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DEPOSITIONAL ENVIRONMENTS AND RESOURCE POTENTIAL OF CRETACEOUS COAL-BEARING STRATA AT CHIGNIK AND HERENDEEN BAY, ALASKA PENINSULA

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ABSTRACT

Cretaceous (Campanian to Maestrichtian) coal-bearing strata occur on the Alaska Peninsula southwest of Wide Bay and extend to Pavlof Bay. The depositional succession consists of the lower member of the Chignik Formation, the Coal Valley Member (middle member, Chignik Formation), the upper member of the Chignik Formation, and the Hoodoo Formation.

Burk (1965) and Mancini and others (1978) have published their respective interpretations of the depositional environments of these formations. Burk suggests that deposition of nonmarine sands of the Coal Valley Member through the nearshore sediments of the Chignik Formation and the deep-water marine Hoodoo Formation represents a marine transgression. Mancini and others (1978) interprets these units as coeval sedimentary facies deposited in different environments: 1) alluvial fan to flood plain (Coal Valley Member); 2) inner-neritic (upper and lower shoreface) continental shelf (Chignik Formation); and 3) outer-neritic continental shelf to bathyal continental slope (Hoodoo Formation). Additional field work by the authors suggests that both previous interpretations should be combined. Upper and lower shallow-marine facies of the Chignik Formation represent transgressive events separated by the nonmarine Coal Valley Member, a regressive phase. The interrelationship of these units indicates that the Coal Valley Member was deposited simultaneously with individual marine facies of the Chignik and Hoodoo Formations in three different environments. This simultaneous, intermediate depositional phase was followed with onlap (transgression) by the upper member Chignik and Hoodoo Formations. This interpretation is supported by

field evidence of lateral interfingering of the sediments and by gradational vertical contacts.

The depositional environment for the sediments of the Coal Valley Member is nonmarine flood plain and alluvial fan. There are indications that marine conditions were nearby and salt-marsh and delta deposition may have taken place. If depositional environments were the same or similar elsewhere in the Late Cretaceous, thick coal accumulations probably cannot be expected to occur in covered areas on the Alaska Peninsula.

Coal resource estimates were computed for two areas within the Coal Valley Member trend. These areas, Herendeen Bay and Chignik Bay contain most of the known potential for commercial coals on the Alaska Peninsula. Resource estimates approach 360 million metric tons in beds 0.9-m or more in thickness.

INTRODUCTION

Rocks of the Upper Cretaceous Chignik Formation, the Coal Valley Member of this formation, and the Hoodoo Formation are exposed in a long, narrow, southwest-to-northeast trending belt on the Alaska Peninsula between Pavlof Bay and Wide Bay (Figure 1). The Herendeen Bay and Chignik coal fields are located about 160 km apart. Herendeen Bay field lies on the Bering Sea side of the Alaska Peninsula about 560 km southwest of Kodiak. The Chignik field lies on the west shore of Chignik Bay about 400 km southwest of Kodiak. Both fields are located on or near tidewater, being accessible to year-round ice-free water transportation. About one-third of the Herendeen Bay field lies on Aleut Native Corporation lands with the remainder, including the original discovery sites of Cretaceous coals at Mine and Lawrence Creeks, on State lands. Almost all of the Chignik field lies on Bristol Bay Native Corporation lands. Cretaceous coal-bearing rocks occupy at least 130 square kilometers in each coal field. The chief coal occurrences in the Herendeen Bay field are Mine Creek (Mine Harbor area), Coal Bluff, Coal Valley and east of Coal Valley, Lawrence Valley, and Coal Point (Figure 2). The four main occurrences of the Chignik field are Chignik River, Whalers Creek, Thompson Valley, and Hook Bay.

Figures 1-3---NEAR HERE

Coal was first discovered along the banks of the Chignik River in 1885. In 1893, the Alaska Mining and Development Company opened a small coal mine on Anchorage Bay near Chignik Lagoon, and the Alaska Packer's Association opened the Chignik River Mine to produce coal for the local fish cannery and for steamers. The Chignik River Mine operated until 1911. Between 1889 and 1904 several attempts were made to mine coal in the Herendeen Bay field (including at Mine Harbor), and between 1900 and 1915 other small mines or prospects opened in the Chignik field at Thompson Valley, Whalers Creek, and Hook Bay. Since this turn-of-the-century mining activity, no significant development in the fields has occurred.

PURPOSE

The purpose of this paper is to examine areas where the Chignik Formation and the Coal Valley Member are exposed with two specific objectives: 1) to establish a model for the deposition of the nonmarine sequence of rocks in order to identify the geometry and continuity of coal beds within the Coal Valley Member; and 2) to determine the coal resources for selected areas within the overall region of Cretaceous deposition.

SCOPE OF FIELD WORK COMPLETED

Initial field investigations were completed over the time period of July 9 to July 14, 1977 by D.L. McGee. Support was by helicopter based at a camp near Bear Lake. The limited time in the field for this expedition prevented extensive examination of areas outside the Herendeen Bay and Chignik Bay coal areas although coal-bearing Tertiary outcrops were examined on Unga Island and elsewhere as time allowed. R.D. Merritt returned to the region from August 1 to August 25, 1984 and re-examined Cretaceous and Tertiary coal-bearing outcrops of the Chignik, Herendeen Bay, and Unga Island fields. (The Unga Island coal deposits will be discussed in a future paper.) Helicopter and fixed-wing support were provided from base stations established at Sand Point, Port Moller, and Chignik. Additional research on coals of the region is in progress.

ACKNOWLEDGMENTS

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STRATIGRAPHIC RELATIONSHIPS

Mancini and others (1978) suggested that the Chignik Formation, Coal Valley Member of the Chignik Formation, and the Hoodoo Formation are sedimentary facies deposited in different environments. This concept is supported in the field where nonmarine beds of the Coal Valley Member grade laterally into marine beds very similar to the upper part of the Chignik Formation (Figure 4).

Figure 4---NEAR HERE

However, Burk (1965) suggests that the Chignik Formation, at the base of the transgressive sequence which includes the Hoodoo Formation, unconformably overlies rocks as old as Kimmeridgian (Late Jurassic) and as young as late Neocomian (Early Cretaceous) exhibiting only minor depositional overlap on the outer Alaska Peninsula. Thus, Burk believes the Chignik and Hoodoo Formations represent a regional transgression.

Where seen in the field the upper member of the Chignik Formation appears to be transitional into the Hoodoo Formation and the Coal Valley Member of the Chignik Formation grades into the upper Chignik Formation. This suggests that a regional transgressive event did occur but that it was preceded by the coeval deposition of the Coal Valley Member (alluvial fan and flood plain), Chignik Formation (neritic) and Hoodoo Formation (outer continental shelf to bathyal continental slope) as proposed by Mancini and others (1978).

The lithologic inconsistencies recognized by Burk (1965) and elaborated on by Mancini and others (1978) include coal stringers in the middle of the marine Chignik Formation; marine beds in the Coal Valley Member; lack of a well-defined Coal Valley Member in certain areas; intertonguing of Hoodoo Formation, marine Chignik Formation, and nonmarine Coal Valley Member; and gradational change in a vertical sense all seem easiest to rectify using the depositional model developed in this paper.

The Hoodoo Formation thickens rapidly to the south of Herendeen Bay and may represent deposition in an embayment and a longer period of deep-water sediment accumulation. This is consistent with and supports a Late Cretaceous transgression.

STRATIGRAPHY

The general succession of Cretaceous rocks in both the Chignik and Herendeen Bay fields (Figure 5) is underlain by the Upper Jurassic Naknek Formation, which includes a monotonous sequence of hard, dense, fine-grained, and massive siltstones with pelecypods of Buchia, pecten, and gastropods. Gray, quartzo-feldspathic, belemnoid-bearing, fine-grained, arkosic sandstones and local thin conglomerates are interbedded with the siltstones. The Late Jurassic to Early Cretaceous age Staniukovich Formation unconformably overlies the Naknek Formation. The Staniukovich Formation is over

Figure 5---NEAR HERE

300-m thick and is composed of distinctive light-tan to brown-weathering interbedded sandstones, conglomerates, and siltstones with occasional interbeds of shale. In the Herendeen Bay field, the Staniukovich Formation is overlain unconformably or is in thrust contact with the Chignik Formation. The Herendeen Limestone is composed of light arenaceous, resistant, cross-bedded limestone and is about 250-m thick at its type locality, Herendeen Bay (Burk, 1965; Vorobik and others, 1981).

In general, the Chignik Formation consists of a lower marine shale unit and an upper unit that is also mainly shale but also includes some conglomerate and sandstone. The upper unit is generally representative of a marine transgression but also shows evidences of oscillations from marine to continental conditions. The middle unit of the Chignik Formation is the Coal Valley Member which contains many coal beds interlayered with shale, sandstone, and conglomerate. An unconformity at the top of the Coal Valley Member probably represents only a minor depositional hiatus. Representative measured and correlated stratigraphic sections from the Herendeen Bay and Chignik fields are shown in figures 6 and 7 respectively.

Figures 6 and 7---NEAR HERE

The Chignik Formation measured by Burk (1965) near Staniukovich Mountain is considered to be in excess of 480-m thick and essentially consists of 120 m of gray and tan friable sandstones and siltstones (at the top) commonly containing pelecypods and carbonaceous plant remains. The lower 360 m is the type section of the Coal Valley Member which in this area consists of 120 m of conglomerate, medium gray to tan and brown, containing volcanic and chert clasts. This unit is underlain by approximately 150 m of gray-green sandstone and siltstone, locally very clayey and carbonaceous with rare thin lenticular seams of coal. The basal unit of the Coal Valley Member is about 90-m thick over a wide area and contains thin coal beds (Figure 8). This unit (essentially unit no. 8 of Burk's Staniukovich Mountain section) is composed of sandstone, siltstone and claystone, predominantly light gray and tan weathering to mottled light brown, reddish brown and tan. The sandstone units are mostly easily friable and grain size is predominantly fine. No marine fossils were noted although numerous intervals contain carbonaceous plant fragments.

Figure 8---NEAR HERE

In the Chignik Bay area north of Thompson Canyon, a sandstone unit, possibly equivalent to the basal unit as described above, was measured (section 7, Figure 7). The bottom of this unit is covered and the top grades into a massive conglomerate. This unit, which is about 140-m thick, contains two coaly intervals separated by 75-m of sandstone and siltstone that contains only a few discontinuous lenses of coal. The unit is thinner and does not contain the upper coal interval in the Chignik Lagoon area to the south of Thompson Canyon apparently because of erosion of the top of the unit.

The Hoodoo Formation, whose type section was originally measured southeast of Hoodoo Mountain and along the west side of Beaver Valley, consists of over 300 m of black siltstone that is highly fractured and weathers into prismatic slivers. An outcrop view of the typical Hoodoo Formation rocks is shown in figure 9. Minor interbeds of dark-gray claystone and tan fine-grained sandstone occur in the black siltstone. Burk (1965) also noted the presence of coarse conglomerates and concluded that these may be related to turbidite deposition.

Figure 9---NEAR HERE

STRUCTURAL GEOLOGY AND REGIONAL TECTONISM

The structure of the Chignik Bay and Herendeen Bay coal fields has been dominated by convergent plate tectonics and arc-trench development, which have resulted in continuous uplift and erosion of plutonic rocks in source regions and subsequent deposition of marine and nonmarine arkose, sandstone, and claystone in subsiding basinal depocenters (Vorobik and others, 1981). Arc-building was initiated on the Aleutian margin by the emergence of an Early Jurassic magmatic arc along the northern edge of the present Alaska Peninsula (Figure 1). Moore and Connelly (1977) identified three periods of magmatic arc and subduction complex activity and infer that plates were mobile from Late Triassic to Paleocene time. Although Burk (1965) and Moore and Connelly (1977) have slightly differing views on the time of onset of convergence in the Alaska Peninsula region, the result of tectonism from Jurassic time onward is well recorded in the stratigraphic sections in the Chignik Bay and Herendeen Bay areas (Vorobik and others, 1981).

The general structure of the Chignik district is that of a moderately to complexly folded rock mass in which the structural components consist of relatively small tilted (dips 20° to 35°) blocks separated by faults or zones of shattering. The dominant trend of faults and major folds is subparallel to the long axis of the Alaska Peninsula, that is, generally slightly north of east (Martin, 1925; Resource Associates of Alaska, 1980).

The first of three major periods of deformation of Upper Cretaceous Chignik Formation rocks in the Chignik Bay area involved penecontemporaneous small-scale, low-amplitude folding in the lower but not upper part of the Chignik Formation. The second deformational period subjected most of the Jurassic and Cretaceous age sediments to intense compressional foreshortening. The most conspicuous structural feature of this period in the Chignik area is the Chignik anticline and overthrust complex (Figure 3). Moderately- to highly-deformed Naknek Formation rocks have been anticlinally arched and thrust southeastward over Cretaceous Chignik and Hoodoo Formations. The strike of the Chignik thrust and anticline is subparallel to the dominant structural trend throughout the Chignik area. The main coal outcrops occur on the southeast limb of this major northeast-trending anticline in a belt of rocks about 40 km long and 1.5 to 5 km wide. Chignik Formation coal-bearing rocks crop out to a limited extent on the north flank of the Chignik anticline. Here they are steeply dipping (to 45°) and are of low coal potential because of the discontinuity and thinness of coals and their intimate association with intrusive rocks. The third deformational event involved local high-angle normal transverse faults. These faults evidently resulted from late tensional adjustment within the Chignik rocks that post-dates the anticlinal arching and is probably a brittle response to a shift in the compressional vector of the convergent plate motion (Vorobik and others, 1981).

The Chignik River coal occurrence is structurally complex with pinching and swelling of beds and displacement by high-angle faults. Beds strike N. 2°E. and dip 24°E. The same coal that crops out at Chignik River is exposed along the northernmost three main branches of Whalers Creek, a stream entering Chignik Lagoon from the north a short distance below the mouth of Chignik River. The beds on Whalers Creek strike N. 5°E. and dip 22°E. The coal beds exposed on the northeast side of Thompson Valley 3.2 km north of Chignik Bay strike N. 60°E. and dip 10° to 18° NW (Figure 10). The coals occur in two horizons separated by a 12-m thick sandstone. The more extensive lower horizon supported the Thompson Valley Mine (Figure 11). The continuity and attitude of the Thompson Valley beds are disturbed by minor faults and flexures. The coal-bearing section 11.3 km northwest of Hook Bay strikes N. 10°E. and dips 35°E. and includes several lenticular seams (Figure 12).

Figures 10-12---NEAR HERE

Generally, the Herendeen Bay field contains coal-bearing strata moderately folded and broken by several small faults. The Chignik Formation and underlying older sedimentary rocks of an area in the Herendeen Bay field are folded into a syncline with the axis approximately paralleling the valley of Mine Creek but displaced slightly north in the eastern part of the drainage. The plunge of the structure is gentle and where measured less than 7°. The syncline is asymmetrical with dips off the north limb ranging from 10° to 18° and from 20° to 37° on the south limb. The south limb has been cut by a fault of 300 m displacement and is broken into blocks by at least three major strike-slip faults which trend almost due north. On one of these faults, a coal bed has been displaced 75 m along the strike of the fault. Numerous minor faults paralleling the major fault systems have displacements as much as several meters. Most of the coal potential in this area lies on the north limb of this synclinal structure (Gates, 1944). Outcropping coal beds are generally less than 0.6-m thick, but include several 0.9-m thick beds and a few 1.5- to 2.5-m thick beds (Figures 13 and 14).

Figures 13 and 14---NEAR HERE

In the Coal Point area on the west side of Herendeen Bay, both Cretaceous and Tertiary coals are exposed along a 6.5-km long beachcrop (Figure 2). A portion of this area is illustrated in the cross section of figure 15. Covered intervals from slumped materials and slope wash hamper conclusive unraveling of structural complications. However, a fault can be inferred near the middle of the section based on field relations and coal character. Coals on the south side of the fault are all lignites (presumably Tertiary, Bear Lake Formation--?) and coals on the north side are all high-volatile bituminous rank (presumably Cretaceous Coal Valley Member).

Figure 15---NEAR HERE

AGE COMPARISON OF THE CHIGNIK AND HOODOO FORMATIONS

Keller and Cass (1956) conclusively dated the Chignik Formation to be Late Cretaceous. The pelecypod *Inoceramus schmidti* occurs sparsely throughout the Chignik Formation but is most abundant near the upper boundary of the Coal Valley Member. The favored ecology for this fauna is in the neritic zone and suggests that the boundary between the Coal Valley Member and the basal part of the upper Chignik Formation (deposits above the Coal Valley Member) represents the Late Cretaceous sea onlap.

Burk suggests that the lower Chignik Formation is irregularly developed and locally absent. The unit can be deposited on any older rock unit and is thickest in those areas where depressions were present in the older rocks.

Nonmarine beds of the Coal Valley Member locally appear to grade laterally into marine beds characteristic of the upper part of the Chignik Formation and thus represent in part a facies of this formation. The lower and upper Chignik Formation contain features characteristic of both marine and nonmarine strata. In some areas the Coal Valley Member appears to thin and becomes absent through depositional overlap.

The Hoodoo Formation is the youngest Cretaceous age formation in the Herendeen Bay and Chignik fields. However, the Hoodoo Formation also appears to contain individual facies that are contemporaneous with the lower (at least in part), middle, and upper Chignik Formation (Figure 4).

PROVENANCE AND PALEOCURRENT DIRECTIONS

The source for the sedimentary rocks that comprise the Chignik and Hoodoo Formations is not definitely known. Burk (1965) suggested that the most convenient source for the Chignik Formation and Hoodoo Formation sediments is the coastal lowlands southwest of Wide Bay bordering the Bering Sea where the nature of the bedrock is entirely unknown and any past source is covered by Tertiary and Quaternary sediments.

Petrographic studies of rock samples of the Chignik Formation determined that the sandstones are composed of approximately 60 percent quartz and other siliceous grains, 30 percent feldspar grains and 10 percent lithic fragments. Sedimentary rocks of this composition are often associated with the decomposition of plutonic rocks. Rocks of this type that fit the proper time-space relationships are not obvious to the northwest of the study area although investigations of paleocurrents would suggest this area as one of two potential source areas (Figures 16 and 17). An alternative possible source, as suggested from a minimum number of field-determined current directions, is to the southeast in the area of the Shumagin Islands. The preferred source area and the one that more nearly fits the available data is to the north and northwest following the suggestions of both Burk (1965) and Mancini and others (1978). Twenty seven paleocurrent events were measured in the Herendeen-Port Moller area followed by thirty four paleocurrent events in the Chignik Bay area. Plots of these data were similar for the two areas. All events were corrected for the dip of the sediments and the following conclusions were drawn: 1) the spread of the events suggests meandering low-energy drainage systems; 2) provenance based on limited data suggests either a northwest source or a source to the southeast; and 3) the bimodal aspect of the transport directions within the channel sandstones may be the result of sedimentation in channels that had minor tidal influence. However, the absence of burrowing above the scour base of the channels in the two areas is interpreted as an indicator of water conditions that were too fresh to serve as a satisfactory environment for marine and brackish-water burrowing organisms.

Figures 16 and 17---NEAR HERE

MODELING OF DEPOSITIONAL ENVIRONMENTS

The following diagnostic criteria were used to determine flood plain and alluvial fan (Coal Valley Member) and neritic (upper and lower members, Chignik Formation) environments: Flood plain/delta plain---lithologies are dominated by carbonaceous, argillaceous, very fine-grained sandstone to mudstone. Alluvial fan deposits are represented by heterogeneous, coarse-grained, poorly sorted, and variously sized sediment wedges rapidly thinning downdip. Channel margin environments apply to swamps, lakes and crevasse splays on a delta plain (Table 1), and are roughly equated with subsidence and sedimentation in fresh-water marshes, swamps, lakes, and splays that occur between channels on the delta plain. Cycles of sediment influx are followed by periods of subsidence and reduced sediment influx typical of a delta plain. Shallow marine neritic environments---lithologies are dominated by very friable, well-sorted, fine-grained sandstone (usually quartz arenites or arkosic subgraywackes), siltstone, claystone, and conglomerate. The gray to grayish brown siltstones and claystones form the finest-grained facies. They commonly grade from argillite to coarse sandy siltstones, are more thickly and continuously bedded than similar lithologies in channel-margin environments, and often contain plant fragments or marine fossils. The conglomerate facies, considered to be representative of a large distributary system active during Late Cretaceous time, form northwest-southeast trending channels that both scour and rest conformably upon sandstones and siltstones (Vorobik and others, 1981).

Table 1---NEAR HERE

The depositional environment for the Coal Valley Member of the Chignik Formation is probably correctly assigned to the valley flat or flood plain. Discussions of coal-bearing strata that formed in similar or analogous near-marine alluvial plain and fan environments can be found in Galloway and Hobday (1983) and Horne and others (1978), for example. In this environmental setting, there were many small shallow lakes and discontinuous swamps. Coal Valley Member sediments are fairly well sorted and stratified and contain abundant organic matter.

Three different types of relatively deep-water deposition are represented by the prodelta Hoodoo Formation---deep neritic, bathyal, and abyssal. The Chignik Formation (upper and lower members) represents delta front sedimentation. The active neritic part of this unit is the destructive part where waves and current action prevented retention of stratigraphic structures. The delta plain is represented by sediments of the nonmarine Coal Valley Member---a complex of swamps, lakes, channels, splay deposits, and to the west alluvial fans as indicated by deposits of coarse-grained sediments and conglomerates.

The most likely mechanism of deposition for part of the Coal Valley Member is sedimentation from a stream(s) migrating over its flood plain and depositing clayey and silty sands unconformably over valley flat, channel, and swamp deposits. This explains in part some of the lateral variations in stratigraphy. In addition, there is evidence in several areas of channel erosion into coal-bearing sediments following which the channel filled and further lateral migration of this particular channel did not occur.

Most of the coals in the Coal Valley Member were developed as the result of preservation of swamps formed on flat and gently sloping areas (Figure 18). Although the swamps were numerous, their lateral extents were limited. Vorobik and others (1981) found that the Coal Valley Member in the Chignik area rested on a 6- to 12-m thick, distinctive arkosic to quartzose platform sandstone (which they referred to as the DBS sandstone, see Figure 19) which in turn overlay conformably the lower Chignik Formation greenish-colored sandstones and conglomerates. They believe that it was on this stable platform surface that the thickest coals and carbonaceous siltstones were deposited. Basins developed locally on these platforms between interdistributary levees and were associated with the stage of the regressive cycle that was operative in any one portion of the Chignik area at any given time.

Figures 18 and 19---NEAR HERE

Because of the typically low sulfur content of the coals (Conwell and Triplehorn, 1978), the ancient coal-forming environments are believed to have been mainly fresh water swamps. Marine swamps may have developed at or near the littoral zone essentially separating the Coal Valley Member from the marine Chignik Formation. These swamps may have developed in lagoons behind barrier islands or in restricted basins between interdistributary levees.

There is little evidence to suggest that conditions were favorable for coal formation during the onlap of upper Chignik Formation sediments. Swamps were undoubtedly formed and then destroyed by the encroaching marine sediments. The presence of rare thin coal seams in the upper Chignik Formation suggests periods of hesitation during which peat areas were preserved by deeper burial.

The particular depositional relationships of the Chignik Formation with the Coal Valley Member, Hoodoo Formation, and older rocks (Herendeen Limestone, Staniukovich, and Naknek Formations) in any specific area include: 1) Coal Valley Member lying on older rocks; 2) Chignik Formation lying on older rocks; 3) Hoodoo Formation lying on older rocks; 4) Coal Valley Member interfingering laterally into the marine Chignik Formation; 5) Coal Valley Member grading vertically into the marine Chignik Formation; and 6) Chignik Formation interfingering laterally or grading vertically into the Hoodoo Formation. The fact that the contact between the Coal Valley Member and the Hoodoo Formation was not seen in the field suggests that the marine Chignik Formation served as a barrier between the Hoodoo Formation and the nonmarine Coal Valley Member.

To satisfy the above relationships, it is easiest to interpret the age of the Coal Valley Member as being equivalent to that of coeval facies of the marine Chignik (neritic) and Hoodoo Formations (outer neritic continental shelf to bathyal continental slope). During this phase, simultaneous deposition was occurring in three distinct environments in three areally different regions (Figure 18).

SUMMARY OF ENVIRONMENTS OF DEPOSITION

The depositional environment of the lower part of the Coal Valley Member is representative of broad alluvial plains cut by meandering distributary levees and includes valley flat (flood plain), paludal (swamp), and lacustrine (shallow lake) deposits (Figure 20). However, the increase of conglomerates in the upper part of the depositional sequence suggests that the distance to the source area was decreasing during deposition of the upper part of the Coal Valley Member or that the source area was more active and shedding coarse material forming coalescing alluvial fans (piedmont environment).

Chignik Formation---Rocks of the Chignik Formation (upper and lower members) were deposited in a mixed continental and marine environment. Their deposition was predominantly in the zone of shallow littoral to inner neritic. However, along the paleocoast deposition was also in marginal lagoons, estuarine, and delta facies.

Figure 20---NEAR HERE

Hoodoo Formation---Sediments of the Hoodoo Formation were deposited in an outer neritic to bathyal environment. The sediments are generally composed of silt-size particles, but there are fine-grained sandstone, shale, and claystone interbedded with the siltstone. Some of the sandstone is associated with coarse conglomerate and is present in the fine-grained clastics. Both Burk (1965) and Mancini and others (1978) interpret the conglomeratic sandstone as a turbidite deposit.

The most favorable environment for the deposition of coals is restricted to the finer-grained sediments of the Coal Valley Member. These are flood plain deposits and occur in a relatively narrow belt between the marine sediments and coarser fan deposits that represent a terrane where the streams had higher gradients. Parts of the mixed continental and marine environments were also favorable for the accumulation and preservation of organic material. Thin coals in the marine Chignik Formation were associated with estuarine, delta, and salt marsh deposition.

GEOMETRY OF COAL SEAMS

A series of detailed stratigraphic sections were measured in Herendeen-Moller Bay areas (Figure 6) and the Chignik Bay area (Figure 7). These sections cover the lower part of the Coal Valley Member and were measured from the base of the Coal Valley Member upward to the base of the first massive conglomerate. This interval contains most of the potentially commercial coal for the two areas. Correlations between individual coal seams is difficult and it is necessary to correlate using gross carbonaceous coaly intervals. In the field it was found that individual coal seams vary considerably in thickness over short lateral distances. The large number of thin coal seams suggest there were many individual areas of peat accumulation and that conditions were never stabilized long enough for a thick bed of peat to form. Thick coal accumulations cannot be expected to occur in covered areas if depositional environments were the same or similar elsewhere in the Upper Cretaceous.

COAL QUALITY

Cretaceous coals of the Herendeen Bay and Chignik fields are predominantly high-volatile bituminous (Table 2). They generally range from 10,000 to 11,500 Btu/lb and have a typically high ash content (averaging about 20 percent). The coals are comparable in quality to bituminous coals of the Matanuska Valley, Alaska. The high ash content will necessitate beneficiation by coal washing. Washability tests have shown that a finished product with less than 10 percent ash and greater than 12,000 Btu/lb can be prepared (Conwell and Triplehorn, 1978). Other analyses have shown that the coals do not hold high concentrations of any elements that would volatilize on combustion and be environmentally deleterious.

Table 2---NEAR HERE

COAL RESOURCES

Conwell and Triplehorn (1978) indicate the possibility of several 30 km^2 blocks with 55 million metric tons of coal each at a 75 percent recovery in beds 0.9- to 2.5-m thick. In the Chignik field, Resource Associates of Alaska, Inc. (RAA, a subsidiary of NERCO Minerals Co.) defined three relatively small resource areas (Vorobik and others, 1981). These include: 1) about 6 million metric tons of measured or indicated coal resources contained in two 1.8-2.0 m horizons in the northern Chignik Bay area; 2) about 135,000 metric tons hosted in a 1.7-m thick zone in the Diamond Point area (Figure 21); and 3) an additional 4.5 million metric tons were postulated to be present in the structurally complex Chignik River area. Detterman and others (1984) estimate inferred total coal resources in the Chignik and Sutwik Island quadrangles at 242 million metric tons and believe that as much as 150 to 160 million metric tons of this is recoverable.

Coal-resource estimates for this study were calculated based on the probable area and distribution of coal beds. Coal thicknesses were obtained from measured sections (Figures 6 and 7). Areas were based on the probable extent of coal beds as correlated with the weight given to the apparent geometry of individual coal beds. Coals with thicknesses in excess of 0.9-m were considered minimum required for surface mining activities. Resources are estimated to an overburden limit of 150 m only. In the Herendeen Bay area, total coal resources amount to about 125 million metric tons, whereas in the Chignik Bay area resources are estimated at about 230 million metric tons (Table 3).

Figure 21, Table 3---NEAR HERE

CONCLUSIONS

The field relationship between the Chignik Formation and the Hoodoo Formation suggests that the lower Chignik Formation was deposited by an initial marine transgression and that the nonmarine Coal Valley Member, marine Chignik and Hoodoo Formations in the middle stage of deposition were time equivalents, deposited in different paleoenvironments. These intermediate and coeval facies were covered by sediments of the upper Chignik Formation deposited by transgressive marine waters. Inner neritic sediments of the upper Chignik Formation were followed by deeper water and finer argillaceous sediments that now comprise the Hoodoo Formation.

The Coal Valley Member contains nearly all the potential commercial coal seams, and forms a narrow belt of mostly nonmarine sediments extending from southwest of Wide Bay to north of Pavlof Bay. The Coal Valley Member is not equally wide throughout its length but is restricted in width by marine embayments and other changes in the configuration of the Cretaceous beachline and by changes in the sediment source.

Much of the area where the Coal Valley Member is probably present in the subsurface is covered with younger Tertiary and Quaternary sediments. Thick overburden would preclude mining activities in these areas.

The Herendeen Bay and Chignik Bay areas were examined in detail in order to obtain data for a resource base study. Both areas contain many thin coal seams and have been mined in past years. The character and bed thickness of the coals in these areas suggest that thick coals with large lateral extent will not likely be encountered anywhere in Cretaceous sediments on the Alaska Peninsula. This does not preclude the possibility and likelihood of small mines being developed.

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FIGURE CAPTIONS

Figure 1...Distribution of Chignik and Hoodoo Formations on the Alaska Peninsula, and the general configurations of the Late Cretaceous tectonic framework and subduction complex (modified from Burk, 1965; and Mancini and others, 1978).

2...Generalized geologic map of the Herendeen Bay coal field, Alaska Peninsula.

3...Generalized geologic map of the Chignik coal field, Alaska Peninsula.

4...Possible relationship between the Chignik Formation, Coal Valley Member, and Hoodoo Formation (after Vorcbik and others, 1981).

5...Stratigraphic relationships of the Late Jurassic to Early Tertiary sedimentary rocks of the Alaska Peninsula (modified from Burk, 1965; Moore, 1974; and Mancini and others, 1978).

6...Herendeen Bay area correlation sections 1,2,3, and 4. See figure 2 for locations.

7...Chignik Bay area correlation sections 5,6,7, and 8. See figure 3 for locations.

8...Coal Valley Member section, Staniukovich Mountain area, Herendeen Bay field.

9...Marine siltstones and sandstones of the Hoodoo Formation in the Canoe Bay area of Alaska Peninsula.

10...Thompson Valley coal occurrence showing thin seams of the upper horizon.

11...Lower coal horizon at the Thompson Valley occurrence which formerly supported a small mine.

12...General view of coal-bearing section northwest of Hook Bay, Chignik coal field.

Figure 13...Outcrop section showing several thin lenticular coal beds on upper Mine Creek. View is generally west toward Mine Harbor at the southern end of Herendeen Bay.

14...Coal bed on lower Mine Creek near the site of early development and small-scale mining. Several other seams from 0.5- to 2.5-m thick occur at this locality.

15...Geologic cross section of Coal Point area, west side of Herendeen Bay, Alaska Peninsula. Average mean-maximum vitrinite reflectance of coal seams (Cretaceous bituminous coals) north of the fault is 0.66 percent and for coal beds (Tertiary lignites) south of the fault is 0.27 percent.

16...Herendeen Bay-Port Moller mixed paleocurrent data sets, 27 specific events. Refer to text for discussion.

17...Chignik Bay-Chignik Lagoon mixed paleocurrent data sets, 34 specific events. Refer to text for discussion.

18...Simultaneous phase of deposition---nonmarine Coal Valley Member, marine Chignik Formation and Hoodoo Formation.

19...Schematic block diagram of the Late Cretaceous paleogeography in the Chignik area. The subduction zone-trench complex was offshore to the southwest (modified slightly from Vorobik and others, 1981).

20...Depositional sequence of the Cretaceous Chignik and Hoodoo Formations. A-Depositional environment of the nonmarine Coal Valley Member, marine Chignik and Hoodoo Formations time-equivalent facies. B-Transgressive onlap of Cretaceous seas with deposition of upper Chignik and Hoodoo Formations. Source is less active and may be farther away.

21...Outcrop view of coal horizon in the Diamond Point area, Chignik field. Hand specimens of the coal show abundant pyrite.

Table 1. Summary of diagnostic criteria for channel margin and channel environments for the Coal Valley Member of the Chignik Formation.

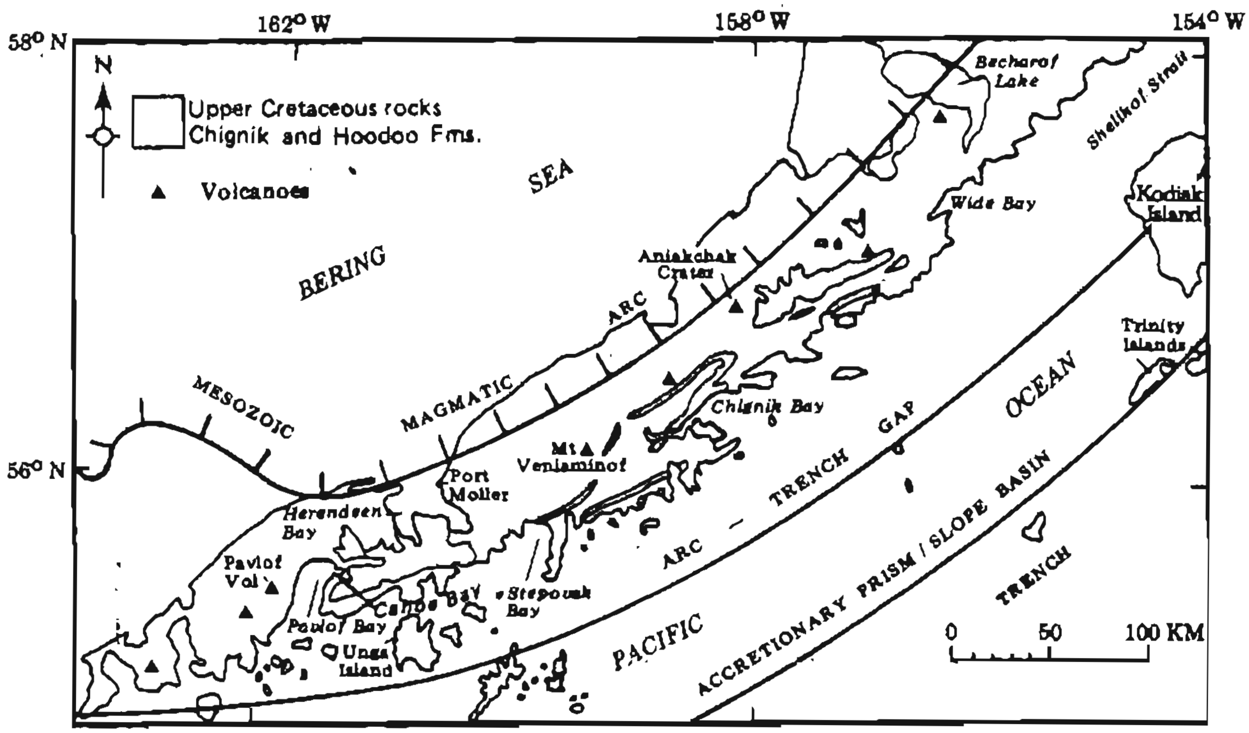
Environment	Lithology	Stratification	Fossils
Well-drained swamp	Light gray silty clay-stone	Massive	Vegetation imprints
Poorly-drained swamp	Mostly coal	Some laminated carbonaceous shale, cross-stratification at top	Carbonized plant remains, roots, burrows
Pseudo-splay	Brown, very fine-grained sandstone with carbonaceous material along bedding	Ripple, climbing-ripple, planar, wavy, and medium-scale trough cross-lamination common	Abundant plant debris
Channel	Brown, fine- to medium-grained sandstone with silty clay clasts near scour base. Some detrital coal fragments	Trough cross strata near base	Little evidence

Table 2. Summary of vitrinite reflectance data for coal samples from the Herendeen Bay and Chignik coal fields. The locality numbers refer to sampling sites on figures 2 and 3.

Region	Coal-Sampling Locality	No. of Samples	$\bar{R}o_{max}$	Apparent Rank
Herendeen Bay	1	6	0.66	hvCb
	2	10	0.27	lig
	3	5	0.67	hvCb
	4	1	0.62	subA/hvCb
	5	6	0.60	subA
	6	7	0.66	hvCb
	7	6	0.59	subA
	8	1	0.67	hvCb
	9	1	0.90	hvAb
	10	2	0.69	hvCb
	11	4	0.58	subA
	12	9	0.61	subA
	13	1	0.60	subA
	14	3	0.55	subA
Chignik	15	3	0.57	subA
	16	3	0.62	subA/hvCb
	17	3	0.62	subA/hvCb
	18	1	0.67	hvCb
	19	1	0.64	hvCb
	20	2	0.82	hvAb
	21	1	1.01	hvAb
	22	1	0.95	hvAb
	23	1	0.79	hvBb
	24	1	1.76	lvb
	25	1	0.58	subA
	26	2	0.62	subA/hvCb
	27	3	0.60	subA
	28	2	0.60	subA
	29	1	0.66	hvCb
	30	1	0.58	subA
	31	5	0.68	hvCb
	32	1	0.69	hvCb
	33	2	0.70	hvCb/hvBb
	34	1	0.71	hvBb
	35	1	0.78	hvBb
	36	1	0.60	subA
	37	6	0.66	hvCb
	38	1	0.65	hvCb
	39	1	0.65	hvCb
	40	2	0.70	hvCb/hvBb

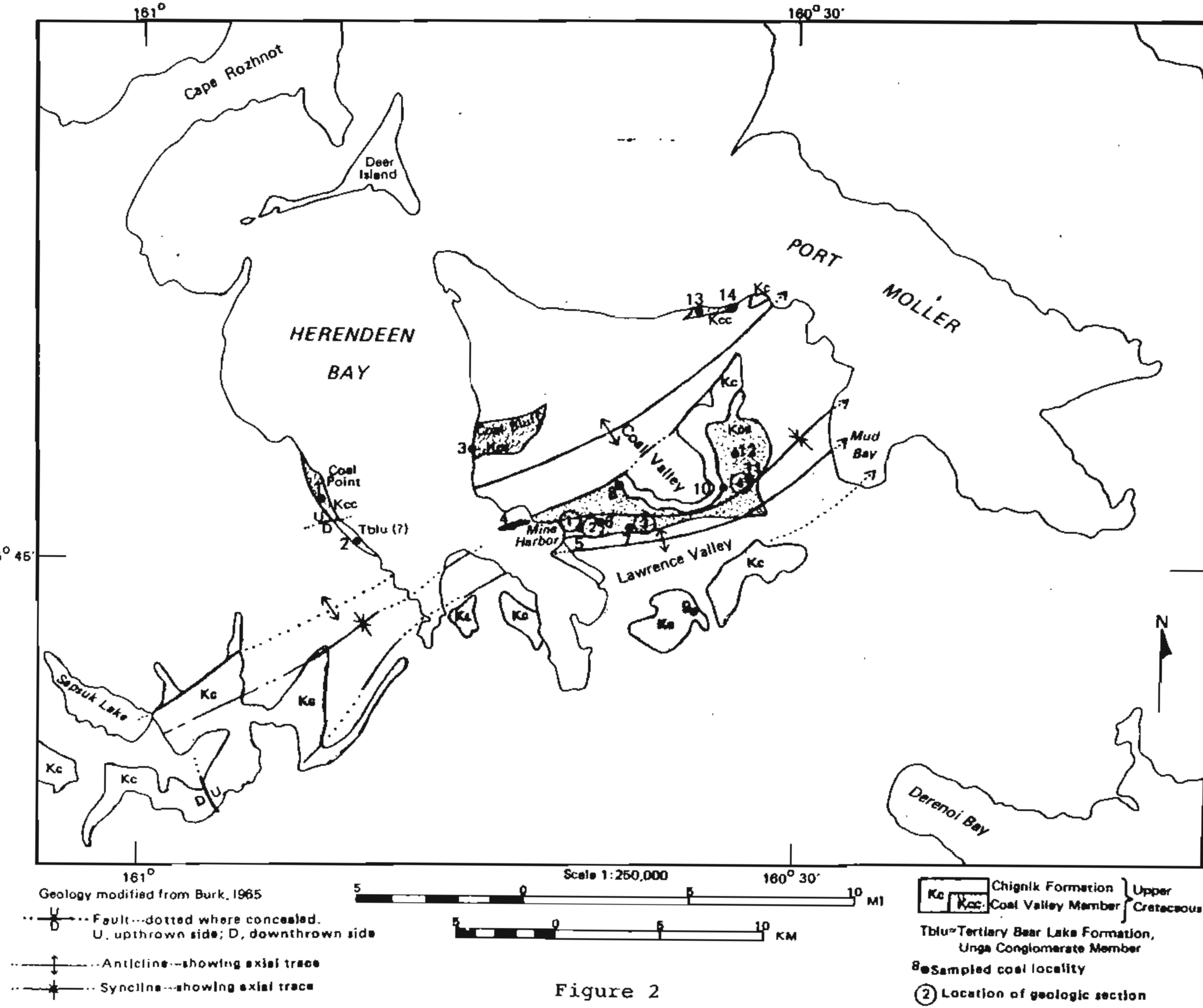
Table 3. Summary of coal resources of the Herendeen Bay and Chignik Bay areas, Alaska Peninsula. mm=million. N.E.=no estimate.

Region Area	Beds 0.3 m + (metric tons)	Beds 0.9 m + (metric tons)
Herendeen Bay		
Mine Harbor	125 mm	45 mm
Coal Bluff	50 mm	20 mm
Coal Point	100 mm	N.E.
Other areas	N.E.	65 mm
Subtotal	275 mm	130 mm
Chignik Bay		
Chignik Lagoon	84 mm	70 mm
Whalers Creek	40 mm	31 mm
Thompson Valley-Hook Bay	235 mm	129 mm
Northwest side of structural anticline	36 mm	N.E.
Subtotal	395 mm	230 mm
TOTAL	670 mm	360 mm



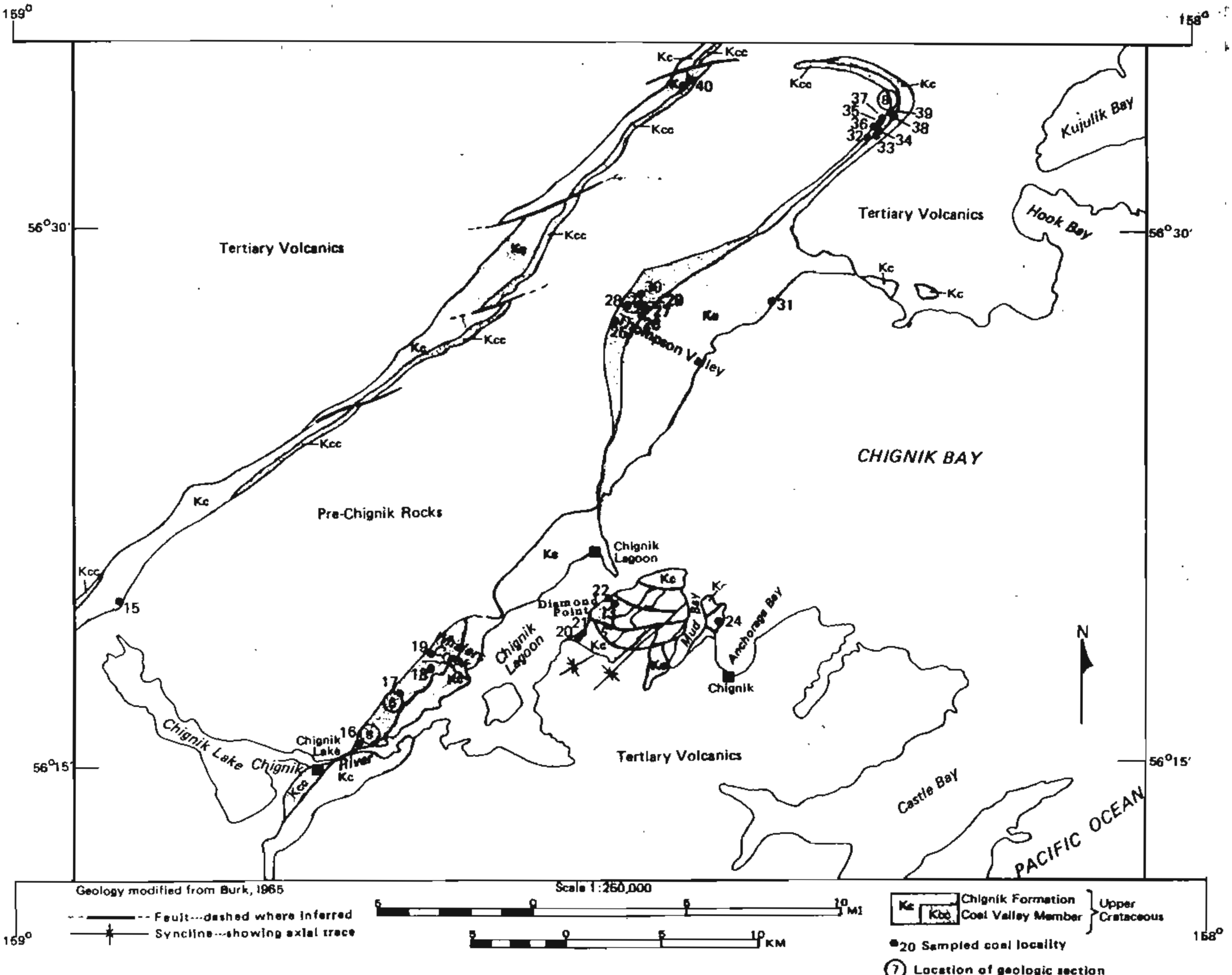
162° W
158° W
154° W
58° N
56° N
N
Upper Cretaceous rocks
Chignik and Hoodoo Fms.
Volcanoes
BERING
SEA
MESOZOIC
MAGMATIC
ARC
Becharof Lake
Shelikof Strait
Wide Bay
Kodiak Island
Aniakchak Crater
Trinity Islands
Chignik Bay
GAP
OCEAN
Mt Veniaminof
Port Moller
Herendeen Bay
Pavlof Vol
Canoe Bay
Stepovak Bay
Pavlof Bay
Unga Island
ARC – TRENCH
PACIFIC
ACCRETIONARY PRISM / SLOPE BASIN
TRENCH
0
50
100 KM

Figure 1



Cape Rozhnot
Deer Island
HERENDEEN BAY
PORT MOLLER
Coal Bluff
Kcc
Coal Valley
Kc
Mud Bay
Coal Point
Tblu (?)
Mine Harbor
Lawrence Valley
Sapsuk Lake
Derenoi Bay
161°
160° 30'
55° 45'
N
Scale 1:250,000
MI
KM
Geology modified from Burk, 1965
Fault---dotted where concealed. U, upthrown side; D, downthrown side
Anticline--showing axial trace
Syncline--showing axial trace
Chignik Formation
Coal Valley Member
Upper Cretaceous
Tblu=Tertiary Bear Lake Formation, Unga Conglomerate Member
Sampled coal locality
Location of geologic section

Figure 2



159°
158°
56°30'
56°15'
Tertiary Volcanics
Pre-Chignik Rocks
CHIGNIK BAY
Kujulik Bay
Hook Bay
Chignik Lagoon
Diamond Point
Mud Bay
Anchorage Bay
Chignik
Chignik Lake
Chignik River
Castle Bay
PACIFIC OCEAN
Kc
Kcc
N
Geology modified from Burk, 1965
Scale 1:250,000
MI
KM
Fault---dashed where inferred
Syncline---showing axial trace
Chignik Formation
Coal Valley Member
Upper Cretaceous
20 Sampled coal locality
7 Location of geologic section

Figure 3

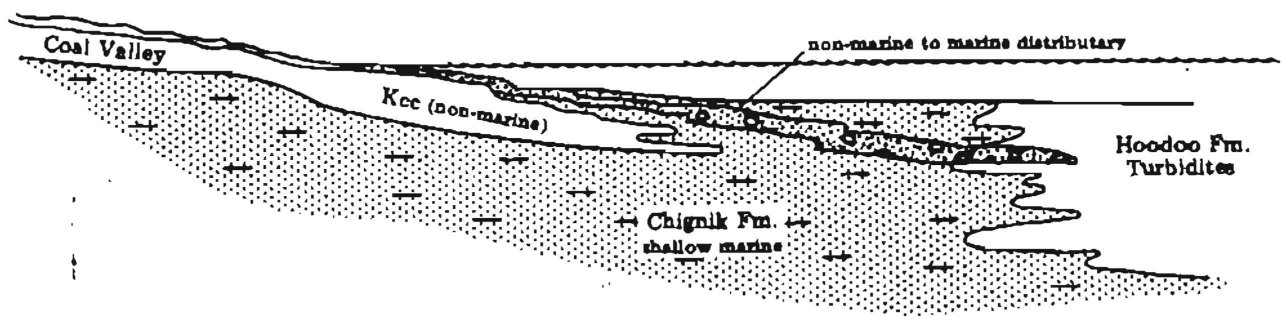

Coal Valley
Kcc (non-marine)
non-marine to marine distributary
Hoodoo Fm.
Turbidites
Chignik Fm.
shallow marine

Figure 4

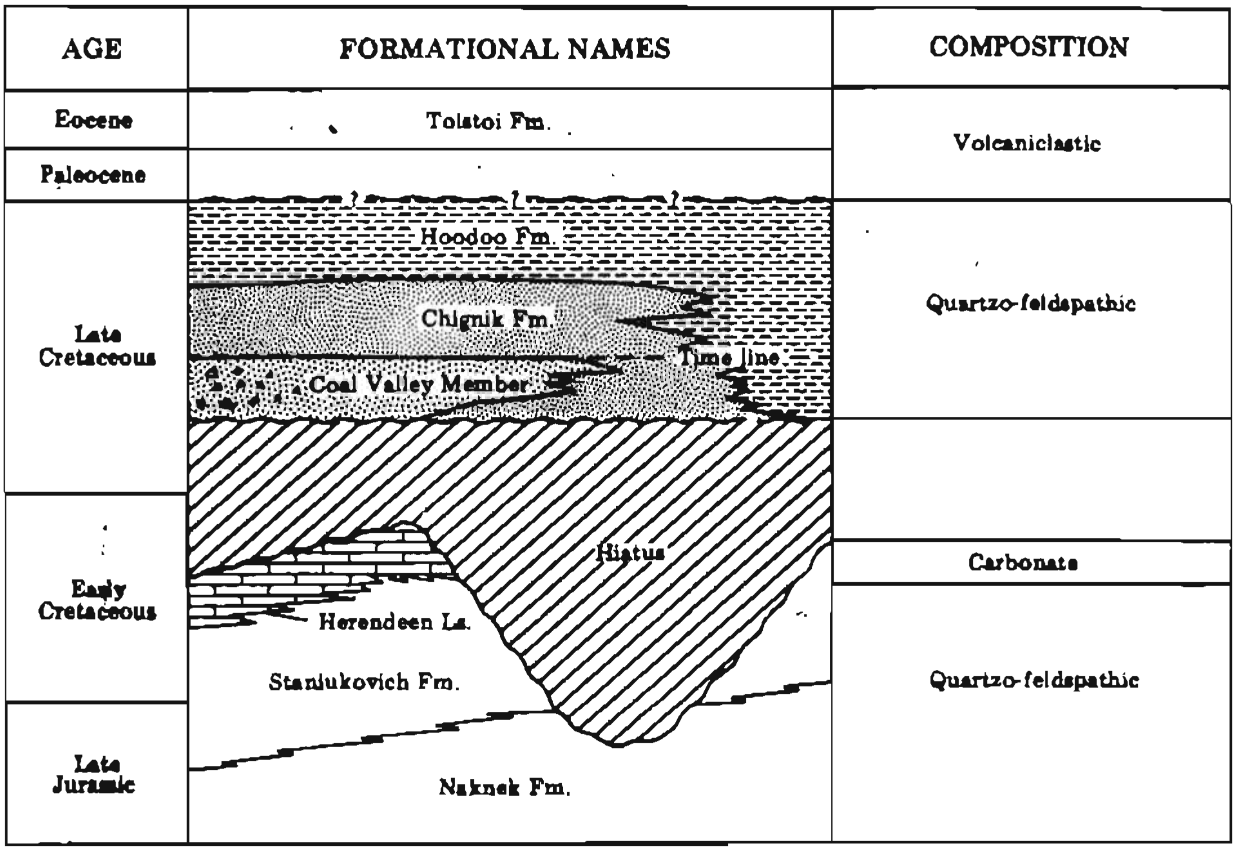
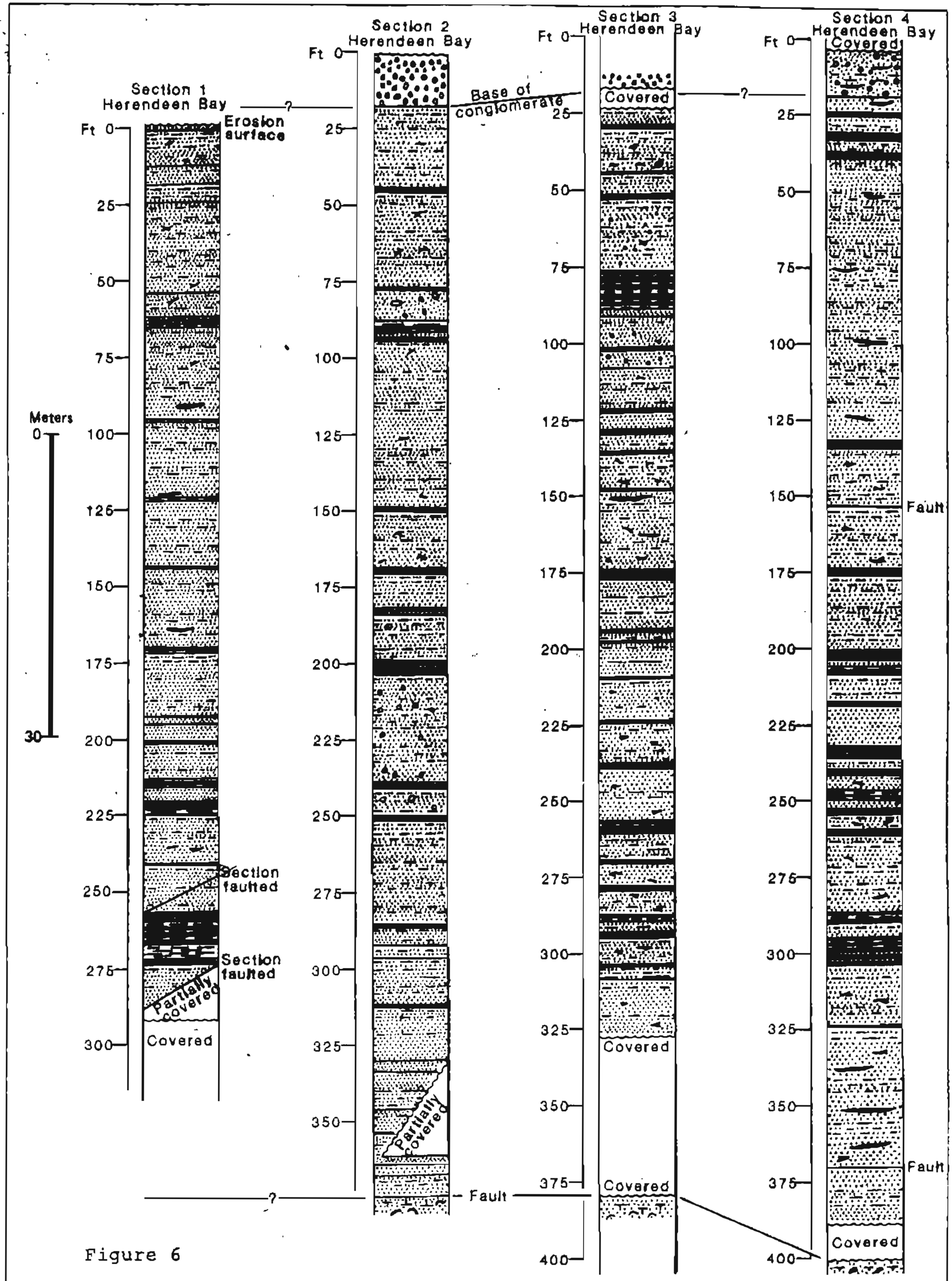

AGE
FORMATIONAL NAMES
COMPOSITION
Eocene
Tolstoi Fm.
Volcaniclastic
Paleocene
Hoodoo Fm.
Chignik Fm.
Time line
Coal Valley Member
Late Cretaceous
Quartzo-feldspathic
Hiatus
Carbonate
Early Cretaceous
Herendeen Ls.
Staniukovich Fm.
Quartzo-feldspathic
Late Jurassic
Naknek Fm.

Figure 5



Section 1
Herendeen Bay
Erosion surface
Section faulted
Section faulted
Partially covered
Covered
Meters
0
30
Ft 0
25
50
75
100
125
150
175
200
225
250
275
300
Section 2
Herendeen Bay
Base of conglomerate
Partially covered
Fault
Section 3
Herendeen Bay
Covered
Covered
Covered
Section 4
Herendeen Bay
Covered
Fault
Fault
Covered
400

Figure 6

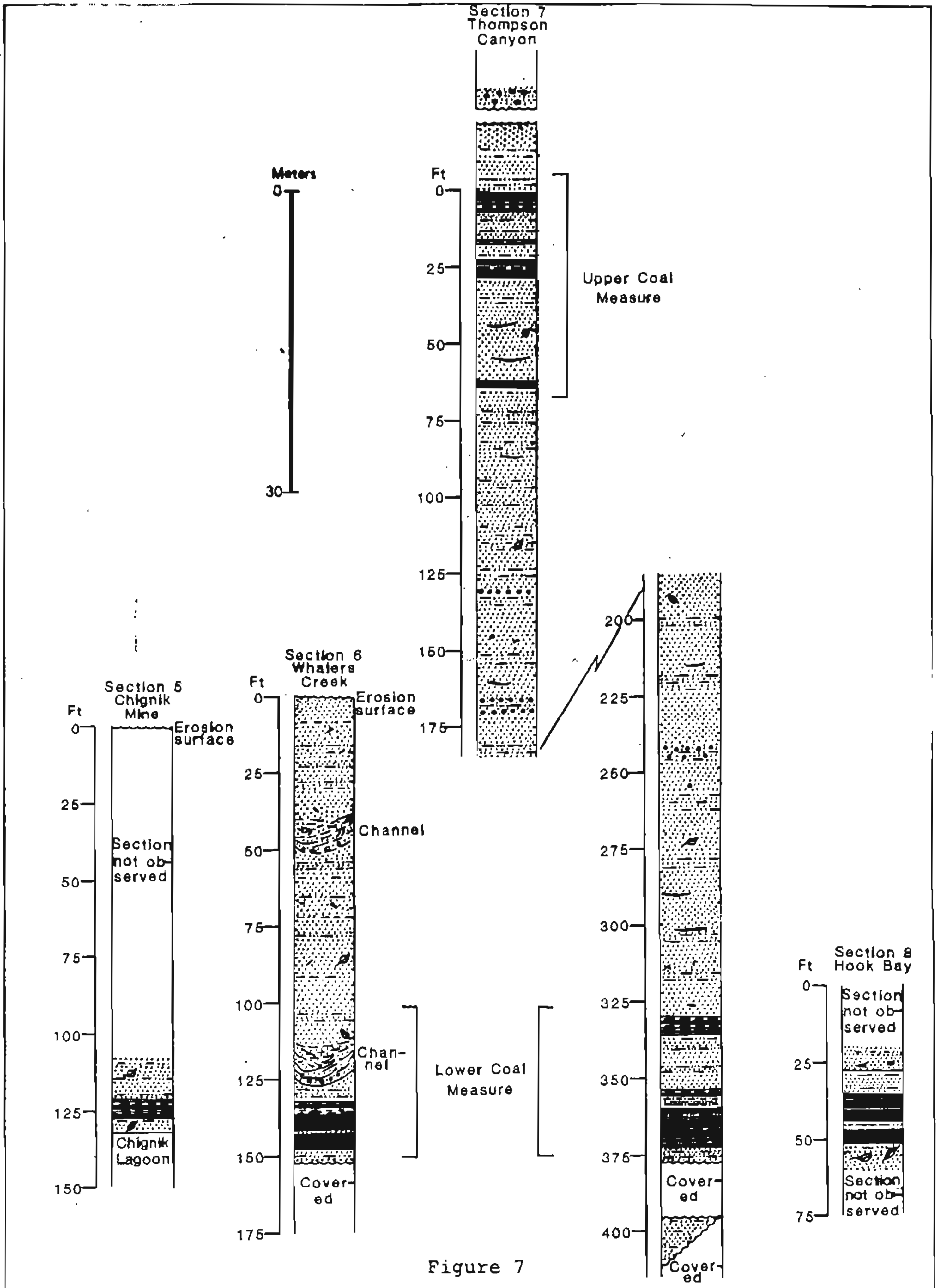

Section 7
Thompson
Canyon
Meters
0
30
Ft
0
25
50
75
100
125
150
175
Upper Coal
Measure
200
225
250
275
300
325
350
375
400
Cover-
ed
Cover-
ed
Section 5
Chignik
Mine
Ft
0
25
50
75
100
125
150
Erosion
surface
Section
not ob-
served
Chignik
Lagoon
Section 6
Whalers
Creek
Ft
0
25
50
75
100
125
150
175
Erosion
surface
Channel
Chan-
nel
Cover-
ed
Lower Coal
Measure
Section 8
Hook Bay
Ft
0
25
50
75
Section
not ob-
served
Section
not ob-
served

Figure 7

Figure 8

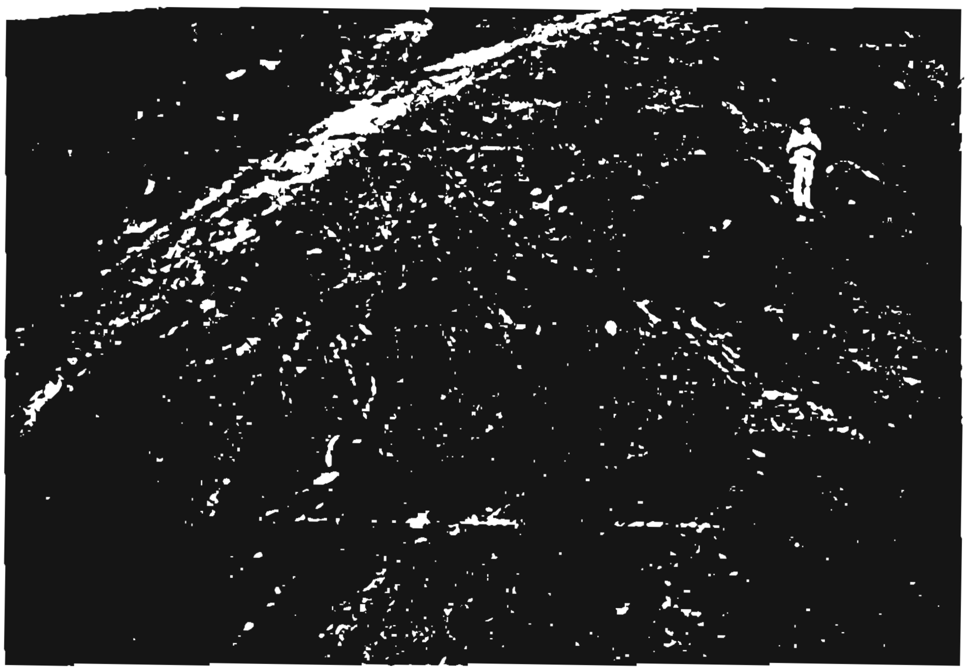


Figure 9

Figure 10

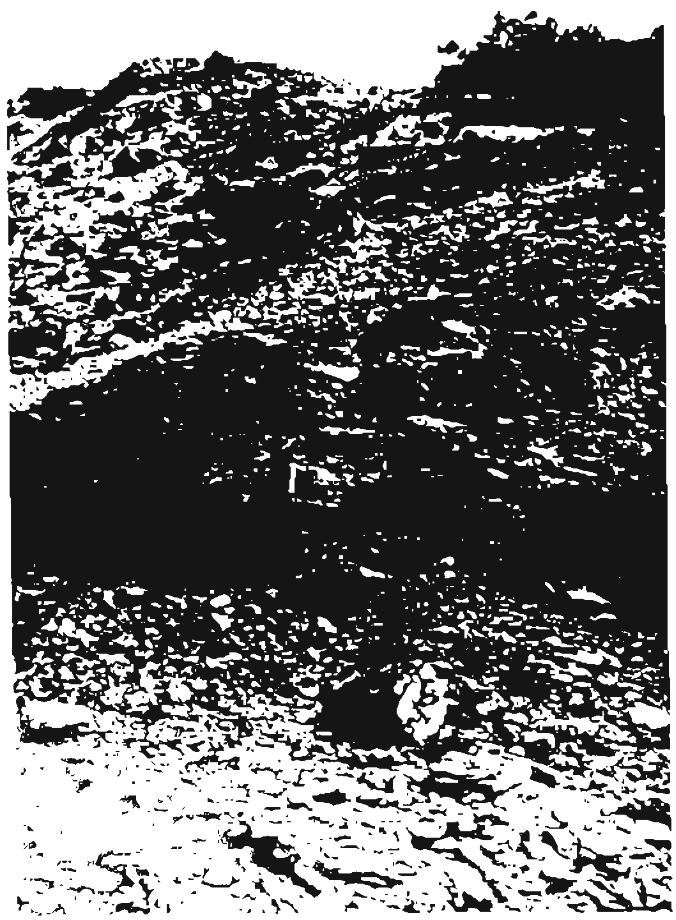
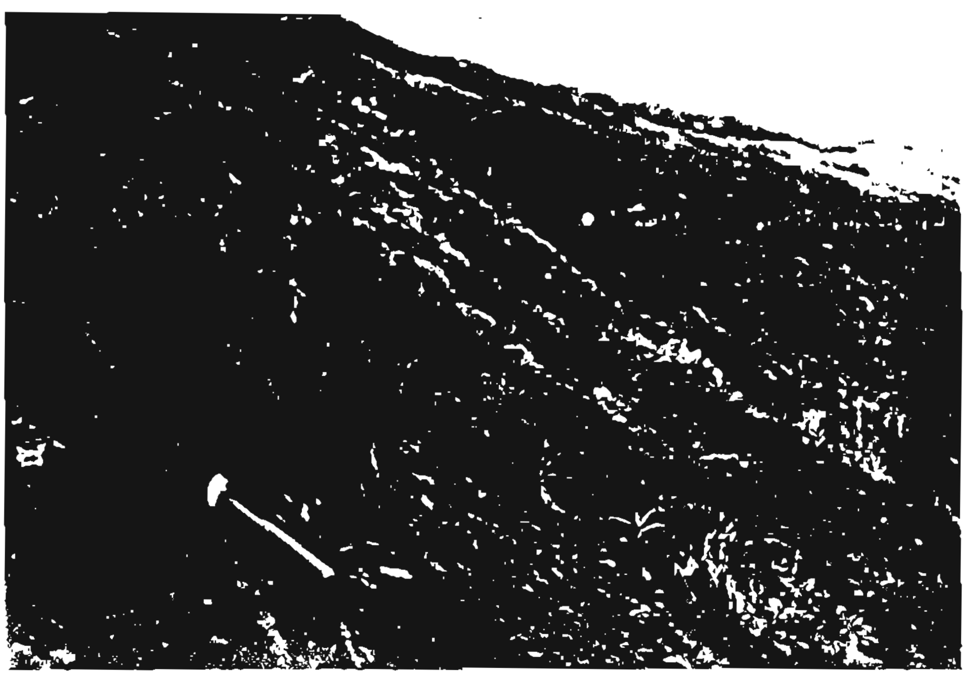


Figure 11

Figure 12

Figure 13



[illegible]

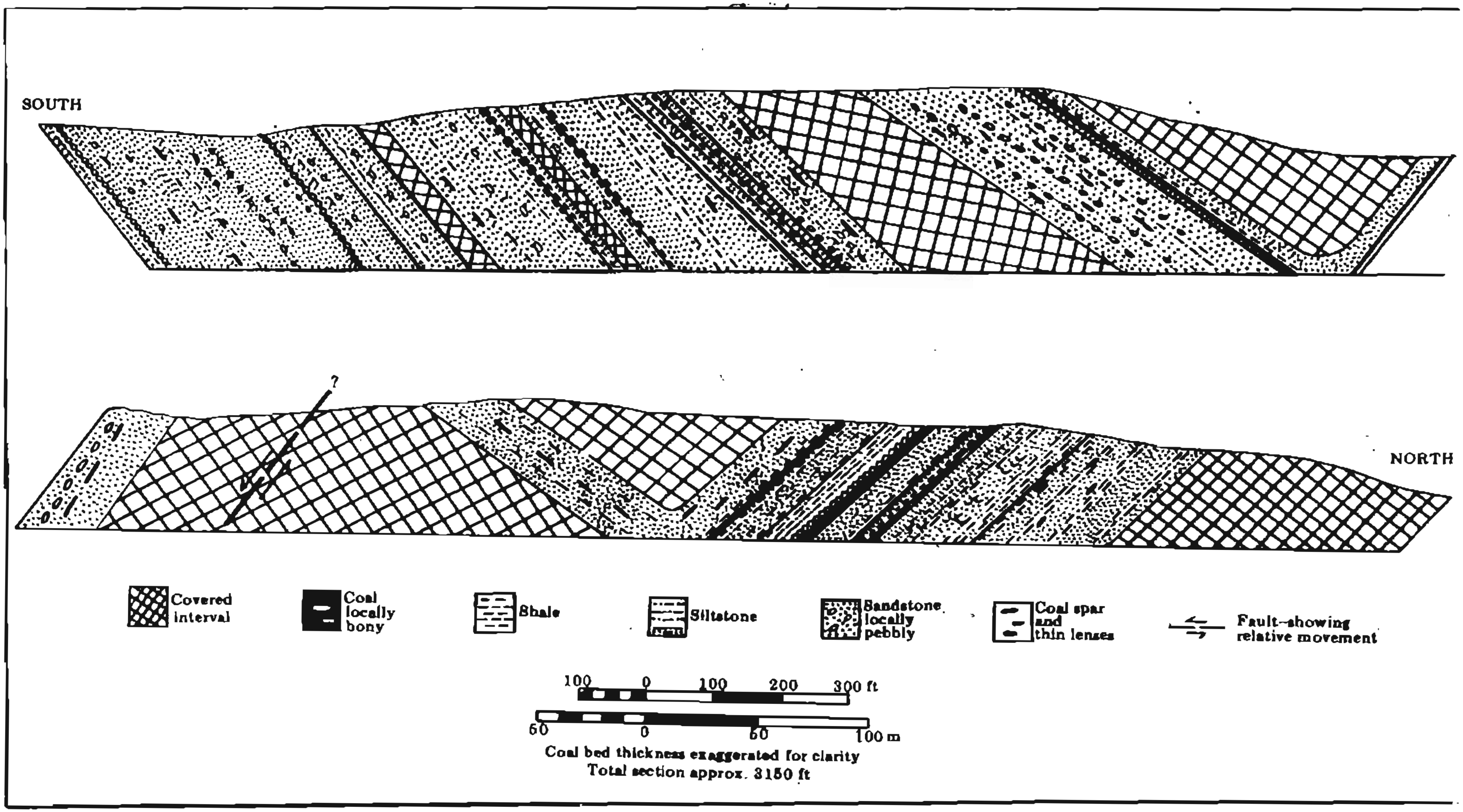
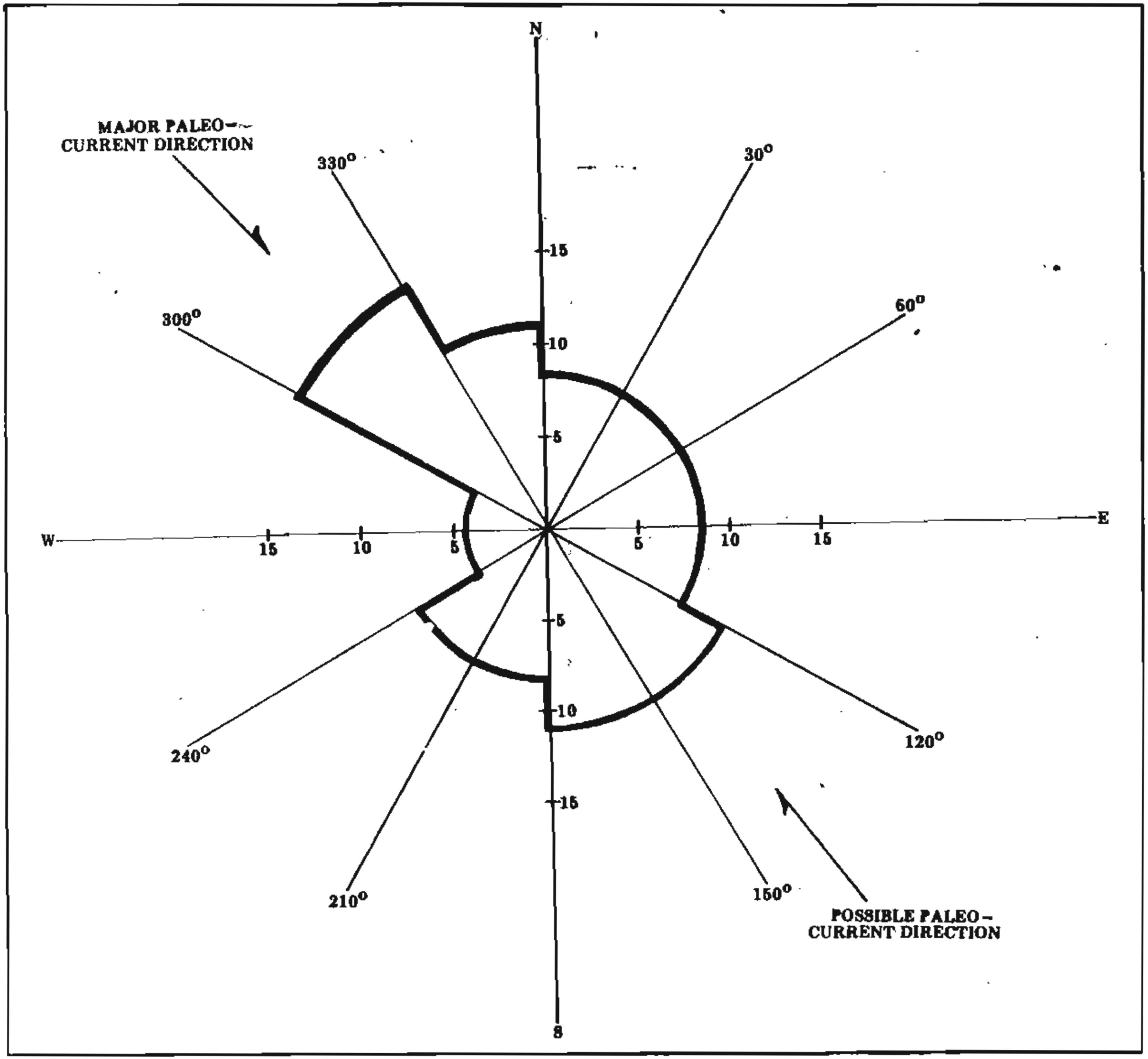
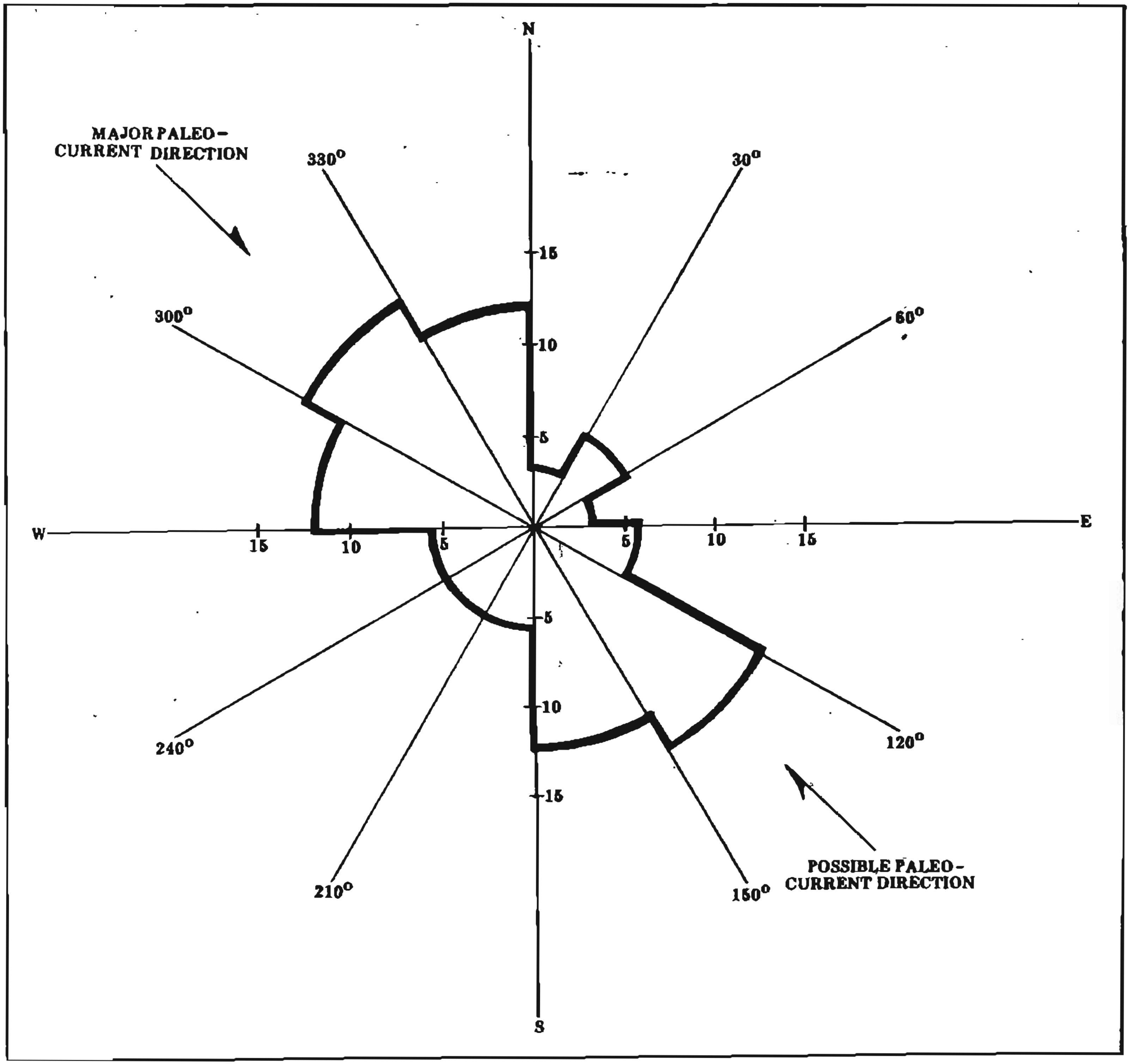

SOUTH
NORTH
?
Covered interval
Coal locally bony
Shale
Siltstone
Sandstone locally pebbly
Coal spar and thin lenses
Fault–showing relative movement
100 0 100 200 300 ft
60 0 60 100 m
Coal bed thickness exaggerated for clarity
Total section approx. 3150 ft

Figure 15



N
S
E
W
MAJOR PALEO-CURRENT DIRECTION
POSSIBLE PALEO-CURRENT DIRECTION
30°
60°
120°
150°
210°
240°
300°
330°
5
10
15

Figure 16


MAJOR PALEO-
CURRENT DIRECTION
N
330°
30°
300°
60°
15
10
5
W
E
15
10
5
5
10
15
5
10
15
240°
120°
210°
150°
POSSIBLE PALEO-
CURRENT DIRECTION
S

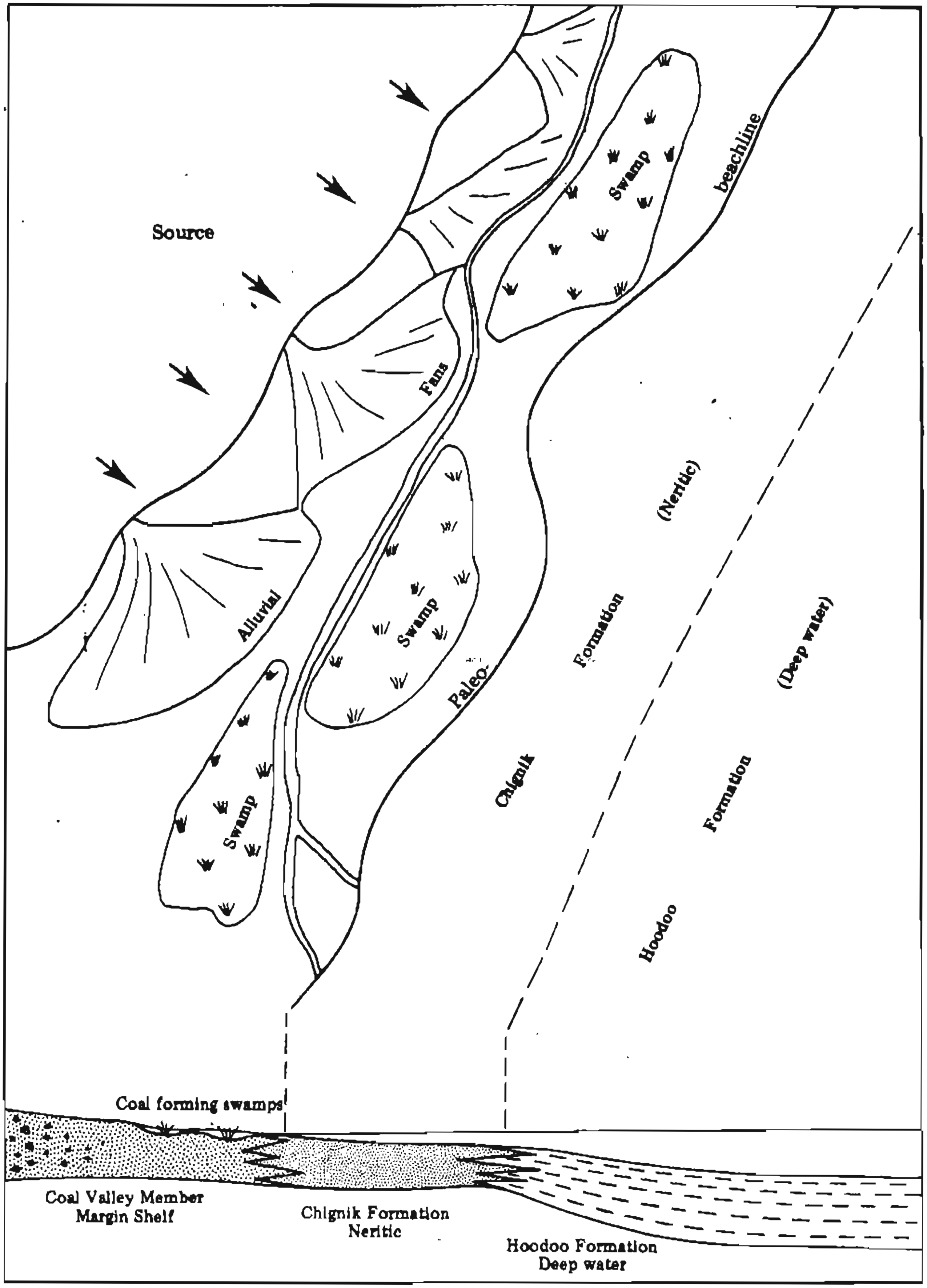

Source
Fans
Swamp
beachline
Alluvial
Swamp
Paleo-
(Neritic)
Formation
Chignik
Swamp
(Deep water)
Formation
Hoodoo
Coal forming swamps
Coal Valley Member
Margin Shelf
Chignik Formation
Neritic
Hoodoo Formation
Deep water

Figure 18

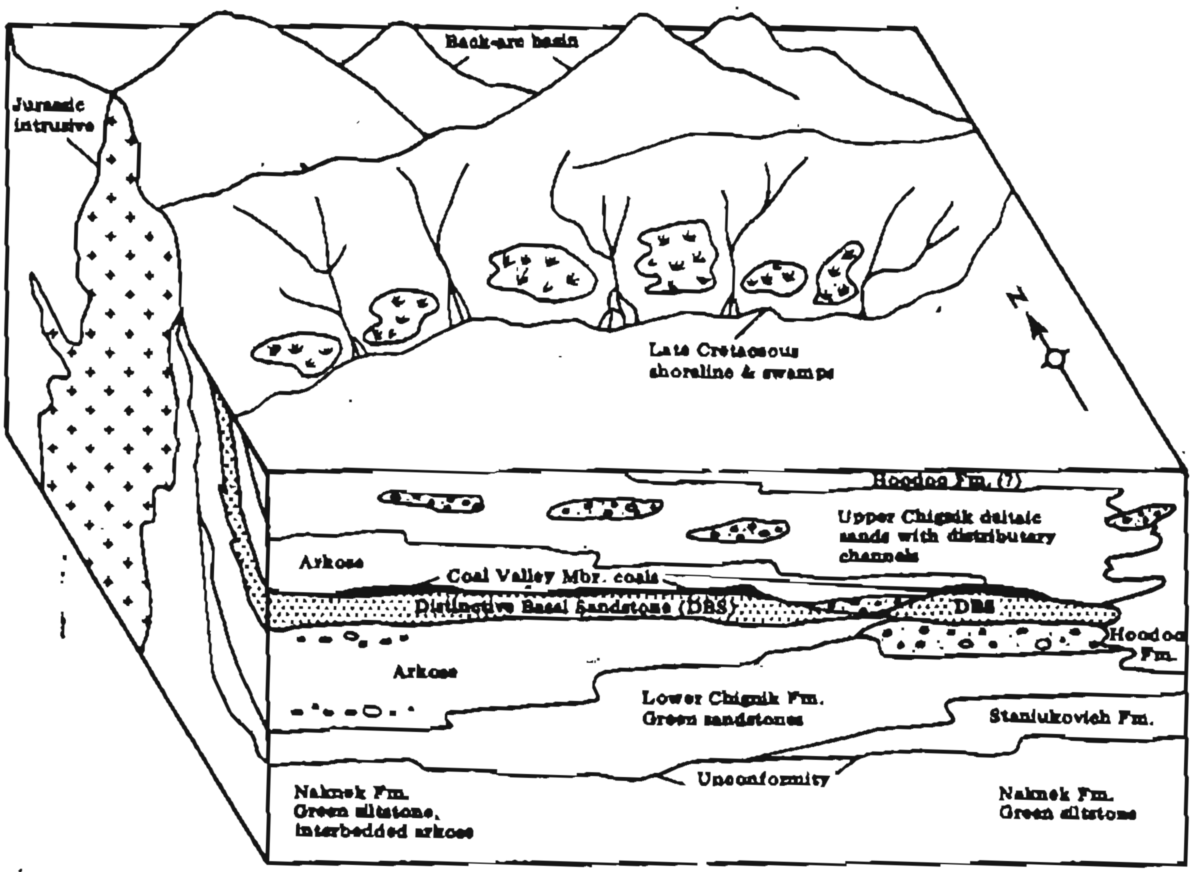
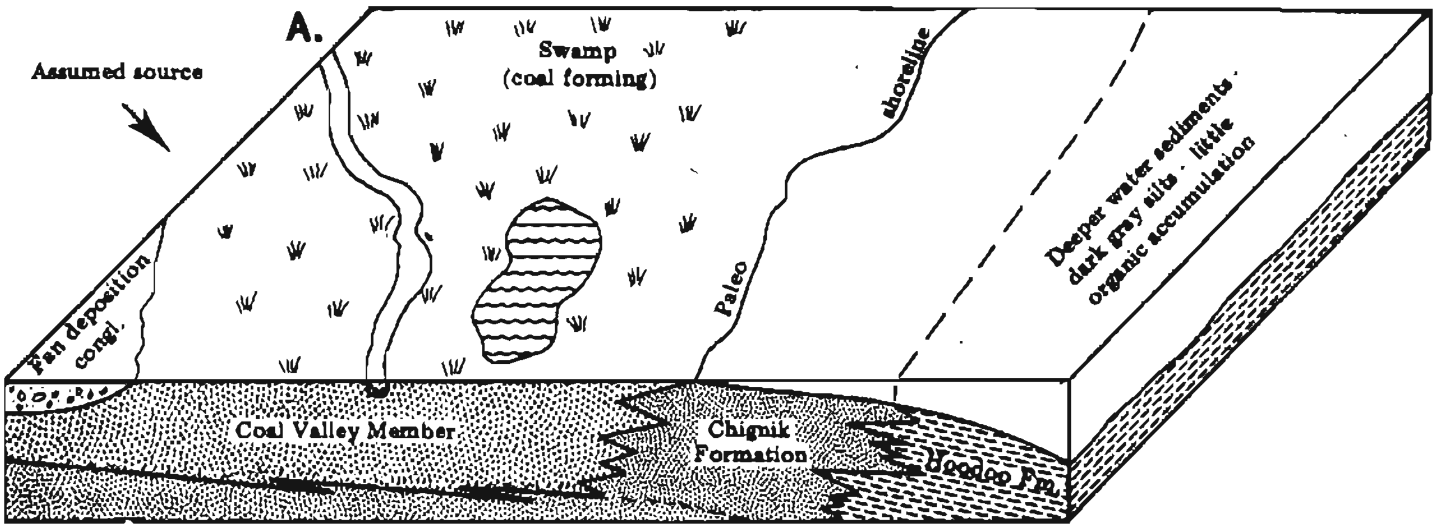

Back-arc basin
Jurassic intrusive
Late Cretaceous shoreline & swamps
N
Hoodoo Fm. (?)
Upper Chignik deltaic sands with distributary channels
Arkose
Coal Valley Mbr. coals
Distinctive Basal Sandstone (DBS)
DBS
Hoodoo Fm.
Arkose
Lower Chignik Fm. Green sandstones
Staniukovich Fm.
Unconformity
Naknek Fm. Green siltstone, interbedded arkose
Naknek Fm. Green siltstone

Figure 19


A.
Assumed source
Swamp
(coal forming)
shoreline
Paleo
Deeper water sediments · dark gray silts · little organic accumulation
Fan deposition congl.
Coal Valley Member
Chignik Formation
Hoodoo Fm.

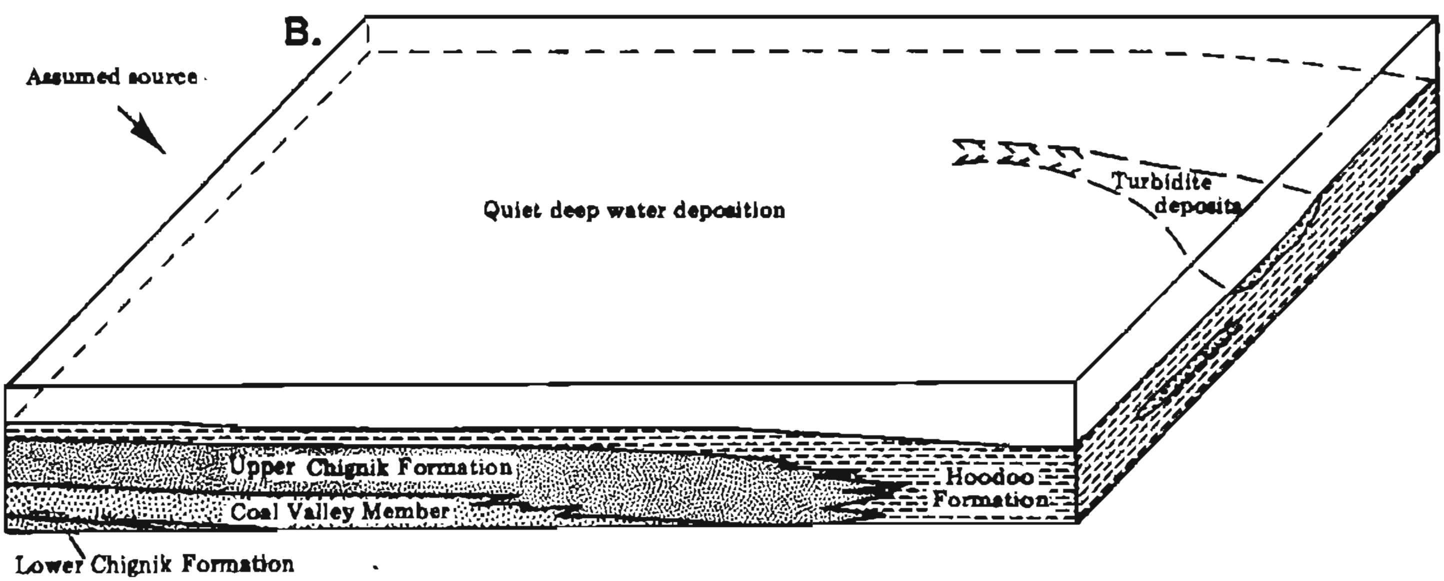

B.
Assumed source
Quiet deep water deposition
Turbidite deposits
Upper Chignik Formation
Coal Valley Member
Hoodoo Formation
Lower Chignik Formation

Figure 20

Figure 21