THESIS

LOWER TERTIARY STRATIGRAPHY IN KATMAI NATIONAL PARK, ALASKA: A LITHOLOGIC AND PETROGRAPHIC STUDY

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY William S. Houston ENTITLED Lower Tertiary stratigraphy in Katmai National Park, Alaska: A lithologic and petrographic study BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF Master of Science.

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ABSTRACT OF THESIS

LOWER TERTIARY STRATIGRAPHY IN KATMAI NATIONAL PARK, ALASKA: A LITHOLOGIC AND PETROGRAPHIC STUDY

Seacliffs in Katmai National Park have been mapped by prior workers as the Eocene(?) West Foreland Formation and the Oligocene(?) Hemlock Conglomerate and/or equivalents. The outcrops comprise a thick sequence of non-marine conglomerates, sandstones, siltstones, shales and coals that were deposited in low to high sinuosity fluvial channels and associated floodplain environments. The sediments were deposited in a fore-arc basin developed during the evolution of the Mesozoic-Cenozoic arc-trench system of the northeast Pacific region.

Lithic arenites, the dominant sandstone type, have major framework constituents of quartz, volcanic and metamorphic rock fragments, chert, and plagioclase. Minor constituents include polycrystalline quartz, potassium feldspars, micas and accessory minerals.

The majority of samples are texturally submature to mature. Sediment from proximal source terrains largely dictated sandstone texture and composition. Systematic vertical trends in texture or composition were not observed.

The dominant source terrain for both formations was the paleo-Alaska Range volcanic arc to the west. Metamorphic sediments were derived from subduction complexes to the east, however, that source was commonly masked by an overwhelming influx of volcanic material.

Authigenic minerals include calcite, phyllosilicates and iron oxides. All three are pore-filling, but only phyllosilicates and iron oxides are pore-lining. The most abundant phyllosilicate is chlorite which occurs as grain coats and in radiating and microcrystalline pore-fill phases. Compaction and/or cementation has completely occluded all primary pore space. Minimal secondary porosity has been created by dissolution of detrital grains and cements, and by microfractures.

A progressive sequence of diagenetic features resembles that of paragenetic sequences developed for formations in other arc-related basins. This suggests a main-line diagenetic sequence for volcanic-rich sediments deposited in fore-arc basins. The sequence appears to be independent of whether the depositional setting is marine or non-marine, and comprises: (1) compaction and development of clay coats; (2) calcite cementation; (3) cementation by chlorite and/or other phyllosilicates; and (4) complex replacement and alteration.

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CHAPTER I

INTRODUCTION

Prelude

In the summer of 1990, field work was conducted in the southern extension of the Cook Inlet Basin in Katmai National Park, southwest Alaska. The research team was comprised of geologists from Colorado State University, the Colorado School of Mines, and the U.S. Geological Survey in Denver, Colorado.

The purpose of the field work was to document the stratigraphic characteristics of and collect samples from two specific Lower Tertiary formations: The Eocene(?) West Foreland Formation and the Oligocene(?) Hemlock Conglomerate. Katmai National Park was chosen as the study area because it is the only area within the southern part of the basin where these two formations are known to be exposed in outcrop.

Samples collected in the field have been analyzed using petrography, scanning electron microscopy, Palynology, and fission track dating. The results of these analyses have been used in conjunction with the measured sections of the outcrops to document the two formations in Katmai National Park.

Objectives

The principle objective of this thesis is to document characteristics of the sedimentary rocks of the West Foreland Formation and the Hemlock Conglomerate within Katmai National Park. Specifics of this objective include: documenting the thicknesses and outcrop expressions of sections of exposed strata; inferring depositional environments; constraining the ages of the formations; and detailing the petrographic and diagenetic characteristics of selected sandstones from both formations. These objectives are achieved using the methods outlined below.

Detailed measured sections are used to compare and contrast the two formations in outcrop by identifying diagnostic outcrop characteristics. These characteristics are used to infer the depositional environments of the formations and evolution of the depositional system over time.

The relative ages of the outcrops are inferred by stratigraphic relationships. Age dates are also estimated from Palynological and fission track dating.

Petrographic data and scanning electron microscopy are used to determine rock and mineral constituents, compositions and textures of sandstones from the two formations. This data is used to infer source terrain(s) and diagenetic histories.

CHAPTER II

OVERVIEW OF THE STUDY AREA

Cook Inlet Basin Tectonics

The Cook Inlet basin is a narrow, fjord-like bay located in south-central Alaska (North, 1985; Fig. 1). Its long axis is oriented in a southwest-northeast direction.

It is a forearm basin that is bounded on the east by the Border Ranges fault and on the west by the base of the Alaska Range volcanic arc (Fig. 2). The Border Ranges fault separates the Peninsular and Chugach terranes (Jones and Silberling, 1979). These terranes are accreted onto the Alaskan margin as part of the Alaska Arc/Aleutian Trench structural system. This structural system is also referred to as a subduction orogenic zone (North, 1985). Cook Inlet lies almost completely on the Peninsular Terrane (Jones, et al., 1984; Jones and Silberling, 1979), which began to accrete onto the Alaskan margin during the Jurassic Period (Wang, et al., 1988).

Although marine deposition continued through the Mesozoic, there was a shift to non-marine deposition in the very late Cretaceous or early Tertiary. A possible model for the formation of a non-marine, forearm basin is shown in Figure 3. The diagram shows a mature, ridged forearm,

Fig. 1. The study area is along the eastern shore of Katmai National Park in southwest Alaska, in the southern extension of the Cook Inlet forearc basin. This is the only known area in the southern part of the basin that contains extensive outcrops of Paleogene rocks of the Kenai Group. Use Cape Douglas as a reference point in following diagrams.

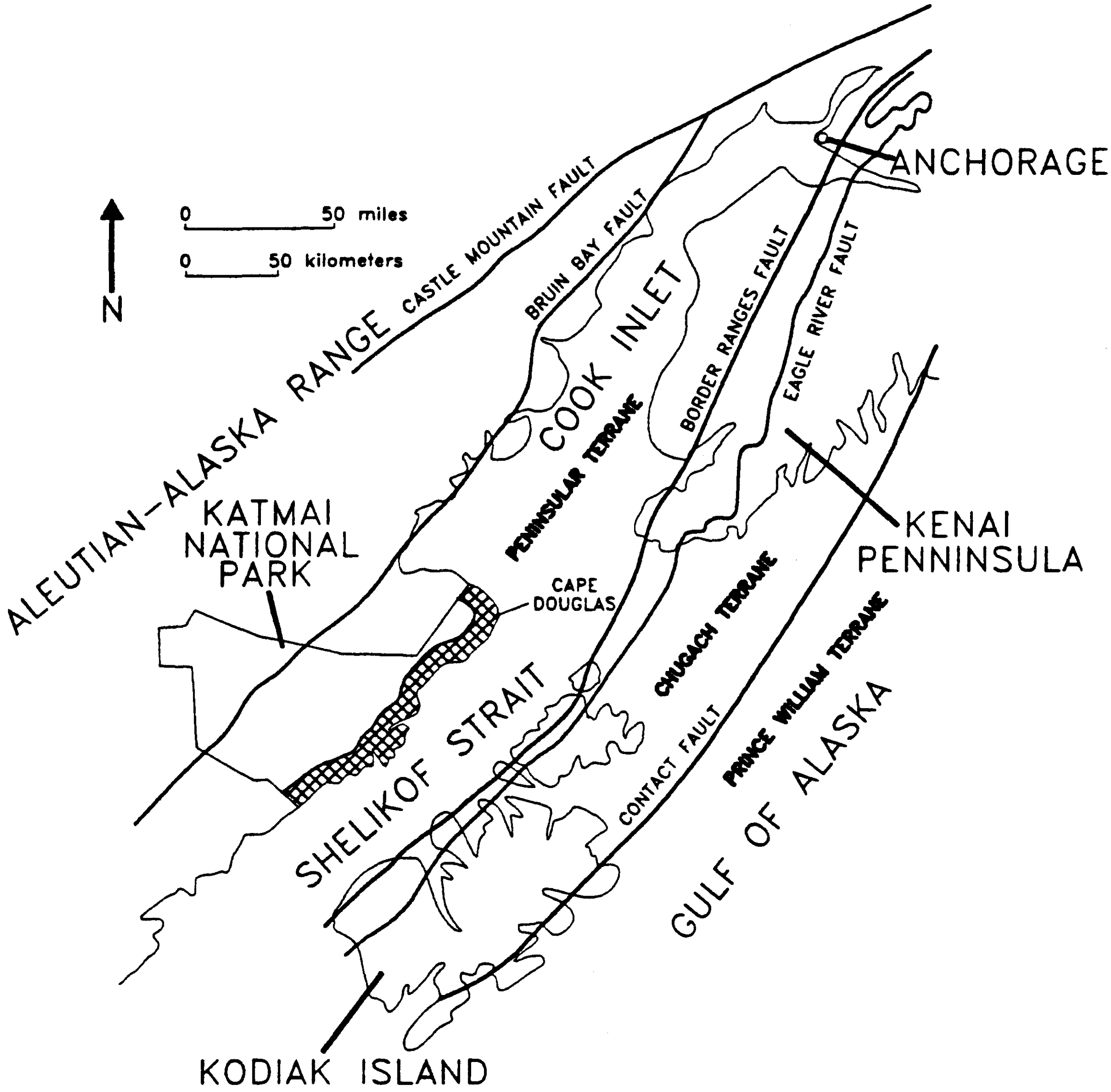


Fig. 2. The forearc basin is bounded by the Bruin Bay and Border Ranges Faults, two of several regional faults. These two faults, along with the contact fault, separate accreted terranes (identified in bold type). Katmai National Park and the Shelikof Strait are almost entirely within the Peninsular Terrane, which began accreting in the early Mesozoic. The study area is cross-hatched. Modified from Magoon and Egbert, 1986.

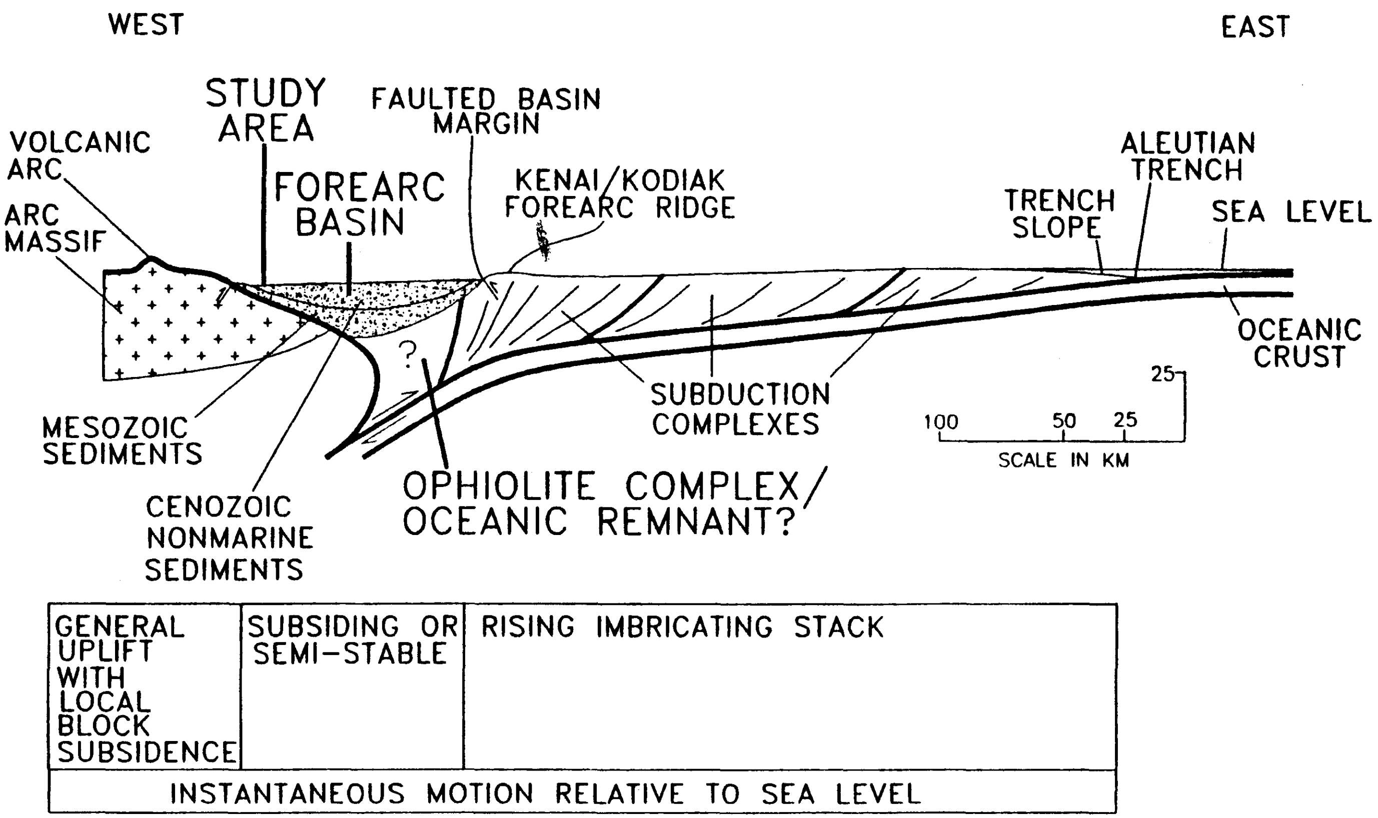


Fig. 3. Schematic tectonic cross-section showing a mature, ridged forearc. Cross-section is drawn east/west across Cook Inlet above Cape Douglas. The "ophiolite" underlying the basin is completely speculative. After the basin was isolated by the forearc ridge, rapid sedimentation in the late Mesozoic filled the basin to non-marine levels. Renewed subduction of the ophiolite could have been responsible for generating accommodation space in the Tertiary. Modified from Dickinson and Seely, 1979.

created when part of the subduction complex wedges beneath the forearm basin (Dickinson and Seely, 1979). This results in a detachment between the complex and the subducting oceanic plate which limits or stops the subduction of material. As subsequent subduction complexes begin to stack seaward behind the blockage, they create a broad ridge which eventually isolates the forearm basin from marine influence. This is referred to as a broad-ridged forearm.

In the case of Cook Inlet, the ridged forearm created a terrestrial basin setting in the early Tertiary. Cook Inlet basin is specifically referred to as the East Aleutian Trench-Cook Inlet Tertiary Great Valley (Dickinson and Seely, 1979).

Rapid sedimentation rates in the late Cretaceous would have filled the basin to non-marine levels (Dickinson and Seely, 1979), allowing the development of fluvial systems in the early Tertiary. Renewed subduction of the trapped subduction complex would effectively drop the bottom out of the basin and renew subduction of the ridge, eventually ending the basins isolation from marine influence.

Mesozoic Stratigraphy of Cook Inlet Basin

The stratigraphic succession in Cook Inlet differs in the northern and southern ends of the basin. This has been due to changes in tectonic regimes across the basin, which in turn have dictated sub-basin geometries and the shifting of local source terrains. Sedimentation through the Mesozoic was largely a function of the activation/deactivation of arc volcanism and shifting of predominantly shallow to deep marine depositional environments.

Triassic through lower Jurassic lithologies are attributed to a broad volcanic arc (Wang, et al., 1988) and nearby shelf depositional sites (Magoon and Egbert, 1986). In the mid-Jurassic, a basinward shift in deposition saw a change from shelf to slope-channel fills and slope deposits (Imlay and Detterman, 1977). Volcanic activity decreased in the late Jurassic, and deposition occurred in a variety of environments from shallow marine to deep marine channel, slope and submarine fan deposits (Magoon and Egbert, 1986).

In the lower Cretaceous deposition shifted back to predominantly shelf environments (Detterman, 1982) with local but significant volcanic sources (Magoon and Egbert, 1986). Upper Cretaceous lithologies represent turbidity and other slope deposits (Moore, 1973a; Grantz, 1964). However, non-marine units are found sporadically at the top of the upper Cretaceous marine lithologies (Magoon and Egbert, 1986; Detterman, 1982; Magoon, et al., 1980).

Tertiary Stratigraphy of Cook Inlet Basin

The Tertiary section in Cook Inlet comprises a thick sequence of non-marine strata that lie unconformably over Cretaceous rocks in the south and Jurassic rocks in the north (Fisher and Magoon, 1978). Lower Tertiary formations reflect pervasive regional volcanism, while upper Tertiary formations (northern Cook Inlet only) indicate the additional influence of local volcanic and metamorphic source terrains (Hayes, et al., 1976).

The lower to mid-Tertiary Kenai Group was first designated by Calderwood and Fackler (1972). It included rocks from the West Foreland through Sterling Formations, and gave the Hemlock oil zone of the Tyonek Formation formational status as the Hemlock Conglomerate (Fig. 4).

Later workers excluded the West Foreland Formation from the Kenai Group because of a major unconformity between the West Foreland Formation and the Hemlock Conglomerate (Boss, et al., 1976). Correlations of Tertiary formations across the basin indicate there is an early Cenozoic sequence represented by the West Foreland and northern Wishbone and Arkose Ridge Formations, and a late Cenozoic sequence, the Kenai Group, which includes the Hemlock Conglomerate through the Sterling Formation (Magoon and Egbert, 1986; Kirschner and Lyon, 1973). The two sequences are separated by a hiatus of approximately twenty million years (Magoon and Egbert, 1986).

The West Foreland Formation is correlated across Cook Inlet based primarily upon its relatively high volcanic content. The Hemlock Conglomerate is correlated as a laterally continuous, coarse-grained facies. These correlations are based almost exclusively on subsurface data.

In the study area, the Tertiary section lies

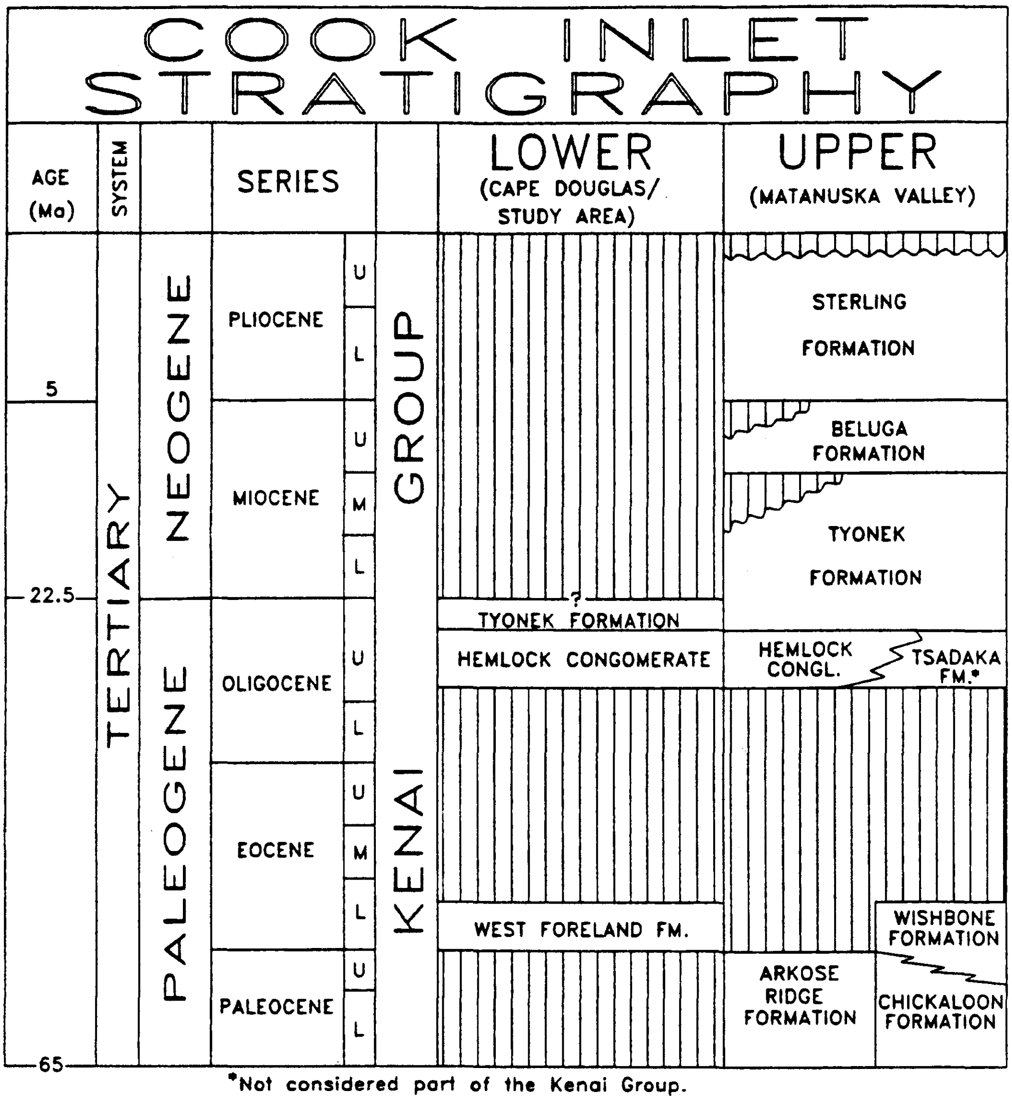


Fig. 4. The formations of interest in this study are the Eocene(?) West Foreland Formation and the Oligocene(?) Hemlock Conglomerate (age dates were inconclusive-see chapter VI). The Kenai Group was first designated by Calderwood and Fackler, 1972. Later workers have excluded the West Foreland Formation from the Kenai Group (Magoon and Egbert, 1986; Boss et al., 1976) citing a 20 m.y. hiatus between the Hemlock and the West Foreland, with near continuous non-marine deposition from the Hemlock Conglomerate through the Sterling Formation (upper Cook Inlet only). No stratigraphic units above the Hemlock Conglomerate were identified in Katmai National Park.

unconformably upon marine Cretaceous rocks, and is represented by the West Foreland Formation and the Hemlock Conglomerate only. Upper Tertiary (Neogene) formations have not been identified in this area.

Published Works on Tertiary Formations in Katmai National Park

The West Foreland Formation and the Hemlock Conglomerate, with some possible equivalents (e.g. "Rocks near Copper Lake"; Magoon, et al., 1976), are the only known early to mid-Tertiary formations exposed in Katmai National Park. Magoon, et al. (1976) compiled a geologic map of Cook Inlet basin, however, the only portion of Katmai National Park included is the Cape Douglas area (Fig. 2). Riehle, et al. (1987) compiled a preliminary geologic map of the entire park (also used as geologic base for Riehle, et. al., 1989). Large-scale stratigraphic sections measured within the park were presented by Petering and Smith (1979). Lankford and Magoon (1978) report QFL compositions and Bolm, et al. (1984) and Bolm and McCulloh (1986) diagenetic alteration of sandstones from the West Foreland Formation in the Cape Douglas area.

CHAPTER III

METHODS OF STUDY

Field Work

Measured Sections

Measured sections from four locations in Katmai National Park and a corresponding legend are presented in Appendix I. The sections were measured with a steel tape and/or Jacob's staff, with one or more individuals citing observations to another person who recorded the observations on a template predesigned by the field party. The template is identical to that used in the appendix. Observations recorded on the templates include lithology, bed thickness, contacts, grains size, textural maturity, pebble/cobble compositions, sedimentary structures, accessories, sample locations and written summaries of lithologic units. The sections were redrawn using a Macintosh computer and Canvas software during and after the course of the field work.

All four sections were measured along well exposed sea-cliffs. Locations were chosen based primarily upon the length of continuously exposed section and accessibility. Identification of specific West Foreland and Hemlock outcrops was based on a preliminary geologic map by Riehle, et al. (1987). The four measured sections are named for prominent geographic features in the vicinity of each section (Fig. 5). The sections can be located on the following U.S.G.S. 7.5 minute quadrangles: Cape Douglas Section-Afognak (D-4) and (D-5); Cape Nukshak Section-Mt. Katmai (B-1); Kinak Bay Section-Mt. Katmai (A-2); Kuliak Bay Section-Mt. Katmai (A-1).

Pebble/Cobble Counts

Estimates were made of pebble and cobble percentages of some lithologic units during the measuring of the stratigraphic sections. Clast percentages are included in the comments on the right side of the stratigraphic sections in Appendix I.

Compositions based on pebble/cobble estimates are inconsistent with compositional data obtained through petrographic analysis due to the fact that they reflect significant amounts of plutonic components. This discrepancy may be due to the difference in grain size examined with each technique, as the sand fraction could contain individual mineral grains (not necessarily identified as plutonic in origin) liberated during the breakdown of pebble/cobble sized plutonic rock fragments. Another possibility is that pebbles and cobbles were misidentified in the field as being plutonic in origin.

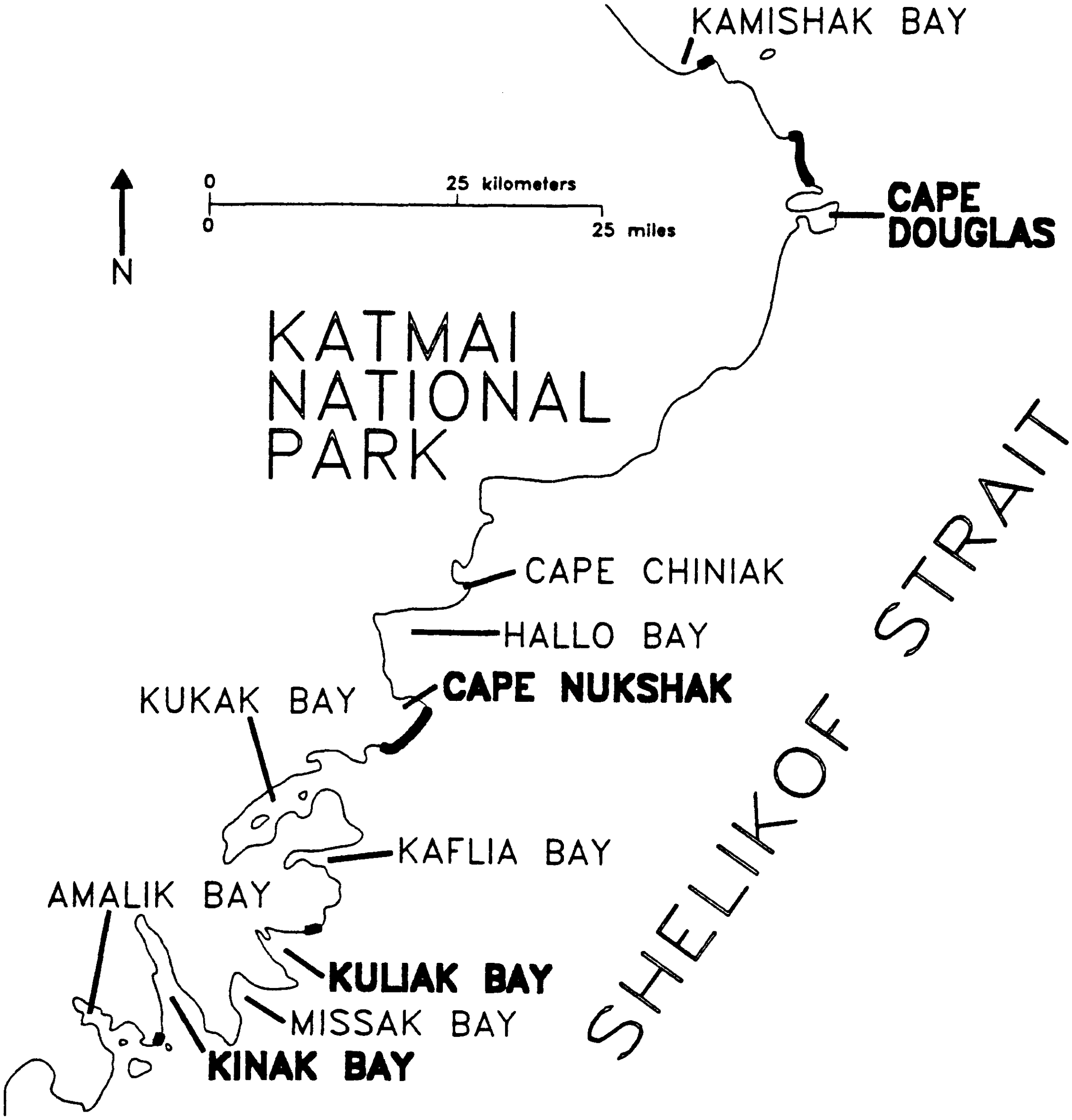


Fig. 5. Seacliffs along the Shelikof Strait provided long, continuous exposures of Tertiary stratigraphic section. Four sections were measured (locations indicated by bold lines on the coastline), and were named for prominent geographic features (in bold type) which include; Cape Douglas, Cape Nukshak, Kuliak Bay and Kinak Bay. Modified from Fisher and von Huene, 1982.

Sampling

Palynology Samples

Thirty six samples were collected from the four sections to be analyzed for palynomorphs which could constrain the ages of the outcrops. Siltstone samples were collected, as coarser-grained samples would tend to have silt-sized palynomorphs winnowed out. Samples were taken away from igneous intrusions to reduce the possibility of obtaining baked, and thus unrecognizable, palynomorphs. Approximately two pounds of material was collected for each sample. The samples were analyzed by Micropaleo Consultants, Inc. of San Diego, California.

Fission Track Samples

Three sandstones in which petrography revealed relatively high amounts of heavy minerals were selected for fission track dating. Approximately one pound of material from each sample was submitted for analysis. The analyses were performed by the University of Wyoming Thermochronology Laboratory.

Petrography Samples

Sandstones and sand lenses from within conglomerates were sampled for petrographic analysis as the stratigraphic sections were measured and described. Samples were taken away from intrusions and weathered surfaces, and were oriented with respect to bedding. a stratified, random sampling plan was used to insure that each major facies type was sampled in both formations. A total of 104 samples were collected for this study.

Sample Designations

All samples cited in this manuscript are identified by a designation that contains three components. The first number indicates the measured section the sample is from: 1 - Cape Nukshak Section; 2 - Kinak Bay Section; 3 - Cape Douglas Section; 4 - Kuliak Bay Section. The second number indicates the footage, measured from the base of the section. The final letter indicates the type of sample: L - lithologic (for petrographic analysis); P - palynology (for palynological dating). For example, sample 3-3172-L4 is from 3,172 feet up from the base of the Cape Douglas Section, and was used for petrographic analysis. The samples are identified in the left margin of the stratigraphic sections in Appendix I.

Data Collection

Petrographic Analysis

Standard 27 x 46 mm thin sections oriented perpendicular to bedding and ground to 30 microns were made by Quality Thin Sections of Tucson, Arizona. All sections were impregnated with blue epoxy for identification of porosity.

Modal analyses of the thin sections were made with a standard petrographic microscope. Before routine point counting began, twelve randomly selected thin sections were point counted ten times each, with 200 points, to determine the minimum number of counts necessary to obtain reproducible results. Two-hundred points were counted on each remaining thin section using linear traverses spaced for maximum coverage of the slides.

Point count categories were selected to represent all constituents observed in both formations, and include detrital rock fragments and minerals and authigenic minerals. Rock fragments were subdivided into volcanic, plutonic, metamorphic, and chert grains. Detrital minerals include monocrystalline and polycrystalline quartz, feldspars, micas, and accessory minerals (all additional monomineralic constituents). Authigenic minerals include calcite, chlorite, iron oxides, and unidentified phyllosilicates. Complete point count data is presented in Appendix II.

Scanning Electron Microscopy

Photographic and Kevex microanalysis (x-ray analysis of the elemental composition of minerals) results from a Phillips 505 scanning electron microscope were of limited use in mineral identification. Samples used for this analysis were thin sections with a ten nanometer sputter coating of gold-palladium. Photographs were taken of the spots selected for Kevex analysis. Interpretation of SEM results are based on comparison with SEM photographs and Kevex data presented in Welton, 1984.

CHAPTER IV

DESCRIPTION OF THE MEASURED SECTIONS

The following descriptions identify diagnostic characteristics of each measured section. Footages given in parenthesis locate primary, but not exclusive, examples of the various characteristics, and correspond to the footages on the stratigraphic sections presented in Appendix I.

All coals observed in the four measured sections are bituminous in rank, and can be defined texturally as either durain, fusain or a combination of both (classification in Blatt, et al., 1980 after Stopes, 1919). Units identified as coals contain less than 20% silt and/or mud.

Cape Douglas Measured Section

Location

Cape Douglas is the northernmost section measured, falling entirely within T. 14 S., R. 25 W, and measuring up section moving down coast to the south. The bottom 186 feet (56.7 m) of the section are located in SE NE, sec. 6 and NE NW, sec. 5., along the eastern shore of Kamishak Bay. Two thousand seven hundred and seventy feet (844.3 m) of covered section in the middle begins in NE NW, sec. 5 and passes through sections 4, 9 and 10, ending in SW SW, sec. 11. It

is an area of glacial outwash and tidal flats north/ northeast of Spotted Glacier, which lies on the northeast flank of Mount Douglas. The upper 1,184 feet (360.9 m) of the section begins in SW SW, sec. 11 and passes through sections 23 and 24, ending in SW SE, sec.
25. Outcrops comprising this upper portion are along the coast of Cook Inlet northeast and east of Spotted Glacier.

Stratigraphy

The Cape Douglas section (Figs. 6 and 7) is characterized by thick cobble conglomerate packages which contain widespread erosional surfaces (3,066-3,159 ft; 934.5-962.9 m), large scale trough cross-beds in one to five foot sets (3,636-3,660 ft; 1108.3-1115.6 m), and large sandstone lenses (3,251-3,323 ft; 990.9-1012.9 m). Commonly found immediately above the erosional surfaces are large siltstone rip-ups (3,251 ft; 990.9 m/ 3,117 ft; 950.1 m/ 3,390 ft; 1033.3 m) which can reach two feet in thickness and ten feet in length.

Sandstone units are found dispersed between conglomeratic units and may contain horizontal bedding (3,453-3,460 ft; 1052.5-1054.6 m), lateral accretion elements (3,555-3,565 ft; 1083.6-1086.6 m), medium scale trough cross-beds in one to two foot sets (3,991-4,002 ft; 1216.5-1219.8 m), asymmetrical ripples (4,047-4,052 ft; 1233.5-1235.0 m), or conglomeratic stringers or lenses (3,660-3,679 ft; 1115.6-1121.4 m). In some cases sandstones

Fig. 6. Interbedded cobble conglomerates and thinner, black, carbonaceous sandstones at 3,300 ft (1,005.8 m)* of the Cape Douglas Section. The sandstones are laterally discontinuous. Scour surfaces separating the conglomeratic packages are laterally continuous for up to 500 feet (152.4 m). Note intrusion on right side of outcrop.

*NOTE: Footage gives the approximate location of the outcrop photographed within the measured section (see Appendix I for measured sections).

Fig. 7. Massive to trough cross-bedded conglomerate separated from the underlying sandstone by a widespread erosional surface with relief of up to three feet, 3,704 ft (1,129.0 m) of the Cape Douglas Section.

are interbedded with siltstones (3,554-3,601 ft; 1083.3-1097.6 m/ 3,681-3,704 ft; 1122.0-1129.0 m). Sills found in this section preferentially intrude the interbedded sandstone and siltstone packages (3,181-3,190 ft; 969.6-972.3 m/ 3,578-3,570 ft; 1090.6-1088.1 m/ 3,586-3,587 ft; 1093.0-1093.3 m).

Interbedded siltstones and mudstones are rare in this section (3,011-3,025 ft; 917.8-922.0 m), as are thick siltstone units (3,206-3,228 ft; 977.2-983.9 m) and carbonaceous siltstones (3,577-3,602 ft; 1090.3-1097.9 m). Only one coal seam was observed in the entire section (3,025-3,026 ft; 922.0-922.3 m).

Erosional basal contacts separating conglomeratic and/or finer-grained packages can be traced laterally for up to 500 feet (152.4 m). Relief on these surfaces is commonly between one and three feet, but can approach five feet.

Remnants of organic material are uncommon. Carbonized wood fragments are found in conglomerates (3,228-3,248 ft; 983.9-990.0 m), sandstones (86-93 ft; 26.2-28.3 m) and siltstones (3,173-3,181 ft; 967.1-969.6 m). Leaf imprints are rare, but very well preserved (3,995-4,005 ft; 1217.7-1220.7 m). Trees and roots were not observed in the section.

In general, there are a few well defined fining-upward sequences expressed in this section (3,066-3,196 ft; 934.5-974.1 m/ 3,420-3,484 ft; 1042.4-1061.9 m). Packages tend to be dominated by single, mostly coarser-grained lithologies with erosional bases.

Cape Nukshak Measured Section

Location

The Cape Nukshak section is located in T. 21 S., R. 29 W and follows a roughly southwest trend up section, beginning in NE NE, section 3 and passing through sections 10, 9 and 16 before ending in NW SW, section 17. It begins on the southern shores of Cape Nukshak along the Shelikof Strait, and ends approximately halfway between Yugnat point and the Kukak sand and mud flats.

Stratigraphy

Cape Nukshak's stratigraphy (Figs. 8 and 9) is characterized by the diversity of lithologies, stacked partial and complete fining-upward packages and rapidly changing lithologies. Thick, complete fining-upward packages are generally conglomerates or interbedded conglomerates and sandstones at the base and grade upward into pebbly sandstones and sandstones, and are capped by varying combinations of interbedded sandstones, siltstones, mudstones and coals (610-712 ft; 185.9-217.0 m/ 1500-1558 ft; 457.2-474.9 m). Sandstones and conglomerates commonly contain trough cross-beds in one to four foot sets (610-625 ft; 185.9-190.5 m). Soft sediment deformation is exhibited in some sandstones (670-672 ft; 204.2-204.8 m). Finer-grained lithologies, such as siltstones and mudstones,

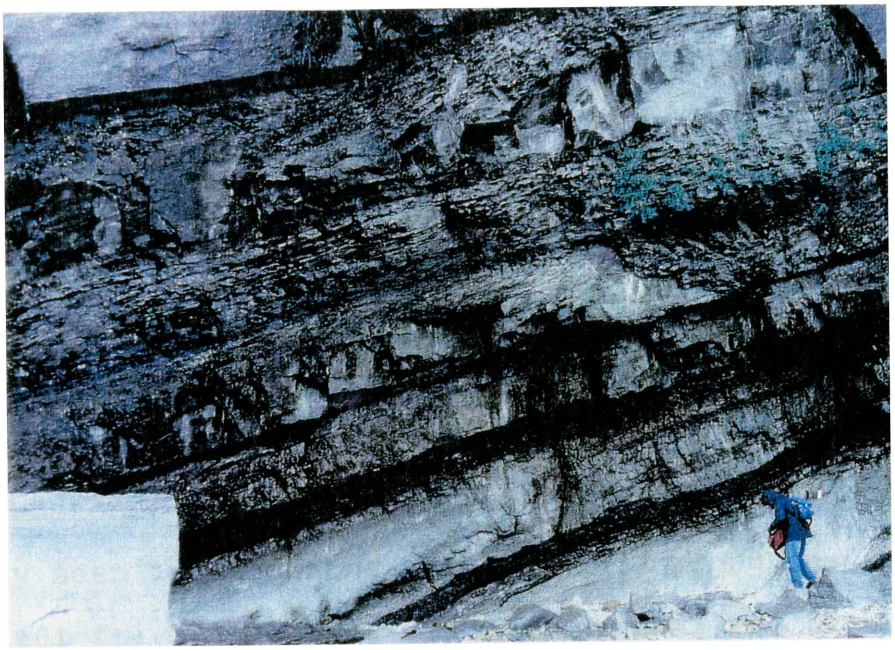


Fig. 8. Interbedded sandstones, siltstones, carbonaceous siltstones and thin coals at 1,310 ft (399.3 m) of the Cape Nukshak Section. Note the multiple small, fining-upward packages grading from sandstones to coals within the larger package (entire photo).

Fig. 9. Sandstones, siltstones and carbonaceous siltstones at 1,220 ft (371.9 m) of the Cape Nukshak Section. Note the thick, columnar jointed sill in the center of the outcrop (pale, white). This sill is unusually thick, however, thin sills (less than one foot; 0.3 m) are scattered throughout the section.

commonly exhibit soft sediment deformation and asymmetrical ripples (1525-1556 ft; 464.8-474.3 m).

Packages containing interbedded lithologies are common. These packages may include: Sandstones and mudstones (740-824 ft; 225.6-251.2 m); sandstones, siltstones and carbonaceous siltstones (1280-1365 ft; 390.1-416.1 m); or conglomerates, conglomeratic sandstones and sandstones (972-1055 ft; 296.3-321.6 m/ 1855-1957 ft; 565.4-596.5 m).

Sandstones vary in thickness and frequency. Features commonly seen in sandstone units include trough cross-beds (1075-1101 ft; 327.7-335.6 m), asymmetrical and climbing ripples (1209-1218 ft; 368.5-371.2 m), soft sediment deformation (1299-1303 ft; 395.9-397.2 m), and conglomerate lenses and stringers (1500-1519 ft; 457.2-463.0 m). Lateral accretion elements are rare (1281-1287 ft; 390.4-392.3 m). A single sandstone unit near the top of the section (2730-2735 ft; 832.1-833.6 m) exhibits small scale lateral accretion with clay drapes on foresets and burrows along the top surface of the unit.

Infrequent thick conglomeratic packages exhibit large-scale trough cross-beds (824-865 ft; 251.2-263.7 m), and some contain sandstone lenses (2640-2670 ft; 804.7-813.8 m). Most conglomeratic units are much thinner and are interbedded with sandstones.

Erosional basal surfaces with relief of a few inches to one foot separate fining-upward packages. Surfaces at the base of the thicker conglomeratic units can exhibit relief of up to two feet.

Organic material is abundant throughout the section. Roots can be found in all types of lithologies (2039-2054 ft; 621.5-626.1 m/ 1293-1354 ft; 394.1-412.7 m), as can leaf imprints and carbonized wood fragments (1010-1030 ft; 307.8-313.9 m/ 1536-1555 ft; 468.2-474.0 m). Carbonized logs are found in conglomeratic units (2640-2666 ft; 804.7-812.6 m). Trees in growth position are found in sandstone units (1291-1295 ft; 393.5-394.7 m/ 1775-1780 ft; 541.0-542.5 m/ 2393-2400 ft; 729.4-731.5 m). Thin coal seams associated with fine-grained carbonaceous packages are dispersed throughout the section (1385-1386 ft; 422.1-422.5 m/ 1736-1746 ft; 529.1-532.2 m).

Other lithologies seen in the section include: breccia (887-960 ft; 270.4-292.6 m); pyroclastic units (1169-1194 ft; 356.3-363.9 m/ 2592-2640 ft; 790.0-804.7 m); sills (1230-1260 ft; 374.9-384.0 m/ 1305-1306 ft; 397.8-398.1 m); a basalt flow (2560-2592 ft; 780.3-790.0 m); and a debris flow (2400-2432 ft; 731.5-741.3 m).

In general, the Cape Nukshak section is comprised of well defined fining-upward packages. The section is relatively fine-grained compared to the one at Cape Douglas and exhibits more diverse lithologies.

Kinak Bay Measured Section

Location

The Kinak Bay Section is within T. 24 S., R. 32. W, beginning in NE NE, sec. 23 and passing through section 24 before ending in SW SW, sec. 13. It is located on the extreme southwestern shore of Kinak Bay, on the eastern side of the point which separates Kinak Bay and Amalik Bay.

Stratigraphy

The Kinak Bay Section (Figs. 10 and 11) is characterized by multiple, stacked, complete fining-upward packages which consistently exhibit similar lithologies. A typical package consists of interbedded sandstones and pebbly sandstones at the base grading up to sandstones, interbedded sandstones and/or siltstones and/or mudstones, with a mudstone and/or carbonaceous shale and/or coal cap (223-267 ft; 68.0-81.4 m/ 355-401 ft; 108.2-122.2 m/ 490-553 ft; 149.4-168.6 m). Packages are separated by erosional basal surfaces exhibiting two to six inches, and infrequently up to one foot, of relief.

Sandstones and pebbly sandstones commonly contain trough cross-beds (some with clay drapes on foresets), asymmetrical ripples and concretions (641-661 ft; 195.4-201.5 m). Some sandstones exhibit soft sediment deformation (612-632 ft; 186.5-192.6 m). Climbing ripples are only exhibited in one sandstone unit (594-602 ft; 181.1-183.5 m).

Roots (632-636 ft; 192.6-193.9 m), wood fragments (720-729 ft; 219.5-222.2 m) and leaf imprints (767-769 ft; 233,8-234.4 m) are infrequent. There are a few coal seams found in the section (552-553 ft; 168.2-168.6 m).

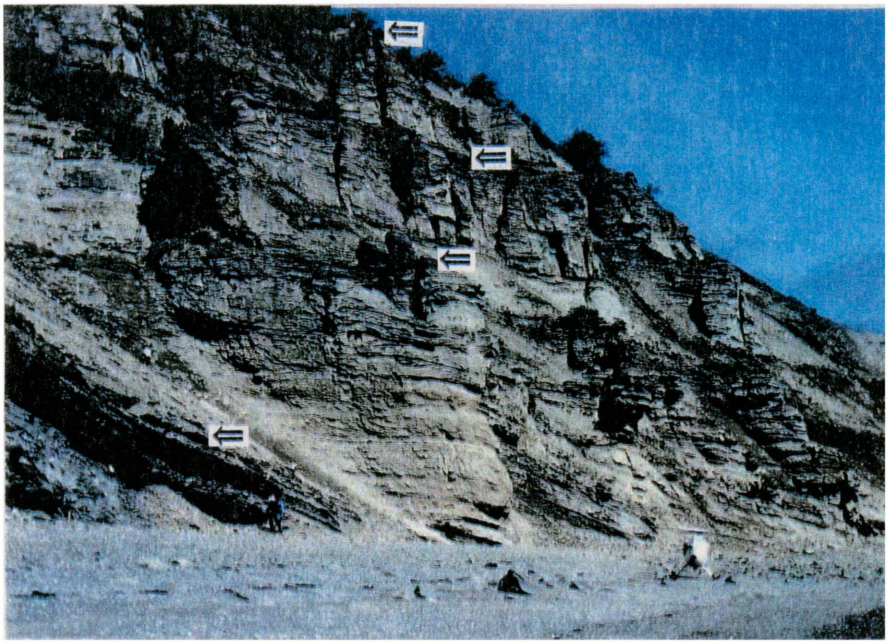


Fig. 10. Well defined, fining-upward packages in the upper part (above 300 ft; 91.4 m) of the Kinak Bay Section (arrows mark the top of packages). Packages consist of interbedded sandstones and conglomerate stringers at the base, grading up to sandstones, siltstones, carbonaceous siltstones and coals.

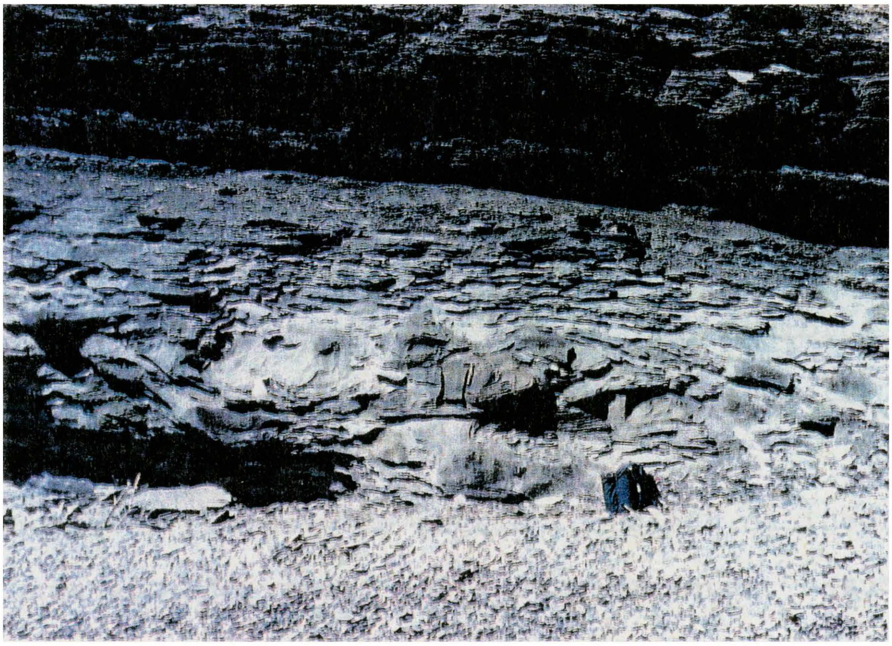


Fig. 11. The top of a fining-upward package at 255 ft (77.7 m) of the Kinak Bay Section. The package grades up from sandstone to siltstone to interbedded siltstones and carbonaceous siltstones. Note the slumping features in the sandstone (near hammer in center of photograph).

Sandstones and finer-grained units are the dominant lithologies in this section. Conglomeratic beds and stringers are generally dispersed within the basal parts of the fining-upward packages.

Kuliak Bay Measured Section

Location

The Kuliak Bay measured section is located in SW NW, sec. 16 and NE SE, sec. 9 of T. 23 S., R. 30 W, and measures up section to the northeast. It is located on the north/ northeast shore of Kuliak Bay where the bay opens out into the Shelikof Strait.

Stratigraphy

The Kuliak Bay Section (Figs. 12 and 13) can be divided into two sub-sections or parts. A lower part (153-197 ft; 46.6-60 m) is characterized by amalgamated conglomeratic units which contain much thinner, discontinuous sandstones. An upper part (units above 224 ft; 68.3 m) exhibits well defined fining-upward packages containing laterally continuous units.

The lower part of the section consists of interbedded sandstones and moderately thick conglomerates. Sandstone units are laterally discontinuous, and contain trough cross-beds, asymmetrical ripples and conglomeratic lenses (153-165 ft; 46.6-50.3 m). Conglomerates contain small, trough cross-bedded sandstone lenses (178-185 ft; 54.3-56.4 m).

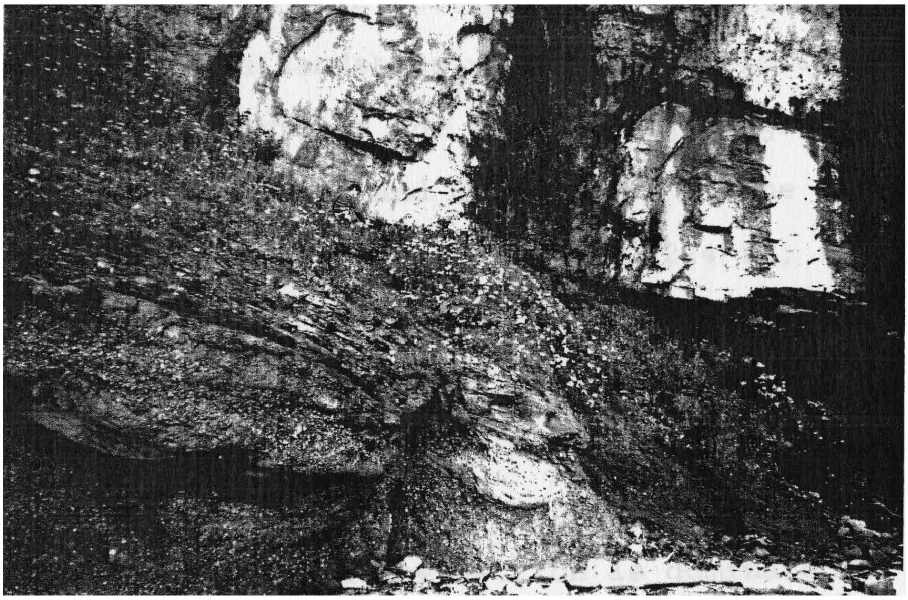


Fig. 12. The covered section at 200 ft (61.0 m) between the lower and upper parts of the Kuliak Bay Section. In the lower left of the photograph, below the covered section, are massive conglomerates containing sandstone lenses. Above the covered section in the upper right are interbedded sandstones and pebbly sandstones.

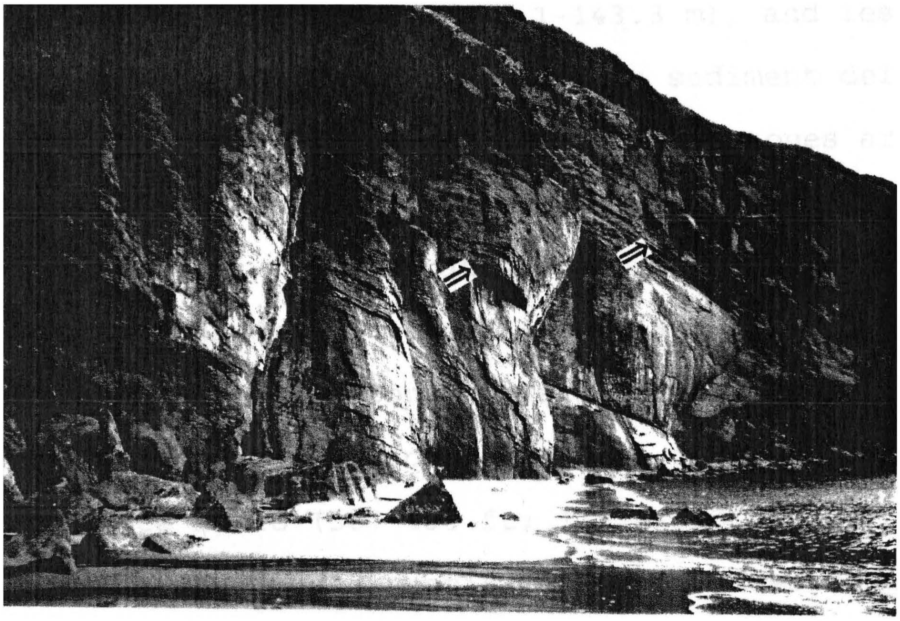


Fig. 13. A view looking up-section (to the right) at the upper part (above 260 ft; 79.2 m) of the Kuliak Bay Section. Within the fining-upward packages, pebbly sandstone content decreases and sandstone content increases up-section. Some packages are capped by siltstones and/or coal seams. Erosional surfaces (indicated by arrows) separate fining-upward packages.

Erosional surfaces with relief of up to two feet (0.6 m) commonly truncate sandstone units, but are difficult to trace laterally through the surrounding conglomerates.

Between the lower and upper parts of the section (as defined above) is a covered zone (199-224 ft; 60.7-68.3 m) which can be traced laterally for approximately 70 feet (21.3 m). Trenching part of the covered zone revealed approximately eight feet (2.4 m) of material resembling a silty mudstone.

The upper part of the section is dominated by packages of interbedded sandstones, pebbly sandstones and thin conglomerates (310-390 ft; 94.5-118.9 m). Sandstones are commonly trough cross-bedded and contain conglomerate lenses and stringers (453-470 ft; 138.1-143.3 m), and less commonly exhibit asymmetrical ripples and soft sediment deformation (683-692 ft; 208.2-210.9 m). Pebbly sandstones are cross-bedded and contain rip-ups and sand lenses (346-368 ft; 105.5-112.2 m). Conglomerates commonly contain trough cross-bedded sandstone lenses (438-453 ft; 133.5-138.1 m).

Some interbedded conglomerate and sandstone packages subtly fine-upward due to an increase in the sandstone to conglomerate ratio (387-438 ft; 118.0-133.5 m). Complete fining-upward packages consist of interbedded conglomerate and sandstone grading up to sandstones and interbedded sandstones and siltstones (224-259 ft; 68.3-78.9 m/ 498-581 ft; 151.8-177.1 m).

Erosional basal surfaces separate fining-upward packages. They rarely exhibit relief of more than one foot (0.3 m), and are laterally continuous for upwards of 100 feet (30.4 m).

The upper part of the section contains minor amounts of transported organic material. Some sandstones contain wood fragments and carbonaceous rip-ups (337-350 ft; 102.7-106.7 m). Carbonized tree stumps in growth position are rare, but can be found rooted into the erosional basal surfaces that separate packages (478-480 ft; 145.7-146.3 m).

In general, there are two distinct outcrop expressions found within this section. The lower part of the section is dominantly conglomeratic, and resembles parts of the Cape Douglas Section. In contrast, the upper part is organized into moderately to well organized fining-upward packages, resembling parts of the Cape Nukshak and Kinak Bay Sections.

CHAPTER V

DISCUSSION OF THE MEASURED SECTIONS

Identification of the Formations in Katmai National Park

Based on the map by Riehle, et al. (1987), the Cape Douglas Section is the West Foreland Formation and the Cape Nukshak and Kinak Bay Sections are the Hemlock Conglomerate. Outcrops at Kuliak Bay are mapped as the Hemlock Conglomerate, although other lower Tertiary rocks (not specifically designated as the West Foreland Formation) are indicated in the vicinity of the base of the measured section.

In outcrop, the lower part of the Kuliak Bay Section resembles the Cape Douglas Section (West Foreland Formation), while the upper part resembles sections at Cape Nukshak and Kinak Bay (Hemlock Conglomerate). The boundary between the lower and upper parts of the section could only be traced for a short distance, and could not be extrapolated to any mapped formational boundary.

Due to the change in outcrop expression between the lower and upper parts of the section at Kuliak Bay, the section is divided and identified as the West Foreland Formation (lower part) and the Hemlock Conglomerate (upper part) for the purposes of this study. However, no other evidence is available to support the presence of a West Foreland-Hemlock unconformity within the Kuliak Bay Section.

General Characteristics of the West Foreland Formation

Outcrops of the West Foreland Formation in Katmai National Park (Cape Douglas, lower Kuliak Bay) show dominantly homogeneous, coarse-grained lithologies. The stratigraphic sections contain thick packages of stacked pebble and cobble conglomerates separated by widespread erosional surfaces. Packages are amalgamated both vertically and horizontally. Sand lenses are common within and between packages of conglomerates, however, laterally continuous finer-grained units (sandstones, siltstones) are uncommon. Conglomeratic packages contain large sets of trough cross-beds and large siltstone rip-ups. Preserved fining-upward packages are rare.

General Characteristics of the Hemlock Conglomerate

Outcrops of the Hemlock Conglomerate in Katmai National Park (Cape Nukshak, Kinak Bay, upper Kuliak Bay) show heterogeneous sedimentary sequences, containing some pyroclastic and igneous lithologies (Cape Nukshak only). The sections exhibit stacked, well defined, fining-upward packages. Lithologies include conglomerates, pebbly sandstones, sandstones, siltstones, carbonaceous siltstones and coals. Syndepositional volcanic events are indicated by lithic tuffs interbedded with the sedimentary units. Sills are also incorporated into the section.

Interpretation of Depositional Environments

The West Foreland Formation and Hemlock Conglomerate in Katmai National Park are interpreted to represent fluvial deposition. However, the styles of deposition for the two formations were distinctly different.

The West Foreland Formation depositional system consisted of numerous cross-cutting fluvial channels on a broad braid plain. This created laterally and vertically amalgamated packages seen in outcrop as thick, homogeneous lithologies. It was a high bed-load system that deposited coarse sediment over broad scour surfaces created by the cross-cutting channels. Lack of accommodation space caused channels to cannibalize the tops of previously deposited packages, preserving only the coarse, lower parts of channels.

The Hemlock Conglomerate depositional system consisted of meandering channels downcutting into non-channel facies. This created the stacked, fining-upward sequences seen in outcrop. A variety of fluvial and related overbank regimes resulted in the heterogeneity of lithologies. Increased accommodation space allowed preservation of upper channel fills, and thus preserved complete fluvial packages.

Clay-draped foresets and burrows are found at the top of the Cape Nukshak section. This indicates tidal encroachment at the mouth of the fluvial system in this part of the Hemlock Conglomerate. This is the only example of marine influence observed in any of the sections measured in the park.

Modern Analogs for the Depositional Systems

Modern analogs for the West Foreland Formation and Hemlock Conglomerate depositional systems are found in Katmai National Park (Figs. 14, 15, 16 and 17). The main sediment supply for these systems is volcanic detritus from the 1912 eruption of Mount Katmai.

Evolution of the Depositional System

Early Tertiary fluvial depositional systems in the Katmai area changed character between the deposition of the West Foreland Formation and the Hemlock Conglomerate. The broad network(s) of braided channels that deposited the West Foreland Formation evolved into a system of more isolated, meandering channels represented by the Hemlock Conglomerate.

One factor which may have been responsible for controlling the change in the fluvial systems was a change in the rate at which accommodation space was being created, as indicated by the differences in preservation of fluvial packages in the two formations. It is speculated that the dynamics of the subduction zone are largely responsible for the changes in depositional systems in the early- to mid-

Fig. 14. Modern analog for the West Foreland Formation depositional system shown by a lower reach of the Savonoski River in Katmai National Park. Note shallow, braided channels and abundant wood debris. Aggradation and lateral shifting of channels would create vertically and horizontally amalgamated packages. Floodplain environments, such as those shown in the upper right corner of the photograph, are not expressed in the West Foreland Formation

Fig. 15. Modern analog in Katmai National Park for the Hemlock Conglomerate depositional system. The channels downcut into surrounding non-channel facies (overbank and floodplain). Fluvial fining-upward packages are preserved as the channels migrate laterally into the non-channel facies.

Fig. 16. Modern analog for rapid deposition causing trees to be buried in growth position, as reflected in the Hemlock Conglomerate outcrops. Location is the northern side of the Katmai River braidplain in southern Katmai National Park.

Fig. 17. Modern analog for the marine-influenced beds of the Hemlock Conglomerate seen near the top of the Cape Nukshak Section. To the right of the shoreline is an ebb-tidal delta. The flood-tidal delta (left of the shoreline) is an example of a marine influence on the lowest reaches of the fluvial system. Location is at the mouths of the Ninagiak River and Hook Creek, northern Hallo Bay, Katmai National Park.

Tertiary. The rate of subduction of complexes beneath the forearm basin directly affected the accommodation potential within the basin.

The halt of subduction in the late Cretaceous caused the subduction complex(es) to "support" the newly created terrestrial basin, while simultaneous rapid sedimentation filled available accommodation space (Dickinson and Seely, 1979). With a decrease in the rate at which accommodation space was being created, the resulting geometry of the West Foreland deposits is one of lateral stacking of sandstone bodies.

In the late Eocene or early Oligocene, renewed subduction of the complex(es) (Dickinson and Seely, 1979) may have been responsible for increasing the rate of accommodation. This also may have resulted in a relative fall in base level within the basin, which could be reflected in increased incision (Shanley and McCabe, 1994) and preservation of more complete fluvial packages by the Hemlock Conglomerate depositional system.

The above scenario is a possible explanation to account for the evolution of the depositional system between the West Foreland Formation and the Hemlock Conglomerate. Other tectonic and/or sedimentological models may also provide reasonable explanations for the evolution of the depositional system through the Tertiary.

CHAPTER VI

FORMATION AGES

Previous Work

Wolfe (1966) estimated the West Foreland Formation to be Eocene and the Hemlock Conglomerate to be Oligocene in age from paleobotanical data. Subsequent workers have used these ages, although with some skepticism (Calderwood and Fackler, 1972; Magoon, 1986). Riehle, et al. (1987) and Petering and Smith (1979) identified the two formations in Katmai National Park as lower Tertiary in age.

This study attempted to pinpoint the ages of the formations in Katmai through the use of three methods; stratigraphic relationships, palynological dating, and fission track dating. Stratigraphic relationships help place the Katmai outcrops within the larger context of the Tertiary section. Palynological and fission track dating provide more specific age dates for the two formations.

Stratigraphic Relationships

Previous workers have shown that the West Foreland Formation lies unconformably on the Cretaceous Kaguyak Formation (Calderwood and Fackler, 1972). Riehle, et al. (1987) mapped this boundary in outcrop west/northwest of

Mount Douglas.

The Cretaceous-Tertiary boundary was observed approximately two miles west of the base of the Cape Douglas measured section (Fig. 18). However, the boundary could not be traced directly to the section. Due to their proximity to the K-T boundary, it is inferred that the Cape Douglas outcrops represent the lowest Tertiary strata in the park.

The possible exposure of the West Foreland-Hemlock unconformity in the Kuliak Bay Section is based solely on the outcrop expressions of that section. There were no other observations made to support the presence of that boundary within the park. If this is the formation boundary, it would represent the base of the Kenai Group as defined by Boss, et al. (1976).

Palynological Dating

Thirty six samples were submitted for palynological dating. Although the ages of eighteen samples were indeterminate, eighteen samples provided age dates (Table 1).

All ages determined for the West Foreland Formation based on palynomorphs are indeterminate. This is due to the fact that samples are barren of palynomorphs (eight samples from the Cape Douglas Section) or observed palynomorphs are undifferentiated and/or poorly preserved (three samples from the Lower Kuliak Bay section).

The ages of seven samples from the Hemlock Conglomerate

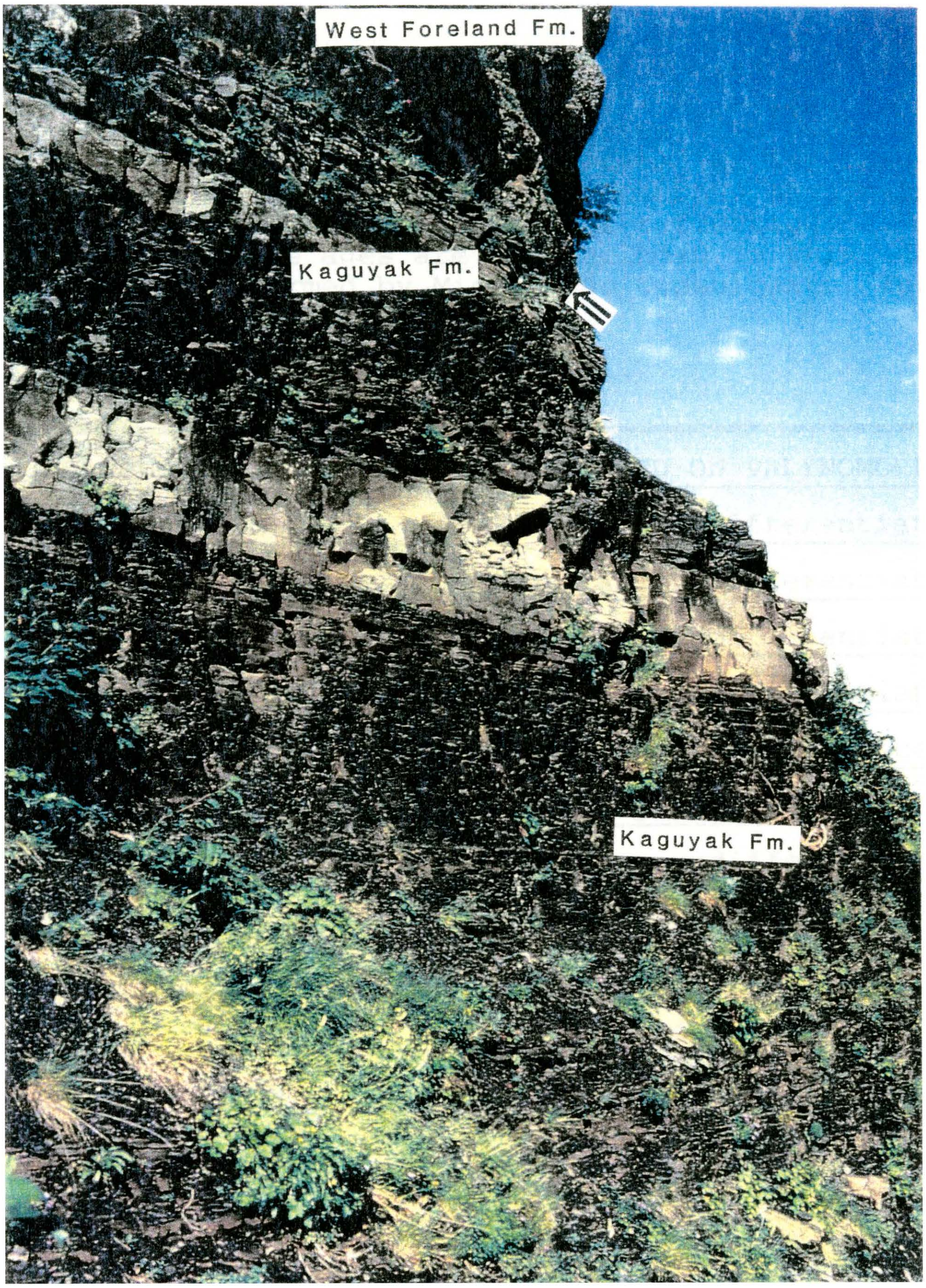


Fig. 18. The Cretaceous-Tertiary contact (indicated by arrow) between the Kaguyak Formation and the West Foreland Formation west of Cape Douglas. The Kaguyak Formation is interpreted to be turbiditic sandstones and mudstones. This contact could not be traced directly to the Cape Douglas measured section. However, the Cape Douglas outcrops are inferred to represent the lowest Tertiary strata in the field area.

Table 1. Palynological ages determined for eighteen samples from the Hemlock Conglomerate; (CN) = Cape Nukshak Section, (KB) = Kinak Bay Section; (KL) = Upper Kuliak Bay Section. Samples dated as Tertiary-undifferentiated contain palynomorphs that existed through the Tertiary. Samples reflecting indeterminate ages are not included in this table. Dating performed by Micropaleo Consultants, Inc., San Francisco, California.

SAMPLE NUMBER	AGE BASED ON PALYNOMORPHS
1-25-P2 (CN)	Tertiary-undifferentiated
1-500-P1 (CN)	Tertiary-undifferentiated
1-1338-P2 (CN)	Tertiary-undifferentiated
1-1385-P1 (CN)	Tertiary-undifferentiated
1-1465-P3 (CN)	Possibly Paleocene/Eocene
1-1557-P1 (CN)	Tertiary-undifferentiated
1-1661-P2 (CN)	Tertiary-undifferentiated
1-1924-P3 (CN)	Tertiary-undifferentiated
1-2010-P4 (CN)	Possibly Eocene
1-2462-P5 (CN)	Possibly Eocene
1-2464-P6 (CN)	Tertiary-undifferentiated
2-168-P1 (KB)	Tertiary-undifferentiated
2-401-P1 (KB)	Tertiary-undifferentiated
2-452-P2 (KB)	Tertiary-undifferentiated
2-478-P3 (KB)	Tertiary-undifferentiated
2-550-P4 (KB)	Tertiary-undifferentiated
4-266-P5 (KL)	Tertiary-undifferentiated
4-267-P6 (KL)	Tertiary-undifferentiated

are indeterminate due to undifferentiated and/or poorly preserved palynomorphs (six from Cape Nukshak, one from Upper Kuliak Bay). Fifteen samples are dated as Tertiary-undifferentiated due to the longevity of the species identified (eight from Cape Nukshak, five from Kinak Bay, two from Upper Kuliak Bay). Three samples from Cape Nukshak are tentatively dated by epoch: Two possible Eocene; one possible Paleocene/Eocene.

Fission Track Dating

Samples containing euhedral, unaltered apatite and/or zircon grains are necessary for fission track dating. Although no such grains were identified during the petrographic analysis, samples from the Hemlock Conglomerate with relatively high amounts of observed heavy minerals were submitted for dating. Three samples were found to contain appropriate grains for this dating technique.

In each sample, there is more than one age population identified. However, there is only one population from each which is considered to be statistically well constrained (Table 2). Sample 1-1504-L6 provides a late Oligocene age which is consistent with ages attributed to the Hemlock Conglomerate (Calderwood and Fackler, 1972; Magoon, 1986). The other two samples provide age dates in the Miocene, which are considerably younger than those given in the literature for the Hemlock.

Table 2. Statistically constrained fission track ages for three samples from the Hemlock Conglomerate; (CN) = Cape Nukshak Section, (KB) = Kinak Bay Section. Dating performed by the University of Wyoming hermochronology Laboratory.

SAMPLE NUMBER	AGE AND MARGIN OF ERROR
1-1442-L4 (CN)	11.84 +/- 5.5 Ma
1-1504-L6 (CN)	20.33 +/- 2.7 Ma
2-4-L1 (KB)	8.54 +/- 3.3 Ma

Five older age dates were also obtained from grains in the three samples: 71.28 +/- 19.1 Ma; 150-240 Ma; ~70 Ma; ~30 Ma; and 70-120 Ma. These dates are not statistically well constrained, and cannot be considered reliable.

Although one age obtained through fission track dating is consistent with ages given for the Hemlock Conglomerate, there are factors which may have affected the usefulness of the technique for this study. The successful employment of this method for dating sedimentary units depends upon two factors: Deposition of apatite and/or zircon grains shortly after their crystallization; and lack of post-deposition alteration of the grains.

Samples providing older dates may reflect the age of crystallization of apatite and/or zircon grains in a source terrain, but not the age of deposition within a sedimentary sequence. Samples providing younger dates may reflect the thermal resetting of the grains at some time after deposition by igneous or hydrothermal activity. In any case, statistical confidence must be considered when evaluating the reliability of an age from a given population.

Formation Ages in Katmai

Precise ages for the West Foreland Formation and the Hemlock Conglomerate in Katmai National Park could not be determined. Age dates obtained are generally contradictory to other studies and/or are statistically unreliable. Palynological evidence indicates that the formations are both Tertiary in age. Fission track dating suggests that the Hemlock Conglomerate may indeed be Oligocene. Stratigraphic position indicates that the West Foreland Formation at Cape Douglas may represent a portion of the lowest Tertiary section in Katmai National Park.

CHAPTER VII

SANDSTONE PETROGRAPHY AND SCANNING ELECTRON MICROSCOPY

Analyses were performed on 104 thin sections from the stratigraphic sections measured and described in this report. Thirty five are from sections designated as the West Foreland Formation, and sixty nine are from sections designated as the Hemlock Conglomerate. The purpose of these analyses were to determine the compositions and textures of sandstones from the two formations.

Petrographic analysis of sandstones from the West Foreland Formation and the Hemlock Conglomerate shows that their compositions are mineralogically and texturally similar. Therefore, the two formations are discussed in unison in this chapter, unless otherwise noted.

Detrital Composition of the Sandstones

The average amount of detrital components (versus authigenic minerals) in the West Foreland Formation and the Hemlock Conglomerate are 82% and 78%, respectively (Table 3). Virtually all of the samples range from sub-lithic to lithic arenites, with a few being feldspathic. Eighty-seven percent of the samples are texturally submature, although

Table 3. Average values for detrital components found in each formation (normalized to 100%). Averages do not include compositions of pyroclastic units. The average total amounts of detrital components (vs. authigenic) for the West Foreland Formation and Hemlock Conglomerate are 82% and 78%, respectively. Categories used in point counting were selected to represent all detrital constituents observed in both formations. See Appendix II for complete point count data.

West Foreland Formation	AVERAGE (%)	STANDARD DEVIATION
quartz (undulose)	18.5	12.6
quartz (non-undulose)	5.9	6.5
polycrystalline quartz (2-3 crystallites)	3.9	2.9
polycrystalline quartz (>3 crystallites)	12.0	8.4
plagioclase	5.8	3.9
potassium feldspars	0.3	0.8
microcline	0.1	0.3
micas	0.9	2.5
accessory minerals	3.2	3.8
igneous fragments (plutonic)	0.2	0.2
igneous fragments (volcanic)	24.9	18.5
chert fragments	15.2	10.6
metamorphic fragments	2.7	4.3
foliated chert fragments	2.3	2.2

Hemlock Conglomerate	AVERAGE (%)	STANDARD DEVIATION
quartz (undulose)	23.4	12.9
quartz (non-undulose)	4.7	5.0
polycrystalline quartz (2-3 crystallites)	3.2	3.3
polycrystalline quartz (>3 crystallites)	7.4	7.3
plagioclase	10.7	9.1
potassium feldspars	0.3	0.7
microcline	0.2	0.5
micas	1.1	1.7
accessory minerals	2.0	2.6
igneous fragments (plutonic)	0.1	0.3
igneous fragments (volcanic)	34.1	29.1
chert fragments	9.7	8.9
metamorphic fragments	1.8	2.8
foliated chert fragments	1.4	2.0

samples have been identified which range from submature to supermature.

Monomineralic Constituents

Monomineralic grains occur in a wide range of abundances. In general, the relative abundance of these grains increases with decreasing volcanic rock fragment content. Grains present in order of decreasing amount are: monocrystalline quartz, polycrystalline quartz, plagioclase, microcline, micas (muscovite and chlorite) and accessory minerals.

Monocrystalline quartz grains are generally subangular to subrounded (Fig. 19). Quartz grains exhibiting weak to strong undulose extinction and biaxial optic axis figures comprise 18.5% of the West Foreland Formation and 23.4% of the Hemlock Conglomerate. Non-undulose quartz grains account for 5.9% and 4.7% of the formations, respectively. Quartz grains with straight extinction tend to be more angular than those exhibiting undulosity. Few quartz grains contain inclusions.

Polycrystalline quartz grains are generally subangular. Grains containing 2-3 crystallites average 3.9% of the West Foreland Formation and 3.2% of the Hemlock Conglomerate, whereas grains containing more than three crystallites (Fig. 20) average 12.0% and 7.4%, respectively. When more than three crystallites are present, their size distribution tends to be bimodal. Crystallites are found in a wide range

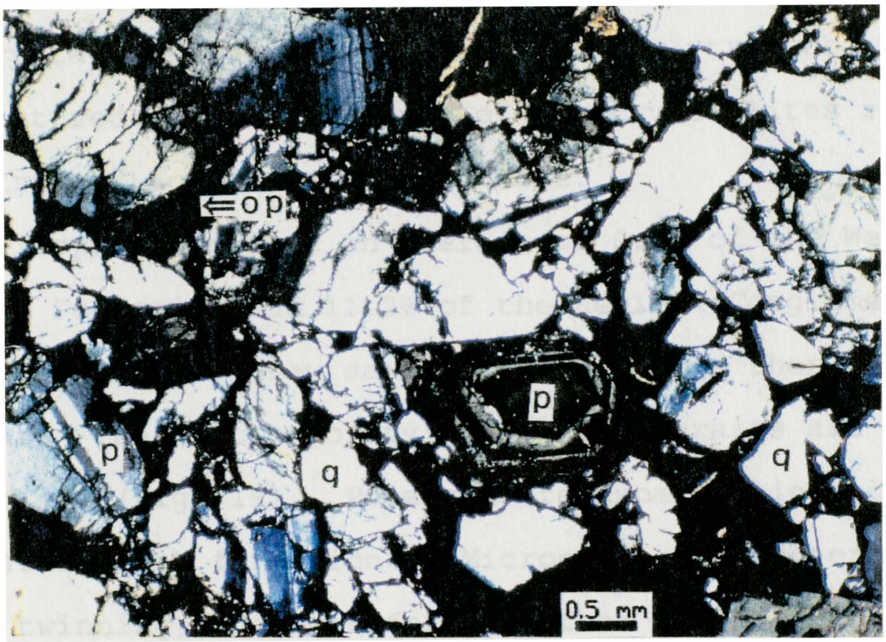


Fig. 19. A sample composed of quartz (q) and plagioclase (p) feldspar. Quartz grains are generally subangular and exhibit different degrees of extinction. The cement in this sample (op) is opaque under plane light and crossed polars. Note that many of the grains are fractured, possibly due to compaction. Sample 3-3172-L4; photomicrograph under crossed polars.

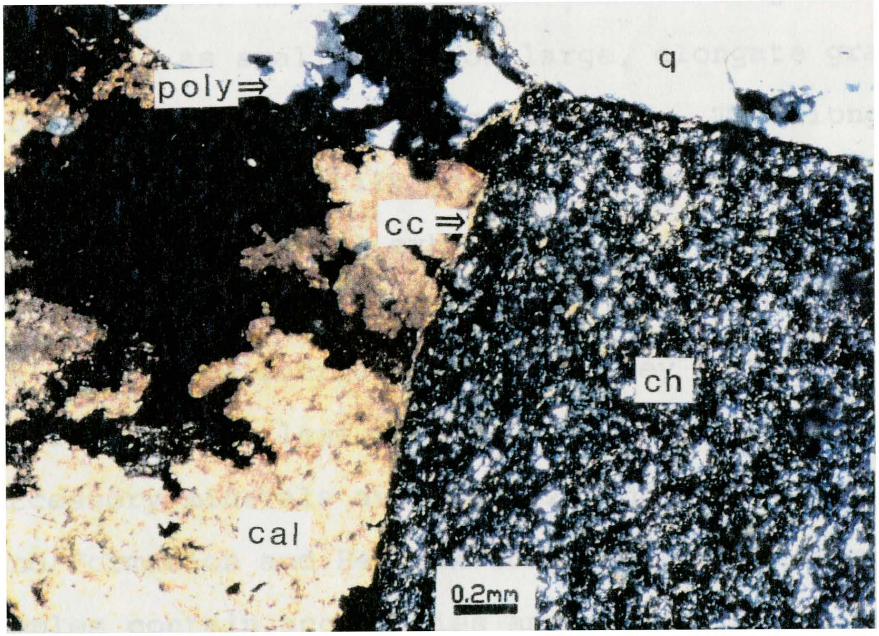


Fig. 20. A sample containing quartz, chert (ch), polycrystalline quartz (poly), clay coats on grains(cc) and calcite cement (cal). Development of a clay coat on the chert grain preceded emplacement of calcite cement. Sample 4-428-L4; photomicrograph under crossed polars.

of shapes, with the most common being polygonal. Intracrystalline boundaries are generally straight, with few being sutured. The extinction of the crystallites ranges from straight to moderately undulose.

Feldspars comprise an average of 6.2% of the West Foreland Formation and 11.2% of the Hemlock Conglomerate (Figs. 21 and 19). Few samples contain more than 20% feldspar. The vast majority of feldspar grains are plagioclase (Fig. 19). Potassium feldspar grains account for 0.3% of both formations. Microcline, characterized by tartan twinning, accounts for less than 0.3% of both formations.

Muscovite grains (Fig. 22) comprise 0.9% of the West Foreland Formation and 1.1% of the Hemlock Conglomerate. They are found as small laths or large, elongate grains, both of which exhibit high birefringence. The elongate grains are commonly ductily deformed or broken.

Elongate mica grains exhibiting pale to deep green pleochroism (Fig. 23) may be chlorite pseudomorphs after biotite (Burns and Ethridge, 1979). They are commonly broken, and average less than 0.2% of both formations.

Accessory minerals average 3.2% and 2.0% of the West Foreland Formation and Hemlock Conglomerate, respectively. Few samples contain accessories amounting to more than 10%. These minerals tend to be more abundant in samples with a relatively high volcanic rock fragment content. They are generally very small, euhedral, and have very high relief

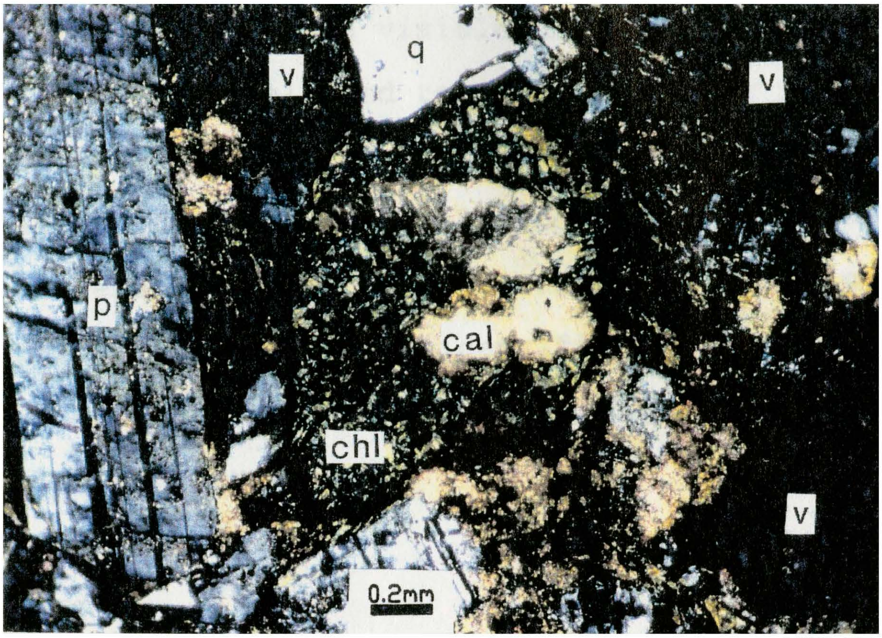


Fig. 21. A sample containing plagioclase, quartz and volcanic rock fragments (v). The grain in the center has been completely replaced by calcite and chlorite (chl). An iron oxide coat preserves the original grain shape, suggesting it may have been a volcanic rock fragment. There is minor replacement of the plagioclase grain, left side of the photo, by calcite. Sample 1-1064-L11; photomicrograph under crossed polars.

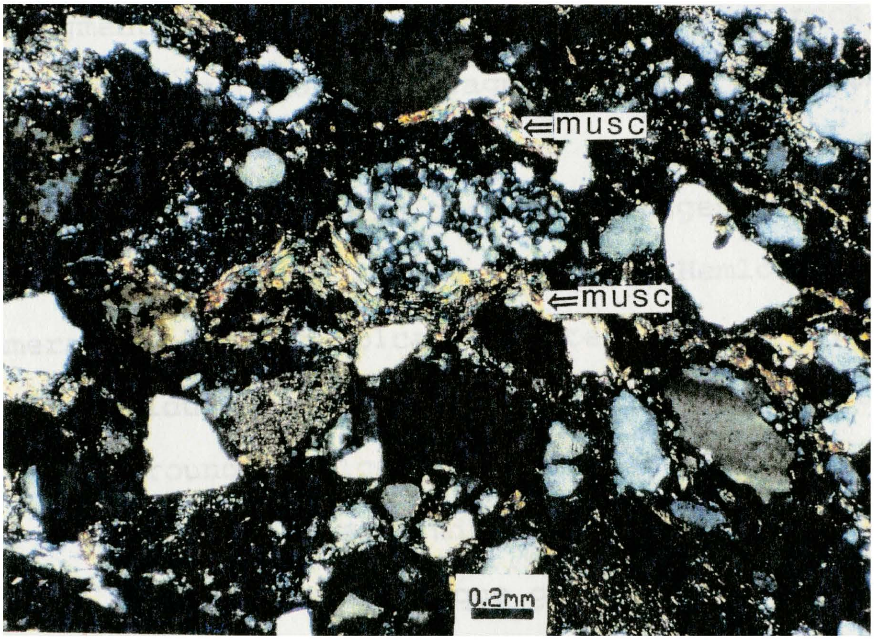


Fig. 22. Muscovite grains (musc) which have been brittly deformed due to compaction. The grains are broken by the pressure exerted on them by overlying grains, such as chert (center of photo, between muscovite grains). Sample 2-268-L3; photomicrograph under crossed polars.

and birefringence. Most appear to be minerals of the amphibole group based upon visible cleavage, however, most are too small and/or altered to determine their optical properties.

Occasionally, detrital grains could not be identified because diagenetic alterations masked grain morphologies and/or optical properties. Unidentifiable grains comprise an average of 2% of the total detrital fraction of each thin section for both formations.

Rock Fragments

Rock fragment content averages 45.3% of the total detrital fraction of the West Foreland Formation, and 47.1% of the Hemlock Conglomerate. Quantitatively, volcanic and chert fragments are the most abundant types of rock fragments, with metamorphic fragments being less common and plutonic fragments being very rare.

Volcanic rock fragment content averages 24.9% of the West Foreland Formation and 34.1% of the Hemlock Conglomerate, although volcanic content ranges from zero to 100% of individual samples (not including pyroclastics). Sub- to well-rounded volcanic rock fragments comprised of quartz, feldspar and opaque mineral phenocrysts in an aphanitic, semi-opaque to opaque groundmass are most common, especially in samples that are relatively coarse-grained (Fig. 24). Aggregates of groundmass and microlites are also common. Trachytic grains are less frequently observed.

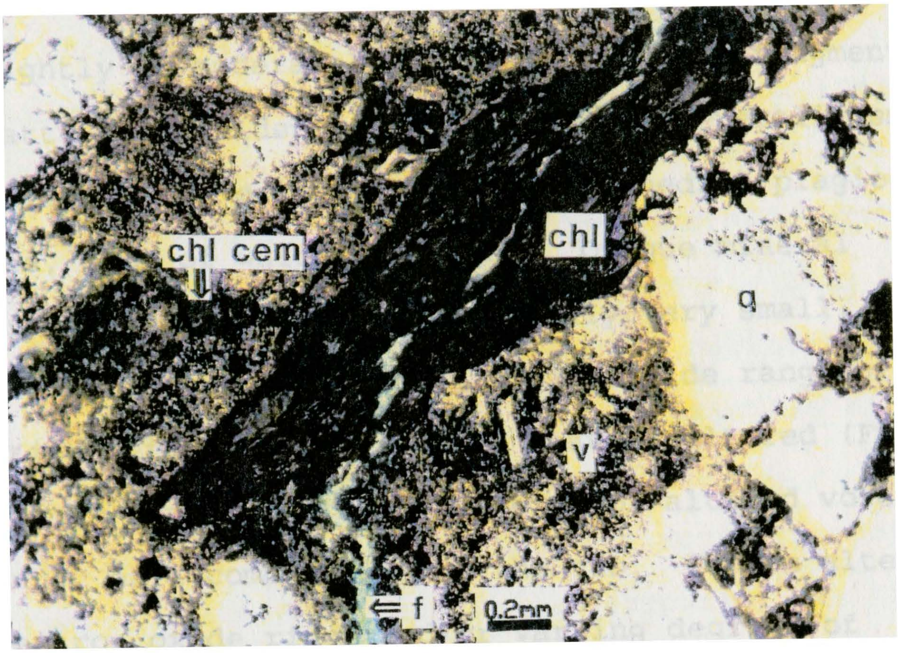


Fig. 23. A detrital mica (chl) which may be a chlorite pseudomorph after biotite. Other constituents include quartz grains and volcanic rock fragments. The sample is cemented with chlorite (chl cem). Note the microfracture (f) that runs through the mica grain, volcanic fragments and chlorite cement. Sample 1-1442-L4; plane light photomicrograph.

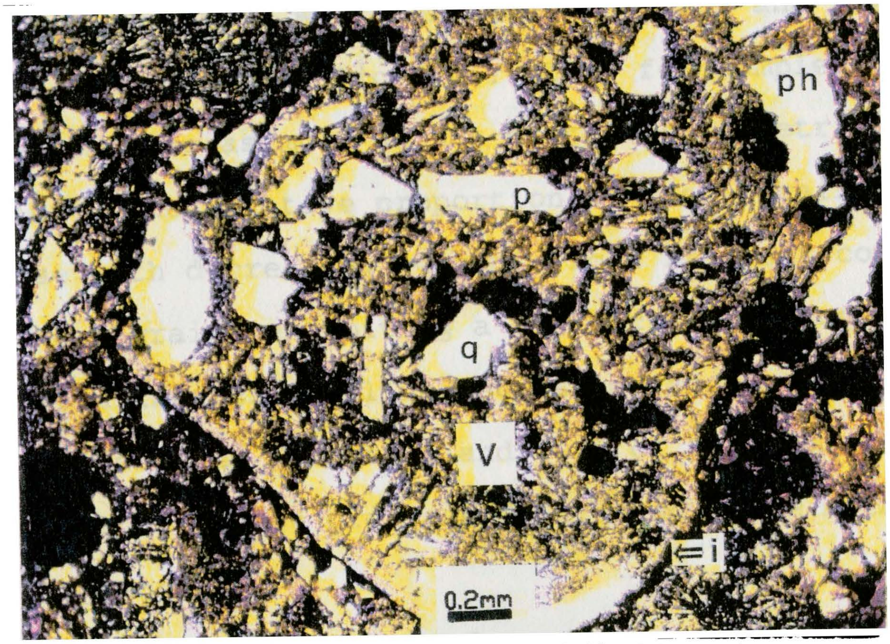


Fig. 24. A volcanic rock fragment (V), defined by an iron oxide rim (i), containing quartz (q) and plagioclase (p) phenocrysts (ph). These fragments are generally recognized by their subrounded to rounded shape, phenocrysts, and greenish to brown color under plane light. They are almost completely opaque under crossed polars, except for the phenocrysts. Sample 1-2393-L6; plane light photomicrograph.

Most quartz phenocrysts exhibit straight extinction and are slightly to moderately embayed. In some fragments they are shattered. Feldspar phenocrysts are generally small plagioclase laths or larger, sub- to euhedral plagioclase crystals, some of which are zoned. Opaque mineral phenocrysts are euhedral and generally very small.

Volcanic rock fragments display a wide range of alteration effects from fresh to heavily altered (Fig. 25). Samples may contain either unaltered or altered volcanic fragments, or a combination of the two. Common alterations include iron oxide rinds and/or varying degrees of replacement by iron oxide, calcite or chlorite (Fig. 21).

Rounded to well-rounded chert fragments account for an average of 15.2% of West Foreland Formation and 9.7% of the Hemlock Conglomerate (Fig. 20). In a few samples, chert grains comprise as much as 30% of the total detrital fraction. The relative proportion of chert grains tends to increase with decreasing volcanic rock fragment content.

Chert grains exhibiting a distinct foliation and crenulated intercrystalline boundaries account for 2.3% of the West Foreland Formation and 1.4% of the Hemlock Conglomerate. These grains are inferred to be metamorphic rock fragments.

Some chert grains have fractures that are filled with microcrystalline quartz which is usually coarser-crystalline than the chert itself. The majority of the chert fragments are unaltered, however, slight to moderate replacement by calcite is not uncommon. Rarely chert grains contain minor amounts of authigenic pyrite.

Subrounded metamorphic rock fragments (not including foliated chert grains) average 2.7% of the West Foreland Formation and 1.8% of the Hemlock Conglomerate. Several samples contain over 10% of these fragments. They are distinctly foliated, and are composed of microcrystalline quartz with interstitial phyllosilicate crystals aligned with the foliation.

Subangular to subrounded plutonic rock fragments were only observed in a few samples, and comprise less than 0.3% of both formations. They are composed of quartz and plagioclase and/or microcline crystals.

Diagenetic Components and Alterations

Both the West Foreland Formation and the Hemlock Conglomerate exhibit the same diagenetic features. Features observed in thin section include compaction, grain coats and rims, authigenic cements, replacement and alteration of framework grains, dissolution of framework grains and cements, and development of secondary porosity. The wide range of isolated and combined diagenetic features observed in thin section indicates regional heterogeneity in diagenetic alteration.

Compaction

The degree of compaction varies greatly from sample to sample, and is inferred to be a function of the timing of initial cementation. In some samples, framework grains float in interstitial cement, indicating cementation prior to significant compaction. Other cemented samples exhibit one or more compactional features including: ductily deformed volcanic rock fragments (Figs. 26 and 24); bent or broken muscovite (Fig. 22) and/or chlorite (replaced biotite?) grains; fractured framework grains (Fig. 19); and intrusion of rigid grains into more ductile grains, such as quartz grains into volcanic rock fragments.

Grain Coats and Rims

Thin, opaque iron oxide grain coats (Figs. 24 and 27) are common, especially in volcanic-rich samples. Phyllosilicate grain coats (crystals tangential to grain surfaces) and rims (crystals perpendicular to grain surfaces) are found in samples of varying composition (Figs. 20 and 26).

Cements

Calcite, recognized by its high, pastel birefringence and relatively high relief (Fig. 20), is the most abundant cement, averaging 52% of the cement fraction of the West Foreland Formation and 50% of the Hemlock Conglomerate. It occurs with a microcrystalline, or less frequently poikilotopic (Fig. 28), texture, with the latter being more common in relatively fine-grained samples. In some samples

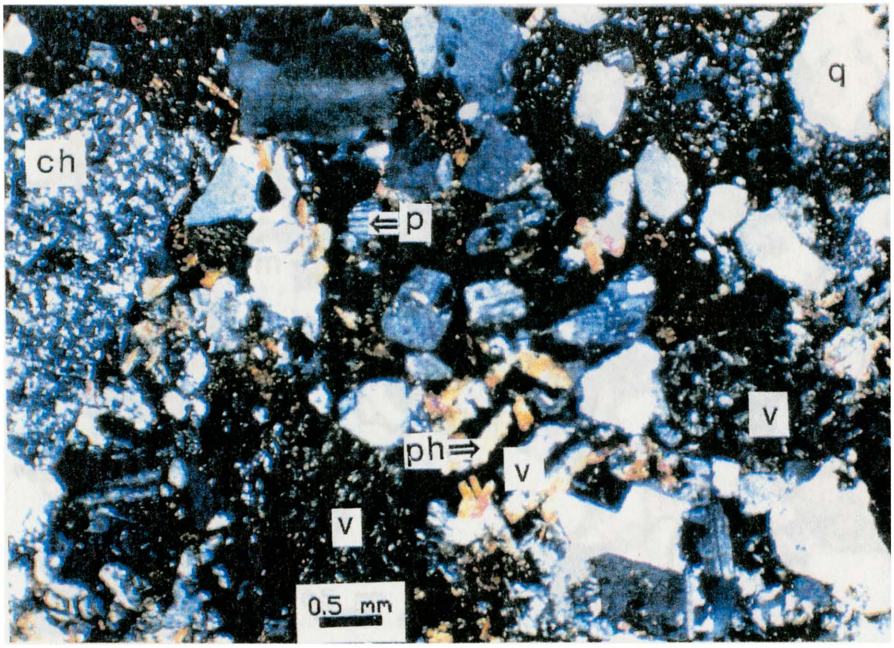


Fig. 25. Phenocrysts in volcanic rock fragments show a wide range of alteration effects within and between samples. The volcanic rock fragment in the center of the photograph shows more severely altered plagioclase phenocrysts (orange, red and yellow laths) than the fragments in the right and upper right (white phenocrysts). Sample 4-662-L11; photomicrograph under crossed polars.

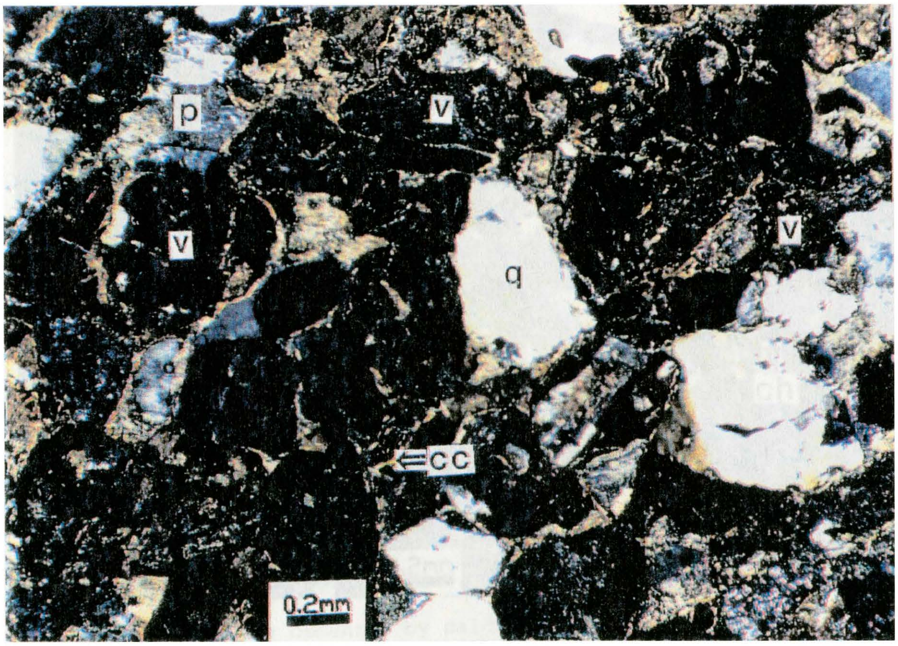


Fig. 26. Volcanic rock fragments which have been slightly to moderately deformed by compaction. Clay coats surround the volcanic fragments, indicating that they formed before the fragments were compacted together. The introduction of calcite cement halted any further compactional effects. Sample 1-569-L1; photomicrograph under crossed polars.

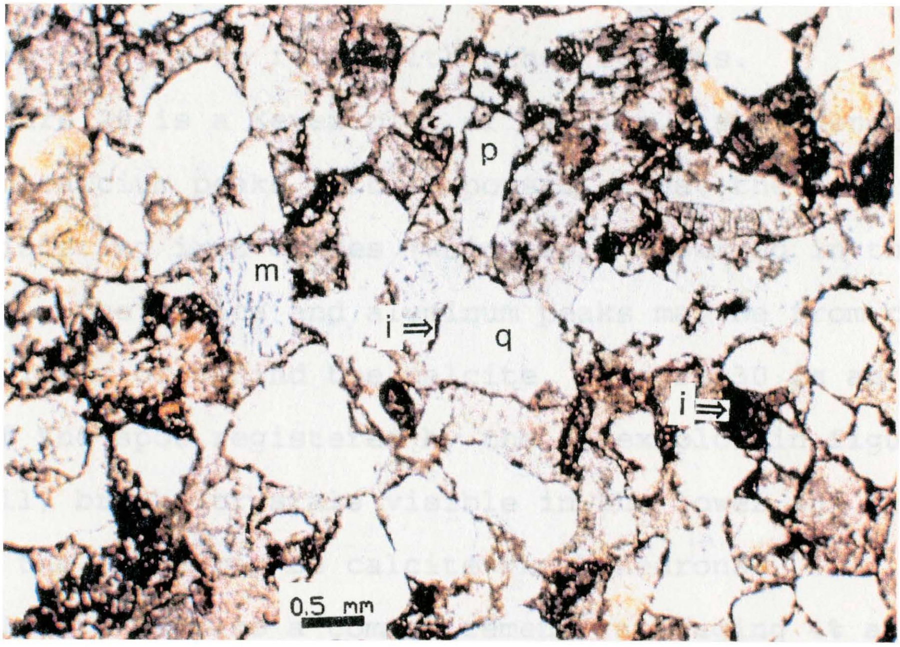


Fig. 27. Pervasive iron oxide rims (i) in a sample composed dominantly of quartz, chert and rare metamorphic rock fragments (m). Iron oxide also fills pores. Sample 1-980-L8; plane light photomicrograph.

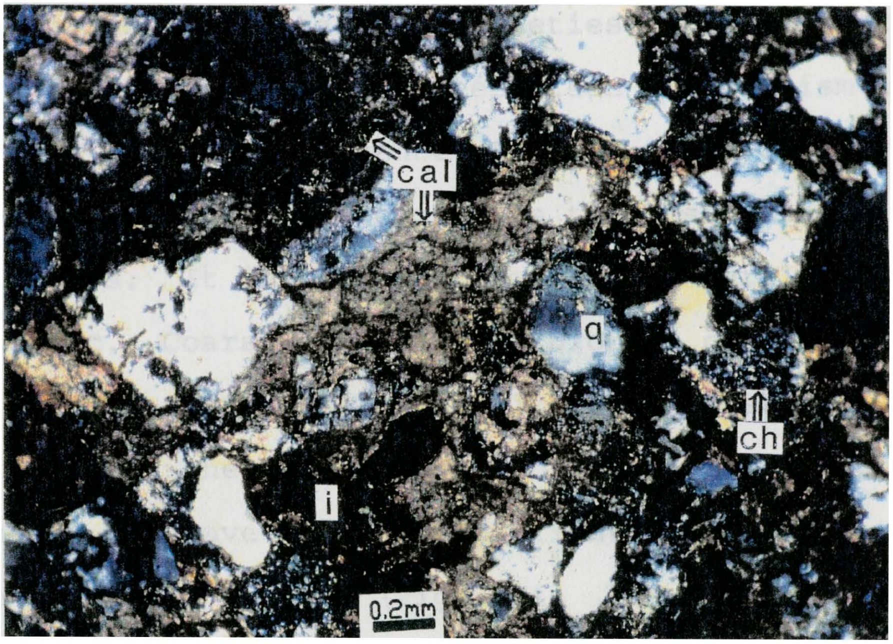


Fig. 28. A sample cemented by calcite which exhibits a poikilotopic texture. The cement in the upper left of the photograph is near extinction, but the cement in the center is not. Dark, brownish patches are pockets of iron oxide cement (i). Sample 1-1210-L15; photomicrograph under crossed polars.

calcite completely occludes all primary pore space, whereas in others calcite is found with other cements.

Figure 29 is a Kevex plot of calcite, as evidence by the high calcium peaks. It is possible that the iron peaks are registering iron oxides (which were observed in thin section). The silica and aluminum peaks may be from clays either within or behind the calcite. Figure 30 is an SEM image of the spot registered by the Kevex plot in figure 29. The small, bright crystals visible in the lower and center left of the image may be calcite rhombohedrons.

Chlorite is also a common cement, averaging 4% and 10% of the total cement fraction of the West Foreland Formation and Hemlock Conglomerate, respectively. It occurs in both coarse- and micro-crystalline varieties. Both varieties are recognized by characteristic deep green pleochroism and high, ultra-blue birefringence (Scholle, 1979). Microcrystalline chlorite cement is the less abundant of the two varieties. It is pore-filling, and is rarely poikilotopic. Coarse-crystalline chlorite cement (Figs. 31 and 32) occurs as fibrous or small bladed crystals. These crystals grow either radially off of framework grains into pore spaces, or have more random orientations and appear to intrude into pore throats (Fig. 33). The microcrystalline chlorite commonly fills pore spaces not completely filled by the radial, coarser-crystalline chlorite.

Figure 34 is a Kevex plot of chlorite, characterized by the high iron peaks and pronounced magnesium, aluminum and

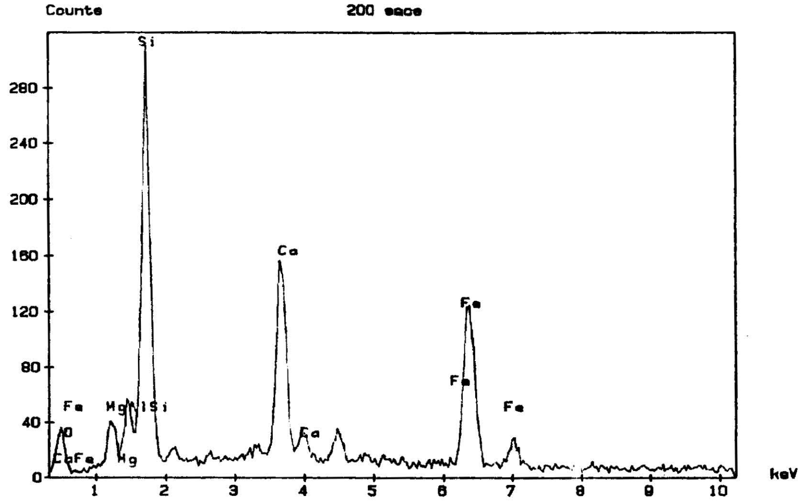


Fig. 29. Elemental x-ray plot from a scanning electron microscope of a dominantly calcite cemented sample (known from petrographic analysis), indicated by the high calcium peaks. The high iron peak may be due to the presence of iron oxides in the sample. Silica and aluminum peaks may indicate clays within or behind the calcite cement. Sample is from 1,553 feet of the Cape Nukshak section.

Fig. 30. SEM image of the spot analyzed in figure 30. The small, bright crystals in the lower left and center left may be calcite rombohedrons.

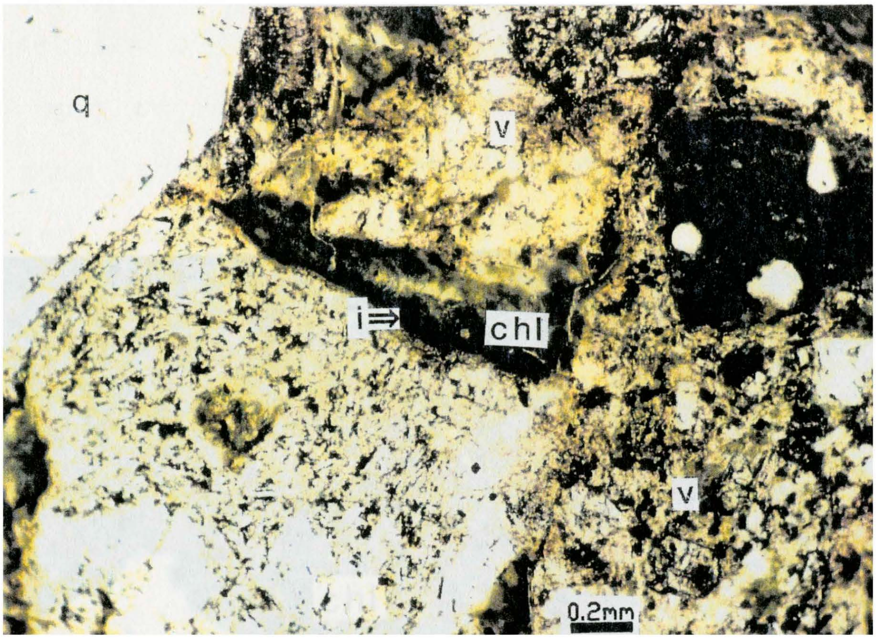


Fig. 31. Radially pore-filling chlorite cement (chl). Note that the cement uses an iron oxide grain coat (opaque brown; bottom of pore) as a substrate. Crystalline green patches in the lower right are chlorite crystals replacing the groundmass of a volcanic rock fragment. Sample 1-1752-L5; plane light photomicrograph.

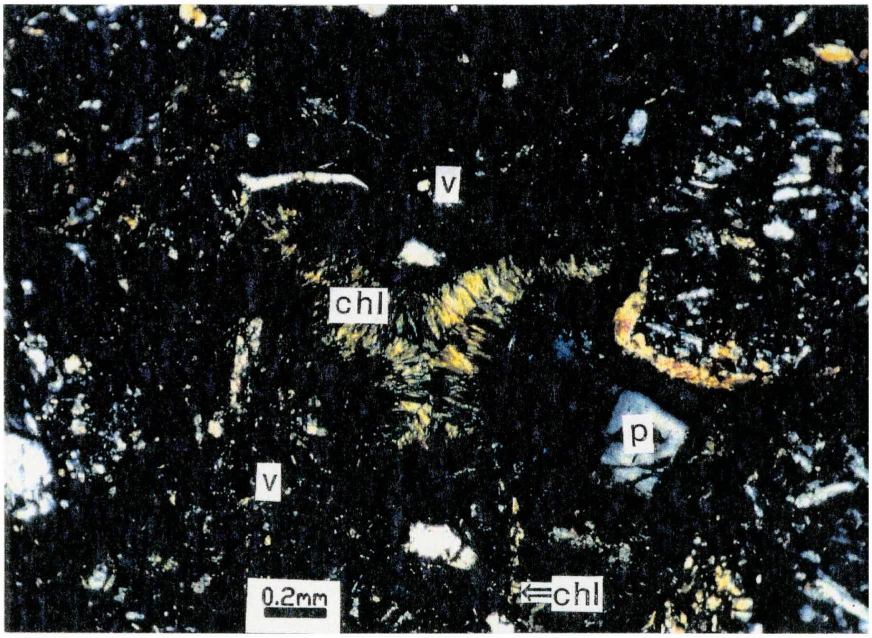


Fig. 32. Radially pore-filling chlorite cement. Chlorite cement is characterized by its yellow, green and "ultra-blue" birefringence (Scholle, 1986). Note the tiny chlorite crystals between volcanic rock fragments in the bottom center of the photograph. This sample is composed almost exclusively of volcanic rock fragments. Sample 1-1752-L5; photomicrograph under crossed polars.

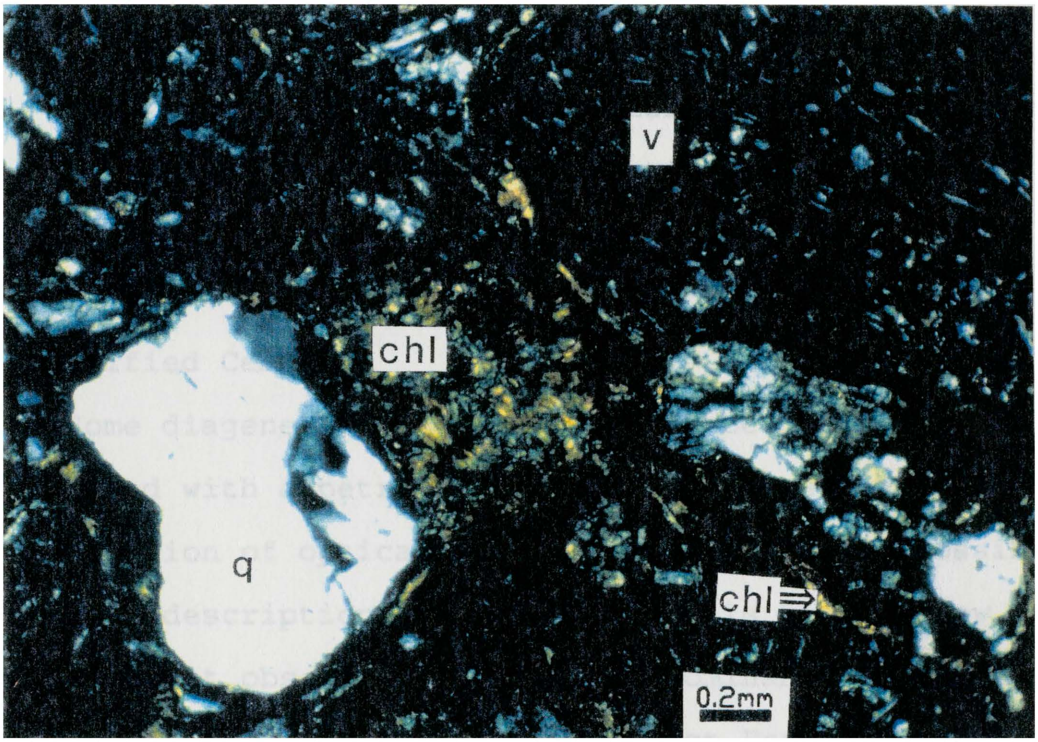


Fig. 33. Pore-filling chlorite with a less organized habit than the radial chlorite. Some small aggregates seem to form "booklets". Note that the chlorite invades even very narrow pore throats. Sample 1-1752-L5; photomicrograph under crossed polars.

silica peaks. The minor calcite peaks are possibly due to the detection of calcite cement. Figure 35 is an SEM image of the spot registered in the Kevex plot in figure 34. It shows some loosely organized platelets, however, the radiating, pore-lining habit of chlorite seen in thin section was not observed in SEM images.

Iron oxide is present as a minor cement most commonly found in volcanic-rich samples. It is brown to black, opaque, and has a grainy appearance.

Unidentified Cements

Some diagenetic cements could not be positively identified with a petrographic microscope because determination of optical characteristics was not possible. A general description of these cements is given below.

A cement observed in a single, dominantly calcite cemented sample (Fig. 36) from the West Foreland Formation, accounts for only 5% of the total cements in the sample. It exhibits very high birefringence, and is found growing radially into isolated pore spaces. Based on its high, pastel birefringence this cement is identified as calcite.

An unidentified cement is found as the sole cement in only two samples from the Hemlock Conglomerate. It is completely opaque in plane light and under crossed polars (Fig. 19), and exhibits mottled shades of gray under reflected light.

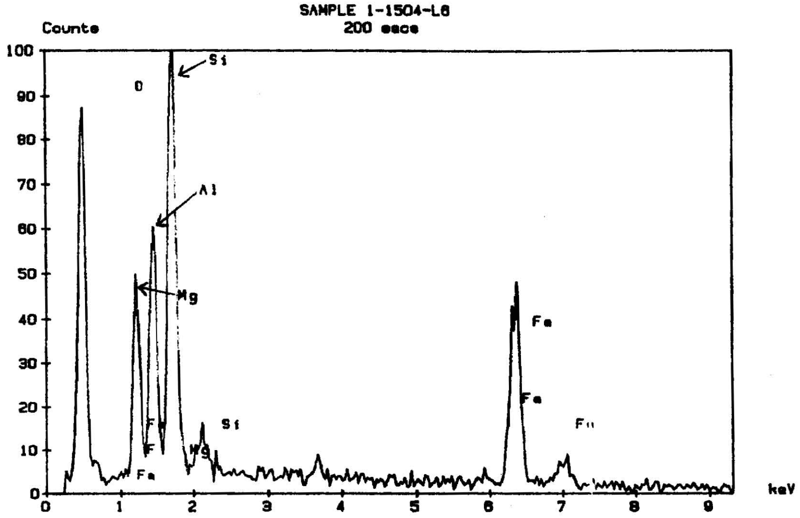


Fig. 34. Elemental x-ray plot from a scanning electron microscope of a dominantly chlorite cemented sample (known from petrographic anaysis), indicated by the high iron and pronounced magnesium and aluminum peaks. Sample is from 1,504 feet of the Cape Nukshak section.

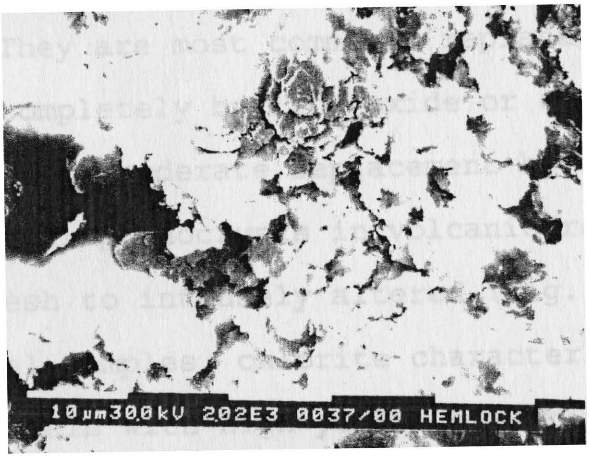


Fig. 35. SEM image of the spot analyzed in figure 34. Platelet-shaped crystals in the center and top center may be chlorite coating the surface of grains. Bright aggregates of platelets to the right resemble the "booklets" seen in the photomicrograph in figure 33.

Alteration and Replacement of Grains

The condition of feldspar grains in both formations ranges from fresh to heavily altered. Slight to moderate alterations of plagioclase grains are present in approximately a quarter of all such grains. Minor to heavy replacement of plagioclase by calcite or chlorite (Figs. 21,37,38 and 39) occurs in approximately 60% of the grains. Approximately 12% of the samples contain plagioclase and/or microcline that is replaced by an unknown mineral that is green in both plane light and under crossed polars (Fig. 40), and contains no recognizable internal structure or habit. These replaced grains are recognized as plagioclase and/or microcline only by the rare preservation of twins in the replacement mineral.

Volcanic rock fragments show a wide range of alteration. They are most commonly replaced either partially or completely by iron oxide or chlorite (Figs. 21 and 41). Minor to moderate replacement by calcite is less common. Feldspar phenocrysts in volcanic rock fragments range from fresh to intensely altered (Fig. 42).

In several samples, chlorite characterized by prismatic or bladed crystals with high yellow birefringence partially or completely replaces grains to the extent that they cannot be identified (Figs. 21, 38 and 43). The host mineral is replaced radially and/or concentrically.

Chert fragments commonly exhibit minor calcite replacement along intracrystalline boundaries (Fig. 44).

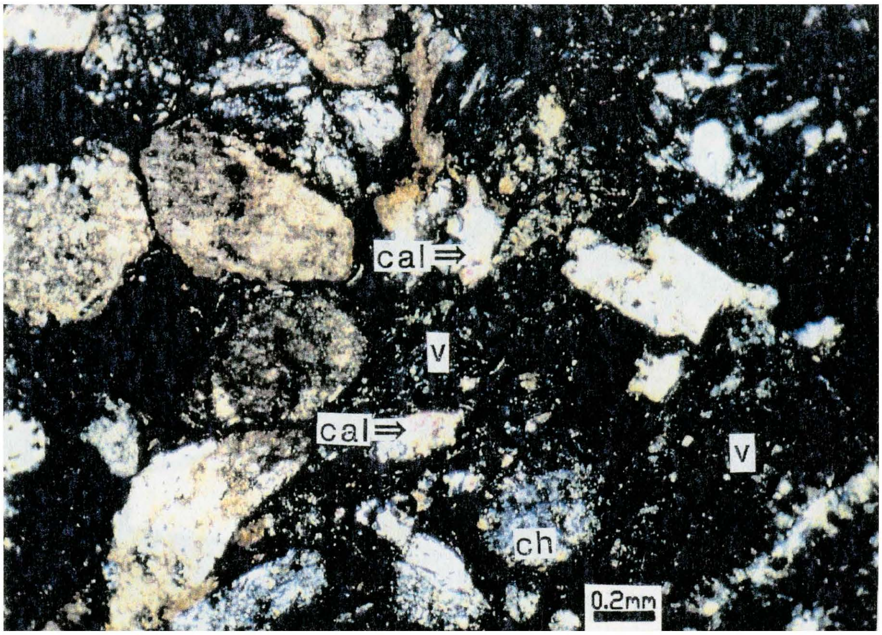


Fig. 36. Two isolated pores containing fibrous, radially pore-filling calcite cement. Primary pore space in this sample was occluded by a combination of compaction of volcanics and calcite cementation. It is inferred that the two pores exhibit a late stage of calcite pore-fill that filled either the last available primary pores or scarce secondary pores after initial pervasive calcite cementation. Note calcite replacement of volcanic fragments in the left of the photograph. Sample 3-3686-L21; photomicrograph under crossed polars.

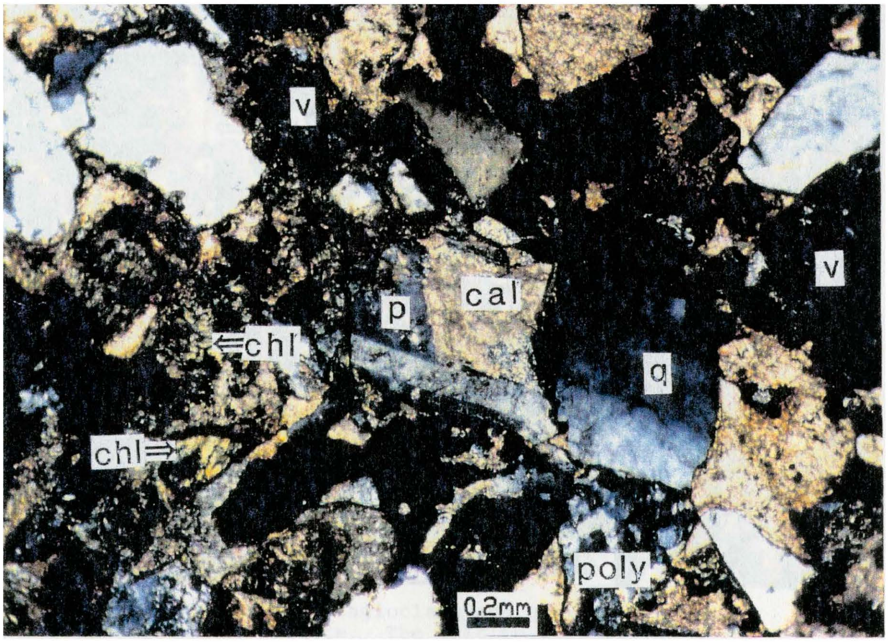


Fig. 37. Calcite replacement of a plagioclase grain (center). This sample contains pervasive iron oxide grain coats, calcite cement and chlorite cement. Sample 1-661-L5; photomicrograph under crossed polars.

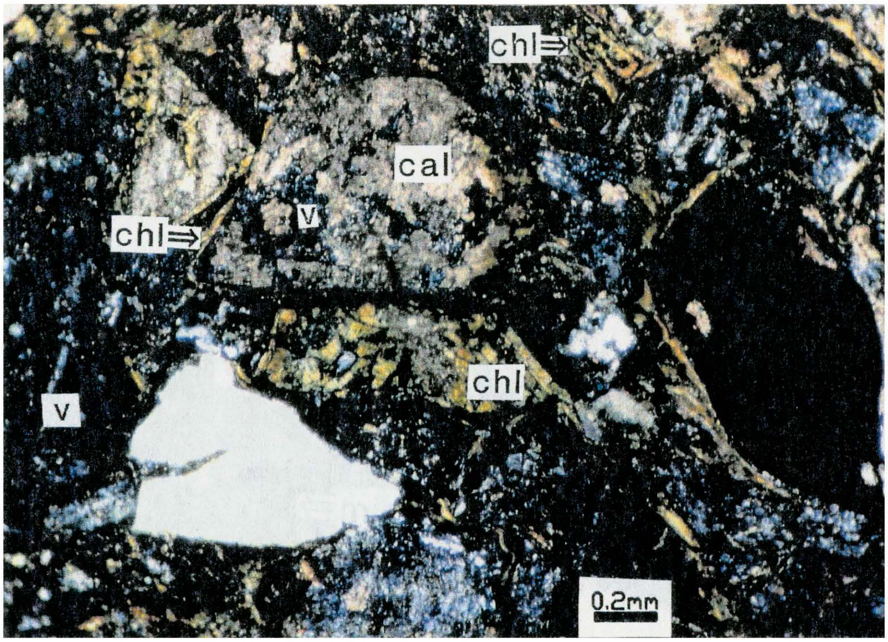


Fig. 38. Replacement of the center (elongate) grain by calcite and chlorite. The grain may originally have been plagioclase (based on relic morphology). Above the elongate grain is a chert grain almost completely replaced by calcite (cal). Note the chlorite grain coats. Sample 2-357-L4; photomicrograph under crossed polars.

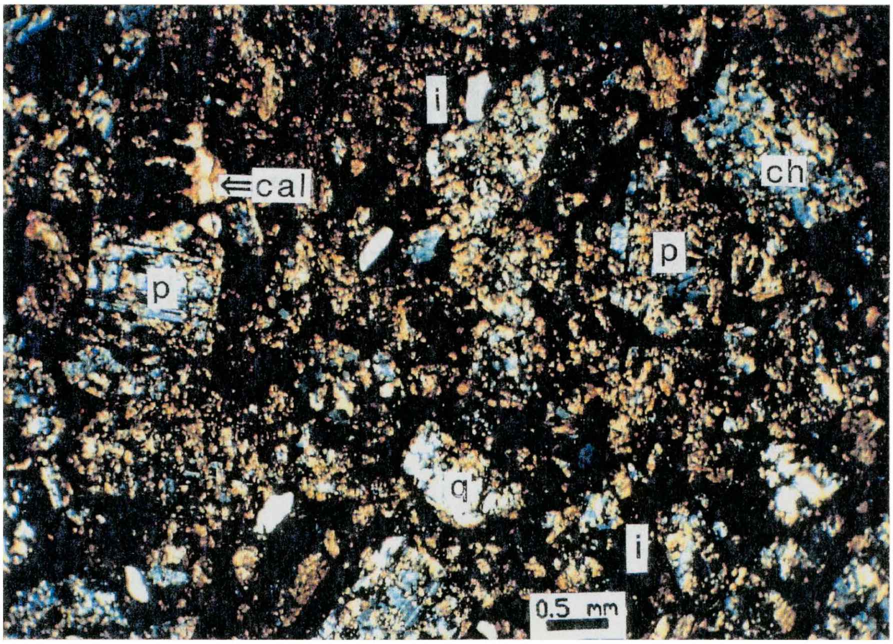


Fig. 39. Replacement of plagioclase and quartz framework grains by calcite. The calcite also replaces the iron oxide cement (opaque, brown to black). Sample 1-1225-L5; photomicrograph under crossed polars.

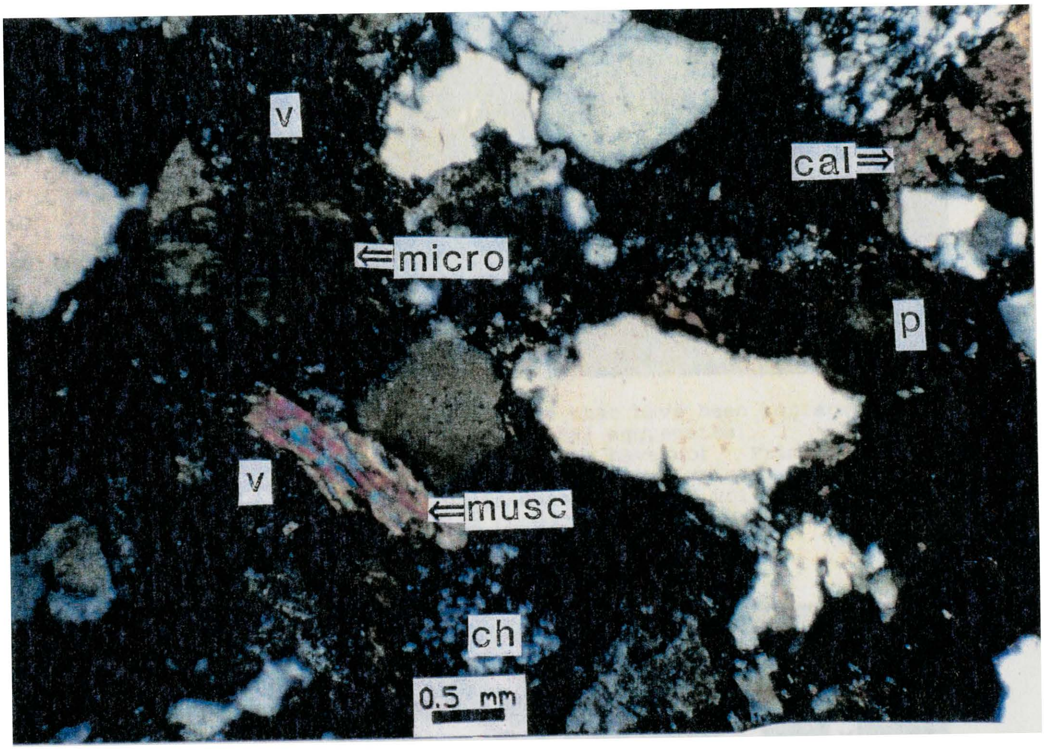


Fig. 40. A mineral, exhibiting pale green pleochroism and birefringence, replacing a microcline grain (micro). The grain is recognized as microcline only by the preservation of ghost twins. The same is true for plagioclase grains replaced by the same mineral. The replacement mineral contains no recognizable internal habit or structure. Sample 2-709-L1; photomicrograph under crossed polars.

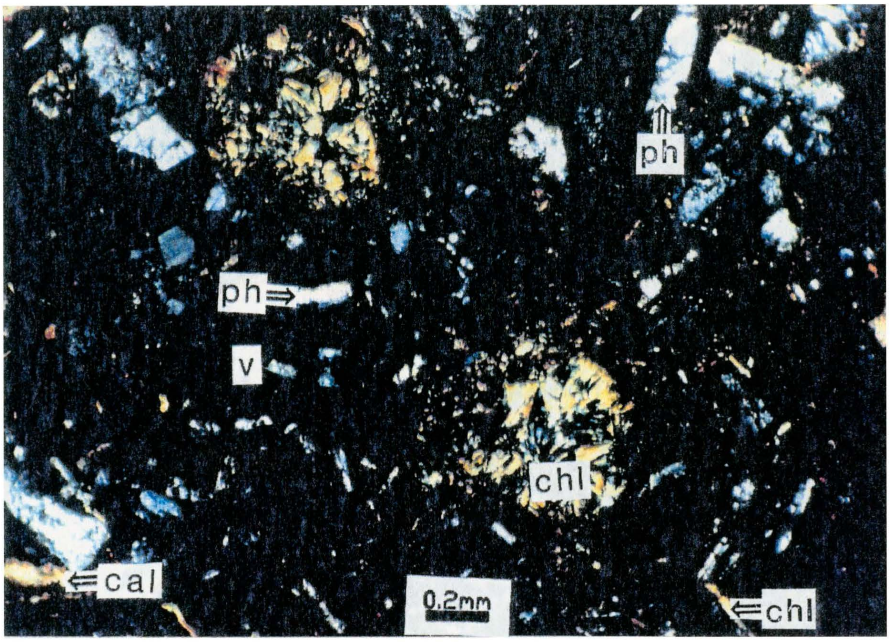


Fig. 41. Two volcanic rock fragments that have been replaced by chlorite (yellowish crystal aggregates), although surrounding fragments have not. Primary porosity in this sample was almost completely occluded by the ductile deformation of volcanic rock fragments during compaction. Sample 1-1386-L1; photomicrograph under crossed polars.

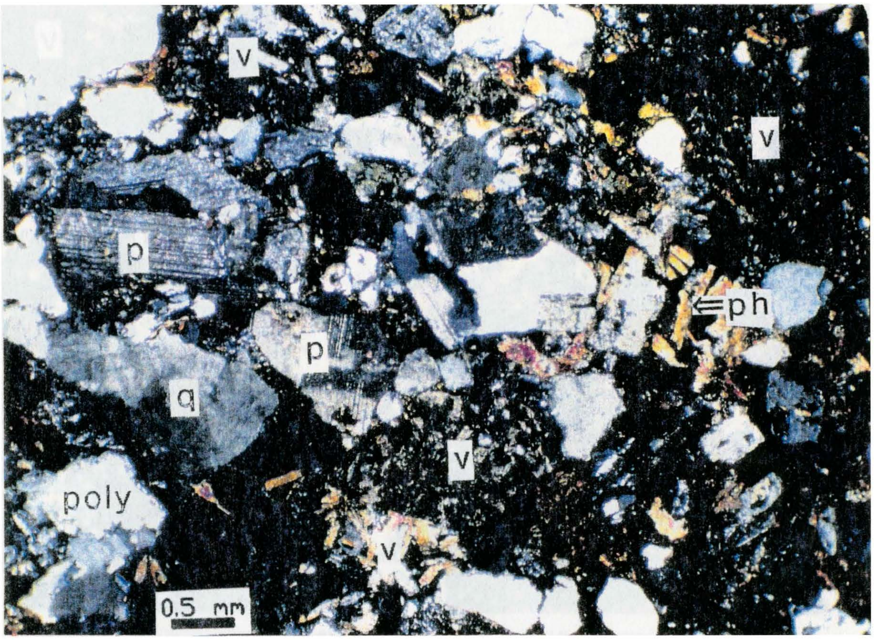


Fig. 42. Altered phenocrysts (ph) in a volcanic rock fragment. Phenocrysts in other volcanic fragments (top left and right) are unaltered. Plagioclase grains (left; twinned) are barely altered. Sample 4-662-L11; photomicrograph under crossed polars.

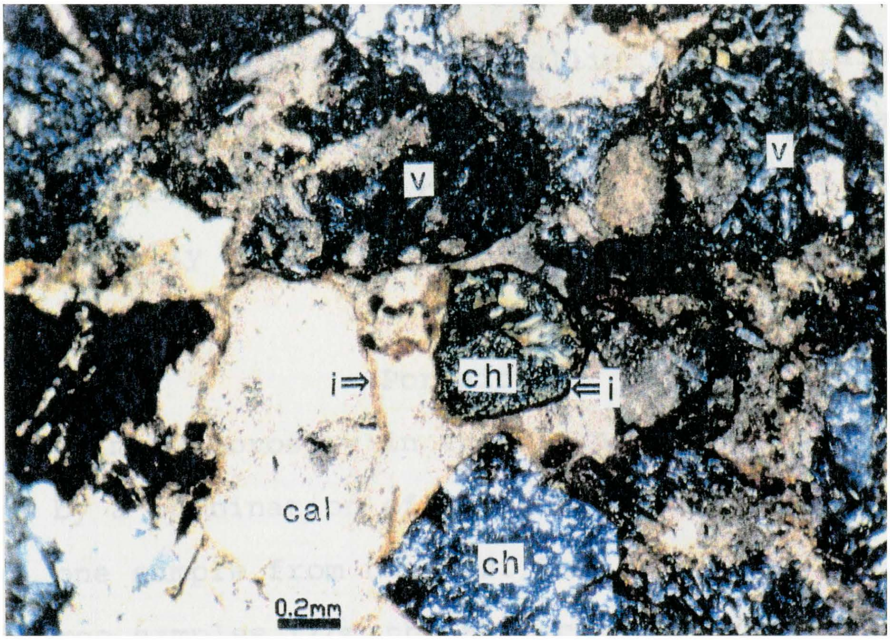


Fig. 43. The center grain is unidentifiable due to complete replacement by chlorite (chl). Iron oxide rims preserve the outline of grains completely replaced by calcite (left of center). Calcite partially replaces volcanic rock fragments (upper center and upper right). Sample 1-615-L3; photomicrograph under crossed polars.

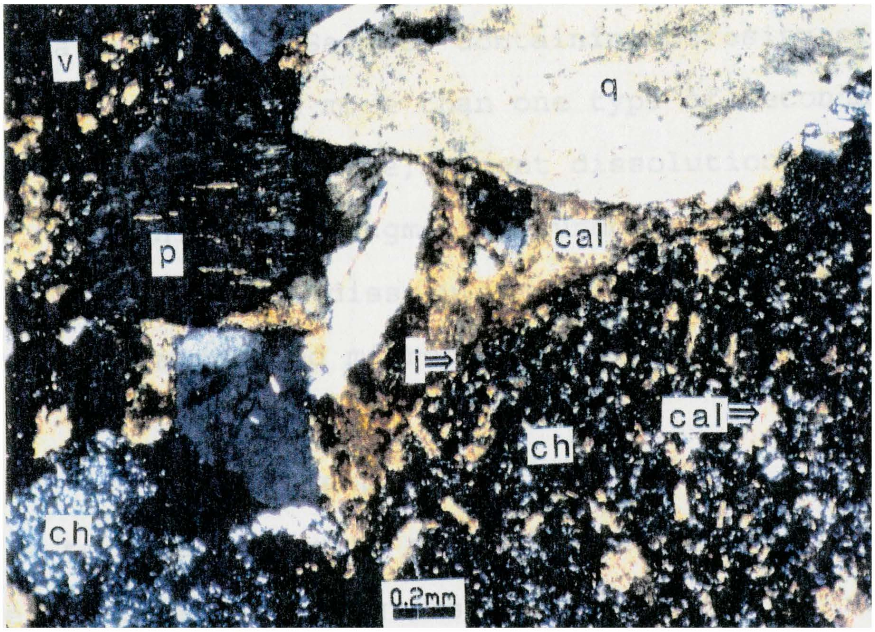


Fig. 44. Minor replacement of a chert grain by calcite (lower right). Note the iron oxide coating on the chert grain. All pore space in this sample is occluded by calcite cement. Sample 1-1040-L9; photomicrograph under crossed polars.

This generally occurs in relatively larger chert grains.

Monocrystalline and polycrystalline quartz grains are generally unaltered. In approximately 20% of the grains, however, slight to moderate replacement by calcite was observed, usually around grain borders.

Porosity

All primary porosity in these sandstones has been occluded by a combination of compaction and cementation. However, one sample from the West Foreland Formation and twenty-three samples from the Hemlock Conglomerate exhibit small amounts of several types of secondary porosity (Table 4). Most samples exhibit between 1% and 5% porosity, with a maximum observed porosity of 10% in one Hemlock Conglomerate sample. Samples containing porosity of 3% or more generally exhibit more than one type of secondary porosity, which may include; cement dissolution (Figs. 45 and 46), volcanic rock fragment groundmass and/or plagioclase phenocryst dissolution (Fig. 47), dissolution of plagioclase grains, and microfractures (Fig. 48).

Textural Maturity

The textural maturity of sandstones in thin section may be determined using a progressive classification (after Folk, 1980) which employs the following criterion; detrital clay/matrix content, sorting, and roundness of quartz grains. Samples containing a minimum of 5% clay/matrix are

Table 4. Samples which exhibit secondary porosity. Observed porosity is created by dissolution of calcite, chlorite, volcanic fragments and plagioclase grains and by microfractures. Sample 3-3161-L3 is from the West Foreland Formation, the rest are from the Hemlock Conglomerate.

	POROSITY TYPE(S)					
SAMPLE NUMBER	DISSOLUTION				MICRO-FRACS.	VISUAL POROSIT
	CALC.	CHLOR.	VOLCS.	PLAG.		
1-1386-L1	yes	—	—	—	yes	3%
1-1463-L1	—	yes	—	—	yes	3%
1-2393-L6	—	—	—	—	yes	2%
1-2541-L1	—	—	yes	—	—	1%
2-4-L1	yes	—	—	—	yes	3%
2-130-L2A	yes	—	—	—	—	4%
2-417-L1	—	—	yes	—	—	2%
2-481-L3	yes	yes	—	—	—	4%
2-582-L4	yes	—	—	—	—	<1%
2-662-L5	yes	yes	—	—	—	<1%
3-3161-L3	—	—	yes	—	—	<1%
4-245-L14	yes	—	yes	yes	—	5%
4-269-L16	yes	—	—	—	—	1%
4-283-L18	yes	—	yes	—	—	3%
4-326-L20	yes	—	yes	yes	—	10%
4-350-L21	yes	—	yes	—	—	3%
4-379-L22	yes	—	—	—	—	<1%
4-414-L6	yes	—	—	—	—	<1%
4-424-L23	yes	—	—	—	—	3%
4-428-L24	yes	—	—	—	—	<1%
4-487-L25	yes	—	yes	—	—	3%
4-523-L7	—	—	yes	yes	—	8%
4-645-L10	yes	—	—	—	—	1%
4-684-L12	—	—	yes	—	—	1%

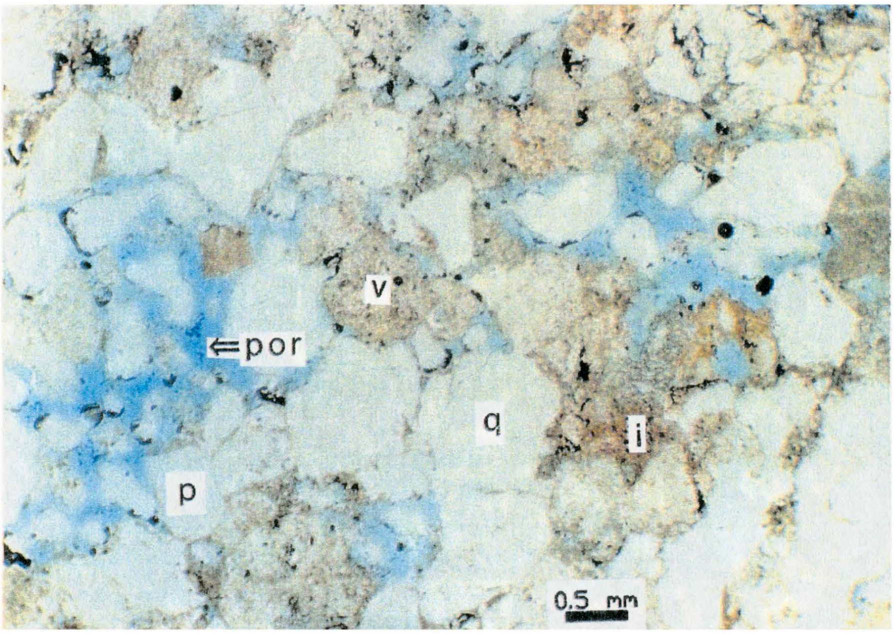


Fig. 45. Porosity (por; light blue) created by cement dissolution. The low ratio of volcanic rock fragments to more rigid grains (quartz, chert) allowed for preservation of primary pore space during compaction, which was subsequently filled with authigenic cement(s) (calcite is observed). This sample has the highest visual porosity of all the samples from both formations. Sample 4-326-L20; plane light photomicrograph.

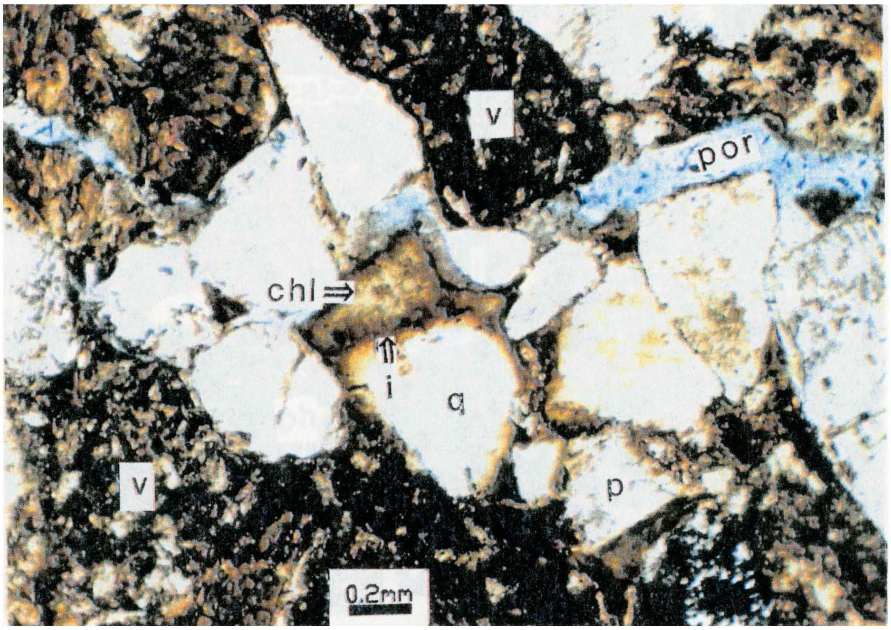


Fig. 46. Porosity (por) created by cement dissolution. Porosity in the upper left is due to a microfracture passing through a volcanic rock fragment. Note that dissolution pores do not pass through detrital grains like microfractures. Sample 2-481-L3; plane light photomicrograph.

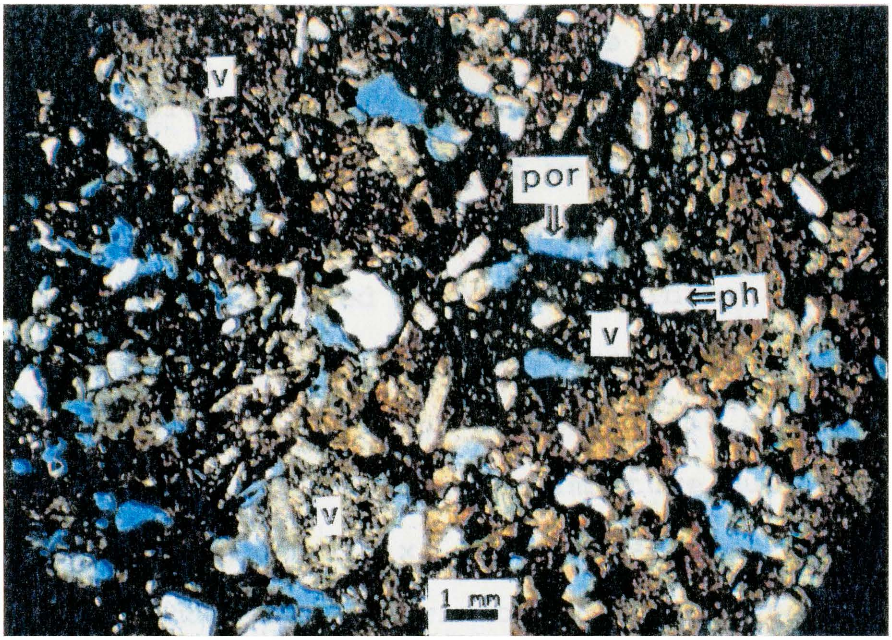


Fig. 47. Porosity created by the dissolution of volcanic rock fragment groundmass and plagioclase phenocrysts. Sample 4-523-17; plane light photomicrograph.

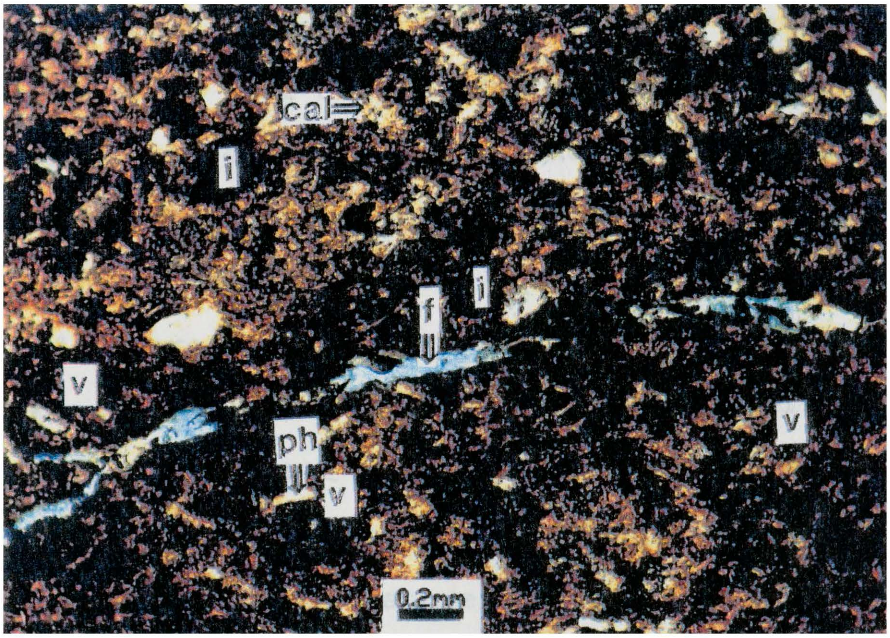


Fig. 48. Porosity created by a microfracture (f) passing through volcanic rock fragments and iron oxide cement. Sample 1-2393-16; plane light photomicrograph.

classified as immature. The remaining classifications are applicable only to samples containing less than 5% clay/matrix. Samples that are at best moderately sorted are submature. Samples that are at least well sorted and contain quartz grains that are predominantly subangular at best are mature. Well sorted samples containing predominantly subrounded quartz grains are supermature.

None of the samples from the stratigraphic sections in Katmai National Park were found to be immature due to the absence of detrital clay/matrix. Several samples from pyroclastic units contain a matrix of glass and/or pumice microlites, however, the textures of such lithologies are not considered in this study.

The majority of samples from the West Foreland Formation are texturally submature (Table 5). Two-thirds of the samples from the Cape Douglas Section are submature, although a single supermature sample and several mature samples are dispersed throughout the section. The lower Kuliak Bay Section contains almost equal amounts of submature and mature samples.

The Hemlock Conglomerate shows a greater diversity of textures (Table 6) than the West Foreland Formation. The Cape Nukshak Section contains an equal amount of submature and mature, and lesser supermature, samples. The Kinak Bay Section contains roughly equal numbers of submature, mature and supermature samples. The upper Kuliak Bay Section contains an almost even combination of submature and mature

Table 5. Textural maturity (after Folk, 1980) of samples from the West Foreland Formation.

Cape Douglas Section		Lower Kuliak Bay Section	
SAMPLE #	MATURITY	SAMPLE #	MATURITY
3-75-L3	mature	4-0-L1	pyroclastic
3-90-L2	mature	4-67-L1	mature
3-130-L1	submature	4-83-L2	submature
3-3034-L1	submature	4-138-L3	mature
3-3119-L2	submature	4-138-L3A	mature
3-3161-L3	submature	4-163-L4	submature
3-3172-L4	submature	4-165-L13	mature
3-3200-L5	mature	4-170-L5	submature
3-3280-L6	submature		
3-3323-L9	submature		
3-3350-L10	submature		
3-3388-L10	submature		
3-3391-L8	submature		
3-3407-L11	submature		
3-3435-L13	mature		
3-3458-L14	submature		
3-3523-L15	submature		
3-3553-L1	mature		
3-3564-L17	submature		
3-3618-L18	submature		
3-3639-L19	submature		
3-3663-L20	submature		
3-3686-L21	submature		
3-3911-L22	mature		
3-3927-L23	supermature		
3-3963-L24	mature		
3-3995-L25	mature		

Table 6. Textural maturity (after Folk, 1980) of samples from the Hemlock Conglomerate.

Cape Nukshak Section

SAMPLE #	MATURITY	SAMPLE #	MATURITY
1-569-L1	mature	1-1463-L1	mature
1-576-L2	mature	1-1472-L5	submature
1-615-L3	submature	1-1474-L2	submature
1-623-L4	supermature	1-1504-L6	supermature
1-661-L5	mature	1-1551-L3	supermature
1-715-L6	submature	1-1660-L4	mature
1-826-L7	submature	1-1752-L5	supermature
1-980-L8	submature	1-1892-L8	mature
1-1040-L9	submature	1-1921-L9	supermature
1-1049-L10	submature	1-2010-L10	submature
1-1064-L11	submature	1-2377-L14	submature
1-1073-L16	submature	1-2393-L6	mature
1-1100-L12	supermature	1-2396-L7	mature
1-1190-L13	supermature	1-2453-L11	pyroclastic
1-1210-L15	mature	1-2500-L12	pyroclastic
1-1297-L3	mature	1-2541-L13	mature
1-1328-L2	submature	1-2593-L1	pyroclastic
1-1386-L1	supermature	1-2696-L2	mature
1-1442-L4	supermature	1-2735-L3	mature

Table 6. (Continued)

Kinak Bay Section		Upper Kuliak Bay Section	
SAMPLE #	MATURITY	SAMPLE #	MATURITY
2-4-L1	supermature	4-245-L14	mature
2-17-L2	supermature	4-260-L15	submature
2-130-L2A	supermature	4-269-L16	submature
2-268-L3	submature	4-271-L17	mature
2-357-L4	supermature	4-283-L18	submature
2-417-L1	mature	4-300-L19	mature
2-462-L2	mature	4-326-L20	submature
2-481-L3	mature	4-350-L21	mature
2-582-L4	mature	4-379-L22	mature
2-662-L5	mature	4-414-L6	submature
2-674-L2	submature	4-424-L23	mature
2-709-L1	submature	4-428-L24	submature
		4-487-L25	mature
		4-523-L7	mature
		4-593-L8	mature
		4-633-L9	submature
		4-645-L10	submature
		4-662-L11	submature
		4-684-L12	mature

samples.

In general, the textures of sandstones from both formations in this study can change markedly over short stratigraphic distances. Frequent changes in the degree of sorting and subtle changes in the overall roundness of quartz grains allow for non-systematic changes in textural classifications throughout the sections.

Grain Size Measurements

Mean quartz grain size was determined for ten samples from the West Foreland Formation (Table 7) and forty-two samples from the Hemlock Conglomerate (Table 8). For each sample the mean was calculated from the apparent long axis diameters of forty quartz grains (technique after Griffiths, 1967).

Samples utilized for grain size measurements required a minimum of forty quartz grains to be identified during linear traverses designed to cover the majority of the thin section. Detrital quartz grains also had to be readily differentiated from volcanic quartz phenocrysts. Quartz grains were measured using a microscope's ocular scale calibrated with a thin section micrometer scale.

Mean quartz grain sizes for the West Foreland Formation and the Hemlock Conglomerate range from 0.10 to 0.38 mm and 0.09 to 0.48 mm, respectively. Standard deviations range from 0.04 to 0.15 in the West Foreland Formation and 0.04 to 0.42 in the Hemlock Conglomerate, with the high and low

Table 7. Mean quartz grain sizes of samples from the West Foreland Formation; AVG = average, STD = standard deviation. Size classes are after Wentworth, 1922.

Cape Douglas Section

SAMPLE #	AVG (MM)	STD	SIZE CLASS
3-75-L3	0.26	0.10	medium sand
3-3119-L2	0.27	0.08	medium sand
3-3172-L4	0.34	0.11	medium sand
3-3391-L8	0.38	0.15	medium sand
3-3435-L1	0.18	0.06	fine sand
3-3564-L1	0.18	0.10	fine sand
3-3686-L2	0.26	0.11	medium sand
3-3995-L2	0.22	0.10	fine sand

Lower Kuliak Bay Section

SAMPLE #	AVG (mm)	STD	SIZE CLASS
4-83-L2	0.10	0.04	very fine sand
4-170-L5	0.30	0.11	medium sand

Table 8. Mean quartz grain sizes of samples from the Hemlock conglomerate; AVG = average, STD = standard deviation. Size classes are agter Wentworth, 1922.

Cape Nukshak Section

SAMPLE #	AVG (mm)	STD	SIZE CLASS
1-569-L1	0.46	0.21	medium sand
1-576-L2	0.23	0.11	fine sand
1-615-L3	0.26	0.10	medium sand
1-623-L4	0.31	0.12	medium sand
1-661-L5	0.46	0.19	medium sand
1-715-L6	0.48	0.42	medium sand
1-826-L7	0.40	0.19	medium sand
1-980-L8	0.27	0.09	medium sand
1-1040-L9	0.46	0.20	medium sand
1-1049-L10	0.30	0.11	medium sand
1-1064-L11	0.51	0.25	coarse sand
1-1073-L16	0.44	0.15	medium sand
1-1100-L12	0.16	0.05	fine sand
1-1190-L13	0.39	0.20	medium sand
1-1191-L14	0.30	0.12	medium sand
1-1210-L15	0.32	0.13	medium sand
1-1225-L5	0.17	0.08	fine sand
1-1297-L3	0.23	0.11	fine sand
1-1328-L2	0.25	0.11	medium sand
1-1442-L4	0.09	0.04	very fine sand
1-1474-L2	0.43	0.35	medium sand
1-1553-L3	0.41	0.13	medium sand
1-1660-L4	0.15	0.06	fine sand
1-1752-L5	0.04	0.19	medium sand
1-1921-L9	0.25	0.07	medium sand
1-2735-L3	0.29	0.09	medium sand

Table 8. (Continued)

Kinak Bay Section

SAMPLE #	AVG (mm)	STD	SIZE CLASS
2-4-L1	0.23	0.11	fine sand
2-17-L2	0.37	0.14	medium sand
2-130-L2A	0.37	0.12	medium sand
2-268-L3	0.18	0.07	very fine sand
2-357-L4	0.30	0.09	medium sand
2-417-L1	0.22	0.06	fine sand
2-462-L2	0.29	0.07	medium sand
2-481-L3	0.27	0.08	medium sand
2-662-L5	0.34	0.10	medium sand
2-674-L2	0.21	0.09	fine sand
2-709-L1	0.46	0.30	medium sand

Upper Kuliak Bay Section

SAMPLE #	AVG (mm)	STD	SIZE CLASS
4-283-L18	0.21	0.07	fine sand
4-350-L21	0.30	0.10	medium sand
4-428-L24	0.14	0.15	fine sand
4-633-L9	0.12	0.14	very fine sand
4-684-L12	0.09	0.13	very fine sand

values corresponding to the high and low mean quartz grain sizes for each formation. However, standard deviations do not necessarily change incrementally with a change in mean quartz grain size.

CHAPTER VIII

SANDSTONE DETRITAL MODES

Sandstone Classification

Sandstones may be classified by combining categories of detrital components to create three end members which are normalized to 100%. End members used for classification in this section are after Dott, 1964, and include: 1) The sum of all monocrystalline and polycrystalline quartz grains (the Q end member); 2) the sum of all feldspar grains and plutonic rock fragments (the F end member); and 3) the sum of all chert grains and volcanic and metamorphic rock fragments (the L end member). By using three end members compositions may be plotted on ternary diagrams.

Average QFL compositions for the West Foreland Formation and the Hemlock Conglomerate in the study area, and for each measured section, are presented in Table 9. See Appendix II for the QFL compositions of individual samples.

West Foreland Formation

Thirty-one sandstones from the West Foreland Formation plot on a ternary diagram (Fig. 49) as lithic arenites due to their high proportion of total rock fragments.

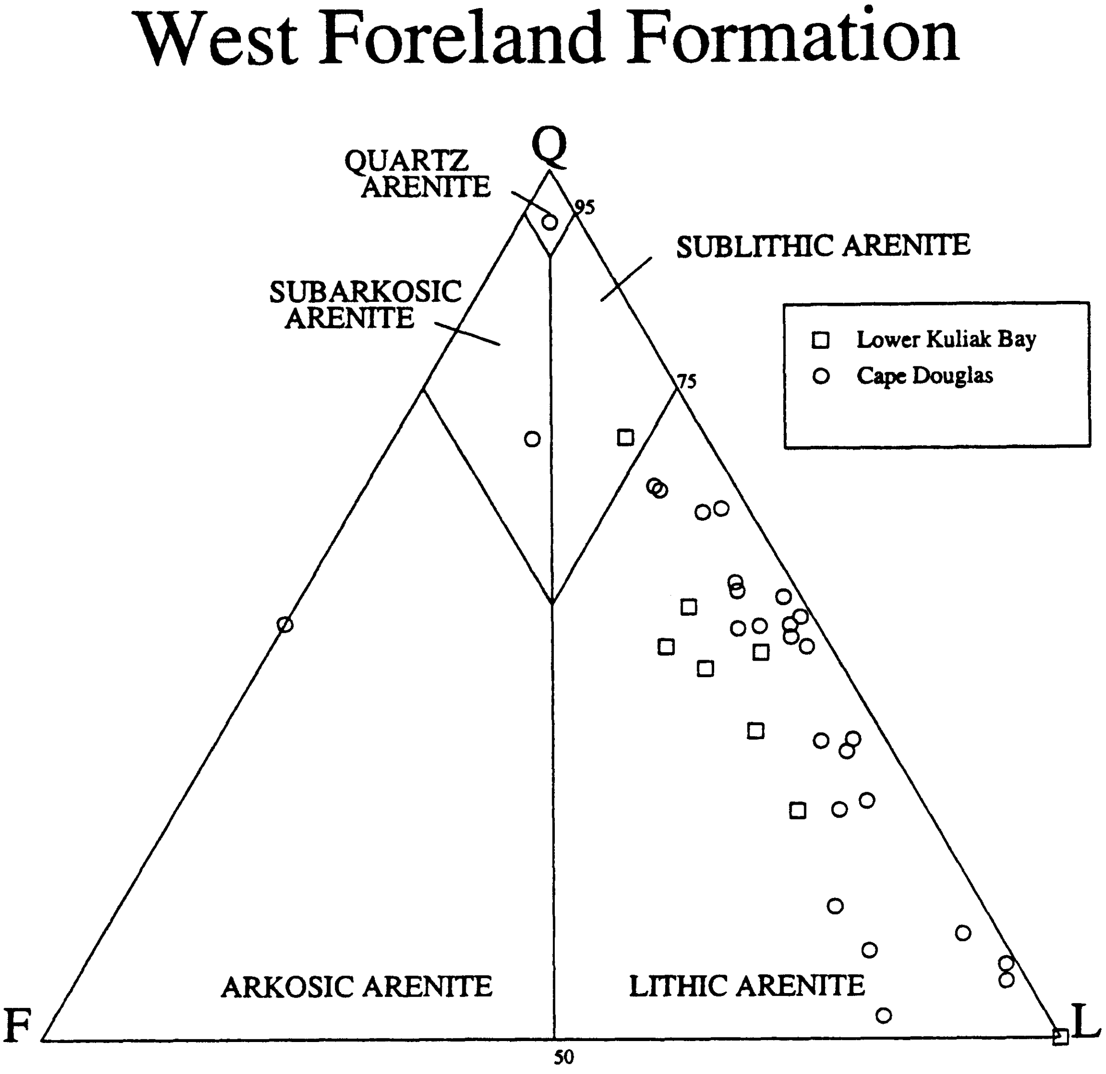


Fig. 49. Ternary diagram showing QFL compositions of sandstones from the West Foreland Formation (after Dott, 1964). The poles are: Q, monocrystalline and polycrystalline quartz grains; F, feldspar grains and plutonic lithic grains; and L, volcanic, metamorphic and chert lithic grains. The majority of samples plot as lithic arenites due to their high chert and/or volcanic rock fragment content. The sublithic arenite contains lesser amounts of volcanic rock fragments. The quartz arenite is almost void of rock fragments and contains rare polycrystalline quartz. The subarkosic sample is volcanic poor and contains quartz, chert and minor plagioclase. The arkosic arenite contains subequal amounts of quartz and plagioclase (zoned and unzoned). Diagram created by PLOTME software, Landsparger, in prep.

Table 9. Average QFL compositions (after Dott, 1964) of Tertiary sandstones in Katmai National Park by formation and by measured section (n = number of samples). The compositions of pyroclastic units identified in the sections are not included in the averages.

WEST FORELAND FORMATION (all samples)	**$Q_{43}F_{7}L_{50}$**
Cape Douglas Section (n=27)	$Q_{42}F_{6}L_{52}$
Lower Kuliak Bay Section (n=8)	$Q_{45}F_{11}L_{44}$
HEMLOCK CONGLOMERATE (all samples)	**$Q_{40}F_{12}L_{48}$**
Cape Nukshak Section (n=37)	$Q_{30}F_{13}L_{57}$
Kinak Bay Section (n=12)	$Q_{52}F_{12}L_{36}$
Upper Kuliak Bay Section (n=20)	$Q_{52}F_{10}L_{38}$

Differences in compositions within the lithic arenite field generally reflect variations in chert and volcanic rock fragment content, in which an increase in one commonly sees a decrease in the other. Twenty-four samples are from Cape Douglas, including six which contain high proportions of volcanic rock fragments. Seven are from Lower Kuliak Bay, including one sample which is composed solely of volcanic rock fragments.

The only sublithic arenite is from Lower Kuliak Bay. It contains more undulose monocrystalline quartz and polycrystalline quartz than the lithic arenites, and subequal amounts of volcanic and chert lithic grains.

A single quartz arenite is from Cape Douglas. It is composed almost exclusively of undulose monocrystalline quartz.

The only subarkosic arenite is also from Cape Douglas, and contains subequal amounts of quartz and plagioclase. Most of the quartz is monocrystalline undulose, and the plagioclase is split approximately 30%/70% between zoned and unzoned.

The Cape Douglas and Lower Kuliak Bay sections have similar average sandstone compositions of $Q_{42}F_6L_{52}$ and $Q_{45}F_{11}L_{44}$, respectively. Cape Douglas sandstones contain a higher percentage of total rock fragments, commonly due to increased amounts of volcanic rock fragments. They are also slightly less quartzose than Kinak Bay sandstones.

Hemlock Conglomerate

Fifty-nine Hemlock Conglomerate sandstones plot on a ternary diagram (Fig. 50) as lithic arenites. Variations in compositions within the lithic arenite field are generally due to differences in volcanic rock fragment content. Thirty samples are from Cape Nukshak, including seventeen which contain the highest proportions of volcanic rock fragments. Eighteen samples from Upper Kuliak Bay and twelve from Kinak Bay are primarily composed of varying amounts of undulose monocrystalline quartz and volcanic and chert lithic grains.

The only sublithic arenite is from Cape Nukshak. It is composed of undulose monocrystalline quartz with significantly lesser amounts of polycrystalline quartz and

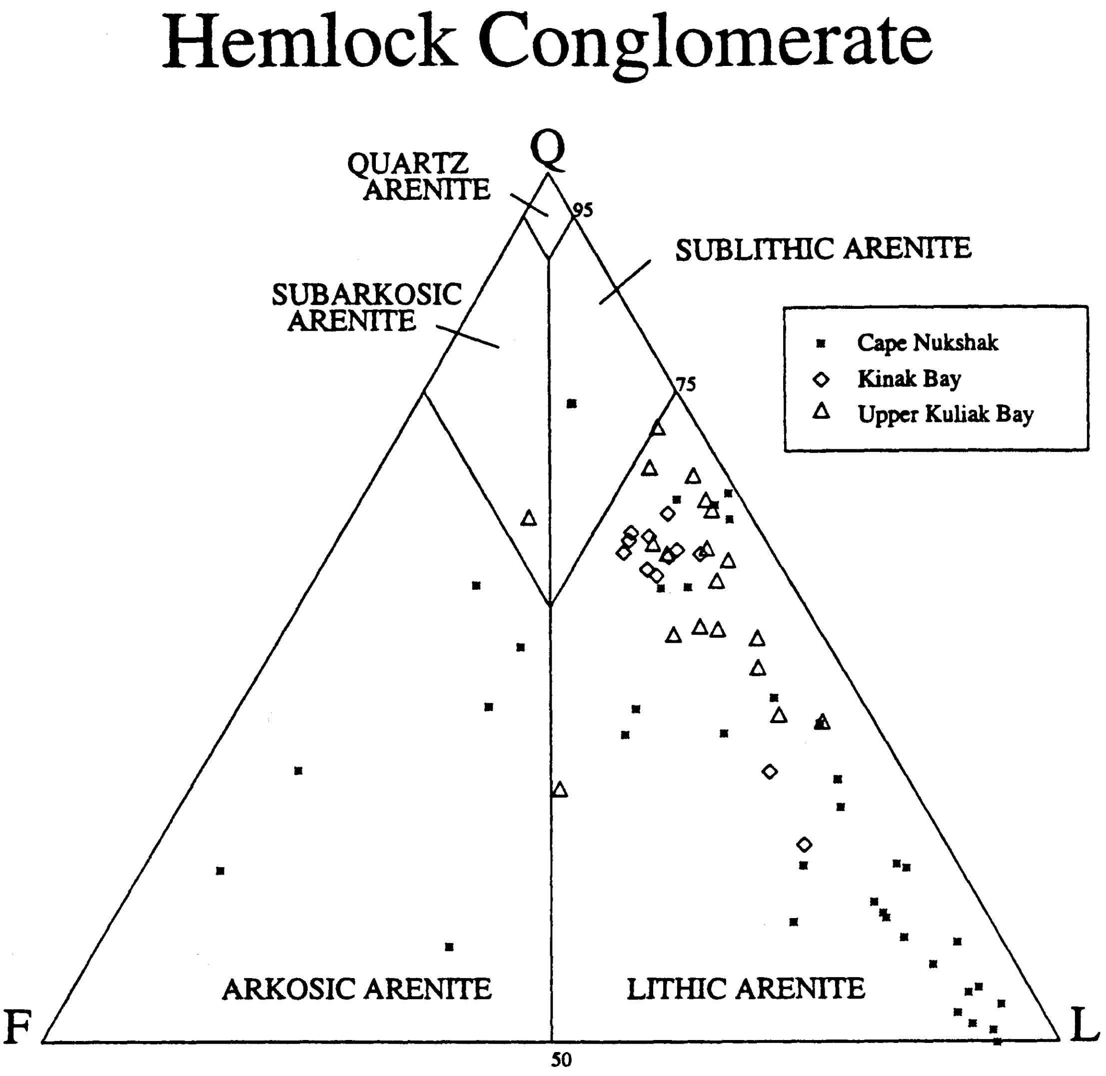


Fig. 50. Ternary diagram showing QFL compositions of sandstones from the Hemlock Conglomerate (after Dott, 1964). General compositions are similar to those of the West Foreland Formation, with the dominant sandstones being lithic arenites. Sublithic, subarkosic and arkosic arenites all contain lesser amounts of volcanic rock fragments. All arkosic arenites contain increased amounts of zoned and unzoned plagioclase. Diagram created by PLOTME software, Landsparger, in prep.

volcanic and chert lithic grains.

A single subarkosic arenite from Upper Kuliak Bay contains subequal amounts of undulose monocrystalline and polycrystalline quartz, some chert grains and few volcanic rock fragments. The great majority of the plagioclase grains in this sample are unzoned.

Six arkosic arenites from Cape Nukshak contain significantly less volcanic rock fragments than the lithic arenites, and very little chert. They are dominated by plagioclase (split approximately 25%/75% between zoned and unzoned) and varying amounts of monocrystalline undulose quartz. They contain almost no polycrystalline quartz.

The three Hemlock Conglomerate measured sections exhibit two disparate compositional averages. Kinak Bay and Upper Kuliak Bay sections have similar compositions of $Q_{52}F_{12}L_{36}$ and $Q_{52}F_{10}L_{38}$, respectively. However, the Cape Nukshak section is markedly more lithic-rich, with a composition of $Q_{30}F_{13}L_{57}$, due to the high volcanic content of samples from that location. These samples also show the widest range in variation in rock type. Average total feldspar content is similar for sandstones from all three locations.

Sandstone Trends

The lateral and vertical relationships between the measured sections in this study are not known, with the exception of the subjective division of the Kuliak Bay

Section into two formations by the author. Specific stratigraphic positions of the sections within the Cook Inlet Basin Tertiary section are also unknown. Therefore, trends discussed in this section are restricted to those observed within the individual measured sections or, where applicable, to the formations as they are represented by the measured sections.

General Compositional Trends

In general, sandstones from the Cape Nukshak Section have a higher proportion of volcanic rock fragments than those from the other measured sections. Sandstones with the highest volcanic rock fragment content are relatively deficient in undulose quartz and plagioclase. Samples containing lesser amounts of volcanic rock fragments are enriched in chert and polycrystalline quartz grains and slightly enriched in nonundulose quartz. A few samples with relatively high chert contents contain increased polycrystalline quartz.

Sandstones from Kinak Bay are compositionally similar to the relatively chert-rich, volcanic deficient samples from Cape Nukshak. They are also enriched in polycrystalline quartz and undulose and nonundulose quartz. In a few samples a significant increase in volcanic rock fragments corresponds to a decrease in undulose quartz and a slight decrease in chert.

Upper Kuliak Bay sandstones are similar in chert content to Kinak Bay sandstones, however, they contain less polycrystalline quartz. No distinct compositional trends are evident in this section.

Sandstones from the Cape Douglas Section generally contain higher proportions of chert and polycrystalline quartz compared to sandstones from the other three locations. Increases in chert content are usually accompanied by a slight increase in metamorphic rock fragment and decrease in volcanic rock fragment content. An increase in polycrystalline quartz always corresponds to a decrease in volcanic rock fragments. The few samples with high volcanic rock fragment contents are slightly enriched in plagioclase, but are deficient in all other detrital components. A few samples contain slightly increased nonundulose quartz corresponding to a slight decrease in the proportions of volcanic rock fragments and chert grains.

Lower Kuliak Bay sandstones also contain relatively higher proportions of polycrystalline quartz. A few samples enriched in polycrystalline quartz, chert and metamorphic rock fragments are deficient in volcanic rock fragments. Several samples deficient in total rock fragments contain slightly increased amounts of nonundulose monocrystalline quartz.

Linear regression analyses were performed to test the relationship between the abundances of certain detrital components within the West Foreland Formation and the Hemlock Conglomerate. The pairs of components tested for each formation included; volcanic rock fragments vs. chert, volcanics vs. polycrystalline quartz, volcanics vs. metamorphic rock fragments, metamorphics vs. chert, and metamorphics vs. polycrystalline quartz.

All of the analyses resulted in high estimated standard errors of the *y* values and low R squared (variance) values. This indicates that there are no significant relationships between the abundances of the pairs of components analyzed.

Quartz Grain Size vs. Composition

Linear regression analyses were also performed to test the relationship between mean quartz grain size and the abundance of certain detrital components in West Foreland and Hemlock sandstones. The components tested for each formation included; quartz, polycrystalline quartz, plagioclase, volcanic rock fragments, metamorphic rock fragments and chert grains.

All of the analyses resulted in very high estimated standard errors of the *y* values and very low R squared values. This indicates that there are no significant relationships between mean quartz grain size and the abundance of each of the components analyzed.

Controls on Sandstone Textures

Forty-six percent of the samples analyzed for this study are texturally submature due to poor to moderate sorting. The other fifty-four percent are well to very well sorted, and are divided between being texturally mature (40%) and supermature (14%) based on the overall roundness of quartz grains.

Proportions of the three stages of textural maturity are distinctly different for the two formations. The West Foreland Formation contains 62% submature, 35% mature and 3% supermature samples. The breakdown within the Hemlock Conglomerate is 38% submature, 42% mature and 20% supermature.

None of the three levels of textural maturity favor a sandstone of specific grain size (Fig. 51), indicating that there is no direct relationship between mean quartz grain size and textural maturity. There are also no distinct relationships between textural maturity and composition, as sandstones of the same textural maturity commonly have vastly different compositions.

Sorting

Since the West Foreland and Hemlock sandstones lack matrix, sorting is the first criterion for establishing textural maturity. It is also the factor which limits almost half of all the samples to being considered texturally submature.

In both formations, poorly to moderately sorted sandstones are common. Observed compositions for these texturally submature samples often include: A wide range of quartz grain sizes; a wide range of volcanic rock fragment

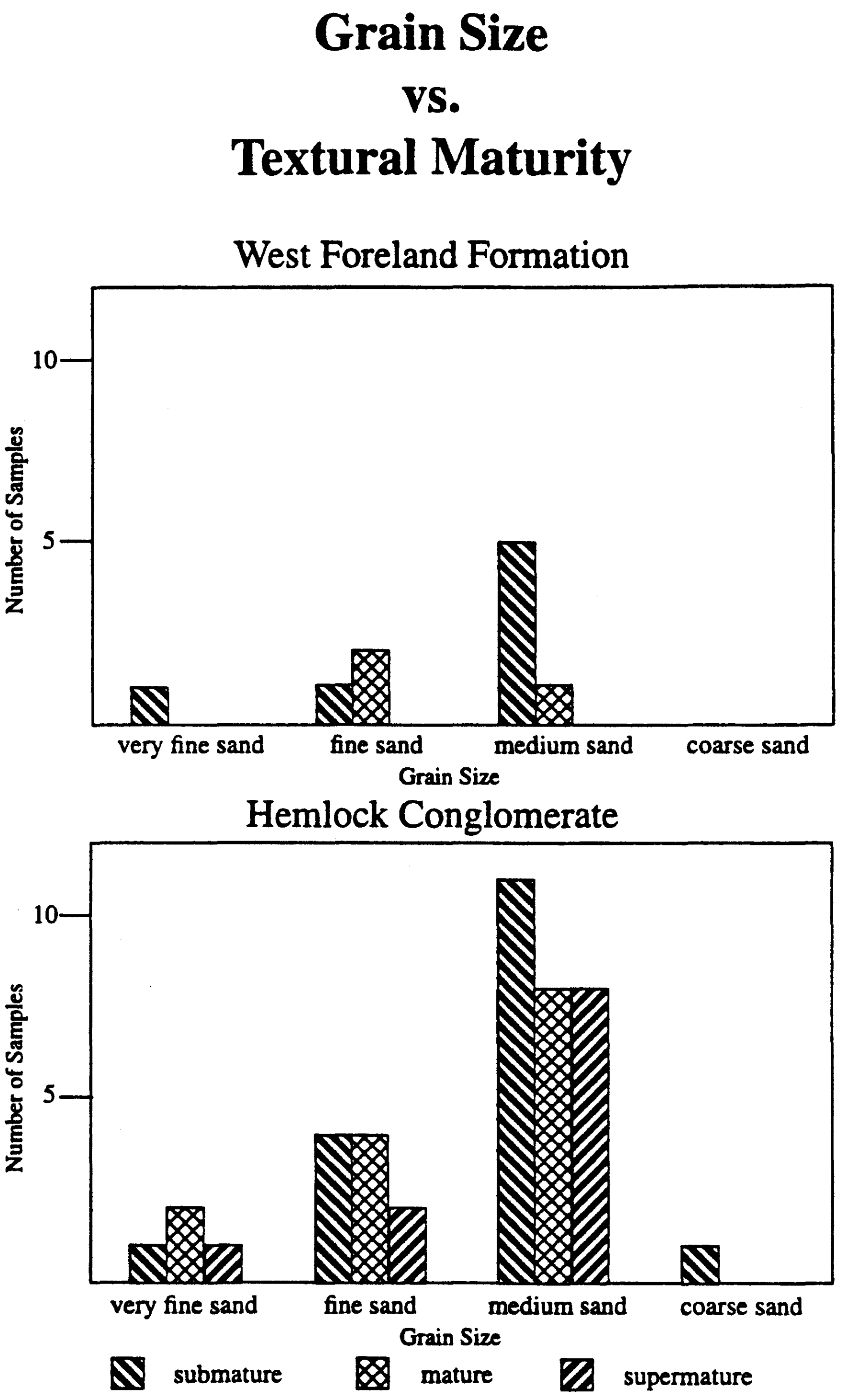


Fig. 51. Graphs of mean quartz grain size vs. textural maturity for the West Foreland Formation (top) and the Hemlock Conglomerate (bottom). Samples of a given grain size do not favor a specific level of textural maturity.

sizes; or relatively large volcanic and/or chert grains mixed with smaller quartz and/or plagioclase grains.

Well sorted samples (mature and supermature) encompass a wide range of compositions, especially with regard to volcanic rock fragment content. Such samples may be dominantly composed of volcanics, almost devoid of volcanics, or fall anywhere in between. Other detrital components which can vary greatly in abundance in well sorted samples include undulose monocrystalline quartz, polycrystalline quartz, plagioclase and chert.

Roundness of Quartz Grains

The majority of samples from both formations exhibit quartz grains encompassing a range of roundness. These ranges commonly include: angular to subangular; subangular to subrounded; and subrounded to rounded. Very angular and well rounded quartz grains are rarely observed.

Samples which exhibit predominantly angular to subangular quartz grains and poor to moderate sorting are texturally submature. However, five West Foreland Formation and seven Hemlock Conglomerate samples which are poorly to moderately sorted contain predominantly rounded quartz grains.

It some cases several well sorted samples from each formation only contain a small percentage of quartz grains. Therefore, evaluation of the overall roundness of quartz grains is based only upon a very small population.

Textures and Sediment Transport

The range of observed textural maturities commonly changes over short vertical distances, and does not correspond to changes in grain size. This could indicate variations in sediment source(s) and/or transport distances within each formation.

The abundance of poorly to moderately sorted, submature samples in both formations could signify depositional environments marked by short transport from primary source terrains. This would also account for the predominance of angular, subangular and subrounded quartz grains, especially in the West Foreland Formation. These conditions would be met where the depositional systems are proximal to the primary source terrain and/or where sediment aggradation is rapid.

Well and very well sorted samples may reflect depositional environments marked by more efficient winnowing. Rounded quartz grains observed in mature and supermature samples may have undergone transport from more distant sources terrains.

Submature samples containing predominantly rounded quartz grains may reflect the mixing of sediments transported by different systems. In this case, quartz grains would be rounded in one system, then contributed into another system prior to final sorting and deposition.

Comparison of the Detrital Compositions of the Two Formations

In this study, the West Foreland Formation and the Hemlock Conglomerate are represented by sandstones exhibiting many similarities in detrital composition and texture. Based on the average composition of samples from each formation, the West Foreland Formation ($Q_{43}F_7L_{50}$) contains slightly more quartzose and lithic grains, and less feldspar, than the Hemlock Conglomerate ($Q_{40}F_{12}L_{48}$). However, these differences are small enough that these average compositions alone would not be adequate for differentiating the two formations.

While both formations are distinctly volcaniclastic, the Hemlock Conglomerate contains significantly more samples dominated by volcanic detritus than the West Foreland Formation. This is especially evident in the Cape Nukshak Section, which has a greater proportion of volcanic-rich samples than any of the other measured sections.

In contrast, the West Foreland Formation exhibits more samples with high percentages of chert and polycrystalline quartz. The Cape Douglas Section contains the highest proportion of these types of samples.

Samples containing slightly higher percentages of metamorphic rock fragments are more common in the West Foreland Formation, whereas samples containing increased nonundulose quartz are typically found in the Hemlock

Conglomerate. However, it should be noted that individual samples exhibiting a relatively high proportion of one or both of these components are observed in both formations.

On average, the Hemlock Conglomerate has a higher plagioclase content than the West Foreland Formation. The Hemlock Conglomerate contains several samples exhibiting anomalously high plagioclase contents (>20% of detrital components). The West Foreland Formation contains only one.

Inference of Source Terrains

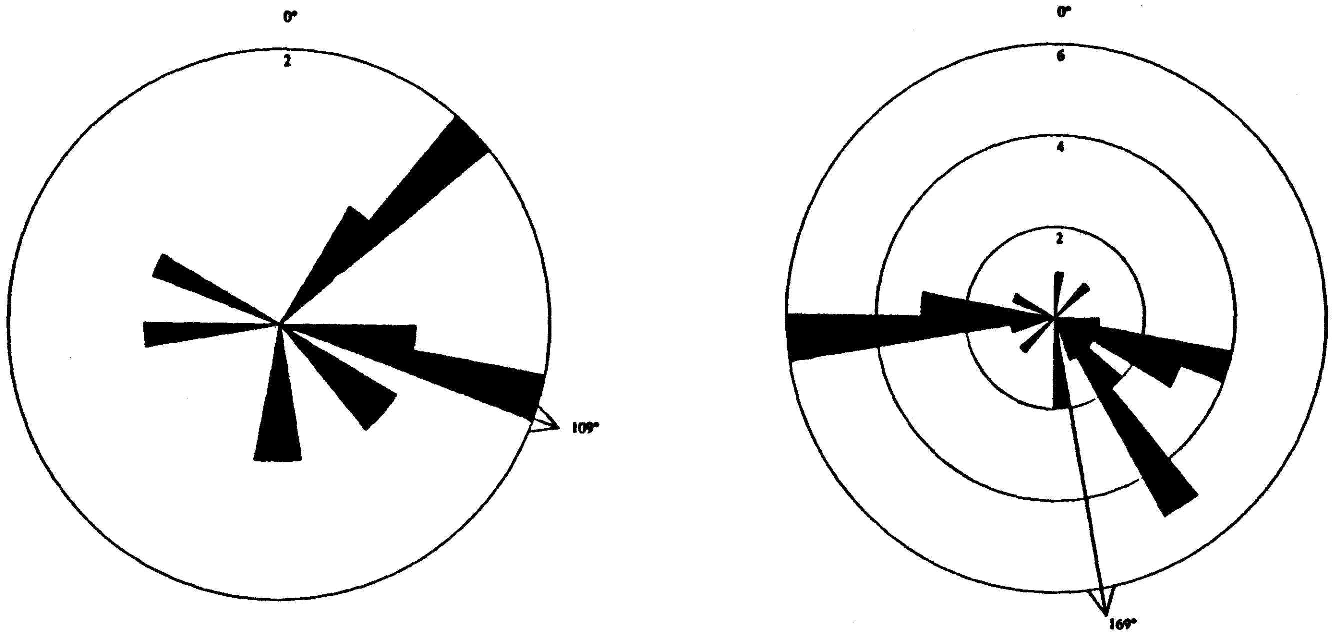
Basin Topography and Provenance

Paleocurrent directional indicators (directions are noted left of the lithologic columns and under "comments" on the stratigraphic sections in Appendix I) in sandstones, pebbly sandstones and conglomerates from both formations show widely dispersed transport directions, often over short vertical distances. Specific indicators, however, do not show preferred directions of transport.

Cross-bed directions from the West Foreland Formation show widely dispersed directions, while pebble/cobble imbrications indicate general transport to the southeast and west (Fig. 52). Hemlock Conglomerate cross-beds indicate south/southwestward transport with a southwestward component, while pebble imbrications indicate general transport in a southerly direction (Fig. 53).

Outcrop characteristics and sandstone textures suggest

WEST FORELAND FORMATION PALEOCURRENT DIRECTIONS



trough and planar cross-beds

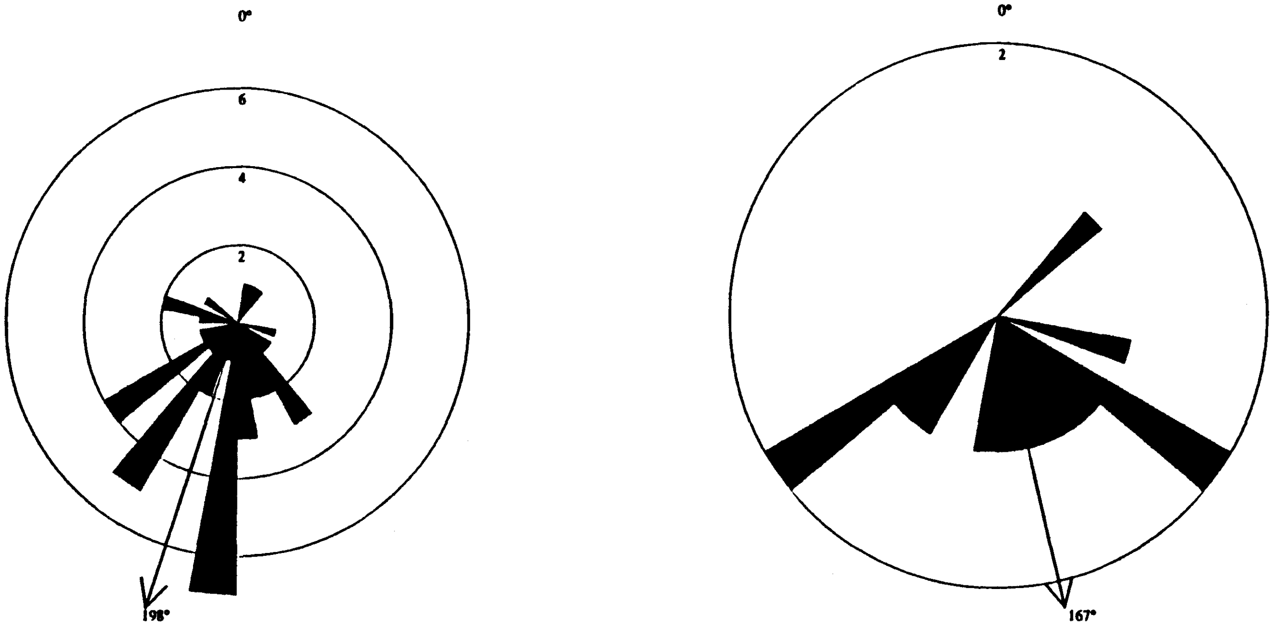
n = 12
mean = 109
standard deviation = 87.5

pebble/cobble imbrications

n = 33
mean = 169
standard deviation = 77.6

Fig. 52. Paleocurrent directions measured in the West Foreland Formation. The few cross-bed measurements show a wide scatter around the rose diagram. The pebble/cobble measurements indicate two general directions of transport, westward and southeastward. Diagrams created by GEOLOGY APPLICATIONS software, Huntoon and Landsparger, in prep.

HEMLOCK CONGLOMERATE PALEOCURRENT DIRECTIONS



trough and planar cross-beds

n = 42
mean = 198
standard deviation = 64.2

pebble imbrications

n = 14
mean = 167
standard deviation = 54.1

Fig. 53. Paleocurrent directions measured in the Hemlock Conglomerate. The few pebble imbrications indicate transport in a generally southern direction. Cross-bed measurements also indicate transport to the south. Diagrams created by GEOLOGY APPLICATIONS software, Huntoon and Landsparger, in prep.

that depositional systems were active in a range of physiographic regions. The coarse-grained lithofacies and sandstones of generally low textural maturity of the West Foreland Formation indicate short, high gradient transport. Finer-grained channel and non-channel facies and generally higher textural maturities of the Hemlock Conglomerate are indicative of transport in longer and/or lower gradient systems.

Relatively unaltered detritus (volcanic rock fragments, plagioclase, micas) in samples from both formations may indicate rapid stripping of source terrain(s), followed by relatively short transport and rapid burial. This is most easily facilitated in areas of considerable relief. Topographic highlands and adjacent basin lowlands, which could account for such relief, were present in southern Cook Inlet Basin between the Late Cretaceous and mid-Tertiary (Hudson, 1986; Raymond, 1980). Two episodes of plutonism and uplift within the Aleutian Range (along the western margin of the basin), Alaska Range (north and northwest of the basin) and Talkeetna Mountains (north of the basin) occurred from 75-50 Ma (Late Cretaceous/Early Tertiary) and from 40-25 Ma (Middle Tertiary).

Accretionary processes, ongoing from the early Mesozoic, provided highlands along the eastern margin of the basin. Tectonics and plutonism uplifted subduction complexes from the Kodiak and Barren Islands northeast to the Kenai Peninsula from the early to mid-Tertiary (Moore and Allwardt, 1980; Connelly, 1978). The Kenai-Chugach Mountains east-northeast of the basin existed as a regional topographic high throughout the Tertiary (Cowan and Boss, 1978; Hayes, et al., 1976).

Between the highlands to the east and west, a largely non-marine basin persisted throughout the Tertiary (Kirschner and Lyon, 1973; Calderwood and Fackler, 1972). The basin has maintained a generally southeast-northwest trending topographic axis from the late Cenozoic to the present (North, 1985). However, the basins depositional axis has shifted laterally to the east and west during the Tertiary in response to the changing highlands on either side of the basin (Hayes, et al., 1976).

Sandstone Mineralogy and Provenance

Outcrop lithologies and sandstone mineralogy identify the Aleutian-Alaska Range as a significant source terrain for the sediments contained in both formations. Abundant volcanic material was derived from large volumes of pyroclastic debris generated by the volcanic arcs in the Tertiary. This detritus was shed east/southeast off of the arcs into the basin, and also down the basin axis to the southwest.

Pyroclastic sources, as opposed to lava flows, are supported by several factors. Explosive eruption has been the style of volcanism in the Aleutian-Alaska Ranges through the Tertiary (Egbert, 1986; McHugh, 1977b) up to the present

(Detterman, 1973). Ash and tuff beds are documented in the West Foreland Formation in the northwest part of the basin (Hayes, et al., 1976; Calderwood and Fackler, 1972).

In this study pyroclastic units (interpreted as lithic tuffs) are recognized in the Hemlock Conglomerate outcrops of the Cape Nukshak Section (beginning at 1,169 ft/356.3 m and 2,592 ft/790.0 m). Ash falls composed of quartz and plagioclase feldspar in a matrix of glass and/or pumice microlites are identified in thin sections from Cape Nukshak (sample numbers 1-2453-L11, 1-2500-L12 and 1-2593-L1).

Abundant volcanic rock fragments found in many samples from both formations are a clear indication of the prevailing influence of a volcanic source terrain. Other observed detrital constituents attributable to volcanic sources include: sub- to euhedral quartz grains exhibiting straight extinction (Folk, 1980; Young, 1976); abundant plagioclase (Folk, 1980); and zoned plagioclase (Pittman, 1970).

Quartz grains with straight extinction are a minor constituent of most samples. However, it is inferred that the abundance of such grains is not as much a function of their abundance as discrete grains in the source terrain, but their liberation during the breakdown of volcanic rock fragments during weathering and/or transport.

Zoned plagioclase is a significant constituent of ash falls, as well as other sedimentary units, observed in the Hemlock Conglomerate, supporting its pyroclastic origin.

Abundant zoned and unzoned plagioclase is consistent with andesitic volcanism (Streckeisen, 1979) associated with the emplacement of quartz diorite, tonalite and granodiorite plutons (Dickinson, 1970) from the early to mid-Tertiary west and north of Cook Inlet Basin (Hudson, 1986).

Finally, abundant pyroclastic detritus may account for the dearth of material attributable to plutonic sources. Frequent replenishment of pyroclastic cover probably prevented significant unroofing of the plutons beneath the volcanic arcs, insuring that the arcs remained undissected through the deposition of the West Foreland Formation and the Hemlock Conglomerate in the study area.

Mineralogy also implicates a contributing metamorphic source for some sandstones of the West Foreland Formation and the Hemlock Conglomerate. Constituents found in both formations which are attributable to a forearm metamorphic (subduction) terrains include; metamorphic rock fragments (Dickinson and Seely, 1979); chert grains (Dickinson, 1982; Dickinson and Seely, 1979; Connelly, 1978); and detrital micas (Hayes, et al., 1976; Moore, 1973; Hayes, 1970). Detrital micas have also been attributed to plutonic igneous sources (Folk, 1980). However, there is no other mineralogical indication that a plutonic terrain contributed significantly to the sandstones from either formation.

Other detrital components cited as potential products of metamorphic terrains include undulose monocrystalline quartz (Blatt, 1967; Blatt and Christie, 1963) and polycrystalline quartz (Young, 1976; Conolly, 1963), both of which are common in the West Foreland Formation and the Hemlock Conglomerate. When located on a Basu (1975) diamond diagram based on undulose and nonundulose monocrystalline quartz and polycrystalline quartz content, all except two sandstones from each formation plot in the low rank metamorphic source terrain field. However, the low percentage of monocrystalline, and especially polycrystalline, quartz grains in many samples indicates that although some quartz grains may have come from a metamorphic terrain, that terrain was not a major contributor to those quartz-deficient samples.

Relative Contributions of the Source Terrains

It is evident from syndepositional pyroclastic lithologies in the Hemlock Conglomerate, and abundant volcanic-rich sandstones observed in both the West Foreland Formation and the Hemlock Conglomerate, that volcanic terrains were major suppliers of sediment to these depositional systems. There is also a suggestion from mineralogical evidence that some sediments were derived from metamorphic and/or subduction terrains.

Carozzi (1993) plots sandstone compositions on QFL and QmFLt ternaries (after Dickinson, et al, 1983; see also Dickinson and Suczek, 1979) that relate sandstone compositions to source terrains which may be present in an active margin setting. When used in conjunction, the two ternaries can help to indicate the relative contribution of the various potential source terrains.

The end members for the QFL ternary are: Q, total quartzose grains, including polycrystalline lithic grains of chert; F, feldspar grains; and L, igneous and metamorphic lithic grains. End members for the QmFLt ternary are: Qm, monocrystalline quartz grains; F, feldspar grains; and Lt, total polycrystalline lithic grains, including polycrystalline quartz and chert.

Ternary plots of QFL compositions (after Carozzi, 1993) of sandstones from the West Foreland Formation (Fig. 54) and the Hemlock Conglomerate (Fig. 55) show similar compositional shifts when compared to the ternary plots after Dott (1964; Figs. 50 and 51). With chert plotting in the Q corner, many of the sandstone compositions shift toward that corner. This places the majority of the sandstones in the "recycled orogenic" field, indicating significant contribution from orogenic belts which may include uplifted subduction complexes and/or metamorphic envelopes encompassing arc terrains.

Both formations exhibit several sandstone compositions that do not shift toward the Q corner, plotting within the "undissected arc" field. These sandstones are composed of sediment derived predominantly from volcanic terrains (as opposed to "dissected arcs" in which volcanic cover is stripped and sources are predominantly plutonic).

One sandstone from the West Foreland Formation and

West Foreland Formation

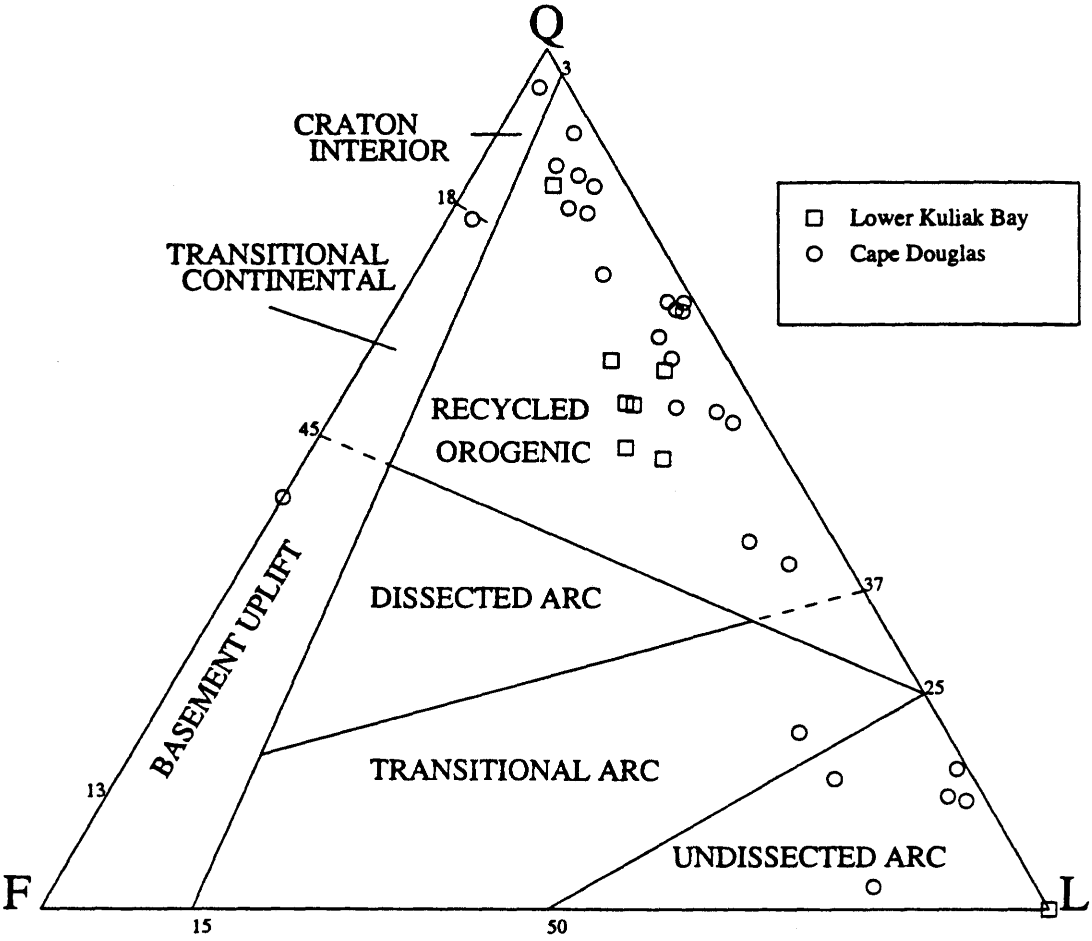
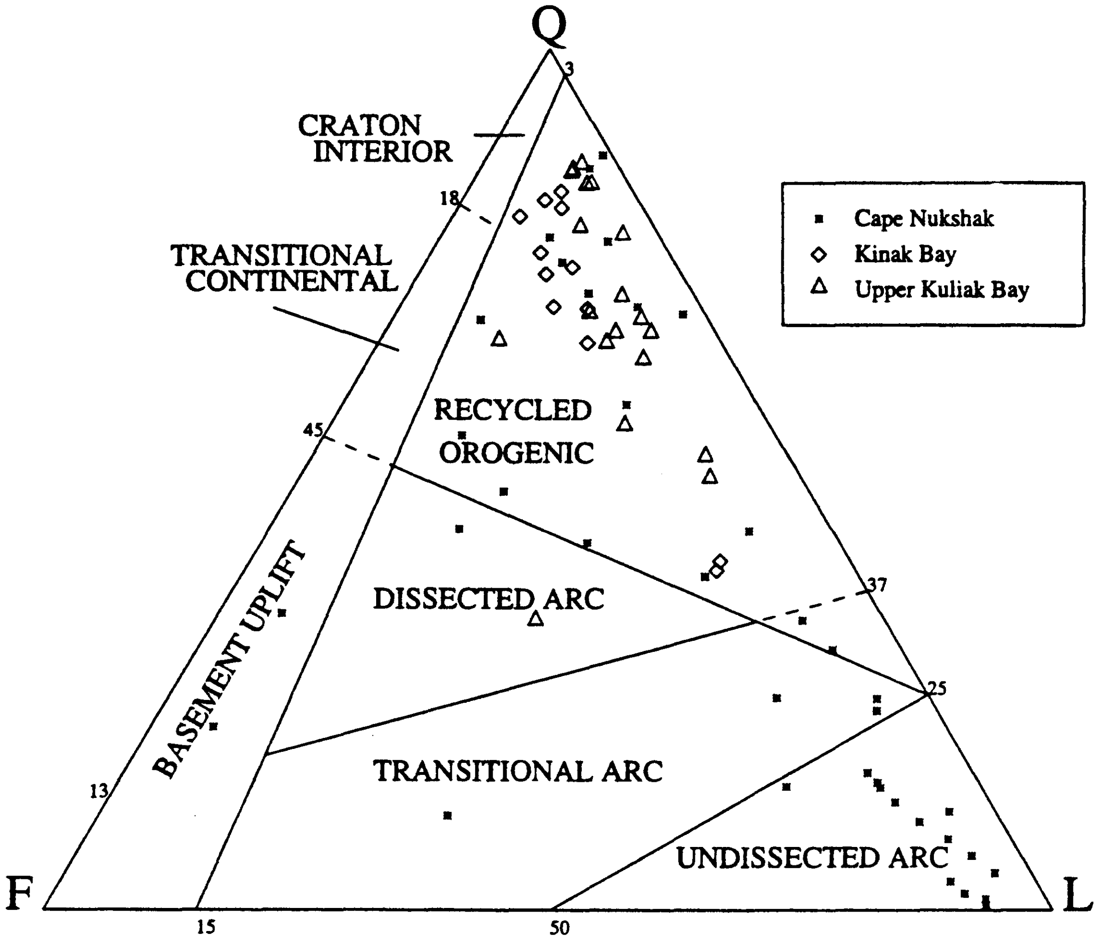


Fig. 54. Ternary diagram showing QFL compositions of sandstones from the West Foreland Formation (after Dickinson et al., 1983, as discussed in Carozzi, 1993). The poles are: Q, total quartzose grains, including polycrystalline lithic grains of chert; F, feldspar grains; and L, igneous and metamorphic lithic grains. The majority of the samples shift toward the Q pole (relative to the Dott, 1964 ternary) reflecting their chert content. Samples remaining near the L pole are dominantly composed of volcanic rock fragments. Diagram created by PLOTME software, Landsparger, in prep.



Hemlock Conglomerate

Fig. 55. Ternary diagram showing QFL compositions of sandstones from the Hemlock Conglomerate (after Dickinson et al., 1983, as discussed in Carozzi, 1993). Compositional shifts (relative to the Dott, 1964 ternary) are similar to those seen for the West Foreland Formation. Diagram created by PLOTME software, Landsparger, in prep.

eight from the Hemlock Conglomerate plot in one of three other source terrain fields; transitional arc, dissected arc or basement uplift. In each of these fields, exposed plutonic terrains are thought to potentially contribute increased amounts of feldspar grains. However, the nine samples mentioned plot in these fields due to increased amounts of zoned and unzoned plagioclase, which are most likely derived from volcanic sources.

Two other source terrain fields are represented by single samples from the West Foreland Formation, transitional continental and craton interior. These samples are composed predominantly of undulose monocrystalline quartz and some chert, and probably represent recycled orogenic sediments in which transport processes have destroyed less competent grains (e.g. feldspars, volcanic rock fragments).

Ternary plots of QmFLt compositions of sandstones from the West Foreland Formation (Fig. 56) and the Hemlock Conglomerate (Fig. 57) show similar compositional shifts when compared to Carozzi's (1993) QFL plots. With chert and polycrystalline quartz plotting in the L corner, most of the sandstone compositions shift toward that corner. Note that many sandstones plot within the undissected arc or transitional arc fields, which are the same as in the QFL ternaries, reiterating the significance of volcanic sediment sources.

However, in the QmFLt ternaries, those two magmatic

West Foreland Formation

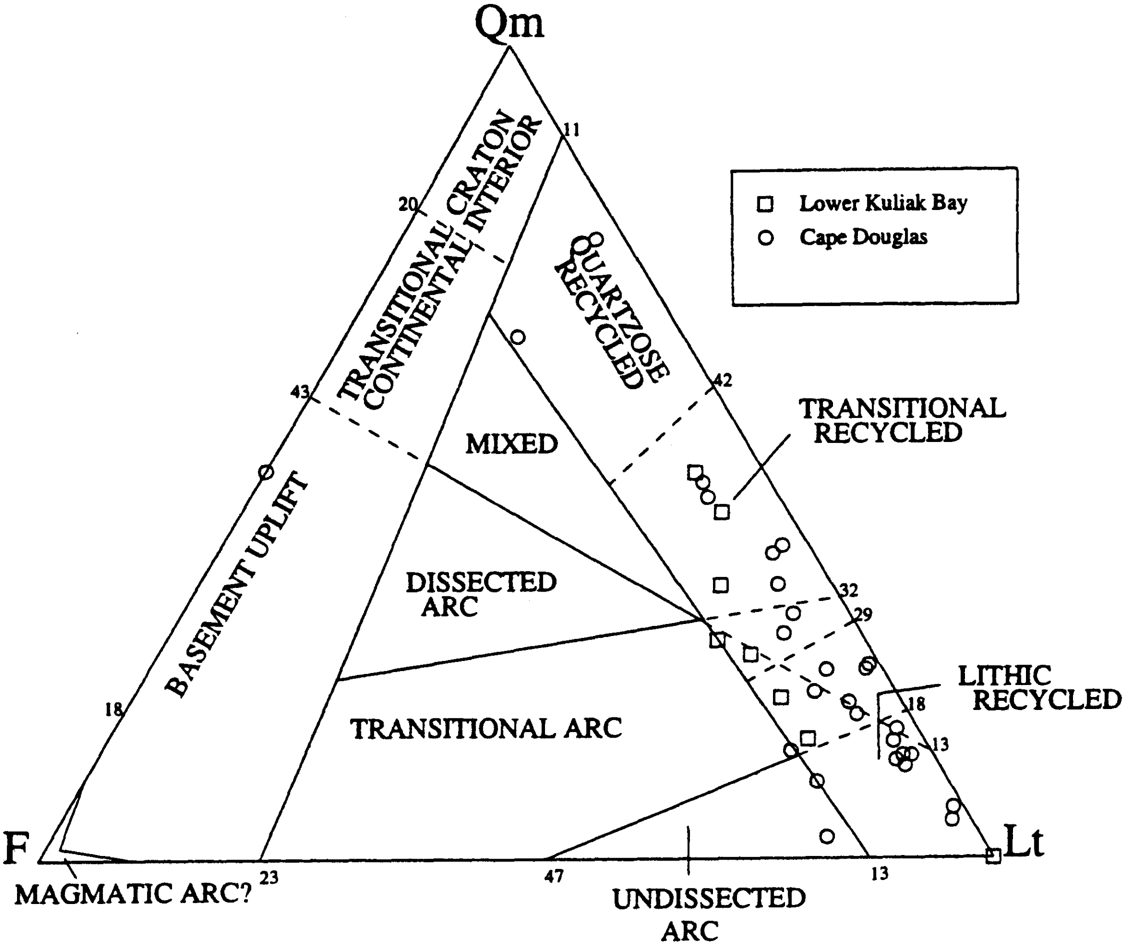


Fig. 56. Ternary diagram showing QmFLt compositions of sandstones from the West Foreland Formation (after Dickinson et al., 1983, as discussed in Carozzi, 1993). The poles are: Qm, monocrystalline quartz grains; F, feldspar grains; and Lt, total polycrystalline lithic grains, including polycrystalline quartz and chert. The majority of samples shift toward the L pole (relative to the Carrozi, 1993 QFL ternary), indicating significant amounts of chert and volcanic rock fragments. Diagram created by PLOTME software, Landsparger, in prep.

Hemlock Conglomerate

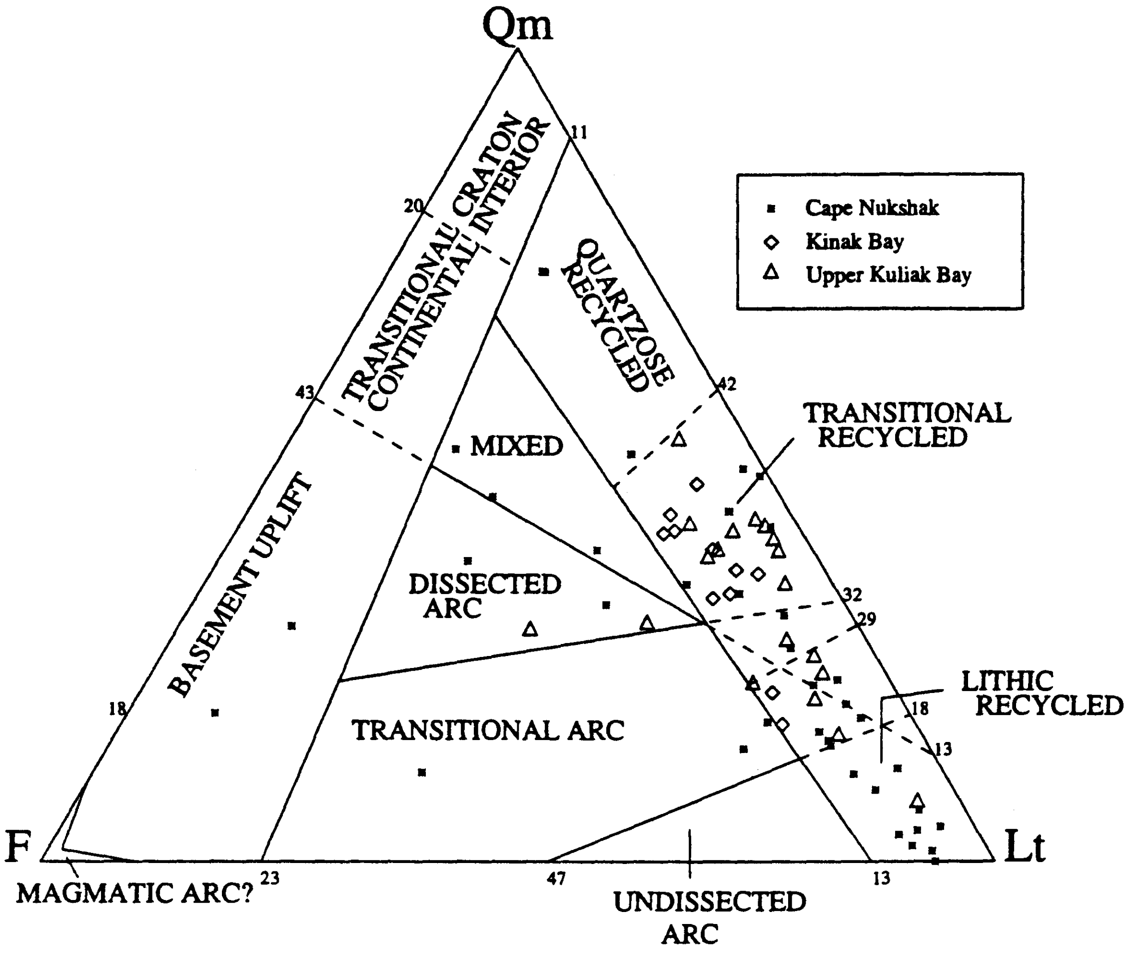


Fig. 57. Ternary diagram showing QmFLt compositions of sandstones from the Hemlock Conglomerate (after Dickinson et al., 1983, as discussed in Carozzi, 1993). Compositional shifts (relative to the Carozzi, 1993 QFL ternary) are similar to those seen for the West Foreland Formation. Diagram by PLOTME software, Landsparger, in prep.

arc fields overlap with two fields representing components of the recycled orogenic field seen on the QFL ternary; lithic recycled and transitional recycled. Most of the sandstones from both formations fall within one of these two fields. Lithic recycled sandstones contain significant amounts of chert possibly derived from subduction complexes (Carozzi, 1993), while transitional recycled sandstones contain quartz grains recycled from their original sources in addition to lesser amounts of chert (Dickinson, et al., 1983).

Two West Foreland Formation and four Hemlock Conglomerate sandstones fall within either the quartzose recycled or mixed fields. These samples are composed predominantly of quartz grains recycled (sometimes several times) from their original sources in addition to lesser amounts of chert and sediment derived from volcanic sources.

As in the QFL ternaries, compositions plotting in the basement uplift field or in the transitional and dissected arc fields toward the F corner of the ternary reflect increased amounts of plagioclase derived from volcanic sources. The transitional continental and craton interior sandstones plotted in the West Foreland QFL ternary shift into the quartzose recycled field in the QmFLt ternary, denoting their small chert content.

From the QFL and QmFLt ternary plots (after Carozzi, 1993) of West Foreland Formation and Hemlock Conglomerate sandstones, and discussions in Dickinson, et al. (1983), Dickinson and Seely (1979) and Dickinson and Suczek (1979), several inferences can be made regarding the relative contributions of volcanic, metamorphic and subduction complex source terrains to early Tertiary depositional systems in Katmai National Park. First, volcanic terrains (Alaska-Aleutian Arcs; volcanics associated with the Talkeetna Mountains) to the west and/or north were dominant suppliers of sediment throughout deposition of the West Foreland Formation and Hemlock Conglomerate. Second, quartz, chert and metamorphic rock fragments were derived from uplifted subduction complexes and/or other metamorphic terrains within the active margin setting (Kenai-Kodiak Highlands/subduction complexes; metamorphic envelopes). Third, pyroclastic events provided abundant volcanic material which frequently inundated the depositional systems, masking the contribution of sediments from other source terrains.

CHAPTER IX

DISCUSSION OF SANDSTONE DIAGENESIS

The diagenetic features observed in the outcrop samples are common to both the West Foreland Formation and the Hemlock Conglomerate. Therefore, the diagenetic characteristics and history of the formations are discussed in unison, unless otherwise noted. Outcrop samples may or may not reflect the same diagenetic assemblages as well core samples. However, in a similar study, Galloway (1974) found no significant differences between the two types of samples.

Relationships Between Diagenetic Features

Alteration of detrital grains in both formations can vary greatly between, as well as within, individual samples. In most cases, samples are largely unaltered or exhibit a combination of altered (predominantly volcanic rock fragments, plagioclase and/or accessory minerals) and unaltered grains (Figs. 25 and 39). Grains are rarely altered to the extent that they are unrecognizable. Only three Hemlock Conglomerate sandstones (two from Kinak Bay and one from Cape Nukshak) contain predominantly altered, unidentifiable grains.

There is no apparent relationship between the stratigraphic location of sandstones containing relatively high proportions of altered grains and the locations of coal seams and/or trees preserved in growth position, both of which indicate periods of subaerial exposure and potential grain alteration in the vadose zone. This may be due to the fact that volcaniclastic sediments are often texturally submature to mature, and their low permeabillities limit weathering effects to a depth of only a few centimeters (Galloway, 1974).

Compaction is the initial post-burial process on sediments, and the degree of compaction can influence subsequent diagenetic processes. The extent of compaction is related to the packing of competent grains as well as the brittle and ductile deformation of less competent grains, and is reflected in the initial loss of primary porosity.

In both formations, samples containing higher proportions of volcanic rock fragments exhibit greater reductions in primary porosity due to the ductile deformation of the fragments through compaction (Figs. 26 and 42). Brittle deformation of micas (Fig. 23) and slight ductile deformation of metamorphic rock fragments via compaction is also observed, however, these are minor constituents in most samples, and do not significantly contribute to the overall loss of primary porosity. The degree of compaction can vary within a single sample depending on the distribution of grains of varying competency.

The degree of compaction influences the potential development of grain coats. In samples that are supported by competent grains (e.g. quartz, plagioclase and chert) iron oxide (Figs. 27 and 43), clay (Figs. 20) and chlorite (Fig. 39) grain coats were able to develop. Complete coats could also develop when their emplacement preceded significant compaction (Fig. 26). For samples exhibiting closely packed/compacted grains, complete coats could not develop. In these cases, grain coats are intermittent (Fig. 33) or appear as pore linings (Fig. 44).

Clay and iron oxide grain coats are features which have been described in sandstones from other arc-related basins. Burns and Ethridge, 1979, Ethridge, et al., 1979 and Galloway, 1979 discuss two stages of clay coat development for sandstones in forearm basins. The first stage, which can be authigenic or infiltrated clays, is commonly poorly crystallized and iron stained, while in the second stage well crystallized, authigenic clay coats develop. In this case, the observed paragenesis would show two layers of clay grain coats, with iron stained clay coats against the grains and well crystallized clay coats using the iron stained clays as a substrate.

It is possible that the West Foreland Formation and Hemlock Conglomerate are exhibiting two stages of clay grain coats. An earlier infiltrated, iron stained clay which does not appear crystalline, and a later stage of well crystallized clay grain coats. This premise will be followed for the remainder of the discussion, however, no distinct paragenetic relationships between these features were observed in the Katmai National Park samples.

Chlorite grain coats are not observed in conjunction with other well crystallized clay coats. They are observed as either the sole grain coating, or less frequently as coats after the development of iron oxide stained clay coats. In most cases where iron oxide grain coats have formed, chlorite occurs as a pore-filling rather than a grain coating phase (Fig. 31).

Early cementation by calcite can preclude significant compaction and/or the development of any grain coats in some samples (Fig. 58). It can also restrict the introduction of later cements, such as chlorite, to isolated pores (Fig. 59).

In a majority of the samples from both formations, grain coats and/or pore lining cements are formed prior to cementation by other authigenic minerals (Figs. 26, 27 and 31). Iron oxide grain coats/pore linings are observed in calcite (Fig. 43) and chlorite (Fig. 31) cemented samples, and clay coats are seen in calcite cemented samples (Fig. 20).

With the introduction of each cement, available pore space is reduced, limiting space for the introduction of subsequent cements. Pervasive iron oxide cement, although uncommon, can preclude the introduction of other cements.

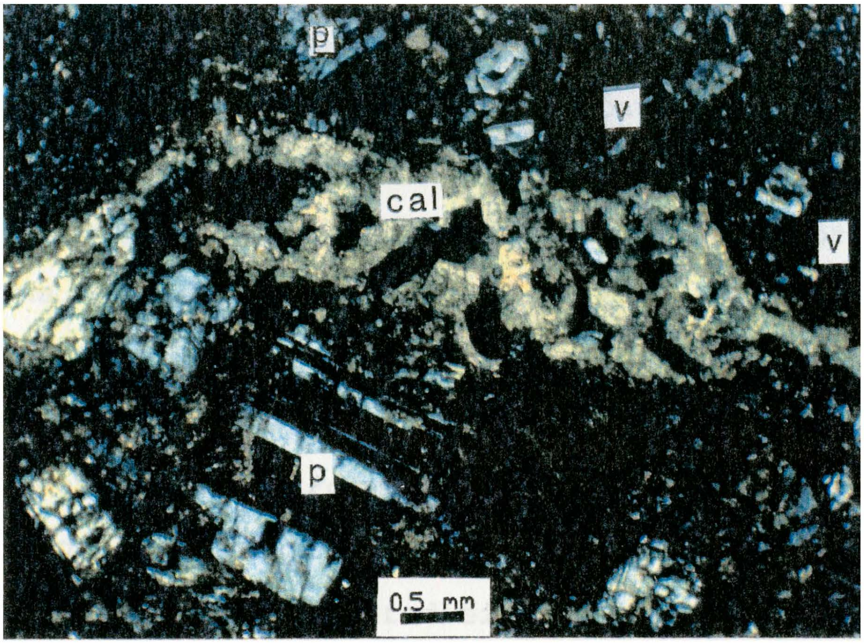


Fig. 58. Early calcite cement which has caused variable degrees of compaction. The combination of calcite cementation and compaction (primarily of volcanic rock fragments) has prevented the formation of grain coats and precluded the introduction of other cements. Sample 1-623-L4; photomicrograph under crossed polars.

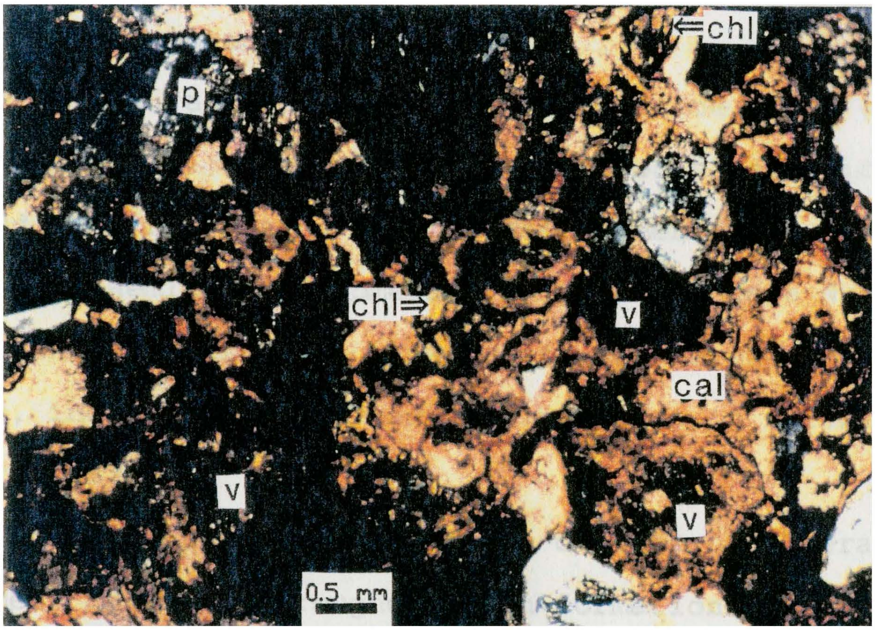


Fig. 59. A dominantly calcite cemented sample in which chlorite has exploited the few remaining pores (either primary or secondary). Calcite and chlorite also replace volcanic rock fragments to different extents throughout this sample. Sample 2-417-L1; photomicrograph under crossed polars.

Calcite cement, either alone or in combination with iron oxides, can preclude the introduction of chlorite cement (Fig. 59), or limit chlorite to pore space not affected by earlier calcite cementation (Fig. 37). Chlorite may also be found as the sole cement (Figs. 32 and 33). In both formations, precipitation of authigenic minerals eventually occludes all primary pore space not eliminated through compactional processes

One West Foreland Formation sample from Cape Douglas exhibits more well crystallized calcite cement (Fig. 36) that appears to have exploited either the last available primary pores or scarce secondary pores after an initial episode of pervasive calcite cementation. This is the only occurrence of this type of calcite crystallization observed in the Katmai samples.

Microfractures can be found in iron oxide (Fig. 48) and chlorite (Fig. 23) cemented samples. In both cases it is evidenced that the fractures post-date cementation. However, one Hemlock Conglomerate sample from Cape Nukshak exhibits chlorite crystals growing off of the sides of a fracture, indicating continued precipitation of chlorite after fracturing.

Detrital grains showing varying degrees of alteration/ replacement are seen throughout both formations (Figs. 21, 25, 37, 38, 39 and 42). Alteration of grains is most likely a continuous process from deposition, with complex replacement and alteration occurring with increasing depth of burial (Galloway, 1979).

Implications for Vertical Trends

Although the Cape Douglas outcrops are speculated to represent the base of the Tertiary section, the stratigraphic positions of the other sections are not known. In addition, there are no diagenetic "markers" which can tie these sections to specific stratigraphic horizons within the basin.

Certain diagenetic features appear to be dominant in specific parts of some stratigraphic sections. For example, Cape Nukshak samples taken from between 715 feet (217.9m) and 1,049 feet (319.7m), inclusive, are dominantly calcite cemented (see Appendix II). However, generalizations made about specific stratigraphic intervals can only be based upon the sandstones sampled within that interval.

In general, most of the observed diagenetic features can be found dispersed throughout each of the measured sections. There are no distinct vertical trends in diagenetic character within the stratigraphic sections analyzed for this study.

Paragenesis of Katmai Samples

A general, progressive paragenetic sequence, applicable to both the West Foreland Formation and the Hemlock Conglomerate in Katmai National Park, can be constructed from observed diagenetic features. However, individual samples may reflect different paragenetic paths within the general sequence, creating a heterogeneity of diagenetic assemblages through the sections.

The first stage of the sequence after deposition is the initiation of compaction. The degree of compactional effects (packing of grains, ductile and/or brittle deformation of grains) varies according to when subsequent stages occur which can limit/halt compaction (e.g. cementation).

The second stage involves the development of iron stained (possibly infiltrated) clay followed by well crystallized, authigenic clay grain coats. In samples that exhibit extreme compaction, complete grain coats cannot develop. However, in more loosely packed samples complete coats can form. Therefore, it is inferred that the development of grain coats post-dates initial compaction, but was initiated at different times as compaction proceeded. The timing relationship between iron oxide and clay coats is unknown from the samples analyzed for this study.

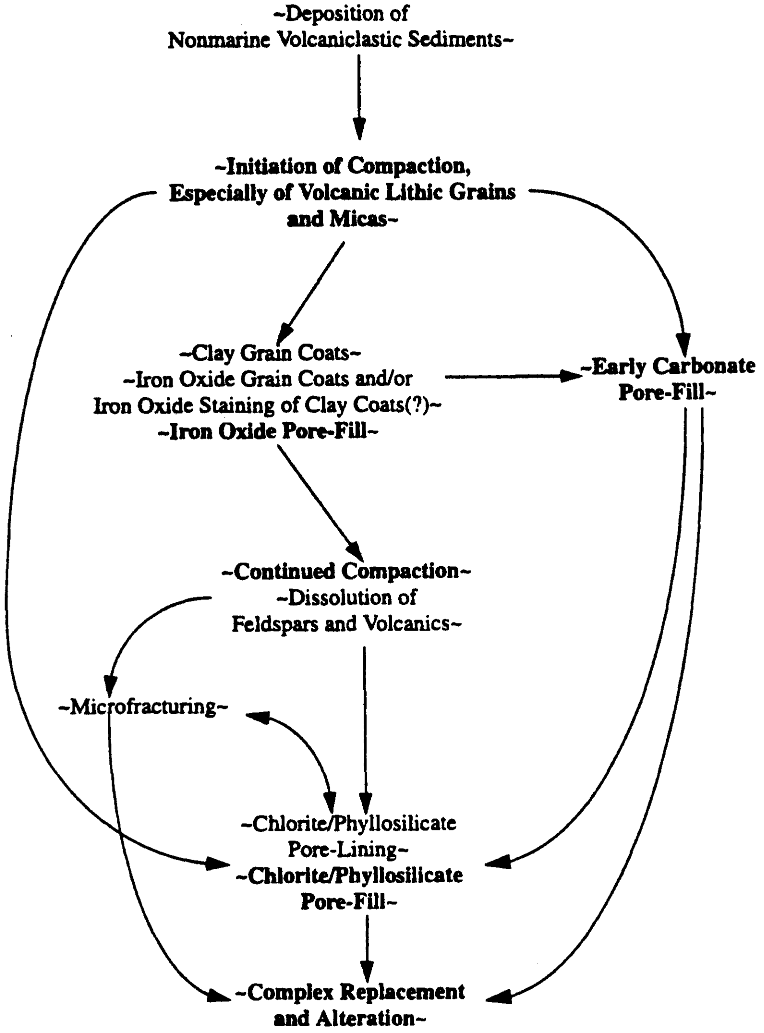
Grain coats can pre- or post-date calcite cementation. In some samples early, pervasive calcite cement surrounds all grains and does not allow the development of coats. However, in a majority of samples from both formations, partial or complete grain coats develop before all pore space is occluded by calcite and/or other authigenic minerals.

Pervasive iron oxide cementation is not seen in conjunction with the well crystallized clay coats, and cannot be differentiated from iron stained clay coats. It may be introduced coevally with or just after development of the iron stained coats.

Calcite cementation can be the second or third stage, depending on the absence or presence of grain coats. In some samples calcite fills all remaining pore space, preventing the possibility of subsequent diagenetic processes. However, partial calcite cementation can leave pore space available for the introduction of chlorite. In samples that did not undergo calcite cementation, chlorite fills all available pore space, indicating that its introduction had to precede all other diagenetic phases. In general, though, chlorite fills pore spaces not previously filled by calcite, making its introduction stage four.

Before complete occlusion of pore space in stages two, three, four, or any combination of the three, dissolution of feldspars and volcanics can occur. The partially or completely dissolved grains may then be replaced by authigenic minerals, or left as secondary porosity. Cements may also be partially dissolved to create secondary porosity during these stages.

Although individual samples may not have been subjected to all of the same diagenetic stages, a general paragenetic sequence (Fig. 60) can be constructed from observed



KEY:

Bold Type - Porosity Reduced

Normal Type - Porosity Created and/or Preserved

Fig. 60. Paragenetic sequence constructed for both the West Foreland Formation and the Hemlock Conglomerate. Arrows indicate possible diagenetic paths for individual samples based on all observed diagenetic features. General paragenetic stages may include grain coats, calcite cementation, grain dissolution, phyllosilicate (chlorite) cementation, microfracturing, or a combination of processes. Early, pervasive cementation tends to limit or cease further diagenetic alterations until conditions exist for complex replacement and alteration. Replacement and alteration of framework grains is probably an ongoing process from deposition. The latest diagenetic stage attained by individual samples can vary greatly over relatively short stratigraphic distances.

features. That sequence, from the youngest to oldest event, includes: 1) Deposition and initiation of compaction; 2) development of iron oxide and/or clay coats around framework grains and/or iron oxide pore-fill; 3) calcite pore-fill; 4) chlorite pore-fill and/or microfracturing; and 5) replacement and alteration of framework grains (probably a continuous process from deposition).

Some early diagenetic alterations preclude later stages of paragenesis through the almost total occlusion of primary pore space. Early and pervasive compaction (primarily of volcanic fragments) coupled with cementation by any combination of iron oxide, calcite and/or chlorite tend to circumvent later paragenetic stages in this way.

Diagenesis in Lower Cook Inlet

There is a dearth of published data on the diagenesis of Tertiary sandstones in lower Cook Inlet, especially within the confines of Katmai National Park. Limited information is available on diagenetic features of the West Foreland Formation in the Cape Douglas area and in the Atlantic Richfield COST No. 1 Well (offshore approximately 50 miles/80.5 km northeast of Cape Douglas). However, information on the diagenesis of the Hemlock Conglomerate in lower Cook Inlet is absent. The following comparisons of data from the literature and from this study consider only the West Foreland Formation.

Ductile deformation of volcanic rock fragments, resulting in the formation of pseudomatrix, is common in the COST No. 1 Well (Bolm and McCulloh, 1986). The higher the volcanic content of the sandstones, the greater the initial reduction of primary porosity through compaction. This is consistent with observations made in samples from this study.

Clay coats found in the COST No. 1 Well have been determined to be mixed layer smectite-chlorite, or discrete phases of either (Bolm, et al., 1984). These coats range in color from yellow to light green depending on the dominance of either smectite (montmorillonite) or chlorite, and the coats become thicker with increasing depth (Bolm and McCulloh, 1986). Chlorite grain coats were optically identified in this study. No smectite or mixed-layer clays were specifically identified either optically or through scanning electron microscopy. Thin clay coats of unidentified composition show little variation in thickness through the measured sections.

In the COST No. 1 Well carbonate cement is found in minor amounts either filling or scattered through pore spaces in sparry and microsparry phases (Bolm and McCulloh, 1986). This is in contrast to the abundant microsparry, pore-filling calcite cement found in samples analyzed for this study.

Bolm, et al. (1984) cite the only occurrence of post-Mesozoic laumontite cement as that in Paleocene rocks of the West Foreland Formation in the Cape Douglas area (the specific location is not noted). However, no zeolites were identified in any samples from this study area.

Comparison to Formations in Other Arc-Related Basins

The paragenetic sequence constructed for this study is similar to those presented for formations in other arc-related basins (Galloway, 1974 and 1979; Burns and Ethridge, 1979; Mathisen and McPherson, 1991, Carozzi, 1993). Diagenetic stages common to these sequences and this study include early clay coats, early calcite cementation, and later phyllosilicate (chlorite) cementation. However, this study reflects some departures from the other general sequences.

Iron stained clay grain coats have been interpreted to be early infiltrated (Ethridge, et al., 1979) or authigenic (Burns and Ethridge, 1979) clays. A subsequent stage of well crystallized, authigenic clay grain coats has also been noted (Galloway, 1979). Grain coats observed in this study may include an earlier infiltrated, iron stained clay and a later well crystallized clay phase.

Zeolite pore-fill, noted as a significant stage in the diagenesis of formations in other similar basins, is conspicuously absent from the sandstones analyzed for this study. Specifically, laumontite is identified as a common authigenic mineral in arc-derived sandstones. There are several reasons which could explain the absence of this mineral in the sandstones from Katmai National Park.

First, carbonates (such as calcite cement) can chemically preclude the development of laumontite (Bolm, et al., 1984). Second, the outcrops in Katmai National Park may be stratigraphically and/or structurally above the laumontite horizon described by Bolm, et al, 1984. Third, the formations at the southern limit of the basin may not have reached the depth of burial required to generate temperature and pressure conditions necessary for zeolite development. A precise stratigraphic location for West Foreland Formation sandstones containing laumontite near Cape Douglas (described, but not located in Bolm, et al., 1984) could be useful in eliminating the second and third options.

Although fracturing is noted in the diagenesis of sandstones from many basins, it is not a mechanism necessarily unique to the fore-arc environment. It is included in the paragenesis of sandstones in this study because of its significance in the development of secondary porosity.

An important difference between this study and others concerning arc-related basins is that this is the first study to see the diagenetic sequence discussed above in a totally non-marine basin. Several authors have not specifically addressed potential similarities or differences for diagenesis in marine versus non-marine settings (Galloway, 1979; Burns and Ethridge, 1979; Carozzi, 1993).

Mathisen and McPherson (1991) determined that although the diagenetic sequences seen in marine and non-marine rocks are similar, they can be differentiated by a lack of pervasive calcite cementation in non-marine sections. The results of this study indicate that pervasive calcite, as well as other diagenetic features seen in marine sections, can be found in a non-marine setting.

CHAPTER X

CONCLUSIONS

DEPOSITIONAL ENVIRONMENTS

The West Foreland Formation was deposited by numerous cross-cutting fluvial channels on a broad braid plain. Lack of accommodation space caused broad scour and cannibalization of previous channel deposits, preserving only the lower parts of channels.

The Hemlock Conglomerate was deposited by meandering channels downcutting into non-channel facies (overbank, floodplain). Increased accommodation space allowed for the preservation of complete, stacked channel deposits.

EVOLUTION OF THE DEPOSITIONAL SYSTEM

One possible mechanism to explain the evolution of fluvial depositional systems in the early Tertiary involves a tectonically controlled drop in base level between deposition of the West Foreland Formation and the Hemlock Conglomerate. This could have resulted in an increase in accommodation potential in the basin, and also facilitated greater incision of the fluvial system over time, accounting for the change in depositional style between the two formations.

FORMATION AGES

Palynological evidence indicates that the West Foreland Formation and the Hemlock Conglomerate in Katmai National Park are indeed Tertiary in age. Fission track dating suggests an Oligocene age for the Hemlock. The West Foreland Formation outcrops at Cape Douglas are inferred to represent the lowest Tertiary section in the park.

SANDSTONE COMPOSITIONS AND TEXTURES

The great majority of sandstones from both formations are lithic arenites containing major framework constituents of volcanic rock fragments, quartz, plagioclase and chert. The average compositions of the West Foreland Formation and the Hemlock Conglomerate are $Q_{43}F_7L_{50}$ and $Q_{40}F_{12}L_{48}$, respectively. The Hemlock Conglomerate contains a greater overall proportion of volcanic rock fragments compared to the West Foreland Formation which contains slightly more chert, polycrystalline quartz and metamorphic rock fragments.

Sandstone textures were largely dictated by contributions from proximal source terrains. Texturally submature samples are dispersed throughout both formations, although they are more abundant in the West Foreland Formation than in the Hemlock Conglomerate.

All primary porosity in the sandstones analyzed for this study has been occluded by a combination of compaction and cementation. Sparse secondary porosity has been created by dissolution of detrital grains and cements, and by microfractures.

SOURCE TERRAINS

The dominant source terrain for both formations was the Aleutian-Alaska Range volcanic arc to the west/northwest of the basin. Sediments were also derived from metamorphic terrains which may have included uplifted subduction complexes to the east and other metamorphic terrains north of the basin. The overwhelming influx of volcanic detritus commonly masked the contributions of metamorphic terrains.

PARAGENETIC SEQUENCE

The West Foreland Formation and the Hemlock Conglomerate in Katmai National Park exhibit the same diagenetic features, and therefore reflect the same paragenetic sequence. The sequence is similar to those developed for other formations in arc-related basins, and comprises: 1) compaction and development of clay coats; 2) calcite cementation; 3) cementation by chlorite and/or other phyllosilicates; and 4) complex replacement and alteration.

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APPENDIX I

STRATIGRAPHIC SECTIONS

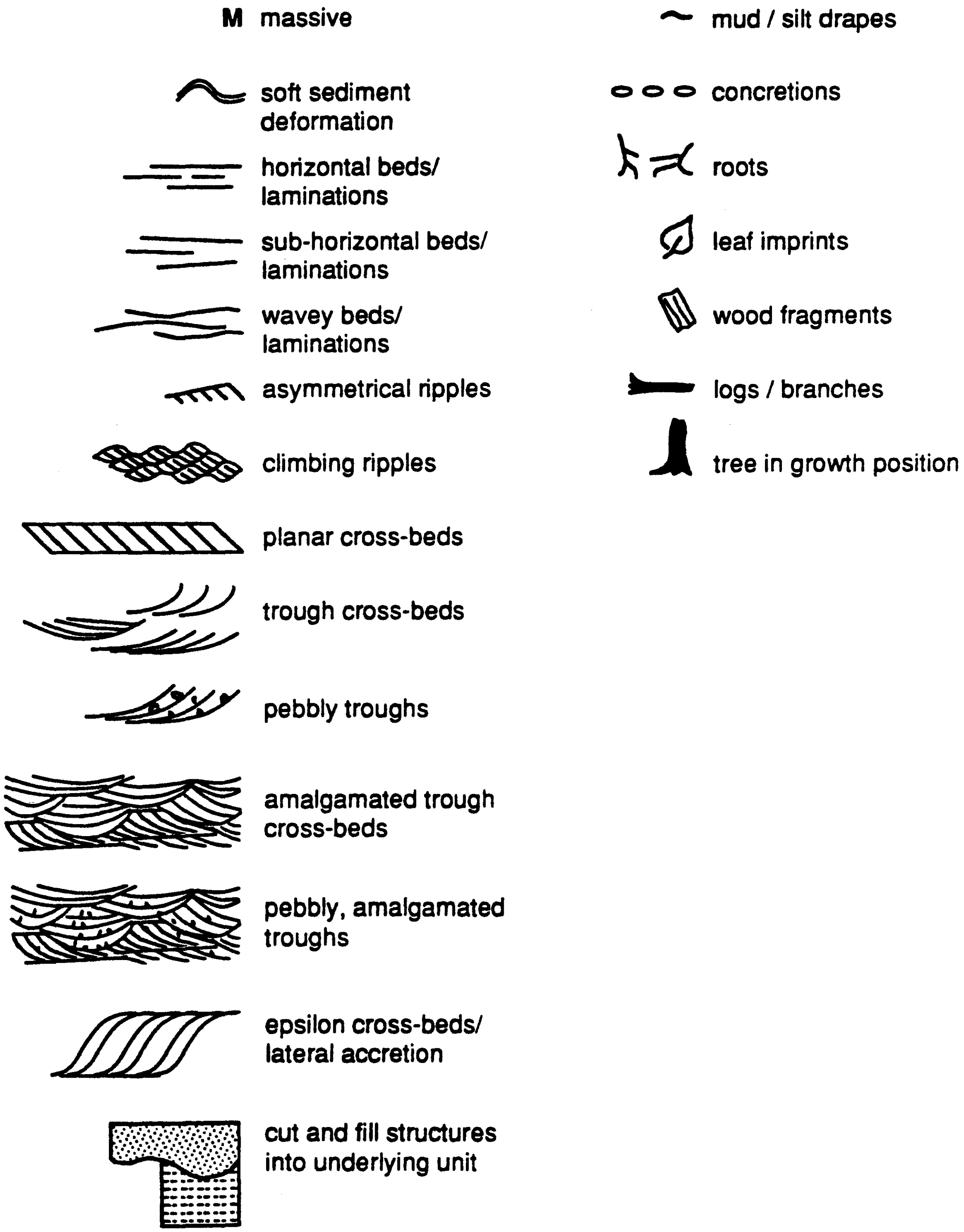
LEGEND

Abbreviations

6" - six inches
2' - two feet
abt - abundant
ARL - asymmetrical ripple laminations
avg. - average
carb. - carbonaceous
congl. - conglomerate
congl. ss - conglomeratic sandstone
diam. - diameter
frags. - fragments
int. - interbedded
max. - maximum
med. - medium
mod. - moderate
mudst - mudstone
n.g. - normally graded
org. - organized
PST - planar cross-stratification
qtz - quartz
ss - sandstone
SSD - soft sediment deformation
sltst - siltstone
sort. - sorted
tf - tuffaceous
TST - trough cross-stratification
u-c - upward-coarsening
u-f - upward-fining
vf - very fine
w/ - with
x-bed - cross bed

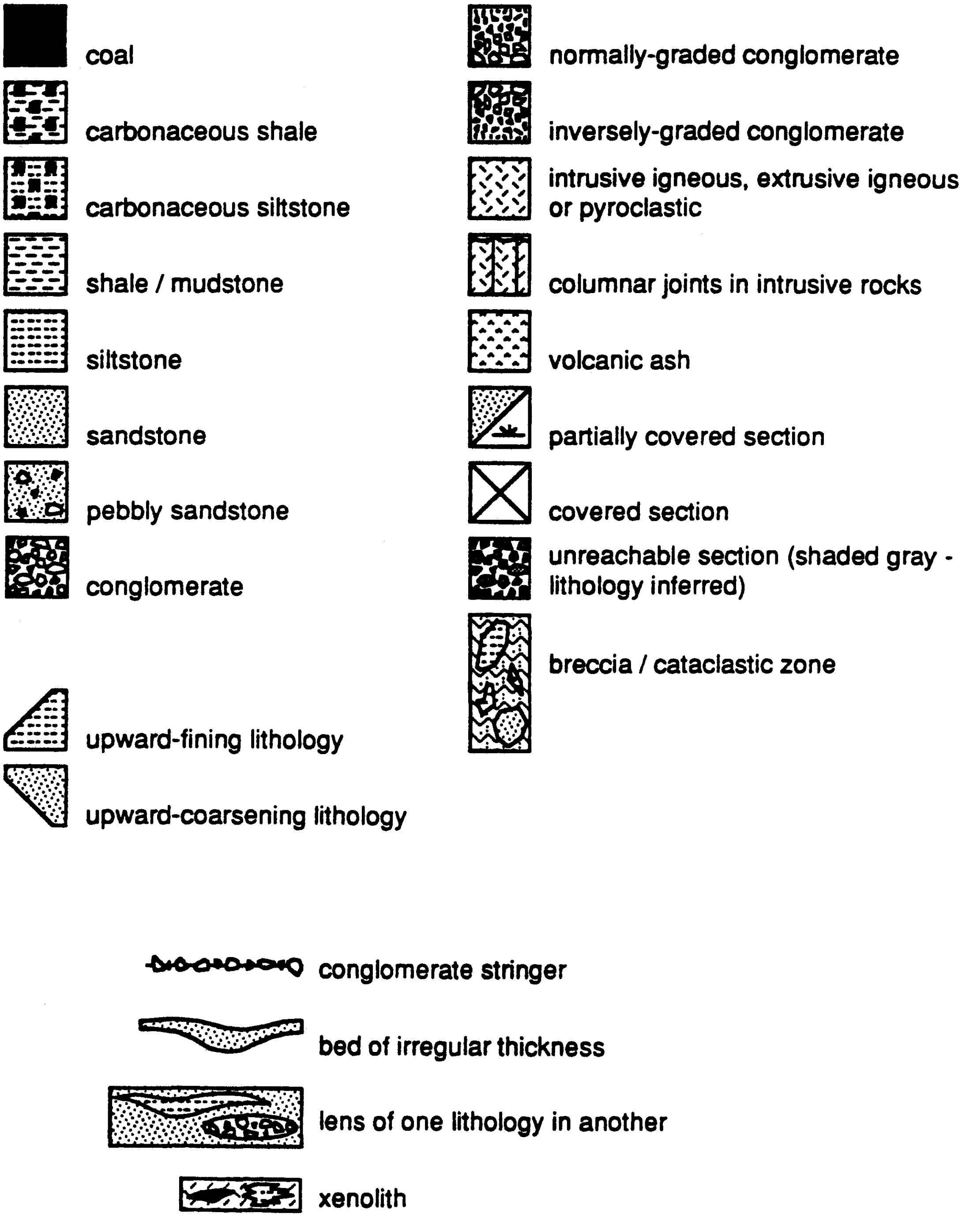
LEGEND

Sedimentary Structures and Objects



LEGEND

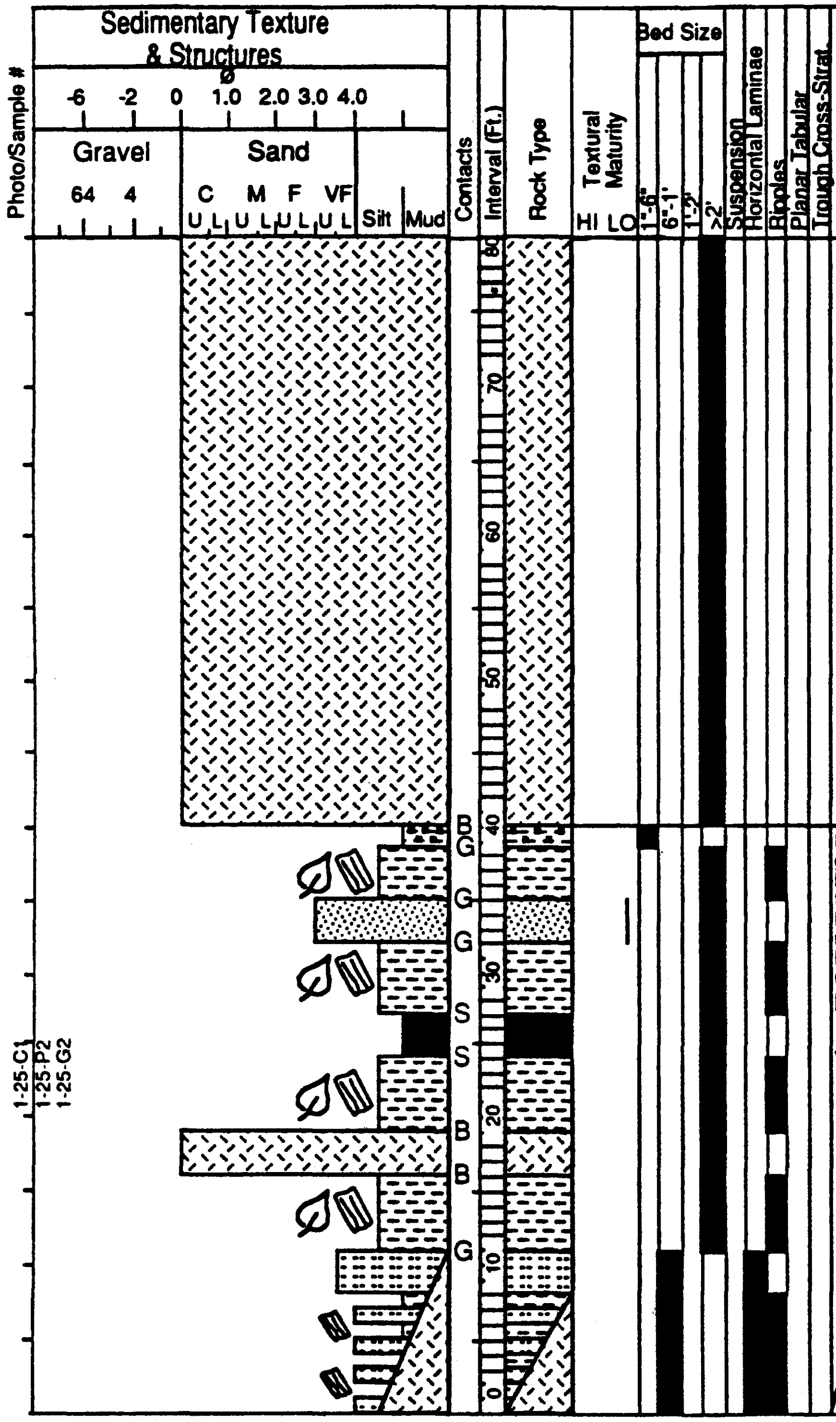
Lithologic symbols



BY Warme

Name Cape Nukshak Structural Setting gently dipping

Location NE NE, sec. 3 - NW SW, sec. 17, T.21S., R.29W. Weather cool and rainy



Date 7/22/90

Unit Hemlock Congl.

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Comments

Massive felsite dike replaces entire section. Top surface is irregular.

Interbedded black mudstone, dark gray siltstone, and sandstone. All beds are massive and baked with faint laminations visible. Sandstone has faint ARL in 2"-4" sets. Beds range from <6" to 3' thick and become increasingly carbonaceous up section. Abundant wood and plant fragments on bedding planes. Thin andesite sill present from 16 to 19 feet. Entire section is baked and very carbonaceous throughout.

Base of section is exposed over igneous rocks on Cape Nukshak itself. Section trends west then southwest.

BY Warme

Name Cape Nukshak Structural Setting gently dipping

Location NE NE, sec. 3 - NW SW, sec. 17, T.21S., R.29W. Weather clear and sunny

Date 7/22/90

Unit Hemlock Congl.

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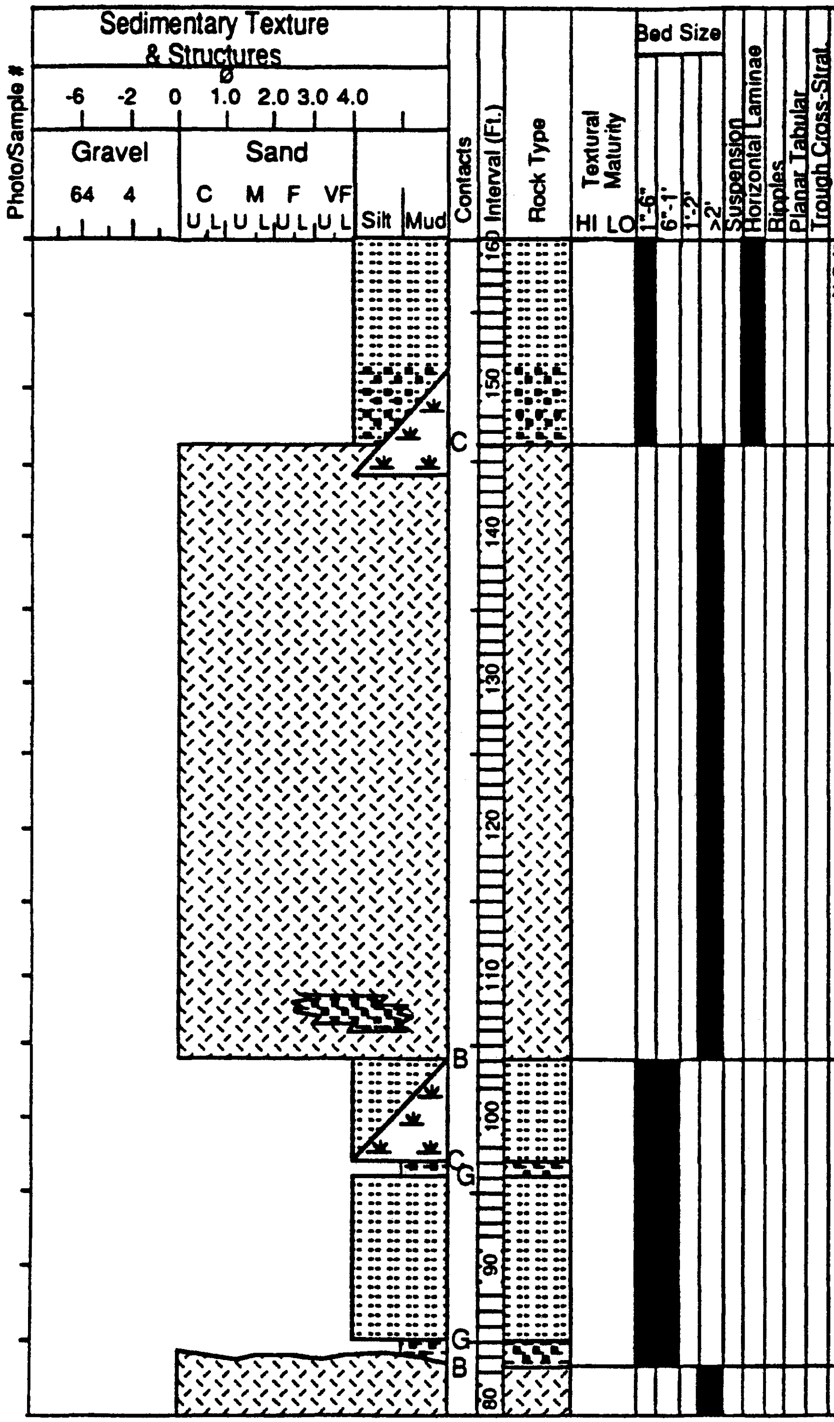


Comments

Silty shale, black, laminated. Very carbonaceous within bottom baked zone.

Large sill of relatively uniform thickness. Sill contains carbonaceous siltstone xenoliths at the base, and is cut by numerous dikes. Upper contact with siltstone is obscure.

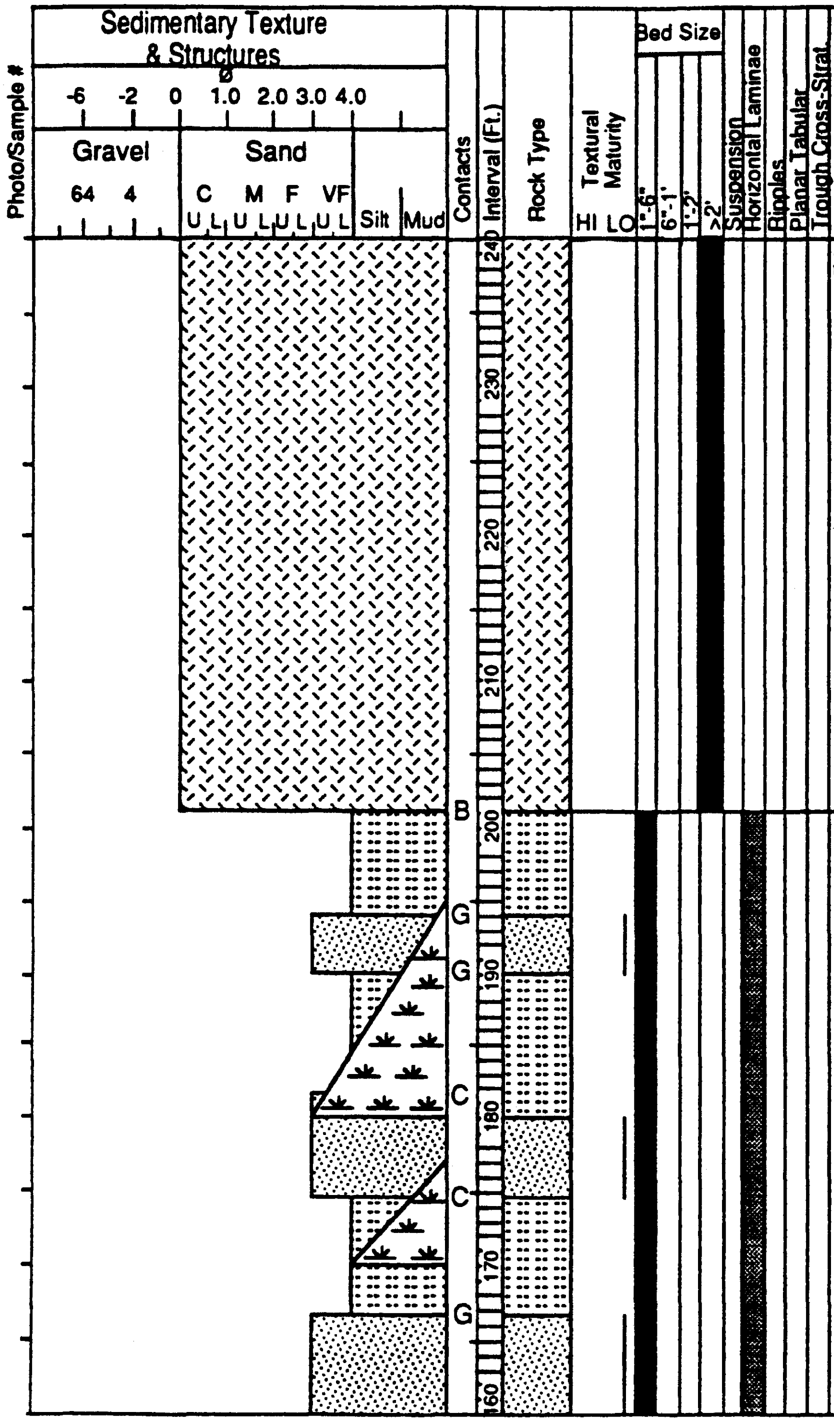
Interbedded siltstone with claystone partings. Thin carbonaceous mudstone beds. Possible thin coal beds. Sequence is baked.

Dike becomes a sill of irregular thickness at top.

BY Warme

Name Cape Nukshak Structural Setting gently dipping

Location NE NE, sec. 3 - NW SW, sec. 17, T.21S., R.29W. Weather clear and sunny



Date 7/22/90

Unit Hemlock Congl.

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Comments

Large sill of relatively uniform thickness.

Unusually thick fine-grained package. No medium to thick bedding. All units thinly bedded or very thinly laminated. Sandstones are gray and massive with faint thin to very thin laminations. Siltstones are interbedded with silty mudstones, with a few silty sandstone interbeds. Siltstones are also massive with faint thin to very thin laminations. Top siltstone is moderately carbonaceous with increased silty sandstone interbeds. Upper contact is baked.

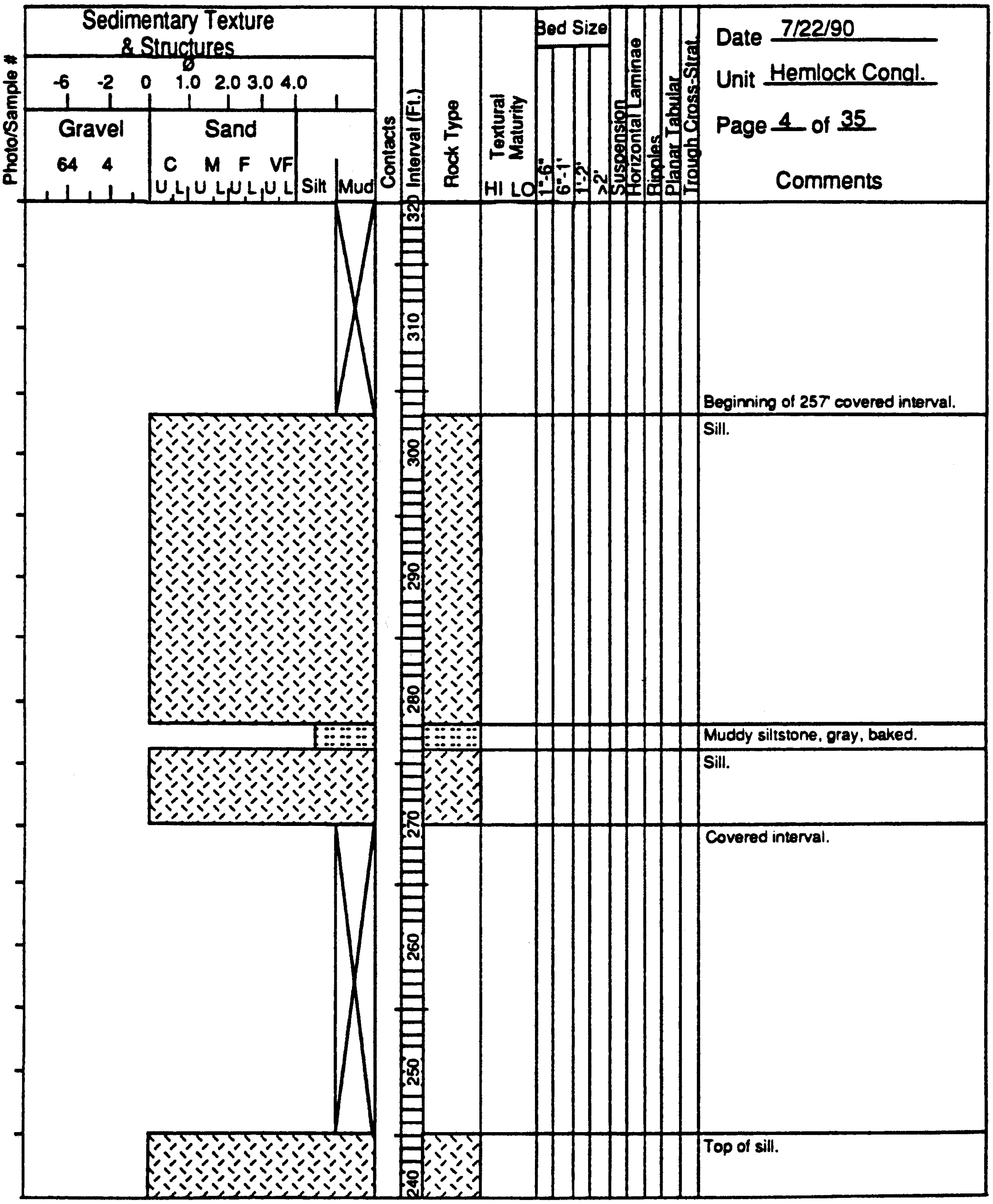
BY Warme

Name Cape Nukshak

Structural Setting gently dipping

Location NE NE. sec. 3 - NW SW. sec. 17. T.21S., R..29W.

Weather clear and sunny



Date 7/22/90

Unit Hemlock Congl.

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Comments

Beginning of 257' covered interval.

Sill.

Muddy siltstone, gray, baked.

Sill.

Covered interval.

Top of sill.

BY Warme

Name Cape Nukshak

Structural Setting covered

Location NE NE. sec. 3 - NW SW. sec. 17, T.21S., R.29W.

Weather cool and sunny

Date 7/22/90

Unit Hemlock Congl.

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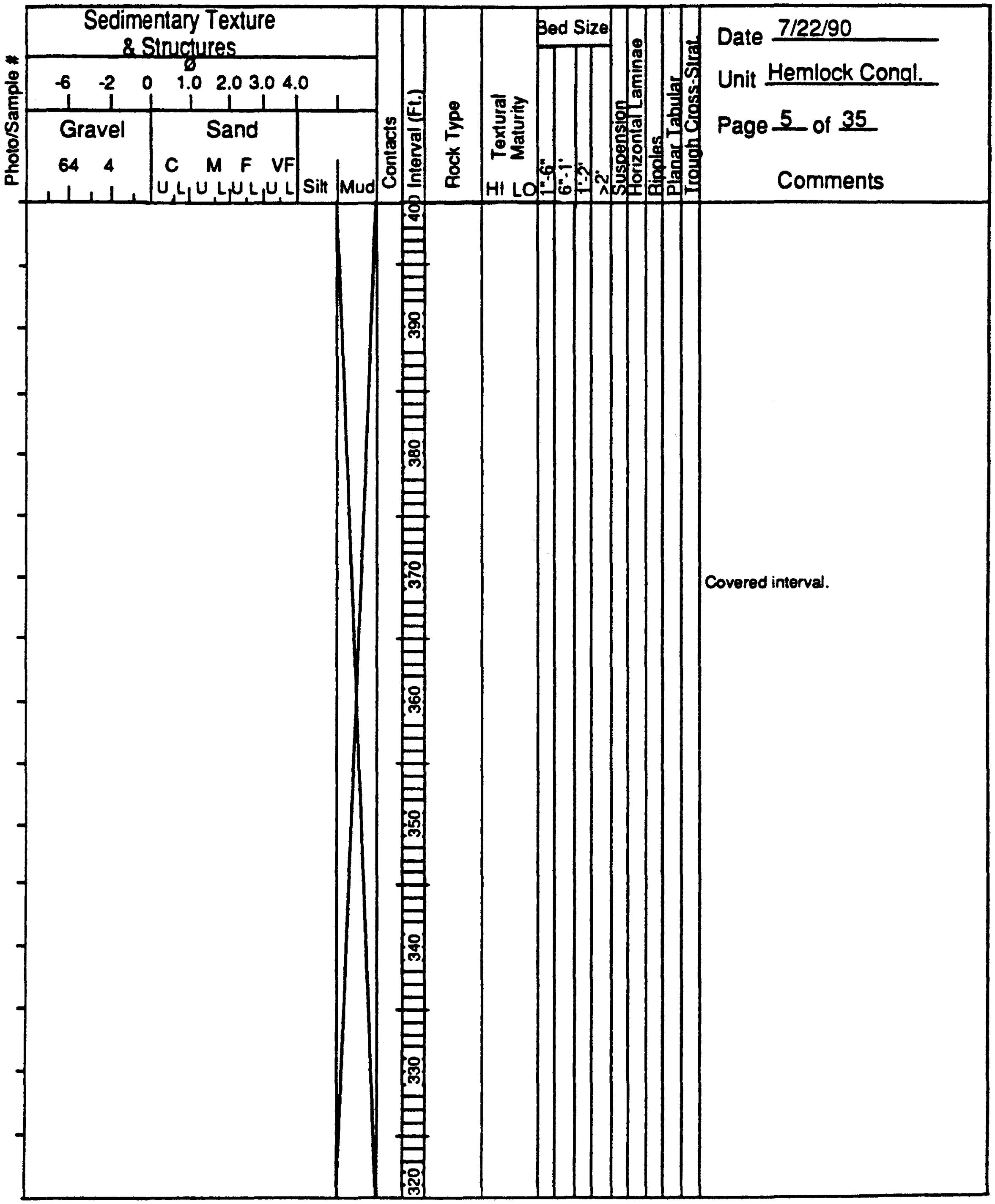

Covered interval.

BY Warme

Name Cape Nukshak Structural Setting covered

Location NE NE. sec. 3 - NW SW. sec. 17, T.21S., R.29W. Weather cool and sunny

Date 7/22/90

Unit Hemlock Congl.

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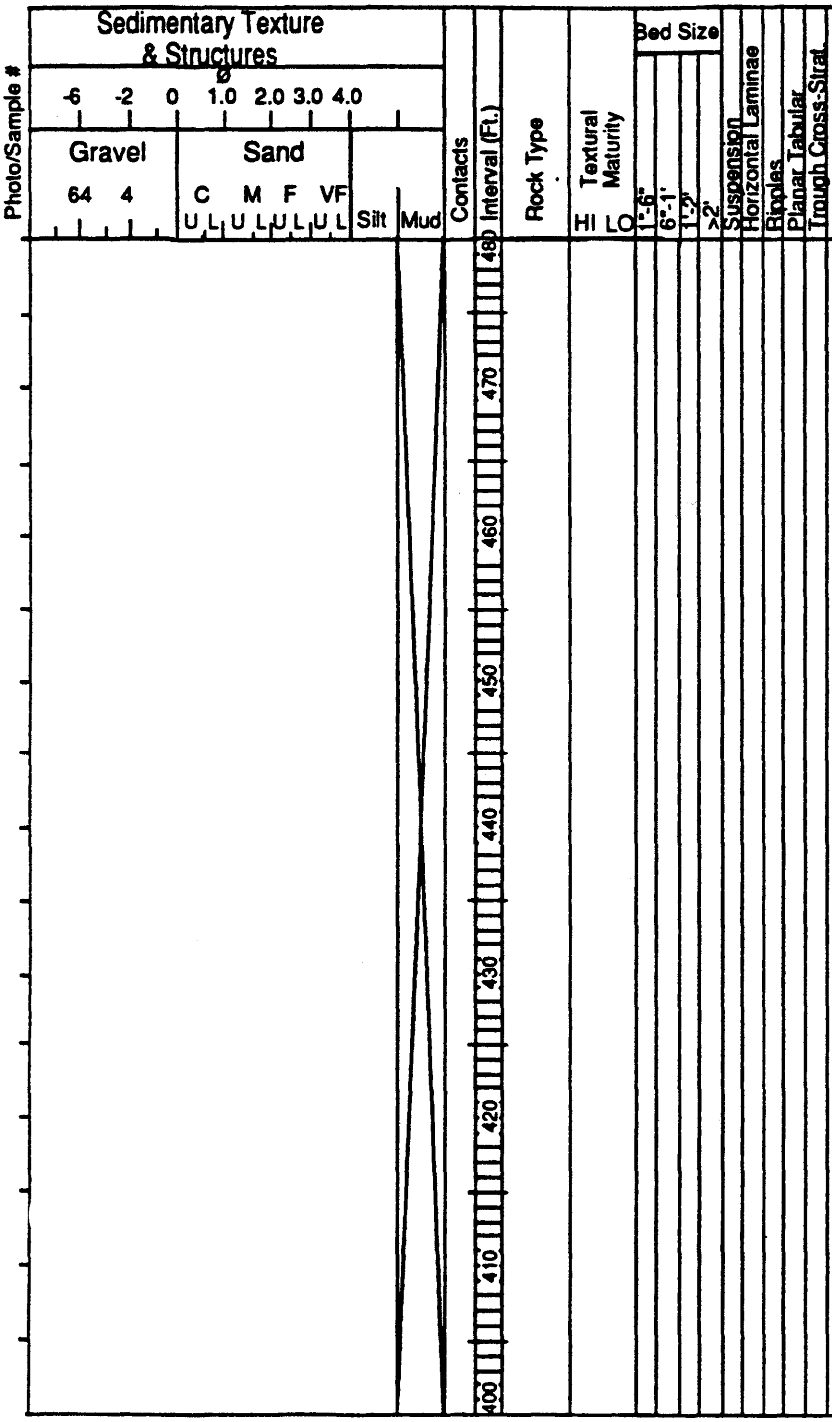

Comments

Covered interval. Inferred from out of place slump blocks to be mudstone and siltstone. Interval forms low relief beach between adjacent promontories.

BY Houston

Name Cape Nukshak

Structural Setting covered

Location NE NE, sec. 3 - NW SW, sec. 17, T.21S., R.29W.

Weather clear and sunny

Date 7/22/90

Unit Hemlock Congl.

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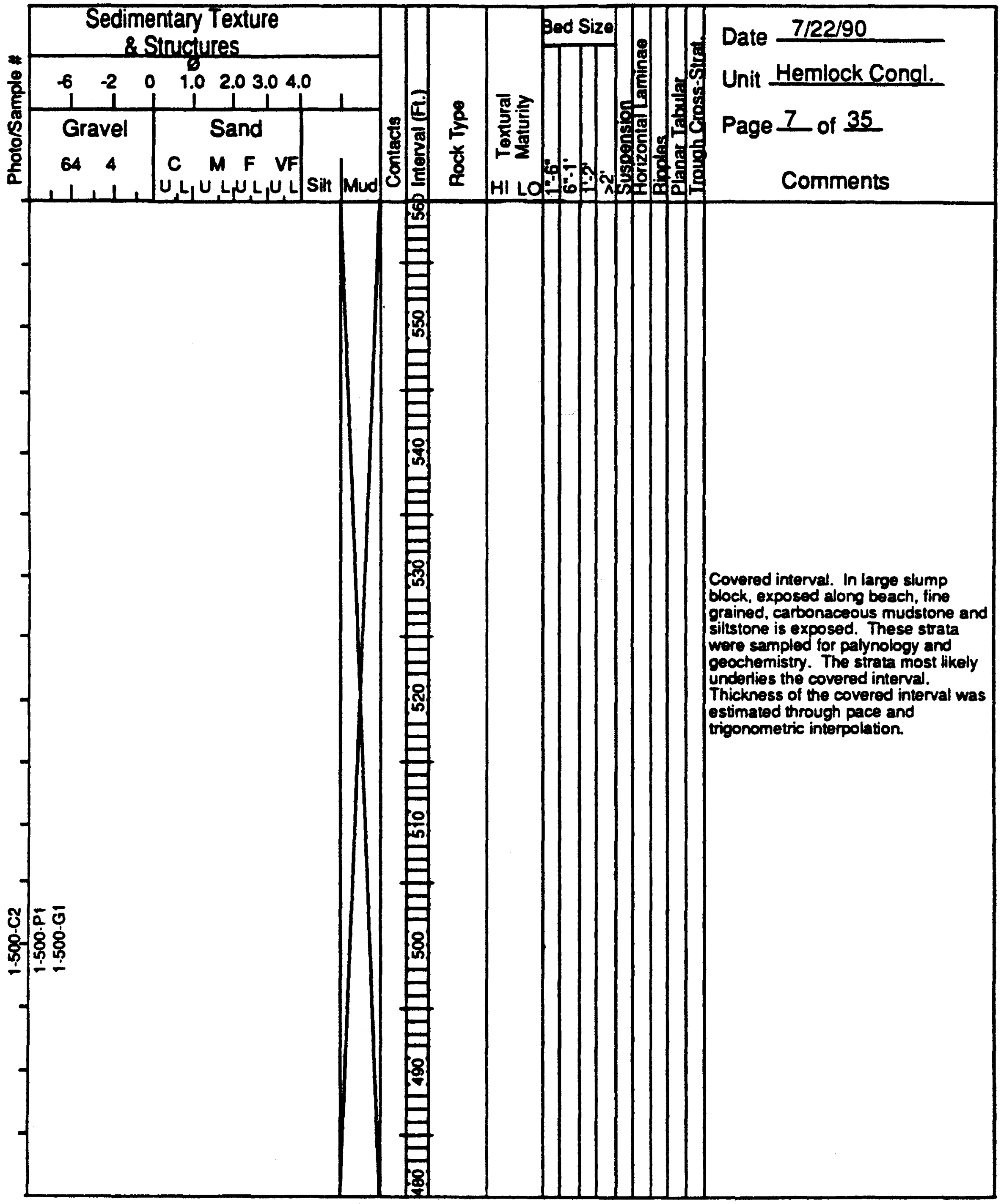
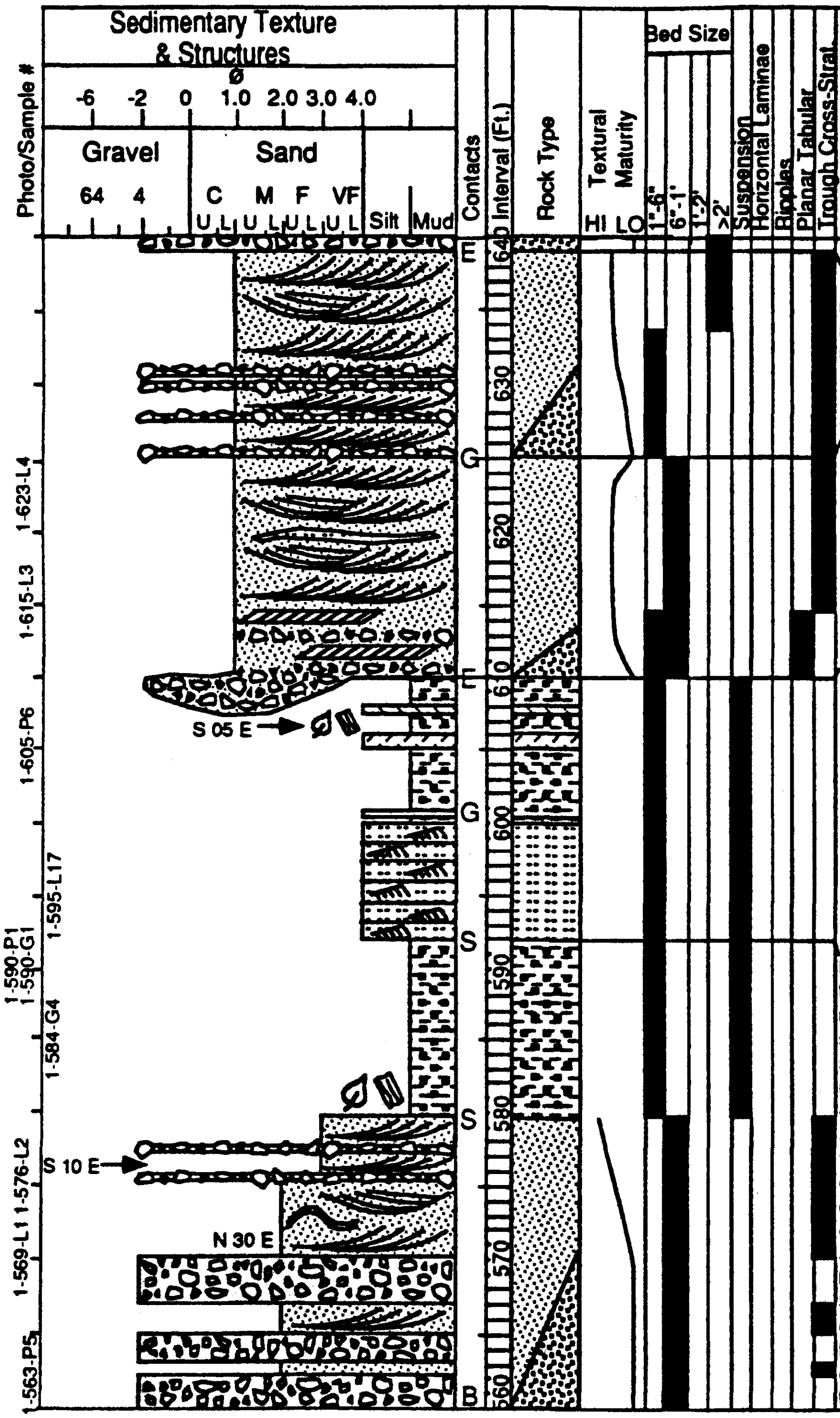


Covered interval. In large slump block, exposed along beach, fine grained, carbonaceous mudstone and siltstone is exposed. These strata were sampled for palynology and geochemistry. The strata most likely underlies the covered interval. Thickness of the covered interval was estimated through pace and trigonometric interpolation.

BY Gardener and Houston

Name Cape Nukshak Structural Setting N 75 E, 16 SE

Location NE NE sec. 3 - NW SW sec. 17, T.21S., R.29W. Weather clear and sunny



Date 7/16/90

Unit Hemlock Congl.

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Comments

[See next page.]

Interbedded, medium-bedded ss and matrix supported conglomerate at the base in pebble lens that grades upward to sandstone, TST in 6"-1' sets with normally graded foreset beds grading from pebbles to coarse ss. Large TST beds >2' near the top.

Sandstone, gray-green, poorly to moderately sorted, sub-angular with thin cobble lag <4" at base, 5% clasts with tuff fragments Tool marks and crude grain imbrication in opposition to TST. Sandstone forms massive unit with faint PST at base in <6" sets grading upward to lenticular TST with thin siltstone drapes with upper bar form thinning to the northwest.

Upward-fining sequence of sandstone at base grading to silty mudstone at top. Unit becomes increasingly carbonaceous upward. Mudstone, black, laminated with thinly bedded siltstone interbeds. Thin felsite sills (1') with chilled margins, injected and deformed with motion along bedding planes. Sandstone, tuffaceous, gray, laminated, with ARL in 1"-2" sets with minor SSD. Unit forms distinctive marker.

Muddy siltstone, black, thinly laminated, carbonaceous with abundant plant material on bedding planes. Coaly streaks at top. Upward-fining sequence of interbedded ss and ss matrix supported conglomerate with 5-40% clasts. Clasts consist of quartz, and plutonic and volcanic rock fragsments. This unit is moderately organized into 3 upward-fining units all of which are marked by conglomeratic channel lag at base overlain by TST and PST in <1' sets overlain by thinly bedded ss with pebble lags. Minor SSD near top. Base of section starts on black laminated siltstone that has been intruded by felsite sill that displays undulatory baked contact between siltstone and sill.

BY Gardener and Houston

Name Cape Nukshak Structural Setting N 75 E, 16 SE

Location NE NE sec. 3 - NW SW sec. 17 T.21S., R.29W. Weather clear and sunny

Date 7/16/90

Unit Hemlock Congl.

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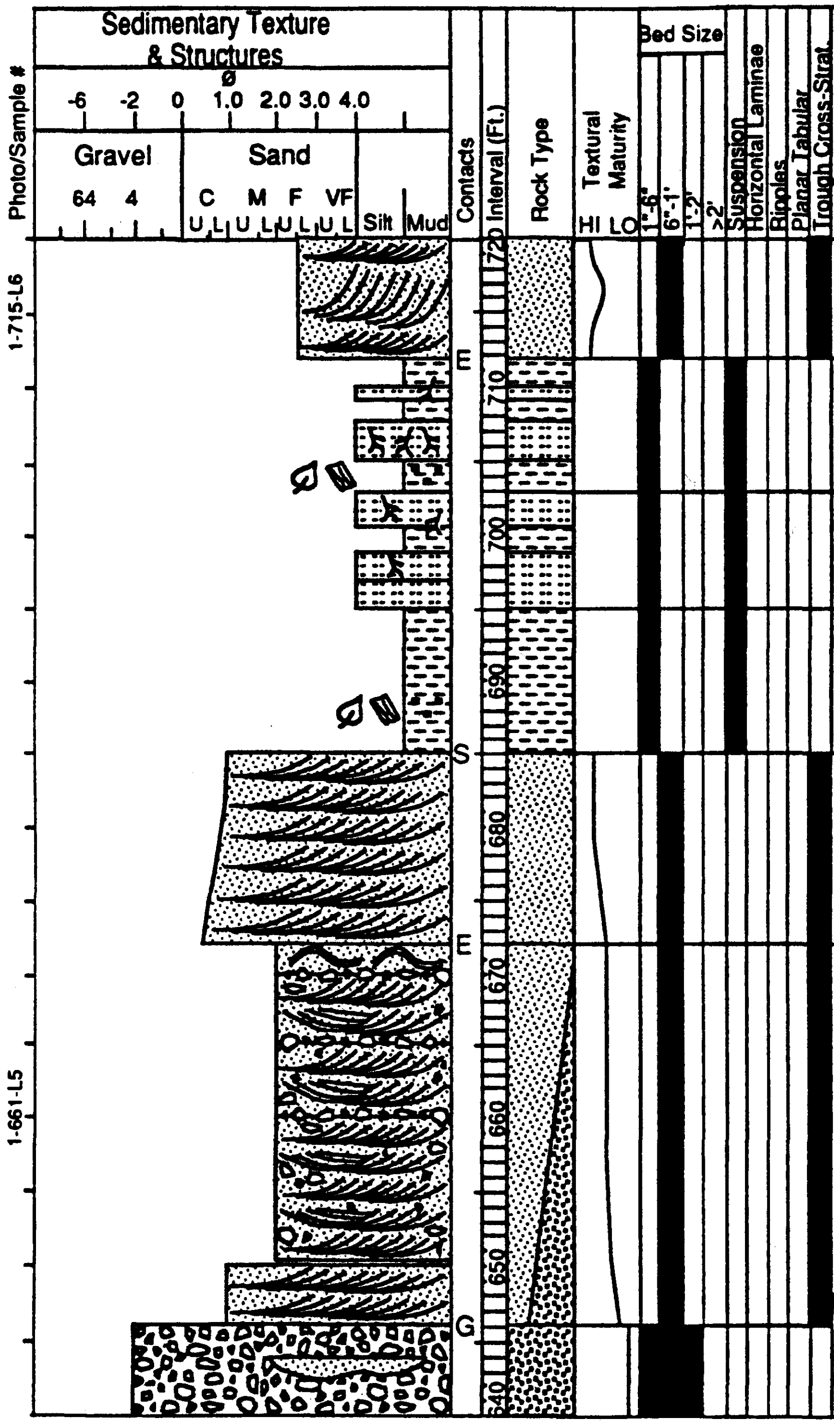


Comments

[See next page.]

Interbedded siltstone, light gray, massive and mudstone, black with abundant carbonaceous laminations. Siltstone beds are extensively rooted.

Siltstone, light gray, massive at base with thin shale partings at top, rooted.

Mudstone, black, laminated with abundant wood impressions and thin coaly streaks. Unit becomes increasingly carbonaceous upward.

Sandstone, tan-gray, moderately sorted, with faint TST in 8" sets. Abundant, thinly bedded mudstone to siltstone interbeds define individual sandstone beds.

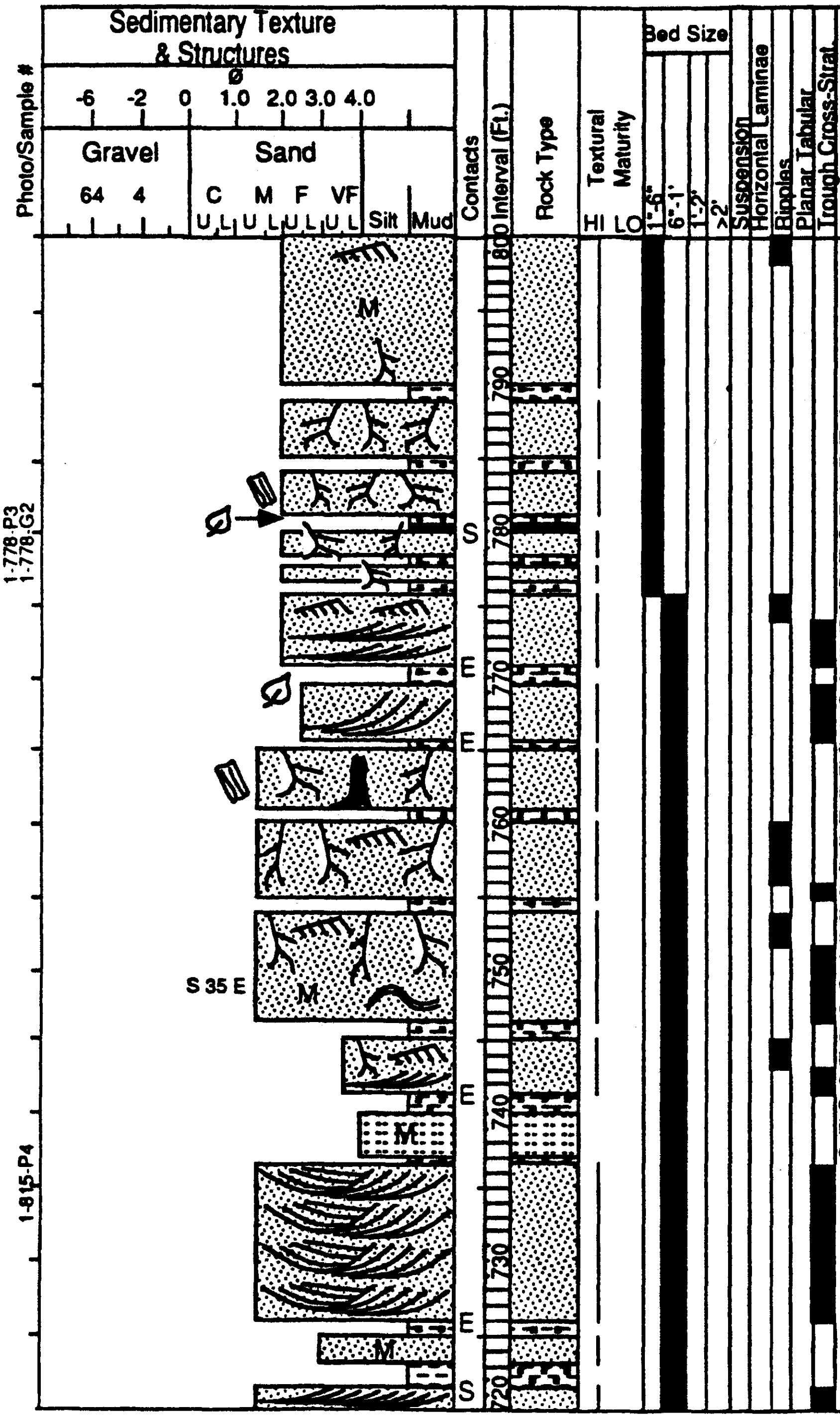
Sandstone, tan-gray, moderately to poorly sorted with pebble lags and some angular mud rip-ups on basal bounding surfaces. TST with normally graded foresets in 6"-1' sets with thin mud drapes present on some foreset beds. Minor SSD at top of unit.

Pebble conglomerate, matrix supported, with thin coarse sandstone interbeds organized into 3 scour and fill units. Beds range from 3"-8" thick. Conglomerate contains 50% clasts.

BY Gardener and Houston

Name Cape Nukshak   Structural Setting N 75 E, 16 SE

Location NE NE, sec. 3 - NW SW, sec. 17, T 21S., R 29W   Weather clear and sunny



Date 7/16/90

Unit Hemlock Congl.

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Comments

Interbedded sandstone, light gray, thinly laminated; mudstone, black, laminated, carbonaceous; thinly bedded siltstone, dark brown. Sandstone beds are massive with roots penetrating the tops and extending down up to 2'. Mudstone beds are laterally discontinuous, range from <1'-3" thick, and contain abundant wood and leaves on bedding planes. Mudstone beds interfinger with bounding sandstone and siltstone beds. Sandstone beds exhibit TST in 6"-1' sets, abundant SSD in the form of wavy bedding and anti- and syn-forms. Subordinate ARL in 1"-2" sets at the top of some ss beds. Load structures present at basal contacts of sandstone beds. Siltstone beds are massive, rooted, and contain thin sandstone streaks and wispy carbonaceous mudstone partings throughout. In general, sandstone beds thin to the north and thicken to the south exhibiting an overall lensoid, channel-form geometry. Upright tree in growth position present from 761'-765' in profile. Predominant paleocurrent direction S 10 E, but diverse orientations in north direction indicated at 772'. Fault with minor displacement present at 784'.

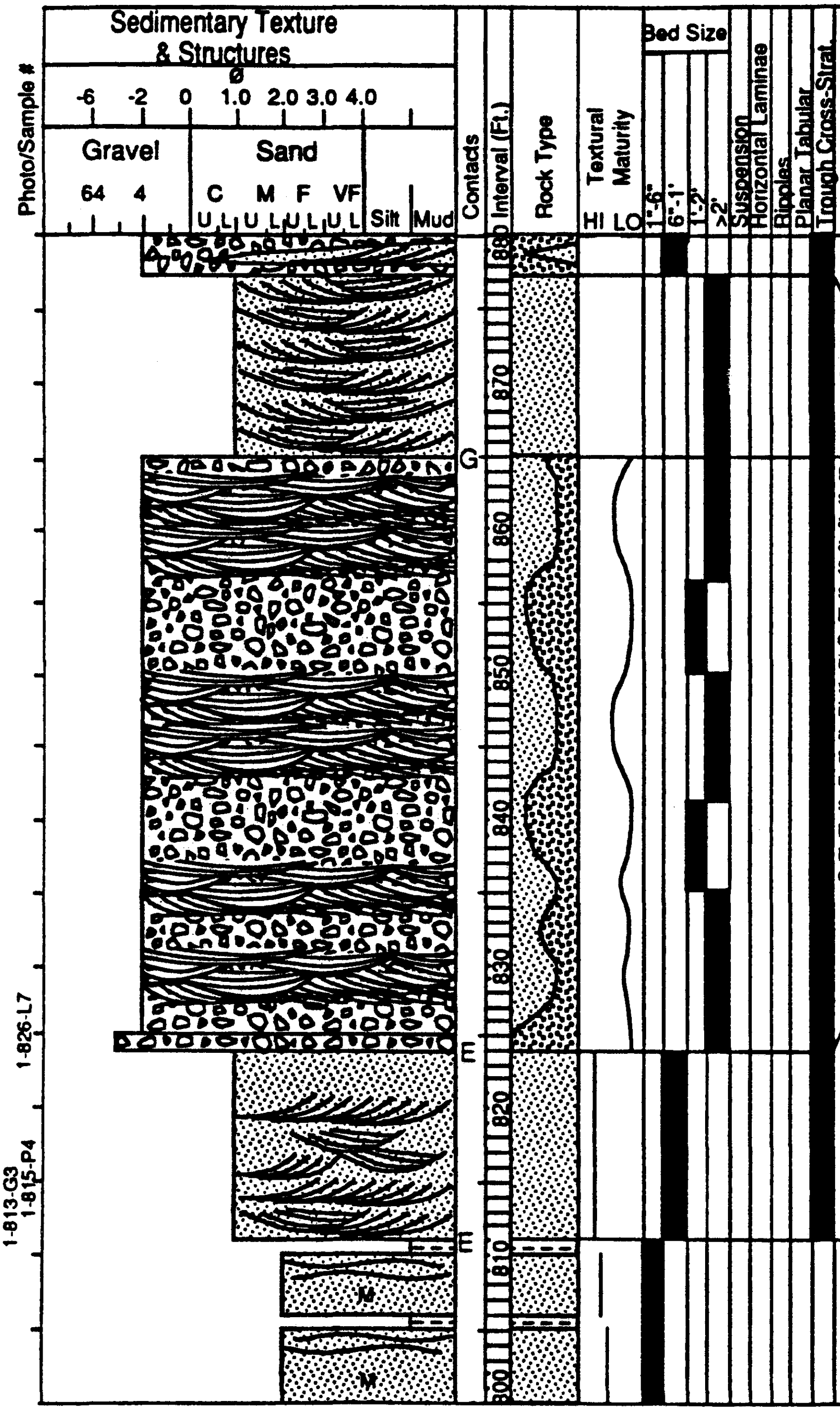
BY Gardener and Houston

Name Cape Nukshak

Structural Setting N 75 E. 16 SE

Location NE NE. sec. 3 - NW SW. sec. 17 T.21S. R.29W.

Weather clear and sunny



Date 7/16/90

Unit Hemlock Congl.

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Comments

Sandstone, light gray, with thinly interbedded conglomeratic lenses. TST in 1' sets.

Sandstone, light gray, with large-scale TST (up to 5' beds) marked by thin conglomerate lags.

Interbedded cobbly, coarse sandstone, matrix-supported conglomerate and sandstone. Clasts up to 31" across present in conglomerate. Several long-axis oriented angular shale rip-ups at base of major bounding surfaces with cobble clasts crudely imbricated. Unit organized into 2'-8' thick upward-fining sequences typically capped by TST ss in 2"-3' sets. Discrete beds are thicker at the base than in the middle, and thicken at the top. Overall unit crudely upward-fining with higher proportion of sandstone at top. Clasts are tightly packed at the base and more loosely packed at top. Unit forms massive cliff.

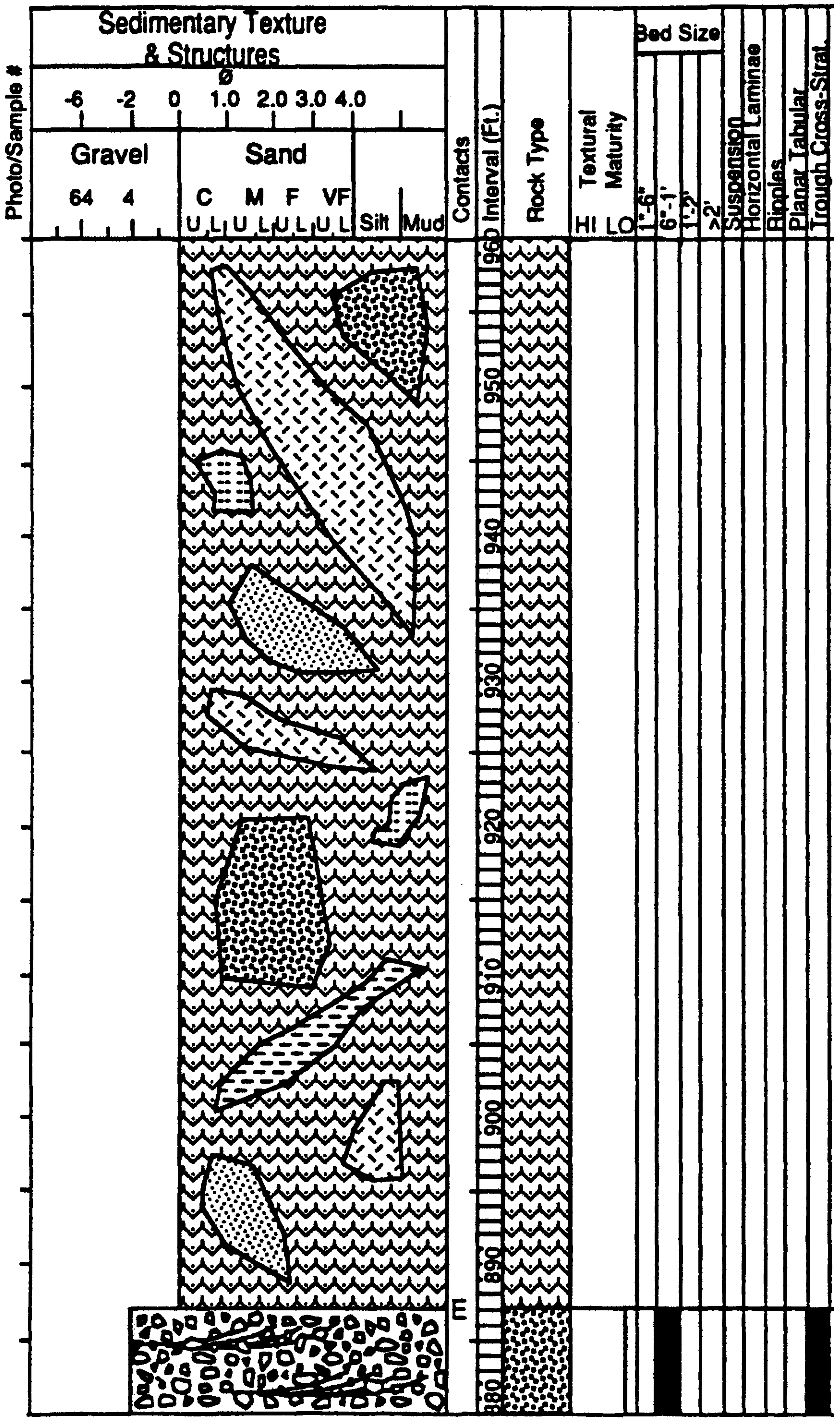
Sandstone, light gray, moderately sorted, uni-directional TST in 1' sets. Unit thins to the north along outcrop and exhibits lenticular channel-form geometry. Major bounding surface extends from upper right to lower left of sandstone forming smaller-order lenticular geometry within sandbody.

[See previous page.]

BY Gardener and Houston

Name Cape Nukshak Structural Setting dike/fault breccia

Location NE NE. sec. 3 - NW SW. sec. 17, T.21S., R.29W. Weather clear and sunny



Date 7/16/90

Unit Hemlock Congl.

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Comments

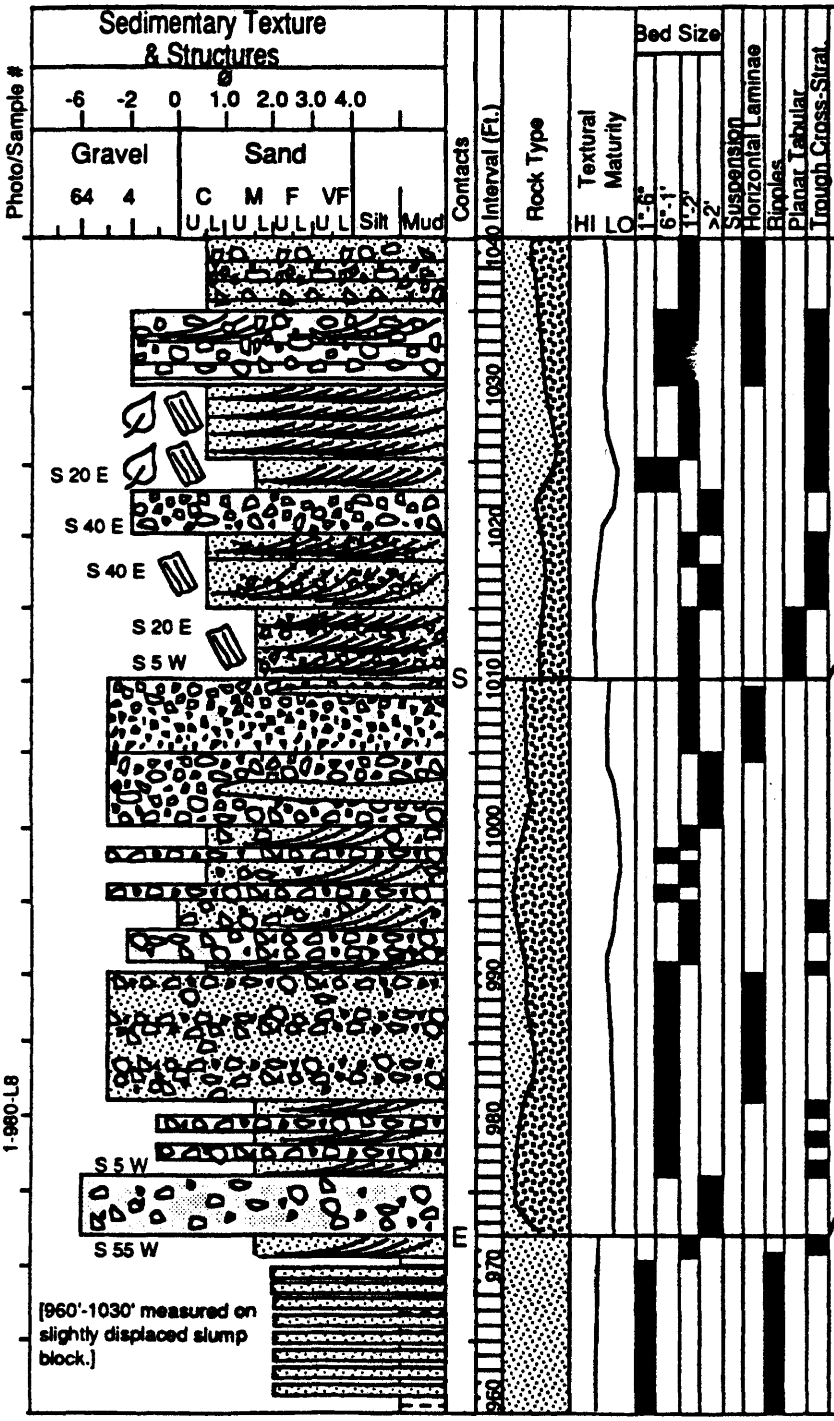
Series of dikes run subparallel to beach bounded by high angle normal faults with minor displacement. Entire stratigraphic section removed or covered by a cataclastic fault(?) breccia. Large 5'-10' wide blocks of deformed sedimentary strata, including conglomerate, sandstone and siltstone appear to float in aphanitic to phaneritic andesite matrix and conglomeratic sandstone. Basal contact between underlying in-place sandstone and overlying breccia is marked by irregular surface that extends entire length of cliff face and truncates stratigraphic section. Upper contact is marked by dike in contact with overlying conglomerate that caps southernmost point of beach near sea cave that exposes trends of dike and breccia. Within breccia are series of irregular dikes that cross-cut outcrop. Relationship between breccia and stratigraphic section is enigmatic due to lack of exposure, orientation of cliff face, and trend of the fault and dikes.

[See previous page.]

BY Gardner and Houston

Name Cape Nukshak Structural Setting N 65 E 17 SE

Location NE NE sec. 3 - NW SW sec. 17 T 21S R 29W Weather bright sun



[960'-1030' measured on slightly displaced slump block.]

Date 7/18/90

Unit Hemlock Congl.

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Comments

Interbedded sandstone and conglomeratic sandstone. Sandstone, poorly sorted, PST at base in 1'-2' sets grading upward to TST in 4"-2' sets. Conglomeratic sandstone, poorly sorted, medium-grained, matrix-supported conglomerate with clasts up to 4". Clasts comprise10% of rock with clasts up to 3". Clast composition includes: tuff, chert, quartz and plutonics. Conglomeratic sandstone is horizontally bedded to TST in 1'-2' sets with normally graded foresets. Abundant wood and leaf imprints on bedding planes.

Interbedded coarse sandstone, matrix-supported conglomerate and conglomeratic sandstone. Unit is poorly sorted with conglomerate beds poorly to moderately organized with 20-30% clast composition. Maximum clast size is 8" with 4" mudstone rip-ups and average clast size of 2". Clasts consist of quartz , black and gray chert, tuff, plutonics, mud rip-ups. Conglomerate beds exhibit crude horizontal stratification and are moderately organized with some inverse grading. Individual beds laterally discontinuous lenses of sandstone. Conglomeratic sandstone is medium to coarse grained, poorly sorted, sub-angular with abundant pebbles and wood scattered throughout. Sandstone is TST in 6"-8" sets. Mudstone rip-ups define major bounding surfaces. Tool marks on basal bounding surfaces.

Interbedded sandstone and mudstone. Sandstone is moderately sorted, ARL in 1"-3" sets with thinly bedded mudstone interbeds. Mudstone, black, laminated. Basal contact with brecciated zone marked by silty, black, laminated mudstone bed.

BY Gardner and Houston

Name Cape Nukshak Structural Setting N 75 E, 20 SE

Location NE NE sec. 3 - NW SW sec. 17, T 21S, R 29W Weather bright sun

Date 7/18/90

Unit Hemlock Congl.

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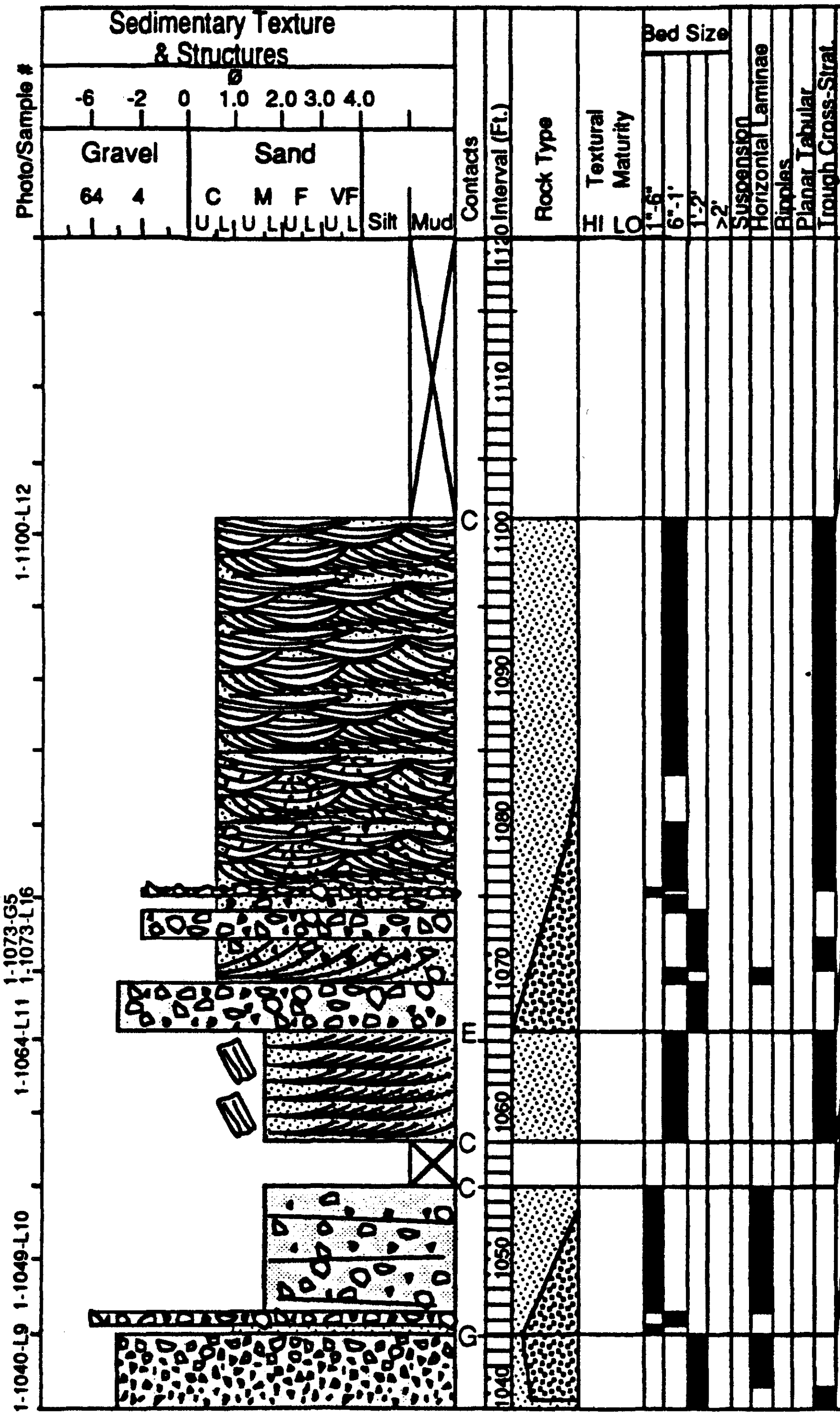


Comments

Covered interval interrupted by 30' thick felsite dike with abundant hornblende. Dike trend is N 30 W. Thickness of covered slope estimated as section was traversed to base of next exposure.

Upward fining sequence of conglomerate at base and sandstone at top. Conglomerate, poorly sorted, coarse sandstone matrix supported, 15 - 30 % clasts. Conglomerate is poorly organized into crude horizontal beds with inverse grading in basal bed and crude normal grading in overlying bed. Maximum clast size is 6". Sandstone, moderately sorted with TST in 8" sets at base with scattered pebbles along foresets that grade upward to amalgamated TST in 6" - 8" sets with minor carbonaceous rip-up clasts. Overall decrease in pebbles toward top.

Sandstone, dark gray, moderate to well sorted, wood debris and shale stringers along bedding planes. Scattered pebbles (<1% clasts) and TST in 6" sets.

Covered interval.

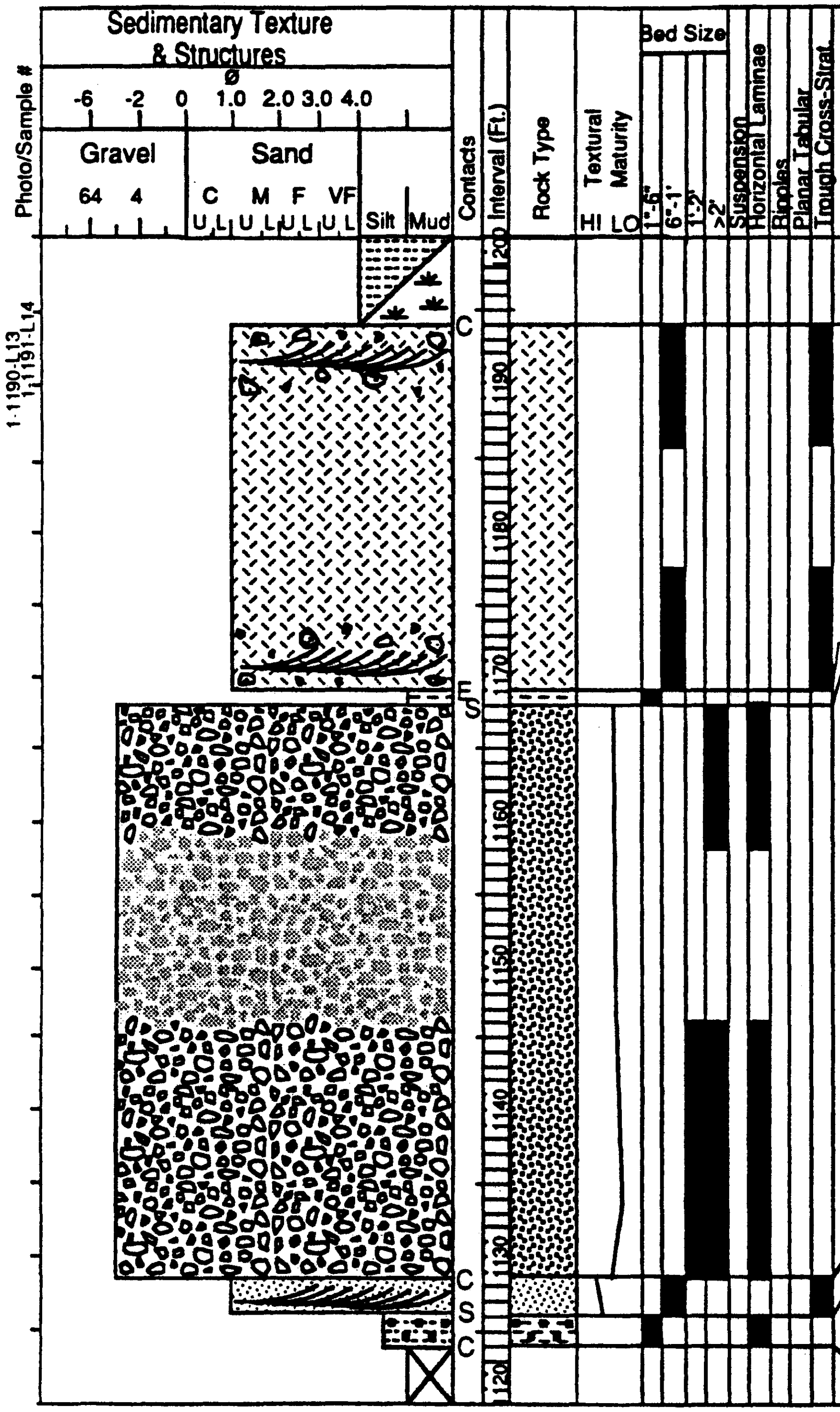
Conglomeratic sandstone, moderately sorted, well indurated with faint, thinly bedded horizonontal stratification. 5% clasts, maximum clast diameter 5". Unit thickens to south.

Conglomerate, sandstone matrix supported, poor to moderately organized. 10-15% clasts, maximum diameter 3". Crude TST and horizontal beds. Crude normal grading in discrete beds with overall unit inversely graded.

BY Gardner and Houston

Name Cape Nukshak Structural Setting N 75 E, 20 SE

Location NE NE sec. 3 - NW SW sec. 17 T 21S R 29W Weather bright sun



Date 7/18/90

Unit Hemlock Congl.

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Comments

Massive siltstone, partly covered.

Lithic tuff, light gray, phaneritic with Ca-plagioclase, glass shards and conglomeratic sedimentary rock clasts . Basal and upper portions, TST in 6"-1' sets. Forms laterally continuous unit at beach level that can be traced south through three adjacent coves south of Cape Nukshak toward Yugnat rocks.

Mudstone, black, laminated.

Conglomerate, poorly sorted, matrix supported (medium grained sandstone) to clast supported at top. 10-15% clasts at base, maximum clast diameter 4". Many clasts are sheared in bottom 15'. Unit poorly organized with very crude horizontal strata to massive appearance. Unit forms massive cliff at south end of cove. Middle portion of unit (shaded gray) is not reacheable but is conglomeratic and similar in appearance to bounding strata. Basal 17' of conglomerate is exposed between 2 vertical andesitic dikes. Base of conglomerate block is marked by pronounced cataclastic gouge with 6' allochthonous blocks. Measured section offset to south side of southernmost sill where conglomerate forms cliff. Upper contact of conglomerate is laterally continuous and can be traced to the south where it caps cliff face.

Sandstone, TST in 6" to 1' sets.

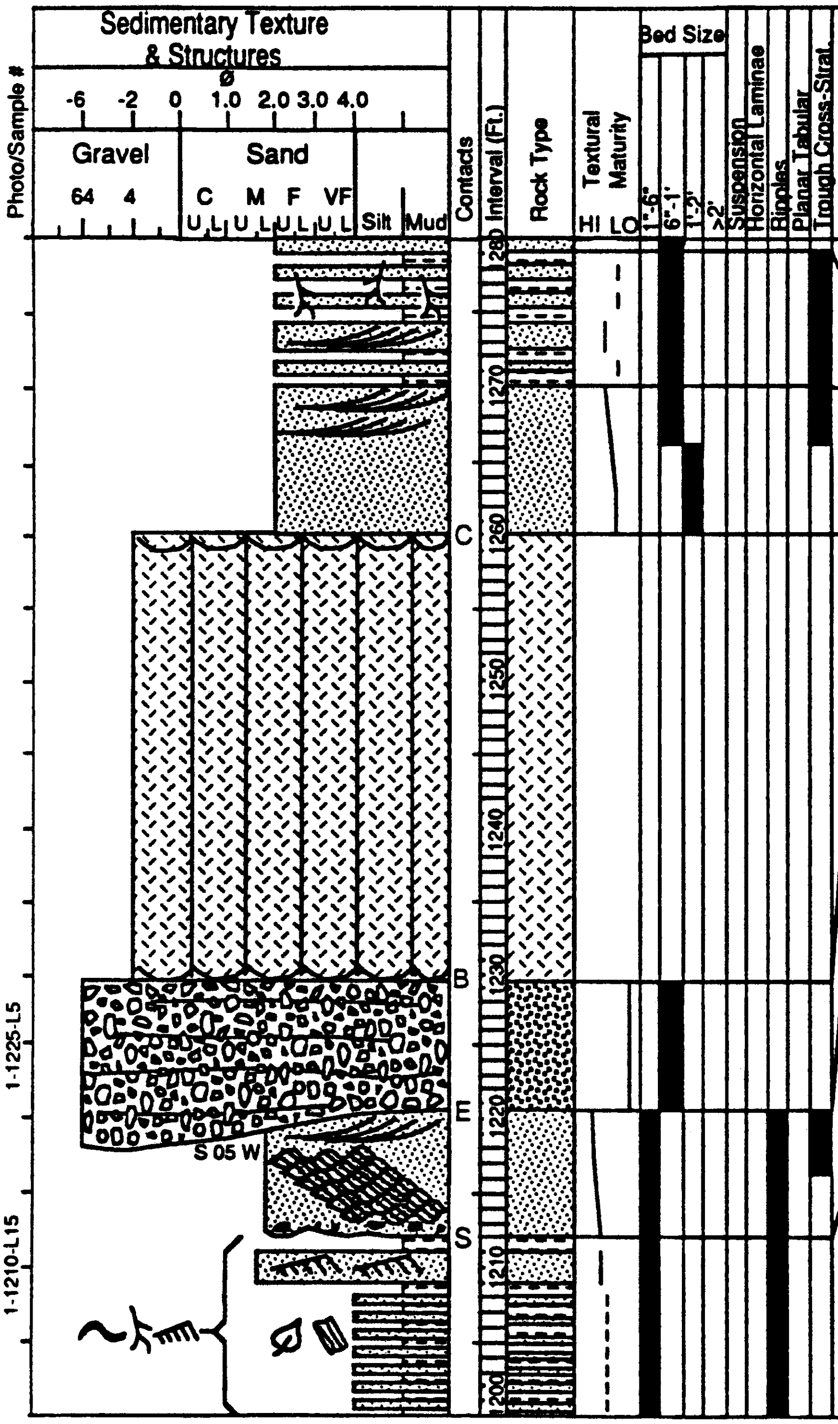
Silty mudstone, black, laminated, carbonaceous. Deformed via intrusions.

Covered interval

BY Gardner and Houston

Name Cape Nukshak Structural Setting gently dipping w/ abt. dikes and sills.

Location NE NE sec. 3 - NW SW sec. 17 T 21S R 29W Weather still beautiful!



Date 7/18/90

Unit Hemlock Congl.

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Comments

[See next page.]

Interbedded tuffaceous sandstone and siltstone. Sandstone beds 1'-2' thick, rooted with faint TST in 6" to 1' sets. Siltstone, black, carbonaceous, laminated. SSD and wavy bedding

Sandstone, moderately sorted, tuffaceous. Faint TST in 6" to 1' sets near top of unit.

Andesite sill, with baked mudstone(?) along top. Distinctive columnar joints allow unit to be traced along outcrop. Abundant Ca-plagioclase phenocrysts and glass shards. 30' maximum observed thickness; 15' minimum observed thickness.

Conglomerate, reddish-brown, clast supported with 30-40% clasts. Clast composition includes: volcanics, chert, plutonics. Normally graded beds in 1' sets. Unit scours out underlying sandstone. Unit faulted out to south by fault at sea cave. Dike cuts outcrop at fault.

Sandstone, brownish-red, well sorted, sub-horizontally bedded with climbing ARL in 1"-3" sets at base grading to TST in 4" - 6" sets at top. Minor SSD seen in thin 1"- 2" mudstone beds. Possible epsilon cross-bedding present in unit. Coal and carbonaceous rip-ups in basal scour; unit thins to northeast.

Upward coarsening sequence of thinly interbedded sandstone and mudstone. Sandstone, well sorted, ARL n 1'-3' sets. Rooted, moderately tuffaceous, minor SSD. Mudstone, black, laminated, forms 2"-6" platy beds. Abundant wood and leaf fragments on bedding planes.

BY Gardener and Houston

Name Cape Nukshak

Structural Setting N 70 W, 11 SW

Location NE NE sec. 3 - NW SW sec. 17 T. 21S R29W

Weather beautiful!

Date 7/21/90

Unit Hemlock Congl.

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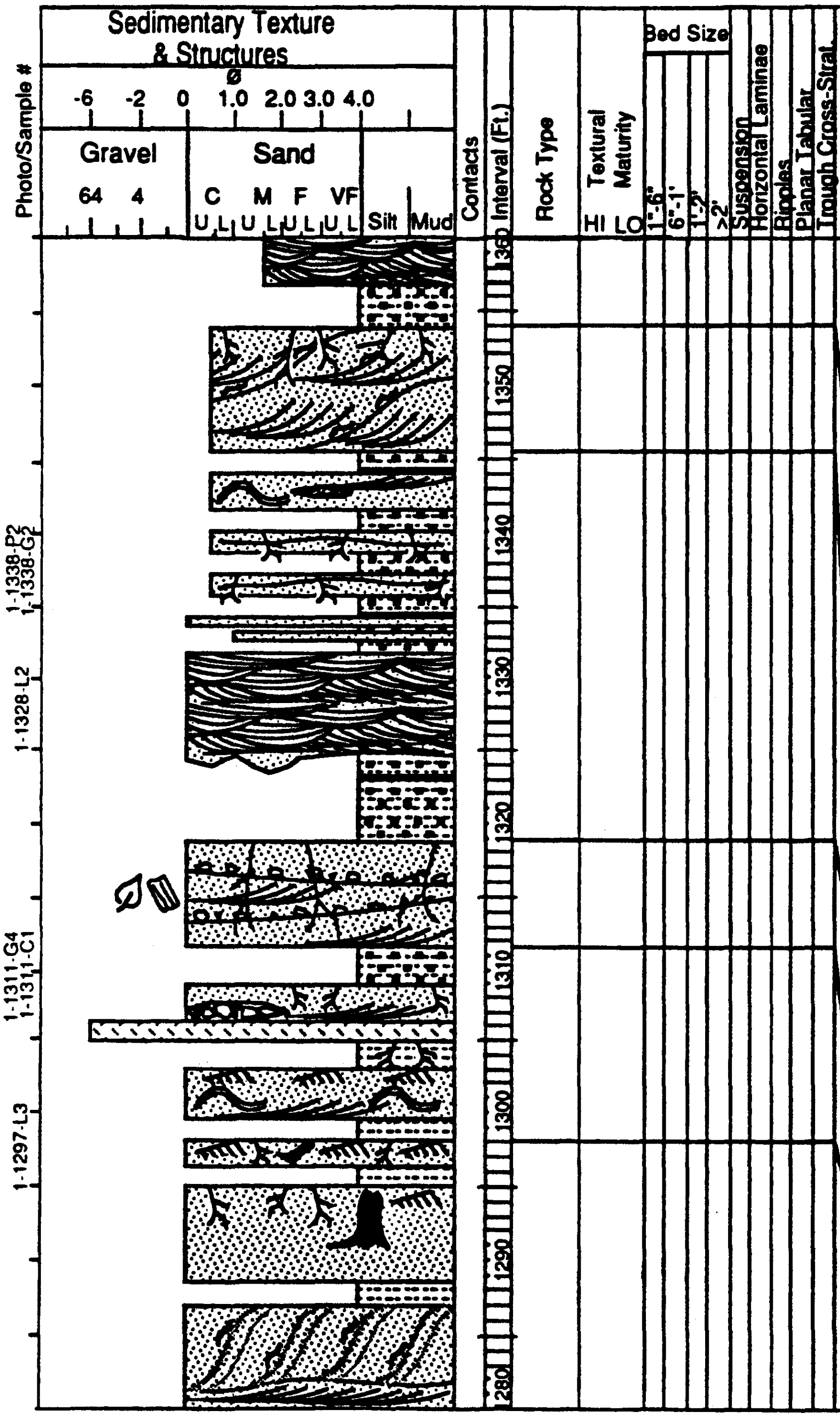

Comments

Interbedded ss, sltst, and carbonaceous sltst. Ss, tf, moderately to well sorted with TST in 6" to rare 1' sets and subordinate ARL in 1"-2" sets. Basal contacts of ss beds exhibit load structures with abundant SSD throughout. Ss beds >6' contain inclined mudst interbeds that pinch out to north suggesting epsilon cross-beds. All beds pinch out to north along cliff face.

Ss, tf, mod. to well sorted with TST in 6" to 1' sets and ARL in 1"-2" sets at top, abundant SSD. Accretionary surfaces w/ mud drapes. Upper surface rooted. Overall lenticular geometry; pinches out to the north.

Interbedded sltst and ss. Ss, well sorted, massive, with coarse ss stringers throughout. Ss extensively rooted. Overall sandbody geometry is lenticular with abundant SSD. Sltst, black, laminated, carbonaceous with coaly streaks in 2"-4" beds. Many sltst beds are laterally discontinuous or thin to siltstone partings. Unit appears platy.

Sandstone, gray, fine-grained, tuffaceous, with normally graded foresets. Thin, lens-shaped lags of coarse sandstone. Contains wood and plant material. Extensively rooted.

Interbedded ss and sltst, interruped by andesite sill at 1305'. Ss, gray-green, mod. sorted, contains tuff and pumice, extensively rooted. Some ARL in 1"-4" sets, faint TST in <8" sets, mod. SSD. Some wavy bedding (via loading?).

Ss, moderately sorted, tuffaceous. Contains large scale surfaces draped with mud that climb to west and dip to south. Faint TST in <1' sets. Undulatory basal surfaces. Muddy sltst, carbonaceous, trees in growth position, mud drapes possibly on epsilon beds of point bar geometries. Entire unit thins to north.

BY Gardener and Houston

Name Cape Nukshak　Structural Setting N 70 W, 11 SW

Location NE NE sec. 3 - NW SW, sec. 17, T 21S, R 29W　Weather overcast

Date 7/22/90

Unit Hemlock Congl.

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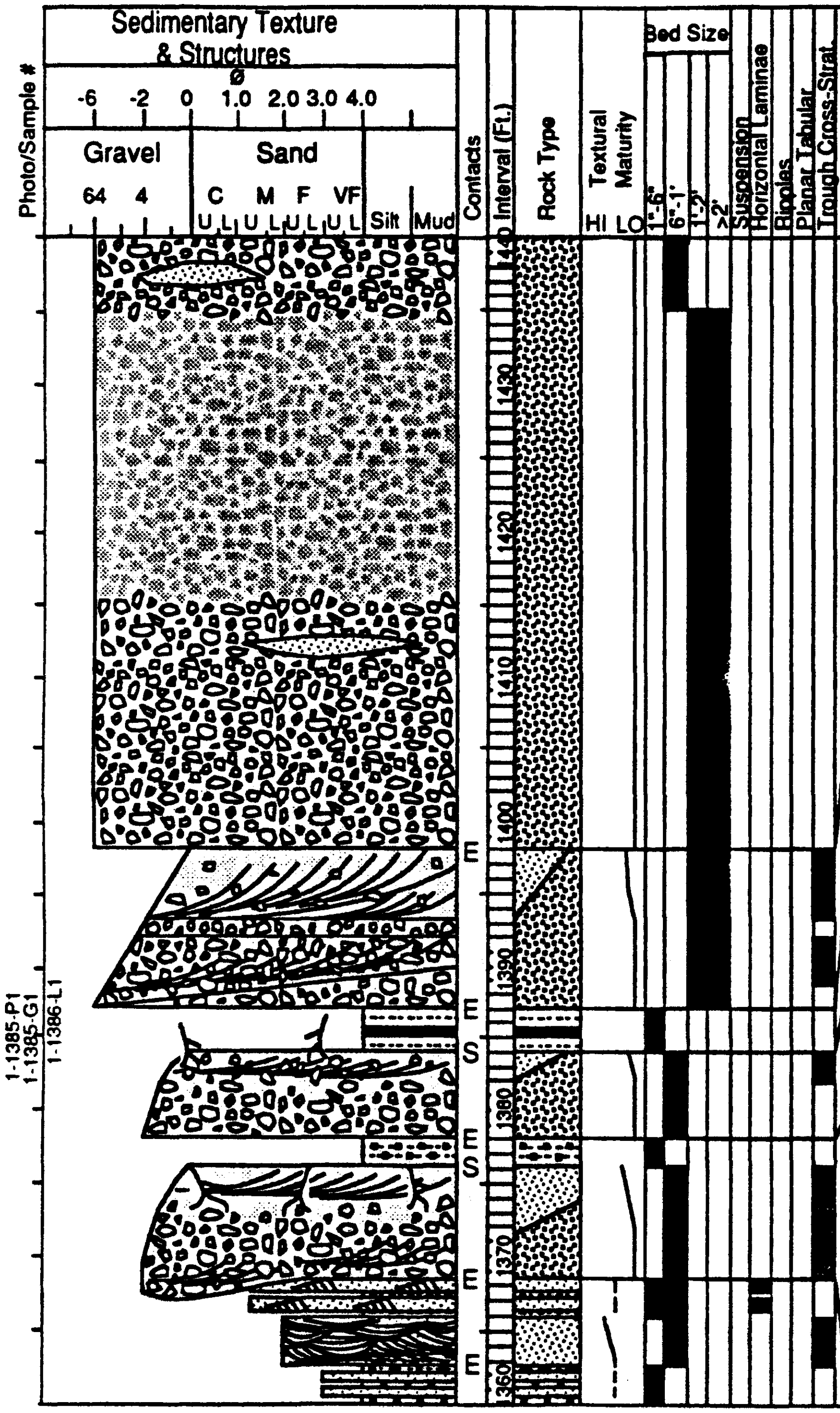


Comments

Tuffaceous, matrix supported (coarse ss), poorly organized congl. at base grading up to congl. ss to ss at top. Base of congl. is 40% clasts, max. diam. 5"; decreases to 30%, max. 4" at top. Clasts include quartz, shale, volcanic fragments, and mud rip-ups. Congl. matrix is dark gray-green. Congl. contains scattered coarse ss lenses up to 5' wide. Change to congl. ss (at 1445') to ss is gradational w/ upper 15' TST in 6"-1' sets, scattered pebbles throughout. Middle part of congl. (shaded gray) is cut by dike with attitude of N 05 W, making description difficult. If congl. cliff face to the east is not repeated section, then the actual thickness of the unit is approximately 127'. Unable to be determined for certain.

Sandstone, tuffaceous, poorly sorted, with abundant pumice fragments. Large scale TST in 1'-3' sets. Base of massive conglomerate forms east point at eagle's nest.

Siltstone, brown, laminated, carbonaceous with very thinly bedded sandstone stringers. Unit cut out by overlying conglomerate to south.

Pebble conglomerate at base grading to conglomeratic sandstone at top. Conglomerate, sandstone matrix supported, 20% clasts. Sandstone, TST in 8" sets. Upper surface rooted.

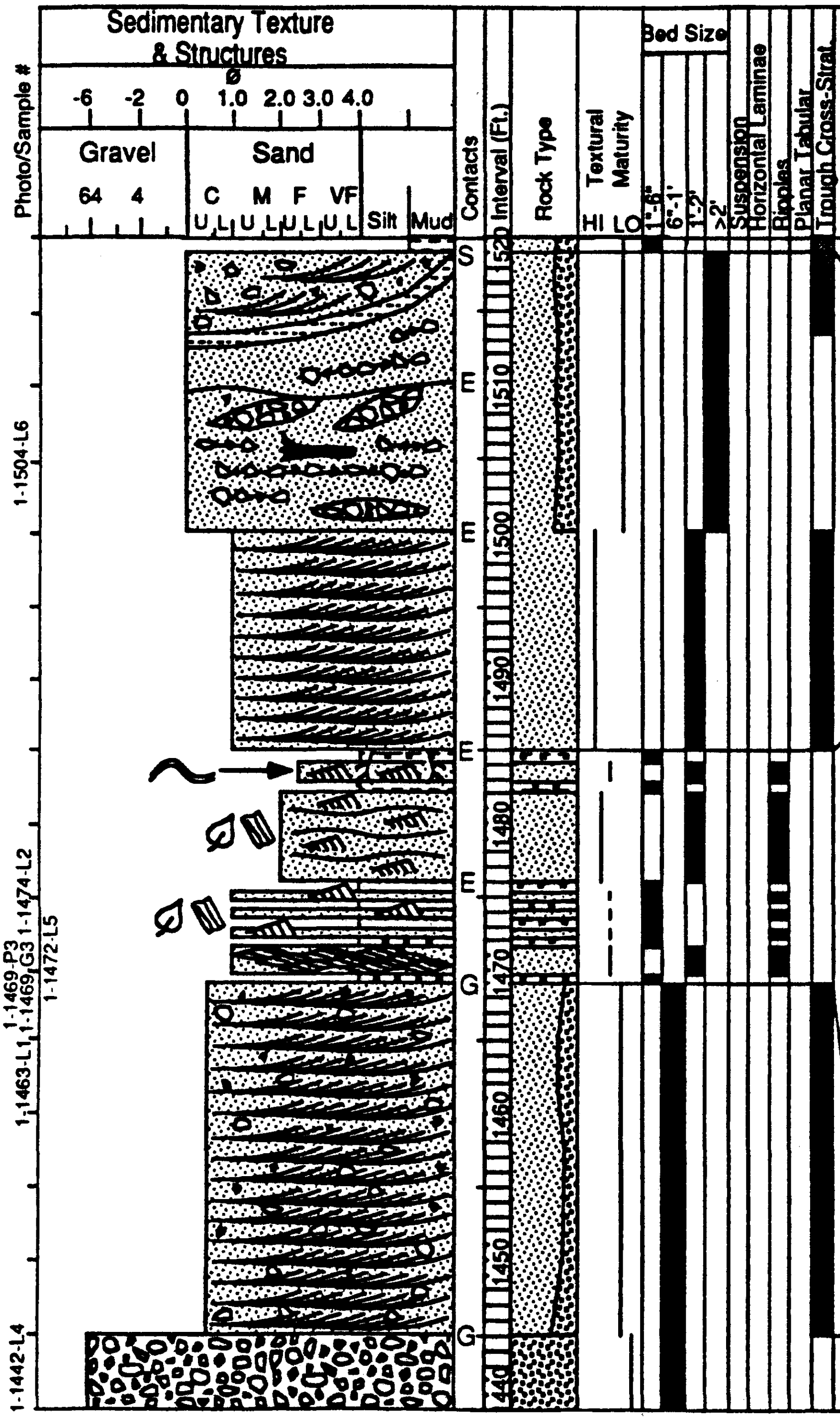
Congl. at base grading to ss at top. Unit capped by a carbonaceous sltst. Congl. is ss matrix supported, 5% clasts, maximum clast diameter 2". Abundant pumice clasts. Ss TST in 1' sets with faint TST in congl. beds. Congl. pinches out to north whereas underlying sltst thickens. Upper contact rooted. Section traversed across dike to the next cove to the south.

[See previous page.]

BY Gardener and Houston

Name Cape Nukshak Structural Setting N 70 W 11 SW

Location NE NE sec. 3 - NW SW sec. 17 T 21S R 29W Weather overcast and windy



Date 7/22/90

Unit Hemlock Congl.

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Comments

[See next page.]

Sandstone at base in erosional contact with pebbly sandstone above. Sandstone is tuffaceous and moderately sorted. Pebbly sandstone contains volcanic and plutonic clasts, with minor amounts of quartz, shale, and carbonaceous wood rip-ups. Volcanic clasts may be rhyolite and dacite. Logs in random orientation. Weak TST in >2' sets at top. Unit forms massive cliff with amalgamated, lenticular channel- form geometries, suggesting multi-story channel belt complex. Individual macroforms are 10'-15' thick and approximately 50 yards wide. Discontinuous mud layers define contacts between macroforms. Top of section projected to next outcrop

Siltstone, black, carbonaceous at base grading up to interbedded tuffaceous sandstone and siltstone Abundant wood on bedding planes, siltstone rip-ups, and some coarse lags. Sandstone, gray-green with climbing ripples at base and ARL further up in 1"-2" sets defined by abundant shale partings. Unit capped by siltstone, black, carbonaceous, with roots extending into the underlying sandstone bed. Sandstone bed at 1483'; thick, weathers platy and exhibits minor SSD.

Tuffaceous sandstone, gray-green, with TST in 8"-2' sets. Scattered pebbles throughout.

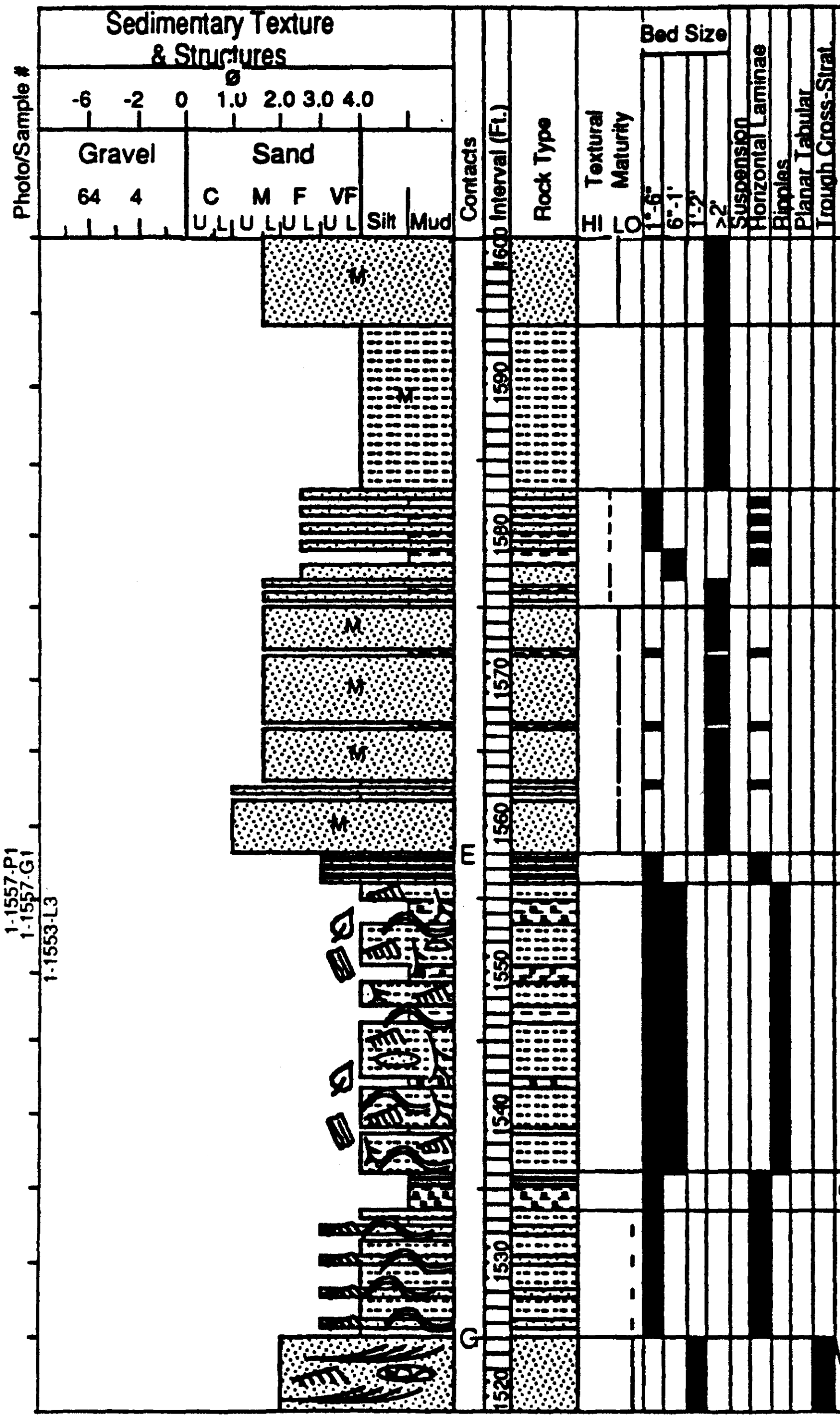
Samples 1-1463-L1 and 1-1474-L2 are from a different outcrop which appears to be stratigraphically equivalent to the outcrop described in this section.

[See previous page.]

BY Gardner and Houston

Name Cape Nukshak Structural Setting N 70 W 11 SW

Location NE NE sec. 3 - NW SW sec. 17 T 21S R 29W Weather excellent



Date 7/19/90

Unit Hemlock Congl.

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Comments

Tuffaceous sandstone, massive, abundant pumice fragments.

Tuffaceous siltstone, poorly exposed, highly fractured because of proximity to dike at 1583'.

Interbedded sandstone and mudstone. Dike between top of this unit and overlying unit strikes N 05 W and is 5' wide.

Interbedded tuffaceous sandstone and thin carbonaceous shales. Sandstones are massive, and lowest one loads into coal partings below.

3 4" coals with sandstone partings.

Tuffaceous siltstone with lenses of sandstone and carbonaceous shale to mudstone layers, thinly bedded. Sandstone beds 2" to 8" thick; mudstone beds <1" to 1" thick. Lenticular to wavy beds, ARL in 1"-2" sets. Abundant SSD, abundant leaves and wood, extensively rooted.

Carbonaceous shale with two 4" coals.

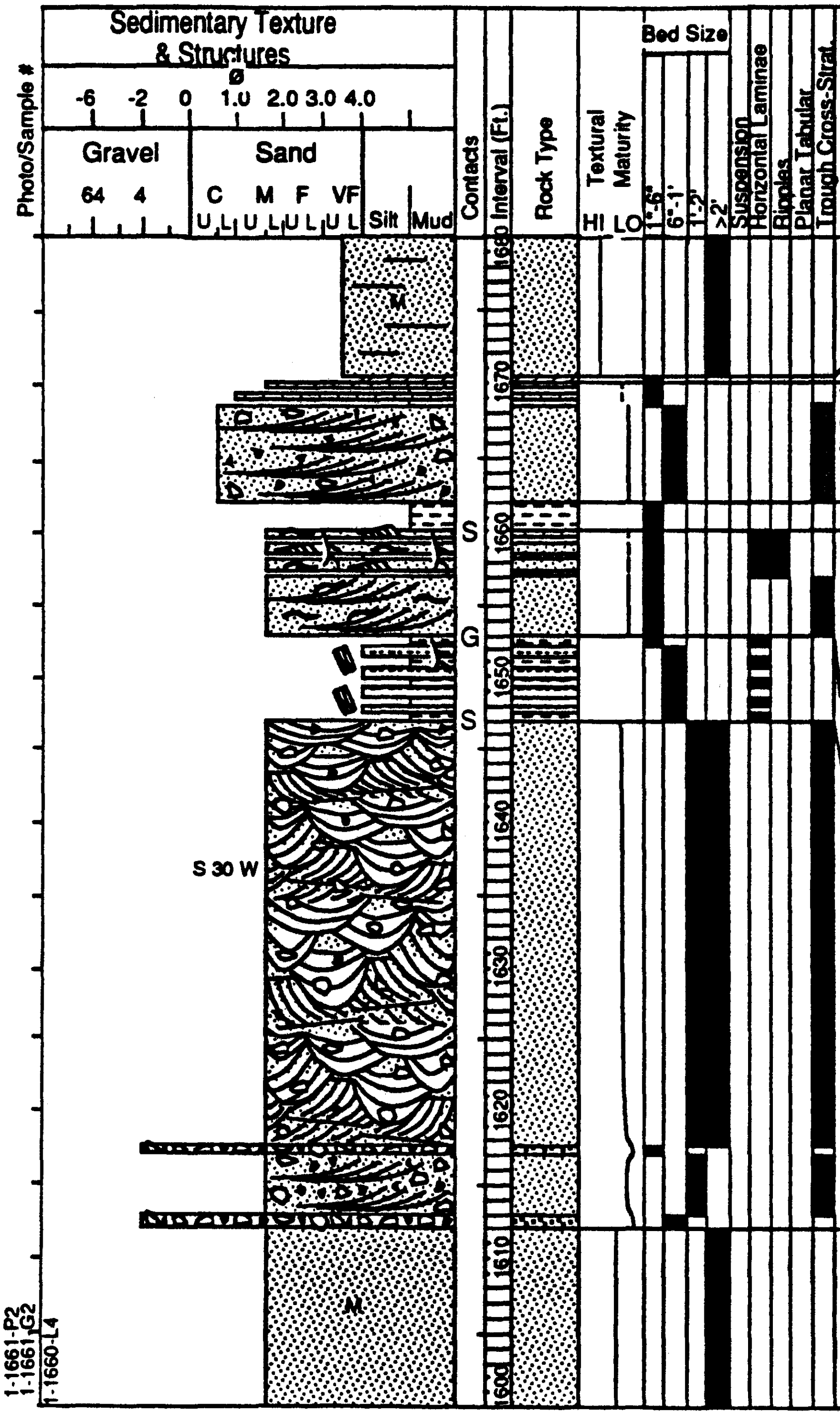
Interbedded muddy siltstone, shale and sandstone. Mud content increases upward. Thin mud and silt interbeds separate sandstone beds which are 2"-4" thick, ARL in sandstone in 1"-2" sets. Abundant SSD.

[See previous page.]

BY Gardner and Houston

Name Cape Nukshak Structural Setting N 70 W. 11 SW

Location NE NE sec. 3 - NW SW sec. 17 T 21S R 29W Weather "tropical" (for Alaska)



Date 7/19/90

Unit Hemlock Congl.

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Comments

Tuffaceous sandstone, greenish-gray, well sorted. Lenticular body bounded by platy beds, pinches out to north. Indistinct bedding; massive appearance.

Sill, 6" thick

Tuffaceous, conglomeratic sandstone containing faint TST? Contains andesite pebbles.

Silty mudstone, laminated.

Sandstone grading upward into Interbedded mudstone, siltstone, and sandstone. ARL in top half in 1"-3" sets. Mud drapes throughout, rooted near upper contact. Load features, abundant SSD. Shale content increases upward.

Thinly bedded sandstone and mudstone. Carbonaceous shale at top. Rooted at top

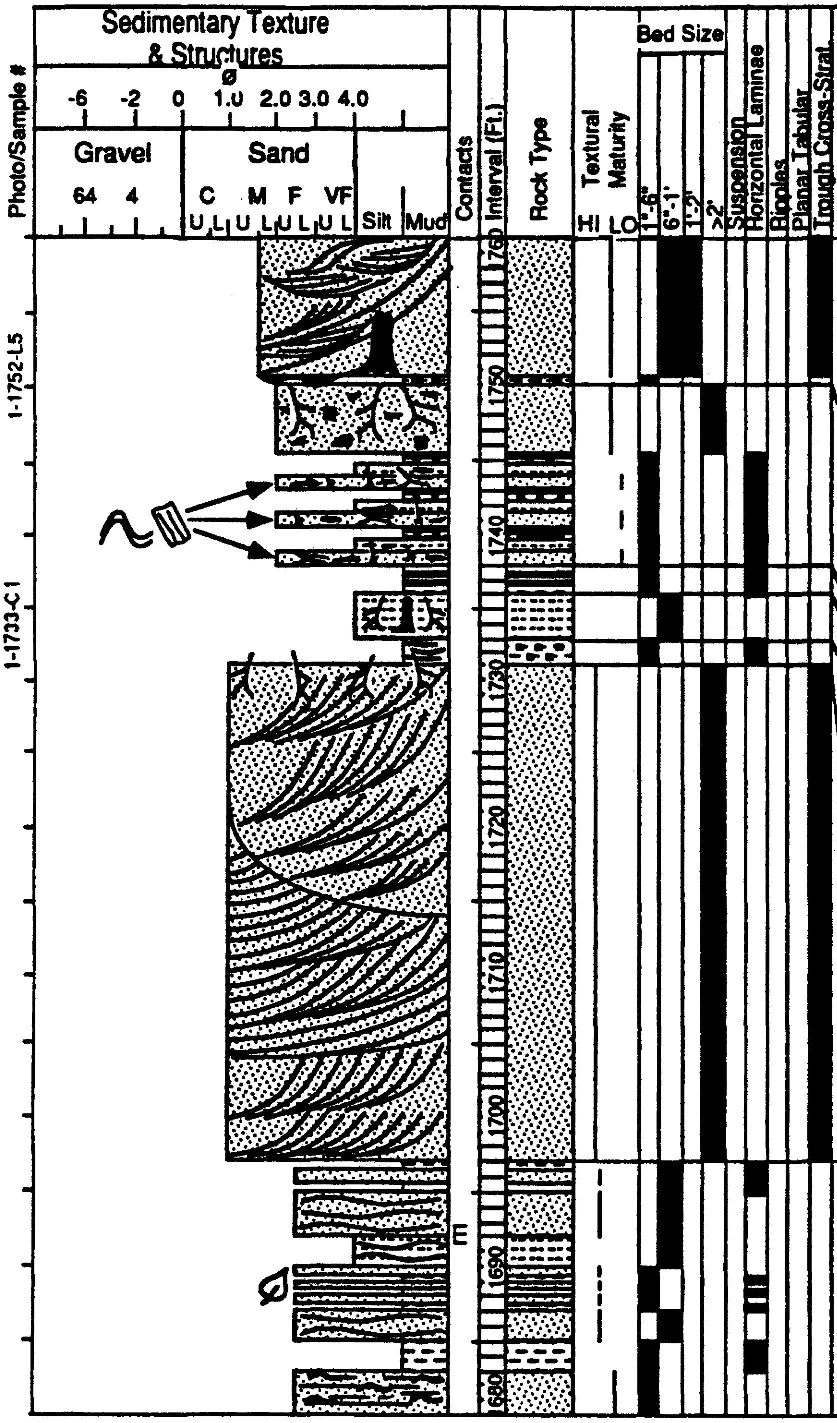
Tuffaceous sandstone, poorly sorted with scattered pebbles. Lenses of amalgamated TST in 1'-3' sets. Some fining-upward sequences from coarse sandstone to siltstone. Some silty, fine-grained beds 1"-6" thick. pumice fragments throughout unit. Two thin mud ripup zones / lags(?) near base.

Massive sandstone [see previous page].

BY Gardner and Houston

Name Cape Nukshak Structural Setting N 70 W, 11 SW

Location NE NE sec. 3 - NW SW sec. 17 T 21S R 29W Weather nice



Date 7/19/90

Unit Hemlock Congl.

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Comments

Sandstone, gray-green, moderately sorted. Faint accretion surfaces from north to south. Faint TST in 6" sets. Large 3' diameter tree at base. Load casts filled with carbonaceous material extend into underlying carbonaceous shale and sandstone.

Three interbedded packages which grade upward: sandstone, siltstone, carbonaceous shale, coal. Carbonaceous shale in 2" to 6" beds grading to coal. SSD common in sands. Top sandstone, moderately sorted, massive in appearance, contains abundant coalified material.

Two coal streaks in mudstone unit.

Two-inch coalified trees in extensively rooted siltstone.

Carbonaceous shale with 3 coaly streaks which are wavy, discontinuous, and exhibit abundant SSD.

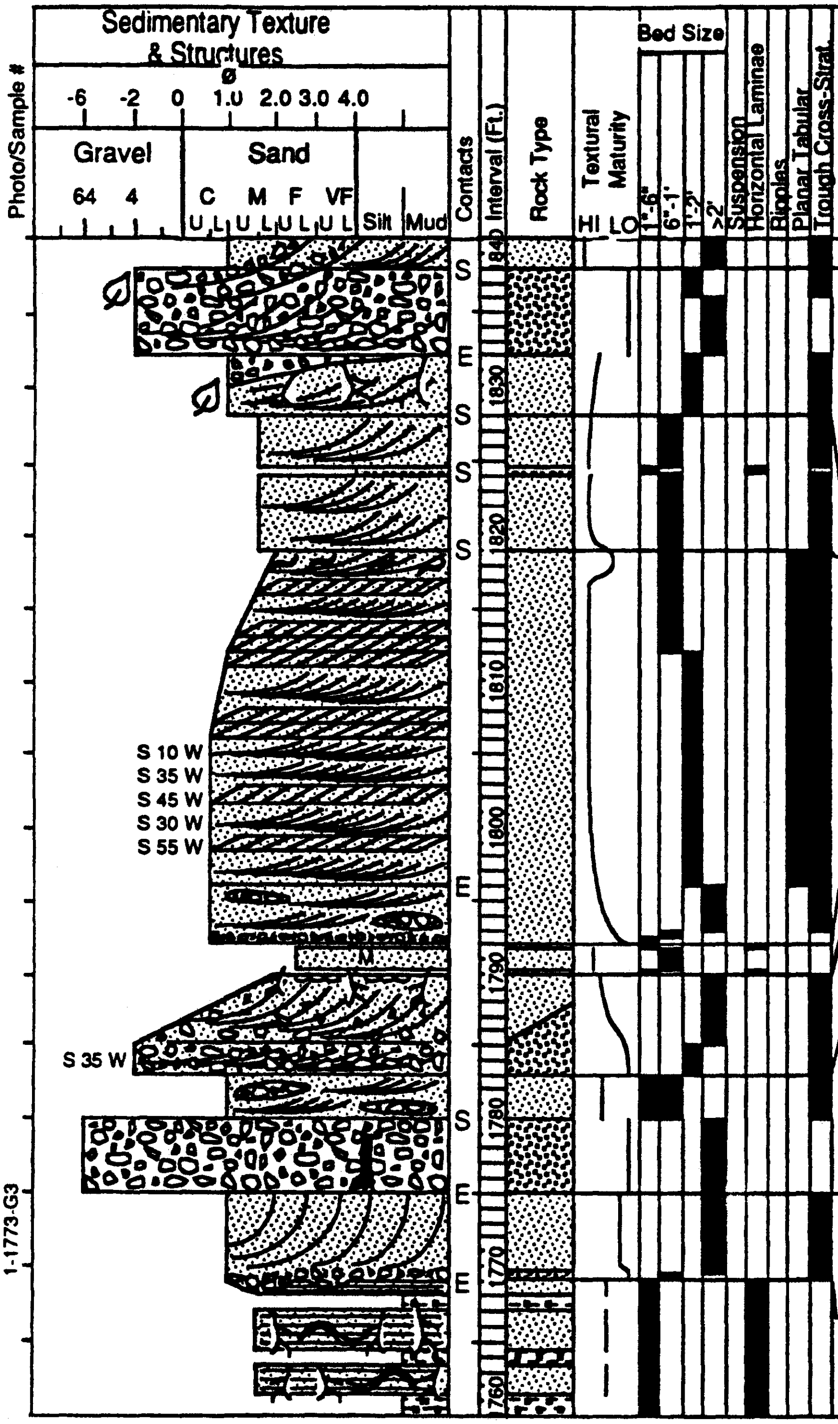
Tuffaceous sandstone, green-gray, massive to TST in 5' sets (best exposed in middle portion). Three large-scale scour and fill sequences, 8 to 10' thick with irregular scoured bases. Entire sandstone body thins to the north. Lowest of the three sequences pinches out to the north.

Interbedded sandstone, mudstone, and siltstone. Massive to wavy bedding in sandstone and mudstone. Mudstones contain very thin silty interbeds. Lowest sandstone contains abundant shale partings, causing it to weather platy. 10' thick dike at top of this unit. Dike strikes east-west

BY Gardner and Houston

Name Cape Nukshak Structural Setting N 70 W, 11 SW

Location NE NE sec. 3 - NW SW sec. 17 T 21S R 29W Weather cold, gray, and wet



Date 7/20/90

Unit Hemlock Congl.

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Comments

[See next page.]

Sandstone at base with overlying conglomerate. Pebble conglomerate fills in scours at top of sandstone. Sandstone contains faint TST, and several large roots. Overlying conglomerate is poorly organized, exhibits faint TST. Conglomerate stringers extend from this unit into the overlying sandstone.

Two sandstone units with TST in 1' sets, separated by dark gray siltstone.

Gradually upward-fining, cross-bedded sandstone. Interbedded PST and TST, in average sets of 1' in bottom 2/3 of unit, 8" in top 1/3 of unit. Fine grained "coffee ground" material in 6" layer at bottom. Sparse conglomerate lenses in bottom 5', average 8" high and 18" long. Mud drapes on TST foresets in top 2' of unit.

Massive, tuffaceous sandstone bounded by light gray siltstones.

Upward-fining sequence of poorly organized congl. at base, grading up to congl. ss to ss at top. All units are tf, with TST in 2'-3' sets with n.g. foresets. Top 6" concretionary; upper contact rooted.

Congl., matrix supported (coarse ss), poorly organized. 30% clasts, max. diam. 10", including; chert, volcanics and plutonics. Few small trees. Top ss contains TST in 4"-1' sets and congl. lenses. Units basal contact obscured by dike.

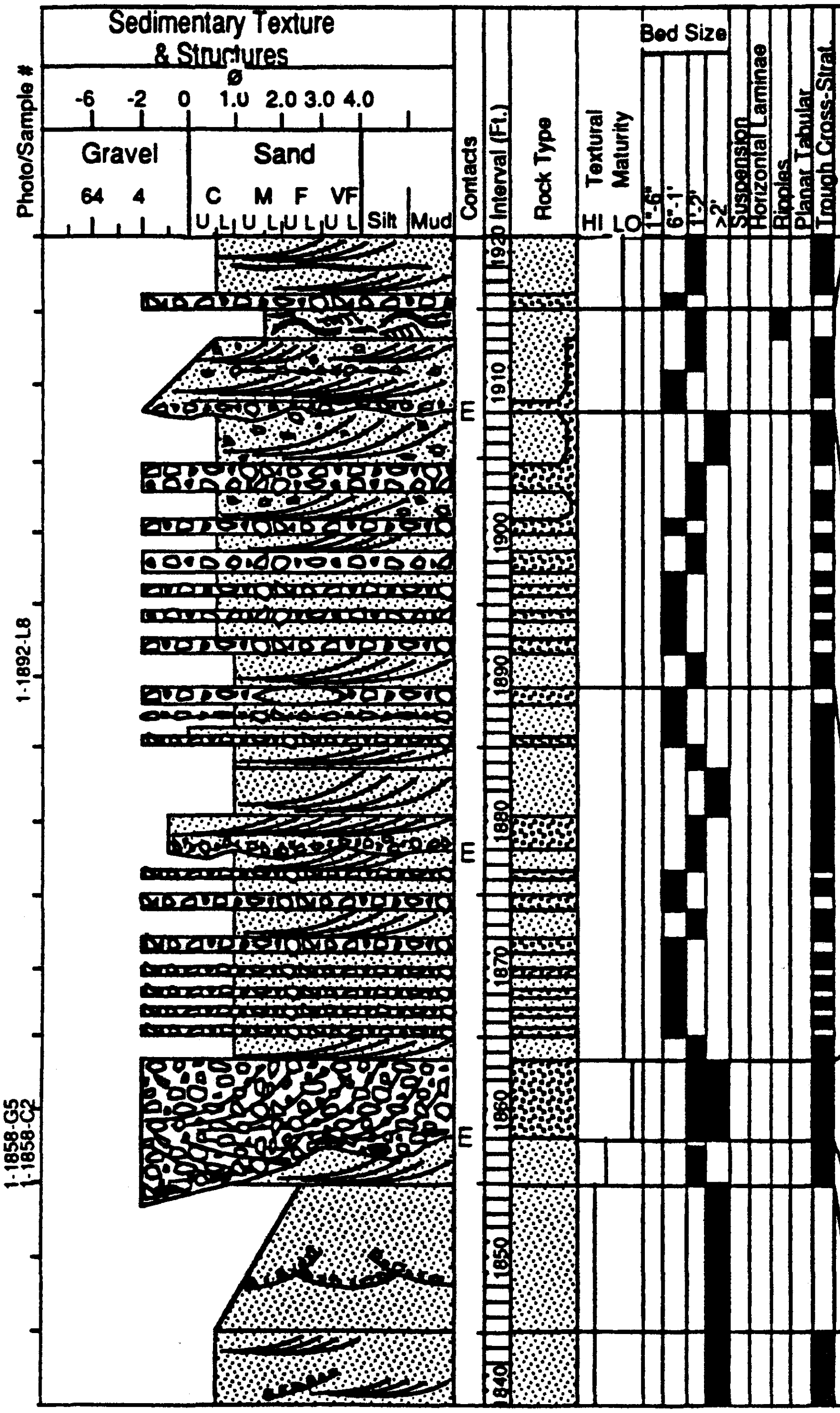
Tf ss, green-gray, poorly sorted with abundant pumice fragments. Unit contains one large scale TST set. Basal lag is 1' thick, 20% clasts, maximum cobble diameter 8".

Interbedded ss and carb. shale. Ss is dark gray and moderately sorted. Abundant SSD, weathers platy due to thin mudstone stringers.

BY Gardener, Houston, and Warme

Name Cape Nukshak Structural Setting N 70 W, 11 SW

Location NE NE sec. 3 - NW SW sec. 17 T.21S. R.29W. Weather overcast



Date 7/22/90

Unit Hemlock Congl.

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Comments

[See next page.]

Congl. grading to ss and interbedded ss and mudstone. Congl., weakly normally graded, TST in 6"-8" sets. 20% clasts, maximum clast diameter 2", predominantly chert, mudstone, and quartz with minor igneous. Pebbles decrease to 0% at top of ss. Top ss TST in 2' sets. Ss overlain by interbedded wavy ss and carbonaceous to coaly mudstone with ARL in 2"-5" sets, mud rip-ups, and abundant SSD.

Interbedded congl., congl. ss and ss. Ss, gray-green, moderately sorted, tuffaceous, TST in 8"-1' sets, gradational contacts at base and top with conglomerates. Congl. ss contains scattered, sub-angular pebbles. Congl. clast compostion ranges from 25%, maximum clast diameter 1" at base to 40%, maximum 3" near top. Bedding grossly thins from base to top.

Interbedded congl. and ss. Congl., matrix suported (medium to coarse ss), maximum clasts diameter 3", average 1". 4"-1' beds with faint TST. Ss, fine to coarse, TST in 6"-2' sets with normally graded foresets, pebble trains on bed contacts. TST in all lithologies predominantly to the southwest.

Conglomerate and conglomeratic sandstone, relief along basal contact of 0-2'. Shale rip-up clasts and igneous clasts define basal contact. Sweeping TST in 5'-7' sets with pebbles on foresets.

Sandstone, TST in 4"-6" sets, unit often cut out by overlying scour.

Sandstone, massive, with abundant conglomerate stringers on scour surfaces.

Sandstone, massive, well sorted, possible faint TST (hard to distinguish from scour surfaces).

BY Gardener and Houston

Name Cape Nukshak

Structural Setting N 75 W 12 SW

Location NE NE sec. 3 - NW SW sec. 17, T 21S, R 29W

Weather overcast

Date 7/23/90

Unit Hemlock Congl.

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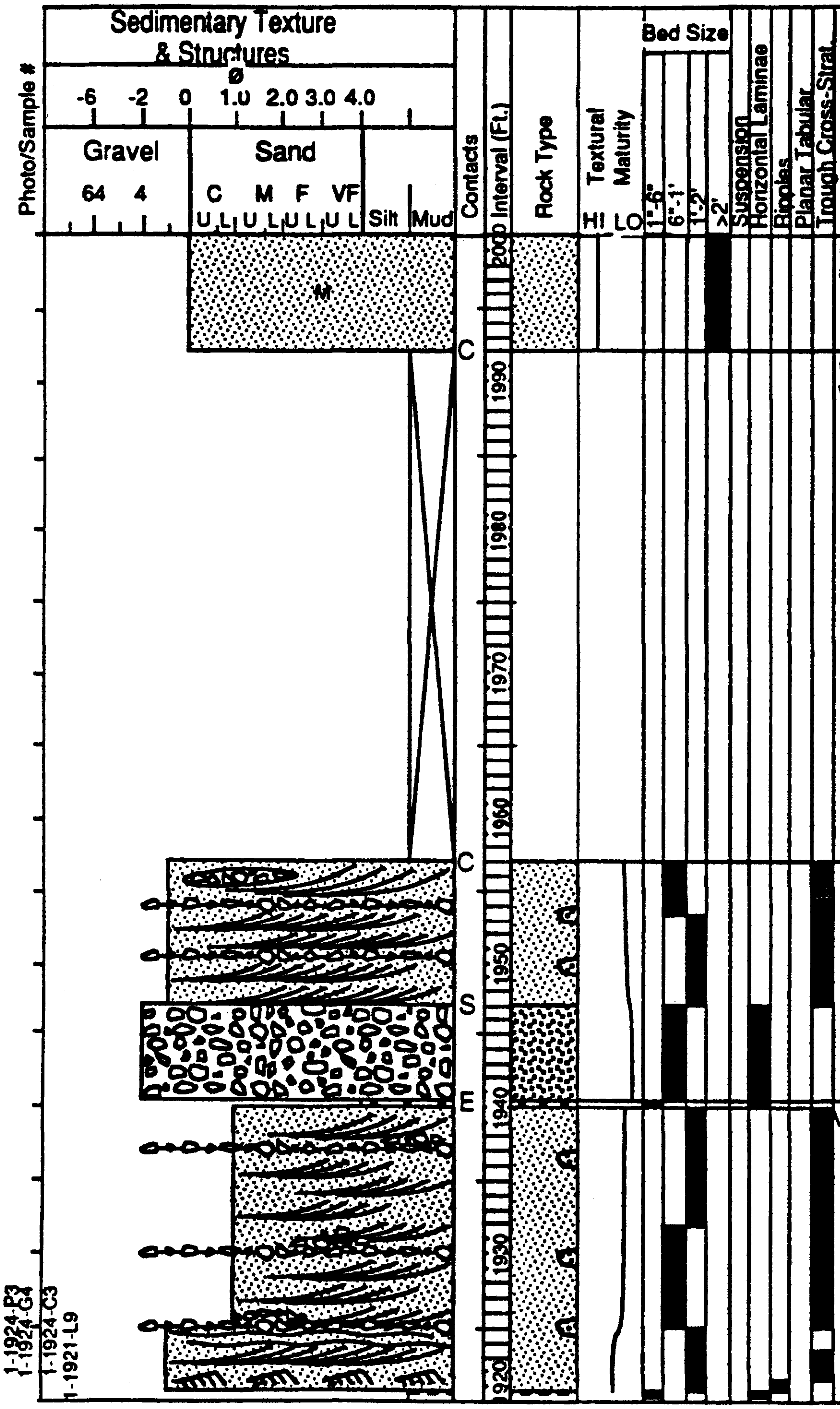


Comments

Massive sandstone. Poorly exposed and highly surface exfoliated.

Covered slope. Interval measured with Jacob's staff to next outcrop.

Basal conglomerate, matrix supported, horizontally bedded in 1' sets. 30% clasts, maximum clast diameter 9", dominantly quartz and chert with minor igneous, shale, and coal. Weakly normally graded. Overlying sandstone brown, TST in 1' sets decreasing to 4" up section; few thin conglomerate lenses.

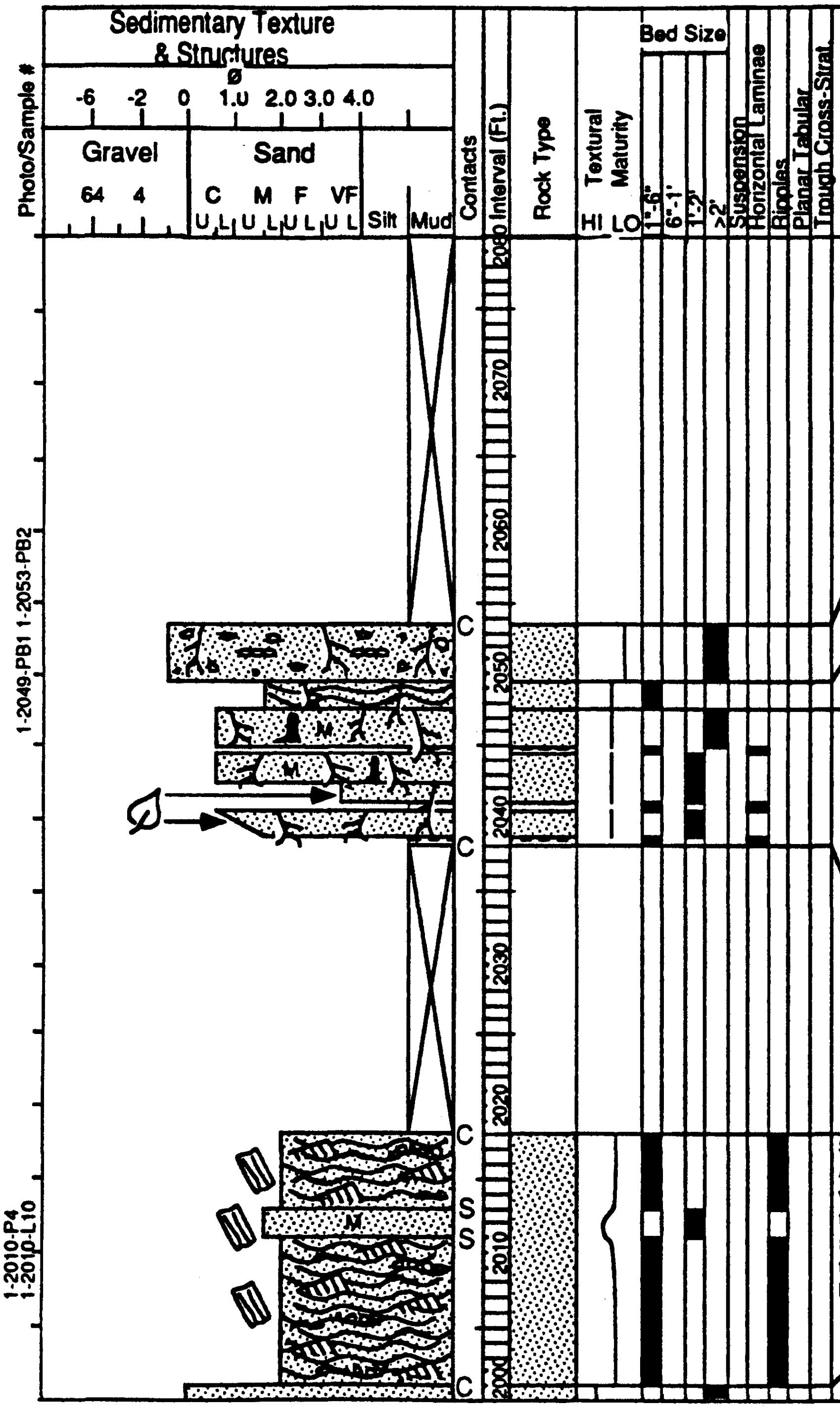
Carbonaceous siltstone, massive.

Interbedded conglomerate and sandstone. Sandstone, TST in 4"-1' sets at base and 1'-2' sets at top. Conglomerate, thinly bedded, poorly organized. Maximum clast diameter 4". Clasts include; quartz, chert and minor igneous. Conglomerate beds are often discontinuous lenses or stringers.

BY Gardner and Houston

Name Cape Nukshak Structural Setting N 75 W, 12 SW

Location NE NE sec. 3 - NW SW sec. 17 T 21S R 29W Weather overcast



Date 7/23/90

Unit Hemlock Congl.

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Comments

Beginning of 320' covered interval, measured with Jacob's staff to next outcrop.

Sandstone, tuffaceous with abundant volcanic pebbles. Concretionary and exfoliated.

Sandstone, faint wavy beds, abundant roots.

Interbedded sandstone and silty mudstone. Sandstone, massive, tuffaceous with granule size pumice, upright trees, abundant roots and leaves. Mudstone, abundant roots and whole leaf impressions (very low energy environment).

Covered interval.

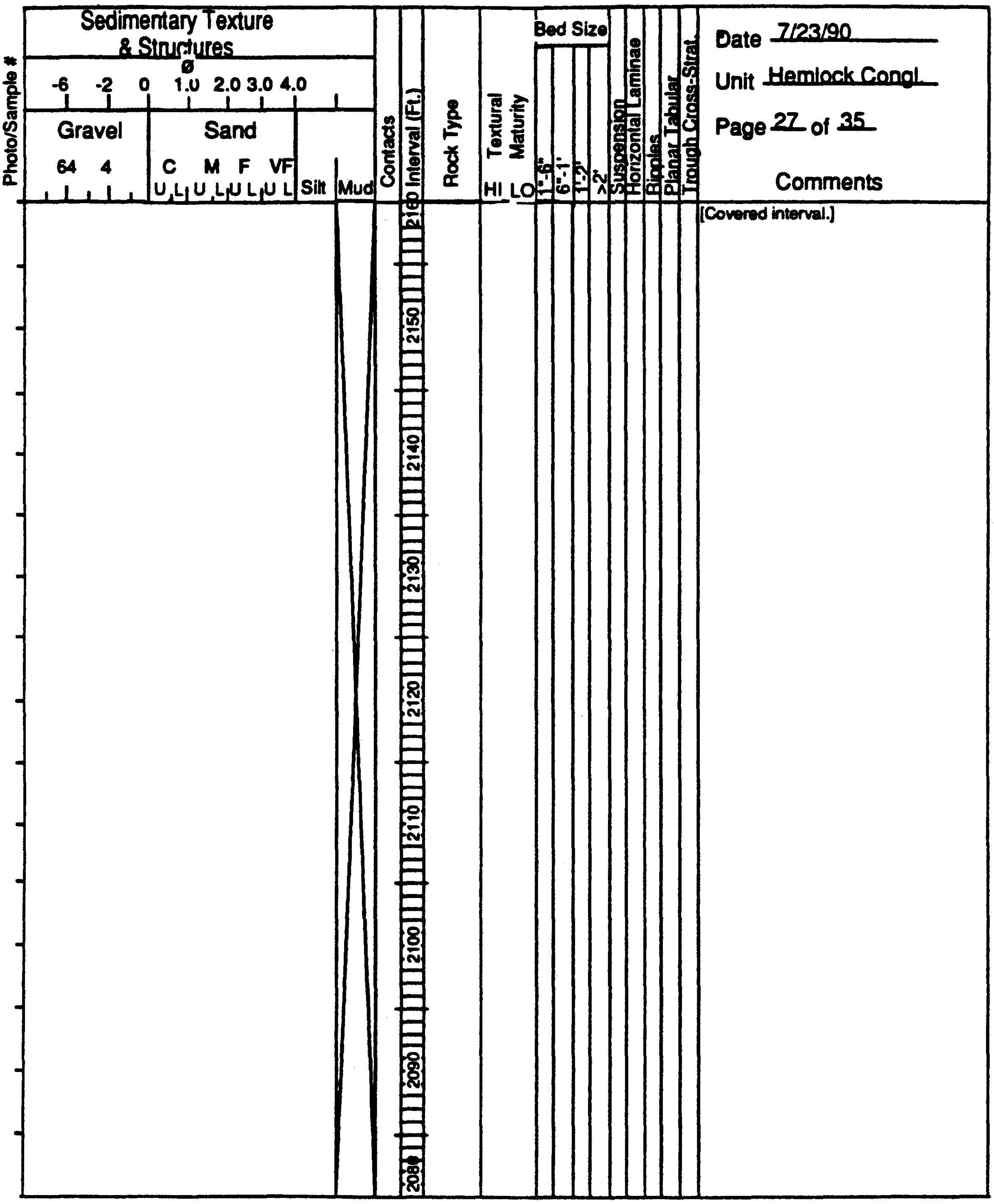
Sandstone, brown, thin, wavy beds. Abundant shaly partings, abundant wood (especially on bedding planes), faint ARL and small scale TST in <4" sets. Discontinuous granule lags throughout. One 2' thick, massive, brown sandstone bed at 2011'.

[See previous page.]

BY Houston

Name Cape Nukshak Structural Setting covered

Location NE NE sec 3 - NW SW sec 17 T 21S R 29W Weather



Date 7/23/90

Unit Hemlock Congl.

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Comments

[Covered interval.]

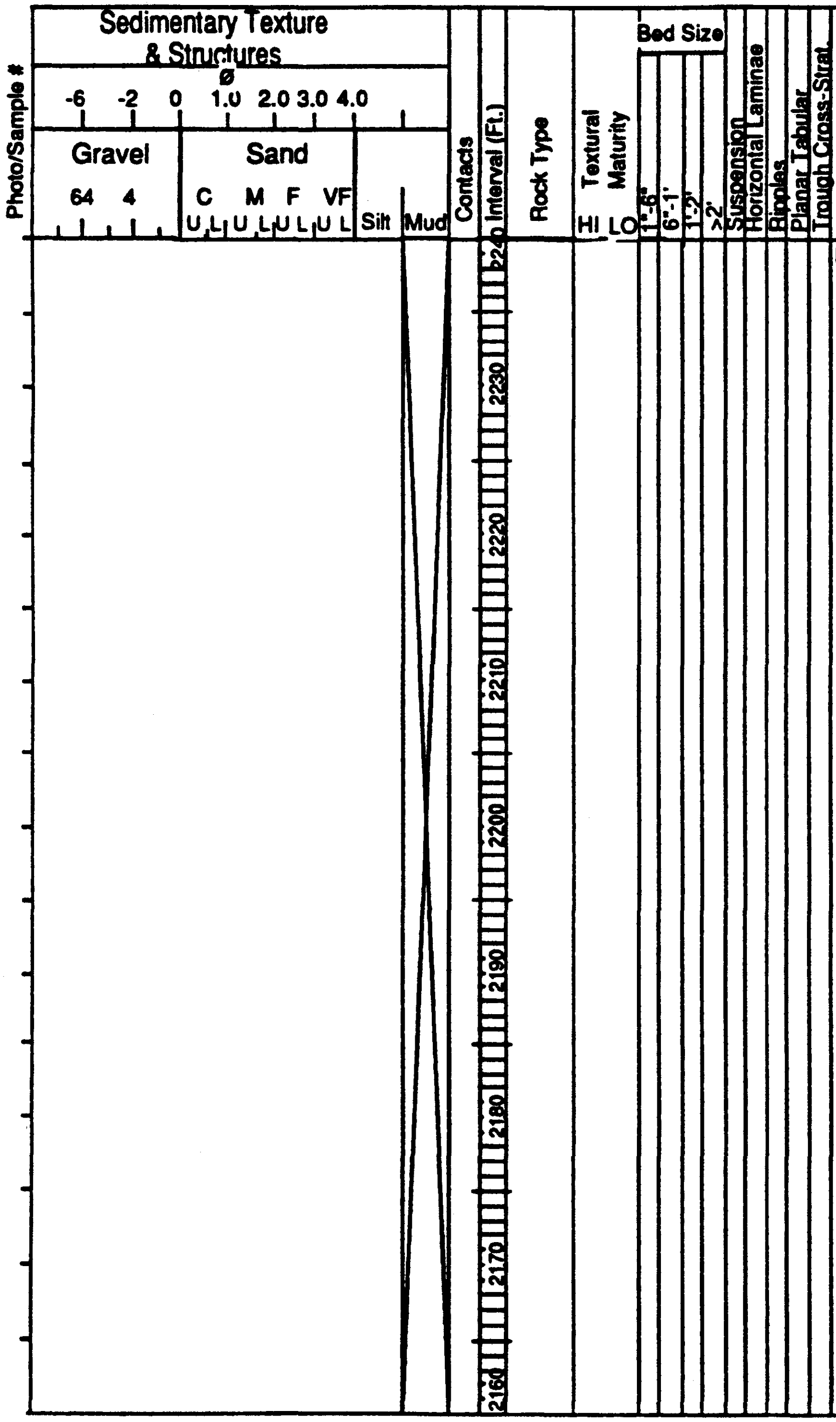
BY Houston

Name Cape Nukshak

Structural Setting covered

Location NE NE sec. 3 - NW SW sec. 17 T 21S R 29W

Weather



Date 7/23/90

Unit Hemlock Congl.

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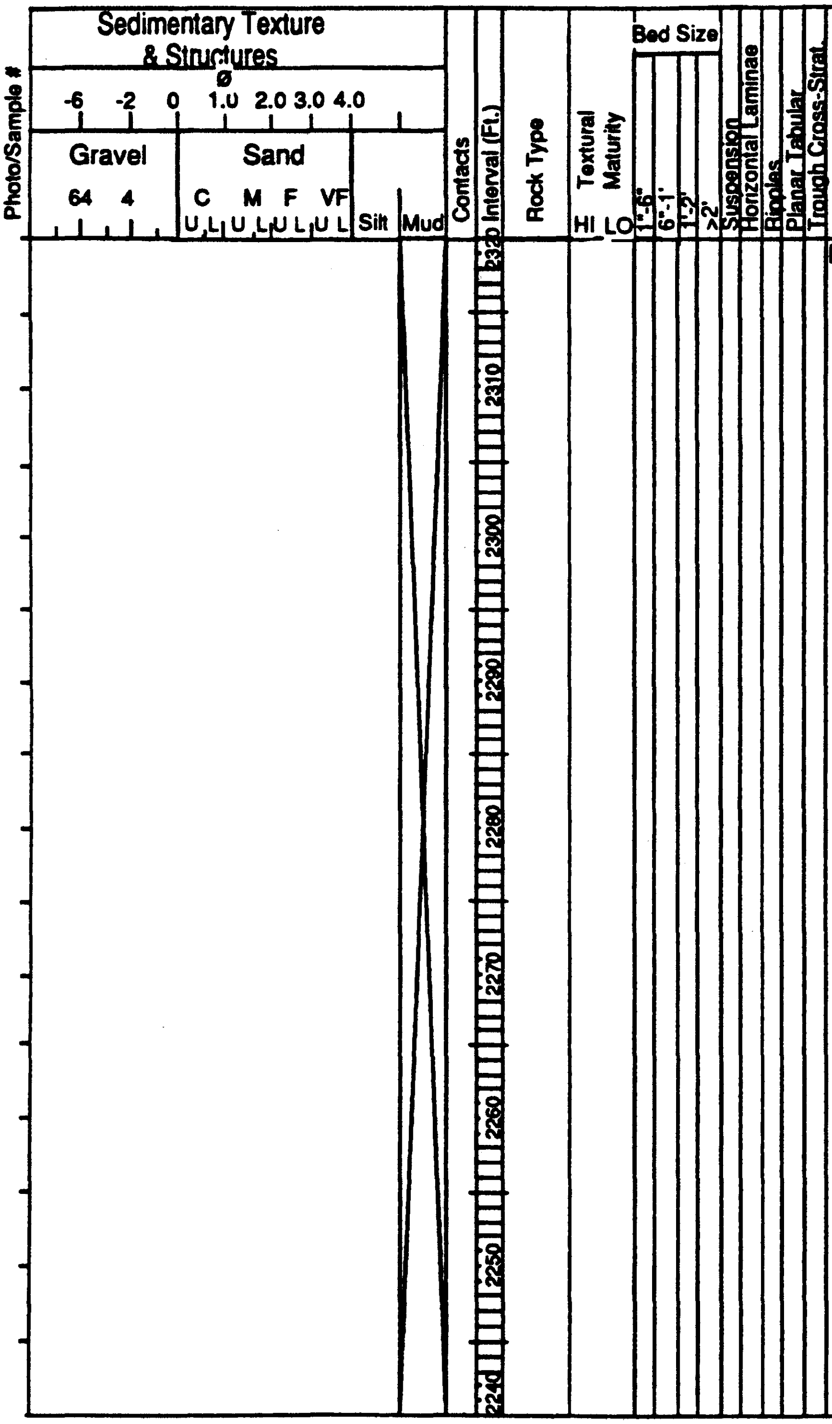
Comments

[Covered interval.]

BY Houston

Name Cape Nukshak Structural Setting covered

Location NE NE sec. 3 - NW SW sec. 17 T 21S R 29W Weather



Date 7/23/90

Unit Hemlock Congl.

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Comments

[Covered interval.]

BY Gardener and Houston

Name Cape Nukshak Structural Setting N 75 W. 11 SW

Location NE NE sec. 3 - NW SW sec. 17 T 21S R 29W Weather overcast

Date 7/23/90

Unit Hemlock Congl.

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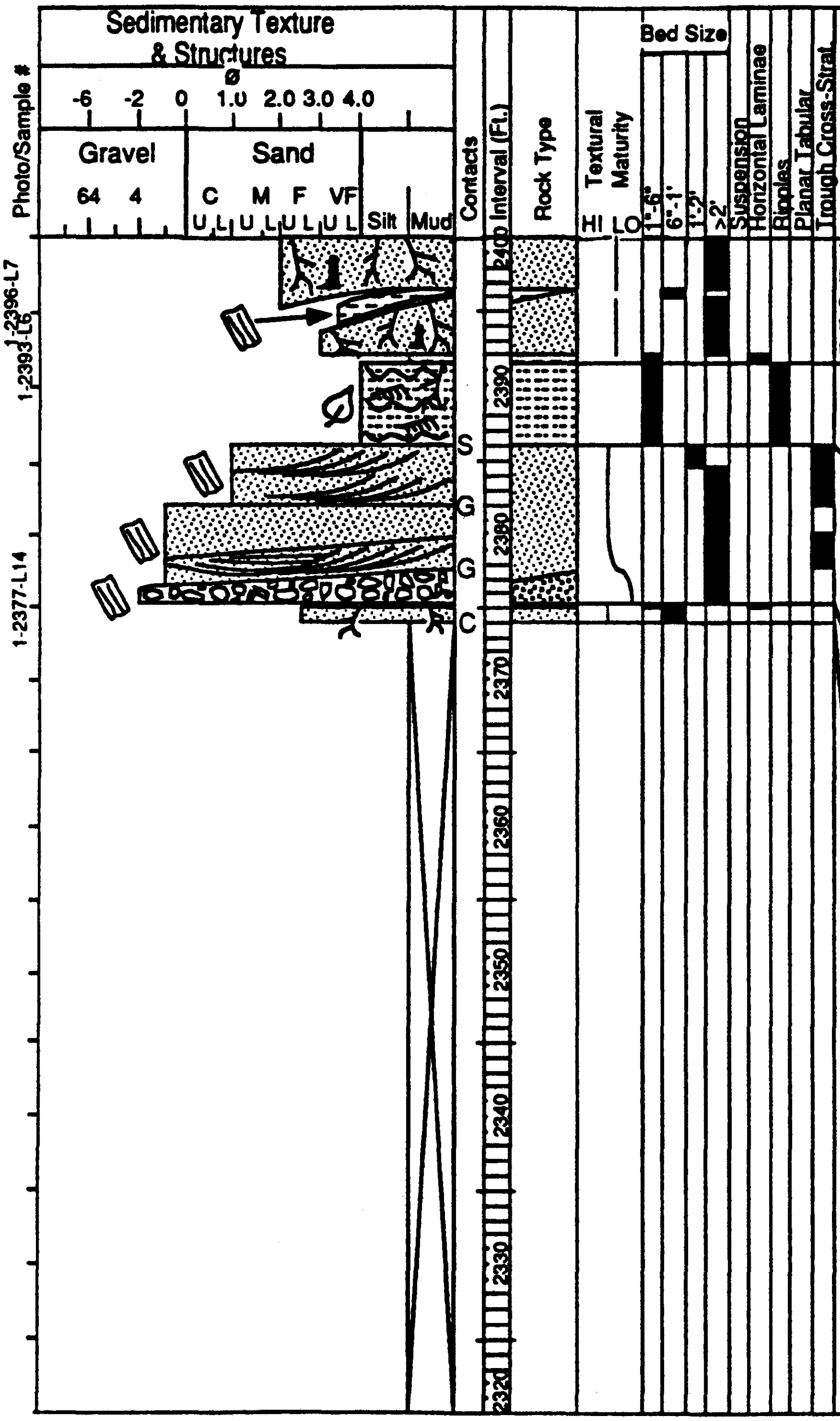


Comments

Two massive sandstones separated by heavily fractured shale. Sandstone contains abundant roots and upright trees. Shale contains abundant wood fragments. All units thin to south.

Siltstone, tan, thin, wavy beds Abundant whole leaf impressions and roots. Faint ARL in 2"-4" sets. Weathers platy.

Matrix supported conglomerate grading up to medium grained sandstone. Conglomerate, gray-green, massive, tuffaceous. Sandstone, scattered pebbles in bottom half, abundant pumice, volcanic fragments and wood. TST in 1'-2' sets.

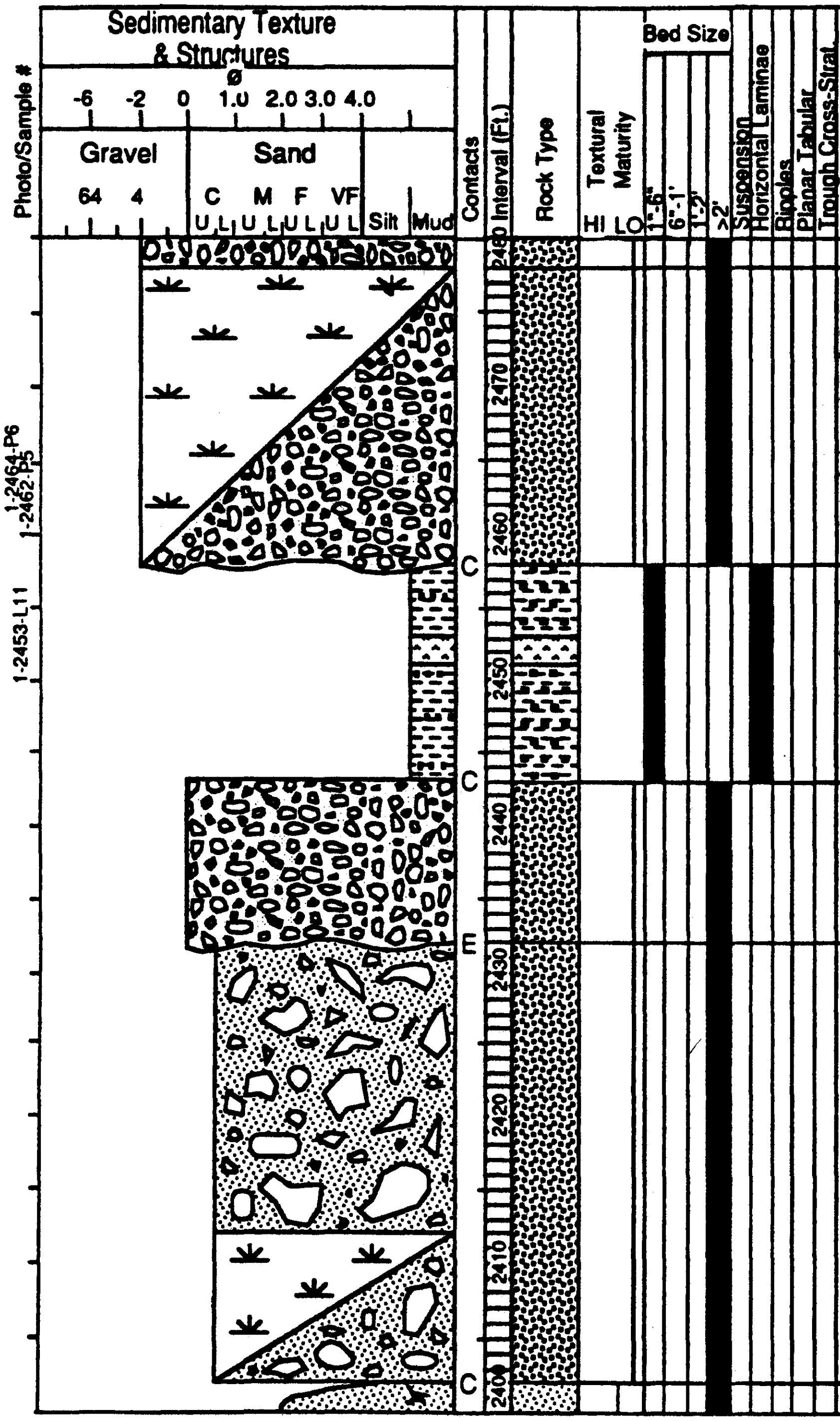
Carbonaceous mudstone overlying massive, extensively rooted sandstone.

End of covered interval.

BY Gardener and Houston

Name Cape Nukshak Structural Setting N 75 W 11 SW

Location NE NE sec. 3 - NW SW sec. 17 T 21S R 29 W Weather rainy



Date 7/23/90

Unit Hemlock Congl.

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Comments

[See next page.]

Conglomerate, green-gray, poorly sorted, very tuffaceous. Fine grained, massive matrix; maximum clast diameter 6". Basal contact very undulatory. Unit exhibits abrupt thickness changes along strike from <5' to >20'. Interval is partly covered and is inferred to be entirely conglomerate. Section from 2478' to 2495' was measured where exposed at beach level.

Claystone, dark olive-gray, laminated with thin carbonaceous partings. At 2451' is a very clay-rich interval, light olive-gray, inferred to be volcanic ash. This unit exhibits extreme variations in thickness via scour at the top.

Conglomeratic lithic tuff, green-gray, poorly sorted. Maximum clast diameter 1', including andesite and trachyte. Very friable. Undulatory basal contact.

Lower 10' is largely covered, but is inferred to be the same as the upper 20'.
Conglomerate, brown-gray, very poorly sorted, matrix supported. Maximum clast diameter 3', crudely decreasing up section. Extremely chaotic texture with clasts "floating" in matrix. Clasts dominantly andesite. Inferred to be a debris flow. First occurrence of this lithology in section.

[See previous page.]

BY Gardener and Houston

Name Cape Nukshak

Structural Setting N 75 W. 11 SW

Location NE NE sec. 3 - NW SW sec. 17 T 21S R 29W

Weather rainy

Date 7/23/90

Unit Hemlock Congl.

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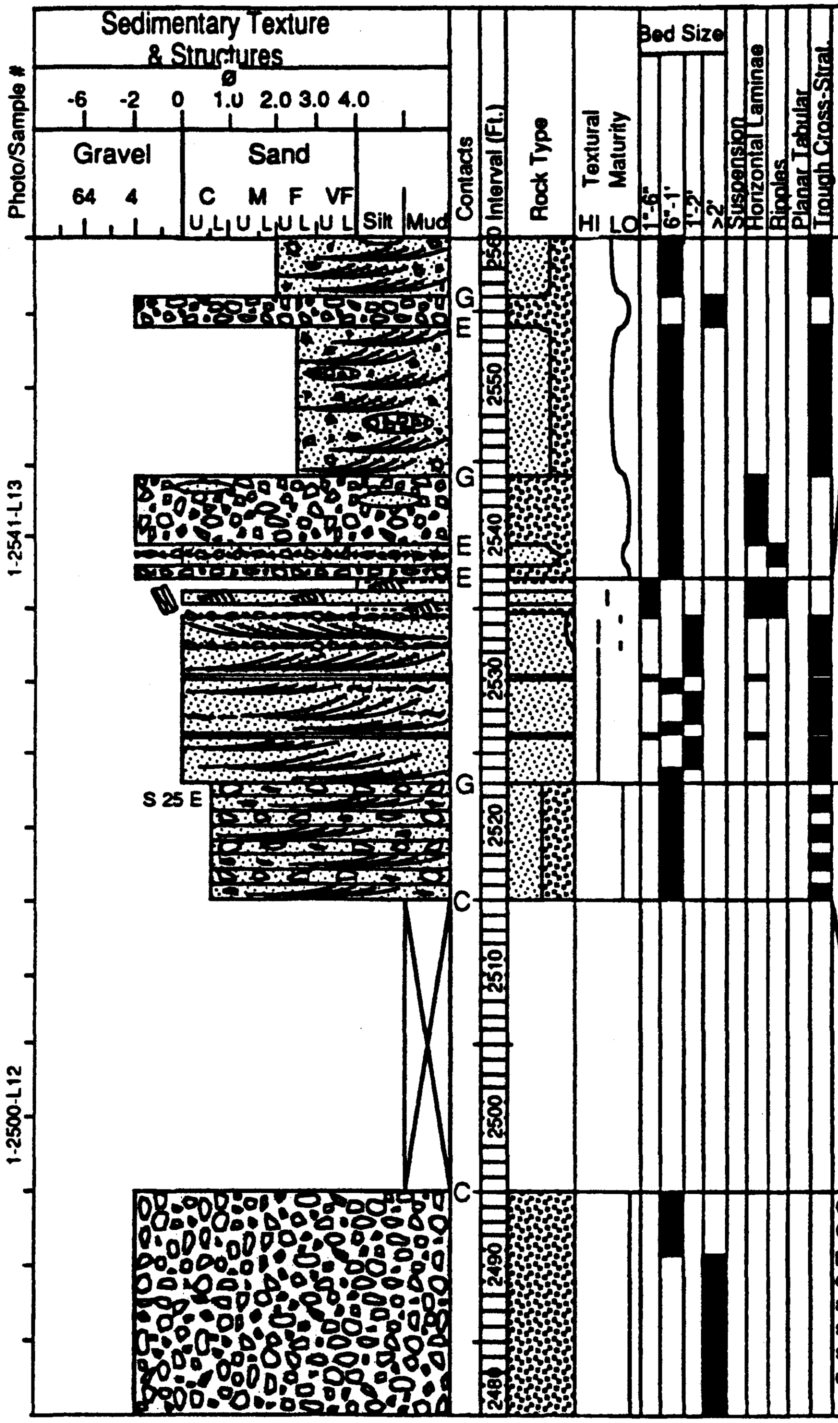
Comments



[See next page.]

Sandstone, tan, moderately to well sorted. TST in 1'-18" sets at base grading to 2"-4" sets at top. Fine, silty mudstone beds drape foresets and bounding surfaces. Sigmoidal, large scale geometries with foresets displaying rhythmic thinning and thickening. Minor <2" conglomerate lags sparse. Upper 2' grades to interbedded sandstone and muddy siltstone. Abundant wood and ARL in top sandstone and siltstone. Herringbone cross-stratification in top 1/3 of unit. Possible bioturbation in mudstone beds. Interval inferred to be at least partially tidal.

Interbedded conglomeratic sandstone and sandstone, tan, tuffaceous and poorly sorted. Beds 8"-1' with faint TST in both lithologies. Crude normal grading in conglomeratic sandstone. Abundant shale rip-ups and pumice. Thin, wavy mudstone interbeds are common.

Covered interval.

Lithologic sample taken from exposed block which may be out of place.

Conglomeratic lithic tuff, gray-green. Contains glass shards, Ca-plagioclase, basalt pebbles and compacted pumice (some of which is argillized). Unit weathers massive, same as underlying unit. Overall clast size fines up slightly through the two units.

BY Gardener and Houston

Name Cape Nukshak Structural Setting N 75 W, 11 SW

Location NE NE sec. 3 - NW SW sec. 17 T 21S R 29W Weather rainy

Date 7/23/90

Unit Hemlock Congl.

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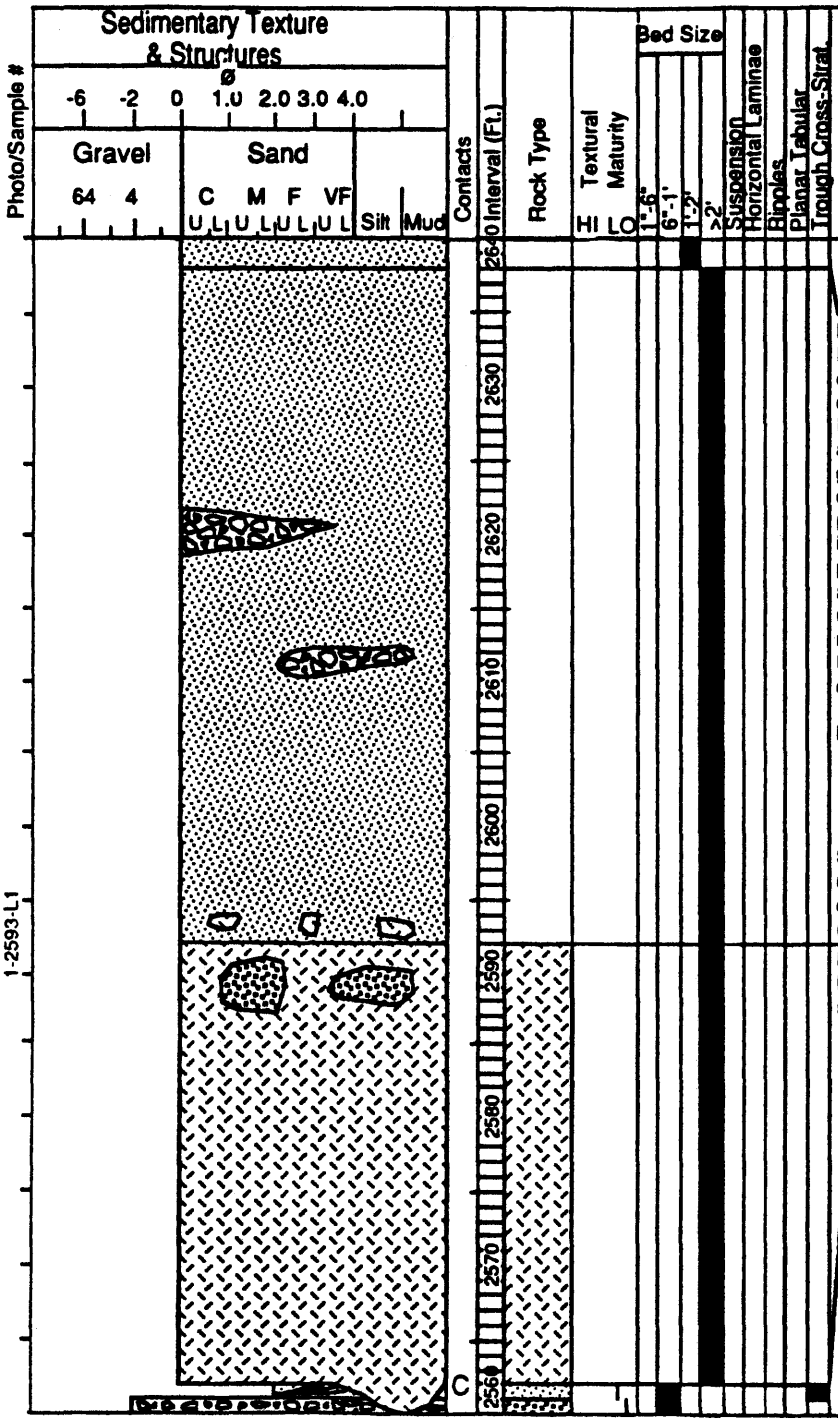
Comments



Lithic tuff, light green, massive. Less resistant than tuff below. Caps top of cliff.

Lithic tuff, light green, massive. Lenses of cobble sized conglomerate, cobble clasts, and compacted pumice throughout. Pheonocrysts are Ca-plagioclase(?) and glass shards in fine- to medium-grained green matrix. Chaotic distribution of clasts makes unit poorly sorted overall. Quartz grains in matrix are coarse. Basal contact is partially covered, however, near base are basalt clasts suggesting underlying basalt is in place. Unit measured 45' thick with a steel tape. Unit forms massive cliff. Strike and dip of bedding measured as N45W, 12SW is questionable because of lack of distinct bedding.

Section started at "top" of basalt flow near creek. Upper portion of basalt contains large conglomeratic blocks (up to 20' wide).

Basalt flow, minimally 30' thick. Maximum thickness unknown due to stream erosion.

Series of 2 fining-upward sequences that grade from pebbly conglomerate lenticular lags at the base to well sorted sandstone with TST in 8"-1' sets. Basal erosional surfaces are undulatory, and downcut from the north to the south. Sandstone weathers massive with TST faintly visible. Geometires are similar to underlying tidal(?) sequence. Upper contact poorly exposed. Large (up to 7' wide) basalt blocks load into underlying sandstone. This suggests that the basalt is part of the stratigraphic section.

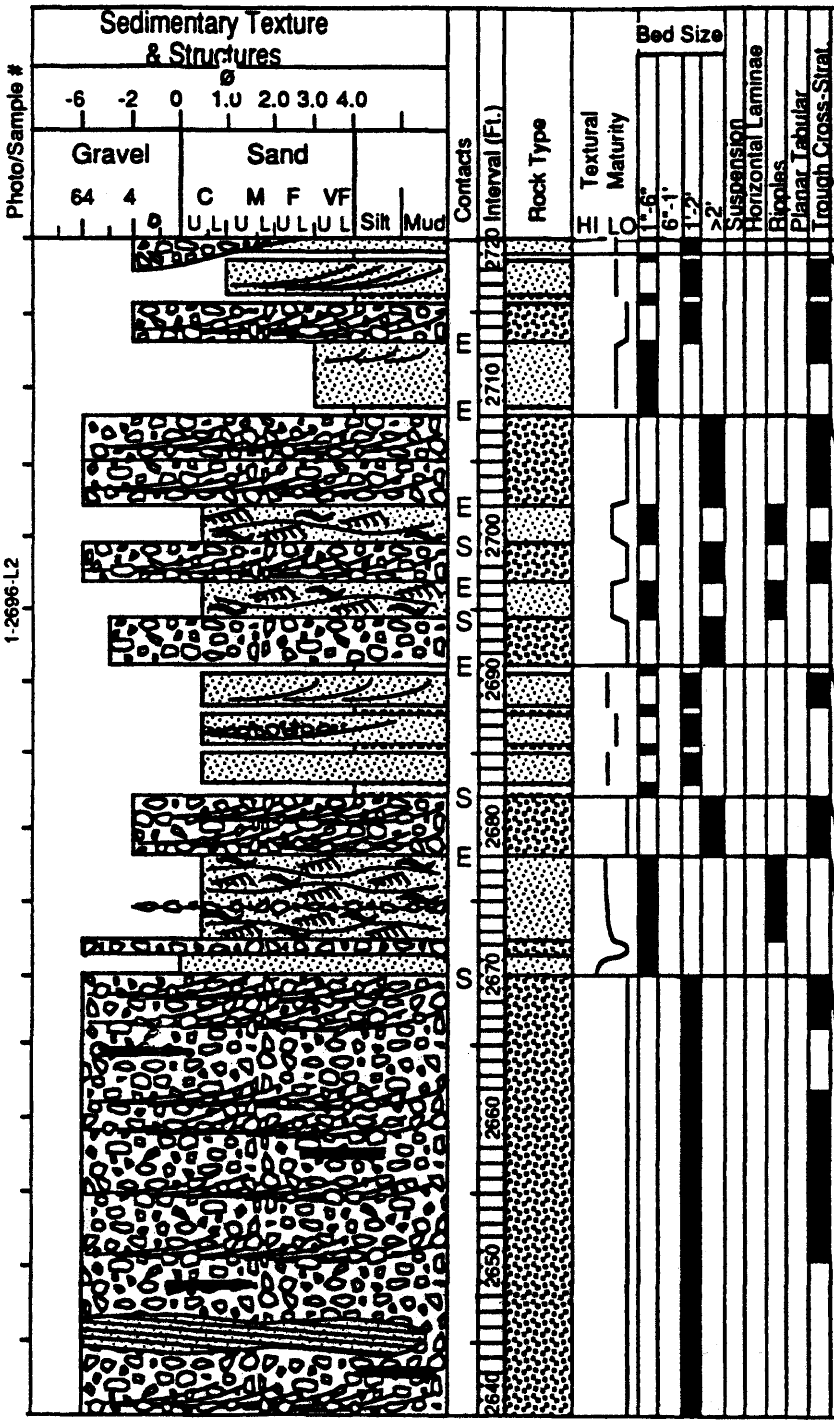
BY Gardener

Name Cape Nukshak

Structural Setting N 45 W, 12 SW

Location NE NE sec. 3 - NW SW sec. 17 T 21S R 29W

Weather rainy



Date 7/26/90

Unit Hemlock Congl.

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Comments

[See next page.]

Int. pebbly ss, ss and silty ss. Pebbly ss, poorly sorted with volcanic pebbles; forms thin lens. Ss, TST in 1' sets with thin, reddish, silty ss beds. Unit thinly bedded at base, 1'-2' beds at top separated by reddish, fine grained beds. Minor SSD and wavy contacts.

Int. congl., congl. ss, and ss with thin sltst interbeds. Overall unit contains inclined beds that dip from W to E along outcrop. Int. ss units are massive, show SSD. Fine grained ss beds are wavy to ARL with mud drapes. Congl., <10% subrounded clasts, mostly red and green volcanics, max. diam. 3", avg. 1". Possible point bar to tidal channel.

Interbedded platy ss and thinly bedded sltst. Sltst., brownish-red, wavy beds. Ss, 1'-2' beds with weak TST and scattered pebbles. Overall unit has massive appearance. Possible weak SSD.

Congl. ss, 10-15% clasts, avg. diam. <1", mostly volcanics. TST in 2'-3' sets. Undulatory basal contact. Unit exhibits lenticular geometry.

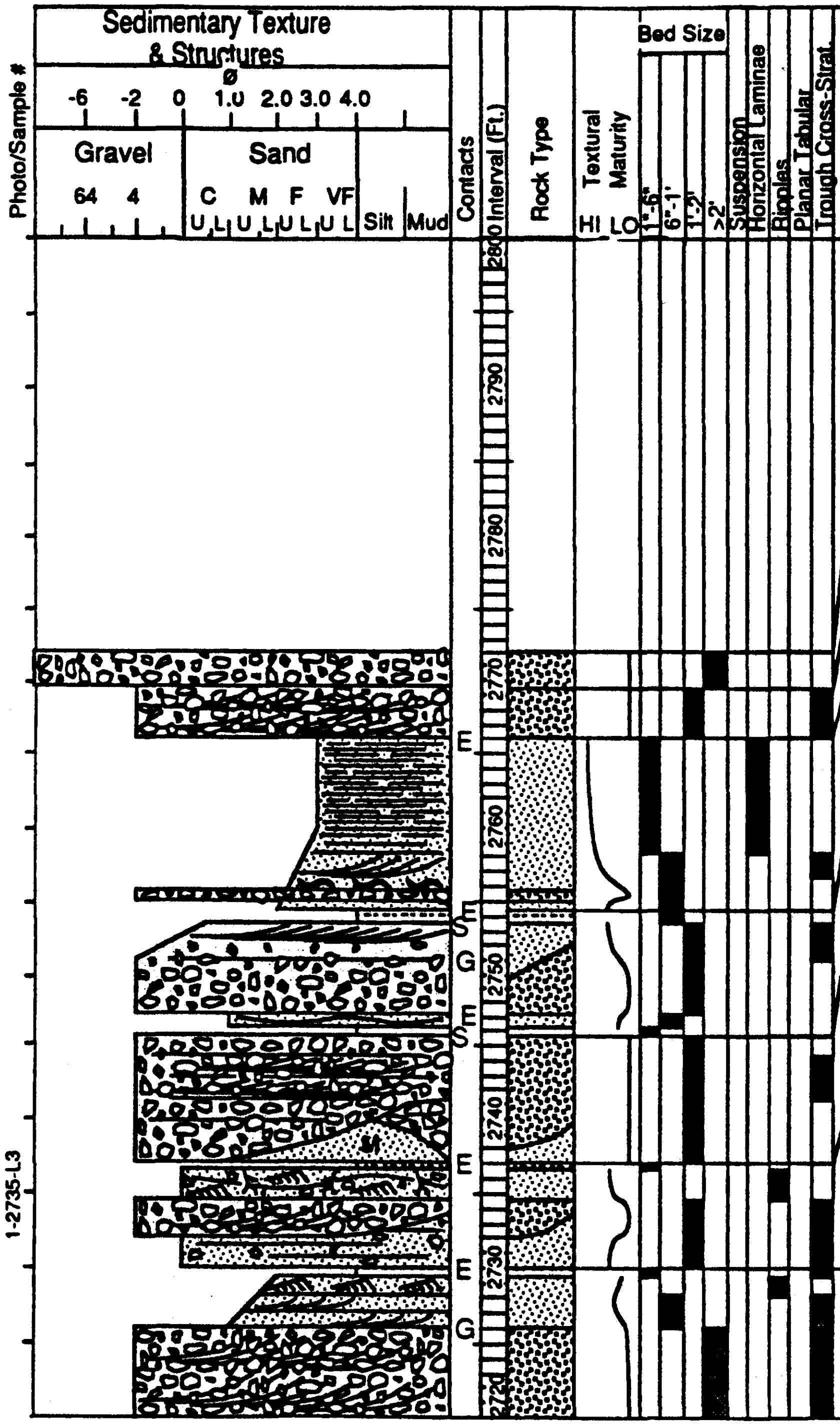
Ss, tan, moderately to well sorted. Arranged in 2"-4" beds that are n.g., with small scale ARL and possibly TST. Thin <1" granule lags and sltst drapes present throughout.

Congl., tan to gray, coarse ss matrix supported, moderately sorted. Organized into 3 upward fining units, each capped by a congl. ss containing scattered pebbles. TST in 1'-2' sets. Entire unit weathers reddish-brown. Clasts are predominantly red, gray and green volcanics, subrounded to subangular. Unit contains 15-20% clasts, max. diam. 6", avg. 2". Bottom 2' 25% clasts, max. diam. 8", avg. 2". 4"-8" diameter logs scattered throughout. Ss lens at 2644' exhibits very low angle cross beds and is weakly normally graded.

BY Gardener

Name Cape Nukshak Structural Setting N 45 W 12 SW

Location NE NE sec. 3 - NW SW sec. 17 T 21S R 29W Weather rainy



Date 7/26/90

Unit Hemlock Congl.

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Comments

Top of section.

Poorly sorted, chaotic conglomerate. Inferred to be a debris flow. Exposure itself is in a slump block.

Congl., matrix supported. Matrix is gray-green, coarse, tuffaceous, moderately sorted ss. TST in 1'-2' sets.

Int. ss with thin sltst partings at base, overlain by thin pebble bed, overlain by ss. Top ss, tan, well sorted, TST in 6"-1' sets at base grading up to thin horizontal laminations at top.

U-f sequence of congl. at base, grading up to pebbly ss to ss at top. Congl., matrix supported, 10% clasts, maximum diameter 3", average 1". Ss, gray- green, tuffaceous, moderately sorted, TST in 1' sets with n.g. foresets. Entire unit exhibits lenticular geometry.

Congl., greenish-gray, tuffaceous, moderately sorted. Crude TST in 1' sets. 10-15% clasts at base, fines to congl. ss, 5% clasts at top, maximum diameter 6", average 1"; Mostly red and gray volcanics.

Ss, tan, moderately sorted, large pebble lens in middle. Ss contains low angle TST in 1' sets with n.g. forsets. top surface is rooted and has filled, cylindrical 1" burrows. SSD and wavy bedding in top 1/3.

Upward-fining sequence of matrix supported congl. at base, grading to ARL ss at top. Congl., 5% clasts, maximum diameter 3", average 1". mostly red, subrounded volcanics. Ss appears massive with faint TST.

BY Houston and Gardner

Name Kinak Bay Structural Setting N 80 W, 19 NE

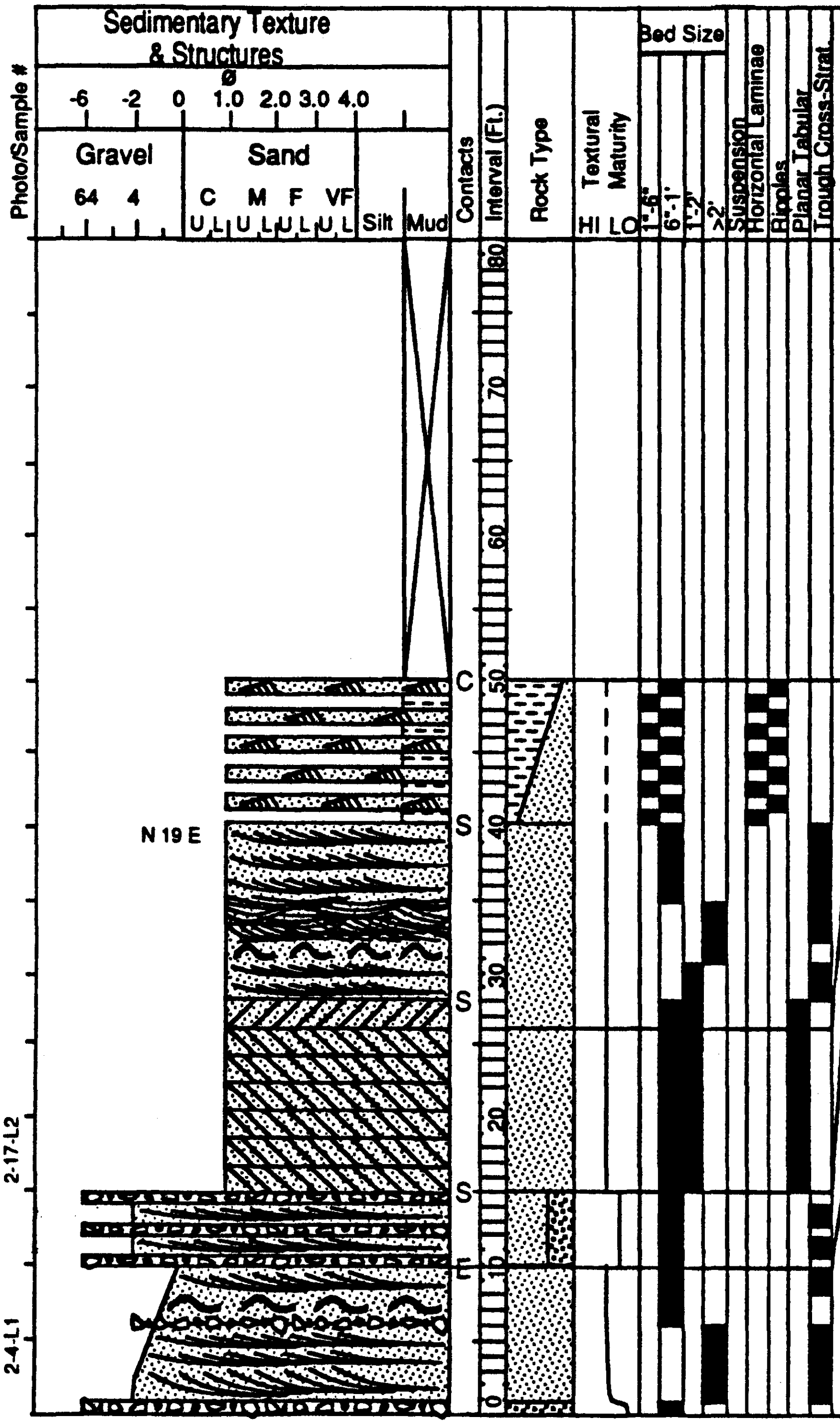
Location NE NE sec. 23 - SW SW sec. 13 T 24S R 32W Weather miserable

Date 8/1/90

Unit Hemlock Congl.

Page 1 of 10

Comments



72' of covered interval.

Sandstone grading upward to interbedded sandstone and mudstone. TST in 6"-3' sets at base. ARL in 1"-2" sets at top. Moderate SSD at base. Mudstone increases up section. Package from 0'-50' is one fining-upward sequence.

Sandstone with abundant, very thin mudstone partings, brownish-gray, very friable. PST in 6"-18" sets with normally graded foresets.

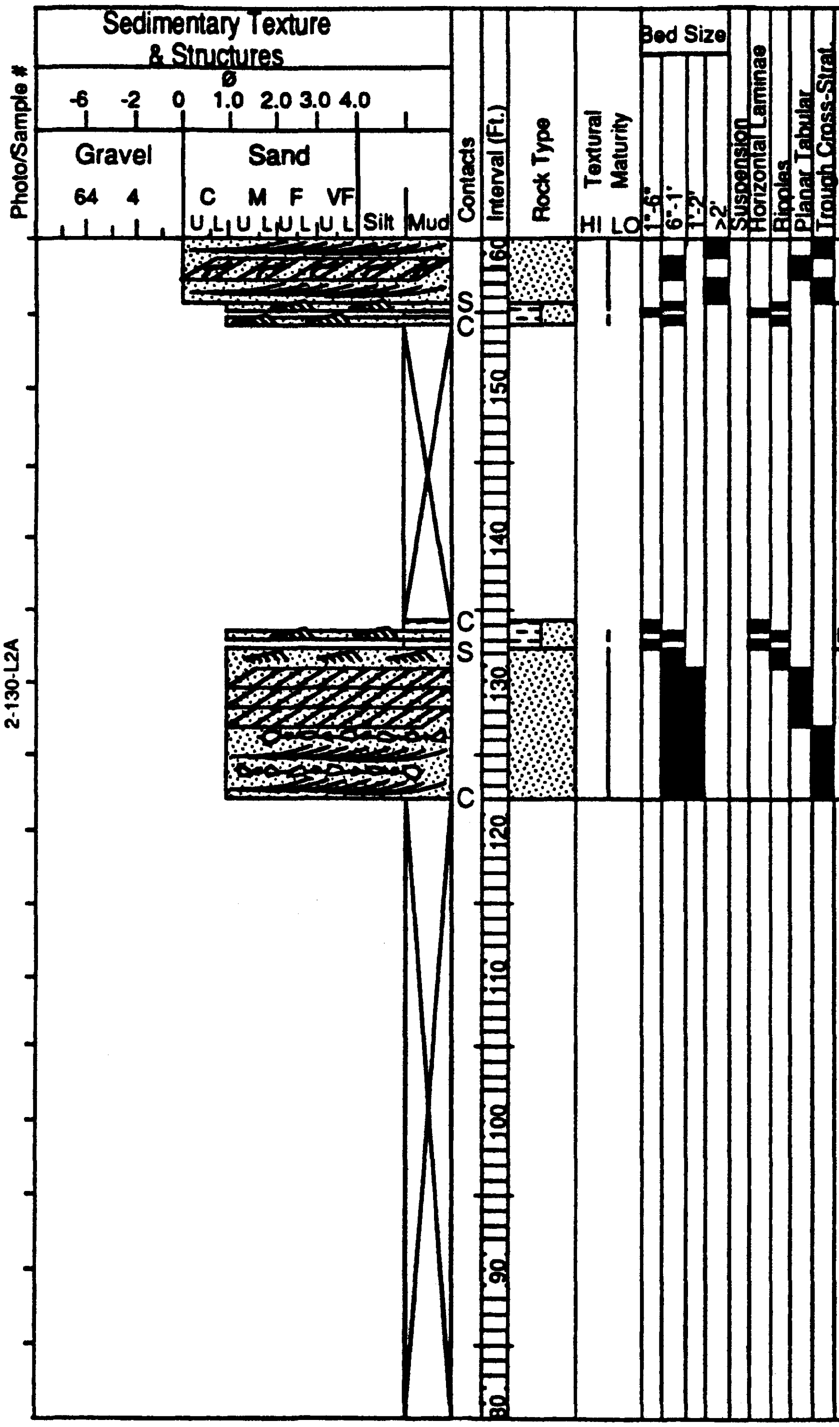
Interbedded conglomerate and sandstone. Conglomerate, matrix supported (coarse sandstone). Clasts include; 60% chert/quartz, 25% volcanic, 15% other. Beds thin up section. Sandstone, TST in 6" sets.

Sandstone, light gray, tuffaceous, moderately sorted, normally graded. TST in 3' sets at base decreasing to 1' sets at top. Foresets are normally graded and oversteepened (crenulated). Abundant SSD throughout unit. Two thin pebble beds, maximum clast diameter 4", average <1", subrounded to rounded, dominantly quartz, chert and volcanic clasts.

BY Houston and Gardner

Name Kinak Bay Structural Setting N 80 W 19 NE

Location NE NE sec. 23 - SW SW sec. 13 T 24S R 32W Weather miserable



Date 8/1/90

Unit Hemlock Congl.

Page 2 of 10

Comments

[See next page.]

TST in 2'-3' sets, PST in 6" sets.

This part of section is continuous, but very poorly exposed and intermittently covered. Interbedded sandstone and mudstone. Sandstone, greenish-gray, moderately sorted. PST in 6"-18" sets, scattered pebble lenses at base. Mudstone, black, laminated, carbonaceous. ARL in 1"-2" sets in 1' beds.

Interbedded sandstone and mudstone.

Sandstone, TST at base, PST in middle, both in 6"-2' sets. ARL at top in 1"-2" sets.

Covered interval.

BY Houston and Gardner

Name Kinak Bay Structural Setting N 80 W, 19 NE

Location NE NE sec. 23 - SW SW sec. 13 T.24S. R.32W. Weather miserable

Date 8/1/90

Unit Hemlock Congl.

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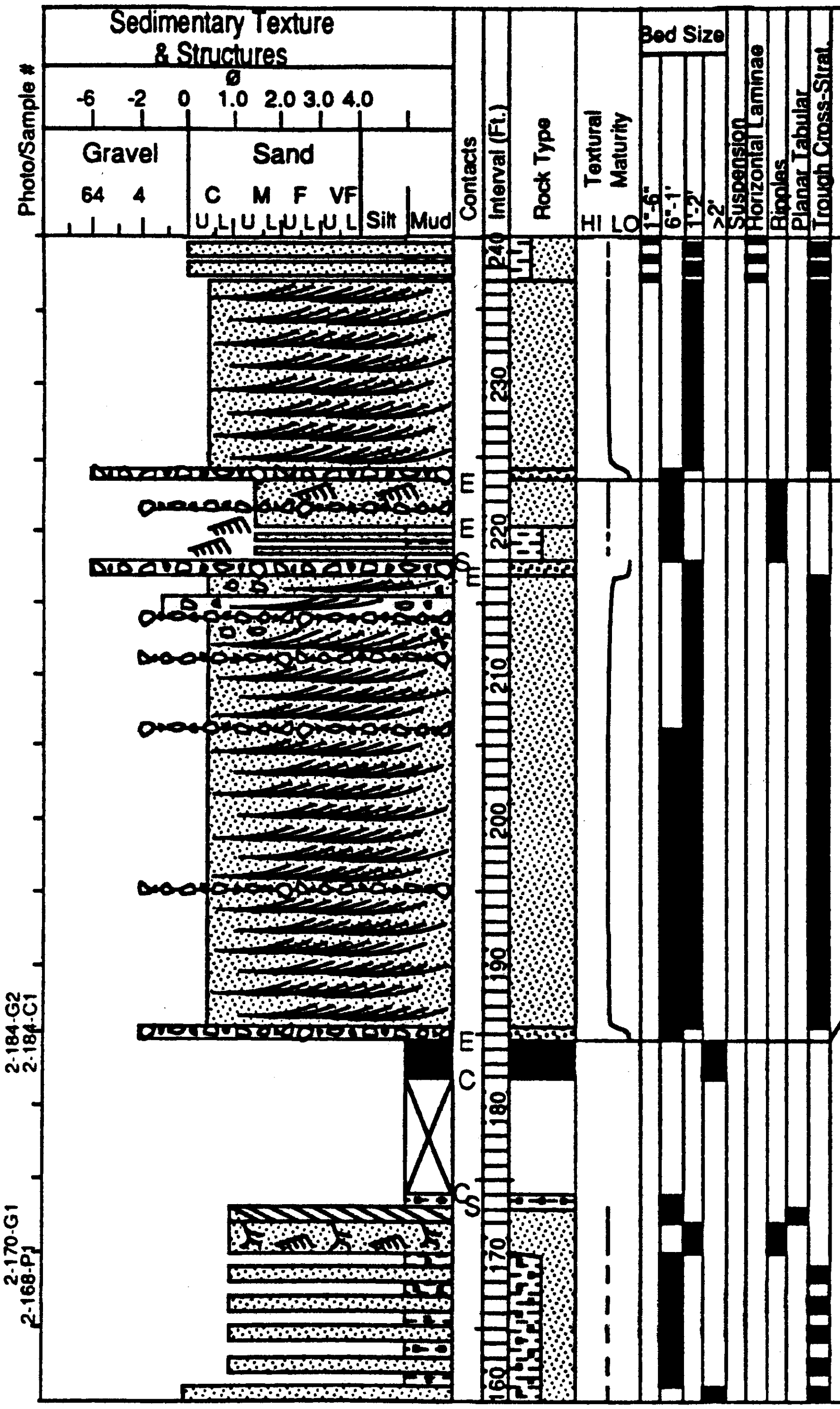

Comments

Thin conglomerate lag overlain by sandstone overlain by interbedded sandstone and mudstone. Sandstone contains TST in 1'-2' sets. Mustone is black and laminated.

Interbedded conglomerate and sandstone grading to interbedded sandstone and mudstone. Conglomerate, matrix supported (coarse sandstone), arranged in thin beds and stringers. Maximum clast diameter 6", average <1", subrounded, low sphericity. Clasts are mostly quartz and chert with minor volcanic and plutonic. Sandstone, grayish-green, TST in 6"-1' sets at base, 1'-2' sets in middle and top, foresets are steepened and normally graded. Silty mudstone, black, laminated. Upper sandstone contains climbing ARL and abundant SSD throughout. All beds from 214'-223' are lenticular, thinning to the southwest. Dominant paleocurrent directions are to the southwest. Structures suggest rapid deposition.

Package from 122'-184' is one fining-upward sequence of ss at base grading to interbedded ss and mdst. Sequence capped by 3' coal. Sandstone, grayish-green, moderately sorted. TST in 2'-3' sets at base grading to 6" sets at top. Highest exposed sand body is massive, contains ARL in 1"-2" sets and small scale PST in <6" sets, and is rooted. Mudstone, olive-brown to black, carbonaceous, beds up to 1' thick. 8' of section below coal is poorly exposed; inferred to be interbedded sandstone and mudstone.

BY Houston and Gardner

Name Kinak Bay Structural Setting N 80 W, 19 NE

Location NE NE sec. 23 - SW SW sec. 13, T 24S, R 32W Weather miserable

Date 8/1/90

Unit Hemlock Congl.

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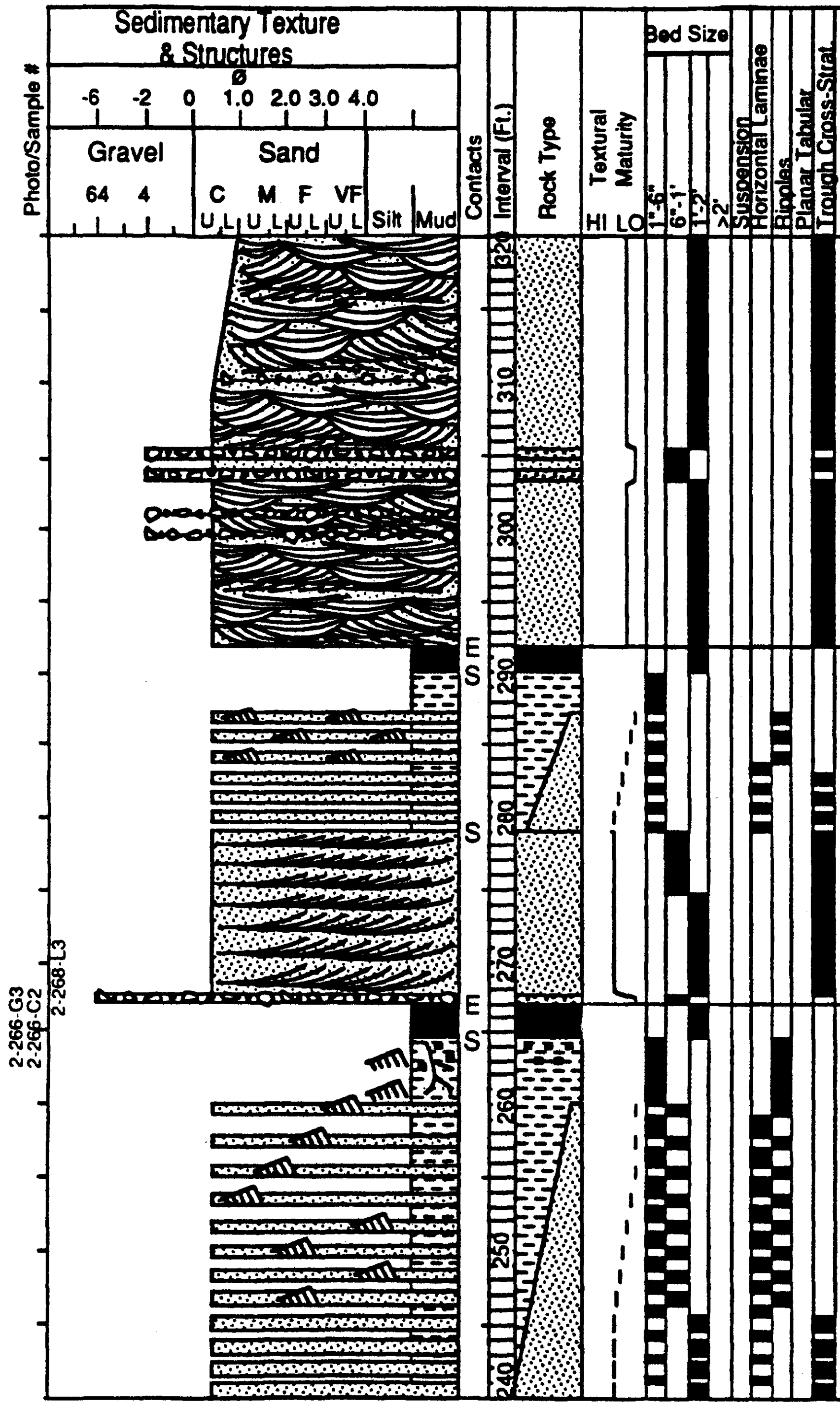

Comments

Upward-fining sequence of sandstone at base to interbedded sandstone and siltstone at top. TST amalgamated in 1'-2' sets. Few continuous conglomerate stringers, scattered pebbles throughout, especially abundant at base of 10'-15' thick lenticular sand bodies. Interbedded sandstone and mudstone, moderate SSD, sandstone ARL in 2"-4" sets, mudstone laminated with faint ARL. Capped by thin, black, carbonaceous shale. Sequence continued on next page.

Upward-fining sequence, similar to underlying sequence. TST in 1' sets at base grading to 6" sets up section. Sandstone beds 1' thick when interbedded with mudstone. Lower mudstone beds 2" thick increasing to 4" thick up section.

Upward-fining sequence of sandstone at base, interbedded sandstone and mudstone in middle, capped by 2.5' coal. Sandstone, grayish-green, moderatly to poorly sorted. TST in1'-2' sets at base grading to ARL in 1"-3" sets in 6"-1' beds at top. Climbing ARL from 253'. Mudstone, black, laminated, increasingly carbonaceous up section. Sandstone beds decrease in thickness up section, mudstone beds increase in thickness and frequency up section. base of sequence is conglomerate lag at 223'.

BY Houston and Gardner

Name Kinak Bay Structural Setting N 80 W, 19 NE

Location NW NW sec. 23 - SW SW sec. 13 T 24S R 32W Weather miserable

Date 8/1/90

Unit Hemlock Congl.

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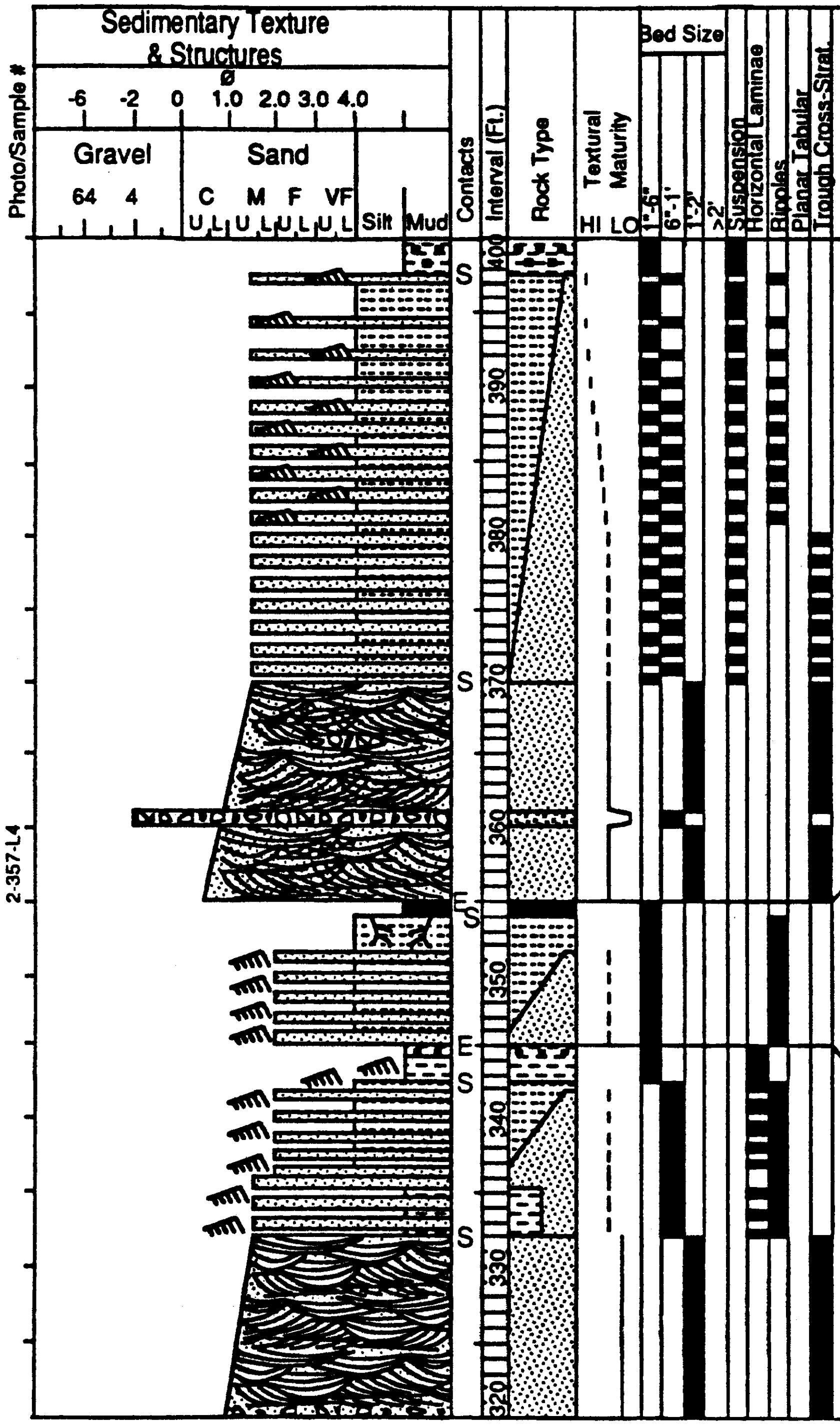


Comments

Upward-fining sequence of sandstone and thin conglomerate at base grading up to interbedded sandstone and siltstone, capped by carbonaceous shale. Conglomerate, poorly sorted, matrix supported (coarse sandstone), maximum clast diameter 6". Unit confined to lenses except for one 1' bed. Sandstone, grayish-green, moderately sorted at base, well sorted at top. Amalgamated TST in 2"-1' sets at base grading to alternating TST in 6" sets and ARL in 2"-4" sets up section. siltstone, black, laminated. Sand decreases, silt increases up section.

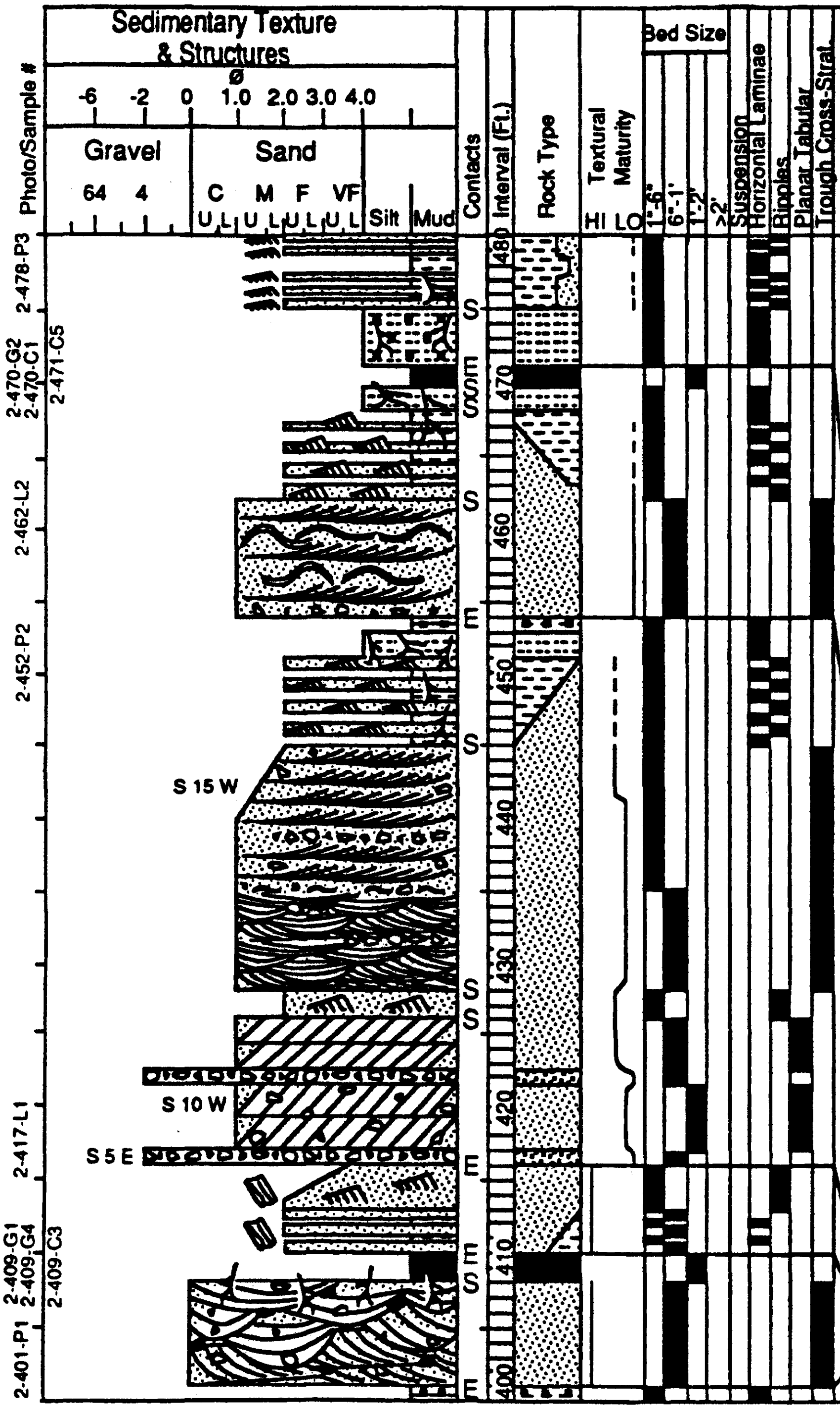
Interbedded sandstone and siltstone. Sandstone beds 4" thick at base, 6" thick at top. Inclined surfaces on ss beds may be epsilon beds. Upper mudstone is rooted. Capped by a 1' coal. Package is inferred to be an abandoned channel fill.

[See previous page.]

BY Houston and Gardner

Name Kinak Bay Structural Setting N 85 W, 16 NE

Location NE NE sec. 23 - SW SW sec. 13 T.24S. R.32W. Weather low ceiling



Date 7/17/90

Unit Hemlock Congl.

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Comments

Upward-coarsening sequence of siltstone grading to thin interbedded sandstone and mudstone. Sandstone beds 1"-2" thick at base, 2"-6" at top. ARL in 1"-2" sets, starved at base, climbing at top. Siltstone, laminated, carbonaceous, mica(?) on bedding planes. Mudstone beds 1"-2" thick at base, partings at top. Interbedded sequence weathers platy. All units are rooted. Sequence is capped by a massive mudstone.

Upward-fining sequence of sandstone at base, coal at top. Sandstone is TST in 6"-1' sets, abundant SSD anti- and syn-forms. Upper 6' is thinly interbedded ARL sandstone (1"-2" beds) and mudstone (1"-4" beds), rooted with 5' roots. Mudstone beds increase in thickness and frequency up section.

Upward-fining sequence of interbedded conglomerate, conglomeratic sandstone and sandstone. Conglomerate forms lags at base with ripups of underlying material. Sandstone beds 6"-3' thick with basal sandstone PST with normally graded foresets. overlying Amalgamated TST with normally graded foresets grades to TST in 6"-1' sets, to ARL up section. At 435' mud drapes define bedding surfaces with mud content increasing upward. Scattered pebbles throughout sandstones. Upper 15' severely weathered. Upper 5' is interbedded sandstone (2"-6" beds) and mudstone (1"-2" beds), sandstone beds contain starved ripples, all beds extensively rooted.

Sandstone, olive green, abundant wood on bedding planes

Sandstone, buff, well sorted. Amalgamated TST in 6"-8" sets, abundant rip-ups and scattered pebbles, upper contact rooted.

[See previous page.]

BY Gardner and Houston

Name Kinak Bay Structural Setting N 85 W 16 NE

Location NE NE sec 23 - SW SW sec 13 T 24S R 32W Weather sunny, scattered clouds

Date 7/17/90

Unit Hemlock Congl.

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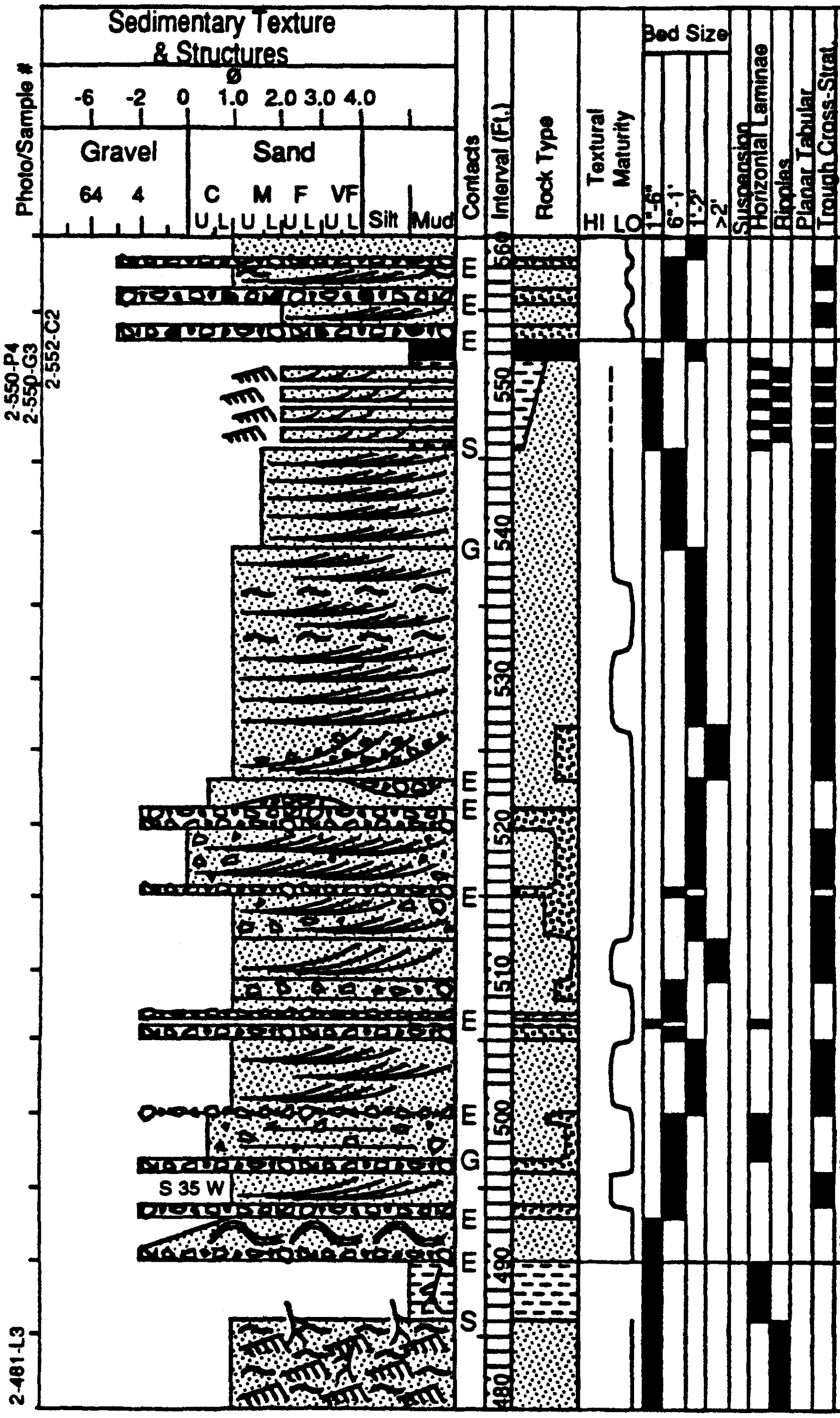

Comments

Three conglomerate lags interbedded with sandstone. Conglomerates contain clasts of quartz, volcanics and underlying coal.

Interbedded conglomerate, conglomeratic sandstone, sandstone and mudstone form series of small, 1'-5' thick upward-fining sequences within an overall upward-fining sequence. Maximum clast diameter for all units 4". Conglomerate decreases, sandstone and mudstone increase up section. Sandstone, medium to coarse grained, moderately to poorly sorted, subangular grains, weathers platy, very friable. Sandstone beds 2"-3' thick, TST sets with normally graded foresets decrease in thickness up section, grades to alternating ARL in 1"-2" sets and TST in 1"-6" sets. in top 7'. Upper 20' contains mudstone partings grading to1"-2" thick interbeds of mudstone up section. Thin, black claystone at 550'. Unit forms massive cliff in middle of beach. Unit capped by 17" thick coal.

TST with normally graded foresets.

Red mudstone, good marker bed.

Poorly sorted sandstone.

Poorly organized conglomeratic sandstone.

3" sub-angular clasts, TST with normally graded foresets.

Severe SSD.

[See previous page.]

BY Gardner and Houston

Name Kinak Bay Structural Setting N 85 W, 16 NE

Location NE NE sec. 23 - SW SW sec. 13 T 24S R 32W Weather scattered clouds

Date 7/17/90

Unit Hemlock Congl.

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Comments

Interbedded mudstone, carbonaceous shale and coal. Bottom mudstone interval extensively rooted. Package marks top of overall fining-upward sequence beginning at 553'.

Highly fractured and exfoliated unit. Bedding and internal structures mostly obscured by shearing from slumps.

Sandstone with low-angle TST with abundant mud drapes on foresets.

Climbing ripples.

Sandstone with low-angle TST.

Layer of 1" diameter pebbles at 587'.

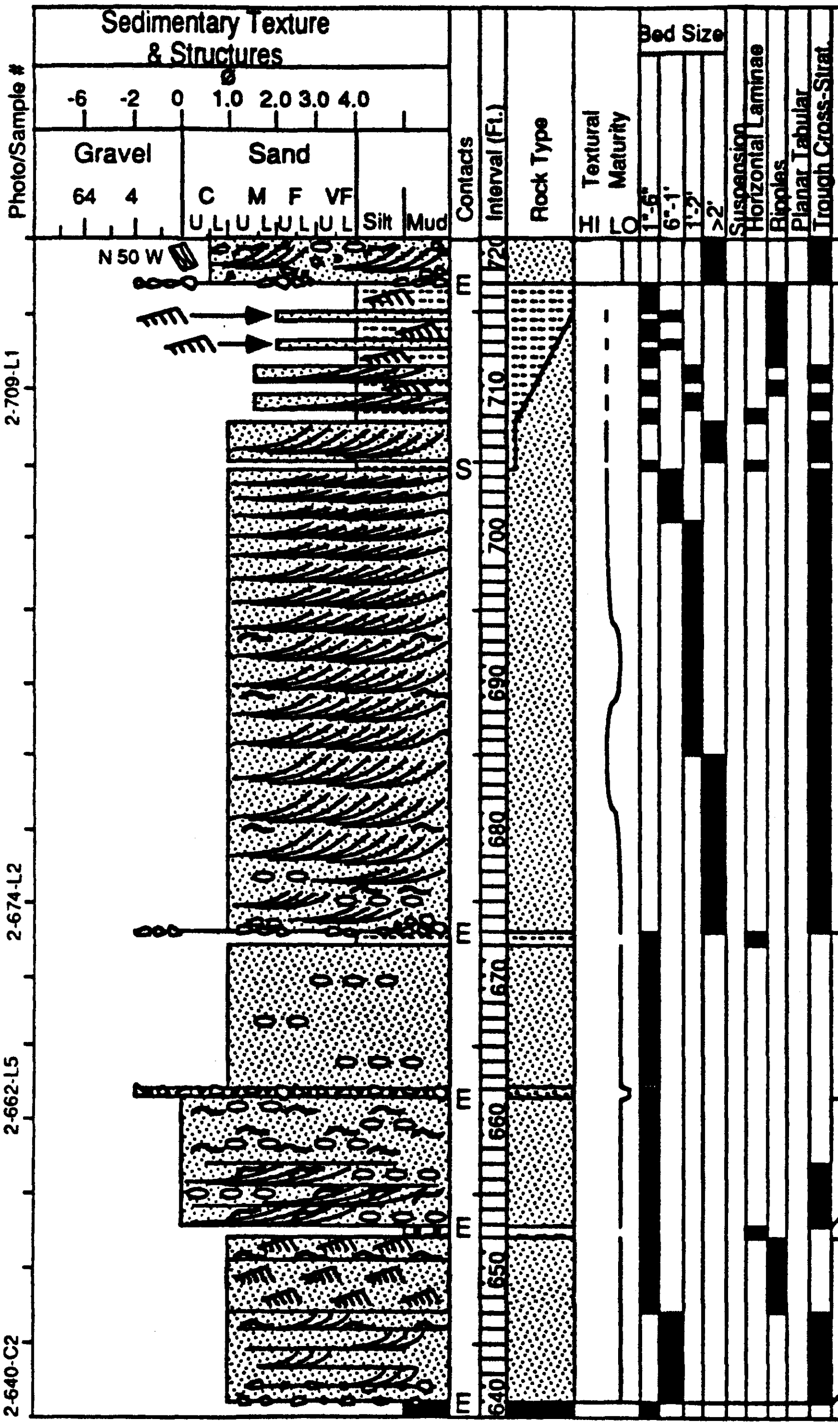
Well organized, horizontal gravel stratification.

Pebbles at top and bottom of beds. Thin conglomerates at 562' and 563' inversely graded.

BY Houston and Mackey

Name Kinak Bay Structural Setting N 85 W, 14 NE

Location NE NE sec. 23 - SW SW sec. 13, T 24S, R 32W Weather beautiful



Date 8/2/90

Unit Hemlock Congl.

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Comments

Basal, discontinuous pebble lag.

Sandstone, grayish-brown to buff, medium grained. TST in 2"-3' sets at base grading to 6"-1' sets up section. Sandstone grades to interbedded sandstone and siltstone up section. Highest sandstones contain weak ARL. Rip-ups and scattered concretions (maximum diameter 1") in bottom 3'. Siltstone, gray, very thinly laminated (<1"), faint ARL. Interbeds of siltstone become more abundant up section.

Shale partings between some TST sets.

Concretionary sandstone, bedding and internal structures obscured by exfoliation.

Concretionary sandstone, TST in 1"-4" sets in bottom half with mud drapes on foresets. Shale partings on bedding planes in upper half.

Carbonaceous shale

Sandstone, scattered pebbles at base. TST in 6" sets in bottom half, ARL in 1"-3" sets in upper half. Shale partings on some bedding planes.

[See previous page.]

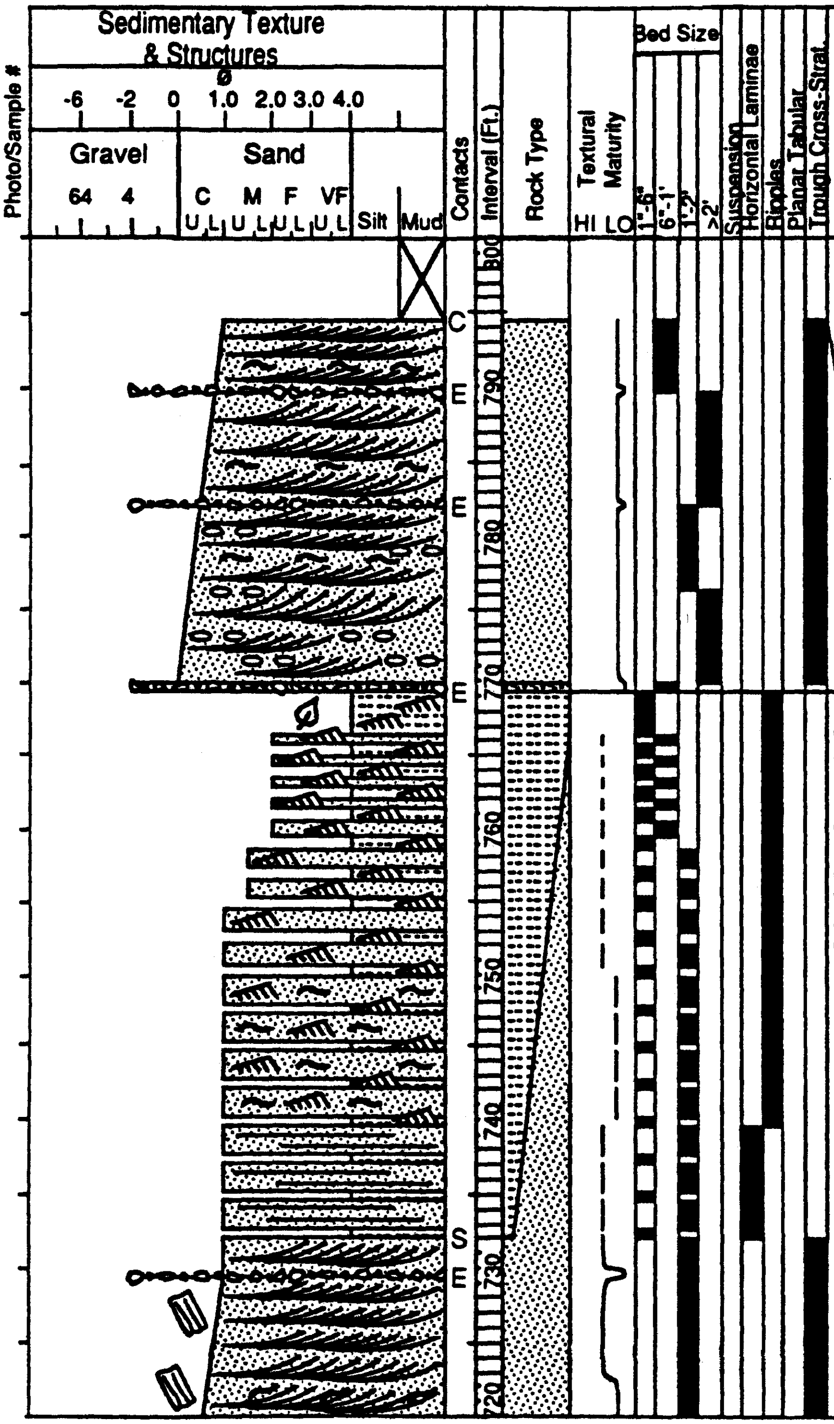
BY Houston and Mackey

Name Kinak Bay

Structural Setting N 85 W, 14 NE

Location NE NE sec. 23 - SE SE sec. 23 T 24S R 32W

Weather beautiful



Date 8/2/90

Unit Hemlock Congl.

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Comments

Gray sltst grading to black mdst (both very thinly bedded) capped by 1' coal. All poorly exposed, inferred to be top of upward-fining sequence similar to upward-fining sequence from 717'-769'. Section above this is completely covered.

Upward-fining sandstone, light brown. TST in 6"-3' sets separated by mudstone stringers, some normally graded foresets (granule to coarse sand), some mud drapes on foresets. Concretions, maximum diameter 8", in bottom half. Pebble layers continuous, contain 80% quartz/chert, 20% rip-ups, rounded with low sphericity. Highly exfoliated. Last well exposed outcrop.

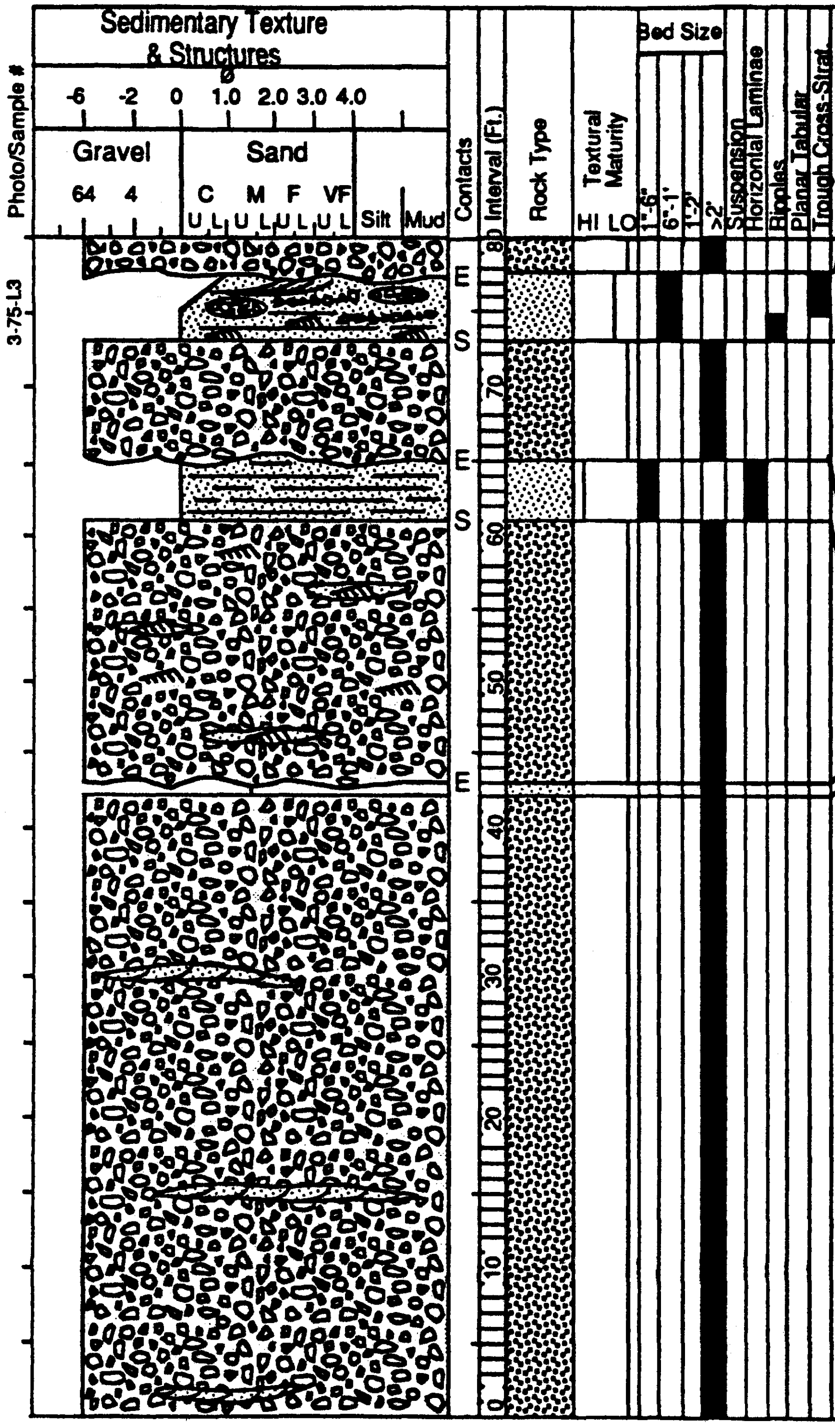
Upward-fining sequence beginning at discontinuous pebble lag at 717'. Sandstone grading to interbedded sandstone and siltstone. Lowest sandstone, buff to brown, coarse grained. TST in 6"-3' sets, foresets normally graded, some with mud drapes. Bottom 3' contains rip-ups, wood fragments, scattered pebbles and several concretions, maximum diameter 6". Section grades to horizontally interbedded coarse sandstone and ARL siltstone, to interbedded siltstone and fine sandstone, with siltstone increasing up section. Unit capped by 3' siltstone. Upper interbedded sandstones, ARL in 1"-2" sets, shale partings on some bedding planes. Siltstone, medium gray, finely laminated with faint ARL(?). Small leaf impressions in top siltstone.

Discontinuous lag ranging from 0-14" thick at 729.5'.

BY Ethridge and Houston

Name Cape Douglas Structural Setting strike section (140 deg.)

Location SE NE. sec. 6 - NE NW. sec. 5. T.14S., R.25W. Weather beautiful



Date 7/29/90

Unit West Foreland

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Comments

Ss, slightly fining-upward (coarse to medium). ARL at bottom, TST at top. Contains conglomeratic stringers and lenses up to 2' thick.

Congl, 50-60% clasts: 80% basalt/sill material, 5% chert, 10% extrusive, 5% other. Maximum clasts diameter 1', bimodal avg. 1" and 3", sub- to well-rounded, very low sphericity. Matrix, gray, medium to coarse grained, moderately sorted. Scour relief 2-3' at base.

Ss, light brown, well to very well sorted. Weathers platy.

Congl. containing lenses of ARL, med. grained sandstone. Unit more homogeneous than two overlying congls. 45-50% clasts: 15% pyroclastic, 10% chert, 75% other igneous. Max. clasts 8", avg. 2", well rounded, low sphericity. Matrix, brownish-gray, med. grained, well sorted, some ARL. Basal scours 1-2'.

Covered by sand and grass.

Congl. with bimodal clast distribution (pebbles and cobbles), containing 1'-4' thick ss lenses 40' to 1/4 mi. long.
Compared to congl. higher in section: little relief on basal surfaces; coarser grained and more poorly org.; fewer rip-ups; no graded beds.
Upper 14' of unit: 45-50% slightly fractured clasts: 20% pyroclastic, 10% chert, 70% basalt/plutonics/sill material. Some pyroclastics appear silicified. Matrix, medium gray, medium grained.
Lower 28' of unit: 45-50% moderately fractured clasts: 15% chert, 5% pyroclastics, 80% igneous. Clasts well rounded, mod. sphericity (0.5). Abundant radially fractured clasts, especially chert containing quartz vveins. Some pyroclastics appear chloritized. 4" rip-ups of rotten, woody, coaly material. Pockets of iron staining.
Good pebble imbrications indicate a transport direction of S 75 E.

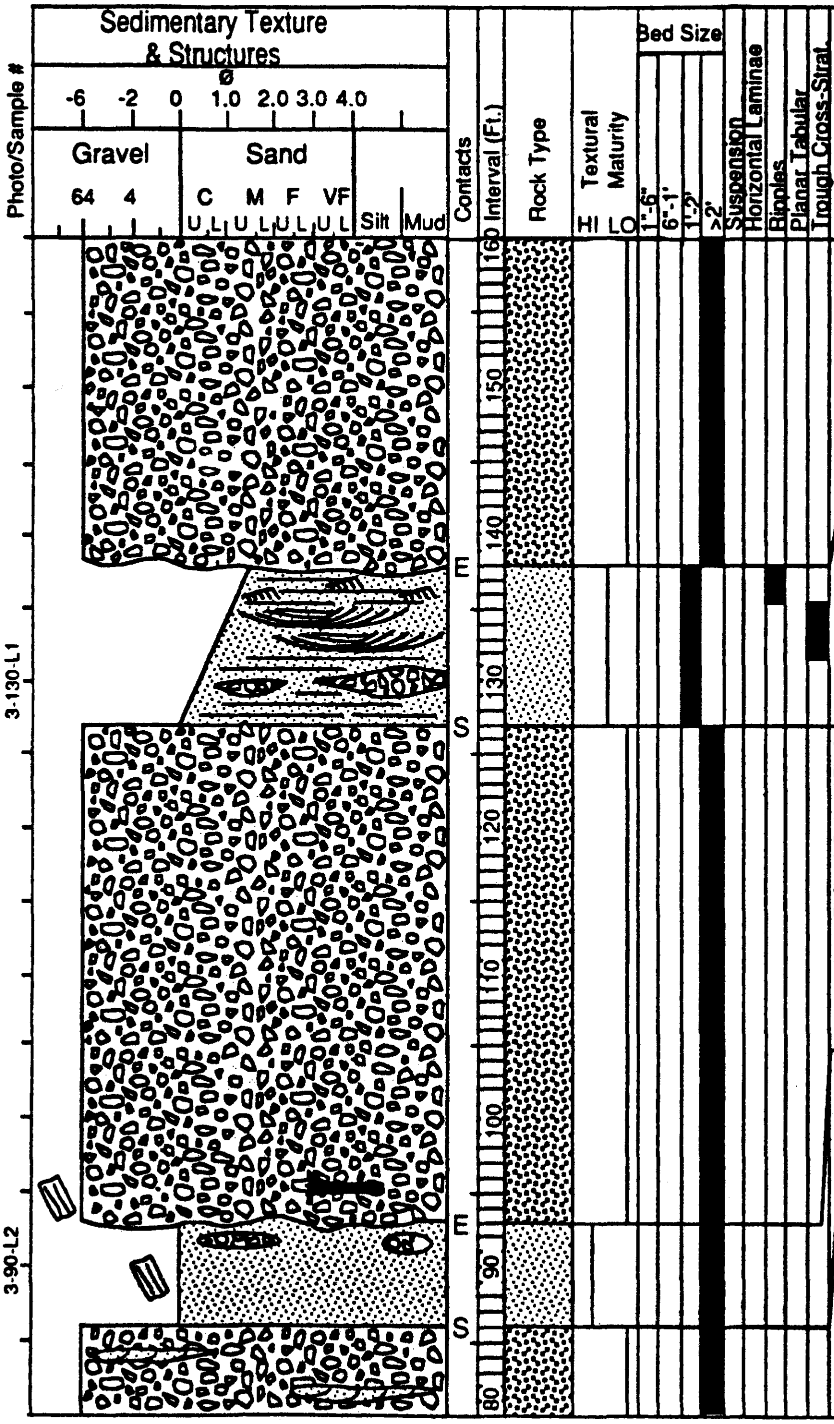
BY Ethridge and Mackey

Name Cape Douglas

Structural Setting N 45 W, 11 SW

Location SE NE sec. 6 - NE NW sec. 5, T 14S, R 25W

Weather nice



Date 7/30/90

Unit West Foreland

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Comments

Conglomerate, clast composition similar to conglomerate below. Few rip-up clasts. Generally flat, erosional base with infrequent scours 2-3' deep. Poor pebble imbrication suggests transport direction of N 80 W.

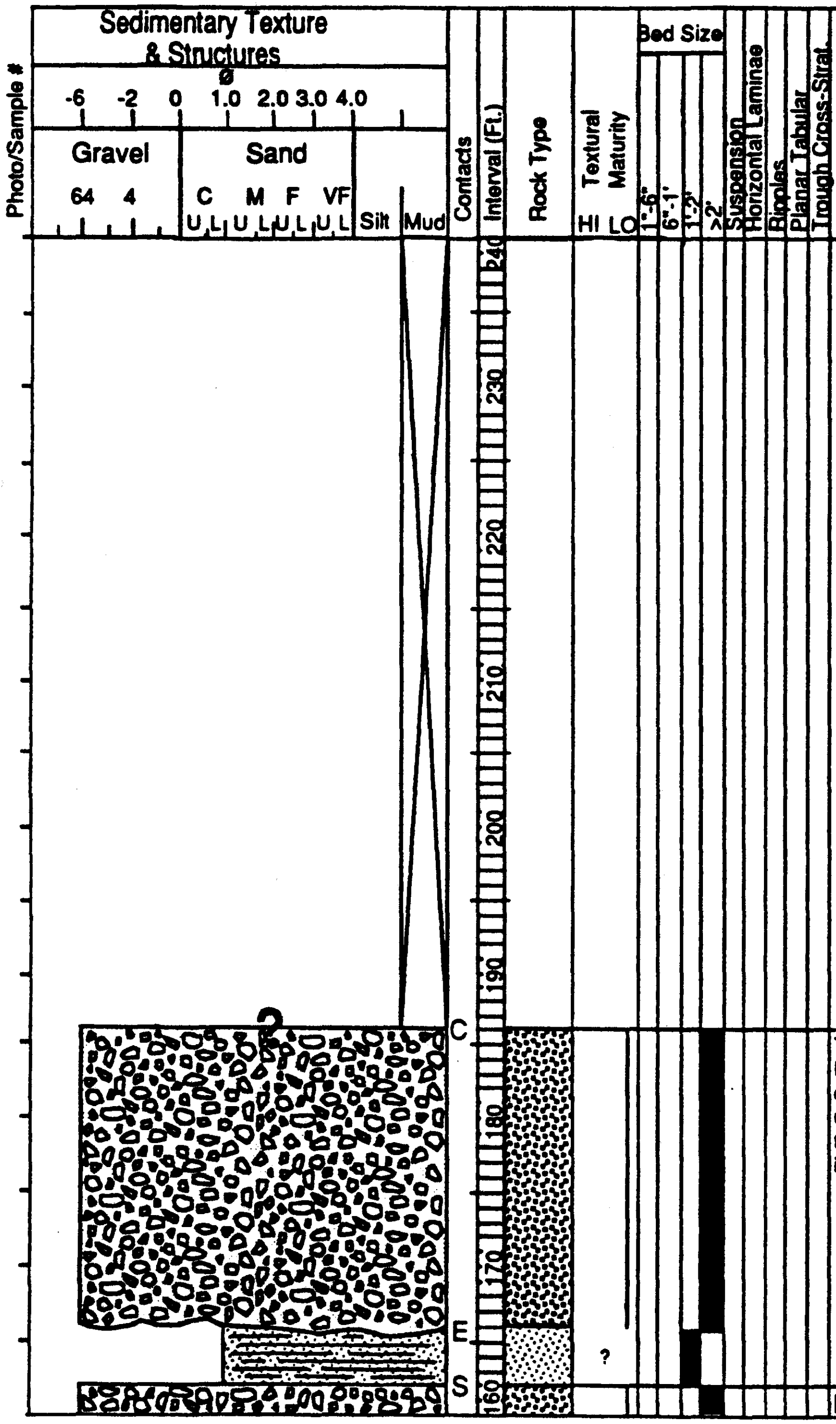
Sandstone, light brown to tan, coarse grained, moderately sorted. Fining-upward sequence. Horizontal beds in lower half, medium to small scale TST grading up into ARL in top half. Discontinuous pebble layer in lower part 0-2' thick. Conglomeratic lenses in bottom 1/4. TST indicates transport direction of N 65 W.

Conglomerate, 50% clasts: 20% pyroclastic, 25% chert, 55% other igneous. Maximum clast diameter 8", bimodal average 1" and 3", well rounded, medium sphericity (0.5). Wood fragments at base up to 2' long and 3" in diameter. Similar matrix as in conglomerate below. Moderate pebble imbrication suggests transport S 85 W.

Sandstone, light tan, medium to coarse grained, well sorted. Lenses of conglomerate. and small wood fragments in upper 2'. Severely fractured, but otherwise structureless.

Congl., 55% clasts: 20% pyroclastic, 20% chert, 60% other igneous. Max. clasts 6", avg. 1"-2", well rounded, med sphericity (0.5). Matrix, med. to light brown, coarse grained, mod. sorted. Local ss lenses 3"-4" thick and 4'-5' long. Lag clasts in congl. 4' long, 3"-6" in diameter. Mod. pebble imbrication shows transport S 85 W.

BY Ethridge and Mackey
Name Cape Douglas Structural Setting N 45 W, 11 SW
Location SE NE sec 6 - NE NW sec 5 T 14S R 25W Weather nice



Date 7/30/90
Unit West Foreland
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Comments

[See next page.]

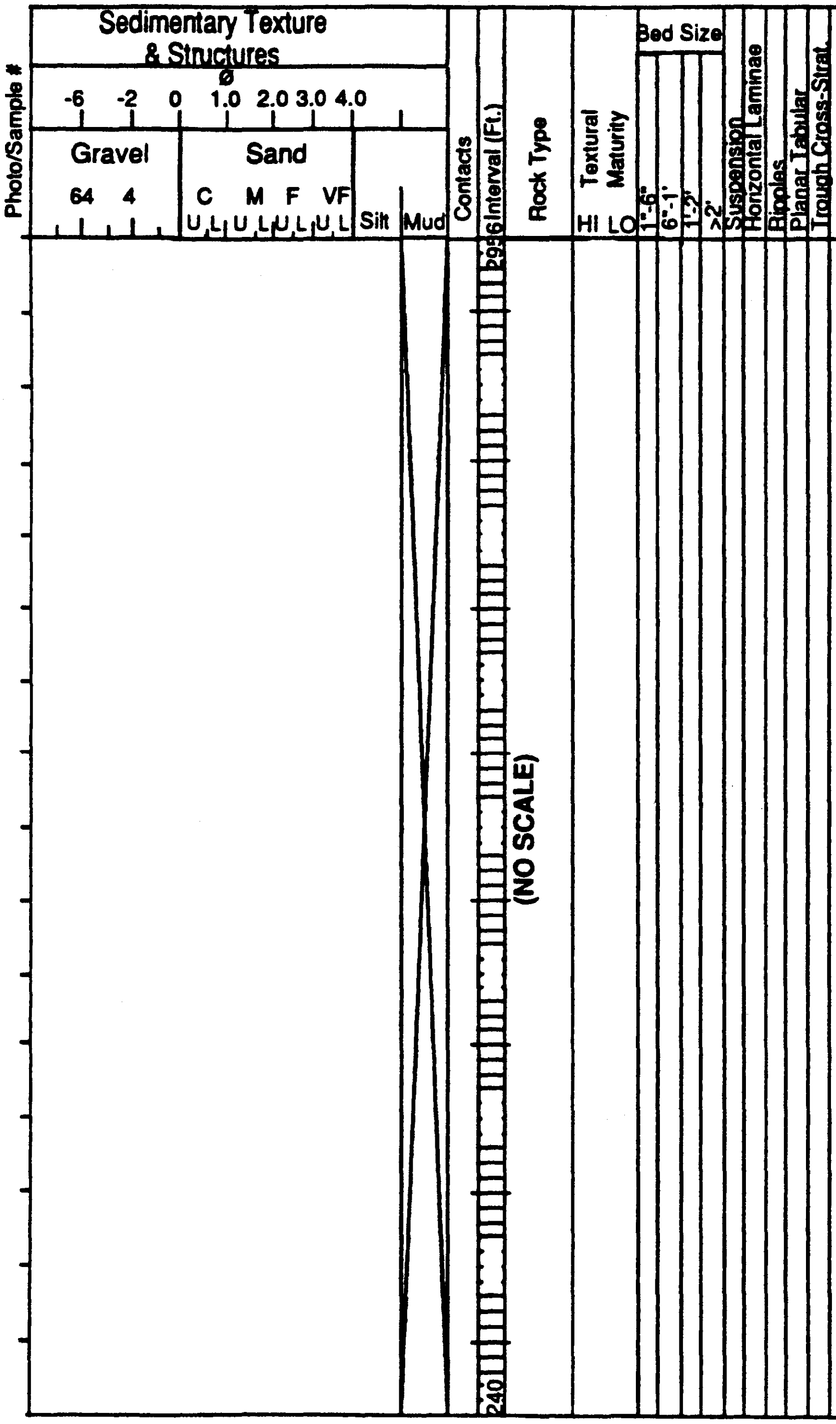
Top two units are unreachable. Inferred to be sandstone (bottom) and conglomerate (top) similar to previous units. Structures are inferred. The total thickness of the top conglomerate is unknown.

[See previous page.]

BY Gardner

Name Cape Douglas Structural Setting covered

Location NE NW sec 5 - SW SW sec 11 T 14S R 25W Weather



Date 7/30/90

Unit West Foreland?

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Comments

2770' of covered section before the next substantial outcrop exposure. The covered interval is outwash plain / tidal flat area north / northeast of Spotted Glacier. Footage of the covered interval was approximated using dip of beds and topographic quadrangle map.

BY Warme

Name Cape Douglas Structural Setting N 45 W 7 SW

Location SW SW sec. 11 - SW SE sec. 25 T 14S R 25W Weather rainy

Date 7/24/90

Unit West Foreland

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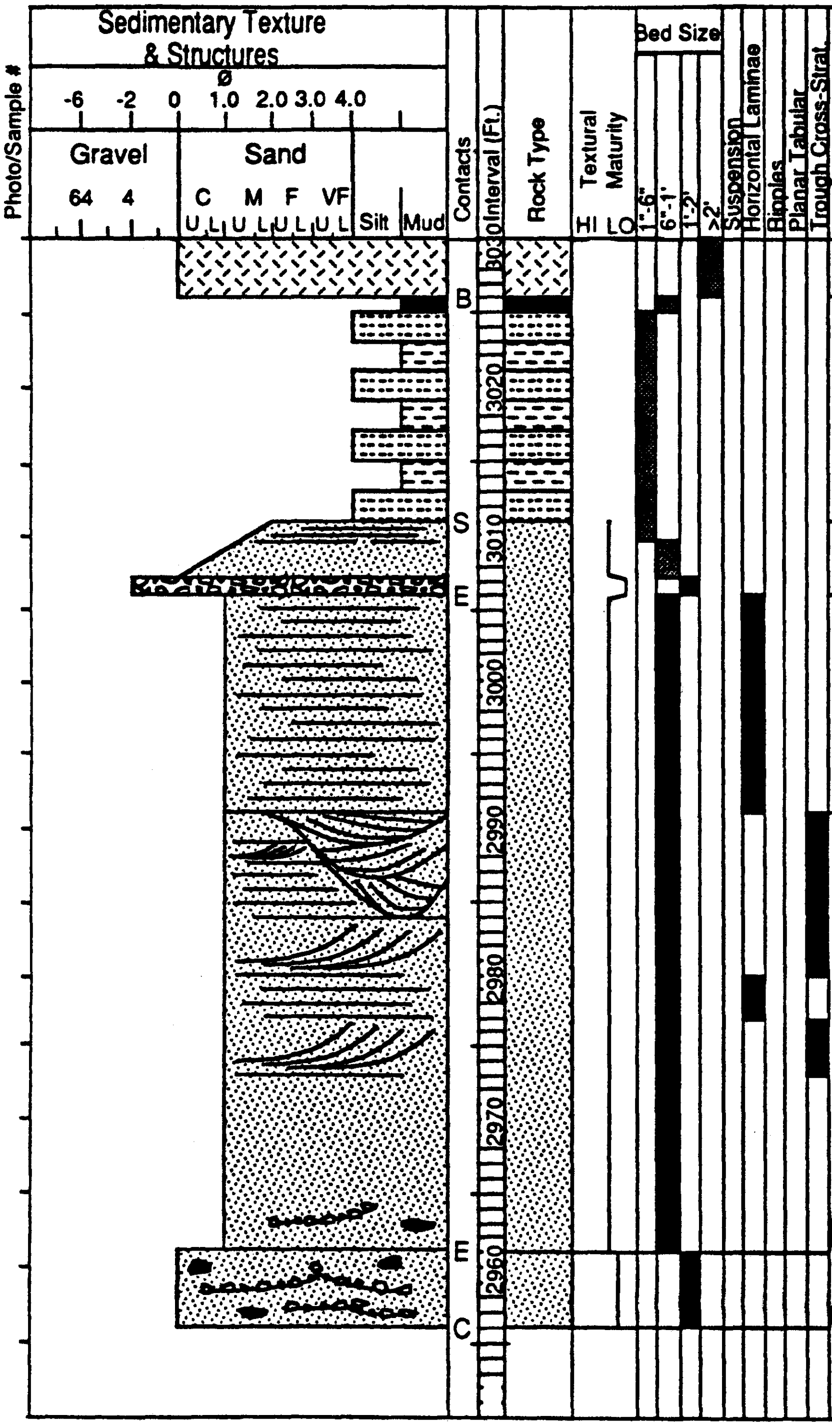

Comments

Sill or low angle dike.

Not accessible. Red striped sequence, most likely via alteration by above sill. Inferred to be baked, carbonaceous shale and coal. Appears to be more carbonaceous toward the top of the unit. Capped by a 1' thick coal.

Not accessible, but appears to be upward-fining.

Baked sandstone, altered to red/maroon color. Similar to below reddish sandstone, but horizontally bedded instead of TST.

7' deep channel at 2991'.

2980' to 2990' only partly accessible. Baked by intrusion (faulted sill) to the south causing alteration to a reddish color. Same characteristics as underlying coarser unit.

Pebbly sandstone, coarse grained. Yellow rip-ups of volcanic ash(?) on scour surfaces. Some boulder-sized rip-ups of yellow mudstone (ash?).

Base of section lowest outcrop south of landslide. "Pocket" beach with landslides at both ends. Second beach south of point traversed to in exposure described down section, 0'-186'.

BY Gardner and Houston

Name Cape Douglas Structural Setting N 50 E, 07 SW

Location SW SW sec 11 - SW SE sec 25 T 14S R 25W Weather overcast and cold

Date 7/24/90

Unit West Foreland

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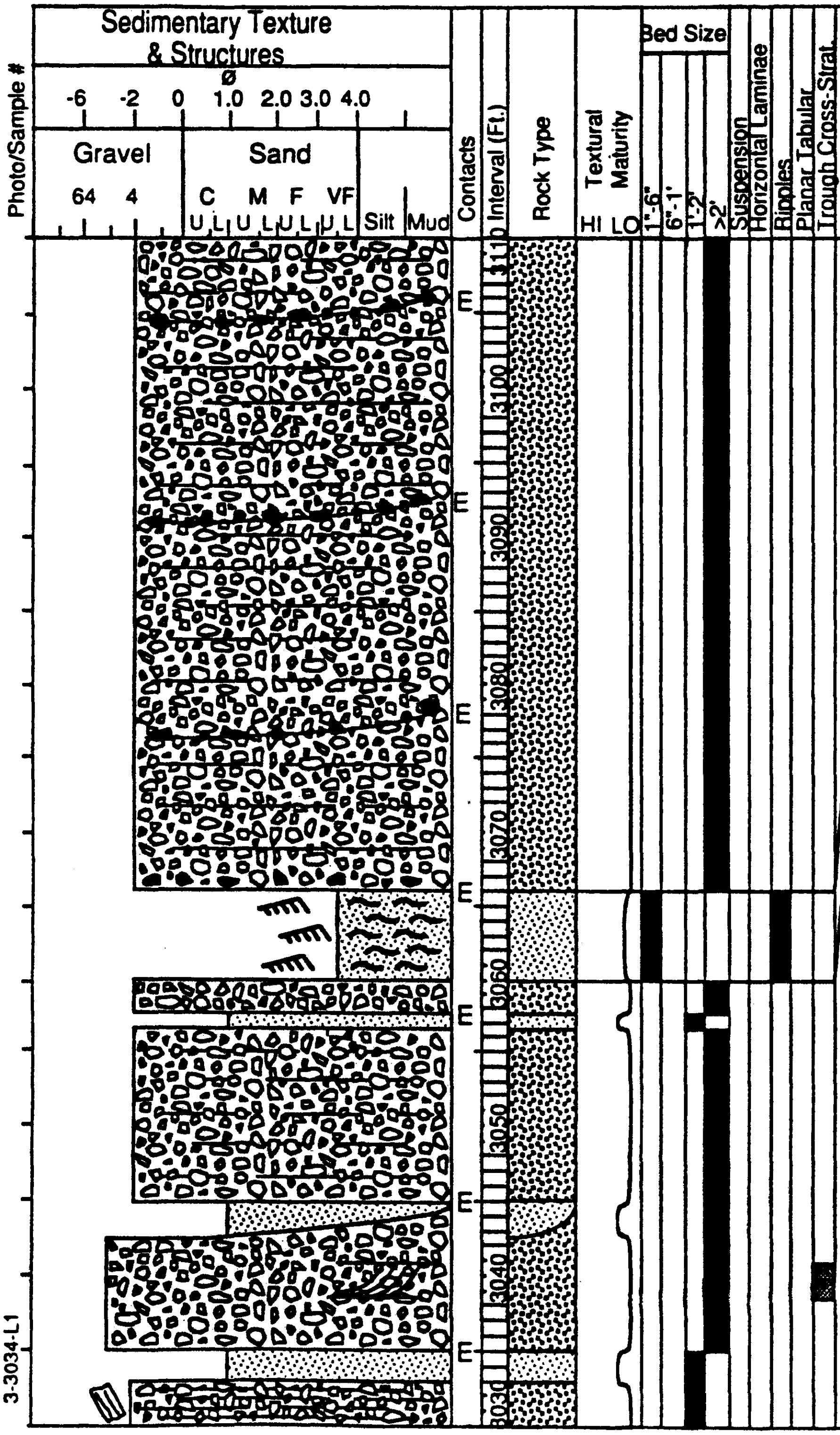

Comments

See next page for description.

Crude TST.

6" beds from 3070' to 3085'.

Ss, black, vf grained, thinly bedded in 1"-2" beds with ARL in 0.5"-1" sets. Abt shale partings throughout, section traced to mdst to south.

Congl., ss matrix, with crude horiz. bedding, n.g. at base with small pebble clasts overlain by lenticular ss lens, overlain by cobble, ss matrix congl. with crude imbrication, overlain by interbedded pebbly congl. and cobble congl. Lenticular ss bodies >20' wide truncated. Upper congl. exhibits crude horiz. bedding. Avg. clast diameter in top congl. 5". Basal contact with downward plunging dike. Entire package is undulatory, thickness is estimated.

20-30% clasts, avg. diameter 6".

Lenticular sand body.

25-30% clasts, avg. diameter 8".

Wood and n.g. beds. 25-30% clasts, avg. diameter 3".

BY Gardner and Houston

Name Cape Douglas Structural Setting N 50 E, 7 SE

Location SW SW sec. 11 - SW SE sec. 25, T 14S, R 25W Weather overcast and cold

Date 7/24/90

Unit West Foreland

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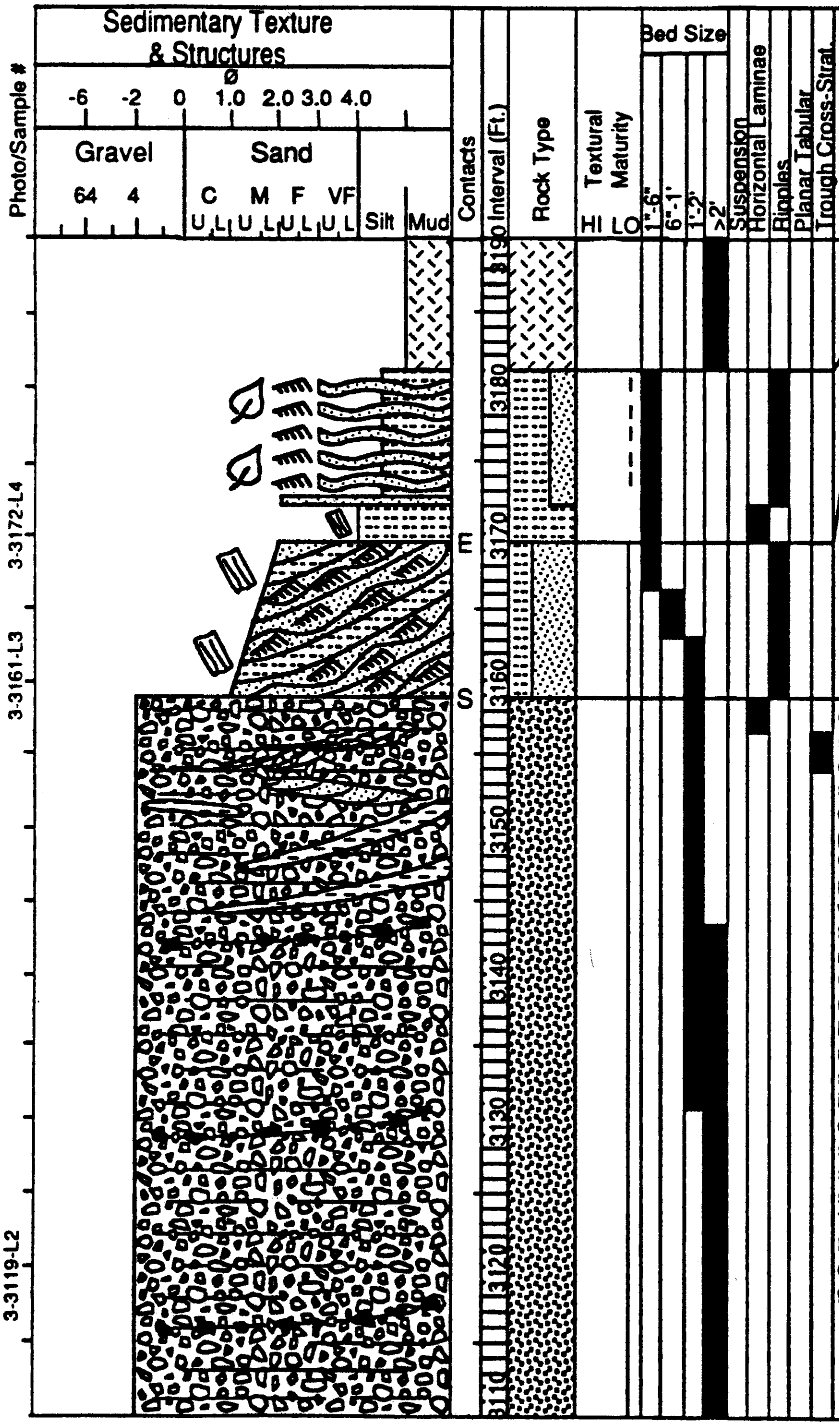

Comments

Sill or low-angle dike.

Sandstone, black, wavy bedding, SSD, ARL. Interbedded with muddy siltstone. Abt plants on bedding planes.

Upward-fining sequence of thinly bedded sandstone with siltstone interbeds. Large scale epsilon cross-beds to the northeast with thin silt drapes top to bottom. ARL <1" in upper parts of beds. Minor SSD throughout gives wavy appearance. Wood imprints on beds. Lateral accretion elements from 3159' to 3169' trend N 46 E.

Gray-green, matrix-supported (coarse sandstone) conglomerate with max. clast diameter 6", but mostly pebble size: dominantly fractured quartz/chert with subordinate volcanic and plutonic rock fragments. Conglomerate is well organized, predominately horizontally bedded with sandy lenses scattered throughout. Overall unit becomes more sand-rich near the top. Conglomerate is organized into 6 units with basal surfaces marked by large (10' wide) black sandstone and mudstone rip-ups. Base is flat, broad surface with low relief. Conglomerate is multistory sedimentary body with discontinuous shale and mudstone stringers up to 3' thick. Black sandstone lags reflect condensed section of time. Upper unit contains TST in 2' sets with inclined surfaces. Most horizontally bedded conglomeratic beds are normally graded.

Section is interrupted by a dike at 3120'.

BY Gardner and Houston

Name Cape Douglas Structural Setting N 70 E, 7 SE to N 65 E, 7 SE

Location SW SW sec. 11 - SW SE sec. 25 T 14S R 25W Weather overcast and cold

Date 7/24/90

Unit West Foreland

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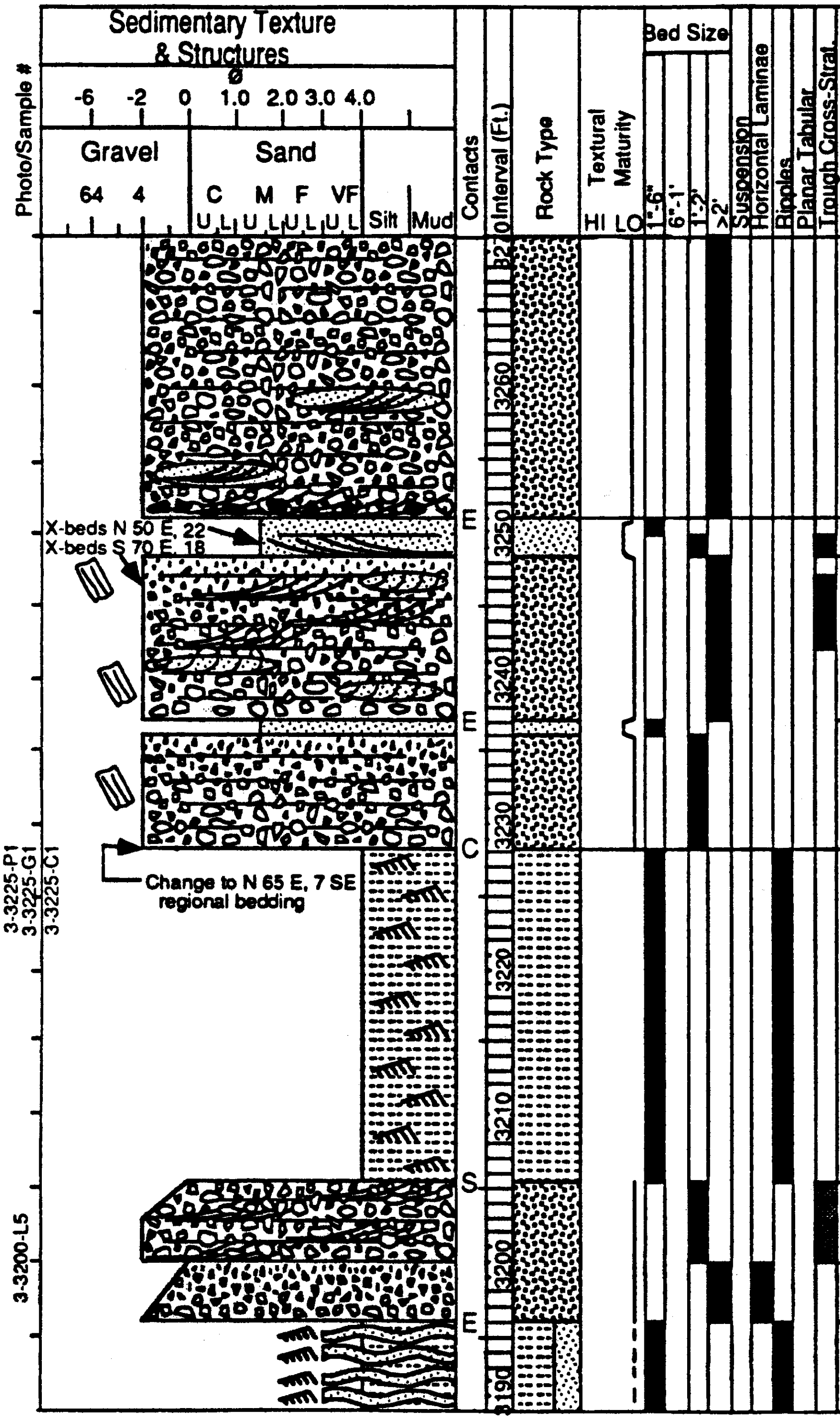

Comments

Veined chert / quartz, volcanic and plutonic clasts. 35% clasts with an average diameter of 5". Carbonaceous material is abundant at the base, and weakly scattered throughout the unit.

Dike interrupts section at 3253'.

Discontinuous sand body.

TST in 3-4' sets and normally graded horizontal beds. Contains wood, rip-ups, plutonic, volcanic, and veined quartz / chert clasts. Average clast size increases from 9" at 3237' to 10" at 3245'.

Contact at 3228' is covered. Section is offset. Dike interrupts section at 3229'.

Thinly interbedded, fining-up, black, sandstone and muddy siltstone. ARL in 1"-2" sets, 2"-6" beds. Possibly an abandoned channel fill. Section traversed to south at overlying contact with conglomerate.

Matrix supported conglomerate. Matrix is coarse sandstone.

Unit from 3196' to 3200' is normally graded.

Sandstone, black, wavy bedding, SSD, ARL. Interbedded with muddy siltstone.

BY Gardner and Houston

Name Cape Douglas Structural Setting N 50 E, 7 SE

Location SW SW sec. 11 - SW SE sec. 25, T 14S, R 25W Weather overcast and cold

Date 7/24/90

Unit West Foreland

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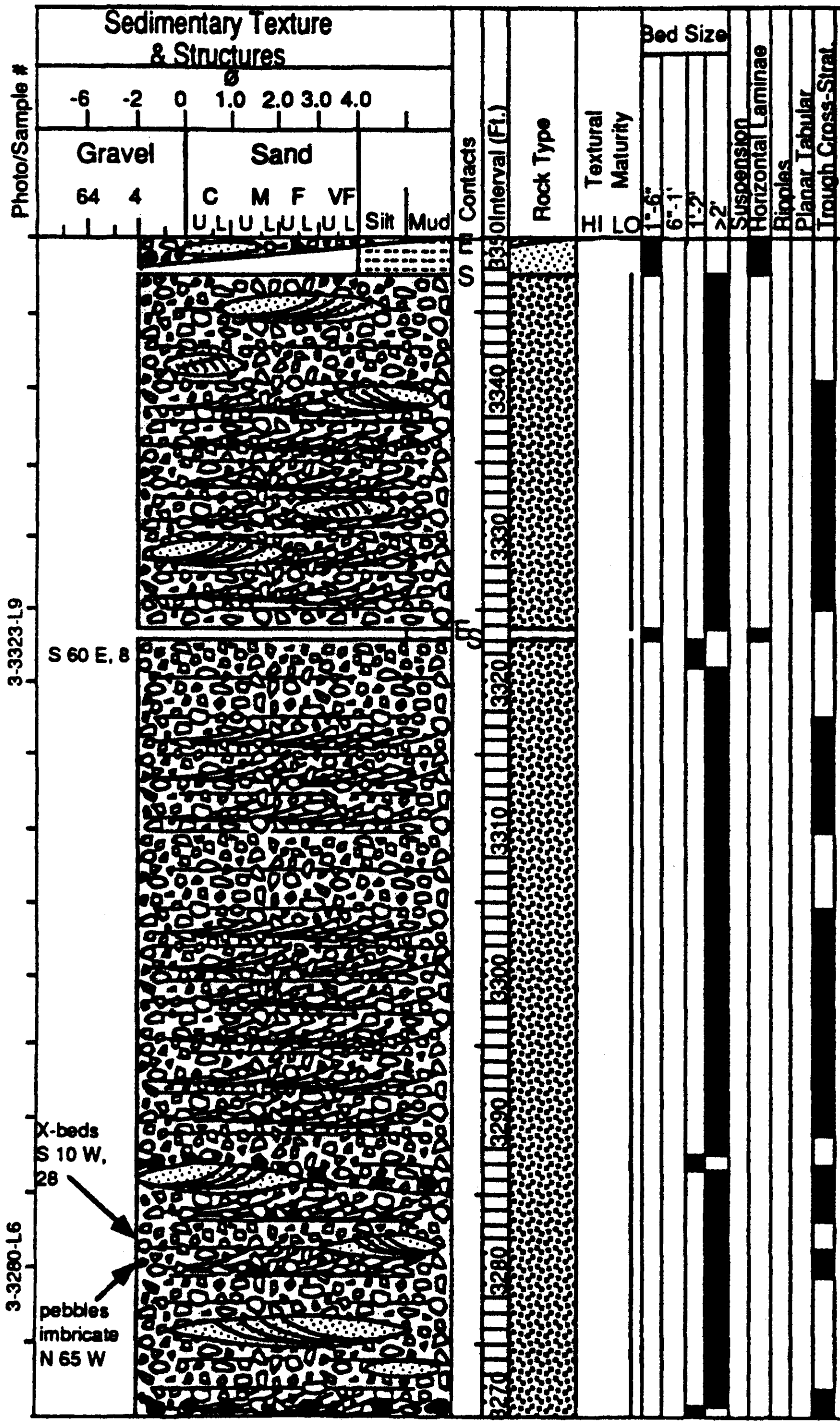
Comments



Sand content increases upward, pebble size decreases upward.

Dike interrupts section at 3315'.

Slight increase in plutonics, but same general clast composition as below. 30% clasts, average diameter 5".

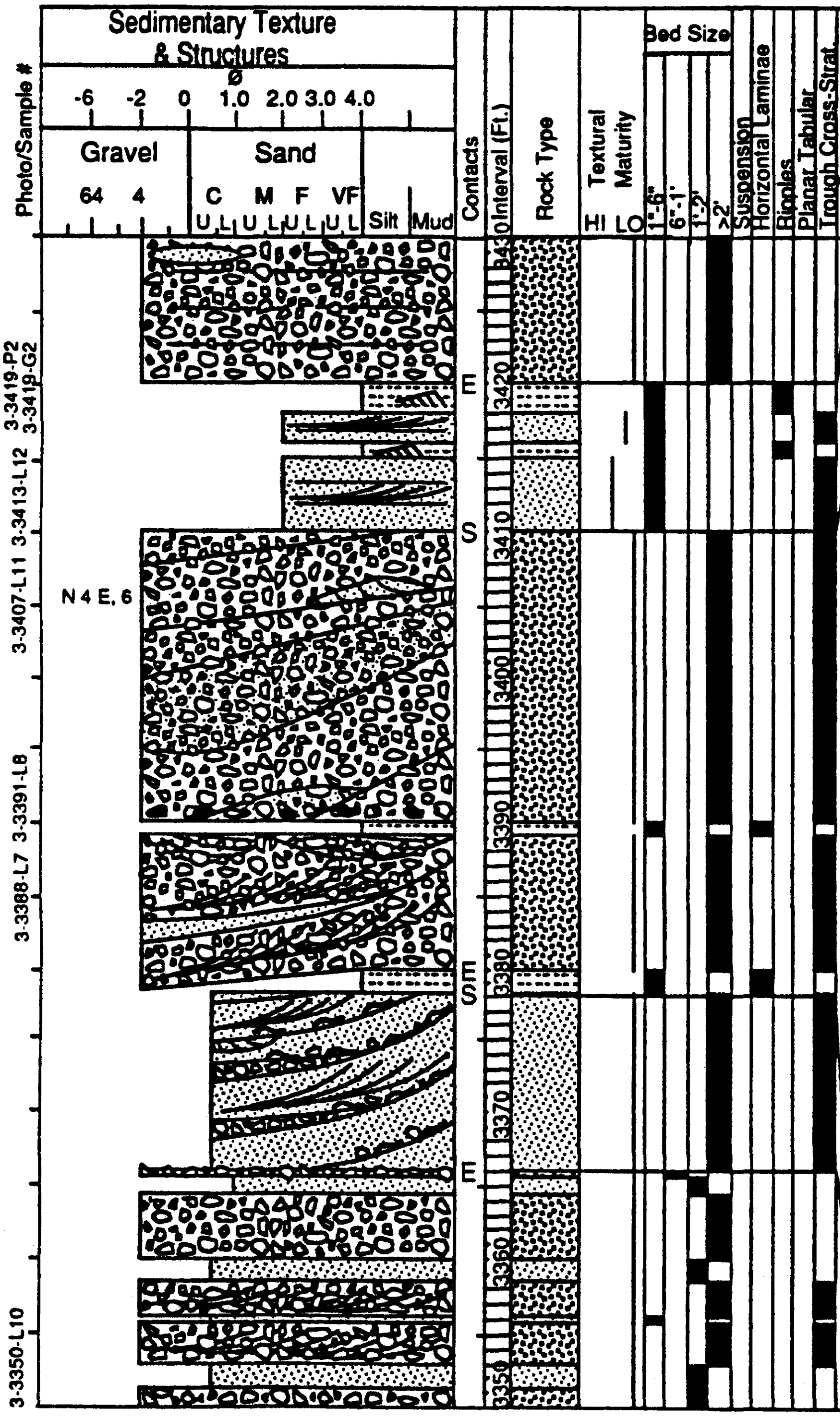
Normally graded foresets, crude inverse grading of some beds. Same clast composition as below; 30% clasts, average diameter 3.5".

Siltstone rip-ups at 3270' up to 12' long. 25% clasts at 3270'.

BY Gardner and Houston

Name Cape Douglas Structural Setting N 50 E, 7 SE

Location SW SW sec. 11 - SW SE sec. 25 T 14S R 25W Weather rainy



Date 7/24/90

Unit West Foreland

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Comments

Basal congl., coarse ss matrix, almost clast supported. Poorly organized, except for 3' TST sets with normally graded foresets around ss lenses.

Basal 4' ss in 4"-6" sets, platy, jointed, faint TST. Middle shale, <1" beds, ARL. Top ss, same as base, but with silty laminae. Top sltst, <1-3" sets of micro-TST, ARL, almost no sand.

Description for 182' of congl. packages below 3410'. Clast (relatively constant composition throughout 180') size and percent decrease slightly to south. Moderately to well organized at top; sand content increases up section. 6 upward- fining "packages" separated by erosional surfaces with large siltstone rip-up clasts up to 12' long. Basal contact covered. Entire sequence capped by thick, shaly mudstone. TST 1'-5' in congl., <2' TST in sand lenses which are <1'-2' thick. Sand lenses increase up section becoming more continuous beds in highest congl. Top two congl. packages contain 4'-10' epsilon latteral accretions at 3387' and 3398'. Discontinuous shale / mudstone lenses <1'-2' thick. Congl. matrix is med. to coarse grained (extremely variable); med. grained in highest congl. Clast compositions: 20% clasts, avg. diam. 2" at 3385'; 20%, avg. 2" at 3391'; 30%, avg. 2" at 3395'; 20%, avg. 3" at 3405'.

Imbricated grains oriented perpendicular to foresets of accretion surfaces.

30% clasts.

25% clasts.

30% clasts.

30% clasts, average diameter 6".

BY Ethridge, Houston and Mackey

Name Cape Douglas Structural Setting N 50 E, 9 SE

Location SW SW sec. 11 - SW SE sec. 25 T 14S R 25W Weather cloudy

Date 7/25/90

Unit West Foreland

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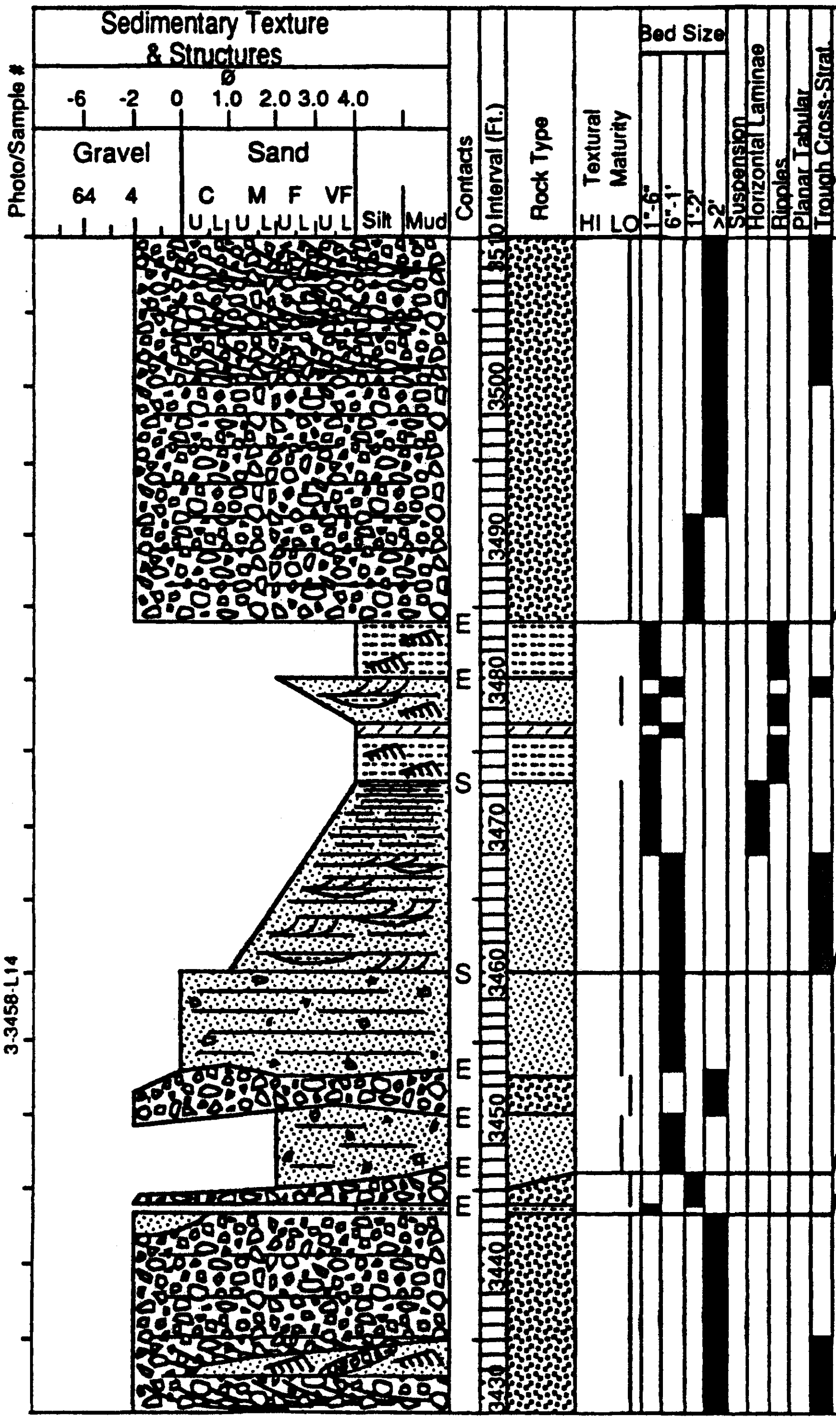
Comments



Conglomerate, coarse sandstone matrix. <5-20% clasts (very erratic), average diameter 4". Abundant veined chert, plutonic, and tuff clasts. Slightly less tuff than in conglomerates below. See next page for further discussion.

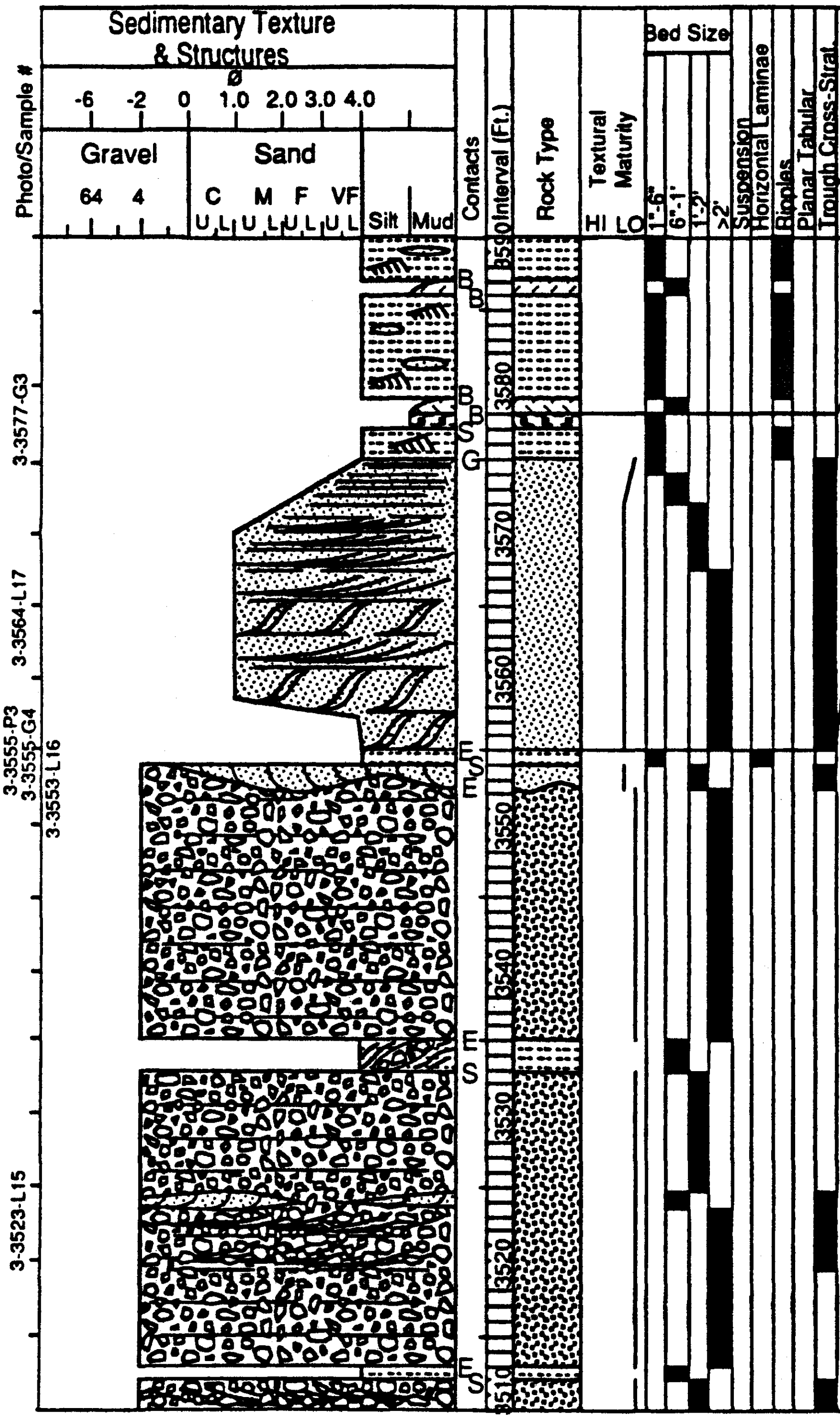
Sandstone grading up into siltstone to a fissle, shaly siltstone within 1' of the sill at 3476'. Above the sill is a fissle siltstone grading up into a fine sandstone. Fissility may have been induced by contact metamorphism. Top 4' is laminated siltstone in erosional contact with the underlying fine sandstone. Sandstone beds 4"-1' thick, weak TST, abundant scour and fill structures. Siltstone beds <1"-3" thick with ARL.
Sill thickness at 3476' varies <1'-3', pinches to 6" to south.

Upper sandstones are separated erosionally from an intervening conglomerate which varies from 1'-6' thick. Bottom sandstone contains, <1% clasts, avg. diam. 0.5"; middle conglomerate 20% clasts, avg. diam. 3"; top sandstone 0-15% clasts (patchy), avg. diam. 1".

Thin sltst at 3443' topped by a discontinuous congl. lens.

Large ss lens at 3433' containing ARL and small congl. lenses. Normally graded granule matrix in 2'-3' TST sets. Below lens is very well organized with 25% clasts, avg. diam. 3". Above lens is poorly organized with coarse ss matrix, 20% clasts, avg. diam. 4". Abundant tuff and chert clasts throughout this congl.

BY Ethridge, Houston and Mackey
Name Cape Douglas
Structural Setting N 50 E, 9 SE
Location SW SW sec. 11 - SW SE sec. 25, T 14S, R 25W
Weather partly cloudy



Date 7/25/90
Unit West Foreland
Page 12 of 19

Comments

Sill at 3578' pinches out to south. Carbonaceous shale is baked via contact metamorphism.

Siltstone grading into one 4' set of alternating siltstone and sandstone lateral accretion elements. Above 4' set is sandstone with both lateral accretion elements and TST. Unit fines upward to micro-TST siltstone, then ARL within 2' below carbonaceous shale. Beds are 4' at base, 1'-3' in middle sandstone, and 1' down to <1" at top.

Conglomeratic package, all TST foresets normally graded, horizontal beds moderately organized at base, poorly organized at top. Clast compostion relatively consistent throughout. Abundant chert clasts, subequal amounts of tuff and plutonic clasts. Package divided into three units:

1) Basal conglomerate, from 3484'-3512', with 1'-2' beds at base increasing to 2'-3' beds at top. Top half 3' sets of TST. <5-20% clasts (patchy), average diameter 3". Separated from middle conglomerate by discontinuous siltstone pockets.

2) Middle conglomerate, from 3513'-3533', with 2'-3' horizontal beds at base, 2'-3' TST sets in middle, and 1'-2' horizontal beds at top. 40% clasts, average diameter 4". Separated from top conglomerate by very discontinuous siltstone containing conglomerate lenses.

3) Top conglomerate, from 3535'-3552', is poorly organized with weak horizontal beds. 35% clasts, average diameter 6". Capped by erosionally discontinuous medium grained sandstone.

BY Ethridge, Houston and Mackey

Name Cape Douglas

Structural Setting N 70 E, 7 SE

Location SW SW sec. 11 - SW SE sec. 25, T 14S, R 25W

Weather partly sunny

Date 7/25/90

Unit West Foreland

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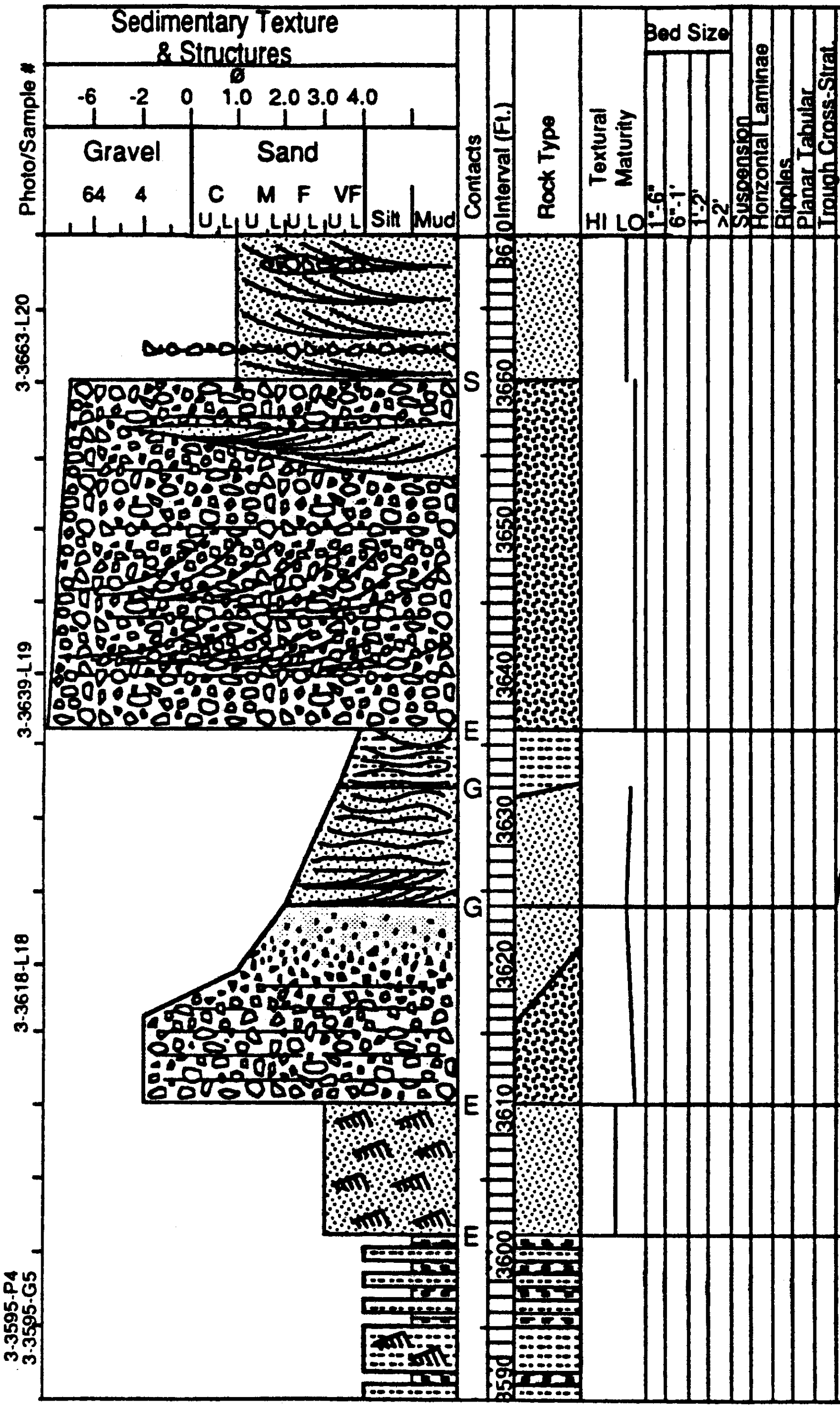


Comments

[See next page.]

Loosely clast supported, gray-green conglomerate with thin sandstone lenses near top. Crude horizontal bedding throughout. Large-scale TST in conglomerate in basal 10'. Medium-grained, poorly sorted matrix. Maximum clast size 10", grossly normally graded, avgerage clast size 3". 40-60% well-rounded, oblong clasts: 15% white quartz 10% chert, 25% plutonic, <10% volcanics. Sorting as a function of composition is absent. Possible faint pebble imbrications in top 2'.

Fine sandstone, TST in lower part, grading into siltstone at top. Lenses of fine sandstone below upper contact. Siltstone wavy bedded, finely laminated at top.

Sandy conglomerate, erosional basal contact with 2'-3' relief. Grades into fine sandstone, platy in upper 2'. Conglomerate has similar clast composition as underlying conglomerate. Contains rip-ups of local derivation up to 7" in diameter. Avgerage clast diameter in bottom 5' is 3.5". Entire sequence is normally graded.

Sandstone, black, massive but extensively jointed, very well indurated.

Interbedded black siltstone and carbonaceous shales with horizontal and wavy bedding. Very fine sandstone lenses found within siltstone units.

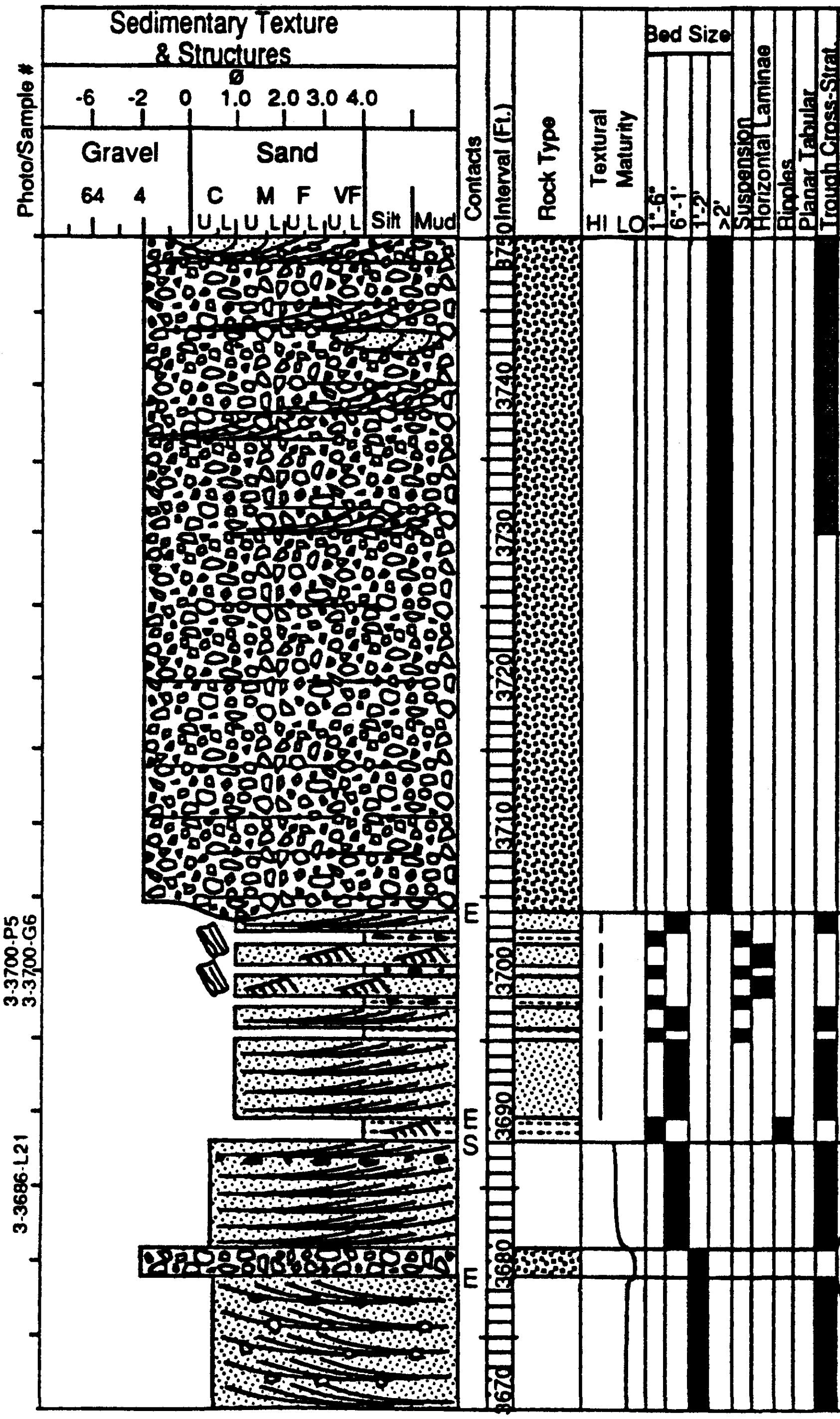
BY Gardner, Warme and Houston

Name Cape Douglas

Structural Setting N 60 E, 11 SE

Location SW SW sec. 11 - SW SE sec. 25 T 14S R 25W

Weather driving rain



Date 7/27/90

Unit West Foreland

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Comments

Conglomerate, clast supported. 50-60% clasts, mostly rounded (few subrounded), 0.7 sphericity. Clast composition: 35% plutonic, 20% volcanic, 20% unidentified fine crystalline, 2% black chert, 2% quartz. Medium grained sandstone matrix, medium gray with black speckles, very well sorted. Lenses of fine sandstone indicate scour and fill structures.

Conglomerate, matrix supported; tuffaceous sandstone matrix, gray-green, well sorted. Clasts up to 2', avg 4". 20-30% rounded to well rounded clasts: dominantly volcanic, minor plutonic, metamorphic, and chert (mostly black). Crude horizontal beds and TST in 2'-3' sets. Relief on "channels" (scour and fill structures) 2'-3'.

First 160' of congl - Altimeter in helicopter read 160' at top of cliff with no rotor torque. Read 0' on beach.

Interbedded sandstone and siltstone. Sandstone, dark gray, well sorted and massive with TST and ARL in 1"-2" sets at base, 6"-1' sets TST in middle and near top. Unit weathers gray-green to brown-green. Less resistant with platy appearance at top. Carbonaceous shale stringers and wood on bedding planes near top.

Sandstone, gray-green, TST in 1'-2' sets at base grading upward to TST in 6"-1' sets.

Congl., coarse ss matrix supported. 30% rounded to subrounded clasts: 95% volcanics, minor chert. Clasts avg. diam. 1", max. of 3".

Mud rip-up zone within 2' below congl. TST in upper portion of unit displays paleocurrent directions in opposition to basal beds. Upper ss lithic-rich.

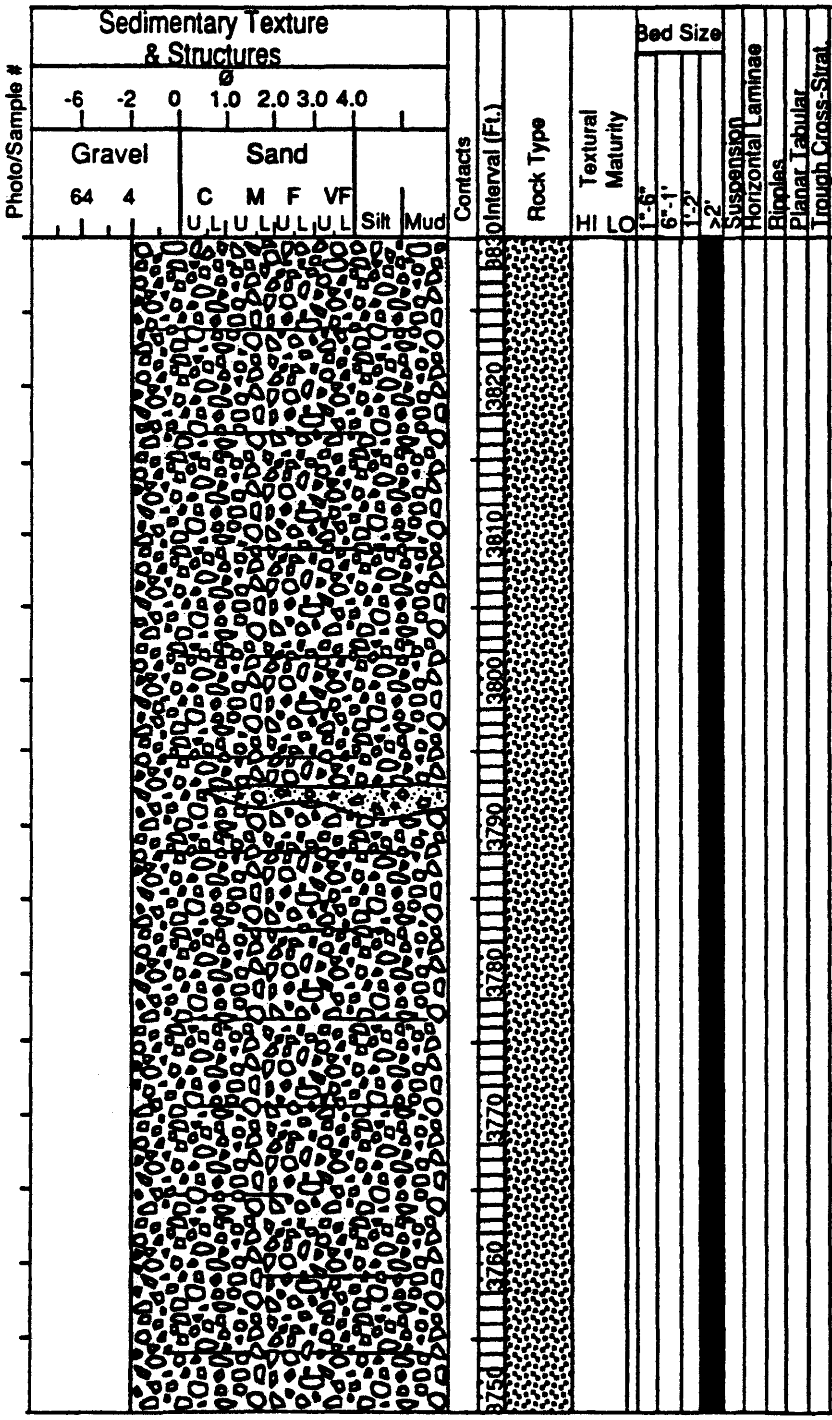
BY Warme, Ethridge and Houston

Name Cape Douglas

Structural Setting N 60 E, 10 SE

Location SW SW sec. 11 - SW SE sec. 25 T 14S R 25W

Weather overcast



Date 7/28/90

Unit West Foreland

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Comments

Conglomerate, clast supported. 60-70% clasts due to slight increase in volcanic clasts (20-30%). Maximum clast diameter 1', average 3". Coarse sandstone to granule matrix. Crude, 1'-3' thick horizontal beds. Pebble imbrications indicate a transport direction of S 30 E.

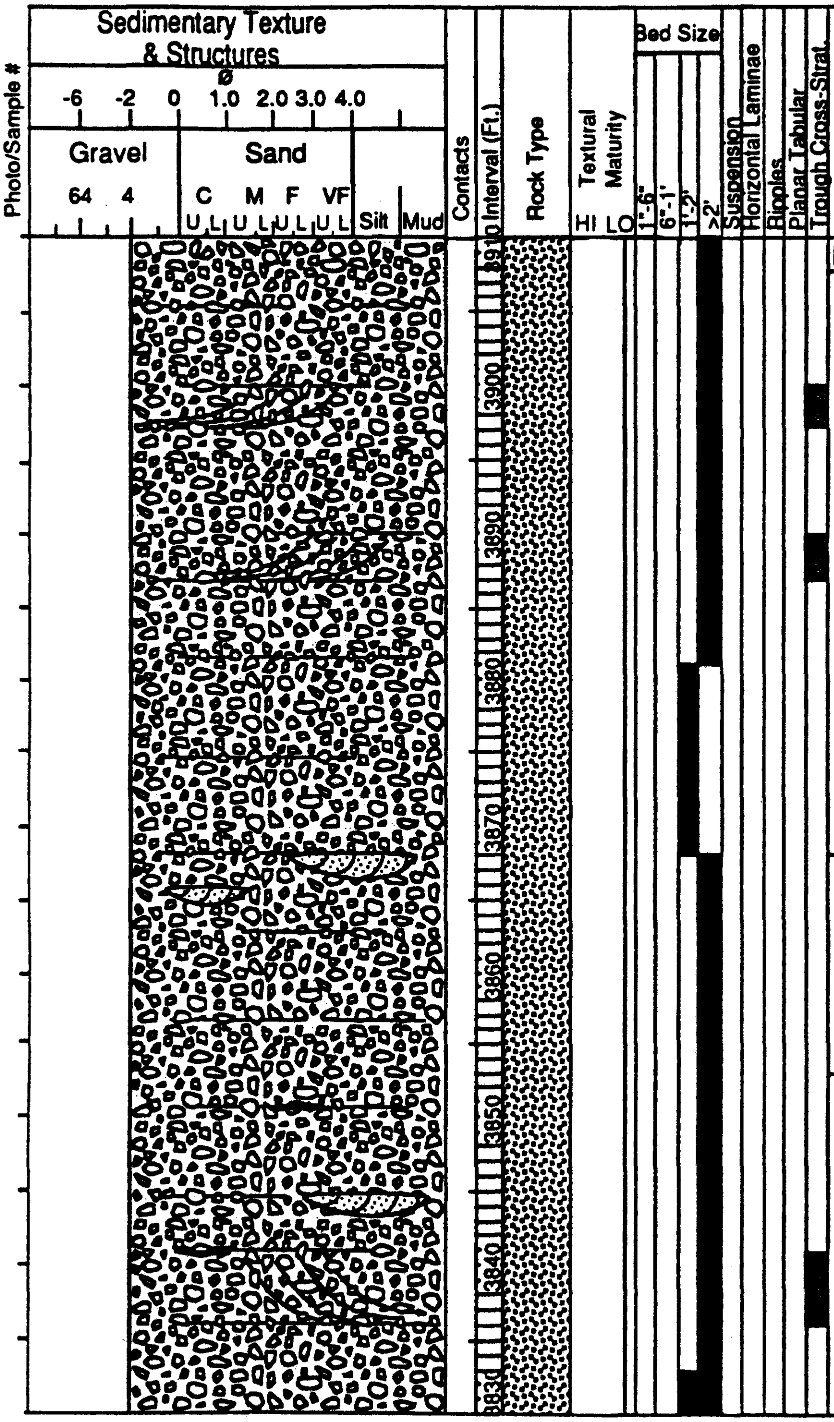
Conglomerate, gray-green, clast supported. 50-60% clasts; composition, sphericity, and roundness same as underlying conglomerate. Maximum clast diameter 14", average 2". Very coarse sandstone to granule matrix. Crude horizontal beds >2' thick. Lenses of finer conglomerate (smaller clasts and finer matrix). Good pebble/cobble imbrications show a transport direction of S 30 E.

Conglomerate, gray-green, clast supported. 50-60% clasts, same composition, sphericity, and roundness as underlying conglomerate. Maximum clast diameter 1', average 2". Very crude horizontal stratification.

BY Warme, Ethridge and Houston

Name Cape Douglas Structural Setting N 60 E 10 SE

Location SW SW sec. 11 - SW SE sec. 25 T 14S R 25W Weather overcast



Date 7/28/90

Unit West Foreland

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Comments

[See next page.]

Conglomerate, clast supported (except in matrix supported patches). 50% rounded clasts with sphericity of 0.7. Dominantly plutonic and volcanic clasts with some chert. Larger overall clasts than in underlying conglomerate, maximum diameter 20", average 3"; quartz and chert clasts up to 5". Well defined horizontal bedding at base, becoming crude up section. Faint TST near top of interval.

Conglomerate, medium to dark gray, clast supported. Coarser than previous description, but same general characteristics. Maximum clast diameter 1', average 2". Crude horizontal beds >3' thick.

Conglomerate, clast supported. 70% clasts due to increases in plutonics (40%) and quartz (5%). Maximum clast diameter 7", average 1". Few rip-ups up to 2' long. Very coarse sandstone to granule matrix, gray with black specks. Sandy lenses with floating pebbles. Generally massive, indistinct beds. Sparse, faint, large scale TST, >3' sets.

BY Ethridge, Houston and Mackey

Name Cape Douglas Structural Setting N 60 E, 10 SE

Location SW SW sec. 11 - SW SE sec. 25, T.14S, R.25W Weather overcast

Date 7/29/90

Unit West Foreland

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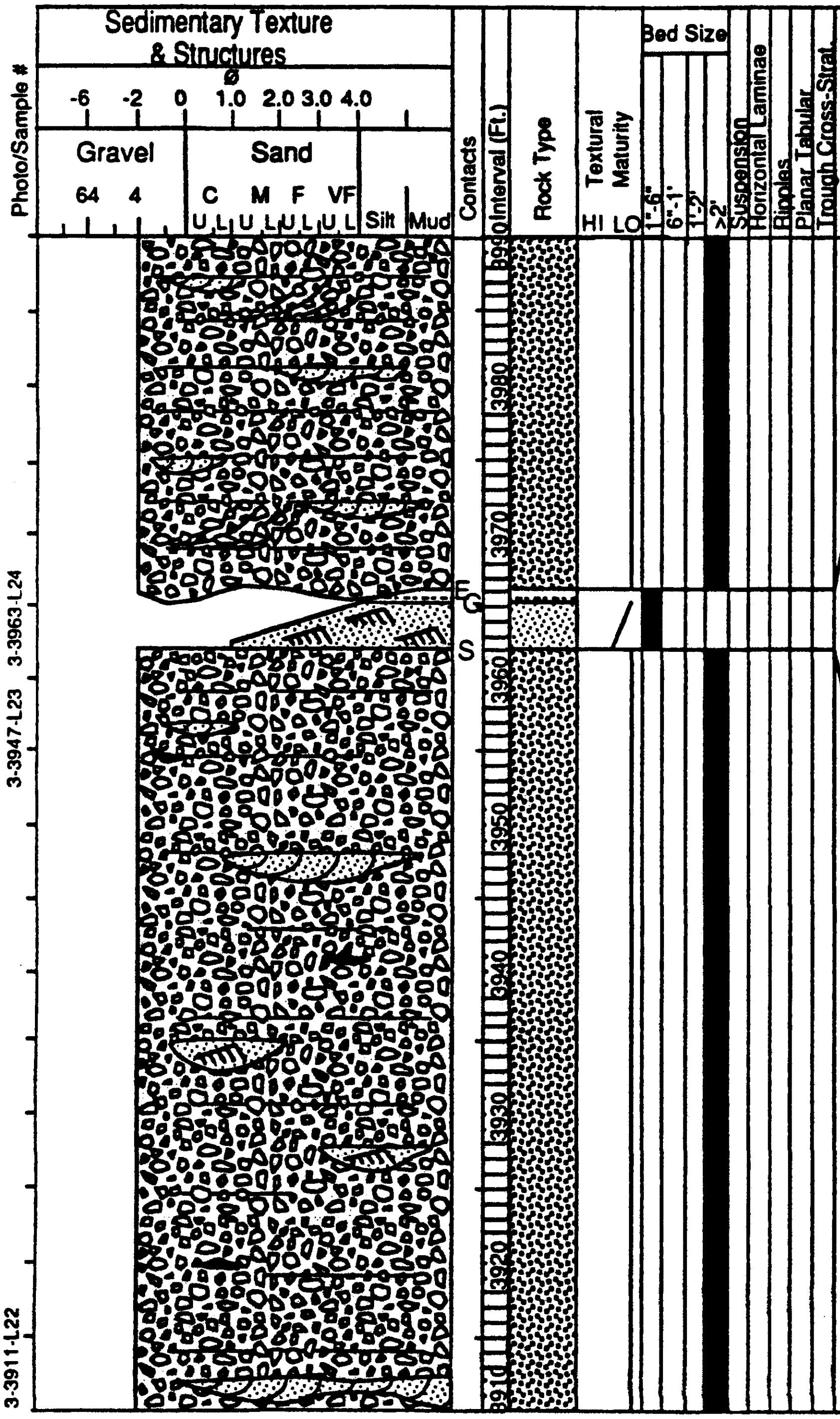

Comments

Conglomerate in a gross fining-upward interval. Maximum clast diameter at base 1', 10" at top. Small scale fining-upward intervals 3'-4' thick. Faint large scale TST indicating a general transport direction to the south. Lenticular scour and fill structures throughout.

Thinnly bedded sequence of dark gray to black, medium grained sandstone, fining-upward to interbedded siltstone and shale. ARL weak in basal sandstone, abundant in overlying siltstone and shale. Basal sandstone for this interval projected to top of sea cliff. Inferred there is no missing section.

Conglomerate, arranged in a series of 2'-3' fining-upward sequences. Maximum clast diameter 1' at base, 4" at top of each sequence. Overall maximum clast diameter 1', average 2", infrequent rip-ups maximum 4" long. Crude horizontal stratification. Crude pebble imbrication indicates a transport direction of S 70 E. Sandstone lenses maximum 2.5' thick, light gray, medium to coarse grained. All lenses discontinuous and contain ARL and/or TST.

BY Ethridge, Houston and Mackey

Name Cape Douglas

Structural Setting S 80 E, 05 SW

Location SW SW sec. 11 - SW SE sec. 25 T 14S R 25W

Weather overcast

Date 7/29/90

Unit West Foreland

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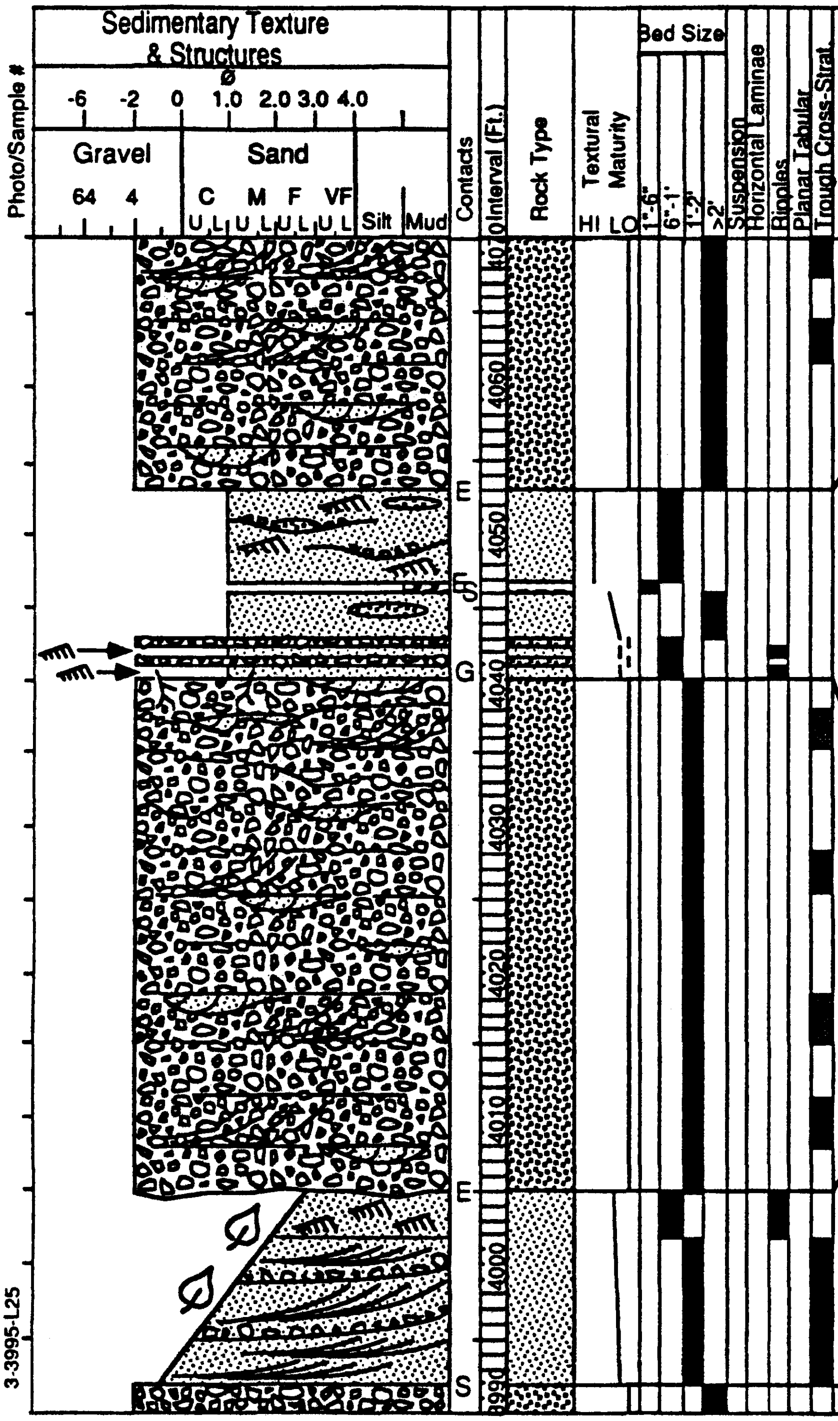

Comments

Conglomerate with abundant sandstone lenses. Similar clast composition to interval between 4005' and 4040'. Weak TST in middle of interval. Scour and fill structures with relief of 6"-1'.

Sandstone, medium gray, medium grained with coarse sandstone lenses. Medium sandstone well sorted, coarse sandstone moderately sorted. Interbedded with conglomerate at base. Thinnly laminated with faint ARL in top half of interval. Scour and fill structures with relief of 6"-1'. Carbonaceous shale layer in middle of interval.

Conglomerate, moderately organized in bottom 3/4, poorly organized in top 1/4. 50-60% subrounded clasts with sphericity of 0.7. Dominantly volcanic and plutonic clasts with some quartz and chert. Maximum clast diameter 7", average 2". Coarse to granule sandstone matrix, greenish-gray. Slightly more matrix than in conglomerate below. TST faint to moderate in 1'-2' sets, weak normal grading of foresets.
Sandstone lenses part of TST in places. 3'-4' scours in top 1/3 of unit. Upper part of conglomerate with sandstone lenses may be rooted.

Sandstone, light gray, medium to coarse with granules. 2"-2' thick fining- upward sequences of coarse to medium sandstone. TST in 2' sets. Two 6" thick conglomeratic zones at 3996' and 4000'; contain pebbles up to 4" in diameter. Entire unit grades into ARL, very fine sandstone.

[See previous page.]

BY Ethridge, Houston and Mackey

Name Cape Douglas

Structural Setting S80 E 05 SW

Location SW SW sec. 11 - SW SE sec. 25 T 14S R 25W

Weather overcast

Date 7/29/90

Unit West Foreland

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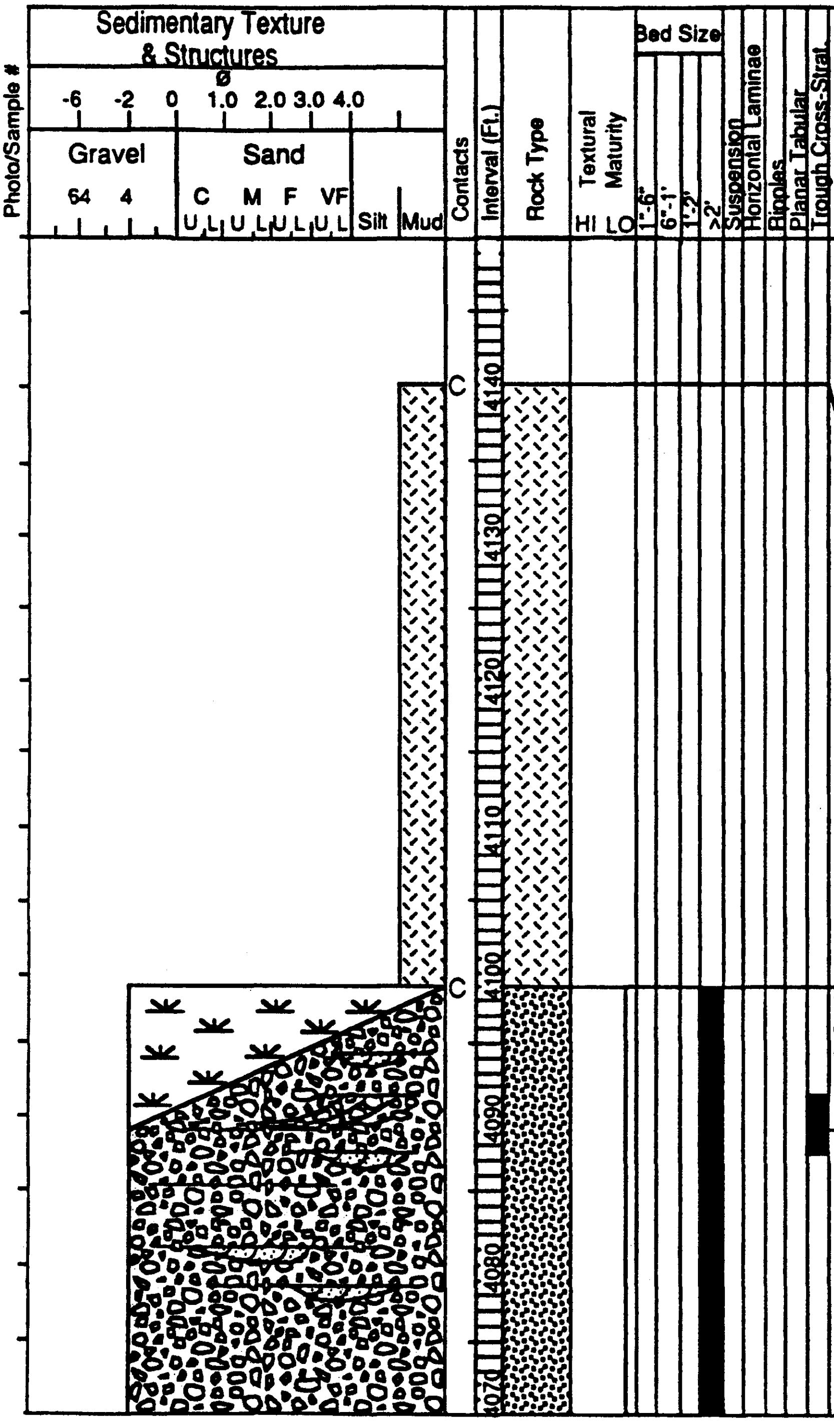


Comments

Minimum 105' thick basalt flow (?). There appears to be a minimum of 50' of congl between this and the intrusion below. Probably more section missing via stream erosion in the synclinal valley. Section to the south of the valley is repeated section due to folding.

Intrusion, minimum thickness of 40', possibly a sill. Possibly ponded in synclinal valley. Appears to be at same stratigraphic level as uppermost conglomerate.

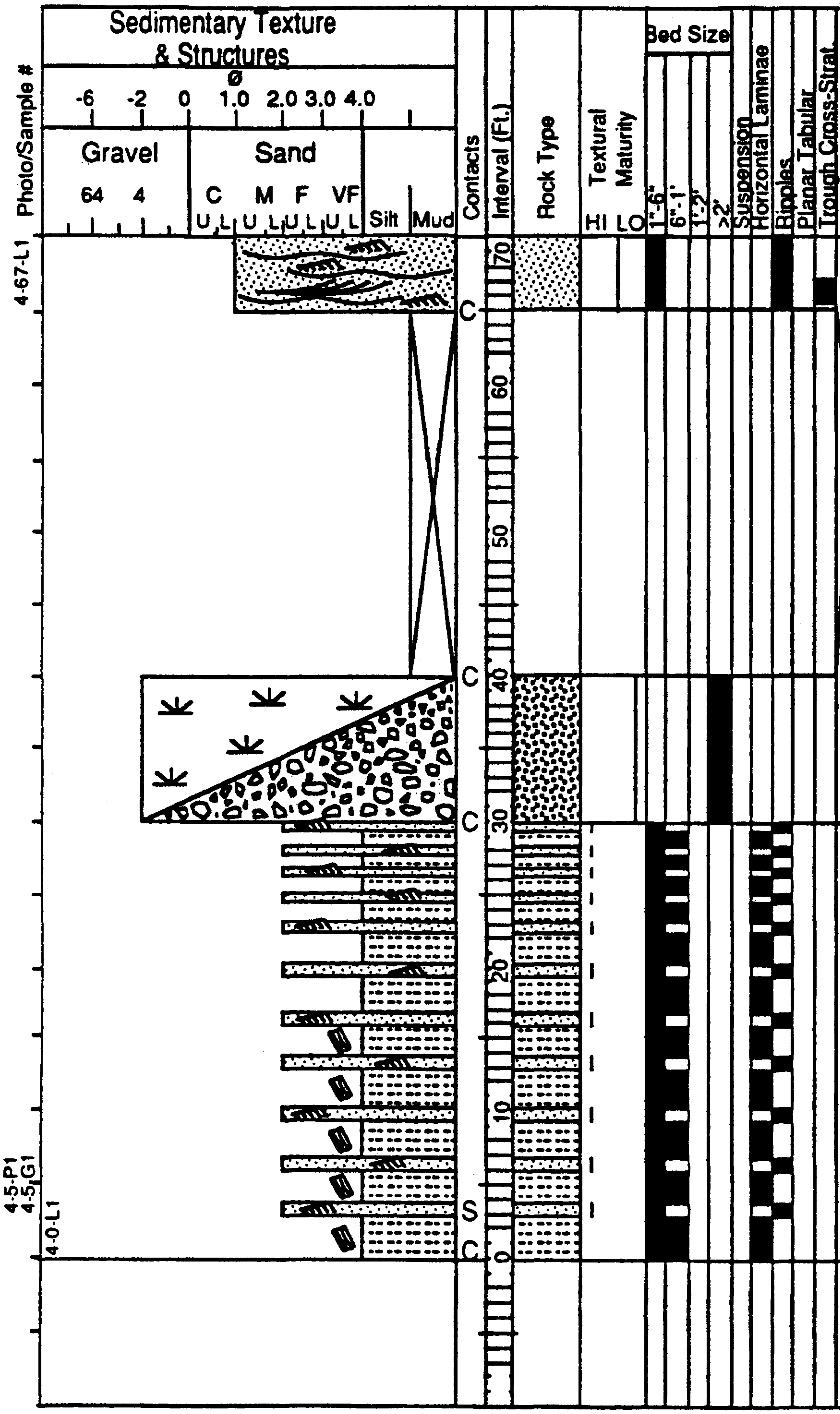
Top 10' estimated because of partial cover. Contact with above intrusion is covered.

[See previous page.]

BY Houston & Gardner

Name Kuliak Bay Structural Setting N 05 E, 18 SE

Location SW NW sec. 16 - NE SE sec. 9, T 23S, R 30W Weather nice



Date 8/3/90

Unit Hemlock Congl.

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Comments

Sandstone, dark gray to black, thinly laminated with ARL in <1" sets, very fine black sand drapes on some ripple foresets. Faint TST in two 6" sets. Becomes black and very fine in top 2".

Covered interval.

Clast supported conglomerate. 50-60% clasts, maximum clast diameter 6", bimotal average 1" and 1/4 ". Clasts include; 50% volcanic, 40% chert, 5% metamorphic, 5% plutonic. Chert is red, green and black, subrounded, low sphericity. Matrix, coarse sandstone, poorly sorted. Crude horizontal beds 6"-1' thick show weak normal grading from large to small pebbles. Conglomerate is only found in landslide blocks. Appears to be in section, but may be previous unit under cover or could have fallen from higher in section.

Alternating sandstone and siltstone beds. Sandstone, light brown, 1"-6" wavy beds, minor SSD, well sorted. Sand increases up section. ARL in 1" sets with abundant starved ripple laminations. Siltstone, black, finely laminated, very carbonaceous at bottom, weakly carbonaceous at top. Abundant wood on bedding planes at base where more carbonaceous. Laminated to wavy bedding at base. Slightly baked due to proximity of intrusion. Wood fragments show boxwork- like texture in 1/16" boxes. Unit reflects very low sedimentation rates. Fair exposure along beach, abundant landslide blocks.

Section begins at covered contact with thick (>100') igneous intrusion. Section measured along shoreline trending southwest-northeast on north side of Kuliak Bay.

BY Houston & Gardner

Name Kuliak Bay

Structural Setting N 05 E, 18 SE

Location SW NW sec 16 - NE SE sec 9 T 23S R 30W

Weather nice

Date 8/3/90

Unit Hemlock Congl.

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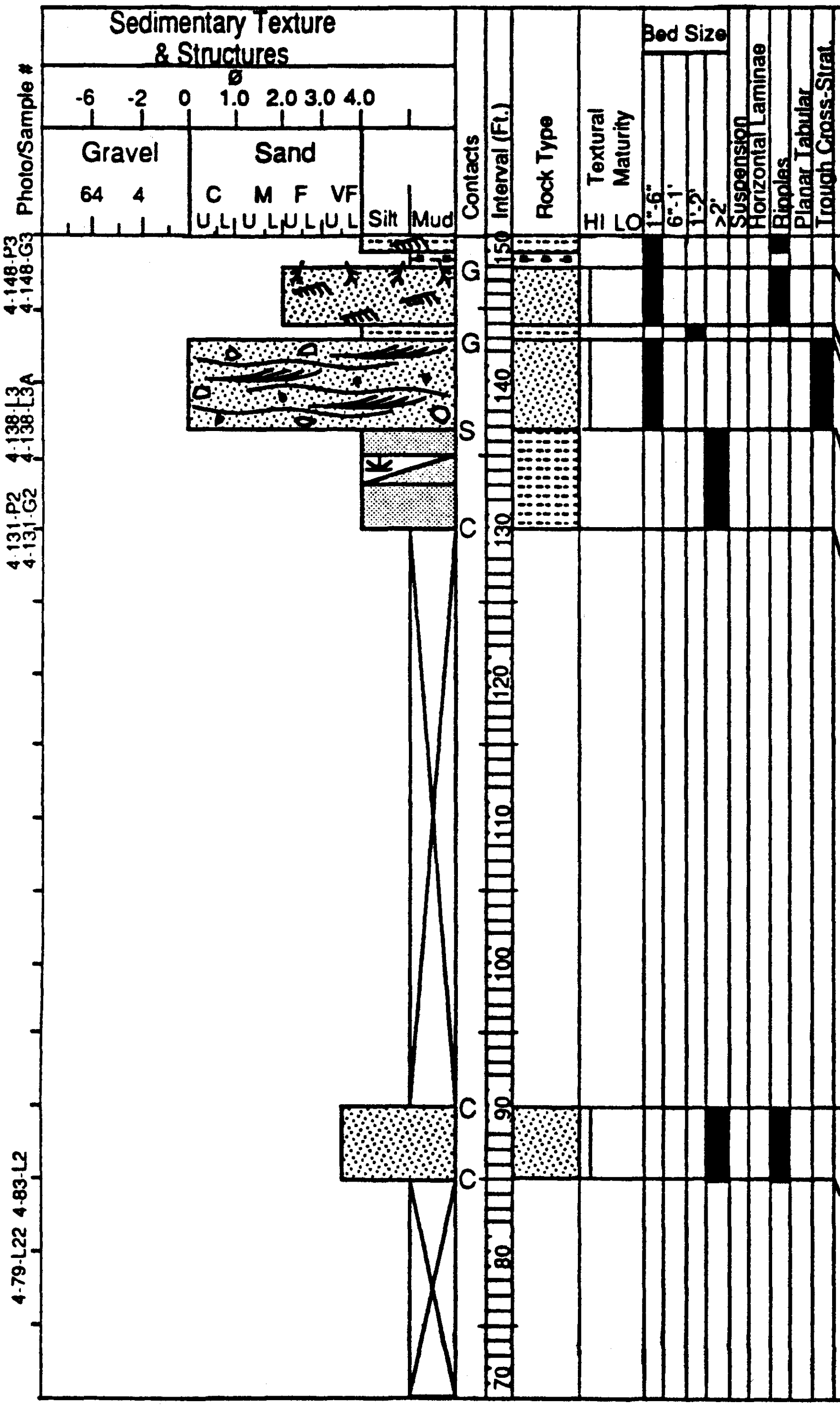

Comments

Interbedded black siltstone and carbonaceous shale, thinly laminated, ARL in <1" sets. Wavy bedding.

Sandstone, light to medium gray, well sorted. Very thinly bedded, ARL in <1"-2" sets, upper contact rooted.

Same as underlying siltstone.

Sandstone, dark gray, poorly sorted. Wavy beds, small scale TST in 1"-6" sets. Contains scattered pebbles.

Siltstone, gray to black, thinly interbedded with <2" thick sandstone beds. Minor wavy bedding. Moderately but pervasively fractured.

Covered interval.

Sandstone, black, massive, moderately fractured (partially along faint ARL planes?).

Covered interval.

BY Houston & Gardner

Name Kuliak Bay Structural Setting N 05 E, 18 SE

Location SW NW sec. 16 - NE SE sec. 9 T.23S R.30W Weather nice

Date 8/3/90

Unit Hemlock Congl.

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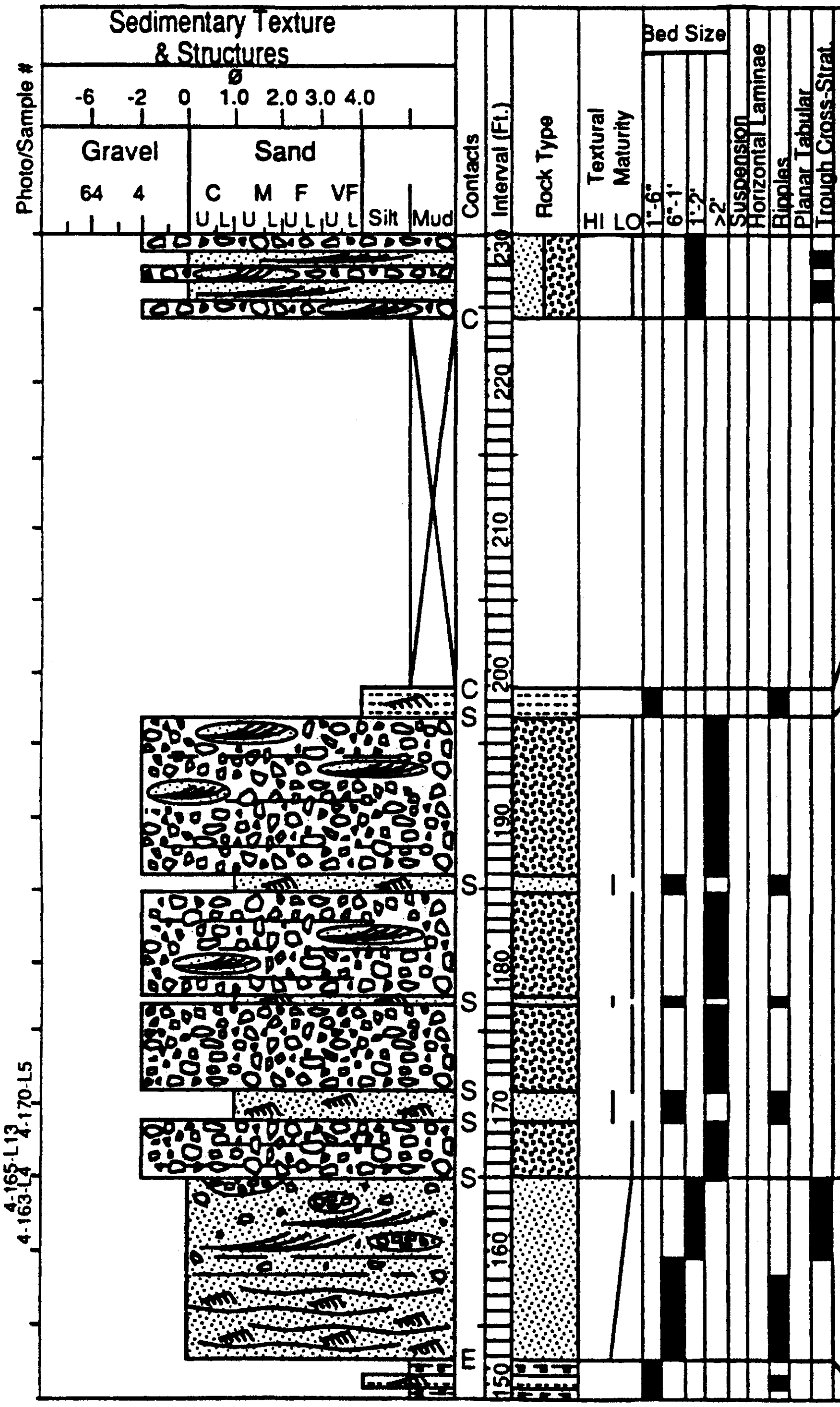

Comments

[See next page.]

Covered interval.

Siltstone, black, thinly laminated with faint ARL. Generally weathers massive.

Conglomerate, moderately to well organized, 45% clasts, maximum clast diameter 4", bimodal average 1" and 1/4", subrounded to subangular with low sphericity. Clasts include; 25% chert (green, gray and red), 20% plutonics, 20% volcanics, 25% quartz, 10% metamorphics. Matrix, medium to coarse sandstone, black, moderately sorted. Unit is blocky in appearance. Normally graded beds 2'-4' thick. Lenticular bodies up to10' thick between interbedded sandstone lenses thin to the southwest. Crude pebble imbrications indicate a general transport direction to the southwest. Sand increases up section. Sandstone lenses are discontinuous, vary in thickness, and contain TST in 1'-2' sets.

Coarse sandstone at base in 6"-8" beds with ARL in1"-2" sets, grading up to sandstone interbedded with thin, discontinuous pebble lenses. Lower 1/2 moderately sorted, upper 1/2 poorly sorted. Unit becomes more massive up section. TST in top 4' in 1' sets.

[See previous page.]

BY Houston & Gardner

Name Kuliak Bay Structural Setting N 05 E, 18 SE

Location SW NW sec. 16 - NE SE sec. 9 T 23S R 30W Weather nice

Date 8/3/90

Unit Hemlock Congl.

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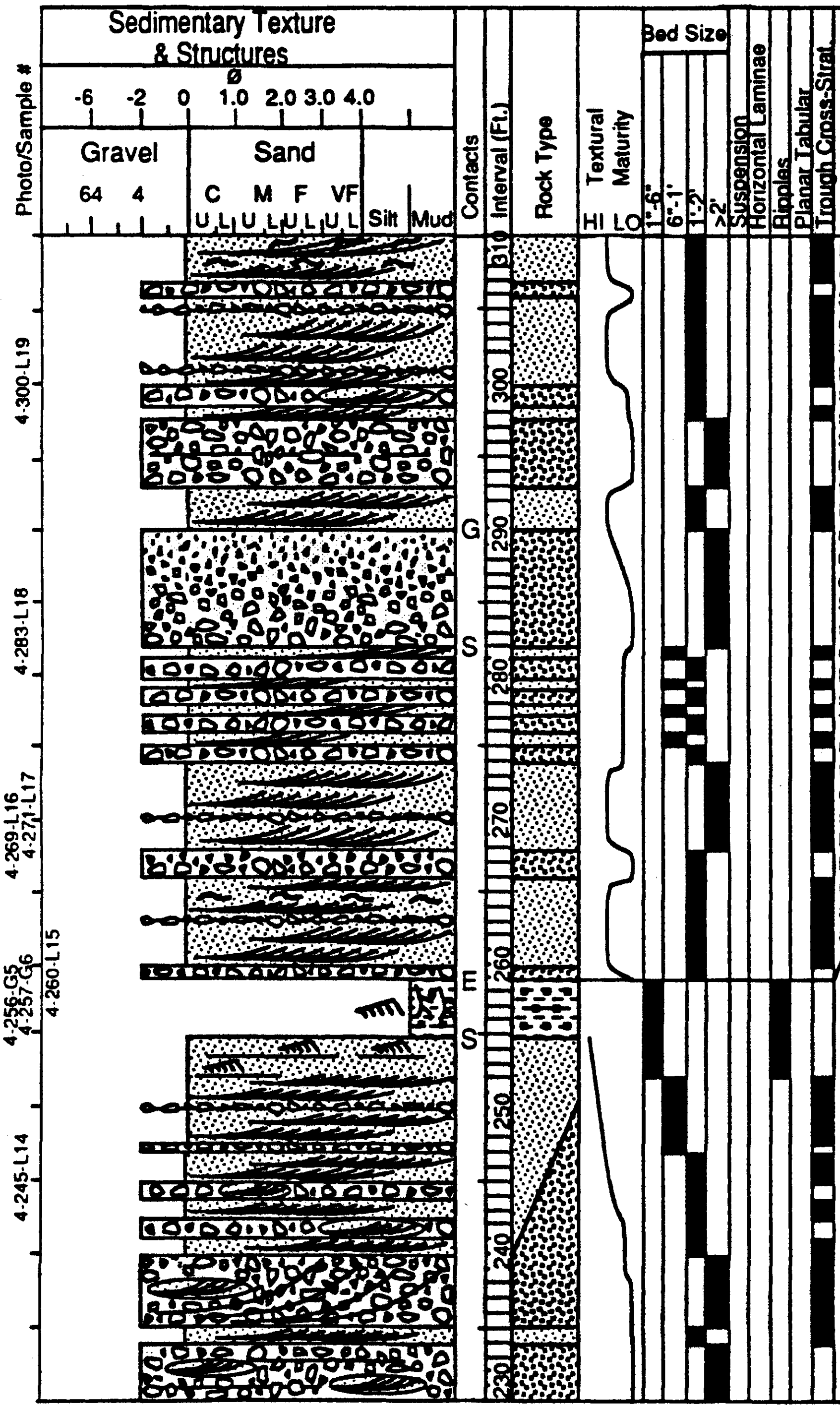

Comments

Interbedded congl., congl. ss and ss. Congl., matrix supported (coarse ss), 30-40% clasts, maximum clast diameter 8", average 1", includes; 50% chert/quartz, 30% volcanic, 10% plutonic, 10% metamorphic. Clasts subrounded to subangular, low sphericity, mud rip-ups angular. Several congl. units contain multiple, normally graded beds. Congl. units from 274'-281'; large, discontinuous lenses w/ poor organization w/in massive ss. Ss, tan to buff, moderately to well sorted with patchy clay-like matrix in scattered pockets. Sand content grossly increases up section. Some ss units contain thin, continuous, <2" mudst stringers. Multiple, very crude fining-upward sequences within this package exhibit TST grading from 1'-3' sets with normally graded foresets which are truncated by smaller <1' sets that climb the back of larger sets, to TST in single <1' sets bounded by thin mudst beds. 259'-275' has distinct reddish brown color, contains rip-ups of underlying units. Orange specks abundant in congl. matrix and clasts and ss units from 259'-310'.

Upward-fining sequence of congl. grading up to interbedded congl. and ss to ss to very thin, sparse sltst stringers. Congl., clast supported, 60% clasts, maximum clast diameter 3", average 1", includes; 30% chert, 30% plutonic, 20% volcanic, 10% quartz, 10% metamorphic. Matrix, coarse ss, poorly sorted with scattered pockets well sorted, contains crystalline orange specks. Well organized into 2'-4' TST sets. Congl. forms 3 lensoid-shaped macroforms pinching to SW. Ss, black, poorly sorted, abundant white and orange specks.; TST in 1'-2' sets; large scale lenticular, wavy beds. Sltst (poorly exposed), black, ARL in 1"-2" sets.

BY Houston & Gardner

Name Kuliak Bay

Structural Setting N 05 E, 18 SE

Location SW NW sec. 16 - NE SE sec. 9 T 23S R 30W

Weather great!

Date 8/3/90

Unit Hemlock Congl.

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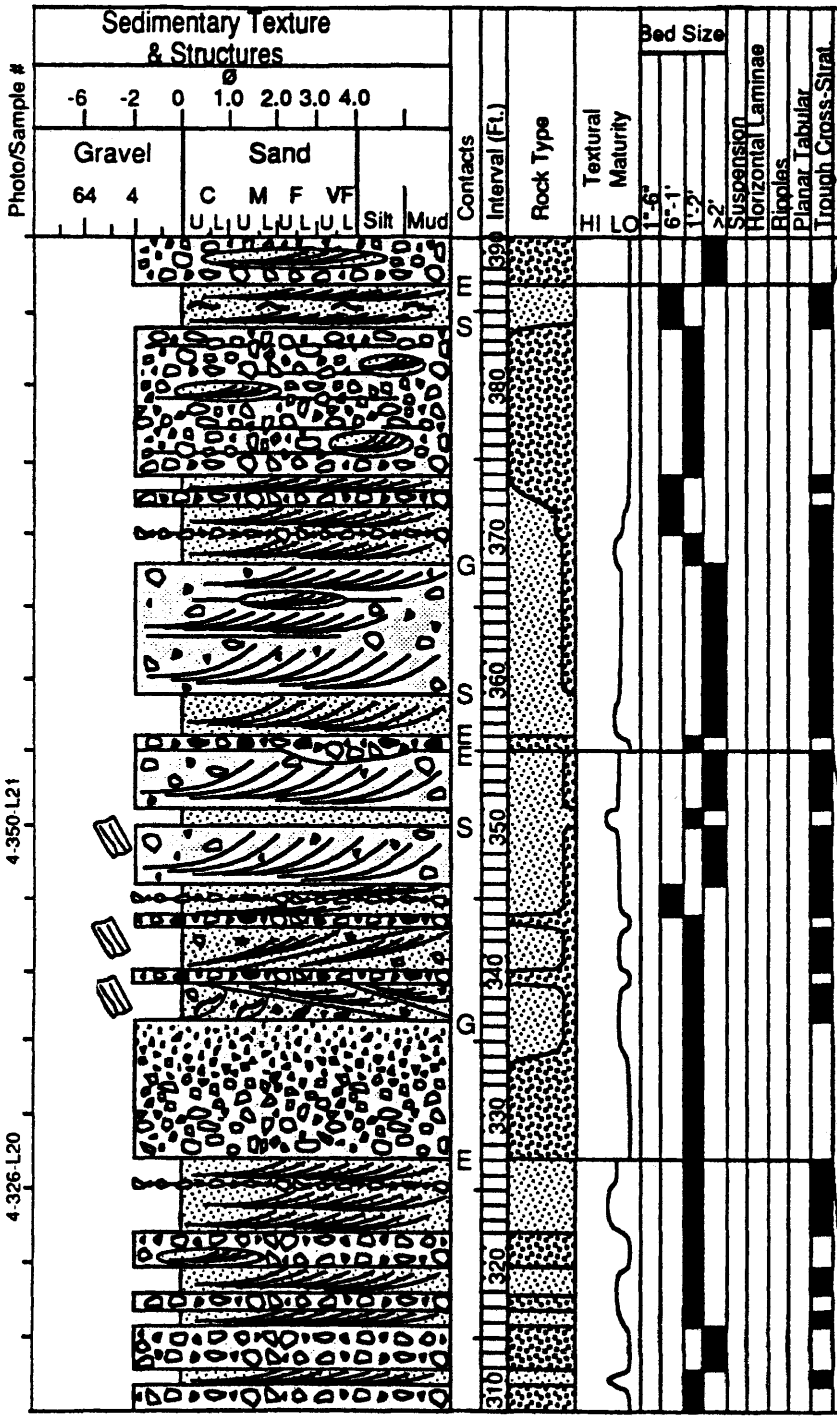
Comments



[See next page.]

Interbedded conglomerate, conglomeratic sandstone, and sandstone. Base of this package begins with thin conglomerate that scours into underlying units. Overlain by eight, broadly lenticular, interbedded sandstones and conglomerates arranged in 1'-2' beds. Conglomerates, matrix supported, maximum clast diameter 10", >60% oblong, angular volcanic clasts; mudstone and coal clasts are angular. Conglomeratic sandstone, TST in 6" sets, some foresets normally graded, units grade into sandstones. Sandstone, tuffaceous, some units interbedded with very thin mudstones in top 4'. TST in 1'-2' sets, or in 1"-6" sets alternating with ARL in 1"-3" sets within 6"-8" beds. Some foresets normally graded, some with mud drapes. Rare orange specks in bottom 10'.

Interbedded conglomerate, conglomeratic sandstone, and sandstone. Conglomerates, clast size same as unerlying conglomerates, but are more angular with lower sphericity. Clasts include; 50% volcanic, 30% chert/quartz, 15% plutonic, 5% metamorphic (volcanic content increases up section). Conglomerate units well organized into 1'-3' tabular beds. Some beds normally graded. Some TST foresets are sandy and/or normally graded. Conglomerate beds of single clast thickness separate sandstone interbeds. Sandstone, faint ARL at tops of some units. Some larger TST sets have foresets mud-draped from top to bottom and reworked tops. Orange specks found throughout, but in lesser amounts than in underlying units. Abundant wood throughout.

[See previous page.]

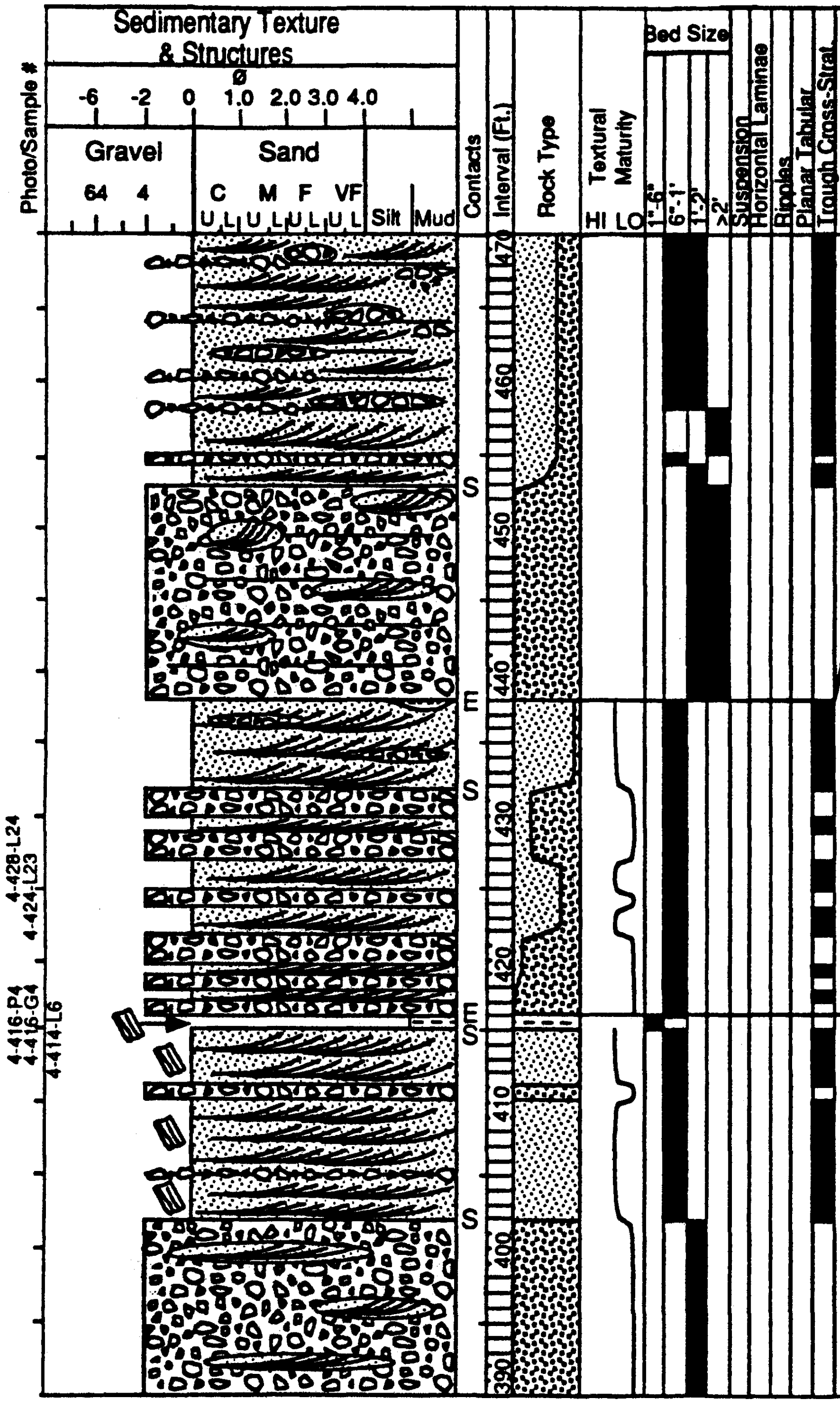
BY Houston & Gardner

Name Kuliak Bay

Structural Setting N 05 E, 18 SE

Location SW NW sec. 16 - NE SE sec. 9, T 23S, R 30W

Weather great!



Date 8/3/90

Unit Hemlock Congl.

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Comments

Conglomerate grading to conglomeratic sandstone and sandstone. Conglomerate is same as underlying conglomerate, arranged in 1'-6' beds which decrease in thickness up section. Geometry changes from tabular to lenticular up section. Sandstone, tan to buff, TST in 3"-6" sets in lenticular beds that are laterally discontinuous. Unit forms unreachable portion of cliff, but some bedforms are well expressed. Upper contact at 478' is marked by discontinuous mudstone bed with tree in growth position extending into overlying unit.

Interbedded conglomerate and sandstone at base grading up to sandstone at top with thin, discontinuous conglomerate beds. Conglomerate, matrix supported (coarse sandstone), maximum clast diameter 4", average 1", subrounded, low sphericity. Clasts include subequal amounts of chert, metamorphic, volcanic and plutonic. Sandstone, tan, tuffaceous moderately to poorly sorted, contains rare orange specks. TST in 1'-2' sets in 1'-2' beds. Unit capped by discontinuous, black siltstone bed.

Basal conglomerate with thin sandstone interbeds abruptly overlain by sandstone with thin scattered pebble lenses. Conglomerate, same composition as underlying conglomerate. Sandstone, moderately sorted, amalgamated TST in 6"-18" sets bounded by thin conglomerate beds. Beds are 1'-2' at base of major sandstone unit, <1' at top. Abundant wood on bedding planes. Unit capped by carbonaceous silty mudstone grading to black laminated siltstone with abundant wood fragments.

BY Houston & Gardner

Name Kuliak Bay Structural Setting N 05 E 18 SE

Location SW NW sec 16 - NE SE sec 9 T 23S R 30W Weather nice

Date 8/3/90

Unit Hemlock Congl.

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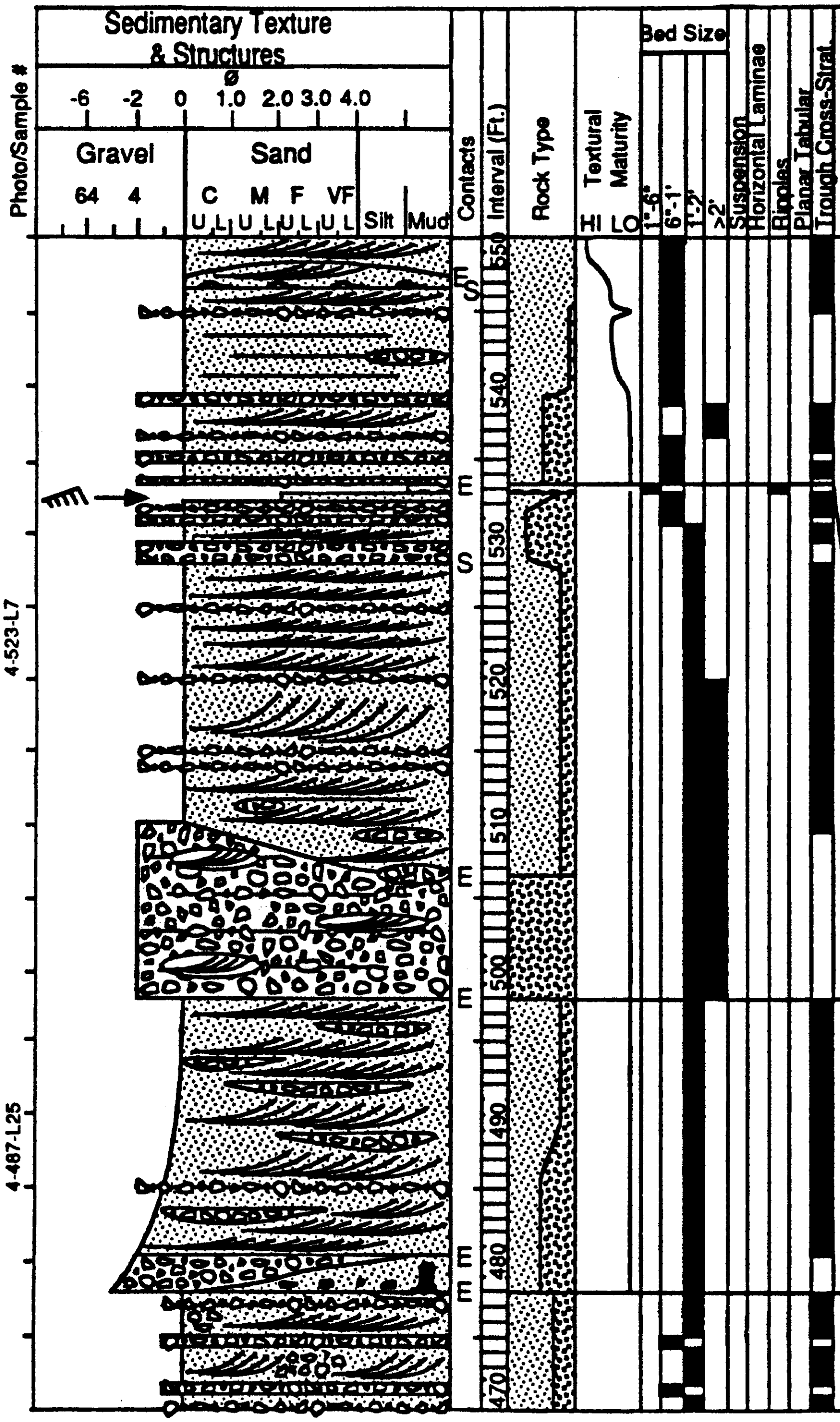


Comments

Upward-fining sequence of interbedded conglomerate and sandstone at base grading to sandstone at top. Conglomerate, dark gray to black, matrix supported (coarse sandstone). Poorly organized, 30% clasts, maximum clast diameter 3", average 1/4", subrounded with low sphericity. Clasts include; 35% quartz, 30% chert, 20% plutonic 5% metamorphic, 5% volcanic. Sandstone, light gray, poorly sorted at base, well sorted at top. TST in 6"-1' sets, some normally graded foresets. Low angle TST grades into ARL in 1"-2" sets at top of unit.

Upward-fining sequence of conglomerate at base and thinly interbedded sandstone and conglomerate at top. Sandstone, tan, poorly sorted, TST in 1'-3' sets in 1'-3' beds.

Upward-fining sequence of interbedded conglomerate and sandstone. Conglomerate forms discontinuous lenses, with texture similar to overlying conglomerate unit. Sandstone, TST in 1'-2' sets in 1'-2' beds. Sandstone content increases upward, conglomerate stringers decrease upward .

[See previous page.]

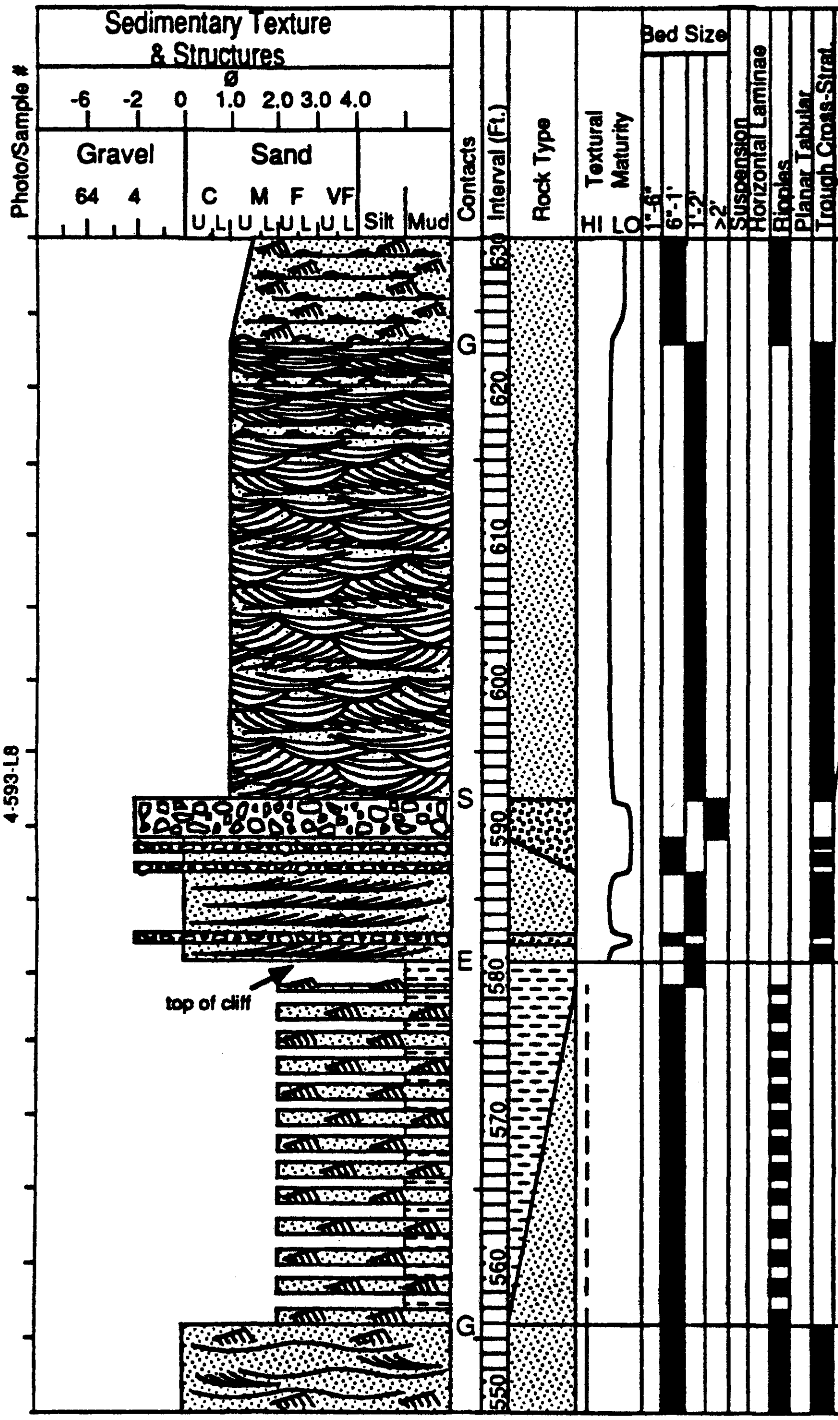
BY Houston & Gardner

Name Kuliak Bay

Structural Setting N 05 E, 18 SE

Location SW NW sec. 16 - NE SE sec. 9 T.23S R.30W

Weather nice



Date 8/3/90

Unit Hemlock Congl.

Page 8 of 9

Comments

Upward-fining sequence of interbedded conglomerate and sandstone at base, grading up to sandstone, with interbedded sandstone and mudstone at top (see previous description for base of sequence, 581'-592'). Sandstone, light gray, moderately sorted. Amalgamated TST in 1'-2' sets, TST has mud drapes on foresets from 616'-623'. Interbedded sandstone and mudstone, ARL in 1"-2" sets in 6"-2' beds. Silty mudstone, low angle and wavy beds averaging 14" thick.

Interbedded conglomerate and sandstone. Conglomerate, matrix supported (coarse sandstone), poorly organized. Maximum clast diameter 4", average 1", generally subrounded. Clasts include; 35% chert, 30% volcanic, 25% quartz, 5% metamorphic, 5% plutonic. Sandstone, tan to gray, TST in 6"-2' sets. Unit is basal lag for overlying fining-upward sequence.

Thinly interbedded sandstone and silty mudstone. Sandstone, light gray, well sorted with shale partings throughout. Sandstone forms 1"-6" thick wavy beds that contain pervasive ARL in 1"-3" sets. Silty mudstone, black, laminated to wavy beds in 1"-1' beds. Mudstone beds increase in size and frequency up section, sandstone beds thin up section. Unit caps massive cliff, and is top an of upward-fining sequence.

ARL in 1"-2" sets in 6" beds.

[See previous page.]

BY Houston & Gardner

Name Kuliak Bay

Structural Setting N 05 E, 18 SE

Location SW NW sec 16 - NE SE sec 9 T 23S R 30W

Weather nice

Date 8/3/90

Unit Hemlock Congl.

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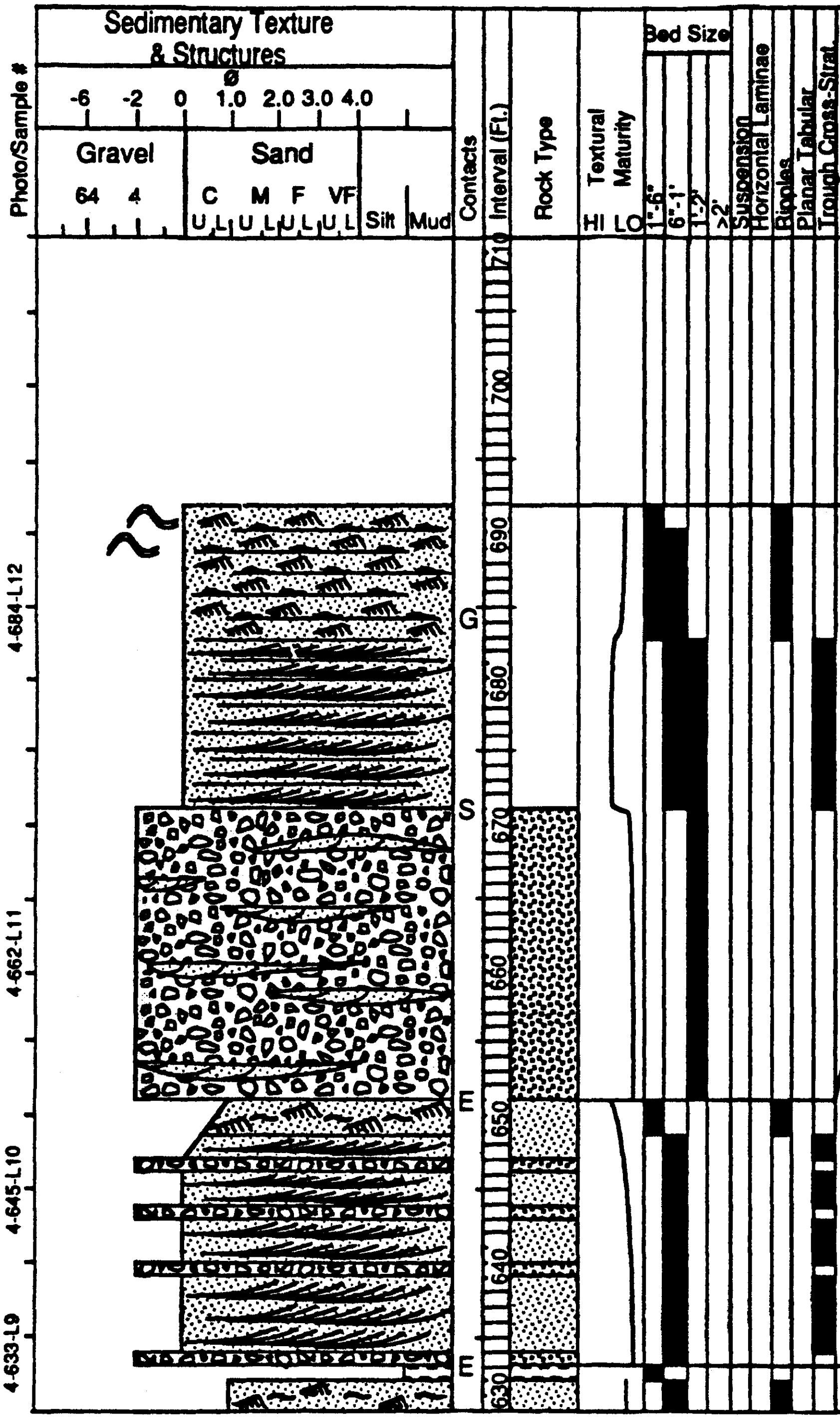

Comments

Top of section forms top of ridge and northernmost outcrop.

Upward-fining sequence of conglomerate at base grading to sandstone to interbedded sandstone and mudstone at top. Conglomerate, gray-green, matrix supported (coarse sandstone), poorly organized. 5-30% clasts, maximum clast diameter 3", average 1/2", subangular to subrounded, low sphericity. Clasts include; 35% quartz, 35%chert, 20% volcanic, 5% plutonic, <5% meta. Indistinct bedding, abundant sandstone lenses. Sharp contact between conglomerate and overlying sandstone. Sandstone, light gray to buff, moderately sorted, scattered patches of clay-like matrix. TST in 8"-2' sets grades up section to ARL in 1"-2" sets in 1"-1' beds. Abundant shale partings in top 8', moderate SSD in top 4'.

Upward-fining sequence of interbedded conglomerate and sandstone at base to sandstone with shale partings at top. Conglomerate, matrix supported, clasts include; 30% quartz, 20% chert 20% volcanic, 10% metamorphic, 10% plutonic. Sandstone, light gray, poorly sorted at base, moderately sorted at top. TST in 1"-8" sets at base grades to ARL in 1"-2" sets in 2"-4" beds. Abundant shale partings at top.

[See previous page.]

APPENDIX II

POINT COUNT DATA

LEGEND

sam#	sample numbers
qtz	sum of all monocrystalline and polycrystalline quartz
fsp/p	sum of all feldspars and plutonic rock fragments
rocks	sum of all volcanic, metamorphic and chert fragments
plut	plutonic rock fragments
volc	volcanic rock fragments
meta	sum of all metamorphic and chert fragments
det	sum of all detrital components
cem	sum of all authigenic minerals
mq-u	monocrystalline quartz - undulose
mq-n	monocrystalline quartz - nonundulose
pq2-	polycrystalline quartz containing 2-3 crystallites
pq>3	polycrystalline quartz containing more than 3 crystallites
plag	plagioclase
kspar	potassium feldspars
micro	microcline
musc	muscovite
acce	accessory minerals
plut	plutonic rock fragments
volc	volcanic rock fragments
chert	chert fragments
meta	metamorphic fragments
folch	foliated chert fragments
other	glass/pumice microlites (pyroclastics only)
chlor	chlorite cement
cal	calcite cement
phyl	phyllosilicate cements (excluding chlorite)
fe2o3	iron oxide cements

(all values are percentages)

LEGEND

sam#	
qtz fsp/p rocks	Group 1 - Sandstone classification (after Dott, 1964)
plut volc meta	Group 2 - Breakdown of rock fragments
det cem	Group 3 - Detrital components vs. authigenic minerals
mq-u mq-n pq2- pq>3 plag kspar micro musc acce plut volc chert meta folch other	Group 4 - Breakdown of detrital components
chlor cal phyl fe2o3	Group 5 - Breakdown of authigenic minerals

(each group normallized to 100%)

Cape Douglas (West Foreland Formation)

sam#	3-75-L3	3-90-L2	3-130-L1	3-3034-L1	3-3119-L2	3-3161-L3
qtz	10.1	12.0	6.6	63.2	51.5	63.6
fsp/p	13.8	3.6	2.0	7.7	5.9	8.0
rocks	76.1	84.4	91.4	29.1	42.6	28.3
plut	0.0	0.0	0.0	1.9	0.0	1.9
volc	91.7	98.6	93.5	33.3	9.7	53.7
meta	8.3	1.4	6.5	64.8	90.3	44.4
det	85.0	85.0	79.5	95.5	86.0	96.5
cem	15.0	15.0	20.5	4.5	14.0	3.5
mq-u	7.6	8.2	3.8	36.1	22.7	31.6
mq-nu	1.2	2.9	0.6	7.9	0.0	11.4
pq2-3	0.6	0.0	1.9	3.7	8.7	5.2
pq>3	0.0	0.6	0.0	12.6	19.2	13.5
plag	8.8	3.5	1.9	6.8	5.2	7.3
kspar	4.1	0.0	0.0	0.0	0.6	0.0
micro	0.0	0.0	0.0	0.0	0.0	0.0
musc	0.0	0.0	0.0	3.1	1.2	1.6
acces	6.5	1.8	5.0	1.6	0.6	1.6
plut	0.0	0.0	0.0	0.5	0.0	0.5
volc	65.3	81.8	81.1	9.4	4.1	15.0
chert	3.5	1.2	5.7	15.7	30.8	9.3
meta	1.2	0.0	0.0	1.0	3.5	2.6
folch	1.2	0.0	0.0	1.6	3.5	0.5
other	0.0	0.0	0.0	0.0	0.0	0.0
chlor	0.0	100.0	92.7	0.0	85.7	0.0
cal	0.0	0.0	0.0	100.0	0.0	100.0
phyl	16.7	0.0	0.0	0.0	0.0	0.0
fe2o3	83.3	0.0	7.3	0.0	14.3	0.0

Cape Douglas (West Foreland Formation)

sam#	3-3172-L4	3-3200-L5	3-3280-L6	3-3323-L9	3-3350-L1	3-3388-L1
qtz	47.8	60.5	47.5	48.5	45.1	33.0
fsp/p	52.2	4.7	2.7	1.2	2.3	4.5
rocks	0.0	34.7	49.7	50.3	52.6	62.5
plut	0.0	1.5	1.1	0.0	0.0	0.0
volc	0.0	25.4	12.0	54.1	43.5	46.4
meta	0.0	73.1	87.0	45.9	56.5	53.6
det	100.0	96.5	91.5	88.0	88.5	96.0
cem	0.0	3.5	8.5	12.0	11.5	4.0
mq-u	27.5	29.0	9.8	17.0	10.2	7.8
mq-nu	0.0	7.8	6.0	5.7	2.3	4.2
pq2-3	0.0	3.1	6.6	2.8	2.8	0.5
pq>3	0.0	19.7	25.1	21.0	29.4	17.7
plag	26.5	4.1	2.2	1.1	2.3	4.2
kspar	3.5	0.0	0.0	0.0	0.0	0.0
micro	0.0	0.0	0.0	0.0	0.0	0.0
musc	0.0	0.0	0.0	0.0	1.1	0.0
acces	0.0	1.6	0.0	4.0	0.0	0.0
plut	0.0	0.5	0.5	0.0	0.0	0.0
volc	0.0	8.8	6.0	26.1	22.6	34.9
chert	0.0	19.7	32.8	16.5	19.2	26.6
meta	0.0	1.0	1.1	1.1	5.1	3.1
folch	0.0	4.7	9.8	4.5	5.1	1.0
other	42.5	0.0	0.0	0.0	0.0	0.0
chlor	0.0	42.9	0.0	0.0	10.0	0.0
cal	0.0	57.1	100.0	91.7	82.6	62.5
phyl	0.0	0.0	0.0	0.0	7.4	0.0
fe2o3	0.0	0.0	0.0	8.3	0.0	37.5

Cape Douglas (West Foreland Formation)

sam#	3-3391-L8	3-3407-L1	3-3435-L1	3-3458-L1	3-3523-L1	3-3553-L1
qtz	47.5	50.8	94.0	46.2	34.4	61.0
fsp/p	5.7	1.7	3.0	3.3	3.2	2.7
rocks	46.8	47.5	3.0	50.5	62.4	36.3
plut	0.0	0.0	0.0	0.0	0.0	0.0
volc	56.8	57.1	50.0	19.6	61.9	66.0
meta	43.2	42.9	50.0	80.4	38.1	34.0
det	79.5	89.5	37.5	96.0	99.5	74.0
cem	20.5	10.5	62.5	4.0	0.5	26.0
mq-u	18.9	17.3	68.0	9.4	8.5	30.4
mq-nu	0.0	5.6	0.0	4.2	3.5	7.4
pq2-3	3.1	7.3	12.0	4.2	1.0	5.4
pq>3	25.2	20.1	4.0	26.0	19.6	16.9
plag	5.0	1.1	2.7	3.1	3.0	2.7
kspar	0.6	0.0	0.0	0.0	0.0	0.0
micro	0.0	0.6	0.0	0.0	0.0	0.0
musc	0.0	0.0	0.0	0.0	0.0	0.0
acces	0.6	1.1	10.7	5.2	5.0	1.4
plut	0.0	0.0	0.0	0.0	0.0	0.0
volc	26.4	26.8	1.3	9.4	36.7	23.6
chert	13.2	13.4	1.3	32.8	16.1	8.1
meta	3.8	1.7	0.0	2.6	1.5	2.7
folch	3.1	5.0	0.0	3.1	5.0	1.4
other	0.0	0.0	0.0	0.0	0.0	0.0
chlor	78.0	47.6	36.0	0.0	0.0	0.0
cal	0.0	52.4	61.6	100.0	100.0	86.5
phyl	0.0	0.0	0.0	0.0	0.0	13.5
fe2o3	22.0	0.0	2.4	0.0	0.0	0.0

Cape Douglas (West Foreland Formation)

sam#	3-3564-L1	3-3618-L1	3-3639-L1	3-3663-L2	3-3686-L2	3-3911-L2
qtz	47.2	52.5	27.2	8.4	15.2	34.2
fsp/p	8.0	5.6	5.4	1.1	14.6	6.4
rocks	44.8	41.9	67.3	90.4	70.2	59.4
plut	0.0	0.0	0.0	0.0	0.0	0.9
volc	60.3	60.0	20.2	91.3	92.5	88.4
meta	39.7	40.0	79.8	8.7	7.5	10.7
det	86.0	90.0	74.5	89.0	77.2	97.0
cem	14.0	10.0	25.5	11.0	22.8	3.0
mq-u	26.2	26.7	11.4	3.4	12.8	14.4
mq-nu	0.0	6.7	6.0	2.8	0.0	14.4
pq2-3	6.4	5.0	2.0	1.1	0.6	1.0
pq>3	12.2	13.9	7.4	1.1	1.3	3.1
plag	6.4	5.6	5.4	1.1	13.5	4.6
kspar	1.2	0.0	0.0	0.0	0.0	0.0
micro	0.0	0.0	0.0	0.0	0.6	1.0
musc	2.3	0.0	0.0	0.0	0.0	0.0
acces	2.9	0.6	1.3	0.0	3.2	3.6
plut	0.0	0.0	0.0	0.0	0.0	0.5
volc	25.6	25.0	13.4	82.6	62.8	51.0
chert	9.9	10.0	51.7	7.3	5.1	5.7
meta	6.4	2.8	0.0	0.0	0.0	0.5
folch	0.6	3.9	1.3	0.6	0.0	0.0
other	0.0	0.0	0.0	0.0	0.0	0.0
chlor	32.1	40.0	0.0	0.0	30.4	0.0
cal	50.0	60.0	96.1	54.5	50.0	100.0
phyl	0.0	0.0	0.0	0.0	0.0	0.0
fe2o3	17.8	0.0	3.9	45.5	19.5	0.0

Cape Douglas (West Foreland Formation)

sam#	3-3927-L2	3-3963-L2	3-3995-L2
qtz	26.3	69.1	2.5
fsp/p	8.6	17.3	16.2
rocks	65.1	13.6	81.2
plut	0.0	0.0	0.0
volc	74.7	18.2	100.0
meta	25.3	81.8	0.0
det	77.0	50.0	100.0
cem	23.0	50.0	0.0
mq-u	7.1	20.0	1.5
mq-nu	13.0	32.0	1.0
pq2-3	1.9	1.0	0.0
pq>3	3.9	3.0	0.0
plag	8.4	13.0	16.0
kspar	0.0	0.0	0.0
micro	0.0	1.0	0.0
musc	0.0	1.0	0.0
acces	1.3	18.0	1.5
plut	0.0	0.0	0.0
volc	48.1	2.0	80.0
chert	15.6	8.0	0.0
meta	0.0	0.0	0.0
folch	0.6	1.0	0.0
other	0.0	0.0	0.0
chlor	69.6	0.0	0.0
cal	28.3	98.0	0.0
phyl	0.0	0.0	0.0
fe2o3	2.2	2.0	0.0

Lower Kuliak Bay (West Foreland Formation?)

sam#	4-0-L1	4-67-L1	4-83-L2	4-138-L3	4-138-L3A	4-163-L4
qtz	0.0	69.3	44.4	35.4	42.6	26.1
fsp/p	0.0	8.0	7.1	12.2	13.5	12.7
rocks	100.0	22.7	48.5	52.4	43.9	61.1
plut	0.0	2.9	0.0	0.0	1.5	1.0
volc	100.0	22.9	6.3	67.5	53.0	46.4
meta	0.0	74.3	93.8	32.5	45.5	52.6
det	100.0	82.0	58.0	78.5	79.5	80.5
cem	0.0	18.0	42.0	21.5	20.5	19.5
mq-u	0.0	27.4	34.5	15.9	21.4	9.3
mq-nu	0.0	15.9	1.7	2.5	1.9	5.0
pq2-3	0.0	6.7	1.7	5.7	6.9	1.9
pq>3	0.0	13.4	0.0	8.9	9.4	9.3
plag	0.0	6.7	6.0	11.5	8.8	11.8
kspar	0.0	0.0	0.0	0.0	3.1	0.0
micro	0.0	0.0	0.0	0.0	0.0	0.0
musc	0.0	0.6	13.8	0.6	0.6	0.0
acces	0.0	7.9	0.9	5.7	6.3	2.5
plut	0.0	0.6	0.0	0.0	0.6	0.6
volc	100.0	4.9	2.6	33.1	22.0	28.0
chert	0.0	11.6	15.5	12.7	14.5	29.2
meta	0.0	2.4	23.3	0.0	3.8	0.0
folch	0.0	1.8	0.0	3.2	0.6	2.5
other	0.0	0.0	0.0	0.0	0.0	0.0
chlor	0.0	55.2	0.0	0.0	36.6	82.1
cal	0.0	41.7	33.3	93.0	53.7	17.9
phyl	0.0	3.1	17.9	0.0	0.0	0.0
fe2o3	0.0	0.0	48.8	7.0	9.8	0.0

Lower Kuliak Bay (West Foreland Formation?)

sam#	4-165-L13	4-170-L5
qtz	49.7	45.1
fsp/p	11.6	16.2
rocks	38.7	38.7
plut	0.0	1.8
volc	60.0	58.9
meta	40.0	39.3
det	78.5	73.0
cem	21.5	27.0
mq-u	22.9	26.0
mq-nu	10.2	0.0
pq2-3	7.0	9.6
pq>3	8.9	8.2
plag	11.5	12.3
kspar	0.0	2.7
micro	0.0	0.0
musc	0.0	2.1
acces	1.3	0.7
plut	0.0	0.7
volc	22.9	22.6
chert	12.7	6.8
meta	1.3	6.8
folch	1.3	1.4
other	0.0	0.0
chlor	0.0	0.0
cal	79.1	33.3
phyl	2.3	0.0
fe2o3	18.6	66.7

Cape Nukshak (Hemlock Conglomerate)

sam#	1-569-L1	1-576-L2	1-615-L3	1-623-L4	1-661-L5	1-715-L6
qtz	20.3	62.5	19.8	26.9	35.3	8.8
fsp/p	15.2	6.3	5.3	8.2	15.3	8.2
rocks	64.6	31.3	74.8	64.9	49.3	83.0
plut	0.0	0.0	0.0	0.0	0.0	0.0
volc	93.1	68.9	93.9	89.7	93.2	98.4
meta	6.9	31.1	6.1	10.3	6.8	1.6
det	79.0	79.5	65.5	68.5	75.0	75.0
cem	21.0	20.5	34.5	31.5	25.0	25.0
mq-u	16.5	30.2	14.5	17.5	34.0	8.7
mq-nu	0.6	8.8	3.1	3.6	0.0	0.0
pq2-3	0.6	5.7	0.8	1.5	0.0	0.0
pq>3	2.5	11.9	1.5	3.6	1.3	0.0
plag	11.4	5.7	5.3	8.0	15.3	8.0
kspar	1.9	0.0	0.0	0.0	0.0	0.0
micor	1.9	0.0	0.0	0.0	0.0	0.0
musc	0.0	3.1	0.0	0.0	0.0	0.0
acces	0.0	6.3	0.0	2.2	0.0	2.0
plut	0.0	0.0	0.0	0.0	0.0	0.0
volc	60.1	19.5	70.2	56.9	46.0	80.0
chert	3.8	6.9	4.6	5.1	3.3	1.3
meta	0.0	1.9	0.0	0.0	0.0	0.0
folch	0.6	0.0	0.0	1.5	0.0	0.0
other	0.0	0.0	0.0	0.0	0.0	0.0
chlor	66.7	22.0	7.2	0.0	0.0	14.0
cal	33.3	73.2	82.6	92.1	78.0	86.0
phyl	0.0	2.4	0.0	0.0	0.0	0.0
fe2o3	0.0	2.4	10.1	7.9	22.0	0.0

Cape Nukshak (Hemlock Conglomerate)

sam#	1-826-L7	1-980-L8	1-1040-L9	1-1049-L1	1-1064-L1	1-1073-L1
qtz	52.3	63.2	36.5	35.3	38.5	31.3
fsp/p	10.3	0.9	5.4	25.0	36.9	59.4
rocks	37.4	36.0	58.1	39.7	24.6	9.4
plut	0.0	0.0	0.0	0.0	0.0	0.0
volc	39.7	17.1	20.9	81.5	76.7	66.7
meta	60.3	82.9	79.1	18.5	23.3	33.3
det	82.0	58.0	75.0	68.0	61.5	68.5
cem	18.0	42.0	25.0	32.0	38.5	31.5
mq-u	22.6	28.4	19.3	30.1	36.6	26.3
mq-nu	8.5	18.1	2.7	1.5	0.0	0.7
pq2-3	9.8	5.2	3.3	2.2	0.0	0.7
pq>3	8.5	10.3	10.7	1.5	1.6	1.5
plag	9.1	0.9	5.3	25.0	36.6	55.5
kspar	0.0	0.0	0.0	0.0	0.0	0.0
micor	0.6	0.0	0.0	0.0	0.0	0.0
musc	3.7	0.9	1.3	0.0	0.0	0.0
acces	1.8	0.9	0.0	0.0	0.8	6.6
plut	0.0	0.0	0.0	0.0	0.0	0.0
volc	14.0	6.0	12.0	32.4	18.7	5.8
chert	17.1	21.6	36.0	7.4	5.7	2.9
meta	3.0	5.2	4.7	0.0	0.0	0.0
folch	1.2	2.6	4.7	0.0	0.0	0.0
other	0.0	0.0	0.0	0.0	0.0	0.0
chlor	0.0	0.0	0.0	0.0	70.1	4.8
cal	91.7	82.1	94.0	87.5	23.4	39.7
phyl	8.3	0.0	2.0	0.0	0.0	0.0
fe2o3	0.0	17.9	4.0	12.5	6.5	55.6

Cape Nukshak (Hemlock Conglomerate)

sam#	1-1100-L1	1-1190-L1	1-1210-L1	1-1297-L3	1-1328-L2	1-1386-L1
qtz	45.4	6.2	38.2	52.5	73.0	20.3
fsp/p	30.3	5.0	22.5	31.1	10.9	6.0
rocks	24.3	88.8	39.2	16.4	15.5	73.6
plut	0.0	0.0	0.0	0.0	3.6	0.0
volc	86.5	100.0	20.0	83.3	64.3	96.3
meta	13.5	0.0	80.0	16.7	32.1	3.7
det	77.0	81.0	52.5	93.5	95.0	91.5
cem	23.0	19.0	47.5	6.5	5.0	8.5
mq-u	39.0	3.7	35.2	48.1	48.4	14.2
mq-nu	5.2	2.5	1.9	1.6	17.9	4.9
pq2-3	0.6	0.0	0.0	0.0	0.5	0.0
pq>3	0.0	0.0	0.0	1.6	0.0	1.1
plag	29.9	4.9	21.0	30.5	10.0	6.0
kspar	0.0	0.0	1.0	0.0	0.0	0.0
micor	0.0	0.0	0.0	0.0	0.0	0.0
musc	0.0	0.0	1.9	0.0	0.0	0.0
acces	1.3	0.6	1.0	2.1	8.4	0.5
plut	0.0	0.0	0.0	0.0	0.5	0.0
volc	20.8	88.3	7.6	13.4	9.5	70.5
chert	3.2	0.0	29.5	2.7	4.7	2.7
meta	0.0	0.0	1.0	0.0	0.0	0.0
folch	0.0	0.0	0.0	0.0	0.0	0.0
other	0.0	0.0	0.0	0.0	0.0	0.0
chlor	0.0	0.0	0.0	0.0	16.7	47.1
cal	65.2	68.4	76.3	53.8	80.0	52.9
phyl	0.0	0.0	6.8	0.0	3.3	0.0
fe2o3	34.8	31.6	16.8	46.2	0.0	0.0

Cape Nukshak (Hemlock Conglomerate)

sam#	1-1442-L4	1-1463-L1	1-1472-L5	1-1474-L2	1-1504-L6	1-1553-L3
qtz	13.7	14.8	30.2	11.9	5.7	52.2
fsp/p	19.4	10.1	6.9	9.5	6.3	13.0
rocks	66.9	75.1	63.0	78.6	88.1	34.8
plut	0.0	0.0	0.0	0.0	0.0	0.0
volc	99.1	100.0	100.0	99.2	97.1	81.3
meta	0.9	0.0	0.0	0.8	2.9	18.8
det	94.0	87.0	97.0	87.5	81.0	51.5
cem	6.0	13.0	3.0	12.5	19.0	48.5
mq-u	12.8	13.8	27.3	9.7	2.5	33.0
mq-nu	0.0	0.6	2.1	0.6	1.2	11.7
pq2-3	0.0	0.0	0.0	0.0	1.2	1.9
pq>3	0.0	0.0	0.0	1.1	0.6	0.0
plag	18.1	9.8	6.7	9.1	6.2	11.7
kspar	0.0	0.0	0.0	0.0	0.0	0.0
micor	0.0	0.0	0.0	0.0	0.0	0.0
musc	0.0	0.0	0.0	0.0	0.0	0.0
acces	6.9	2.9	2.6	4.0	1.9	10.7
plut	0.0	0.0	0.0	0.0	0.0	0.0
volc	61.7	73.0	61.3	74.9	84.0	25.2
chert	0.5	0.0	0.0	0.6	2.5	3.9
meta	0.0	0.0	0.0	0.0	0.0	0.0
folch	0.0	0.0	0.0	0.0	0.0	1.9
other	0.0	0.0	0.0	0.0	0.0	0.0
chlor	66.7	84.6	0.0	88.0	94.7	0.0
cal	0.0	11.5	100.0	0.0	0.0	89.7
phyl	0.0	0.0	0.0	8.0	0.0	0.0
fe2o3	33.3	3.8	0.0	4.0	5.3	10.3

Cape Nukshak (Hemlock Conglomerate)

sam#	1-1660-L4	1-1752-L5	1-1892-L8	1-1921-L9	1-2010-L1	1-2377-L1
qtz	73.5	3.3	60.2	36.9	1.9	4.3
fsp/p	11.1	8.5	2.3	8.3	7.7	3.7
rocks	15.4	88.2	37.6	52.2	90.3	92.0
plut	0.0	0.0	0.0	4.7	0.0	0.0
volc	88.9	100.0	66.0	80.2	100.0	100.0
meta	11.1	0.0	34.0	15.1	0.0	0.0
det	66.5	80.5	71.0	79.0	78.0	87.0
cem	33.5	19.5	29.0	21.0	22.0	13.0
mq-u	63.9	1.2	38.7	20.3	1.9	4.0
mq-nu	0.0	1.9	6.3	5.7	0.0	0.0
pq2-3	0.0	0.0	5.6	3.8	0.0	0.0
pq>3	0.8	0.0	5.6	7.0	0.0	0.0
plag	9.8	8.1	2.1	8.2	7.7	3.4
kspar	0.0	0.0	0.0	0.0	0.0	0.0
micor	0.0	0.0	0.0	0.0	0.0	0.0
musc	0.0	0.0	4.9	0.0	0.0	0.0
acces	12.0	5.0	1.4	0.6	0.6	6.3
plut	0.0	0.0	0.0	2.5	0.0	0.0
volc	12.0	83.9	23.2	43.7	89.7	86.2
chert	1.5	0.0	7.7	6.3	0.0	0.0
meta	0.0	0.0	3.5	1.3	0.0	0.0
folch	0.0	0.0	0.7	0.6	0.0	0.0
other	0.0	0.0	0.0	0.6	0.0	0.0
chlor	64.2	97.4	0.0	57.1	84.1	0.0
cal	20.9	0.0	93.1	38.1	6.8	0.0
phyl	0.0	0.0	0.0	0.0	0.0	0.0
fe2o3	14.9	2.6	6.9	4.8	9.1	100.0

Cape Nukshak (Hemlock Conglomerate)

sam#	1-2393-L6	1-2396-L7	1-2453-L1	1-2500-L1	1-2541-L1	1-2593-L1
qtz	1.3	11.4	0.0	19.7	61.8	10.9
fsp/p	6.0	4.5	6.3	72.7	2.9	54.7
rocks	92.7	84.1	93.8	7.6	35.3	34.4
plut	0.0	0.0	0.0	0.0	0.0	0.0
volc	100.0	100.0	99.4	80.0	19.7	100.0
meta	0.0	0.0	0.6	20.0	80.3	0.0
det	76.5	89.0	89.0	100.0	89.0	100.0
cem	23.5	11.0	11.0	0.0	11.0	0.0
mq-u	1.3	9.6	0.0	3.5	29.8	1.5
mq-nu	0.0	1.7	0.0	2.5	10.1	2.0
pq2-3	0.0	0.0	0.0	0.5	5.6	0.0
pq>3	0.0	0.0	0.0	0.0	14.6	0.0
plag	5.9	4.5	6.2	23.5	2.8	17.5
kspar	0.0	0.0	0.0	0.0	0.0	0.0
micor	0.0	0.0	0.0	0.5	0.0	0.0
musc	0.0	0.0	0.0	0.0	0.0	0.0
acces	1.3	1.1	1.1	4.0	2.8	0.0
plut	0.0	0.0	0.0	0.0	0.0	0.0
volc	91.5	83.1	92.1	2.0	6.7	11.0
chert	0.0	0.0	0.6	0.5	18.5	0.0
meta	0.0	0.0	0.0	0.0	3.9	0.0
folch	0.0	0.0	0.0	0.0	5.1	0.0
other	0.0	0.0	0.0	63.0	0.0	68.0
chlor	34.0	95.5	72.7	0.0	0.0	0.0
cal	0.0	0.0	0.0	0.0	4.5	0.0
phyl	0.0	0.0	0.0	0.0	0.0	0.0
fe2o3	66.0	4.5	27.3	0.0	95.5	0.0

Cape Nukshak (Hemlock Conglomerate)

sam#	1-2696-L2	1-2735-L3
qtz	16.0	14.2
fsp/p	10.4	10.1
rocks	73.6	75.7
plut	0.0	0.0
volc	100.0	100.0
meta	0.0	0.0
det	84.5	90.5
cem	15.5	9.5
mq-u	14.8	13.3
mq-nu	0.6	0.0
pq2-3	0.0	0.0
pq>3	0.0	0.0
plag	10.1	9.4
kspar	0.0	0.0
micor	0.0	0.0
musc	0.0	0.0
acces	3.6	6.6
plut	0.0	0.0
volc	71.0	70.7
chert	0.0	0.0
meta	0.0	0.0
folch	0.0	0.0
other	0.0	0.0
chlor	90.3	0.0
cal	0.0	0.0
phyl	0.0	0.0
fe2o3	9.7	100.0

Kinak Bay (Hemlock Conglomerate)

sam#	2-4-L1	2-17-L2	2-130-L2A	2-268-L3	2-357-L4	2-417-L1
qtz	31.1	56.7	58.6	55.8	22.6	56.3
fsp/p	13.0	9.2	12.7	10.4	13.9	14.6
rocks	56.0	34.2	28.7	33.8	63.5	29.1
plut	0.0	0.0	0.0	0.0	0.0	0.0
volc	81.5	17.1	26.7	30.8	73.6	43.2
meta	18.5	82.9	73.3	69.2	26.4	56.8
det	96.5	62.5	78.2	82.5	69.0	77.5
cem	3.5	37.5	21.8	17.5	31.0	22.5
mq-u	19.7	20.0	36.7	21.2	8.0	38.7
mq-nu	1.0	14.4	5.7	14.5	8.7	0.6
pq2-3	1.6	4.8	5.1	3.6	0.7	5.8
pq>3	8.8	15.2	10.8	12.7	5.1	9.7
plag	11.4	8.0	12.0	7.3	13.0	12.9
kspar	1.0	0.0	0.0	0.0	0.0	0.0
micor	0.5	0.8	0.6	2.4	0.7	1.3
musc	0.0	3.2	0.6	3.6	0.7	1.3
acces	0.0	0.8	0.0	3.0	0.0	1.3
plut	0.0	0.0	0.0	0.0	0.0	0.0
volc	45.6	5.6	7.6	9.7	46.4	12.3
chert	8.3	21.6	15.2	15.2	15.2	12.9
meta	1.0	2.4	3.2	4.2	0.0	2.6
folch	1.0	3.2	2.5	2.4	1.4	0.6
other	0.0	0.0	0.0	0.0	0.0	0.0
chlor	14.3	0.0	0.0	34.3	48.4	22.2
cal	28.6	40.0	75.0	54.3	16.1	68.9
phyl	14.3	4.0	18.2	0.0	0.0	0.0
fe2o3	42.9	56.0	6.8	11.4	35.5	8.9

Kinak Bay (Hemlock Conglomerate)

sam#	2-462-L2	2-481-L3	2-582-L4	2-662-L5	2-674-L2	2-709-L1
qtz	57.7	54.4	53.7	60.8	58.2	56.1
fsp/p	13.4	13.3	12.7	8.0	11.2	7.2
rocks	28.9	32.3	33.6	31.2	30.6	36.7
plut	0.0	0.0	0.0	0.0	0.0	0.0
volc	31.7	43.1	13.3	33.3	36.5	15.7
meta	68.3	56.9	86.7	66.7	63.5	84.3
det	76.0	79.5	68.0	64.0	85.5	72.0
cem	24.0	20.5	32.0	36.0	14.5	28.0
mq-u	28.9	39.0	30.1	43.8	31.0	29.9
mq-nu	1.3	1.3	11.8	1.6	1.8	4.2
pq2-3	11.2	2.5	0.7	6.3	11.1	6.3
pq>3	12.5	11.3	10.3	7.8	14.0	13.9
plag	11.8	11.3	12.5	7.0	9.4	6.9
kspar	0.0	0.0	0.0	0.8	1.2	0.0
micor	0.7	1.9	0.0	0.0	0.6	0.0
musc	4.6	0.6	0.7	2.3	0.0	2.8
acces	2.0	0.0	0.7	0.0	0.6	0.7
plut	0.0	0.0	0.0	0.0	0.0	0.0
volc	8.6	13.8	4.4	10.2	11.1	5.6
chert	12.5	11.3	23.5	16.4	9.9	21.5
meta	3.3	6.9	2.2	0.0	7.6	3.5
folch	2.6	0.0	2.9	3.9	1.8	4.9
other	0.0	0.0	0.0	0.0	0.0	0.0
chlor	30.1	0.0	0.0	0.0	24.1	0.0
cal	18.8	43.9	75.0	76.4	20.7	21.4
phyl	7.4	7.3	0.0	2.8	3.5	19.6
fe2o3	43.8	48.8	25.0	20.8	51.7	58.9

Upper Kuliak Bay (Hemlock Conglomerate?)

sam#	4-245-L14	4-260-L15	4-269-L16	4-271-L17	4-283-L18	4-300-L19
qtz	60.6	37.0	36.2	55.6	46.3	70.2
fsp/p	3.8	9.1	5.3	10.7	14.7	4.3
rocks	35.6	53.9	58.5	33.7	39.0	25.5
plut	0.0	0.0	0.9	1.7	0.0	0.0
volc	47.4	72.3	15.3	63.8	56.6	25.0
meta	52.6	27.7	83.8	34.5	43.4	75.0
det	80.5	85.0	94.0	86.0	68.5	51.5
cem	19.5	15.0	6.0	14.0	31.5	48.5
mq-u	29.2	12.9	6.4	26.7	21.2	24.3
mq-nu	11.2	4.7	0.5	10.5	0.0	13.6
pq2-3	9.3	5.9	2.1	6.4	8.8	7.8
pq>3	10.6	10.0	27.1	11.0	16.1	18.4
plag	3.7	6.5	4.8	9.9	10.9	3.9
kspar	0.0	1.8	0.0	0.0	2.9	0.0
micor	0.0	0.0	0.0	0.0	0.7	0.0
musc	0.0	1.2	0.0	1.7	0.7	4.9
acces	0.6	0.0	0.0	0.0	0.0	3.9
plut	0.0	0.0	0.5	0.6	0.0	0.0
volc	16.8	35.3	9.0	21.5	21.9	5.8
chert	16.8	10.6	38.3	9.9	7.3	8.7
meta	1.2	1.8	0.0	0.6	7.3	4.9
folch	0.6	1.2	11.2	1.2	2.2	3.9
other	0.0	8.2	0.0	0.0	0.0	0.0
chlor	0.0	23.3	0.0	0.0	17.5	0.0
cal	87.2	70.0	100.0	89.3	55.6	91.8
phyl	5.1	0.0	0.0	3.6	0.0	0.0
fe2o3	7.7	6.7	0.0	7.1	27.0	8.2

Upper Kuliak Bay (Hemlock Conglomerate?)

sam#	4-326-L20	4-350-L21	4-379-L22	4-414-L6	4-424-L23	4-428-L24
qtz	65.5	64.5	61.8	54.7	52.5	45.9
fsp/p	7.4	3.6	3.8	5.1	7.4	6.8
rocks	27.0	31.8	34.4	40.1	40.1	47.4
plut	0.0	0.0	0.0	0.0	0.0	0.0
volc	40.0	5.7	31.5	21.8	50.8	17.5
meta	60.0	94.3	68.5	78.2	49.2	82.5
det	76.0	57.7	81.0	71.5	83.0	68.5
cem	24.0	42.3	19.0	28.5	17.0	31.5
mq-u	38.8	34.5	27.2	18.9	26.5	21.2
mq-nu	11.2	2.6	9.3	13.3	12.7	0.7
pq2-3	2.6	9.5	5.6	6.3	6.0	5.8
pq>3	11.2	14.7	17.9	14.0	6.0	16.8
plag	7.2	3.4	3.7	4.9	7.2	4.4
kspar	0.0	0.0	0.0	0.0	0.0	1.5
micor	0.0	0.0	0.0	0.0	0.0	0.7
musc	2.6	3.4	2.5	0.7	1.8	0.7
acces	0.0	1.7	0.6	3.5	0.6	2.2
plut	0.0	0.0	0.0	0.0	0.0	0.0
volc	10.5	1.7	10.5	8.4	19.9	8.0
chert	11.8	18.1	21.0	27.3	16.3	14.6
meta	2.6	7.8	1.2	0.7	1.2	16.1
folch	1.3	2.6	0.6	2.1	1.8	7.3
other	0.0	0.0	0.0	0.0	0.0	0.0
chlor	0.0	23.5	0.0	0.0	0.0	25.4
cal	68.8	41.2	47.4	78.9	76.5	55.6
phyl	0.0	0.0	13.2	14.0	0.0	0.0
fe2o3	31.3	35.3	39.5	7.0	23.5	19.1

Upper Kuliak Bay (Hemlock Conglomerate?)

sam#	4-487-L25	4-523-L7	4-593-L8	4-633-L9	4-645-L10	4-662-L11
qtz	47.2	56.2	56.8	28.6	46.9	42.4
fsp/p	11.7	6.5	11.5	34.9	10.1	8.4
rocks	41.1	37.3	31.7	36.6	43.0	49.2
plut	0.0	0.0	0.0	0.0	2.5	0.0
volc	52.2	57.1	61.4	87.5	57.0	78.7
meta	47.8	42.9	38.6	12.5	40.5	21.3
det	86.0	88.0	71.5	88.5	90.5	96.5
cem	14.0	12.0	28.5	11.5	9.5	3.5
mq-u	26.7	21.0	30.1	27.7	8.3	19.7
mq-nu	8.1	2.8	9.8	0.0	6.6	6.7
pq2-3	1.7	8.0	5.6	0.0	4.4	2.1
pq>3	8.1	22.2	9.8	0.6	27.1	13.5
plag	11.0	3.4	11.2	34.5	8.8	8.3
kspar	0.0	2.3	0.0	0.0	0.0	0.0
micor	0.0	0.6	0.0	0.0	0.0	0.0
musc	4.1	1.7	2.1	0.0	1.1	0.0
acces	1.2	1.7	0.7	1.1	0.0	1.0
plut	0.0	0.0	0.0	0.0	1.1	0.0
volc	20.3	20.5	18.9	31.6	24.9	38.3
chert	15.7	7.4	11.2	4.0	13.3	9.8
meta	1.2	5.1	0.0	0.0	1.1	0.5
folch	1.7	2.8	0.7	0.6	3.3	0.0
other	0.0	0.6	0.0	0.0	0.0	0.0
chlor	0.0	83.3	0.0	0.0	0.0	0.0
cal	64.3	0.0	71.9	73.9	52.6	42.9
phyl	7.1	0.0	0.0	17.4	0.0	0.0
fe2o3	28.6	16.7	28.1	8.7	47.4	57.1

Upper Kuliak Bay (Hemlock Conglomerate?)

sam#	4-684-L12
qtz	59.9
fsp/p	22.2
rocks	18.0
plut	0.0
volc	43.3
meta	56.7
det	92.0
cem	8.0
mq-u	25.0
mq-nu	1.1
pq2-3	6.0
pq>3	22.3
plag	17.4
kspar	2.7
micor	0.0
musc	8.7
acces	0.5
plut	0.0
volc	7.1
chert	4.3
meta	3.8
folch	1.1
other	0.0
chlor	43.8
cal	0.0
phyl	0.0
fe2o3	56.3