the likely presence of Homeric (middle to late Miocene) strata on the lower Cheeneetuk River. It is unknown whether the present day outcrop belt represents the exhumed fill of a single depositional basin or several depositional basins (Bundtzen and Kline, 1986).

SHALLOW GAS POTENTIAL

This section summarizes stratigraphic features and geochemical data of significance in assessing the shallow gas potential of the Tertiary Holitna basin. Reservoir and trap potential are discussed first utilizing information presented in the previous sections. Source rock potential is discussed using data gathered in this study and previously published sources. The shallow gas potential is summarized at the end of the section.

Reservoir and Trap Potential

Conglomerate and sandstone bodies similar to those exposed at White Mountain and between the Middle and Windy forks of the Kuskokwim River could form hydrocarbon reservoirs if present in trapping configurations in the subsurface of the Holitna basin with sufficient effective porosity. Conglomerates in outcrop have an apparent sheetlike geometry, but quantitative information on the lateral extent of conglomerate bodies is unavailable owing to the limited extent of most outcrops. Conglomerates are clast-supported and include poorly sorted sandstone and granule conglomerate as matrix between the larger clasts. Clast compositions are dominated by metamorphic rock fragments, vein quartz, and locally important felsic volcanic and limestone fragments (Dickey, 1982). Most clasts are likely to have near-zero porosity and permeability. The poorly sorted material between clasts can be expected to have low porosity and permeability.

Sandstones are common in all exposures west of Deepbank Creek, but are less abundant than conglomerates. Most sandstones examined comprise bedsets up to a few meters thick that are interbedded with conglomerate and mudstone. Thick sandy successions appear to be lacking. Sandstone composition is dominated by metamorphic rock fragments including schist, argillite, and quartz. As with the conglomerates, sandstones with felsic volcanic and limestone grains are locally important. Most

sandstones are tightly cemented, exhibit little visible indication of porosity, and appear to have low reservoir potential.

Bed dips in most exposures are moderate to steep and no outcrop examples of structural closures were noted. Most exposures are cut by minor faults and exposure boundaries are usually defined by major high-angle faults. The degree of faulting observed in outcrop suggests reservoir geometries would be complex and reservoir units would have low lateral continuity.

Lithologies capable of forming reservoir topseals are present in outcrop, but are not volumetrically abundant or aerially widespread. Most fine-grained rocks in the Tertiary section are silty and at shallow burial depths (less than 2,000 m), at best, would probably form leaky reservoir topseals.

These observations suggest that reservoirs would be structurally complicated, highly compartmentalized, laterally discontinuous, and leaky. The presence of alternating successions of conglomerate and mudstone suggest that stratigraphic traps may be present if thick conglomerate bodies pinchout in mudstones. However, the same observation regarding topseal integrity applies. Overall, the reservoir potential of conglomerates and sandstone is probably poor to fair, which increases the risk associated with the first of the two plays identified above.

Source Rock Potential of Tertiary Strata in Outcrop

The abundance of carbonaceous mudstone and coal in outcrop in the McGrath Quadrangle suggests that they represent the primary potential source rocks in the Tertiary Holitna basin. Terrestrial organic material is most commonly gas-prone; however, lacustrine shales enriched in algal material can be excellent source rocks for liquid hydrocarbons (Tissot and Welte, 1984). To assess their potential, DGGS collected samples of carbonaceous mudstones and coal for laboratory analysis. Analytical tests included standard coal quality tests (proximate and ultimate), coal petrology, high pressure methane adsorption, Rock-Eval pyrolysis, kerogen microscopy, and whole extract gas chromatography. Our coal quality and vitrinite reflectance data add to the database of publicly available information for these rocks (Sloan, 1979; Solie and Dickey, 1982). To our knowledge no coal petrology, high-pressure methane adsorption, or organic geochemistry data have been published. This section summarizes DGGS geochemical data from samples collected by DGGS. Vitrinite reflectance determinations

from coal petrology and kerogen microscopy are discussed at the end of this section. Results from whole extract chromatography are included in the appendix and are not discussed below. The sample suites subjected to these various analyses was small and we are not certain how representative they are of source rock potential over the wider area.

Coal Quality

Twenty two samples were submitted to Geochemical Testing in Somerset, PA, for proximate and ultimate analyses. The data are summarized in Table 1 and sample collection sites are shown in Figures 2b and 2c. Most of the samples contained high ash contents (greater than 8 percent), and many samples are high ash coals or carbonaceous mudstones. Most coal samples collected from the thick lacustrine and swamp successions along Middle and Windy Forks have high ash contents. The ash content of coal exposed at the Little Tonzona River and Deepbank Creek localities are much lower (less than 21 percent), on average, than elsewhere in the outcrop belt. The sulfur content of most samples ranges from 0.02 to 0.75 weight percent. Coals at the Little Tonzona River have sulfur concentrations between 1.04 and 2.25 weight percent, significantly higher than others locations represented in our sample suite. Solie and Dickey (1982) report high sulfur contents (up to 8.19 % by weight) in coal samples from exposures along the Cheeneetnuk River southwest of White Mountain. Coal quality data from our study are available from DGGs (Raw Data-file 2002-xx, in press). Additional coal quality data are presented in Player (1976) and Solie and Dickey (1982).

Coal Petrology

Thirteen coal and carbonaceous mudstone samples were submitted to R.M.B. Earth Science Consultants in British Columbia, Canada, for petrographic analysis. Many samples include abundant mineral material and are classified as high-ash coal or carbonaceous mudstone. All samples consist predominantly of vitrinite group macerals (about 90 percent) with minor amounts of inertinite (less than 2 percent) and trace amounts of liptinite. Microlithotype bands vary from a few micrometers to tens of micrometers and are interbanded with claystone. Coal petrology data from our study are available from DGGs (Raw Data-file 2002-xx, in press).

High Pressure Methane Adsorption

Six samples were analyzed by R.M.B. Earth Science Consultants in British Columbia, Canada, for high-pressure methane adsorption isotherms. All analyses were run at an inferred reservoir temperature of 40°C. The volume of methane (standard cubic feet, or SCF) adsorbed to create a saturated monolayer in moist (equilibrium moisture), ash-free samples ranged from 64 SCF/ton (00DL43A Deepbank Creek) to 309 SCF/ton (00DL33E Windy Fork). The thermal maturity of coals and carbonaceous mudstones is low, reducing the ability of these lithologies to adsorb methane. If Tertiary age coals and carbonaceous shales are present near the base of the Holitna basin (4,000+ meters depth), the adsorption capacity may be higher.

High pressure methane adsorption data for the six samples and details on the test methodology are available from DGGS (Raw Data-file 2002-2). It is important to emphasize that all samples were collected from outcrops subjected to surface weathering processes. The freshest material available, obtained by hand excavating the outcrop, was sampled in every case. It should also be pointed out that these data are not a measure of the actual gas content of coals and carbonaceous mudstones in outcrop, but are an indication of the gas holding capacity of these lithologies. Meaningful gas content data (desorption data) can be obtained on subsurface core samples that are containerized immediately after removal from the core barrel. For more information on adsorption isotherms and desorption measurements, the reader is referred to *A Guide to Determining Coalbed Gas Content* published by the Gas Research Institute (GRI Reference No. GRI-94/0396).

Rock-Eval Pyrolysis

A small suite of 12 samples of claystone and carbonaceous mudstone were submitted to Baseline-DGSI, Inc., in Houston, TX, for Rock-Eval pyrolysis analysis (Table 2). A brief summary of the Rock-Eval technique is presented below followed by discussion of Rock-Eval sample results.

The Rock-Eval pyrolysis technique involves heating a small quantity of ground sample to 300°C in a helium atmosphere and maintaining that temperature for 3-4 minutes to pyrolyze the sample (Peters, 1986). The sample chamber is connected to a flame ionization detector that senses any organic compounds liberated from the sample during initial heating. Following initial heating, the sample is step-heated at 25°C/minute up to 550°C. The output from Rock-Eval pyrolysis includes the concentration of organic

carbon (TOC in weight percent) and three peaks, referred to as S1, S2, and S3 (each expressed in mg/g). The S1 peak represents the products evolved at pyrolysis temperatures up to about 300°C. The S1 peak represents free hydrocarbons (bitumen) in the rock prior to analysis. The S2 peak represents the amount of hydrocarbons evolved during thermal degradation of kerogen. The S2 peak is a measure of the amount of hydrogen-rich kerogen is present in a source rock – that is, it represents the amount of hydrocarbons that the rock can generate if heated to sufficient temperatures. The temperature associated with the S2 peak is referred to as T_{max} , a parameter that provides information about the thermal maturity level of the sample. T_{max} has been shown to increase as the thermal maturity of the sample increases. The S3 peak is related to the amount of CO₂ generated during the pyrolysis process. The area under each peak is related to the volume of hydrocarbons or CO₂ generated (expressed in milligrams per gram).

Several bulk parameters can be derived from Rock-Eval pyrolysis data. The most significant parameters for the purpose of the Holitna basin study are the hydrogen index (HI) and oxygen index (OI). Formulas for each of these parameters can be found in Peters (1991). The HI corresponds to the quantity of hydrocarbons from S2 relative to TOC; the OI corresponds to the quantity of CO₂ relative to TOC. Both indices are commonly displayed graphically on a modified Van Krevelen diagram by plotting the HI on the y-axis and the OI on the x-axis (Jacobson, 1991). This type of diagram allows visual discrimination of kerogen type (type I, II, III, and IV). Type I kerogen is characterized by high HI values (greater than 400 to 500) and very low OI values (less than 25 to 30); type IV kerogens have very low HI values (less than 75) and variable OI values. Types II and III kerogens are intermediate between those two end members. Type I and II kerogens are capable of generating liquid hydrocarbons; Type III kerogen is gas-prone; Type IV kerogen is widely regarded as inert and incapable of generating hydrocarbons (Peters, 1986).

Eleven samples of carbonaceous mudstone and claystone were submitted for Rock-Eval pyrolysis (Table 2 and Fig. 16). The organic carbon content ranges from 0.06 weight percent to 15.76 weight percent TOC (Table 2). Of the 11 samples, one has less than 0.5 percent TOC, indicating poor generative potential; four samples have 1-2 percent TOC, indicating good generative potential; and six samples have greater than 2 percent TOC, indicating very good generative potential (see Table 1 in Peters, 1986). S1 are all

less than 0.9 mg/g and indicate the rocks are thermally immature and little, if any, hydrocarbons have been generated. S₂ ranges from 0.02 mg/g to 60.32 mg/g and suggests significant hydrocarbon generative potential for some samples (Table 2). By comparison with S₂ values in Peters (1986, his Table 1), five samples have poor generative potential, two have fair generative potential, and four have S₂ values suggesting good to very good generative potential. A plot of HI versus OI shows that most samples contain type III and/or IV kerogen. Two samples (00DL49-265 and 00DL49-327.5) collected from the thick lacustrine succession exposed at the north end of the Middle Fork exposure contained HI values of greater than 380 and plotted near the type II kerogen pathway, suggesting potential for liquid hydrocarbons (second play identified above). It may be notable that palynologic samples from this same stratigraphic interval yielded abundant fungal remains and conifer pollen that may have contributed type II kerogens. However, some coal known from elemental analysis to consist of humic (type III) kerogen plot between type III and type II on modified Van Krevelen diagrams due to poorly understood analytical problems with Rock-Eval apparatus (Peters, 1986). As a result, plots of HI vs. OI may misrepresent kerogen type and the data shown in Figure 16 should be viewed with caution.

Six of the 11 samples have elevated OI values (greater than 50), probably owing to surface weathering. Surface weathering tends to result in lower HI and TOC levels, and elevated OI values, thus making the results overly pessimistic.

Kerogen Microscopy

Three samples from the lacustrine succession exposed along the Middle Fork were submitted for kerogen microscopy. The following information was taken from a report submitted to DGGs by the laboratory (Baseline-DGSI).

Sample 00DL48-2 included organic material consisting of large, lipid-rich vitrinite fragments and unstructured material with very small lipid-rich vitrinite inclusions. Lipid-rich vitrinite is slightly soluble in immersion oil. Unstructured material may be degraded humic debris or oxidized unstructured lipids.

Samples 00DL49-265 and 00DL49-327.5 included organic material consisting of lipid-rich vitrinite fragments with liptodetrinite inclusions and a small amount of unstructured material. Lipid-rich vitrinite in both samples is slightly soluble in immersion oil. Sample 00DL49-265 included abundant liptodetrinite that fluoresced.

To summarize, all three samples contain primarily humic (coaly) organic material, primarily consisting of lipid-rich vitrinite. Samples 00DL49-265 and 00DL49-327.5 include lipid-rich vitrinite with fluorescing liptodetrinite inclusions. According to the laboratory (Baseline-DGSI), this material is responsible for the high HI values and low pyrolysis T_{max} compared to other samples, and indicates some ability to generate wet gas and possibly some condensate or light crude oil (conventional oil play). Encouraging as the results from these two samples are, they may not be representative of the source rock potential over a greater stratigraphic thickness or a wider geographic area. Kerogen microscopy (and whole extract gas chromatography data not discussed in this report) are available for DGGS (Raw Data-file 2002-xx).

Thermal Maturity

Vitrinite reflectance (termed R_o) data is widely used in the oil industry as an indicator of organic maturation (thermal maturity) in sedimentary rocks. Its value comes from an empirical relation between the reflectivity of vitrinite, maximum temperature a rock (containing fragments of vitrinite) has been experienced, and petroleum generation (Tissot and Welte, 1984). Organic maturation data can be used along with estimates of the geothermal gradient to calculate depth of burial required to initiate oil and gas generation. The threshold for oil generation is 0.6 % R_o; the threshold for methane generation is about 0.8 % R_o. Organic maturation information (such as vitrinite reflectance) combined with information on the geothermal gradient (typically bottom hole temperatures obtained in nearby exploration wells) allow calculation of the burial depths required for the onset of oil and gas generation.

Vitrinite reflectance (R_o) measurements were obtained from samples submitted for coal petrology and kerogen microscopy (Table 3). R_o measurements were made on several fragments of vitrinite in each sample. Mean R_o values range from 0.14 to 0.64 and indicate the Tertiary section in outcrop is immature to marginally mature with respect to oil generation (oil window). Vitrinite reflectance between 0.6 and 1.0 define the oil window; R_o values between 1.0 and 1.3 define the wet gas window. Vitrinite reflectance values between 1.3 and 4.0 define the dry gas window and indicate source rocks that are post-mature. These data are consistent with T_{max} values shown in Table 2 and published R_o data (Solie and Dickey, 1982).

Vitrinite reflectance data from the McGrath Quadrangle indicate that the carbonaceous and coal-bearing successions there could not have generated thermogenic hydrocarbons. However, gravity data from the Holitna basin to the southwest suggest up to 4,500 m (14,600 feet) of Tertiary strata. If carbonaceous mudstones and coals are present at depth in the Holitna basin, R_o values would probably be significantly higher. The depth to the oil window (0.6% R_o) and gas window (0.8 % R_o) can be calculated if the geothermal gradient is known. Using bottom hole temperatures from two wells in the Nenana basin and data from Barker and Pawlewicz (1986) on R_o -burial temperature correlations, Stanley (1991) estimated the depth to the top of the oil window in that basin between 1,400 m to 2,700 m (4,536 feet to 8,748 feet). Tyler and others (1998) used data from the Beaver Lakes State #1B well in the northern Susitna basin to estimate the depth to the top of the gas window in the Minchumina basin (east of McGrath and northeast of the Holitna basin) at greater than 3,086 m (greater than 10,000 feet). These estimates may apply to the Tertiary Holitna basin if the geothermal gradient derived from the two Nenana basin wells and the Susitna basin well are valid for the Holitna basin.

Vitrinite reflectance data from this project are available from DGGs (Raw data-file 2002-xx). Additional vitrinite reflectance data on the Tertiary section in outcrop are available in Sloan and others (1979) and Solie and Dickey (1982).

Summary of Shallow Gas Potential

Available data suggest that coal and carbonaceous mudstone are the most likely potential source rocks for petroleum in the Holitna basin. Hydrocarbons generated in the basin could be sorbed to coal and carbonaceous material or stored in conventional sandstone and conglomerate reservoirs. Interbedded coal, carbonaceous mudstone, conglomerate, and sandstone in outcrop suggest that reservoir lithologies would have ample access to petroleum charge. However, visible porosity is lacking in outcrop samples, suggesting low reservoir potential for sandstones and conglomerates, thereby reducing the chances for success in the conventional gas and oil plays. The coalbed methane play is discussed below.

Tyler and others (1997) compared the geologic and hydrologic characteristics of San Juan, Greater Green River, and Piceance basins in the Lower-48 states in an attempt to explain differences in coalbed methane production. Through this process they developed a coalbed methane producibility model that incorporates geologic and

hydrologic factors considered critical to high coalbed methane production. Important geologic and hydrologic factors influencing coalbed methane producibility include: 1.) a depositional setting for coal-bearing strata favorable for deposition of thick, laterally continuous coal seams [and carbonaceous mudstone successions]; 2.) tectonic and structural setting for the coal basin that maintains the necessary balance between subsidence rate and peat accumulation or promotes deposition of thick carbonaceous mudstone successions; 3.) coal rank and gas content – higher rank coals generate greater volumes of methane; and 4.) basin hydrogeology characterized by regional ground water flow from uplands, where thick laterally continuous coals are exposed to meteoric recharge, basinwards to no-flow boundaries such as fault zones and fold hinge lines, where gas can be resorbed and trapped in conventional reservoirs. If the Tertiary section in outcrop is a valid analog for the Holitna basin, the basin fill probably includes a thick succession of alluvial deposits, including organic-rich flood plain deposits, and lacustrine strata.

The original extent of coal swamps and larger lake basins in the Holitna basin was probably influenced by faulting and fault-induced subsidence. Coal swamps and larger lake basins may have been elongated parallel to fault trends, which in this area strike northeast-southwest. Most coals in outcrop are thin and likely to be laterally discontinuous – the Little Tonzona River coals are a notable exception – and by analogy coals in the Holitna basin may be similarly thin and discontinuous. Carbonaceous mudstone successions in outcrop are thick (100s of meters) and probably characterized by greater lateral continuity. Coals and carbonaceous mudstones in outcrop are submature with respect to both oil and gas generation. At the depths necessary to generate thermogenic methane, the coal cleat system (orthogonal fractures in coal) and fractures in carbonaceous mudstones are likely to be closed. This reduces that ability of the rock to transmit methane in the fracture system.

Given the low thermal maturity of coal and carbonaceous mudstone in outcrop, gas contents in similar lithologies in the basin would likely be relatively low above a depth of 3,100 m (approximately 10,000 feet), unless thermogenic gas from deep in the basin migrated into shallow coal beds or biogenic gas is an important component. Biogenic gas may be present in the basin-fill. Coal gases in the Powder River Basin are entirely biogenic and biogenic gases account for a significant proportion of shale gases from the Antrim Shale in the Michigan Basin (Scott, 2001). Several shallow gas fields

are present in Miocene to Pliocene age rocks in the Cook Inlet Basin (Claypool and Magoon, 1980). Geologic and geochemical evidence suggests that gases in these Cook Inlet fields are accumulated marsh gas of biogenic origin. These shallow Cook Inlet gas field may serve as analogs for the Tertiary Holitna basin.

Data on regional ground water flow patterns in and around the Holitna basin are not available, but regional ground water probably flows toward the northwest and southeast from the Alaska Range and Kuskokwim Mountains, respectively. Regional flow paths probably converge in the vicinity of the Kuskokwim River, which flows parallel to and just to the northwest of the basin axis (fig. 1). The absence of exposures of Tertiary coal- and carbonaceous mudstone around the perimeter of the basin suggests that regional ground water flow is not directed through thick, laterally continuous coals and carbonaceous mudstones, thereby reducing the chance for biogenic gas.

For the reasons outlined above and due to potential structural complexities, any accumulations, if present, are likely to be small and non-commercial. Kirschner (1994) arrived at a similar conclusion. However, a small- to moderate-sized gas accumulation (100 to 200 billion cubic feet) could represent a significant resource for local consumption.

CONCLUSIONS

The Alaska Division of Geological and Geophysical Surveys evaluated the shallow gas potential of the Tertiary Holitna basin using high-resolution aeromagnetic and gravity surveys and detailed studies of outcrops of Tertiary sedimentary rocks along the Alaska Range mountain front from the Little Tonzona River to the Cheeneetnuk River. The task of reprocessing and interpreting the geophysical data sets was performed by a geophysical contractor. The results of the geophysical investigation will be summarized in a final geophysical report in 2002.

The closest exposures of Tertiary strata to the Holitna basin are located approximately 20 km away, along the Cheeneetnuk River in the northern Lime Hills Quadrangle and southwestern McGrath Quadrangle, where mudstone with thin coal stringers are present in small overgrown exposures along the north bank of the river. Coal and carbonaceous mudstone are absent near White Mountain in the McGrath Quadrangle, where over 500 m of conglomerate, pebbly sandstone, and siltstone are exposed south of the Cheeneetnuk River and are interpreted as products of high-gradient, low-sinuosity streams and adjacent flood basins. Between the Middle and Windy forks

of the Kuskokwim River over 1,000 m of Tertiary strata are exposed along river banks. In this area, the southern two-thirds (stratigraphic base) of the outcrop belt is dominated by coarse-grained lithologies similar to those recognized near White Mountain and are similarly interpreted. The northern third (stratigraphic top) of the outcrop belt consists of carbonaceous mudstone, thin high-ash coal stringers, and scattered thin pebble conglomerate, sandstone, and siltstone beds that are interpreted as lacustrine deposits. The thickest and cleanest (low-ash) coal is located at the northeast end of the outcrop belt, between Deepbank Creek and the Little Tonzona River, where individual seams up to 12 m thick have been documented. Biostratigraphic data suggest that rocks become progressively younger to the southwest, from the Little Tonzona River (late Eocene to early Miocene) to the Lower Cheeneetuk River (middle to late Miocene).

The relation between the outcrop section and the subsurface Holitna basin remains unknown. The apparent age progression from late Eocene-early Miocene at the Little Tonzona River to middle to late Miocene in the lower Cheeneetuk River area suggests that the fill of the basin to the southwest may be middle Miocene or younger in age. This assumes the age progression in outcrop is a reflection of deposition in a single depositional basin, but the validity of this assumption is unknown. The outcrop belt may represent deposition in multiple disconnected basins that have no spatial relation to the subsurface Holitna basin.

The reservoir and trap potential is probably poor. Conglomerates are well-indurated, clast-supported, and have poorly sorted sandstone as matrix between clasts. The sandstone matrix in conglomerates lack visible porosity in outcrop. Similarly, sandstones are generally tightly cemented and lack visible porosity in outcrop. Clast composition and sandstone composition indicate a low-grade metamorphic provenance; notable exceptions are present along the Khuchaynik River, where one conglomerate succession includes a high percentage (over 50 percent) of limestone clasts. Traps are likely to be complex structural (faults and faulted folds) and combination stratigraphic-structural traps.

Suitable seal lithologies have not been recognized in outcrop. Coal and carbonaceous mudstones are often silty and only rarely “clean” claystones. This suggests that seal lithologies will be leaky.

Carbonaceous mudstone, lignite, and sub-bituminous coal at the Little Tonzona River, Windy Fork, Middle Fork, and Cheeneetuk River localities are potential source

rocks. Coal petrology, Rock-Eval pyrolysis, and kerogen microscopy indicate abundant type III and IV kerogens and the potential to generate gas. Limited Rock-Eval pyrolysis data also suggest the presence, at least locally, of lipid-rich vitrinite (HI over 380 in two samples) in the lacustrine succession at the north end of the Middle Fork exposure.

Baseline-DGSI, Inc. suggests that this organic facies may be capable of generating wet gas, condensate, or possibly light oil. We caution the reader to avoid drawing overly optimistic conclusions from these data as our data set is very limited. DGGS plans to collect a more extensive Rock-Eval sample suite during the 2002 field season.

Vitrinite reflectance data indicate the outcrop section is submature to borderline mature for oil (mean Ro between 0.14 and 0.62). These data suggest shallow burial to depths less than 1500 meters (less than 4,860 feet), depending on geothermal gradients. Shallow gas (less than 1,600 to 2,000 m depth) in the Holitna basin, if present, would have to have migrated from more deeply buried source rocks or have been derived from biogenic processes. Accumulations of biogenic gas, if present, are likely to be small as indicated by the structurally disrupted Tertiary section in outcrop to the northeast. Overall, the shallow gas potential of the Holitna basin is regarded as low to fair.

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APPENDIX

GEOCHEMICAL ANALYSIS OF CARBONACEOUS SHALES HOLITNA BASIN, SOUTHWEST ALASKA

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October 3, 2001

DISCUSSION

Twelve carbonaceous shales from outcrops in the Hilitna Basin, Southwest Alaska were analyzed according to client instructions. Organic carbon contents vary greatly (0.06 to 15.76 wt. % TOC) and Rock-Eval pyrolysis indicates low hydrocarbon yield, gas-only generating, type III to type IV organic matter in most samples (Figure 1). This low yield, however, may be due at least in part to outcrop oxidation.

Three of the most organic-rich samples (Nos. 118, 121, and 123) with the highest hydrogen indices (198 to 386) contain more hydrocarbon generating capability than the others. These three samples were analyzed with kerogen microscopy and with solvent extract gas chromatography.

Kerogen microscopy shows that all three samples contain primarily humic (coaly) organic matter, primarily consisting of lipid-rich vitrinite (Appendix). Samples 121 and 123 contain lipid rich vitrinite with fluorescing liptodetrinite inclusions (see Appendix). This material is the reason for the high hydrogen indices and low pyrolysis T_{max} values compared to the other samples and indicates some ability to generate wet gas and possibly some condensate or light crude oil as well. Vitrinite reflectance maturities range from 0.45 to 0.53% R_o , which is in the late immature, pre-oil generation zone. This agrees with the pyrolysis T_{max} data (except for the samples with reduced T_{max} values due to liptodetrinite), the immature appearance of the kerogen, and extract gas chromatography results. This maturity at the surface, however, indicates substantial overburden removal since maximum burial and that hydrocarbon generation is currently suspended.

The same three samples that were analyzed with kerogen microscopy yielded between 897 and 6,138 ppm of total extract (Appendix). Whole extract gas chromatograms are very characteristic of immature, terrigenous organic matter. High pr/ph ratios (Appendix) and the position of the samples on Figure 2 are consistent with this interpretation. Sample 118 with the lowest TOC content, HI ratio, and extract recovery is different than samples 121 and 123 which are both very similar. This agrees with the kerogen microscopy and the gas chromatography data. All three samples, however, contain immature, primarily terrigenous organic matter with little oil-generating capability. It is noted that lower molecular weight hydrocarbons, less than about nC_{15} , have been largely lost due to evaporation and this is the fraction that should be generated in greatest abundance by the type of organic matter present in the samples.

FOOTHILLS PROJECT
HOLITNA BASIN
BaselineDGSi Project: 00/474G

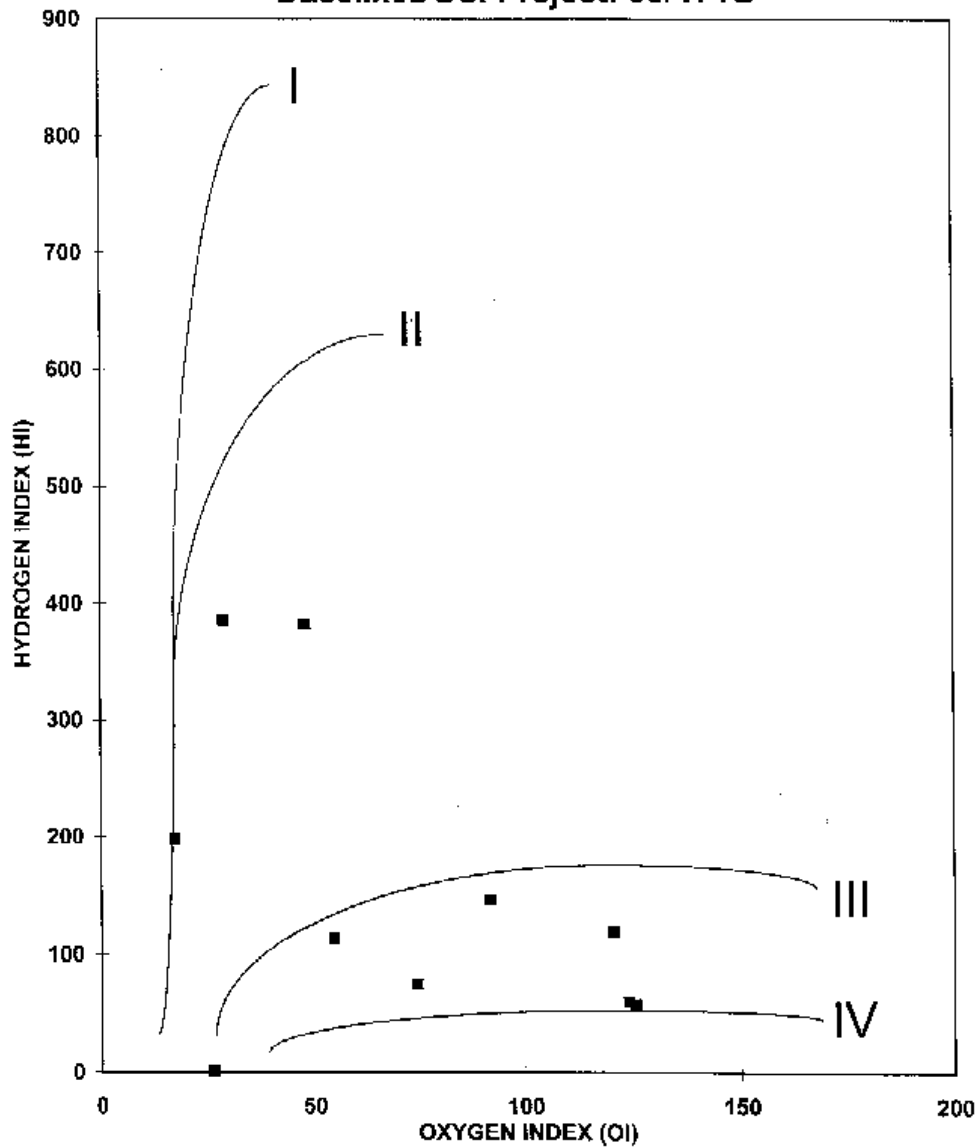


FIGURE -1 Kerogen type determination from TOC and Rock-Eval pyrolysis data. Types I and II will generate oil, type III gas, and type IV little or no hydrocarbons.

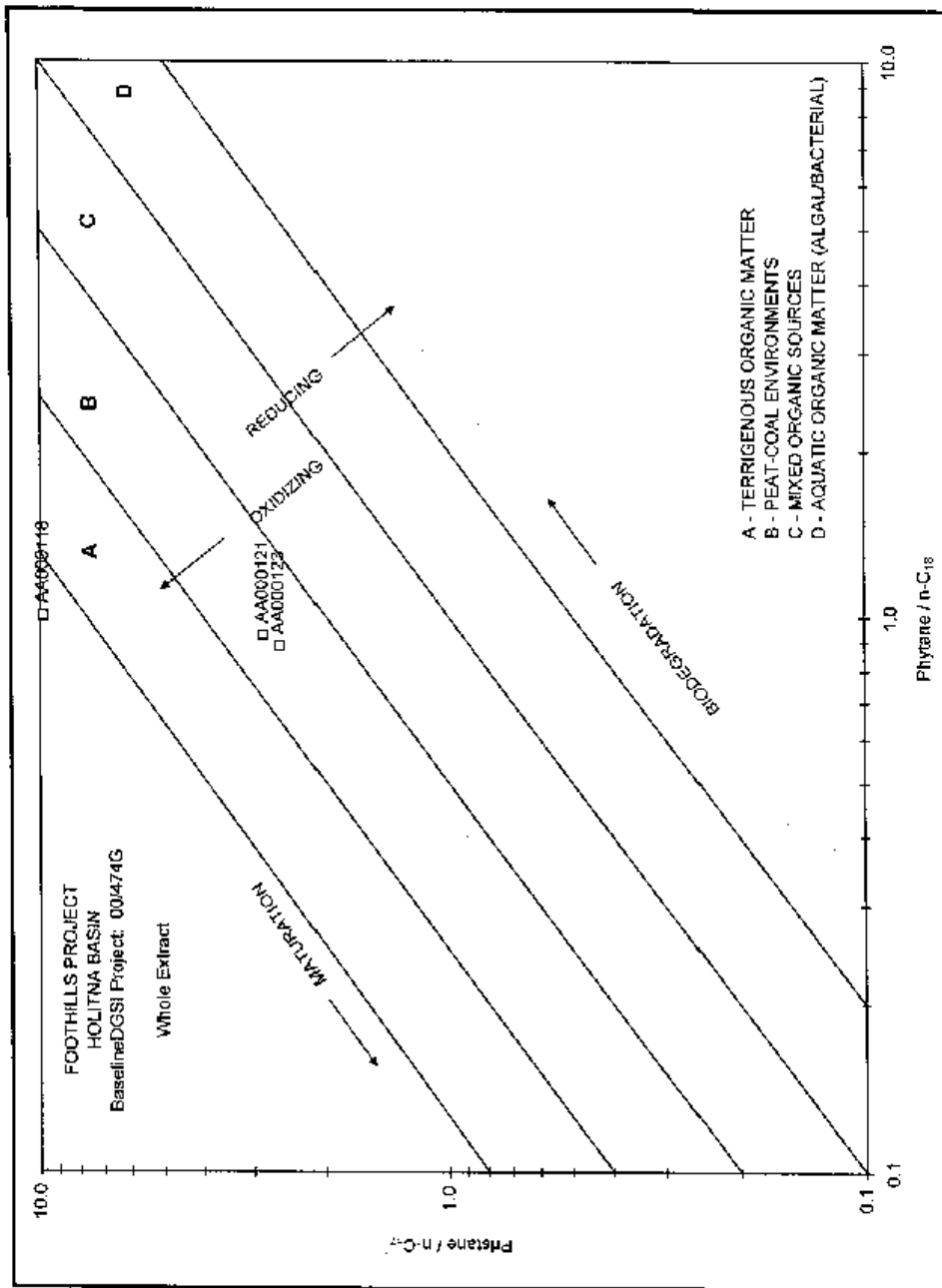


FIGURE 2 - Plot from chromatography data showing organic matter type, source rock depositional environment, and thermal maturity.

ANALYSES BY ROCK-EVAL 6

KINETICS

Reaction rate profiles derived from pyrolysis FID are used to determine activation energy and frequency factor kinetic parameters. These kinetic parameters can be incorporated into hydrocarbon generation models to quantitatively simulate the thermal conversion of various kerogen types to oil and gas. Combining this data with basin modelling and geochemical analysis of the source rock can provide more accurate estimates of a source rocks' contribution to oil and/or gas in a basin and determine the timing of oil and/or gas generation and migration.

Whole rock or isolated kerogens are analyzed with the Rock-Eval 6 by Vinci Technologies to acquire accurate temperature and reaction rate profiles. The instrument contains a temperature measuring device at the sample being analyzed and this reduces the temperature correction factor necessary to acquire accurate data. Heating rates of 2, 5, 10, 15, and 25° C/min. are normally utilized to provide rate profiles for the kerogen to oil generation. The data are then processed using kinetics software developed by Lawrence Livermore National Laboratories.

Tabular and graphical data of the activation energy distribution and the selected frequency factor are provided. Graphs of the measured and computed rate profiles are included.

CARBONATE DETERMINATION

A rock sample is heated to 850°C during pyrolysis which decomposes the carbonates to yield CO and CO₂. CO and CO₂ are then measured with an I. R. detector for mineral carbon value. The mineral carbon value that is obtained is converted to % carbonate by using a molecular wt. formula which assumes that all carbonate is calcium carbonate.

API GRAVITY

API gravity of oils, heavy oils and oil shows is useful for identification and characterization. When determined early in the drilling process, it is helpful for economic evaluation by evaluating tar mats and heavy oil. API determined by Rock-Eval 6 shows good correlation to gravimetric results in the range of 30° API or less. The recommended procedure for evaluation requires a known set of oils to be analyzed to establish a trend line. Then a set of samples, either heavy oils or tars, may be evaluated. It is possible for DCSI to provide existing established trend lines for evaluation if necessary. (Trabelsi, K., J. Espitalie, A. Y. Hus, IFP, "Characterization of Extra Heavy Oils and Tar Deposits by Modified Pyrolysis by Modified Pyrolysis Methods").

ROCK-EVAL PYROLYSIS with TOC

Rock-Eval 6 Plus TOC is used to determine both Rock-Eval data (S₁, S₂, S₃, T_{max}) and TOC of a 0.08 gram ground sample. With this instrument, the pyrolysis stage (S₂) ramps to 650°C at which point the sample is switched to an oxidation oven where the sample is oxidized at 850°C for 5 minutes in air to measure the residual organic matter. A laboratory standard is run every 10 samples. S₁, S₂, S₃, and residual organic matter are summed appropriately to calculate TOC. The extended temperature range of RF6 overcomes the shortcomings of the RE II in TOC evaluation. The infrared detection of CO₂ and CO also improves its reproducibility.

ORGANIC CARBON AND ROCK-EVAL PYROLYSIS DATA

**FOOTHILLS PROJECT
HOLITNA BASIN
BaselineDGS1 Project: 00/474G**

SAMPLE IDENTIFICATION		TOC	S1	S2	S3	Tmax	S1/ TOC	HI	OI	S2/ S3	PI
ID		Wt%	mg/g	mg/g	mg/g	degC					
AA000116	00DL58-3B	3.09	0.04	3.72	3.73	432	1	120	121	1.00	0.01
AA000117	00DL48A-2.0	1.32	0.01	0.80	1.64	437	1	61	124	0.49	0.01
AA000118	00DL49-2	8.45	0.08	16.76	1.46	425	1	198	17	11.48	0.00
AA000119	00DL58-49.6	1.57	0.01	1.79	0.86	428	1	114	55	2.08	0.01
AA000120	00DL49-2/U	9.58	0.21	14.03	8.79	428	2	147	92	1.60	0.01
AA000121	00DL49-327.5	15.76	0.86	60.32	7.57	410	5	383	48	7.87	0.01
AA000122	00DL49-6.6	3.94	0.02	2.96	2.94	437	1	75	75	1.01	0.01
AA000123	00DL49-265	15.25	0.57	58.80	4.44	418	4	386	29	13.24	0.01
AA000124	00DL32F	0.08	0.01	0.02	0.40	434	17	33	667	0.95	0.33
AA000125	00DL48A-4.8	1.66	0.01	0.96	2.09	440	1	58	128	0.46	0.01
AA000126	00DL42C	1.82	0.02	0.02	0.43	558	1	1	27	0.05	0.50
AA000127	00DL42B	0.33	0.01	0.00	0.17	N.A.	3		52	--	--

KEROGEN MICROSCOPY

Visual kerogen analysis employs a Zeiss Universal microscope system equipped with halogen, xenon, and tungsten light sources or a Jena Lunar microscope equipped with halogen and mercury light sources. Vitrinite reflectance and kerogen typing are performed on a polished epoxy plug of unfloats kerogen concentrate using reflected light from the halogen source. In certain situations, the whole rock is used for analysis. This approach is used for coals, where acid treatment is unnecessary in studies of solid bitumen and graptolites where preservation of rock structure is important, and in samples too small for acid treatment. The digital indicator is calibrated using a glass standard with a reflectance of 1.02% in oil. This calibration is linearly accurate for reflectance values ranging from peat (R_G 0.20%) through anthracite (R_G 4.0%).

Vitrinite Reflectance

Reflectance values are recorded only on good quality vitrinite, including obvious contamination and recycled material. The relative abundance of normal, altered, lipid-rich, oxidized, and coked vitrinite is recorded. When good quality, normal vitrinite is absent, notations are made indicating how the maturity is affected by weathering, oxidation, bitumen saturation, or coking. When normal vitrinite is absent or sparse, other macerals may be substituted. Solid bitumen, for example is present in many samples. Although solid bitumen has a different reflectance than vitrinite, Landis and Castaño's calibration chart is used to obtain an estimated vitrinite reflectance equivalent. Graptolites have a slightly higher reflectance than vitrinite and can often be used to obtain maturity data in Upper Cambrian-Silurian rocks that have no vitrinite.

Maturity calculations are made from the vitrinite reflectance histograms. Decisions as to which reflectance measurements indicate the maturity of the sample are based not only on the histogram but on all of the kerogen descriptive elements as well. Because it is not done at the time of measurement, alternate maturity calculations can be made if kerogen data and geological information dictate.

DGSI's vitrinite reflectance histograms contain much useful information. All reflectance measurements are graphically displayed and the individual readings are listed below the histogram in numeric order. In the reflectance table, each reading is coded with a letter corresponding to the measured maceral. Capital letters are used to designate reflectance values that are used in calculating the mean reflectance while reflectance values falling outside the selected range are shown with a lower case letter code. Reflectance readings lying inside the selected range are marked with a pattern on the histogram diagram and readings falling outside the selected range are left open. Each maceral has a different pattern.

Codes currently in use include: Solid bitumen - B, Granular solid bitumen - X, Coked solid bitumen - Y, Graptolites - G, Inertinite - I, Other1 - O, Other2 - W, Vitrinite - V, Lipid-rich vitrinite - L, and Coked Vitrinite - Z. The use of two 'other' categories allows us the flexibility of measuring unusual materials that do not fall into one of the other classes or contamination from mud additives or caving. Specific information regarding 'other' material is shown in the Comments section at the lower right corner of the Figure and in the Comments section of the VKA data sheet.

Statistics for selected macerals are listed adjacent to the histogram and the mean reflectance values are also listed below the TOC and Rock-Eval data at the upper right corner of the Figure. The measured reflectance values for solid bitumen and graptolites are recalculated in order to obtain a vitrinite reflectance equivalent (VRE). Therefore, for these two macerals we show both the measured reflectance and the VRE. For example, VRE-B signifies vitrinite reflectance equivalent for solid bitumen and VRE-G is the vitrinite reflectance equivalent for graptolites.

In summary, vitrinite reflectance measurements are performed on a polished plug in reflected light, TAI is performed on a slide in transmitted light, and kerogen typing is estimated from both preparations using a combination of reflected, transmitted, and fluorescent light techniques. Fluorescence in blue light is used to enhance the identification of structured and unstructured lipid material, solid bitumens, and drilling mud contaminants. Fluorescence also correlates with the maturity and state of preservation of the sample. Maturity calculations from measured reflectance data are made from the histograms and are influenced by all of the kerogen data.

Visual Kerogen Analysis Techniques

Unstructured lipid kerogen changes in texture and color during the maturation process. Typically, unstructured kerogen at low maturity is reddish brown and amorphous. Somewhere between R_o 0.50 to 0.65%, the kerogen takes on a massive texture and is gray in color. At higher maturity, generally above R_o 1.30%, unstructured kerogen is light gray and micrinized.

Kerogen typing and maturity assessments from the polished plug are enhanced by utilizing fluorescence from blue light excitation. The xenon or mercury lamp is used with an excitation filter at 495 nm coupled with a barrier filter of 520 nm. With the Jena microscope we also have the option of observing fluorescence under ultraviolet excitation. The intensity of fluorescence in the epoxy mounting medium (background fluorescence) correlates well with the onset of oil generation and destruction. The identification of structured and unstructured liptinite is also enhanced with the use of fluorescence in those samples having a maturity less than R_o 1.3%. The relative abundance and type of pyrite is also recorded.

Thermal alteration index (TAI) is performed using tungsten or halogen light source that is transmitted through a glass slide made from the unfloated kerogen concentrate. Ideally, TAI color is based on sporinite of terrestrial origin. When sporinite is absent, TAI is estimated from the unstructured lipid material. Weathering, bitumen admixed with the unstructured material and micrinization can darken the kerogen and raise the TAI value. The character of the organic matter in transmitted light is correlated with observations made in reflected light for kerogen typing.

Kerogen typing and maturity assessments from the slide preparation are also reinforced by using different light sources. The slide is first observed in transmitted light to obtain TAI color and organic matter structure or type. The light is then switched to reflected halogen light to observe structure and amount of pyrite and finally to reflected blue light excitation from the xenon or mercury source for fluorescence. The fluorescence of structured and unstructured liptinite is not masked by the epoxy fluorescence as it is in the reflected light mode because the mounting medium is non-fluorescent. Lipid structures (e.g. sporinite and alginite) within the unstructured kerogen can often be identified in blue light.

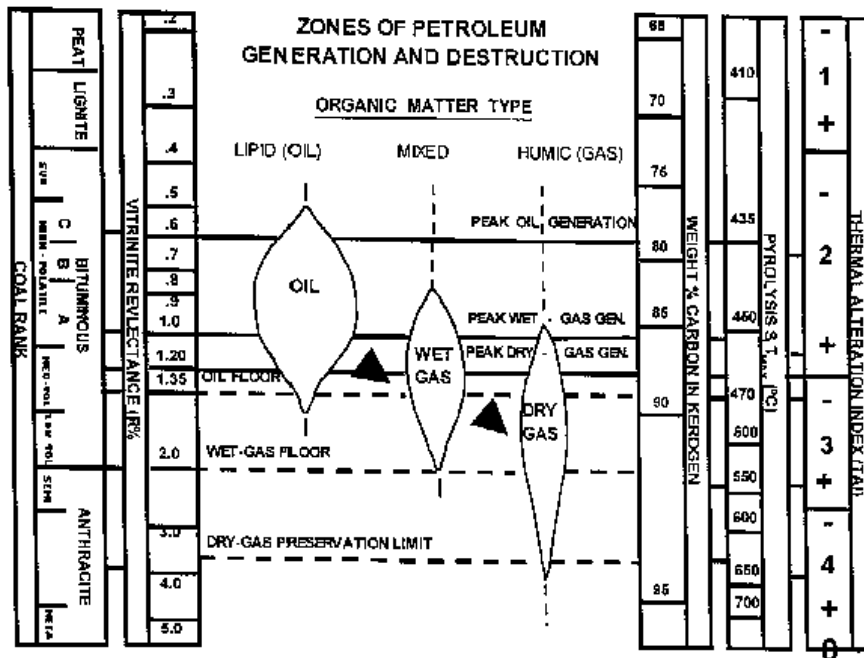
VISUAL KEROGEN ANALYSIS GLOSSARY

Several key definitions are included in this glossary in order to make our reports more self-explanatory. In our reports, we refer to organic substances as macerals. Macerals are akin to minerals in rock in that they are organic constituents that have microscopically recognizable characteristics. However, macerals vary widely in their chemical and physical properties and they are not crystalline.

1. **UNSTRUCTURED KEROGEN** is sometimes called structureless organic matter (SOM) or bituminite. It is widely held that unstructured kerogen represents the bacterial breakdown of lipid material. It also includes fecal pellets, minute particles of algae, organic gels, and may contain a humic component. As described on the first page of this section, unstructured lipid kerogen changes character during maturation. The three principal stages are amorphous, massive, and micrinized. Amorphous kerogen is simply without any structure. Massive kerogen has taken on a cohesive structure, as the result of polymerization during the process of oil generation. At high maturity, unstructured kerogen becomes micrinized. Micrinite is characterized optically by an aggregation of very small (less than one micron) round bodies that make up the kerogen.
2. **STRUCTURED LIPID KEROGEN** consists of a group of macerals which have a recognized structure, and can be related to the original living tissue from which they were derived. There are many different types, and the types can be group follows:
 - a. Alginite, derived from algae. It is sometimes very useful to distinguish the different algal types, for botryococcus and pediastrum are associated with lacustrine and non-marine source rocks, while algae such as tasmanites, gloeocapsomorpha, and nostocopsis are typically marine. Acritarchs and dinoflagellates are marine organisms which are also included in the algal category.
 - b. Cutinite, derived from plant cuticles, the remains of leaves.
 - c. Resinite, (including fluorinitic) derived from plant resins, balsams, latexes, and waxes.
 - d. Sporinite, derived from spores and pollen from a wide variety of land plants.
 - e. Suberinite is derived from the corky tissue of land plants.
 - f. Liptodetrinite is that structured lipid material that is too small to be specifically identified. Usually, it is derived from alginite or sporinite.

The algae are an important part of many oil source rocks, both marine and lacustrine. Alginite has a very high hydrogen index in Rock-Eval pyrolysis. Resins, cuticles, and suberinite contribute to the waxy, non-marine oils that are found in Africa and the Far East. At vitrinite reflectance levels above R_o 1.2 - 1.4%, structured lipid kerogen changes structure and it becomes very difficult to distinguish them from vitrinite.

3. **SOLID BITUMEN** also is called migrabitumen and solid hydrocarbon. In 1992, the International Committee for Coal and Organic Petrology (ICCP) decided to include solid bitumen in the Exsudatinitic group. Solid bitumens are expelled hydrocarbon products which have particular morphology, reflectance and fluorescence properties which make it possible to identify them. They represent two classes of substances: one which is present at or near the place where it was generated, and second is a substance which is present in a reservoir rock and may have migrated a great distance from its point of origin. The solid bitumens have been given names, such as gilsonite, impositonic, grahmanite, etc., but they represent generated heavy hydrocarbons which remain in place in the source rock or have migrated into a reservoir and mature along with the rock. Consequently, it is possible to use the reflectance of solid bitumens for maturation determinations when vitrinite is not present.
4. **HUMIC TISSUE** is organic material derived from the woody tissue of land plants. The most important of this group are vitrinite and inertinite:
 - a. Vitrinite is derived from woody tissue which has been subjected to a minimum amount of oxidation. Normally it is by far the most abundant maceral in humic coals and because the rate of change of vitrinite reflectance is at a more even pace than it is for other macerals, it offers the best means of obtaining thermal maturity data in coals and other types of sedimentary rocks. Because the measurement of vitrinite is so important, care is taken to distinguish normal (fresh, unaltered) vitrinite from other kinds of vitrinite. Rough vitrinite does not take a good polish and therefore may not yield good data. Oxidized vitrinite may have a reflectance higher or lower than fresh vitrinite; this is a problem often encountered in outcrop samples. Lipid-rich vitrinite, or saprovitrinite, has a lower reflectance than normal vitrinite and will produce an abnormally low thermal maturity value. Coked vitrinite is vitrinite that has structures found in vitrinite heated in a coke oven. Naturally coked vitrinite is the product of very rapid heating, such as that found adjacent to intrusions. Where it is possible to do so, vitrinite derived from an uphole portion of a well will be identified as caved vitrinite. Recycled vitrinite is the vitrinite of higher maturity which clearly can be separated from the indigenous first-cycle vitrinite population. Often, the recycled vitrinite merges in with the inert group.
 - b. Inertinite is made up of woody tissue that has been matured by a different pathway. Early intense oxidation, usually involving charring, fungal attack or biochemical gelification, creates the much more highly reflecting fusinite and semi-fusinite. Sometimes the division between vitrinite and fusinite is transitional. Sclerotinite, fungal remains having a distinct morphology, are considered to be inert. An important consideration is that the inerts, as the name implies, are largely non-reactive "dead carbon" and they have an extremely low hydrogen index in Rock-Eval pyrolysis.
5. **OTHER ORGANIC MATERIAL**
 - a. Lipid-rich, caved and recycled vitrinite. These are put in this section so we can show the percentages of these macerals; they are described above.
 - b. Exsudatinitic. Oil and oily exudates fall in this group. Exsudatinitic differs from the solid bitumens on the basis of mobility and solubility. We prefer to maintain this distinction although the ICCP has now included the solid bitumens in with the Exsudatinitic group.
 - c. Graptolites are marine organisms that range from the Cambrian to the lower Mississippian; it has been found that they have a reflectance slightly higher than vitrinite. Because vitrinite is lacking in early Paleozoic rocks, the proper identification and measurement of graptolites is important in these sediments.
6. **PYRITE**. Various forms of pyrite can be readily identified under the microscope. Euhedral is pyrite with a definite crystalline habit. Framboidal is pyrite in the form of grape-like clusters which are made up of euhedral to subhedral crystals. Framboidal pyrite is normally found in sediments with a marine influence; for example, coals with a marine shale roof rock usually contain framboidal pyrite. Massive pyrite is pyrite with no particular external form. Often this is pyrite that forms rather late in the pore spaces of the sediment. Replacement/infilling is self-explanatory.



CORRELATION OF VARIOUS MATURATION INDICES AND ZONES OF PETROLEUM GENERATION AND DESTRUCTION

FOOTHILLS PROJECT
HOLITNA BASIN

AA000118: 00DL48-2

Organic matter consists of large, lipid-rich vitrinite fragments and unstructured material with very small lipid-rich vitrinite inclusions. Lipid-rich vitrinite is slightly soluble in immersion oil. Reflectance values were measured quickly, but some values may still be slightly lowered by rough texture or slight suppression. Unstructured material may be degraded humic debris or oxidized unstructured lipids. TAI values on unstructured lipids may not be valid. Reflectance, fluorescence, and pyrolysis data agree that maturity is just entering the top of the oil generation zone.

AA000121: 00DL49-327.5

Organic matter consists of lipid-rich vitrinite fragments with liptodetrinite inclusions and a small amount of unstructured material. Lipid-rich vitrinite is slightly soluble in immersion oil. Some reflectance values may be slightly lowered by rough texture or slight suppression. Oxidation may cause unstructured lipids to appear more mature than they actually are. Reflectance and fluorescence indicate the organic matter to be slightly immature, but near the top of the oil window. Abundance of structured lipids may lower the T_{max} value.

AA000123: 00DL49-265

Organic matter consists of lipid-rich vitrinite fragments with liptodetrinite inclusions. Fluorescing liptodetrinite is abundant when observed in the transmitted light slide. Lipid-rich vitrinite is slightly soluble in immersion oil. Some reflectance values may be lowered by rough texture, lipid content, or slight suppression. Reflectance and fluorescence indicate the organic matter to be slightly immature, but near the top of the oil window. Abundance of structured lipid inclusions may lower the T_{max} value.



**FOOTHILLS PROJECT
HOLITNA BASIN
BaselineDGSi Project: 00474G**

BaselineDGSi Number	ORGANIC MATTER (%)														RELATIVE ABUNDANCE										REFLECTED				FLUORESCENCE /TAI				Ro								
	UNSTRUCTURED							STRUCTURED							DUMIC			OTHER				VITRINITE			LIPIDS				LIPIDS												
	Amorphous	Miscellaneous	Type	Type	Type	Type	Solid Bitumen	Inertinite	Vitrinite	Type	Pyrite Type	Pyrite Type	Organic Concentration	Normal	Rough	Lipid-Rich	Oxidized	Coked	Color	Intensity	Color	Intensity	Background Intensity	Value	Color	Intensity	Value	Color	Intensity	Value	Color	Intensity		Value	Color	Intensity	Value	Color	Intensity		
AA000118	00DL48-2	K	OC	20	LD	C	Y	76	VL	MA	T	+	N	M	+	DB	1	2	2+	BL	D	OC	1	OC	1	OC	1	OC	2	OC	2	OC	2	OC	2	OC	2	OC	2	V0.53	
<i>Comments: Unstructured lipids may be hump debris or oxidized unstructured lipids. Lipid-rich vitrinite is slightly soluble in immersion oil - some Ro values may be lowered.</i>																																									
AA000121	00DL49-327.5	OC			7	LD	C	T	VL	MA	T	+	N	M	+	DB	1	2	3	ind.																				V0.45	
<i>Comments: Oxidation may cause unstructured lipids to appear more inertite. Lipid-rich vitrinite is slightly soluble in immersion oil.</i>																																									
AA000123	00DL49-285	K	OC	?	LD	C	S	80	VL	MA	T	+	N	M	+	DB	1	2	3																						V0.49
<i>Comments: Lipid-rich vitrinite slightly soluble in immersion oil. Fluorescing structured lipid inclusions are abundant when observed in transmitted light slide.</i>																																									
<i>Comments:</i>																																									
<i>Comments:</i>																																									
ANALYST X O'Connor																																									
MICROTYPE X Zeiss Jena Leitz																																									

FLUOR. COLOR INTENS. ABUND. PYRITE OTHER ORGANIC MATTER STRUCTURED LIPIDS SAMPLE TYPE/PREP

W White
G Green
Y Yellow
O Orange
R Red
B Brown
Bl. Black
i. Light
D Dark
4+ Black-Opaque

R Bitumen
G Graphitic
VL Lipid-Rich Vitrinite
VC Vitrite + Coal
VR Recycled Vitrinite

0 None
1 Weak
2 Moderate
3 Strong
4 Intense

N None
T Trace
M Small Amt
M+ Mod Amt
+ Large Amt
+ Abundant

E Enriched
F Fossilized
MA Massive
MI Micaceous
indl Indistinct

B Extractions
C Gasolines
VL Lipid-Rich Vitrinite
VC Vitrite + Coal + indl
VR Recycled Vitrinite

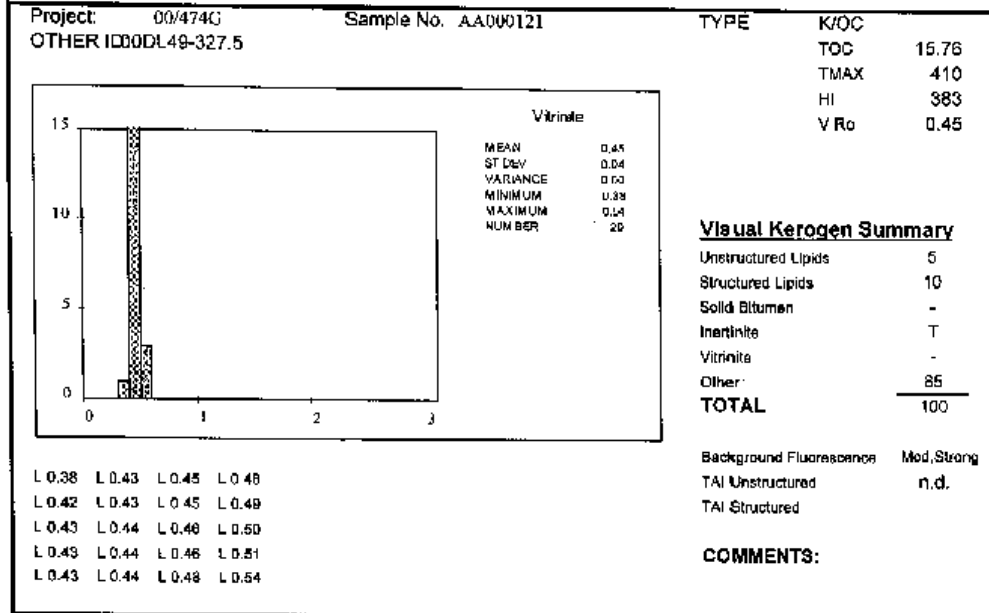
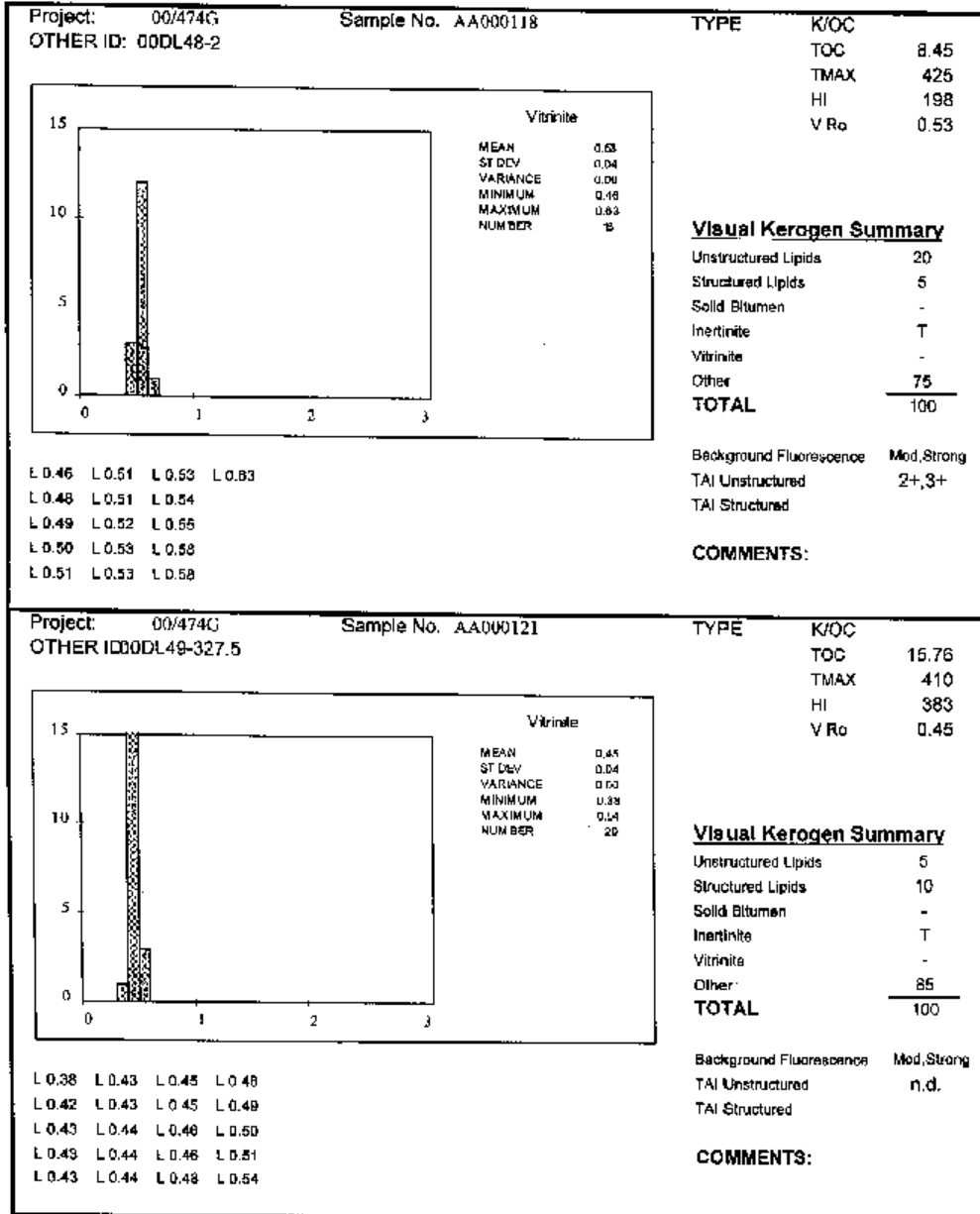
AL Aliphatic
Su Substrate
C Collinite
LD Lipocondensate
I Unaltered
S Spinite
R Resinite
O Other

OC Oil
CC Clay
SWC Siltstone/Walton
OC Oilstone
R Rill
C Coal
K Kerogen
WR Whole Rock
ind. Non-Determined

**VISUAL KEROGEN ANALYSIS
Total Quality Geochemistry**

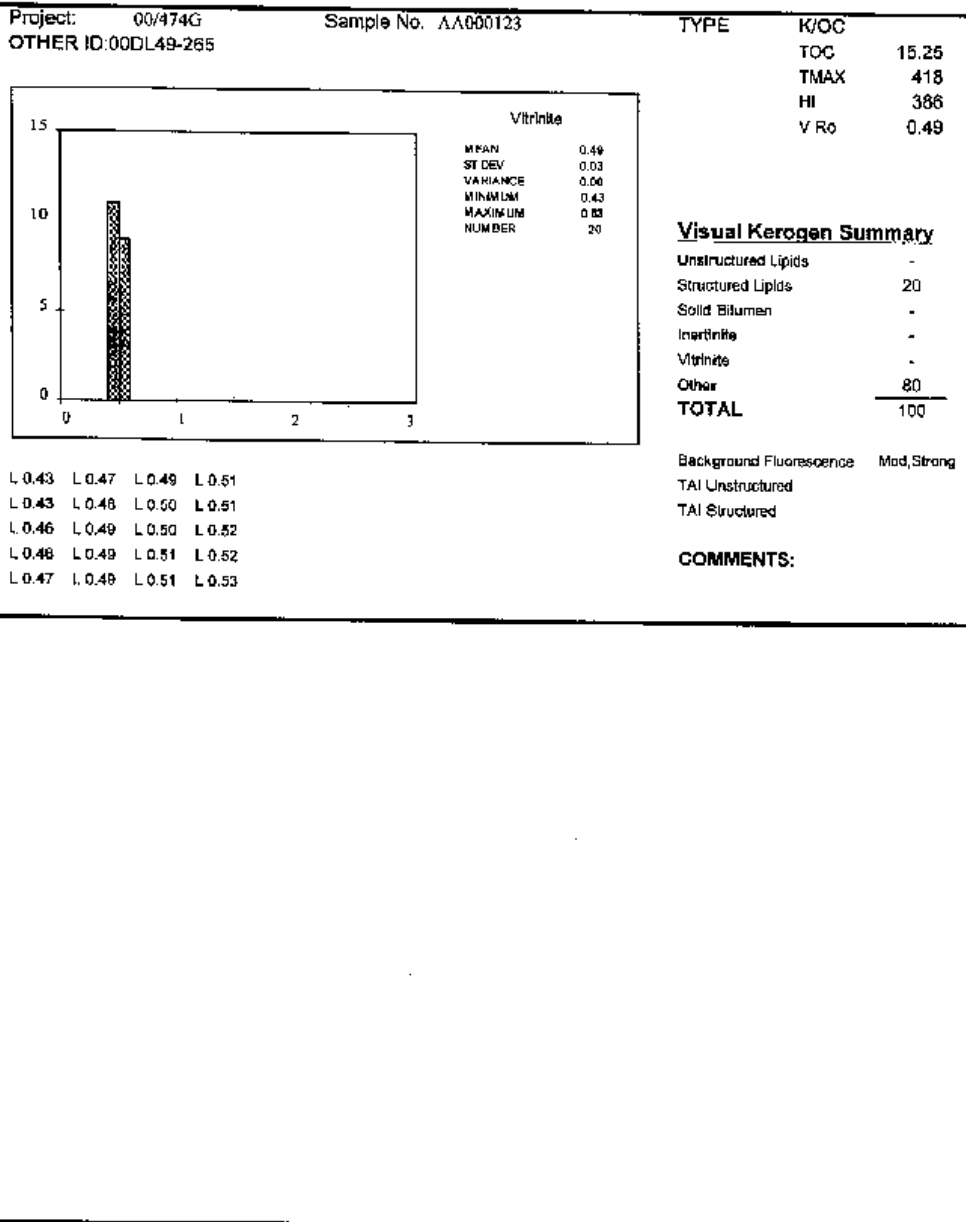
VITRINITE REFLECTANCE

**FOOTHILLS PROJECT
HOLITNA BASIN**



VITRINITE REFLECTANCE

**FOOTHILLS PROJECT
HOLITNA BASIN**



GAS CHROMATOGRAPHY High Resolution Capillary GC (HRCGC)

Techniques and Parameters

High Resolution Capillary Gas Chromatography (HRCGC) is an analytical technique which is used to separate and identify a multitude of hydrocarbon compounds in a crude oil or a rock extract. A single analysis on an oil can resolve compounds in great detail between C_2 and C_{40} which previously took three separate runs to achieve. For a rock extract only the fraction C_{12} is preserved. Compounds less than C_{12} are partially lost during extraction. Key compounds are identified and ratios calculated which are then used to interpret the kerogen type, organic facies, depositional environment and thermal history in the source rocks; the origin, type, thermal maturity and other alteration effects including water washing, biodegradation and evaporative fractionation in crude oils; and to help make oil-oil and oil-source rock correlations.

Whole Extract Gas Chromatography

About 50 grams of sample are crushed, passed through a 20 micron sieve, accurately weighed, and Soxhlet extracted for 16 hours with dichloromethane. Other solvents can be substituted if desired. The solvent is evaporated and the residue weighed to obtain the weight percent of total organic extract. The advantage to doing whole extract chromatography is that more of the lighter fraction ($C_{10} - C_{15}$) is preserved than if the saturated fraction were separated by column chromatography. A disadvantage is that nonsaturate compounds are retained which may complicate the chromatogram. Fortunately, this is a problem only in some relatively immature extracts. A sample of whole extract is injected directly into a gas chromatograph fitted with the same GC column and using the same temperature programming and computer software described in the section on whole oil analysis. A gas chromatogram as shown in Figure 1A is provided.

Whole extract gas chromatography provides information on the organic facies and thermal maturity of source rocks, on migrated petroleum, and serves as a basis for oil-rock correlations. It is recommended primarily to evaluate known or suspected source beds, oil shows, samples with anomalous pyrolysis S_1 values and to identify possible contamination products.

Aromatic GC

High Pressure Liquid Chromatography is used to prepare an aromatic fraction, which is then injected into a Varian model 3400 gas chromatograph, fitted with a Quadrex 50 meter fused silica capillary column. The GC is programmed from 40°C to 350°C at 10°C/minute with a two minute hold at 40°C and a 20 minute hold at 350°C. Analytical data are processed with Genie Software System® and HP ChemStation data acquisition software. This software system facilitates data processing and graphic display as well as electronic data transmission. Thirty-three aromatic hydrocarbons are separated and detected and these are broken down into six aromatic hydrocarbon types.

Whole Oil GC

A sample of whole oil is injected directly into a Varian model 3400 gas chromatograph fitted with a Quadrex 50 meter fused silica capillary column. The GC is programmed from 40 to 350° C at 10° C/minute with a 2 minute hold at 40° and a 20 minute hold at 350° C. Analytical data are processed with Genie Software System and HP ChemStation data acquisition software. This software system facilitates data processing and graphic display as well as electronic data transmittal. All standard calculations are made including pristane/phytane ratio, carbon preference index, and other key parameters (Tables 1 and 2). Two gas chromatograms are provided, one showing all compounds between nC_2 and nC_{40} (Figure 1A) and the other a computer enhanced version of the chromatogram between nC_2 and nC_{10} (Figure 1 B). Compounds as low as ethane can be detected if present. In addition, the concentration of C_{15} to C_{20} isoprenoids are determined and plotted (see example of standard report).

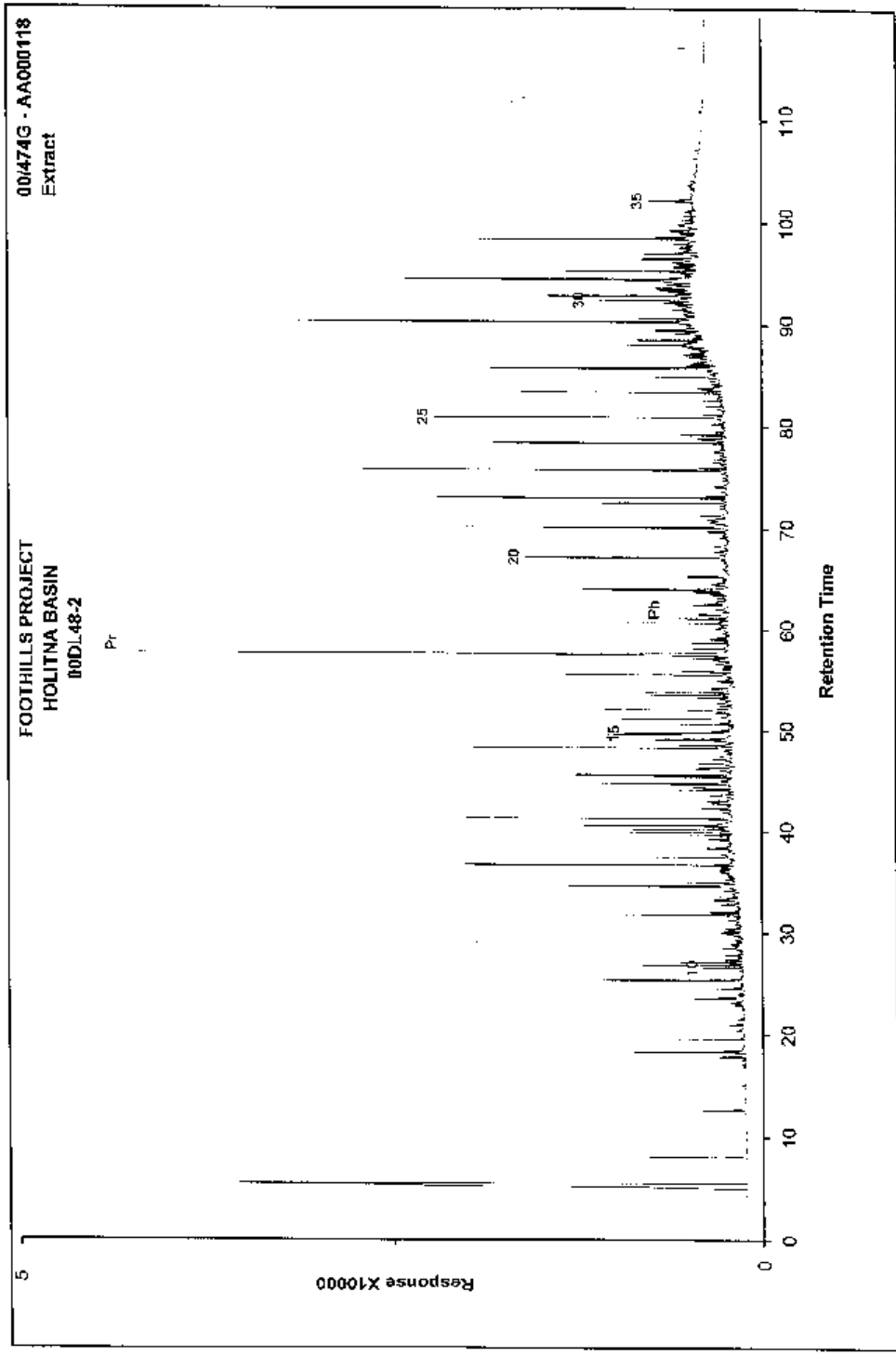
Whole Oil Light Ends: Compound Identification

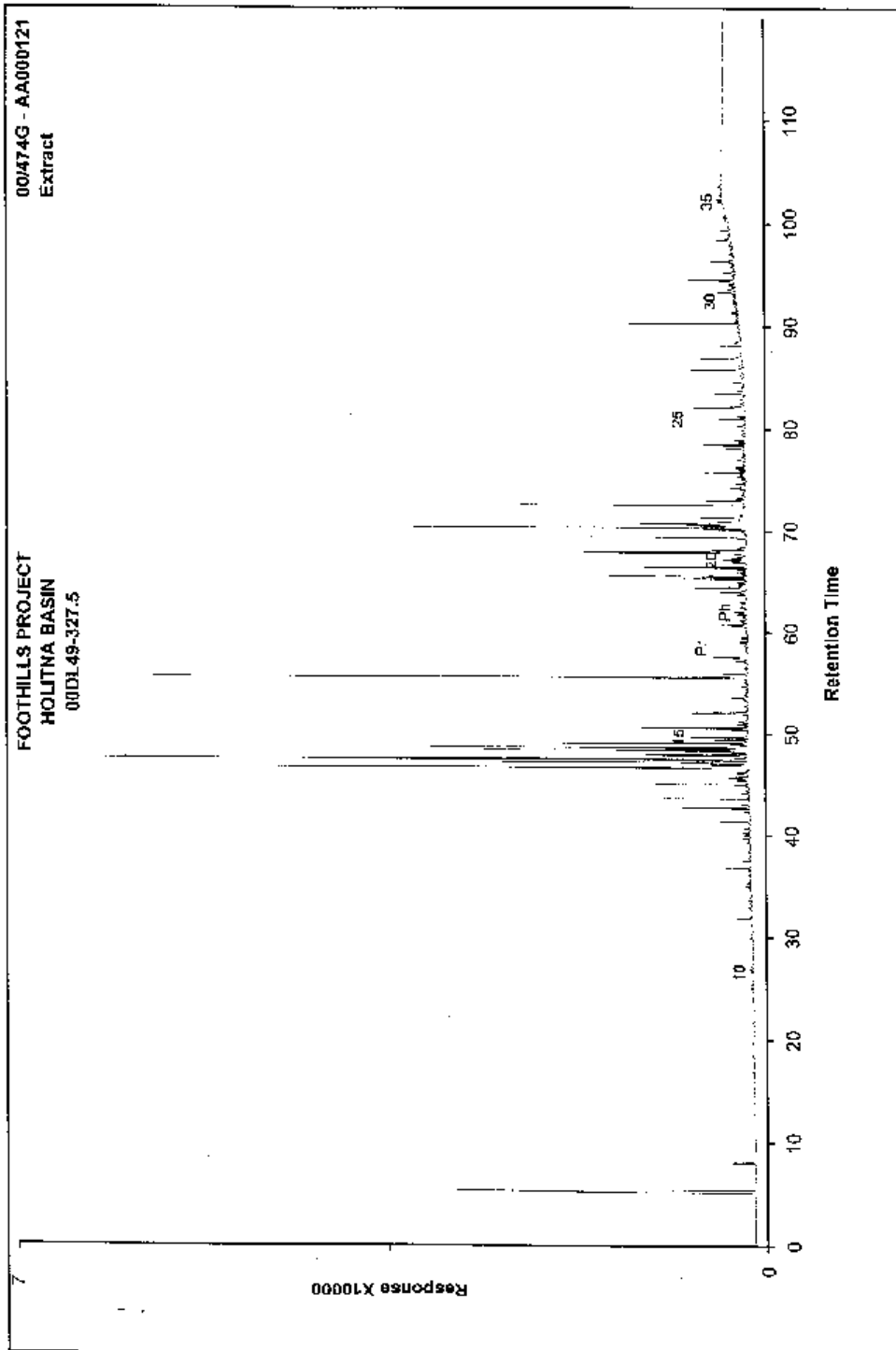
<u>No.</u>	<u>Abbreviation</u>	<u>Name</u>
1.	n-C ₂	Ethane
2.	n-C ₃	Propane
3.	i-C ₄	Isobutane
4.	n-C ₄	n-Butane
5.	i-C ₅	Isopentane
6.	n-C ₅	n-Pentane
7.	22DMB	2,2-Dimethylbutane
8.	2MP	2-Methylpentane
9.	3MP	3-Methylpentane
*10.	n-C ₆	n-Hexane
11.	24DMP+MCP+22DMP	2,2 & 2,4 Dimethylpentane + Methylcyclopentane
12.	BZ	Benzene
13.	CH	Cyclohexane
14.	2MH	2-Methylhexane
15.	23DMP	2,3-Dimethylpentane
16.	11DMCP	1,1 Dimethylcyclopentane
17.	3MH	3-Methylhexane
18.	1C3DMCP	1-c-3-Dimethylcyclopentane
19.	1T2DMCP+3EP	1-t-2-Dimethylcyclopentane + 3-Ethylpentane
20.	1T3DMCP	1-t-3-Dimethylcyclopentane
*21.	n-C ₇	n-Heptane
*22.	MCH	Methylcyclohexane
*23.	TOL	Toluene
*24.	n-C ₈	n-Octane
*25.	n-C ₉	n-Nonane
*26.	n-C ₁₀	n-Decane

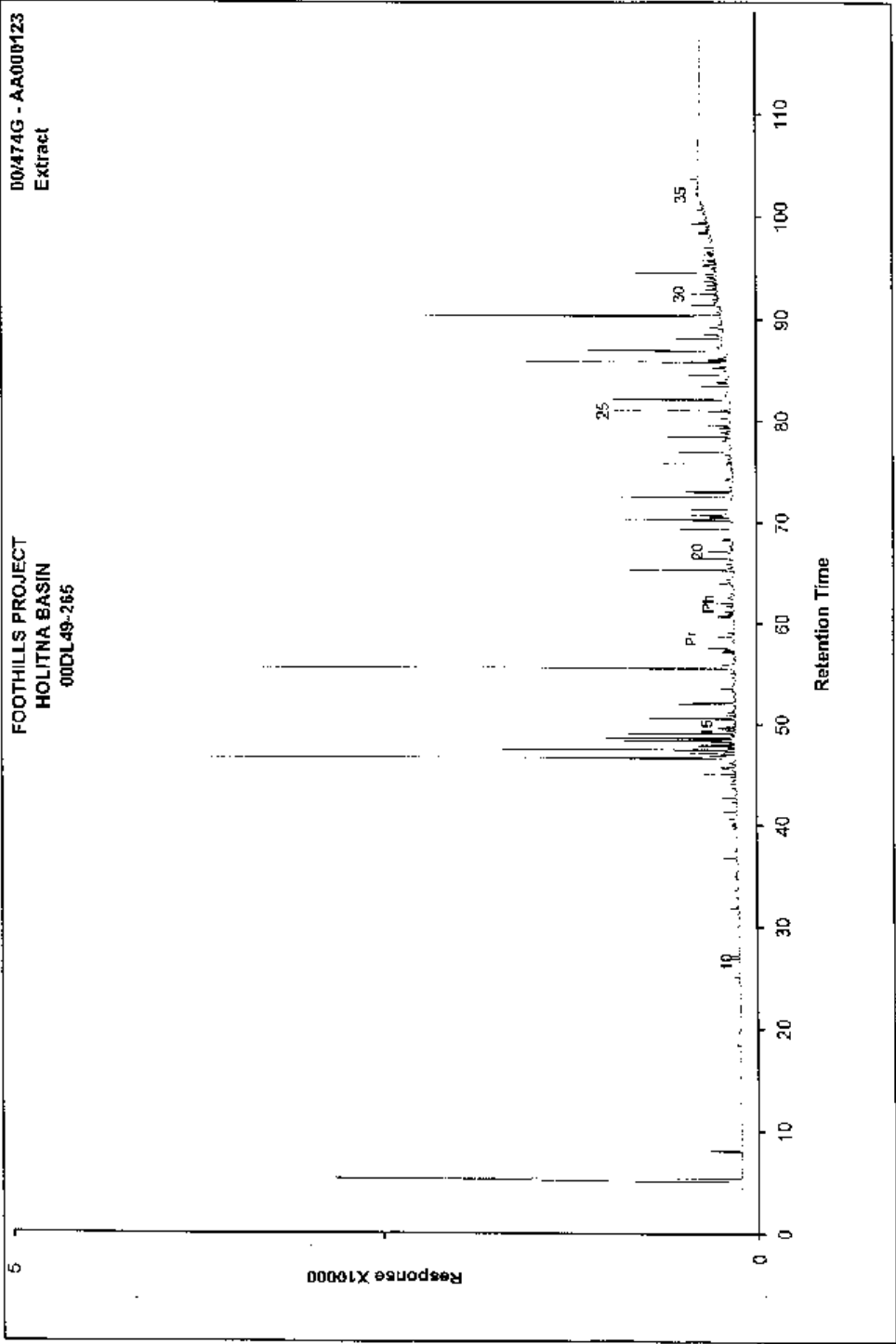
* These compounds are identified on the chromatograms.

WHOLE EXTRACT GAS CHROMATOGRAPHY									
FOOTHILLS PROJECT HOLITNA BASIN BaselineDGSi Project: 00/474G									
Sample Identification		TOC	GAS CHROMATOGRAPHY RATIOS						
ID		Wt%	PPM	Ext./TOC	Pr/Ph	Pr/C17	Ph/C18	QEP	
AA000118	: 00DL48-2	8.45	897	0.011	7.3	9.80	1.00	3.71	
AA000121	: 00DL49-327.5	15.76	2040	0.013	2.5	2.84	0.83	4.89	
AA000123	: 00DL49-265	15.25	8138	0.040	2.2	2.59	0.89	6.84	
ID	Sample Weight	Extract Weight	C17	Pr	C18	Ph	C28	C29	C30
AA000118	: 59.0830	0.0530	21675	212443	28889	28945	37117	133715	34902
AA000121	: 45.1478	0.0921	4943	14024	6155	5710	8296	37429	7678
AA000123	: 36.8852	0.2264	3574	9255	4931	4276	12886	78702	9427

Sample Identification		NORMALIZED ISOPRENOID PERCENT						
ID		iC13	iC14	iC15	iC16	iC18	iC19	iC20
AA000118	: 00DL48-2	5.1	5.0	7.7	15.7	10.7	49.1	6.7
AA000121	: 00DL49-327.5	8.9	6.6	10.2	17.8	N.A.	33.9	16.2
AA000123	: 00DL49-265	5.0	5.4	8.8	17.1	N.A.	45.7	20.2
ID	Sample Identification	AREA DATA						
		iC13	iC14	iC15	iC16	iC18	iC19	iC20
AA000118	: 00DL48-2	22248	21544	33232	58113	46268	212443	28345
AA000121	: 00DL49-327.5	3137	2414	3596	5260	n.d.	14024	5710
AA000123	: 00DL49-265	1055	1137	1861	3818	n.d.	9255	4276







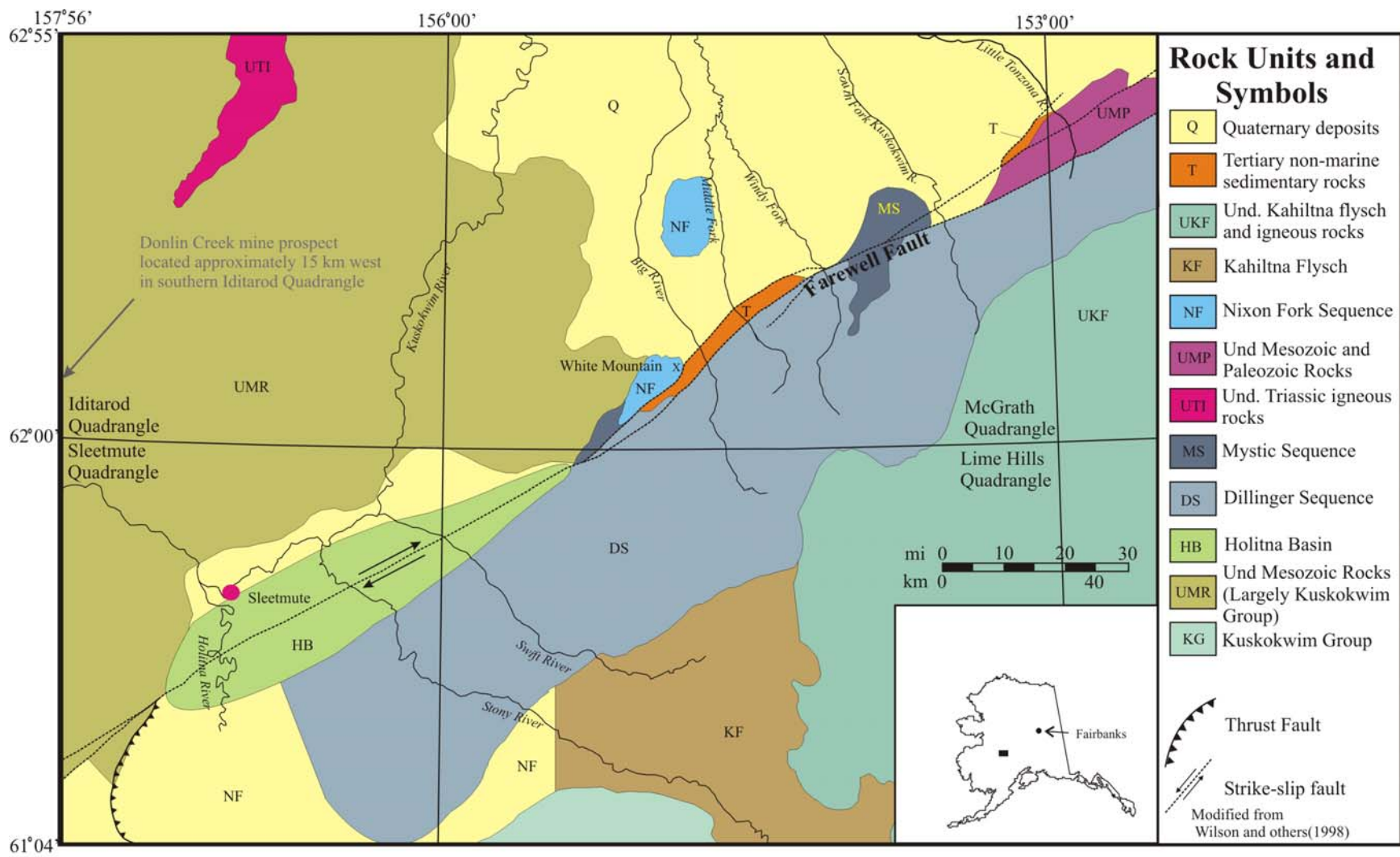
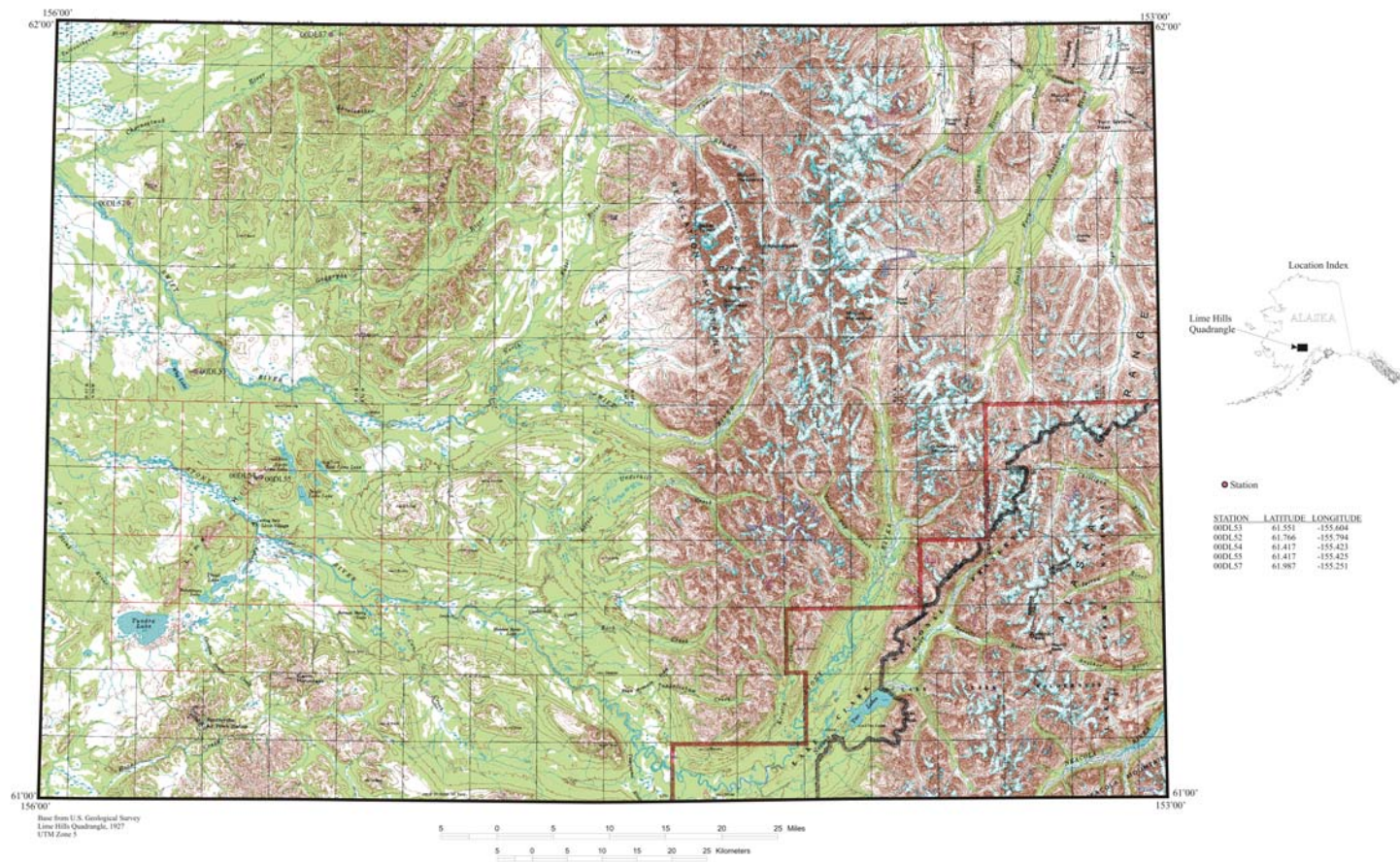
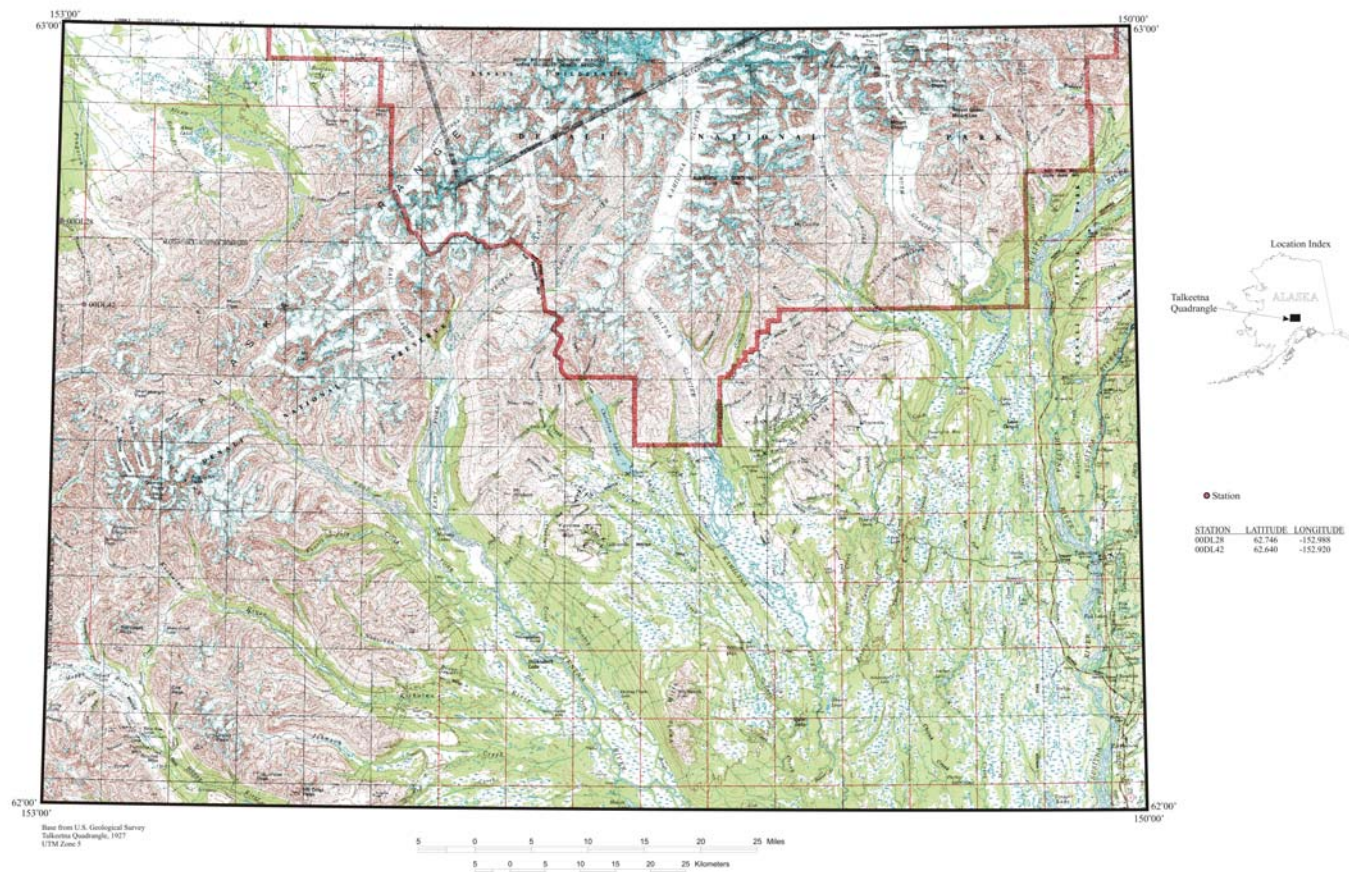


Figure 1. Generalized geologic map of the Holitna Lowland region, Sleetmute and Lime Hills quadrangles, and the Tertiary outcrop belt in southern and central McGrath Quadrangle.



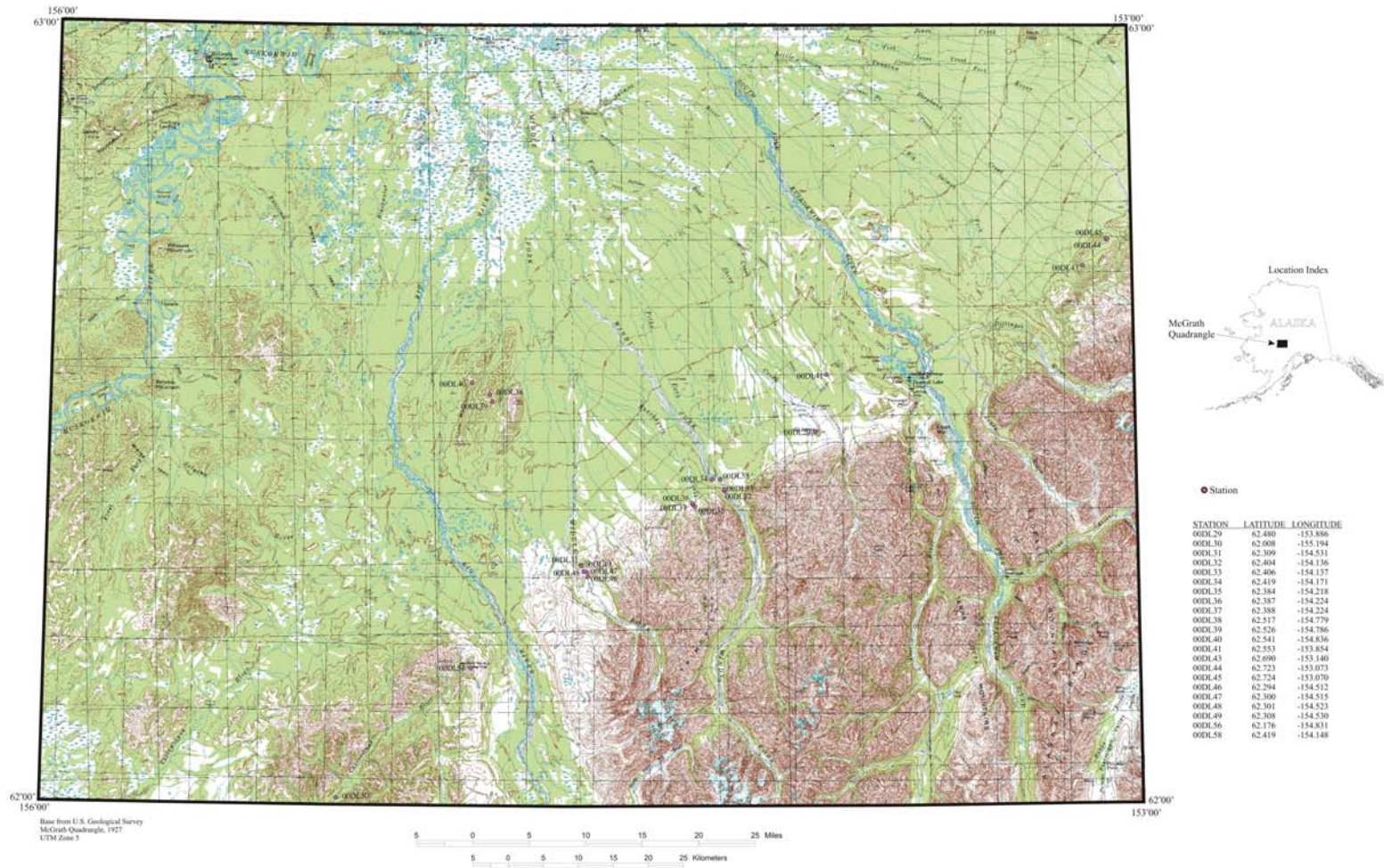
STATION MAP HOLITNA SHALLOW GAS STUDY
LIME HILLS QUADRANGLE, ALASKA

Figure 2a. Map showing sample locations in the Lime Hills Quadrangle. Locations 00DL52 through 00DL55 are in Paleozoic strata and are not discussed in the text. Location 00DL57 is the southwestern-most exposure of Tertiary strata examined in this study. No additional exposures of Tertiary strata are known along the Cheeneetnuik River southwest of this location.



STATION MAP HOLITNA SHALLOW GAS STUDY
TALKEETNA QUADRANGLE, ALASKA

Figure 2b. Map showing sample locations in the Talkeetna Quadrangle. Location 00DL28 is the northeastern-most exposure of Tertiary strata examined in this study. Location 00DL42 is not discussed in the text, is located south of the mountain front, and includes exposures of steeply dipping sandstone, siltstone, and bituminous (?) coal. Location 00DL42 appears to be in the footwall of a thrust fault and is interpreted to be older than, and unrelated to, the Tertiary section exposed at the mountain front to the north and discussed in the text. The age of this coal-bearing section was reported as Paleocene by Reed and Nelson (1980).



STATION MAP HOLITNA SHALLOW GAS STUDY
MCGRATH QUADRANGLE, ALASKA

Figure 2c. Map showing sample locations in the McGrath Quadrangle. Locations 00DL38 through 00DL40 include exposures of Proterozoic and lower Paleozoic strata and are not discussed in the text.

ERA	System	Series/ Epoch	Cook Inlet ^{1,2,3}	Cantwell Basin ^{4,5}	Nenana Basin (Healy) ⁶	Upper Ramparts/ Canyon Village ⁷	McGrath Basin ^{8,9,10,11,12}
CENOZOIC	TERTIARY	Pliocene	Sterling Fm.		Nenana Gravel	Unnamed strata at Canyon Village	? ?
		Miocene	Beluga Fm.		Grubstake Fm.		L. Cheeneetuk River ?
			Tyonek Fm.		Lignite Creek Fm.		?
					Suntrana Fm.		Windy and Middle Forks, Khuchaynik River (?) White Mountain
		Oligocene	Hemlock Cgm.		Sanctuary Fm.	Unnamed strata, Upper Ramparts Canyon	? ?
		Eocene			Healy Creek Fm.		Little Tonzona River ?
Paleocene	W. Foreland Fm.		Upper Cantwell Fm.				
MESOZOIC		Maastrichtian	Matanuska Fm.	Lower Cantwell Fm.			
		Campanian					

¹Wolfe and others (1966)

⁴Csejtey and others (1992)

⁵Wahrhaftig and others (1969)

⁷Fouch and others (1994)

⁸Axelrod (1980)

²Magoon and Claypool (1980)

³Ridgway and others (199)

⁹ARCO report cited in Dickey (1984)

³Magoon (1994)

¹⁰Blodgett (written comm., 2000)

¹¹Ravn (written comm., 2001)

¹²Zippi (written comm., 2001)

¹³Ridgway (2000)

Figure 3. Correlation of Tertiary stratigraphic units in southwest, central, and south-central Alaska.

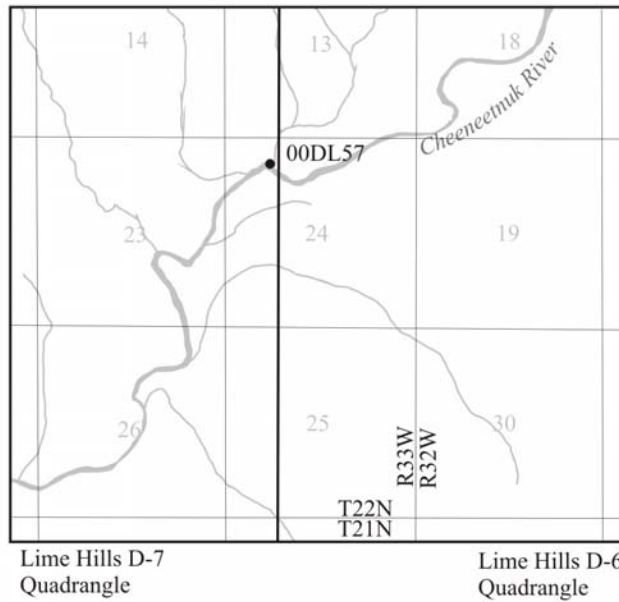
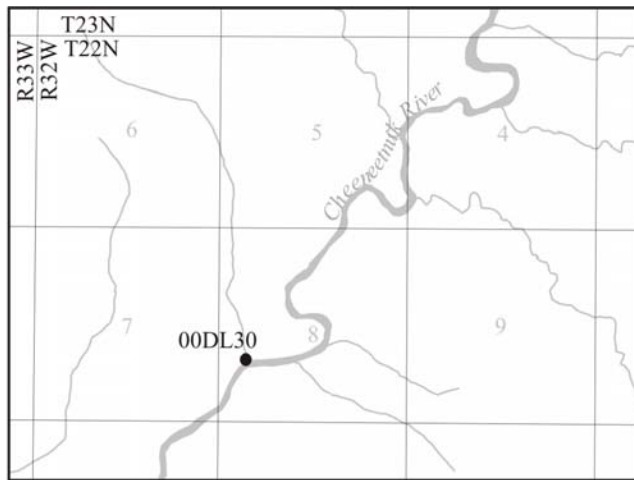


Figure 4. Map showing the locations of small exposures on the banks of the lower Cheeneetuk River in the McGrath A-5 and Lime Hills D-7 quadrangles. Both exposures are located on the north bank of the river. See Gilbert (1981) for geologic map showing these exposures.

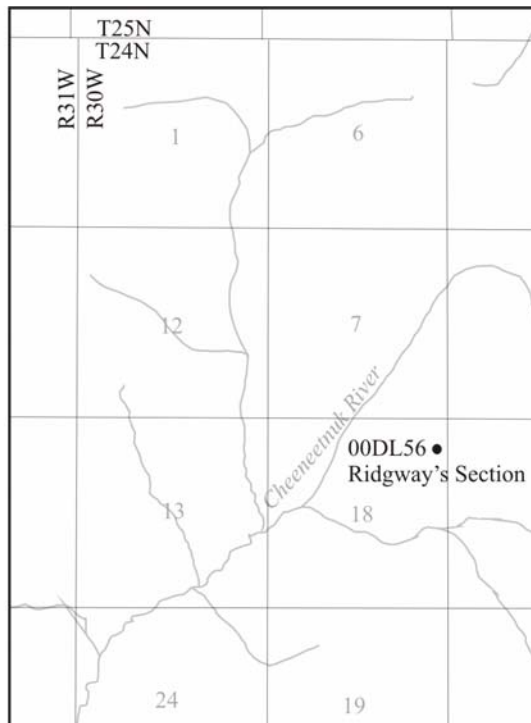


Figure 5. Map showing the approximate location of section measured by Ridgway and others (2000), McGrath A-4 Quadrangle.

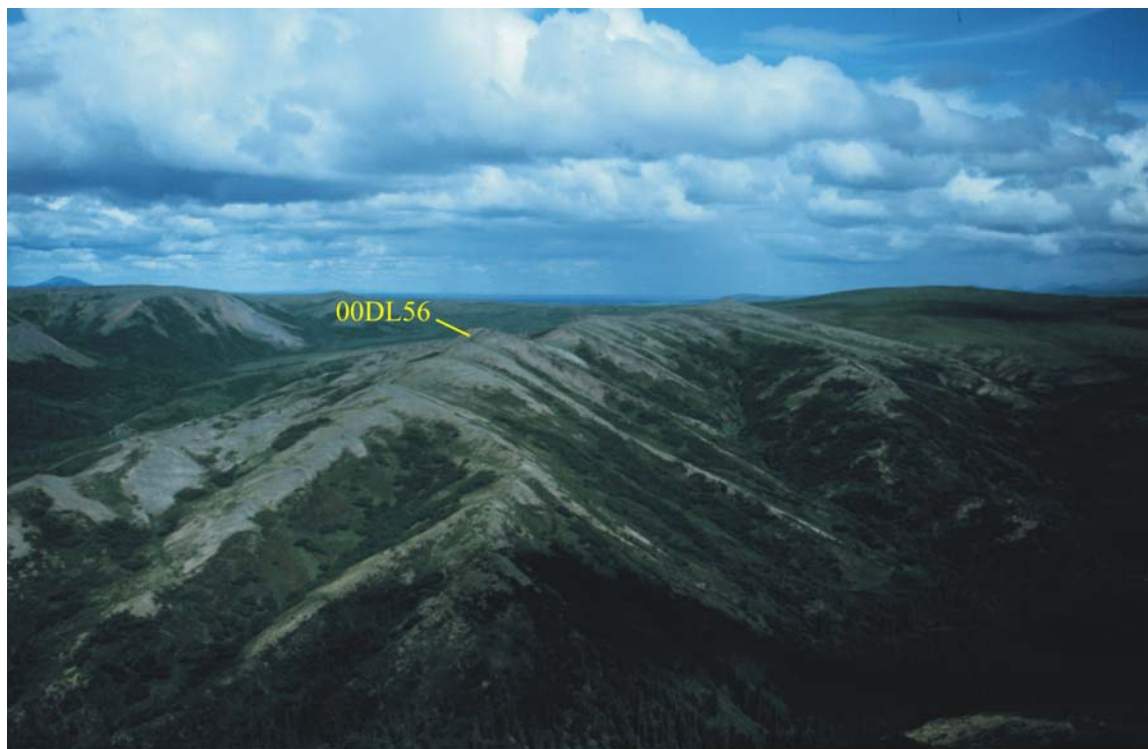


Figure 6. Helicopter view of the southeast dipping Tertiary section immediately south of White Mountain, southwestern McGrath Quadrangle. View toward the northeast. Light gray and white material is pebble conglomerate and minor interbedded sandstone.

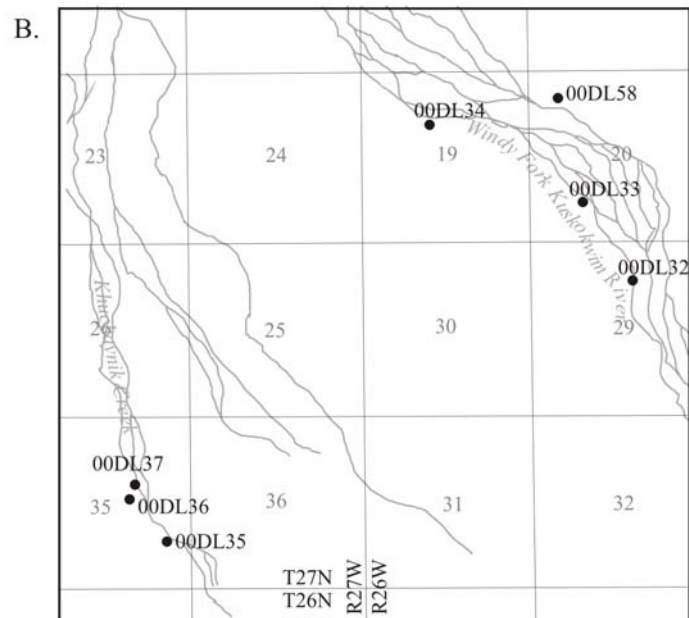
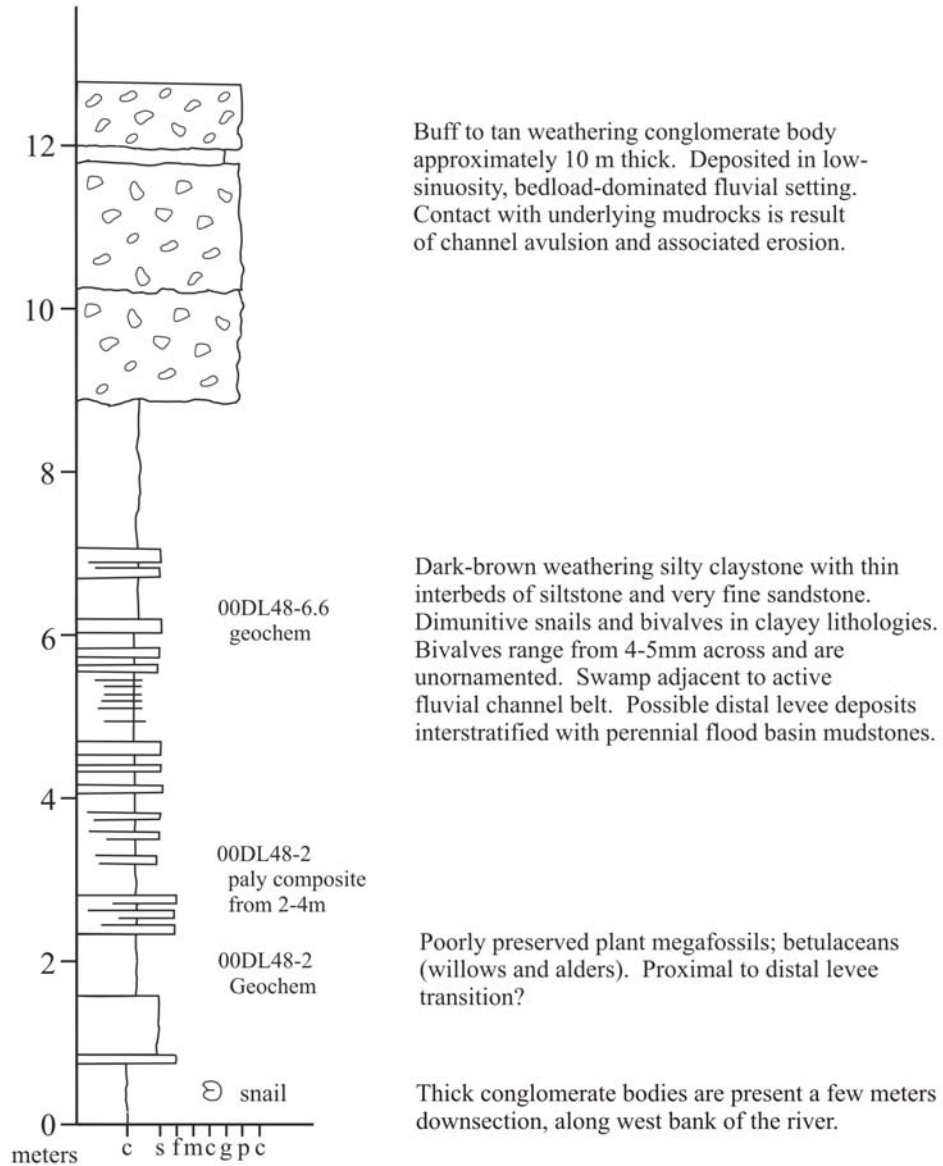


Figure 7: A. Map showing station locations along the Middle Fork of the Kuskokwim River, McGrath B-4 Quadrangle. A short section through a portion of the Tertiary section was measured at 00DL48 (see Fig. 8a). A longer (345 m) section was measured at 00DL49 (see Fig. 8b). The location of the base of each section is provided in figures 8a and 8b. B. Map showing station locations along the Windy Fork of the Kuskokwim River and the Khuchaynik River, McGrath B-3 Quadrangle.

00DL48 Middle Fork, west bank
 62°18.08'N Latitude 154°31.36'W Longitude



Measured by D. LePain, July 2000

Figure 8a. Measured section of probable middle Miocene strata from the west bank of the Middle Fork of the Kuskokwim River in McGrath B-4 Quadrangle. The succession shown is located at least a few hundred meters down-section from the thick mudstone deposits shown in Fig. 8b.

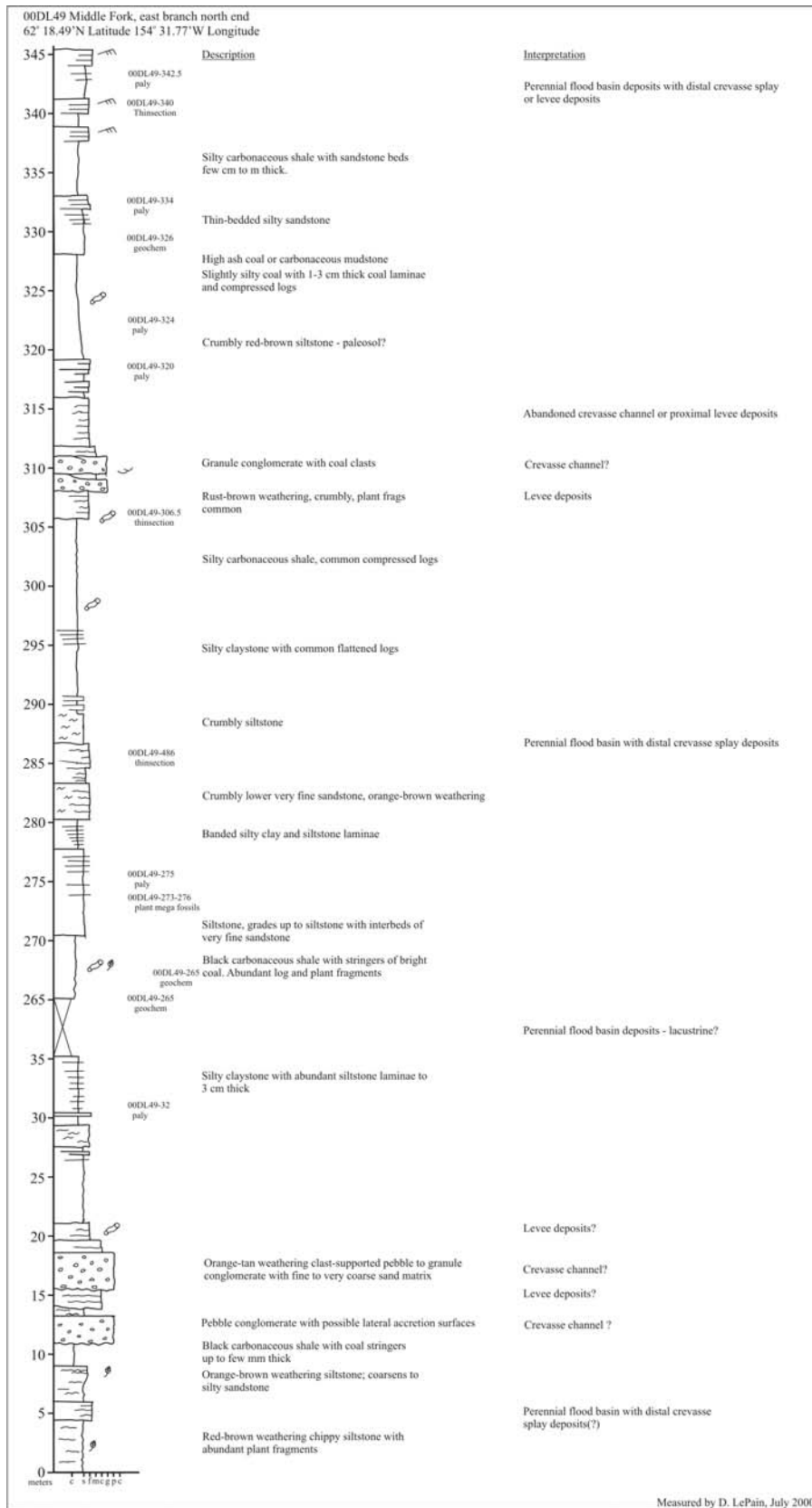


Figure 8b. Measured section through probable middle Miocene strata exposed on the east bank of the Middle Fork of the Kuskokwim River, in McGrath B-4 Quadrangle. Section is located at the northern outcrop limit of Tertiary strata, at least a few hundred meters up-section from the succession shown in Fig. 8a.

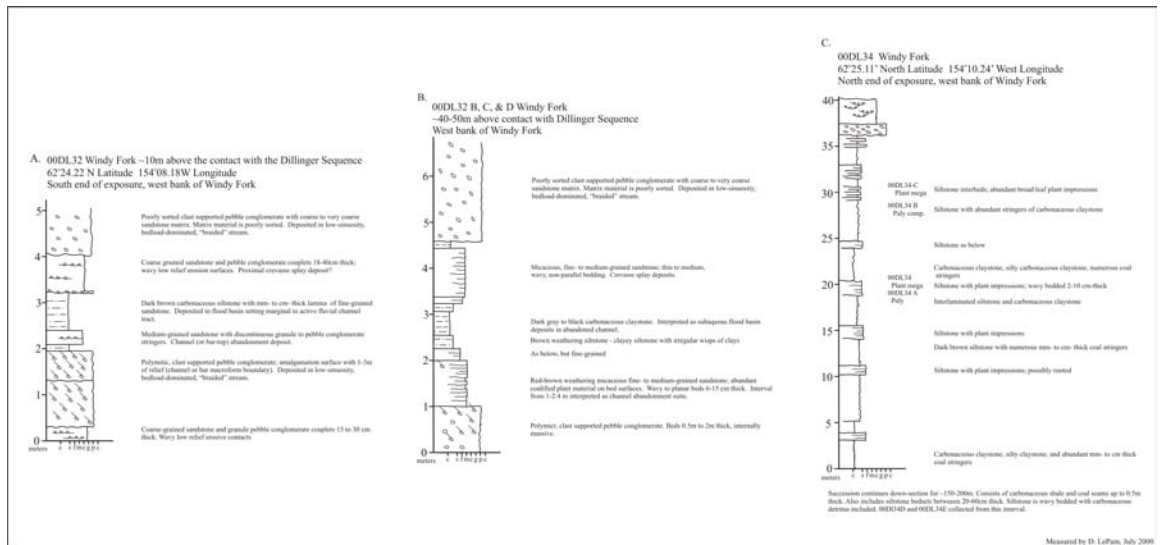
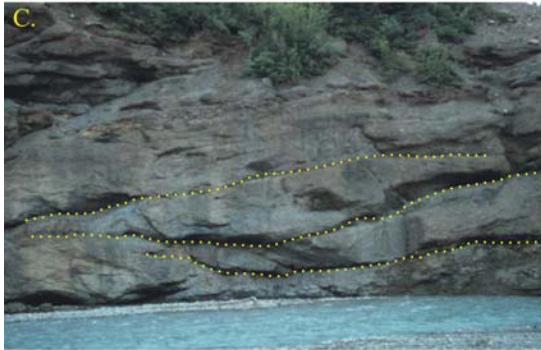


Figure 9. Measured sections from the Windy Fork of the Kuskokwim River: A. Section located near the south end of the exposure, west bank of Windy Fork; B. Section located approximately 45 m above contact with deformed rocks of the Dillinger sequence and approximately 35 m stratigraphically up-section from 00DL32 shown in Fig. 9a; C. Section through lacustrine succession at north end of exposure, west bank of Windy Fork, north of synclinal axis. 00DL34 is stratigraphically near the top of the Tertiary succession exposed along Windy Fork.



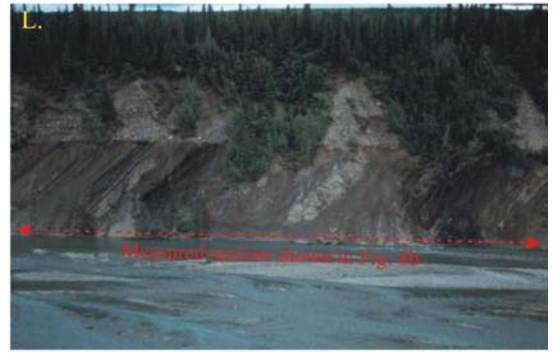


Figure 10. Selected photographs of the Tertiary section exposed on the Middle and Windy forks of the Kuskokwim River. A. Interbedded conglomerate-sandstone and mudstone packages exposed on the west bank of Windy Fork. Bedding is near vertical and stratigraphic up is toward the right (north). Approximately 100 m of section is shown. Succession shown in photograph is located midway between 00DL32 and 00DL34; B. Amalgamated conglomerate bodies above a thin lacustrine/flood basin succession at 00DL48, located on the west bank of the Middle Fork. Conglomerate unit visible in photograph is at least 3 m thick. The vertical red line shows the location of the measured section in Figure 8a; C. Concave-upward erosional scours (dashed yellow lines) between channel and bar macroforms exposed on the east bank of the Middle Fork. Approximately 8 m of section visible in photograph. Exposure located approximately 1/4-mile downstream (north) of 00DL48 shown in Fig. 10b; D. Channel abandonment succession (dashed yellow line) at 00DL47 located on the east bank of the Middle Fork approximately 0.4 miles downstream (north) of 00DL46. Yellow line is approximately 3 m long. Dashed red line shows trace of high-angle normal(?) Fault; E. Plant leaf impressions in silty sandstone at 00DL32B, located on the west bank of the Windy Fork. Photograph shows silty sandstone at approximately the 2.3 m level in the measured section shown in Fig. 9b; F. Sandstone lens in pebble conglomerate near the base of exposures of probable lower to middle Miocene (Seldovian) strata on the west bank of the Middle Fork. Contact between sandstone lens and conglomerate is shown by the dashed yellow line. Note hammer for scale near right center of photograph; G. Sandstone lenses in pebble conglomerate, Middle Fork. Staff is 1.3 m long; H. Tree trunk (red arrow) on sandstone bed surface, located on the east bank of the Windy Fork; I. Lacustrine succession overlain by pebble conglomerate of fluvial origin located on the west bank of the Middle Fork. This photograph is a close-up view of Fig. 10b that show thin resistant siltstone beds in a silty shale interpreted as lacustrine deposits; J. Carbonaceous mudstone and pebbly sandstone succession between two thick pebble conglomerate bodies. Mudstone and enclosed pebbly sandstone are interpreted as a channel abandonment deposit. Succession corresponds approximately to the 2 m to 4 m interval shown Fig. 9a. K. Mudstone succession with pebble conglomerate interbed (red arrow) exposed on the west side of the Middle Fork. Pebble conglomerate bed is 0.85 m thick and pinches out approximately 20 m beyond the left edge of the photo in the silty shales shown in Figs. 8a, 10b, and 10i. The 0.85 m-thick conglomerate is interpreted as a crevasse splay deposit along the margin of a lacustrine setting. Thicker body at the upper left of the field of view is a fluvial conglomerate body; L. Thick carbonaceous mudstone succession exposed on the east bank of the Middle Fork. Bedding dips toward the north. Approximately 150 m of section is shown. Red arrow points to coarsening-upward package shown in Fig. 10n. Fining-upward succession shown in Fig. 10m is located approximately 190 m down-section, beyond the right edge of the photograph; M. Fining-upward sandstone body with lacustrine succession, 5 to 25 m interval in measured section 00DL49 (Figure 8b), Middle Fork; N. Coarsening-upward sandstone cycle within lacustrine succession, 295 to 309 m interval measured section 00DL49 (Figure 8b), Middle Fork. Note 1.5 m-long staff in lower right of photograph for scale.

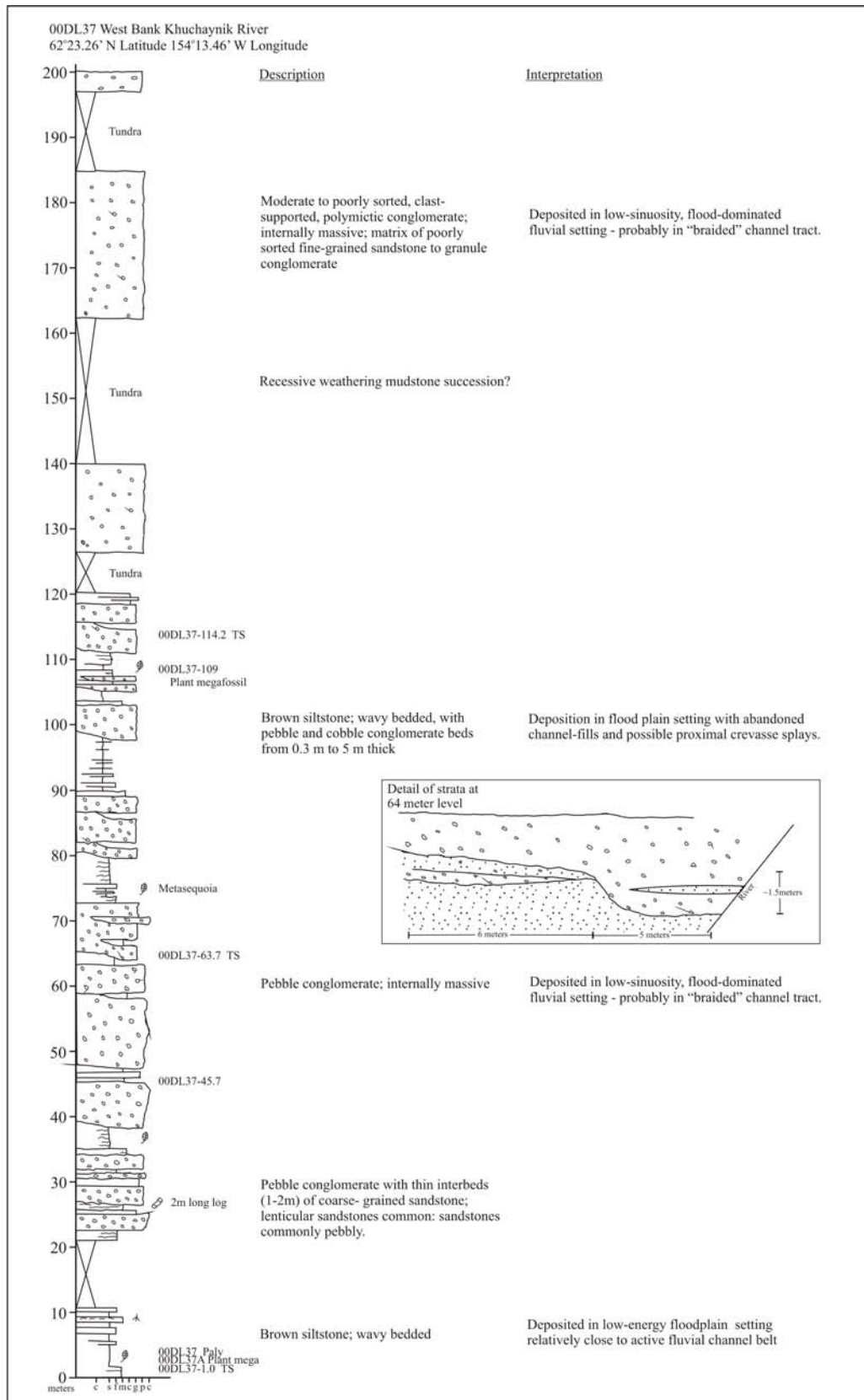


Figure 11. Measured section through part of Dickey's (1982) unit Tqa, showing probable early to middle Miocene strata. Measured by LePain, July 2000.

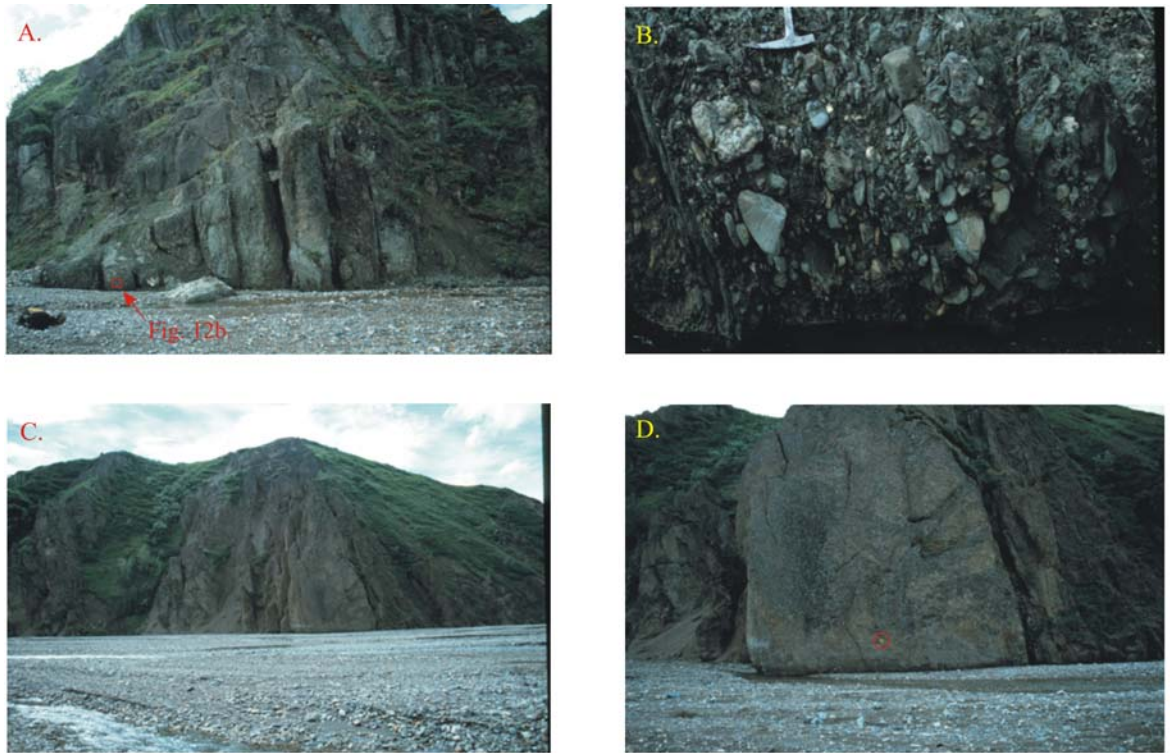
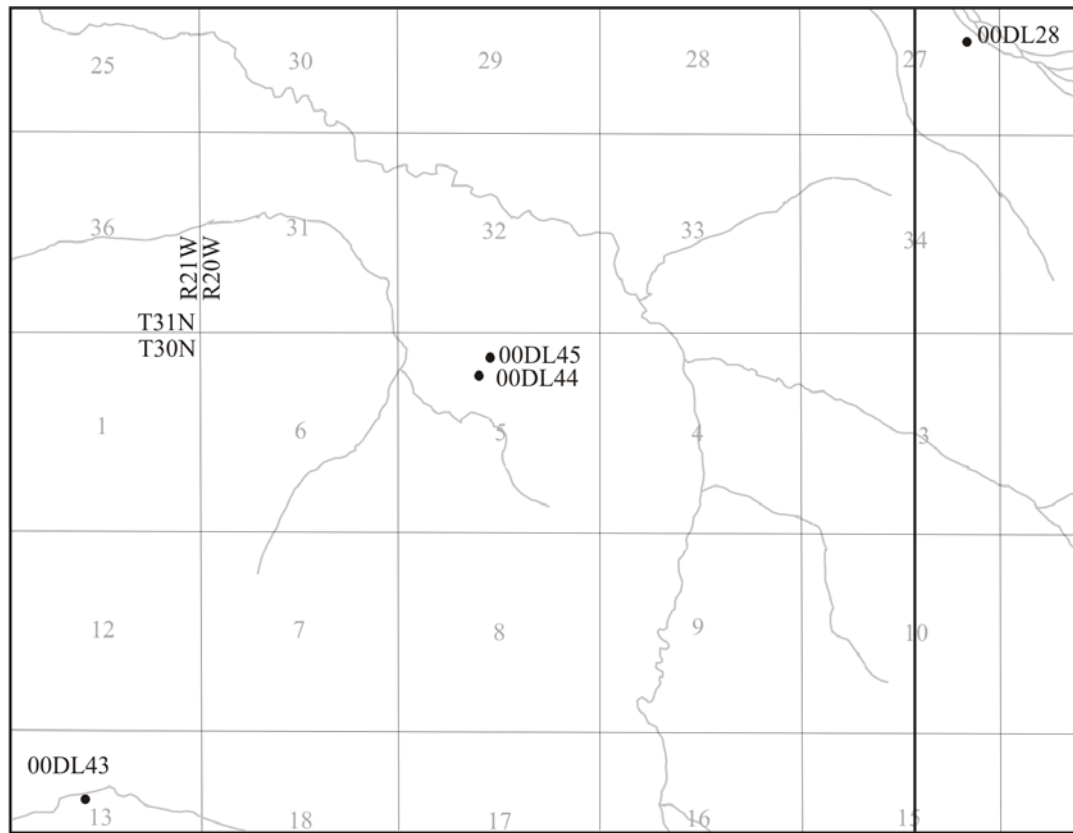


Figure 12. Selected photographs of the Tertiary section on the west bank of the Khuchaynik River. A. Near vertical pebble conglomerate beds exposed on the west bank of the Khuchaynik River at 00DL35. Unit corresponds to Dickey's Tc1. View toward the west-southwest. Clasts are dominantly limestones similar to lithologies in the Dillinger sequence; B. Clast segregation based on size and shape in unit Tc1 at 00DL35. Field of view is outlined by red box in Fig. 12a. Note distinct imbricate fabric in middle bed with platy clasts; C. Thick conglomerate beds exposed on the west bank of the Khuchaynik River at 00DL37. Succession shown corresponds to the 32 m - 78 m interval in the measured section shown in Fig. 11. Organization and clast composition are similar to conglomerate succession on Middle and Windy forks; D. Thick conglomerate body (47 m to 64 m level in Fig. 11) with cryptic amalgamation surfaces exposed on the west bank of the Khuchaynik River at 00DL37. Note yellow field notebook for scale (22 cm long) inside red circle.



McGrath C-1 Quadrangle

Talkeetna C-6
Quadrangle

Figure 13. Map showing outcrop locations in the vicinity of the Little Tonzona River and Deepbank Creek in the McGrath C-1 and Talkeetna C-6 quadrangles. Boundary between the two quadrangles is shown by the heavy black vertical line near right side of map. Location 00DL43 is above the bank of a tributary to Deepbank Creek. Locations 00DL44 and 00DL45 are on the flanks of a northeast-trending rubble-covered hill located east of another tributary to Deepbank Creek. Location 00DL28 is on the west bank of the Little Tonzona River. The rubble at locations 00DL44 and 45 indicate that coal is probably continuous between the 00DL28 and 00DL43.

00DL28 Little Tonzona River, Talkeetna C-6
 62° 14.73' North Latitude 152° 59.27' West Longitude

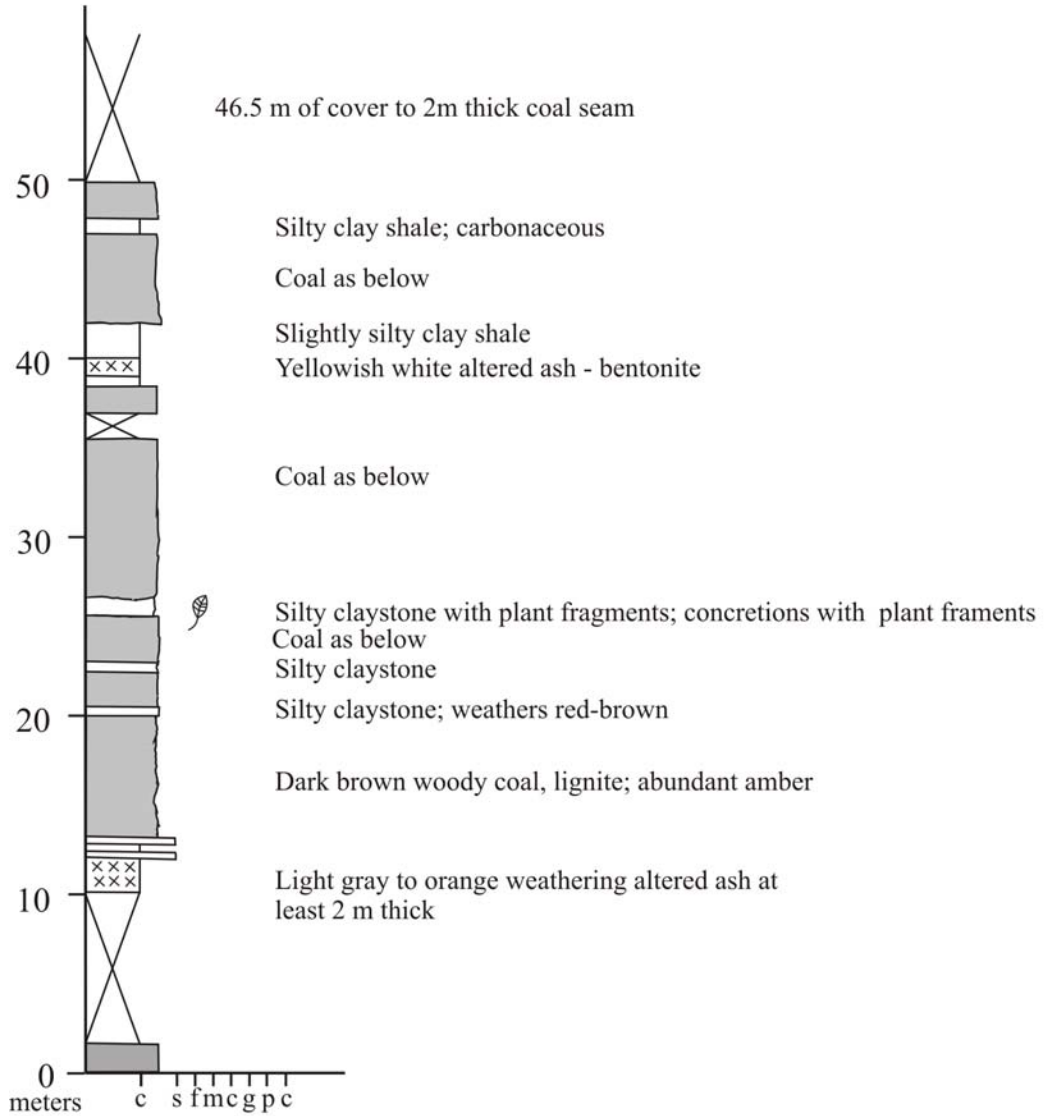


Figure 14. Measured section of probable early Oligocene coal-bearing strata exposed along the west bank of the Little Tonzona River. Samples are tied to measured section by last two digits of sample number (position is meters above base of section).



Figure 15. Selected photographs of the Tertiary section at the Little Tonzona River and Deepbank Creek. A. Steeply dipping coal seam exposed on the west bank of the Little Tonzona River at 00DL28, also shown in Fig. 14; B. Exposure of coal a few meters above the banks of Deepbank Creek at 00DL43; C. Helicopter view of rubblecrop of baked siltstone, very fine-grained sandstone, and altered volcanic ash between Deepbank Creek and the Little Tonzona River at 00DL45.

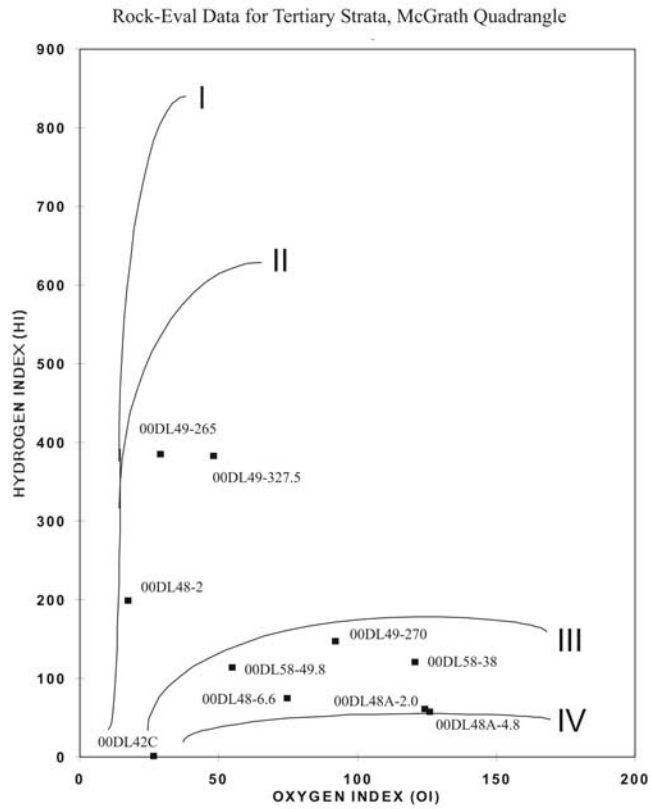


Figure 16. Kerogen type determination from total organic carbon and Rock-Eval pyrolysis data. Types I and II kerogen will generate oil and gas (if thermal maturity is high enough), type III will generate gas, and type IV will generate little or no hydrocarbons. Sample locations are shown in Fig. 2.

Table 1. Coal quality data from Tertiary strata exposed along the Alaska Range mountain front between the Little Tonzona River and the Cheeneetnuk River, Alaska.

Sample	Location	Air Dry Loss	Residual Moisture	Proximate											
				Moisture			Ash			Volatile Matter			Fixed Carbon		
				1	2	3	1	2	3	1	2	3	1	2	3
00DL28-1.0	Little Tonzona River	22.46	8.38	28.96	NA	NA	7.67	10.79	NA	34.16	48.08	53.9	29.21	41.13	46.1
00DL28-17	Little Tonzona River	22.05	13.53	32.6	NA	NA	8.18	12.13	NA	35.4	52.52	59.77	23.82	35.35	40.23
00DL28-23	Little Tonzona River	23.69	9.60	31.02	NA	NA	8.26	11.97	NA	35.13	50.93	57.85	25.59	37.1	42.15
00DL28-28	Little Tonzona River	25.53	10.57	33.4	NA	NA	7.68	11.53	NA	34.8	52.25	59.06	24.12	36.22	40.94
00DL28-32.5	Little Tonzona River	28.79	8.91	35.13	NA	NA	12.54	19.33	NA	30.59	47.15	58.45	21.74	33.52	41.55
00DL28-44	Little Tonzona River	20.83	12.90	31.04	NA	NA	5.8	8.42	NA	37.74	54.73	59.76	25.42	36.85	40.24
00DL28-48.5	Little Tonzona River	26.24	11.41	34.66	NA	NA	7.1	10.87	NA	35.15	53.8	60.36	23.09	35.33	39.64
00DL30B	Cheeneetnuk River	14.88	6.31	20.25	NA	NA	11.65	14.61	NA	34.02	42.66	49.96	34.08	42.73	50.04
00DL32A	West side Windy Fork	9.40	1.92	11.14	NA	NA	54.05	60.83	NA	15.93	17.92	45.76	18.88	21.25	54.24
00DL33	West side Windy Fork	5.47	3.34	8.63	NA	NA	38.75	42.41	NA	24.97	27.33	47.46	27.65	30.26	52.54
00DL33E	West side Windy Fork	9.67	3.59	12.91	NA	NA	20.1	23.08	NA	30.18	34.65	45.05	36.81	42.27	54.95
00DL34D	West side Windy Fork	4.99	4.02	8.81	NA	NA	30.2	33.12	NA	29.44	32.29	48.28	31.55	34.59	51.72
00DL34E	West side Windy Fork	6.96	4.11	10.78	NA	NA	36.87	41.33	NA	24.71	27.7	47.21	27.64	30.97	52.79
00DL34F	West side Windy Fork	7.57	3.37	10.68	NA	NA	58.89	65.93	NA	16.54	18.51	54.34	13.89	15.56	45.66
00DL42A	Upper Little Tonzona	1.30	0.71	2	NA	NA	88.38	90.18	NA	7.92	8.08	82.26	1.7	1.74	17.74
00DL42B	Upper Little Tonzona	18.43	8.53	25.39	NA	NA	7.54	10.1	NA	39.85	53.41	59.41	27.22	36.49	40.59
00DL43	Deepbank Creek	20.63	7.47	26.56	NA	NA	15.22	20.72	NA	35.51	48.35	60.99	22.71	30.93	39.01
00DL43A	Deepbank Creek	24.76	10.97	33.01	NA	NA	5.67	8.47	NA	36.4	54.34	59.37	24.92	37.19	40.63
00DL49-326-327.5	Middle Fork	10.65	3.26	13.56	NA	NA	49.72	57.53	NA	18.84	21.8	51.33	17.88	20.67	48.67
00DL58-36-39.5	East side Windy Fork	6.41	3.06	9.27	NA	NA	59.43	65.5	NA	17.81	19.63	56.91	13.49	14.87	43.09
00DL58-47.2-48	East side Windy Fork	8.65	2.31	10.76	NA	NA	71.56	80.19	NA	11.46	12.84	64.81	6.22	6.97	35.19
00DL58-49	East side Windy Fork	8.95	3.72	12.34	NA	NA	53.44	60.97	NA	18.45	21.04	53.91	15.77	17.99	46.09

Sample	Ultimate														
	Hydrogen			Carbon			Nitrogen			Sulfur			Oxygen		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
00DL28-1.0	6.58	4.71	5.28	44.71	62.93	70.55	0.68	0.96	1.08	1.23	1.74	1.95	39.13	18.87	21.14
00DL28-17	6.87	4.78	5.44	40.7	60.38	68.72	0.67	0.99	1.13	1.1	1.5	1.71	42.57	20.22	23
00DL28-23	6.66	4.62	5.25	41.41	60.03	68.2	0.57	0.83	0.94	1.3	1.88	2.14	41.8	20.67	23.47
00DL28-28	6.83	4.64	5.24	39.59	59.44	67.19	0.38	0.57	0.64	1.26	1.89	2.14	44.26	21.93	24.79
00DL28-32.5	6.72	4.3	5.33	34.76	53.58	66.43	0.43	0.67	0.83	1.18	1.81	2.25	44.37	20.31	25.16
00DL28-44	6.72	4.71	5.15	41.55	60.25	65.79	0.44	0.64	0.7	0.84	1.22	1.33	44.65	24.76	27.03
00DL28-48.5	6.91	4.64	5.21	37.9	58	65.07	0.4	0.61	0.68	0.6	0.93	1.04	47.09	24.95	28
00DL30B	5.88	4.53	5.3	50.11	62.83	73.59	1.57	1.96	2.3	0.93	1.16	1.36	29.96	14.91	17.45
00DL32A	3.2	2.2	5.61	25.03	28.17	71.92	0.7	0.79	2	0.15	0.17	0.44	16.87	7.84	20.03
00DL33	3.88	3.19	5.54	38.18	41.79	72.55	1.03	1.13	1.96	0.23	0.25	0.43	17.93	11.23	19.52
00DL33E	5.22	4.33	5.63	51.47	59.1	76.83	1.22	1.4	1.82	0.25	0.29	0.38	21.74	11.8	15.34
00DL34D	4.4	3.74	5.59	43.95	48.2	72.07	1.3	1.43	2.13	0.46	0.5	0.75	19.69	13.01	19.46
00DL34E	4.02	3.15	5.37	36.98	41.44	70.64	1.05	1.18	2.01	0.35	0.4	0.68	20.73	12.5	21.3
00DL34F	2.94	1.96	5.75	19.84	22.21	65.19	0.76	0.85	2.49	0.14	0.16	0.46	17.43	8.89	26.11
00DL42A	0.79	0.57	5.85	4.06	4.14	42.15	0.17	0.17	1.74	0.01	0.01	0.1	6.59	4.93	50.16
00DL42B	6.26	4.59	5.1	43.18	57.88	64.38	0.56	0.75	0.84	0.38	0.5	0.56	42.08	26.18	29.12
00DL43	6.06	4.21	5.31	37.99	51.73	65.25	0.62	0.84	1.06	0.28	0.38	0.48	39.83	22.12	27.9
00DL43A	6.72	4.52	4.94	39.96	59.65	65.17	0.53	0.79	0.86	0.47	0.7	0.76	46.65	25.87	28.27
00DL49-326-327.5	3.71	2.54	5.98	26.63	30.8	72.52	1.11	1.28	3.02	0.01	0.01	0.02	18.82	7.84	18.46
00DL58-36-39.5	2.99	2.15	6.24	21.16	23.32	67.61	0.81	0.9	2.6	0.1	0.11	0.33	15.51	8.02	23.22
00DL58-47.2-48	2.41	1.35	6.83	10.2	11.43	57.73	0.53	0.59	3	0.05	0.06	0.31	15.25	6.38	32.13
00DL58-49	3.35	2.25	5.76	23.46	26.77	68.57	0.94	1.07	2.74	0.15	0.17	0.43	18.66	8.77	22.5

1 - As received
 2- Dry
 3 - Dry ash-free

Table 2. Summary of Rock-Eval pyrolysis data for samples collected from Tertiary sedimentary rocks in the southern McGrath Quadrangle, Alaska. Analyses performed by Baseline-DGSI, Inc., Houston, TX.

SAMPLE ID	LOCATION	SAMPLE LITHOLOGY	SEDIMENTARY FACIES	TOC Wt%	S1 mg/g	S2 mg/g	S3 mg/g	Tmax degC	S1/TOC	HI	OI	S2/S3	PI
00DL32F	Windy Fork	Carbonaceous claystone	Floodplain lake	0.06	0.01	0.02	0.40	434	17	33	667	0.05	0.33
00DL42C	S. Little Tonzona River	Fissile shale	Unknown	1.62	0.02	0.02	0.43	558	1	1	27	0.05	0.50
00DL42B	S. Little Tonzona River	Bituminous coal	Mire										
00DL48-2	Middle Fork	Claystone	Floodplain lake or swamp	8.45	0.08	16.76	1.46	425	1	198	17	11.48	0.00
00DL48-6.6	Middle Fork	Claystone	Floodplain lake	3.94	0.02	2.96	2.94	437	1	75	75	1.01	0.01
00DL48A-2.0	Middle Fork	Claystone	Floodplain lake or swamp	1.32	0.01	0.80	1.64	437	1	61	124	0.49	0.01
00DL48A-4.8	Middle Fork	Claystone	Floodplain lake	1.66	0.01	0.96	2.09	440	1	58	126	0.46	0.01
00DL49-265	Middle Fork	Carbonaceous claystone	Lacustrine	15.25	0.57	58.80	4.44	418	4	386	29	13.24	0.01
00DL49-270	Middle Fork	Carbonaceous claystone	Lacustrine	9.56	0.21	14.03	8.79	428	2	147	92	1.60	0.01
00DL49-327.5	Middle Fork	High-ash coal	Lacustrine	15.76	0.86	60.32	7.57	410	5	383	48	7.97	0.01
00DL58-38	Windy Fork	Carbonaceous claystone	Floodplain lake or swamp	3.09	0.04	3.72	3.73	432	1	120	121	1.00	0.01
00DL58-49.8	Windy Fork	Silty carbonaceous claystone	Floodplain lake or swamp	1.57	0.01	1.79	0.86	428	1	114	55	2.08	0.01