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PETROLOGY OF CRETACEOUS AND TERTIARY COALS OF SOUTHERN ALASKA

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Geological and Geophysical Surveys

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ABSTRACT

Petrologic analysis of more than 400 coal samples from four general areas of southern Alaska show that the coals possess overall similar compositions. The areas sampled include the Nenana field, Susitna lowland (Beluga and Yentna fields), the Matanuska field, and Alaska Peninsula (Chignik, Herendeen Bay, and Unga Island fields). The coals are all of Tertiary age except for those of the Chignik Formation (Chignik and Herendeen Bay fields) which are of Late Cretaceous age. The Tertiary coals are from the Healy Creek, Suntrana, and Lignite Creek Formations (Nenana field), Kenai Group---Tyonek and Beluga Formations (Beluga and Yentna fields), Chickaloon Formation (Matanuska field), and Bear Lake Formation (Unga Island field).

The southern Alaska coals share broad compositional affinities with coals from other areas of the world including British Columbia and Australia. They are consistently high in vitrinitic or huminitic components, and have variable but typically low amounts of inertinitic and liptinitic components. The coals with relatively high liptinite contents, the hydrogen-rich components, may be well-suited for use in synthetic fuel generation. Variations in the maceral compositions generally reflect changes in the primary vegetation cover and in the environment of coal formation. However, post-depositional thermal effects have progressively more severely altered coal-maceral assemblages eastward in the Matanuska field, and also have more strongly influenced the compositions of bituminous coals of the Chignik Formation on the Alaska Peninsula.

Petrology of the southern Alaska coals indicate that they formed predominantly in forest-moor backswamp (paludal) environments on valley flats or flood plains of nonmarine, continental-fluvial systems. They typically originated as tree-vegetation peats in the telmatic zone.

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INTRODUCTION

Coal investigations have been conducted in several major fields located in the southern part of Alaska since 1981. These coal-bearing regions are shown in Figure 1, and include (from north to south) the Nenana field, the Beluga and Yentna fields of the Susitna lowland, the Matanuska field, and the Chignik, Herendeen Bay, and Unga Island fields on the Alaska Peninsula.

Figure 1---NEAR HERE

Coals of the Nenana field are found principally in three formations of the Tertiary coal-bearing group (the Healy Creek, Suntrana, and Lignite Creek Formations). Coals of the Beluga and Yentna fields of the Susitna lowland occur in the Tertiary Kenai Group, principally the Tyonek and Beluga Formations. Coals of the Matanuska field are limited to the Tertiary Chickaloon Formation. Coals from the Alaska Peninsula fields (Chignik, Herendeen Bay, and Unga Island) are chiefly from two geologic units---the Late Cretaceous Chignik Formation, mainly the Coal Valley Member, and from the Tertiary Bear Lake Formation, Unga Conglomerate Member. The stratigraphy and age of these coal-bearing formations are shown in Figure 2.

Figure 2---NEAR HERE

A total of 428 coal samples from 132 different sites were collected and analyzed petrologically during this study (Table 1). For the most part, the samples represent individual coal seams. However, some samples from the Beluga and Yentna fields represent only portions of certain seams.

Table 1---NEAR HERE

The purpose of this paper is to consider the general petrologic characteristics of the coals of this broad region of southern Alaska, and to compare their composition with coals from

other areas. Sufficient data has been collected so that preliminary conclusions can be drawn as to the significance of the maceral compositions to other coal characteristics.

NENANA FIELD

The coals of the Nenana field are similar petrologically to Tertiary coals of British Columbia and Australia (cf. Stach and others, 1982). They are all predominantly huminitic with minor inertinite and variable liptinite contents. However, the main liptinites in Nenana coals are resinite and suberinite, while in the aforementioned coals, it is mainly sporinite. Sclerotinite, fusinite, and inertodetrinite are commonly the main inertinites in all the coals, and micrinite is not present. However, Nenana coals do usually contain macrinite, while the Tertiary coals of British Columbia and Australia usually do not (Williams and Ross, 1979; Stach and others, 1982).

Table 2 summarizes the maceral compositions of Nenana field coal samples. Photomicrographs of coal macerals from samples of the region are shown in Figure 3 and display the general types, morphology, and common associations. The huminite group of macerals is the most abundant in the coals of the Nenana field; the huminite group content ranges from over 68 percent to about 91 percent, and the mean content is about 83 percent (volume, mineral-matter-free basis) in the 70 samples analyzed. Ulminite is the main huminite (mean content over 74 percent) and often occurs partially gelified (texto-ulminite) or more rarely completely gelified (eu-ulminite). Corpohuminites are present as primary cell infillings (phlobaphinites) and secondary cell infillings (pseudophlobaphinites), but they usually compose less than 1 percent by volume. Porigelinite is also very low (mean less 0.5 percent). Rare pseudovitrinites were observed in a few coal samples. Whether these resulted from primary (fossil) oxidation or secondary oxidation (weathering) is uncertain, but since the samples were collected from outcropping seams, the latter may be more

probable. Following ulminite, humodetrinite (usually as attrinite but sometimes as densinite) is consistently the most abundant huminite. It tends to be more abundant in high ash coals and typically increases in the upper portions of thick seams and in the relatively thin coals toward the top of coal-bearing sections. The mean humodetrinite content is over 7 percent.

Table 2, Figure 3---NEAR HERE

Inertinites occur as minor constituents in most of the Nenana coal samples analyzed with a mean content of 2.7 percent, but they range up to over 20 percent (volume, mineral-matter-free basis). The coals with a relatively high inertinite content point to a terrestrial or 'dry' paleoenvironment where the precursor peat was highly oxidized (Stach and others, 1982). The most common of the high-carbon inertinites are inertodetrinite, macrinite, and semifusinite. Sclerotinite and fusinite are fairly consistently present, but relatively lower in abundance. Inertodetrinite and macrinite result in the peat stage through the biochemical disintegration of plant remains, particularly by the activity of fungi and bacteria under somewhat oxidizing conditions (Stach and others, 1982). Sclerotinite is diagnostic of Tertiary coals, and is believed to be indicative of intense fungal activity at the time they were formed. They occur as celled or lumenated chitinous fungal spores, and often too as plectenchyma from the stroma of tubular fungi (Stach and others, 1982). They are especially resistant to alteration and destruction. Sclerotites multicellulatus, other Sclerotites species, and plectenchyma occur in Nenana field Tertiary coals. Semifusinite is commonly more abundant than fusinite; these macerals were produced by forest fires and compose the microlithotypes fusite and semifusite and the lithotypes fusain and semifusain. Fusinization of the Nenana coals has produced both the perforated screen ('screen structure') and bogen- or star-structured varieties. Micrinites were not identified in the coals of this region.

The liptinites (or exinites) occur as significant components in the coals of the Nenana field. In fact, they are relatively

high (to 30 percent or more, volume, mineral-matter-free basis) in some samples. The mean liptinite content is about 14 percent. Resinite, suberinite, and exsudatinite form by far the most abundant liptinites, with rare sporinite, cutinite, liptodetrinite, and alginite.

Resinite predominates in abundance over suberinite and exsudatinite in Nenana field samples. Resinite occurs as cell fillings, secretions, and isolated elongate or spherical bodies. Resinite fluoresces bright orange under blue light irradiation, while exsudatinite fluoresces dark orange. Exsudatinite fills cracks in vitrinite, cell lumina of fusinite or semifusinite, and the chambers in sclerotinite (Spackman, Davis, and Mitchell, 1976). Resinite can be transformed into gray or whitish, 'grapestone,' inertinitic or vitrinitic bodies by oxidation (Stach and others, 1982), and these forms are rarely observed in the Nenana coals. Suberinite is diagnostic of Tertiary coals and may compose up to 5 percent of the volume (mineral-matter-free basis). Sporinite is generally less than 1 percent, and occurs as squashed elongate bodies with slitted centers. Cutinite occurs as crenulated or toothed yellow stringers in both the thin-walled (tenuicutinite) and thick-walled (crassicutinite) varieties. Preserved algal remains (alginites) are extremely rare in the Nenana coals. Although some Tertiary brown coals (particularly the bright lithotypes) are reported to contain abundant liptodetrinite (Stach and others, 1982), it is found to compose no more than 0.5 percent of the volume in the samples analyzed during this study.

Figure 4 shows ternary diagrams for maceral compositions of Nenana coal samples analyzed. The end members of the inner (larger) triangle are the three major maceral groups---huminite, inertinite, and liptinite. The patterned area of this triangle shows that the huminite group is by far the most abundant. Each of the major groups has been subdivided in the smaller triangles into its chief components. The contents of the individual or combined macerals and maceral types for most of the Nenana samples fall within the patterned areas of the smaller triangles. The huminite triangle shows the high proportion of ulminite, the liptinite tri-

angle the abundance of resinite and suberinite, and the inertinite triangle the predominance of the combined macrinite, inertodetrinite, and sclerotinite end member. In addition, the huminite triangle shows that the humodetrinite end member is of secondary importance to ulminite and is more abundant than the corpohuminite and porigelinite end member; in the liptinite triangle that sporinite is typically more abundant than the combined cutinite, alginite, and liptodetrinite end member; and in the inertinite triangle the usual predominance of semifusinite over fusinite.

Figure 4---NEAR HERE

Table 3 shows that certain general trends can be expected in the maceral compositions of coals sampled from the different coal-bearing formations in the Nenana field. Huminite contents are high in coals from all of the formations. Exinite or liptinite contents tend to be somewhat more abundant in the older formation (Healy Creek Formation and probable equivalent undifferentiated Tertiary coal-bearing unit) and is typically less abundant in the Lignite Creek Formation and more variable in the Suntrana Formation. Inertinite shows a trend toward increasing abundance upward in the coal-bearing formations.

Table 3---NEAR HERE

Mean maximum reflectance values ($\bar{R}om$) for selected Nenana coal samples are summarized in Figure 5. Reflectance values measured in the Nenana coal samples range from 0.21 to 0.53 percent, and generally support the subbituminous C rank assigned by proximate and ultimate analyses.

Figure 5---NEAR HERE

The petrology of Nenana field coals is consistent with their interpreted origin in Tertiary continental-fluvial systems and associated subenvironments. It suggests that most of the coal

seams formed from tree-vegetation peats with abundant preservation of woody materials as huminites. The woody peats accumulated in poorly drained forest-moor swamps filling nearly isotopographic lows. The thicker and more continuous peats originated during relatively quiescent periods that alternated with periods of uplift and the influx of clastics that ended each peat-forming cycle. A forest-terrestrial moor environment is envisaged for certain coals in the Lignite Creek Formation as indicated by their higher content of inertinite. They would have formed under drier conditions than the coals of the forest-moor in the telmatic (or groundwater level) zone, as did most coals of the Suntrana and Healy Creek Formations.

BELUGA AND YENTNA FIELDS

Maceral composition of Beluga and Yentna coal field samples analyzed during this study is summarized in Table 4 and Figure 6. The petrology of the raw coals is commonly similar based on maceral group proportions. However, the relative contents of individual macerals and maceral types vary considerably both within a seam and among different seams. Photomicrographs of representative coal macerals from coals of the Beluga and Yentna fields are shown in Figure 7.

Table 4, Figures 6-7---NEAR HERE

The huminite group of macerals is by far the most abundant in the coals of this region; typically, the huminite group contains over 90 percent of all macerals, and is always over 75 percent (volume, mineral-matter-free basis; Table 4). Ulminite, the main huminite present, usually appears fairly uniform in structure and reflectance, and is medium to light gray, and sometimes has desiccation cracks or microfractures. Texto-ulminite is partially gelified, whereas eu-ulminite is completely gelified. The corpohuminites occur as both phlobaphinite (primary cell infillings) and pseudophlobaphinite (secondary cell infillings). Pseudovitrinite was not identified in the coals.

Rao and Wolff (1981) found humodetrinite (finely dispersed humic debris) to be highest in the top seam of a coal-bearing sequence. They postulated that the changing paleoenvironmental regime caused physical degradation of the humic matter and the end of conditions conducive to coal formation. This trend is not well established in most coal-bearing sequences of the Beluga and Yentna fields, but can generally be observed in certain coal-bearing sections.

Inertinites commonly occur as minor constituents in the coals of the Beluga and Yentna fields. However, several seams, particularly those of the northern Yentna field, have inertinitic contents ranging up to over 18 percent by volume on a mineral-matter-free basis. The inertinites are typically white or very light gray and bright in normal incident light; they exhibit the highest reflectances of all macerals. The most predominant inertinitic macerals in the Beluga and Yentna field coals are macrinite, fusinite, and semifusinite. Inertodetrinite (dispersed clastic fragments of inertinite) and sclerotinite (hard fungal remains found mainly in younger coals such as those of the Tertiary period) were also observed. The sclerotia may be rounded or elliptical; its lumens or cavities may contain resinite, pyrite or other mineral matter. Micrinite (fine granular inertinitic debris) was not identified in the coals of this region.

The inertinites have been affected by more intense physical and chemical alteration than huminites, but are still chiefly derived from wood and bark. They may have been attacked by bacteria before burial. The fusinitic and semifusinitic components consist of charcoal and other partially burned materials. These macerals are thermally resistant and inert; hence, they are not easily oxidized or hydrogenated. Rao and Wolff (1981) found that the lowest percentage of inert macerals occurs at the base of a given seam and increases toward the top. They interpret this trend as reflecting a gradual change to a drier paleoenvironment during formation of the seam.

The liptinites occur as minor constituents in the coals of the Beluga and Yentna fields; they range up to about 12 percent

by volume on a mineral-matter-free basis. The most abundant liptinites present are resinite and suberinite. The liptinites have the lowest reflectances of all macerals. They are black to dark gray in normal incident (reflected) light but are fluorescent under blue-light irradiation. The liptinites share broad chemical affinities such as relatively high hydrogen and volatile contents. Compared to other maceral groups, they have a higher concentration of aliphatic substances such as tar. Liptinites can represent diverse coal components that may range from spore and pollen exines and perines to cuticles, algae, and other resinous substances and tannin derivatives (Spackman and others, 1976).

Resinite occurs as cell fillings (of lumens) or secretions and may be found as isolated, elongate or spherical bodies; it typically displays an orange fluorescence. Exsudatinite was not counted separately but was included with resinite. Exsudatinite commonly fills cracks in vitrinite (ulminite), the cell lumina of fusinite, or the chambers of sclerotinite (Spackman and others, 1976). Suberinite is commonly found in Tertiary coals; it originates from cork cell walls mainly in barks and root tissues. Sporinite occurs as squashed elongate bodies with slitted centers. Yellow stringers (in fluorescent light) of cutinite typically are crenulated or toothed on one side, may be thin-walled (tenuicutinite) or thick-walled (crassicutinite), and sometimes are folded. Alginites---preserved algal remains---are rare in the coals of the Beluga and Yentna fields; they fluoresce yellow under blue-light irradiation.

Mean maximum reflectance values for Beluga and Yentna field coals are summarized in Figure 8.The reflectance values range from 0.23 to 0.45 percent, and confirm that most of the coals are subbituminous to lignitic. Little variation occurs in the reflectance values within a seam or among all the seams analyzed.

Figure 8---NEAR HERE

Most of the coals of the Beluga and Yentna fields probably formed from tree-vegetation peats. The coal samples were not

collected close enough---either vertically or laterally---to permit detailed interpretation of facies changes from the petrographic variations within the coal seams. However, the main microlithotypes present were very generally determined by selectively counting the maceral associations on the polished pellets and from the extensive maceral composition data collected. The different groups of microlithotypes can be subdivided into individual microlithotypes by taking account of these maceral associations (Stach and others, 1982). Vitrite is the dominant microlithotype in the coals of the Beluga and Yentna fields, with clarite containing minor interbands of vitrinertite and trimacerite (duroclarite). Williams and Ross (1979) found similar maceral compositions and microlithotypes in Tertiary (Eocene) bituminous coals in the Tulameen field of south-central British Columbia. They also found vitrite to be the dominant microlithotype, with clarite containing minor interbands of trimacerite (clarodurite) and durite. Based on their research, they proposed that the coal-forming peats there developed in a forest-moor-swamp environment in a poorly drained low-lying basin that was adjacent to an eroding upland during a warm, moist climatic period.

The forest-moor-swamp environment, where predominantly vitrite and vitro-clarite are deposited, is typical of most coals of the Beluga and Yentna fields, as it is for coals of the Tulameen field. The types of vegetation and conditions of preservation of the plant materials in this environment indicate that most of the coals of the Beluga and Yentna fields formed in the telmatic zone.

MATANUSKA FIELD

Matanuska field coals show petrologic compositions high in vitrinite with minor inertinite and liptinite contents. The respective maceral terminology used for classification in low- and high-rank coals are summarized in Table 5. Typical maceral compositions for Matanuska field subbituminous coals are listed in Table 6, and Tables 7 and 8 list average maceral compositions for bituminous and anthracite coal samples respectively. Photo-

micrographs of mainly liptinitic macerals from Matanuska field samples are shown in Figure 9.

Tables 5-8, Figure 9---NEAR HERE

The vitrinite group content in Matanuska field bituminous coals ranges from 89 percent to essentially 100 percent (volume, mineral-matter-free basis), and the mean content is about 96 percent in the 56 samples analyzed (Table 7). Vitrinite and vitrodetrinite are the main macerals of this group. Corpocollinites, gelinite, and pseudovitrinite are of very minor occurrence. Semianthracite-anthracite (Table 8) and subbituminous (Table 6) coals show similarly high vitrinite contents. The anthracitic coals also have a mean content of altered vitrinite of 5.5 percent.

Inertinites show a mean content over 1 percent in both bituminous and semianthracite-anthracite coals of the Matanuska field, but range up to over 4 percent. Fusinite, semifusinite, sclerotinite, macrinite, and inertodetrinite are all present in these high-rank coals but consistently average less than 0.3 percent each. Matanuska field subbituminous coals show similar inertinite contents.

Liptinites (or exinites) occur as minor components in coals of the Matanuska field. The mean liptinite content in the bituminous coals is 3 percent, but in the semianthracite-anthracite coals it is only 0.1 percent. In the bituminous coals, liptinites range to about 9.5 percent but to only 1.0 percent in the anthracitic ranks. The few subbituminous coals analyzed show a range in liptinite content from 2.2 to 8.8 percent. Liptodetrinite, resinite, and suberinite are the most abundant liptinite maceral types, and exsudatinite, cutinite, sporinite, and alginite are very rare.

Figure 10 shows a ternary diagram for maceral compositions of Matanuska field coal samples. Maceral group proportions are plotted by rank in an enlarged-scale triangular diagram beginning at the established 89 percent vitrinite base level. In

general, the bituminous coals exhibit the broader distribution in this plot. The anthracitic coals plot near the vitrinite end member and the subbituminous coals fall relatively closer to the liptinite end member.

Figure 10---NEAR HERE

Mean-maximum vitrinite reflectance values ($\bar{R}$om) for Matanuska field coal samples are summarized in Figure 11. Reflectance increases with the rank of a coal as indicated in Figure 12 by the plot of $\bar{R}$om vs. dry, ash-free carbon content for Matanuska field coals. Reflectance values in Matanuska field samples show a broad range from 0.47 to 5.34 percent, and generally support the rank grades (subbituminous B to meta-anthracite) assigned by coal quality assessment. Considering that these samples are from outcrops containing weathered and oxidized coal, vitrinite reflectance should be considered a more reliable measure of rank than proximate analysis data.

Figures 11-12---NEAR HERE

Vitrinite reflectance values increase from the lower to upper Matanuska field (Figure 13). This generally corresponds to rank increases eastward in the region. The generalized isopach map also shows a lowering in vitrinite reflectance around the margins of the Matanuska field. However, this has not been demonstrated conclusively because of the amount of data used in constructing this illustration.

Figure 13---NEAR HERE

Locally, the thermal effects of contact metamorphism have produced natural coke. Merritt (1985) discussed an occurrence of natural coke at the Castle Mountain mine and estimated temperatures of formation at 450°C to 500°C. Fracturing due to rapid cooling locally produced well-developed prisms at the

site. The apparent rank of the highly altered coal was established as anthracite.

The petrology of Matanuska field coals is consistent with their interpreted origin in Early Tertiary paludal (swamp) environments associated with a continental-fluvial depositional system. It also reflects the strong influence of post-depositional thermal effects that have progressively more severely altered coal maceral assemblages eastward in the region.

CHIGNIK, HERENDEEN BAY, AND UNGA ISLAND FIELDS

Bituminous coals analyzed from the Chignik and Herendeen Bay fields are from the Late Cretaceous Chignik Formation, predominantly from the Coal Valley Member of this unit. Table 9 summarizes the maceral compositions of these bituminous coals. Subbituminous and lignite coals analyzed are from the Chignik Formation and from the Tertiary Bear Lake Formation, Unga Conglomerate Member; since these coals are similar in composition, they have been grouped together for purposes of discussion (Table 10). Only three coals from the Unga Island field were analyzed petrologically. These results are also reported in Table 10.

Tables 9-10---NEAR HERE

Figure 14 is a ternary plot for the maceral compositions of Chignik, Herendeen Bay, and Unga Island coals. The coals are plotted by rank, that is, a bituminous group and a subbituminous/lignite group. The mean contents of vitrinite, inertinite, and liptinite are relatively the same in both groups. Photomicrographs of representative macerals from coals of this region are shown in Figure 15.

Figures 14-15---NEAR HERE

The vitrinite group content in the bituminous coals ranges from 73 percent to essentially 100 percent (volume, mineral-mat-

ter-free basis), and the mean content is 91 percent for the 61 samples analyzed. Besides vitrinite, vitrodetrinite (mean content over 9 percent) and gelinite (mean content 2.4 percent) are the main macerals of the group. Corpocollinite and pseudovitrinite are of very minor occurrence. The subbituminous/lignite group shows similar proportions of individual macerals.

Inertinites reveal a mean content over 6 percent in both bituminous and subbituminous/lignite coals of the Chignik, Herendeen Bay, and Unga Island fields. The range in total inertinites is larger in the subbituminous/lignite coals (to 24 percent) than in the bituminous coals (to over 18 percent). Fusinite, semifusinite, and inertodetrinite are the main inertinitic macerals in both groups.

Liptinites are somewhat more abundant in the bituminous coals (mean content 2.7 percent) than in the subbituminous/lignite coals (mean content 1.8 percent). The contents of the individual macerals of the liptinite group are fairly evenly distributed for both the bituminous and subbituminous/lignite coals.

Mean-maximum vitrinite reflectance values ($\bar{R}om$) for coal samples from the Chignik, Herendeen Bay, and Unga Island fields are summarized in Figure 16. Reflectance values range from 0.21 to 1.76 percent, and generally support the rank grades (lignite to low-volatile bituminous) assigned by coal quality assessment.

Figure 16---NEAR HERE

The coals of the Late Cretaceous Chignik Formation, Coal Valley Member, are believed to have formed in nonmarine valley flat or flood plain environments, as part of a complex of swamps, lakes, channels, splay deposits, and local alluvial fans. This relatively narrow belt of finer-grained flood plain deposits was situated between marine facies of the formation and coarser fan deposits of a piedmont environment. The coal swamps, which were preserved on flat or gently sloping areas, were numerous but their lateral extents were limited. The large number of thin coal seams found in the unit suggests there were

many individual areas of peat accumulation but that conditions were never stabilized long enough for thick beds of peat to form.

Sediments of the Tertiary Bear Lake Formation were deposited in transitional marine to nonmarine environments. The Unga Conglomerate Member is a nonmarine, subaerial deposit including fluvial sandstones and conglomerates and paludal thin coals. The unit is reflective of a marine regression. Marginal marine (nearshore, inner neritic) volcaniclastic conglomerates, sandstones, and claystones make up the remaining portion of the Bear Lake Formation and probably represent a minor transgressive phase of deposition.

CONCLUSIONS

The results of a large sampling and petrological analysis program of several major coal fields of southern Alaska show that the coals share broad compositional affinities with coals from other areas of the world, particularly British Columbia and Australia. The southern Alaska coals are consistently high (70-95 percent on volume, mineral-matter-free basis) in vitrinitic or huminitic components, and reveal variable but typically low amounts of inertinitic (less 5 percent to 20 percent) and liptinitic (less 5 percent to 15 percent, occasionally to 30 percent or more) components. The coals with relatively high liptinite contents, the hydrogen-rich components, may be well-suited for use in synthetic fuel generation.

The excellent preservation of macerals in the coals of the Nenana, Beluga, and Yentna fields may be indicative of relative rapid subsidence and early burial of peat beds. In general, the maceral compositions of the coals reflect changes in the primary vegetation cover and in the environment of coal formation. However, post-depositional thermal effects have progressively more severely altered coal-maceral assemblages eastward in the Matanuska field, and have strongly influenced the ultimate quality and rank of these coals.

Evidence from this petrological analysis program indicates that these coals formed predominantly in forest-moor backswamp (paludal) environments on valley flats, flood or alluvial plains of nonmarine, continental-fluvial systems. They typically originated as tree-vegetation peats in the telmatic (or groundwater level) zone. Coals with higher inertinite contents may have developed in somewhat drier conditions of forest-terrestrial moor environments.

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FIGURE CAPTIONS

Figure 1...Coal fields of southern Alaska sampled for this petrological study---A=Nenana field; B=Beluga and Yentna fields; C=Matanuska field; and D=Chignik, Herendeen Bay, and Unga Island fields.

2...General stratigraphic nomenclature and age of the coal-bearing rocks examined from the A) Nenana field (after Wolfe and Tanai, 1980), B) Beluga and Yentna fields (after Calderwood and Fackler, 1972, and Magoon and others, 1976), C) Matanuska field (after Magoon and others, 1976), and D) Chignik, Herendeen Bay, and Unga Island fields (after Wilson, 1980).

3...Photomicrographs of liptinites and associated macerals and maceral types from the Nenana coal field samples analyzed (oil immersion, normal reflected light).

A. Sporangium with resinite cell fillings, porigelinite, humodetrinite, and dispersed mineral matter. Outside the sporangium are ulminite, humodetrinite, and exinite (300X).

B. Resinite, ulminite, and porigelinite (400X).

C. Resinite, ulminite, and inertodetrinite (400X).

D. Resinite filling lumen and surrounding sclerotinite with ulminite and humodetrinite (400X).

E. Suberinite, resinite, ulminite, cutinite, humodetrinite, and dispersed mineral matter (400X).

F. Suberinite, phlobaphinite, and ulminite (500X).

G. Suberinite, sporinite, humodetrinite, inertodetrinite, dispersed mineral matter, and resinite (400X).

H. Thick-walled cutinite with humodetrinite, exinite(?), inertodetrinite, and dispersed mineral matter (400X).

Figure 4...Ternary diagrams for maceral composition of Nenana field coal samples. Refer to text for explanation.

5...Vitrinite reflectance frequency histogram for coal samples from the Nenana field. Number in brackets indicates total number of grains counted at the given reflectance interval.

6...Ternary diagram for maceral group composition of Susitna lowland coal samples.

7...Photomicrographs of various macerals from Tertiary coals of the Tyonek and Beluga Formations, Beluga and Yentna fields, Susitna lowland, Alaska (oil immersion, normal reflected light).

A. Phlobaphinite and porigelinite (400X).
B. Pseudophlobaphinites (250X).
C. Phlobaphinite cell fillings and thick suberinite cell walls (400X).
D. Sporinites in ulminite (625X).
E. Fusinite (315X).
F. Fusinite with bogen structure (400X).
G. Sclerotinite, ulminite, and porigelinite (315X).
H. Fungal spores with mineral matter and humic material (625X).

8...Vitrinite reflectance frequency histogram for coal samples from the Susitna lowland. Number in brackets indicates the total number of grains measured at the given reflectance interval.

9...Photomicrographs of selected macerals in Matanuska field coal samples. Polished section, oil immersion, width of field of view about 140 microns.

A. Sclerotinite---twin-celled teleutospore and teleutospore with four cells, resinite, and

liptodetrinite. Teleutospores are winter cells of fungi.

B. Sclerotinite---triple-celled teleutospore, partly deformed, resinite, liptodetrinite.

C. Sclerotites sp. with resinite filling cells, sporinite, liptodetrinite.

D. Sporinite.

E. Altered vitrinite in natural coke.

F. Graphitoid sphaeroliths or small spheres formed by deposition from the gas phase during heat alteration.

G. Altered vitrinite and massive-grained pyrite.

H. Thick cutinite.

10...General ternary plot of petrologic data for Matanuska field coal samples by rank. End members shown are the three major maceral groups.

11...Distribution of vitrinite reflectance data for Matanuska field coal samples. Number in parentheses indicates the total number of grains counted at the given reflectance class interval.

12...Scatter plot showing the general direct relationship of mean-maximum vitrinite reflectance values ($\bar{R}om$) with percent carbon (dry, ash-free basis) in coal samples analyzed from the Matanuska field.

13...Highly generalized isopach map of mean-maximum vitrinite reflectance variation in coal samples of the Matanuska field.

14...Ternary diagram for maceral group composition of Alaska Peninsula (Chignik, Herendeen Bay, and Unga Island fields) coal samples.

Figure 15...Photomicrographs of selected macerals in Alaska Peninsula coal samples. Polished section, oil immersion, width of field of view about 140 microns.

A. Resinite and cutinite surrounded by vitrinite.
B. Sporinite in vitrinite.
C. Suberinite and phlobaphinite.
D. Pyrite and sporinite in vitrinite.
E. Sporinite, resinite, and semifusinite in vitrinite.
F. Suberinite, resinite, sporinite, and sclerotinite in vitrinite.
G. Alginite in vitrinite.
H. Vitrinite and resinite.

16...Vitrinite reflectance frequency histogram for coal samples from the Alaska Peninsula (Chignik, Herendeen Bay, and Unga Island fields). Number in brackets indicates the total number of grains counted at the given reflectance interval.

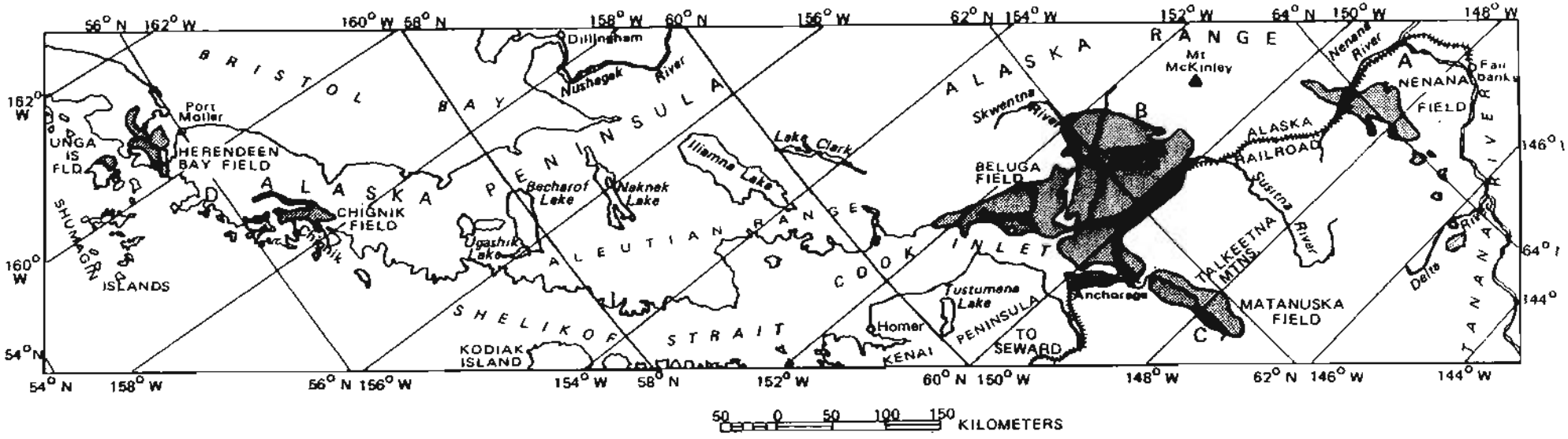
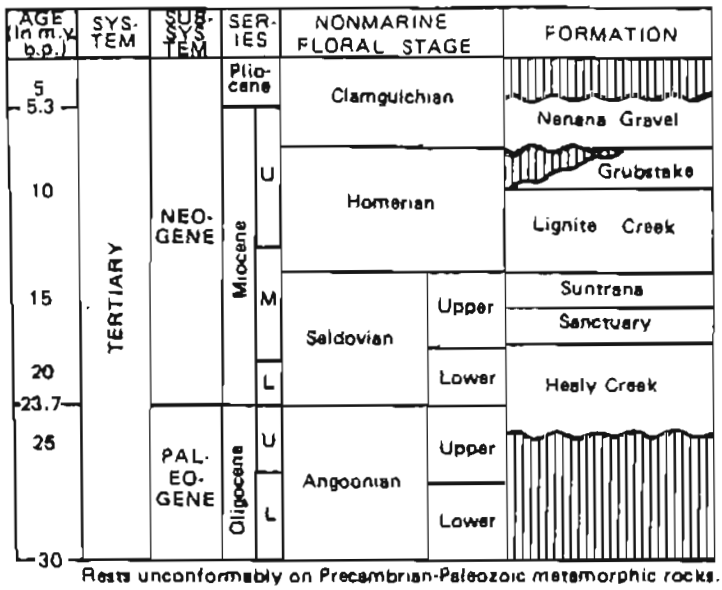
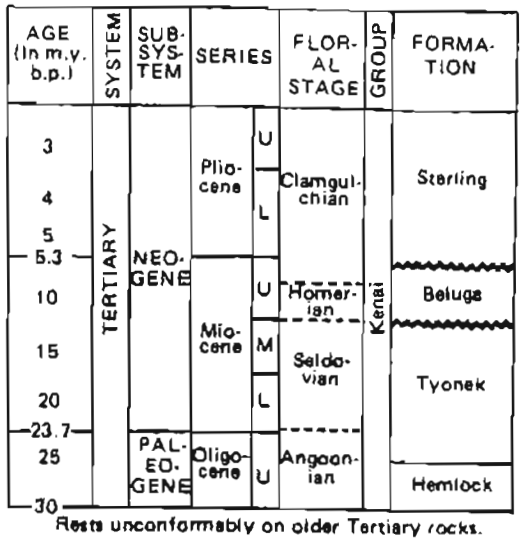

BRISTOL BAY
ALASKA PENINSULA
ALEUTIAN RANGE
ALASKA RANGE
COOK INLET
SHELIKOF STRAIT
Port Moller
UNGA IS FLD
HERENDEEN BAY FIELD
SHUMAGIN ISLANDS
CHIGNIK FIELD
KODIAK ISLAND
Becharof Lake
Naknek Lake
Ugashik Lake
Nushagak River
Dillingham
Iliamna Lake
Lake Clark
Skwentna River
BELUGA FIELD
Mt McKinley
Nenana River
NENANA FIELD
Fairbanks
ALASKA RAILROAD
Susitna River
TALKEETNA MTNS
MATANUSKA FIELD
Anchorage
Tustumena Lake
Homer
KENAI PENINSULA
TO SEWARD
Delta River
TANANA RIVER
A
B
C
KILOMETERS

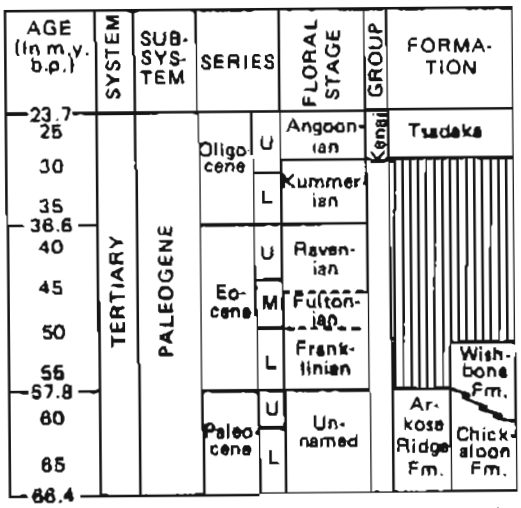
Figure 1



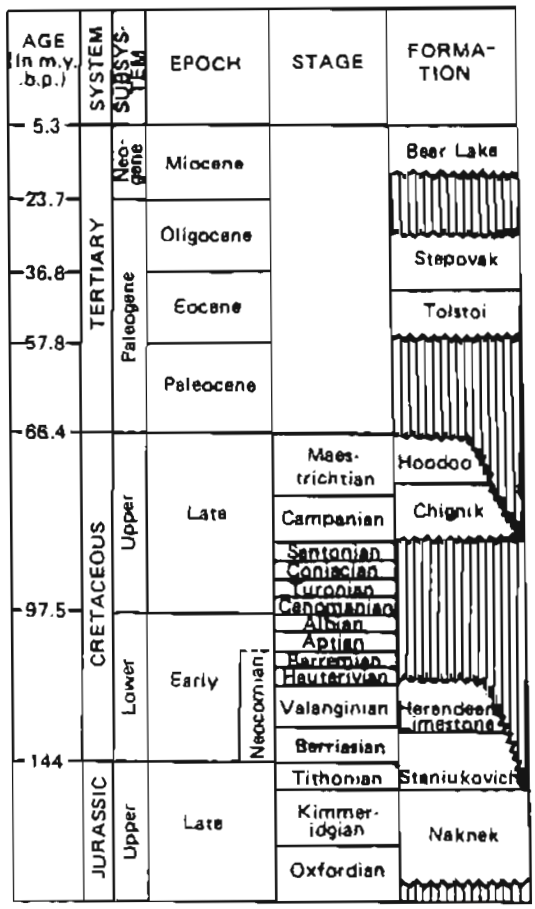
A. NENANA FIELD



B. BELUGA AND YENTNA FIELDS



C. MATANUSKA FIELD



D. CHIGNIK, HERENDEEN BAY, AND UNGA ISLAND FIELDS

Figure 2

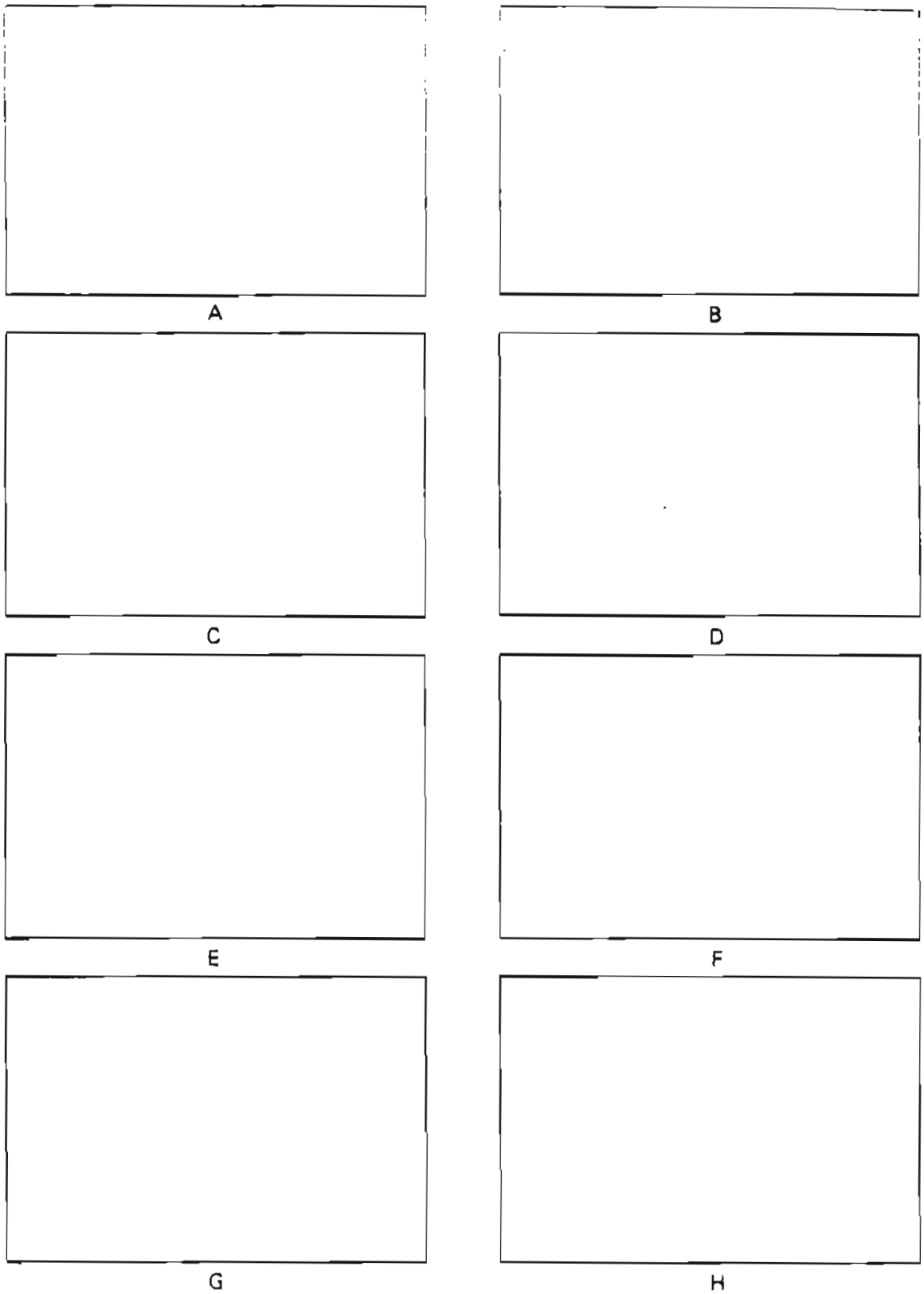


Figure 3

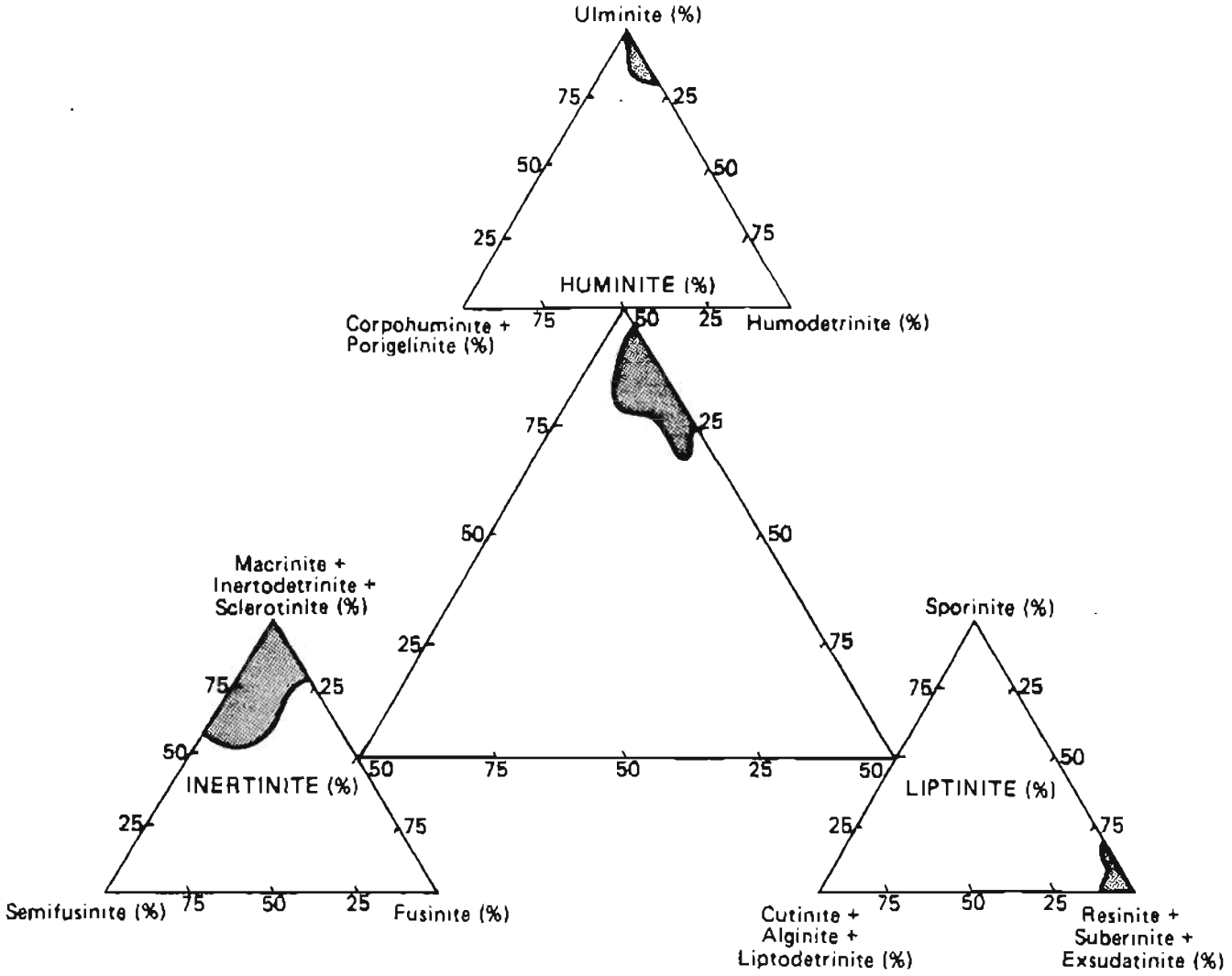

Ulminite (%)
HUMINITE (%)
Corpohuminite + Porigelinite (%)
Humodetrinite (%)
Macrinite + Inertodetrinite + Sclerotinite (%)
INERTINITE (%)
Semifusinite (%)
Fusinite (%)
Sporinite (%)
LIPTINITE (%)
Cutinite + Alginite + Liptodetrinite (%)
Resinite + Suberinite + Exsudatinite (%)

Figure 4

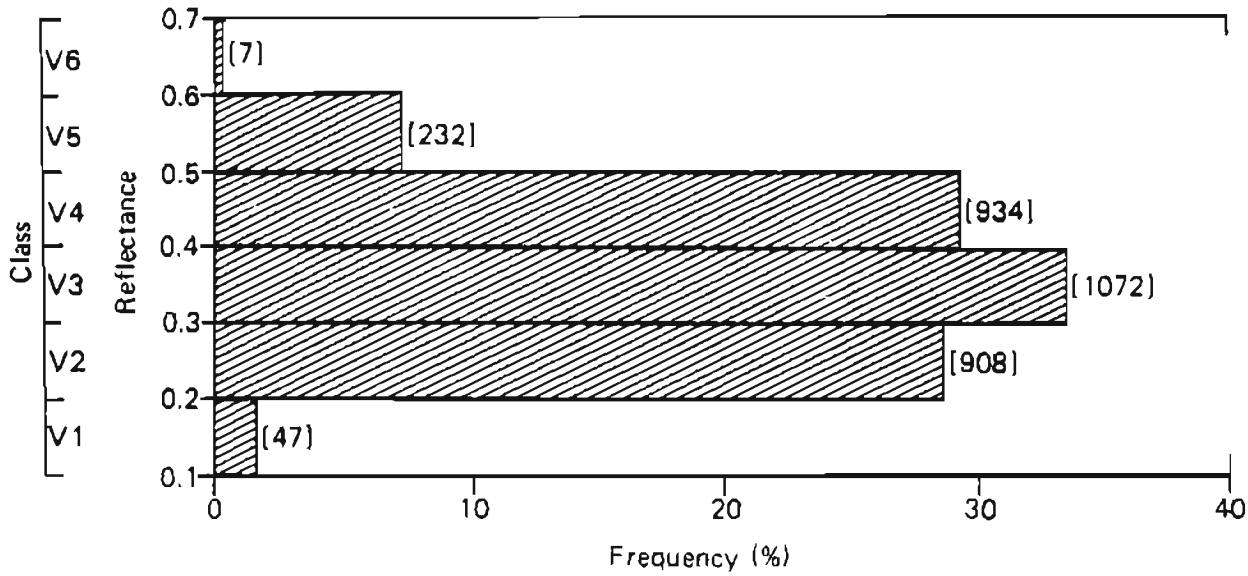

Class
V6
V5
V4
V3
V2
V1
Reflectance
0.7
0.6
0.5
0.4
0.3
0.2
0.1
[7]
[232]
[934]
[1072]
[908]
[47]
0
10
20
30
40
Frequency (%)

Figure 5

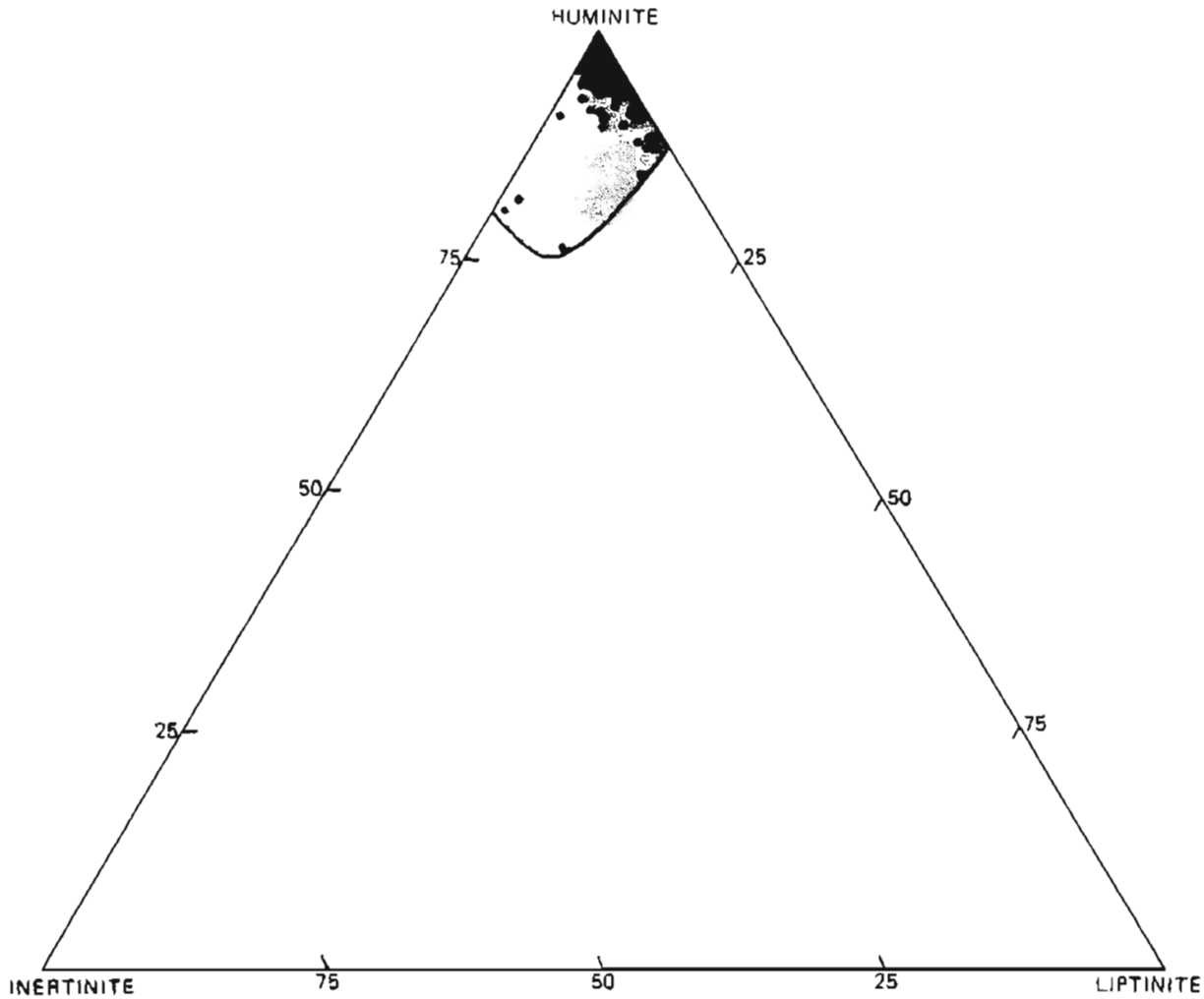


Figure 6

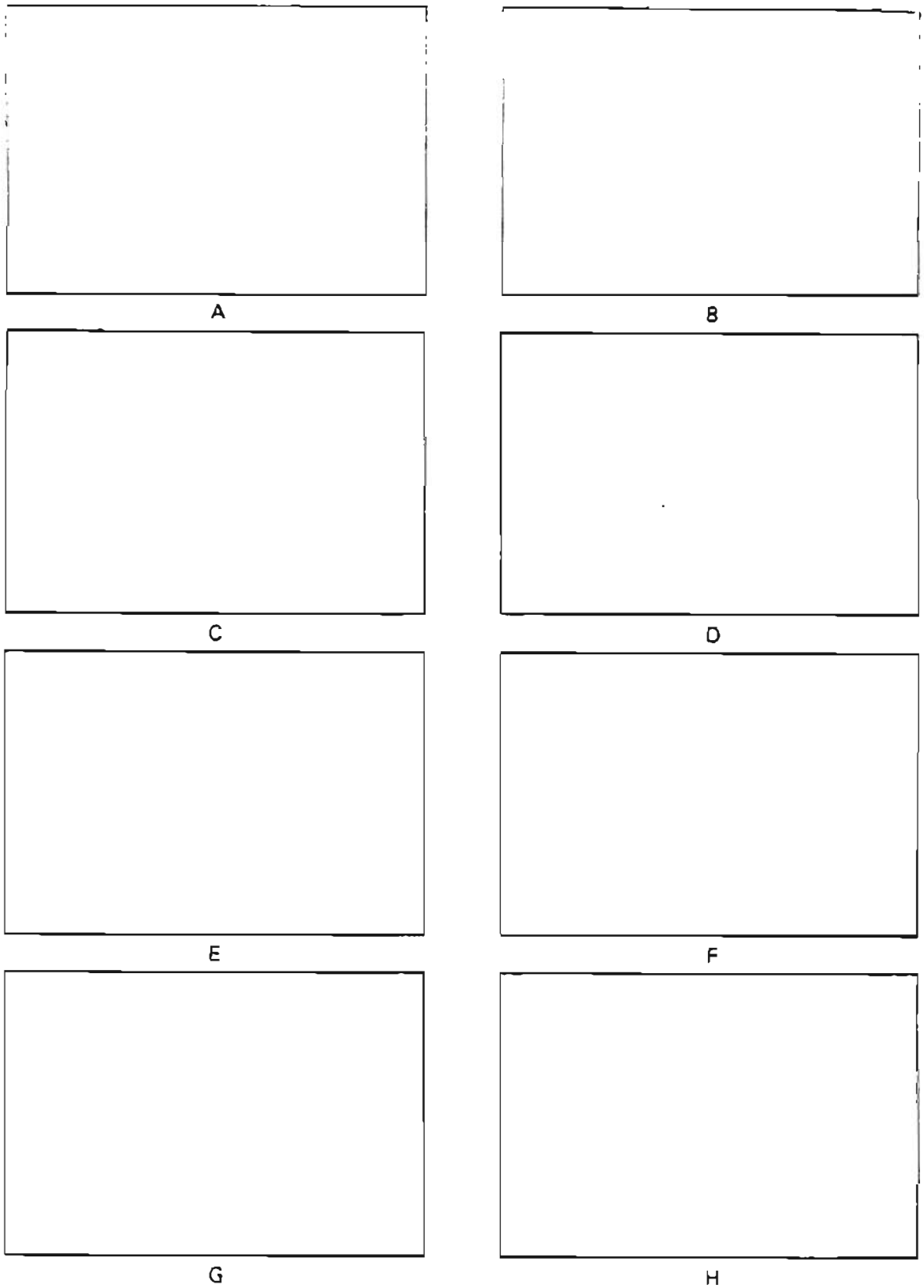


Figure 7

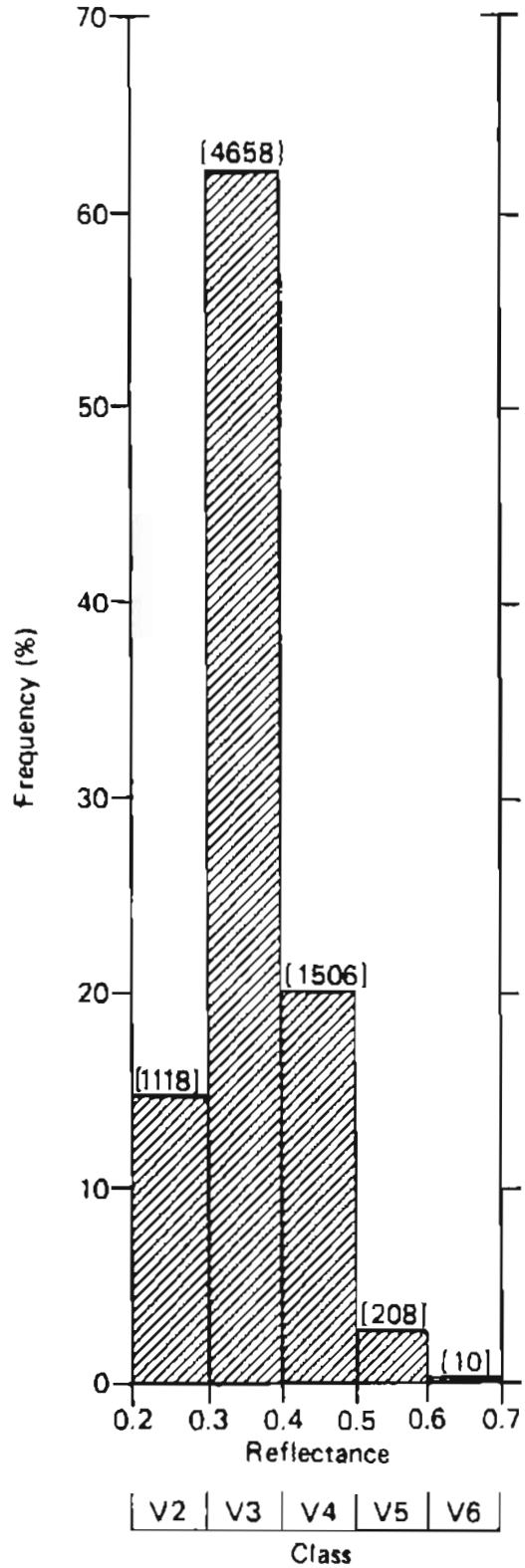

70
60
50
40
30
20
10
0
Frequency (%)
[4658]
[1506]
[1118]
[208]
[10]
0.2
0.3
0.4
0.5
0.6
0.7
Reflectance
V2
V3
V4
V5
V6
Class

Figure 8

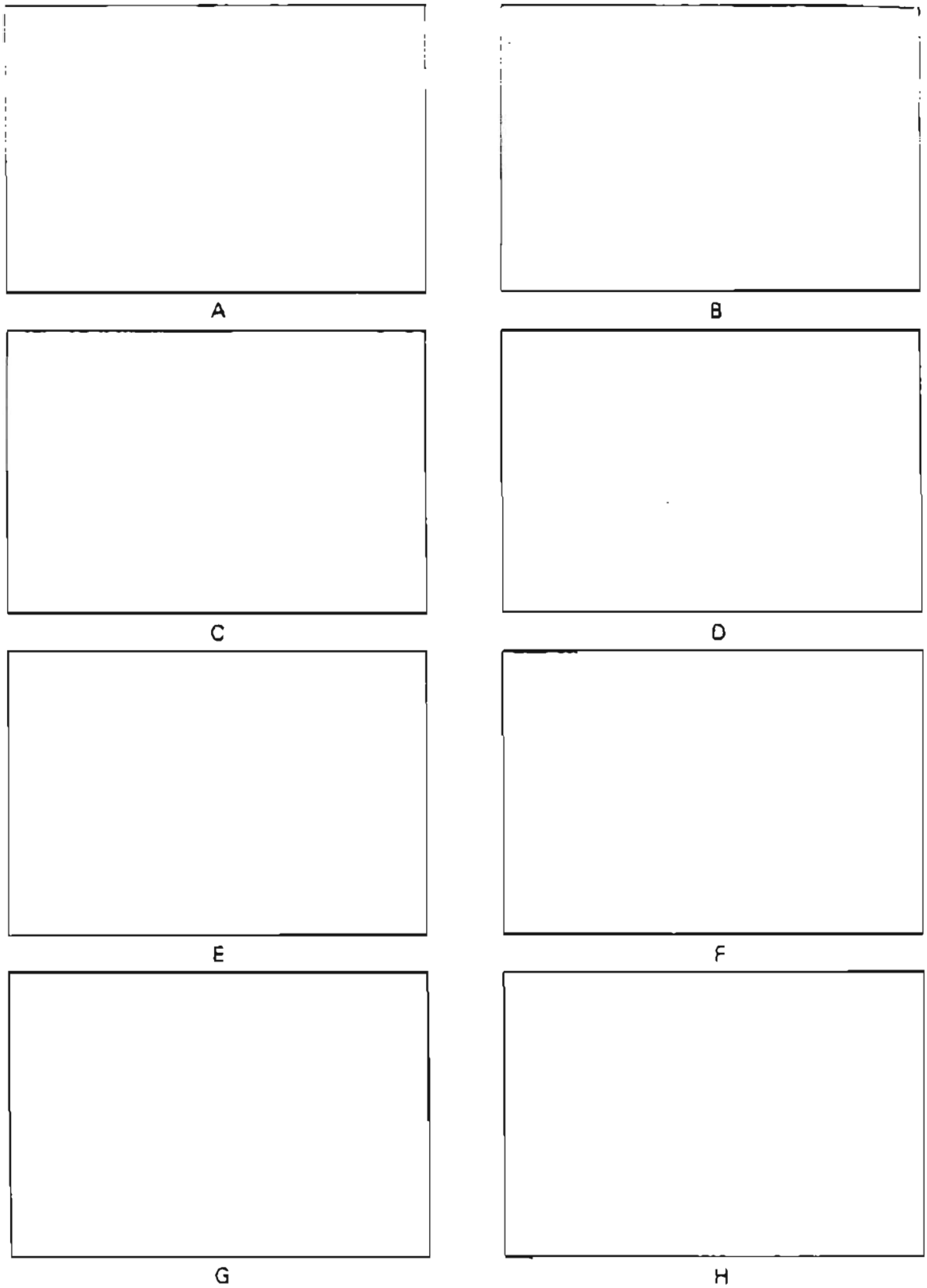
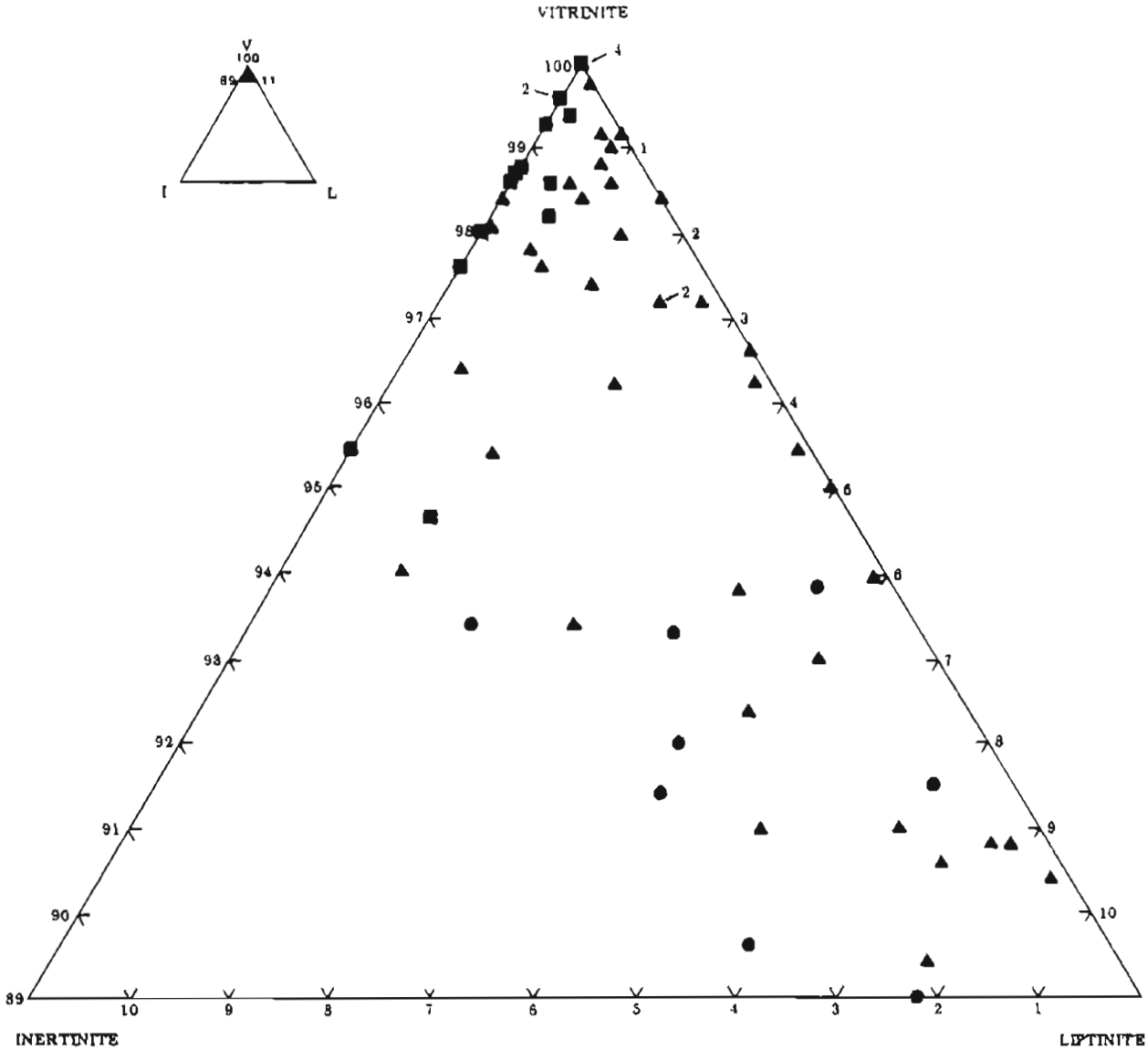


Figure 9



● Subbituminous

▲ Bituminous

■ Semi-Anthracite/Anthracite

Figure 10

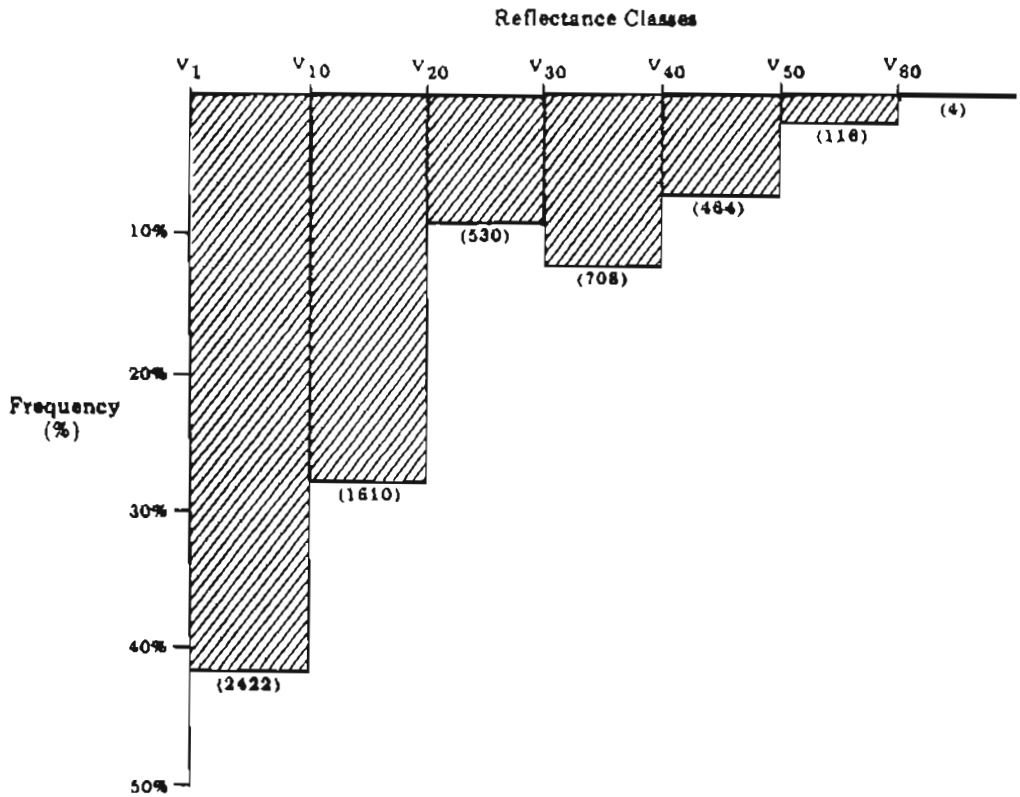

Reflectance Classes
V1
V10
V20
V30
V40
V50
V60
(4)
(118)
(484)
(530)
(708)
(1610)
(2422)
10%
20%
30%
40%
50%
Frequency
(%)

Figure 11

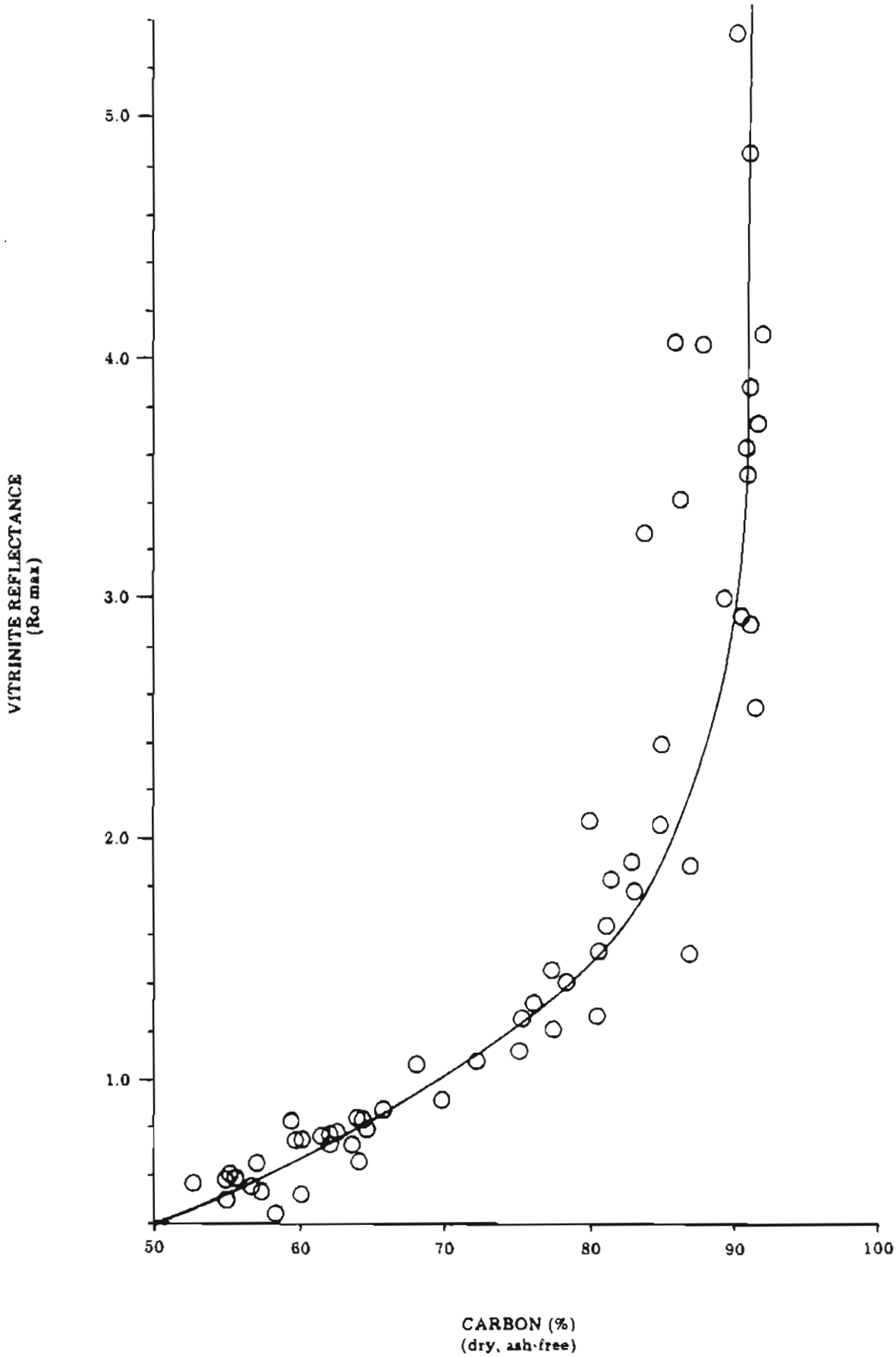

VITRINITE REFLECTANCE
(Ro max)
5.0
4.0
3.0
2.0
1.0
50
60
70
80
90
100
CARBON (%)
(dry, ash-free)

Figure 12

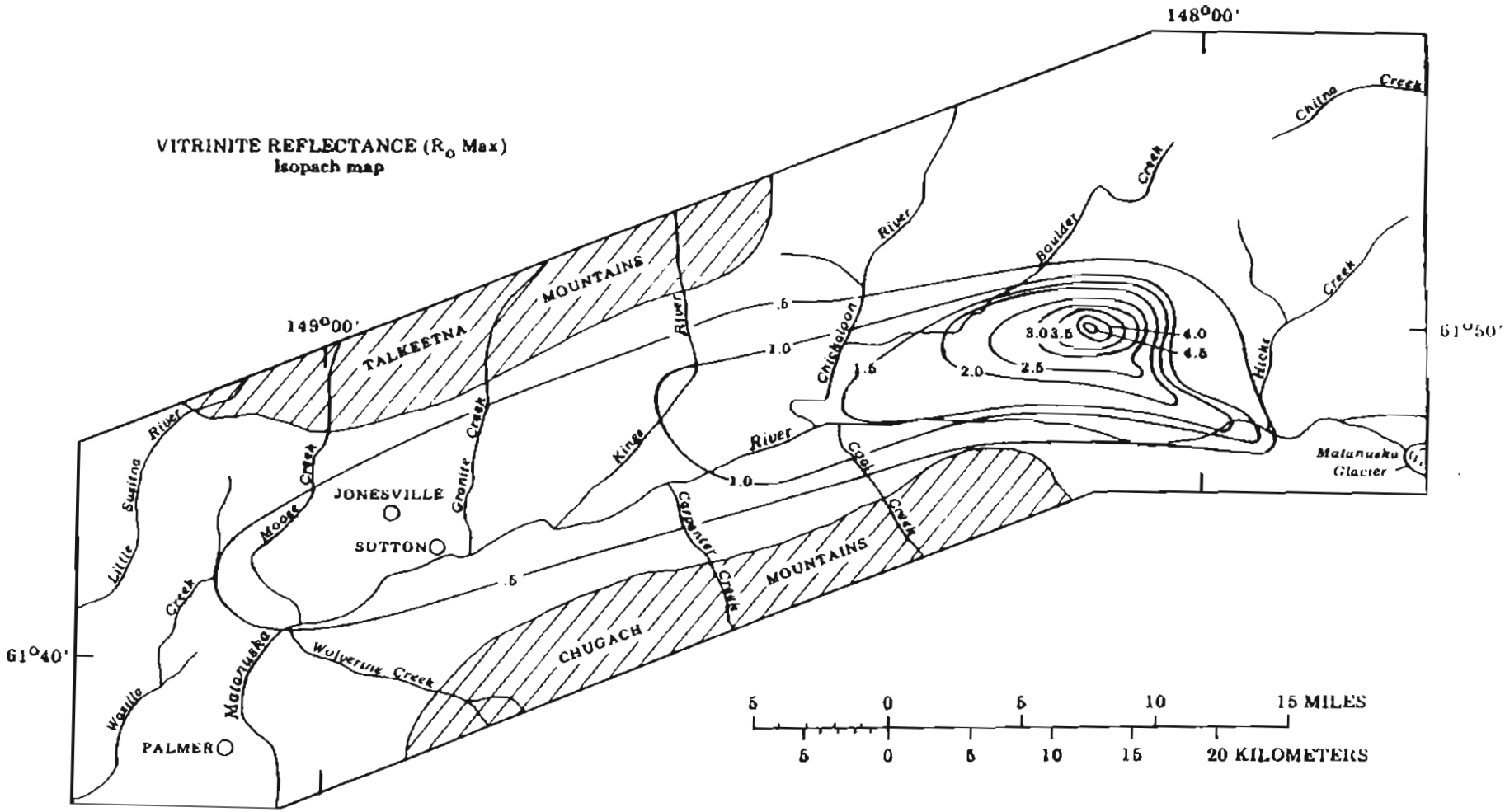

VITRINITE REFLECTANCE (R_o Max)
Isopach map
148°00'
149°00'
61°50'
61°40'
TALKEETNA
MOUNTAINS
CHUGACH
MOUNTAINS
JONESVILLE
SUTTON
PALMER
Little Susitna River
Moose Creek
Granite Creek
Kings River
Chickaloon River
Boulder Creek
Chitna Creek
Hicks Creek
Coal Creek
Carpenter Creek
Wolverine Creek
Matanuska
Matanuska Glacier
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5 0 5 10 15 MILES
5 0 5 10 15 20 KILOMETERS

Figure 13

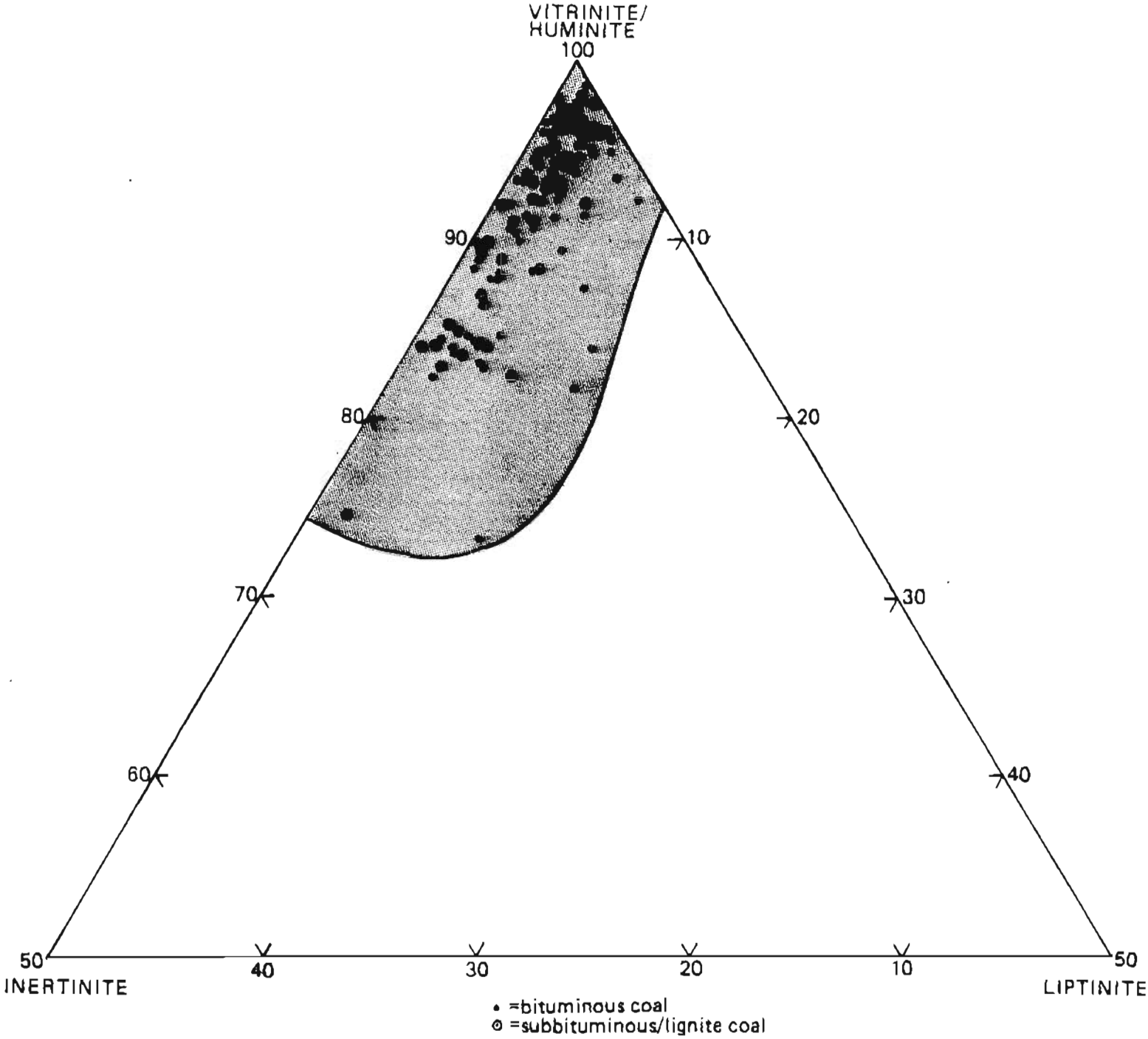

VITRINITE/
HUMINITE
100
90
80
70
60
50
INERTINITE
40
30
20
10
10
20
30
40
50
LIPTINITE
• =bituminous coal
⊙ =subbituminous/lignite coal

Figure 14

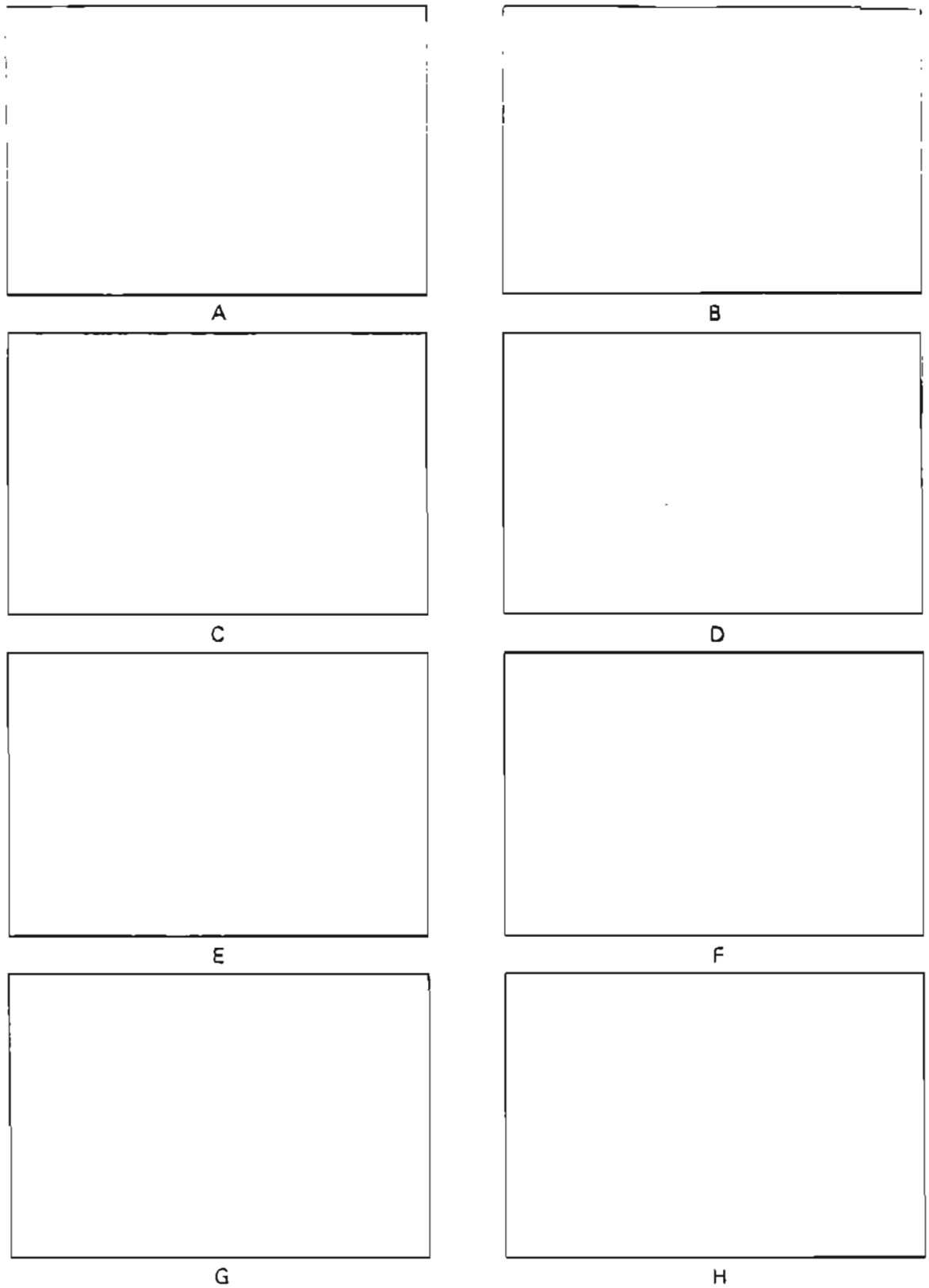


Figure 15

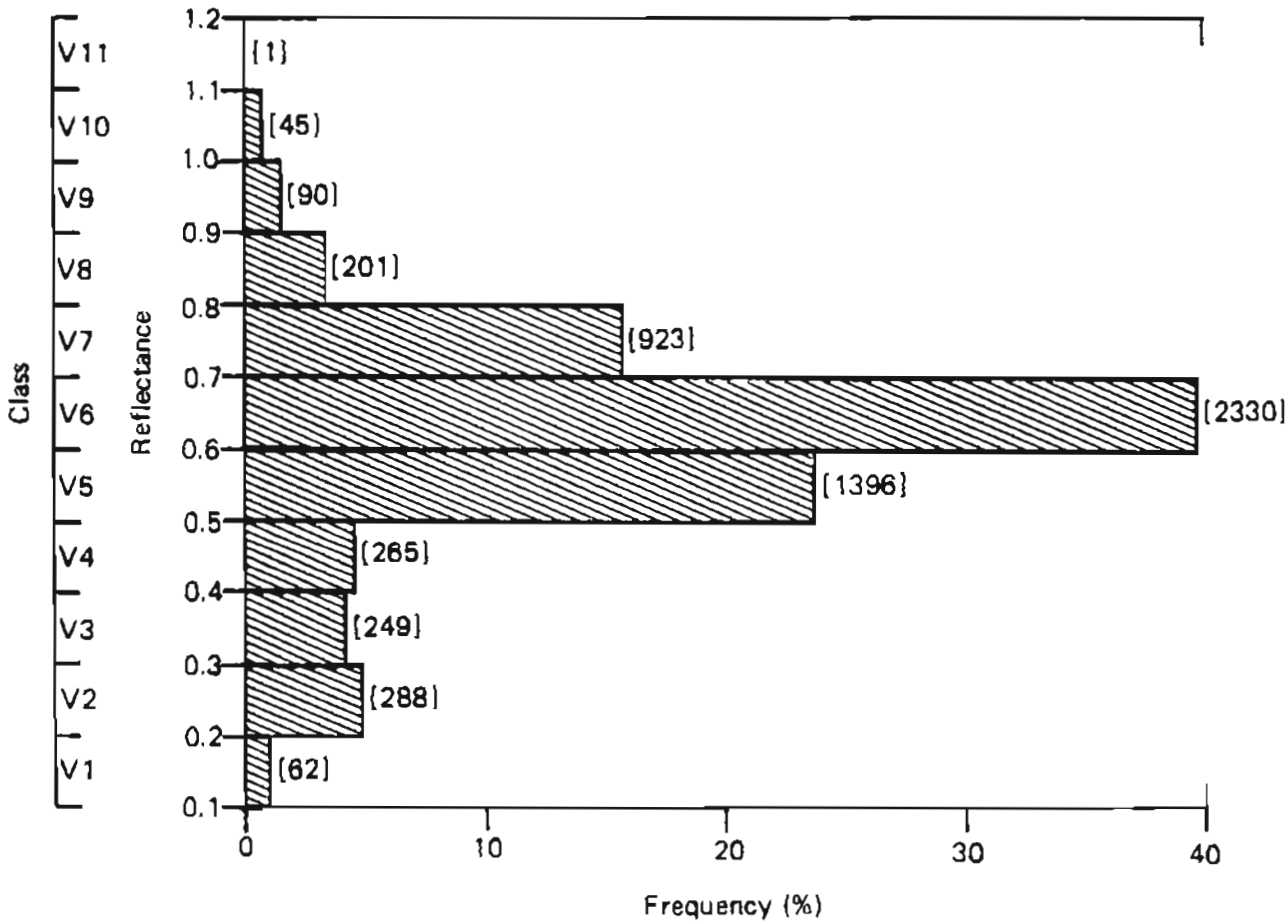

Class
V11
V10
V9
V8
V7
V6
V5
V4
V3
V2
V1
Reflectance
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
[1]
[45]
[90]
[201]
[923]
[2330]
[1396]
[265]
[249]
[288]
[62]
0
10
20
30
40
Frequency (%)

Figure 16

Table 1. Summary of sample location information for coal-bearing regions of southern Alaska examined in this paper. Refer to Figure 2 for the general stratigraphy of each region.

REGION	COAL FIELD(S)	NO. SAMPLES	NO. SITES	GEOLOGIC UNIT
A Nenana basin	Nenana	70	25	Tertiary coal-bearing group; Healy Creek, Suntrana, and Lignite Creek Formations
B Susitna lowland	Beluga	89	19	Tertiary Kenai Group; Tyonek and Beluga Formations
	Yentna	88	15	Tertiary Kenai Group; Tyonek Formation
C Matanuska Valley	Matanuska	63	29	Tertiary Chickaloon Formation
D Alaska Peninsula	Chignik	49	26	Cretaceous Chignik Formation
	Herendeen Bay	66	15	Cretaceous Chignik Formation
	Unga Island	3	3	Tertiary Bear Lake Formation, Unga Conglomerate Member

Table 2. Summary of coal petrologic data for 70 coal samples from the Nenana field.

MACERAL/MACERAL TYPE	RANGE	MEAN
Ulminite*/vitrinite	35.8-90.9	74.3
Pseudovitrinite	0.0- 1.1	0.0
Porigelinite	0.0- 1.9	0.4
Phlobaphinite	0.0- 2.3	0.5
Pseudophlobaphinite	0.0- 2.5	0.5
Humodetrinite	0.6-34.3	7.1
Total huminite	68.5-93.9	82.9
Fusinite	0.0- 1.8	0.2
Semifusinite	0.0- 4.7	0.4
Sclerotinite	0.0- 1.4	0.3
Macrinite	0.0- 7.9	0.6
Inertodetrinite	0.0- 6.4	1.2
Total inertinite	0.2-20.1	2.7
Cutinite	0.0- 0.7	0.0
Sporinite	0.0- 1.1	0.2
Resinite**/suberinite/ exsudatinite	2.5-27.6	14.1
Alginite	0.0- 0.4	0.0
Liptodetrinite	0.0- 0.4	0.0
Total liptinite	2.6-27.6	14.4

*Almost exclusively ulminite.

**Predominantly resinite.

Table 3. Proportions of the three maceral groups in coal samples of the coal-bearing formations of the Nenana field.

FORMATION	MACERAL GROUP		
	HUMINITE	LIPTINITE	INERTINITE
Lignite Creek	H	L-M	M-H
Suntrana	H	L-H	L-M
Healy Creek	H	M-H	L
Undifferentiated Tertiary coal-bearing unit*	H	M-H	L

Criteria as used here:		Low (L)	Moderate (M)	High (H)
	Huminite	<50%	50-75%	>75%
	Liptinite	<5%	5-15%	>15%
	Inertinite	<5%	5-15%	>15%

*Most of these samples were taken from stratigraphic sections that probably correlate with the Healy Creek Formation.

Table 4. Maceral composition summary for 180 coal samples from the Susitna lowland reported on a volume percent, moisture- and ash-free basis.

MACERAL GROUP	MACERAL/ MACERAL TYPE	RANGE IN CONTENTS	MEAN CONTENT
	Ulminite	15.8- 99.0	65.0
	Porigelinite	0.0- 35.4	9.0
HUMINITE	Phlobaphinite	0.0- 18.2	2.7
	Pseudophlobaphinite	0.0- 21.6	3.9
	Humodetrinite	0.2- 63.2	15.7
	Total	76.6-100.0	
	Fusinite	0.0- 9.6	0.6
	Semifusinite	0.0- 5.2	0.3
INERTINITE	Sclerotinite	0.0- 1.4	0.1
	Macrinite	0.0- 2.0	0.9
	Inertodetrinite	0.0- 5.2	0.2
	Total	0.0- 18.6	
	Cutinite	0.0- 3.4	0.4
	Sporinite	0.0- 5.6	0.4
LIPTINITE	Resinite	0.0- 9.2	1.0
	Suberinite	0.0- 3.8	0.5
	Alginite	0.0- 2.0	0.05
	Total	0.0- 11.8	

Table 5. Maceral terminology used in petrologic analysis of Matanuska field coals. Modified from Rao and Smith, 1983.

Low Rank Coal Classification				Bituminous Coal Classification		
Maceral Group	Maceral Subgroup	Maceral	Maceral Class for this study	Maceral Type	Maceral	Maceral Group
huminite	humo-telinite	ulminite	vitrinite	telinite		vitrinite
				vitro-detrinite		
	humo-detrinite			telo-collinite	collinite	
	humo-collinite	gelinite	gelinite	gelo-collinite		
		corpo-huminite	phlobaphinite	corpo-collinite		
			pseudo-phlobaphinite			
	—		pseudo-vitrinite		pseudo-vitrinite	

Classification Applicable To All Coals

Maceral Group	Maceral Class for this study
inertinite	fusinite
	semifusinite
	macrinite
	inertodetrinite
	sclerotinite
	micrinite

Maceral Group	Maceral Class for this study
liptinite	sporinite
	resinite
	exsudatinite
	cutinite
	thick cutinite
	alginite
	other liptinite
	suberinite

Table 6. Petrology of Matanuska field subbituminous coals.

MACERAL GROUP/ MACERAL	SAMPLE (VOLUME %, MINERAL-MATTER-FREE BASIS)							
	CC1-4	EC1-1	MM1-4	MM1-6	RM1-2	WH3-2	WH3-5	WH3-8
Ulminite/ vitrinite	68.2	80.0	76.8	78.7	78.2	75.6	76.0	79.4
Pseudovitrinite	0.0	0.0	0.0	0.7	0.0	0.0	0.1	0.0
Gelinite	0.0	0.5	1.0	0.5	0.4	2.2	0.0	2.2
Phlobaphinite	0.0	0.0	0.0	0.2	0.2	0.2	0.0	0.0
Pseudophloba-phinite	0.0	0.2	0.0	0.0	0.4	0.2	0.0	0.0
Humodetrinite	25.2	10.8	13.6	13.2	9.8	11.4	15.9	12.2
Total huminite	93.4	91.5	91.4	93.3	89.0	89.6	92.0	93.8
Fusinite	0.2	0.0	0.6	0.4	0.0	0.4	0.2	0.0
Semifusinite	0.4	0.0	0.2	0.0	0.8	0.4	0.7	0.0
Sclerotinite	1.4	0.1	0.6	0.3	0.6	1.4	0.6	0.2
Macrinite	0.4	0.2	0.2	0.2	0.0	0.0	0.0	0.2
Inertodetrinite	2.0	0.5	2.0	1.6	0.8	1.4	1.6	0.4
Total inerti-nite	4.4	0.8	3.6	2.5	2.2	3.6	3.1	0.8
Cutinite	0.2	0.0	0.0	0.9	0.6	0.4	1.4	0.2
Sporinite	0.0	0.0	0.0	0.2	0.0	0.0	0.3	0.2
Resinite	1.2	5.2	4.2	0.7	5.4	4.6	1.0	3.2
Suberinite	0.0	0.0	0.0	0.4	0.2	0.0	0.1	0.2
Alginite	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Liptodetrinite	0.8	2.5	0.8	1.0	2.6	1.8	1.9	1.6
Total lipti-nite	2.2	7.7	5.0	4.2	8.8	6.8	4.9	5.4

Table 7. Summary of coal petrologic data for 38 bituminous coal samples from the Matanuska field.

MACERAL	RANGE	MEAN
Vitrinite	57-97	80
Pseudovitrinite	0.0-0.2	0.0
Gelinite	0.0-1.0	0.1
Phlobaphinite	0.0-0.2	0.0
Pseudophlobaphinite	0.0-3.6	0.3
Vitrodetrinite	2-42	15
Total vitrinite	89-100	96
Fusinite	0.0-1.8	0.2
Semifusinite	0.0-2.0	0.2
Sclerotinite	0.0-1.2	0.3
Macrinite	0.0-0.4	0.3
Inertodetrinite	0.0-3.2	0.3
Total inertinite	0.0-4.8	1.1
Cutinite	0.0-2.2	0.1
Sporinite	0.0-0.2	0.0
Resinite	0.0-4.4	0.9
Suberinite	0.0-5.8	0.7
Alginite	0.0-0.2	0.0
Liptodetrinite	0.0-7.2	1.6
Exsudatinite	0.0-0.8	0.1
Total liptinite	0.0-9.4	3.0

Table 8. Summary of coal petrologic data for 17 semianthracite and anthracite coal samples from the Matanuska field.

MACERAL	RANGE	MEAN
Vitrinite	52-98	82
Altered vitrinite	0-34	5.5
Pseudovitrinite	0.0-7.8	0.7
Gelinite	0.0-0.0	0.0
Phlobaphinite	0.0-0.0	0.0
Pseudophlobaphinite	0.0-0.0	0.0
Vitrodetrinite	2-34	10
Total vitrinite	66-100	98.7
Fusinite	0.0-2.6	0.3
Semifusinite	0.0-1.6	0.1
Sclerotinite	0.0-1.4	0.3
Macrinite	0.0-1.0	0.1
Inertodetrinite	0.0-1.6	0.3
Total inertinite	0.0-4.2	1.2
Cutinite	0.0-0.0	0.0
Sporinite	0.0-0.0	0.0
Resinite	0.0-0.8	0.1
Suberinite	0.0-0.0	0.0
Alginite	0.0-0.0	0.0
Liptodetrinite	0.0-0.4	0.0
Total liptinite	0.0-1.2	0.1

Table 9. Summary of coal petrologic data for 61 bituminous coal samples from Chignik and Herendeen Bay coal fields, Alaska Peninsula.

MACERAL GROUP	MACERAL/ MACERAL TYPE	RANGE IN CONTENTS	MEAN CONTENT
	Vitrinite	57.8- 89.8	78.3
	Pseudovitrinite	0.0- 3.4	0.1
VITRINITE	Gelinite	0.0- 12.8	2.4
	Corpocollinite	0.0- 4.4	0.5
	Vitrodetrinite	1.6- 38.8	9.7
	Total liptinite	73.0-100.0	91.0
	Fusinite	0.0- 7.8	2.2
	Semifusinite	0.0- 4.0	1.1
INERTINITE	Sclerotinite	0.0- 2.4	0.4
	Macrinite	0.0- 2.6	0.5
	Inertodetrinite	0.0- 6.4	2.0
	Total inertinite	0.0- 18.4	6.2
	Cutinite	0.0- 2.0	0.4
	Sporinite	0.0- 3.8	0.8
	Resinite	0.0- 4.0	0.6
LIPTINITE	Exsudatinite	0.0- 0.8	0.2
	Suberinite	0.0- 1.0	0.1
	Alginite	0.0- 0.8	<0.1
	Liptodetrinite	0.0- 3.4	0.6
	Total liptinite	0.0- 9.0	2.7

Table 10. Summary of petrologic data for 54 subbituminous coal and lignite samples from the Chignik, Herendeen Bay, and Unga Island coal fields, Alaska Peninsula.

MACERAL GROUP	MACERAL/ MACERAL TYPE	RANGE IN CONTENTS	MEAN CONTENT
HUMINITE	Ulminite	56.6-92.4	78.4
	Pseudovitrinite	0.0- 0.2	<0.1
	Porigelinite	0.2-13.2	3.4
	Phlobaphinite	0.0- 4.4	0.6
	Pseudophlobaphinite	0.0-11.6	1.3
	Humodetrinite	1.4-26.4	8.3
	Total huminite	82.4-98.0	92.0
INERTINITE	Fusinite	0.0- 5.0	1.2
	Semifusinite	0.0- 6.2	1.2
	Sclerotinite	0.0- 2.4	0.4
	Macrinite	0.0- 6.0	0.8
	Inertodetrinite	0.2- 9.0	2.6
	Total inertinite	0.2-24.0	6.2
LIPTINITE	Cutinite	0.0- 1.2	0.2
	Sporinite	0.0- 1.8	0.3
	Resinite	0.0- 2.2	0.5
	Exsudatinite	0.0- 2.4	0.3
	Suberinite	0.0- 2.6	0.2
	Alginite	0.0- 0.2	<0.1
	Liptodetrinite	0.0- 1.4	0.3
	Total liptinite	0.4- 5.6	1.8