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PETROGRAPHIC, MINERALOGICAL AND CHEMICAL CHARACTERIZATION OF CERTAIN ALASKAN COALS AND WASHABILITY PRODUCTS

P. Dharma Rao and Ernest N. Wolff

MASTER

May, 1981

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PETROGRAPHIC, MINERALOGICAL, AND CHEMICAL CHARACTERIZATION OF CERTAIN ALASKAN COALS AND WASHABILITY PRODUCTS

Final Report

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ABSTRACT

Petrological, mineralogical and chemical characterization provides basic information needed for proper utilization of coals. Since many of these coals are likely to be beneficiated to reduce ash, the influence of coal washing on the characteristics of the washed product is important.

Twenty samples of Alaskan coal seams were used for this study. The coals studied ranged in rank from lignite to high volatile A bituminous with vitrinite/ulminite reflectance ranging from 0.25 to 1.04. Fifteen raw coals were characterized for proximate and ultimate analysis, reflectance rank, petrology, composition of mineral matter, major oxides and trace elements in coal ash. Washability products of three coals from Nenana, Beluga and Matanuska coal fields were used for characterization of petrology, mineral matter and ash composition.

Petrological analysis of raw coals and float-sink products showed that humodetrinite was highest in top seam in a stratigraphic sequence and higher towards the top of a seam. Suberinite was identified in all tertiary coals studied and none were found in the two cretaceous coals from northern Alaska. Significant differences were found in the petrology, mineralogy and ash composition of float-sink products, indicating that in evaluating coal resources it is not adequate to characterize the raw coals alone. Characterization of float-sink products will help understand the nature of the product obtainable from the raw coal rather than coal as mined.

ACKNOWLEDGEMENTS

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INTRODUCTION

Coal utilization is dictated by the characteristics of the coal. Among the characteristics most generally sought are the proximate analysis, ultimate analysis, mean maximum reflectance of vitrinite, coal petrological composition, composition of ash, both major oxides, minor as well as trace elements, nature and concentration of mineral matter in coal, and finally the washability characteristics that permit evaluation of the coal to its amalnability to reduction of ash and sulfur and improvement in heating value. It is also important to know the characteristics of the washed coal in terms of coal petrology, ash and mineral matter composition since they would be different from the raw coal.

Twenty samples--collected under the washability characterization program sponsored by the Department of Energy (Rao and Wolff (1)(2))--were used for this study. Two samples were selected for total characterization as described above. Twelve samples were selected for raw coal characterization. Ash analysis and vitrinite reflectance were determined for the five remaining samples.

COAL FIELDS SAMPLED

The twenty samples used for this study were collected for the Department of Energy Washability study program. Six hundred pound channel samples were collected and transported to the laboratory in heavy-duty plastic bags in gunny sacks. Details of sample location, geology of the area, the stratigraphic section and complete washability data are presented elsewhere by Rao and Wolff (1)(2). Certain essential information is reviewed here for completeness. Figure 1 is a map of Alaska showing major coal resource areas and sampling locations.

Nenana Coal Field

The Nenana Coal field is located about 110 miles south of Fairbanks on the Parks Highway at Healy. The field extends 80 miles in the east-west direction and is one to thirty miles wide (3)(4)(5). The coal bearing formation consists of sandstones, siltstones, claystone, shale and numerous thick coal beds and is divided into five foramtions by Wahrhaftig et al (6). Samples numbered UA-100, 101, 102, 103, 104, 105 and 119 were collected in this field at Usibelli Coal Mine.

Jarvis Creek Coal Field

The Jarvis Creek coal field is located about 125 miles southeast of Fairbanks on the north side of the Alaska Range. The coal field is 16

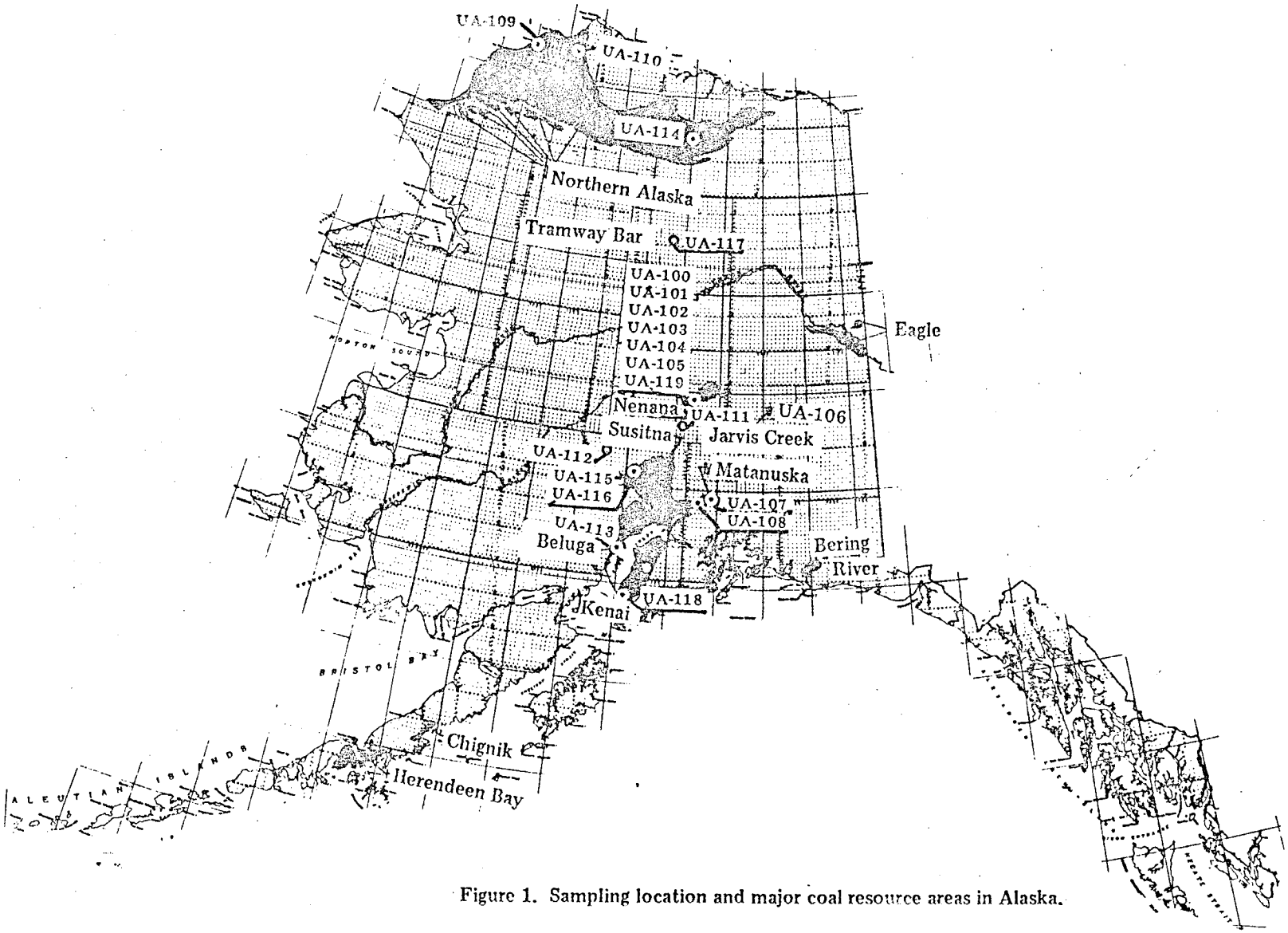


Figure 1. Sampling location and major coal resource areas in Alaska.

sqaure miles in area and the site of sporadic mining activity. It is about 6 miles via a pioneer gravel raod from the Richardson Highway, Mile 242. The coal field has been mapped by Wahrhaftig and Hickcox (7). It is Tertiary in age and has been correlated to the Healy Creek formation of the Nenana coal field, 100 miles to the west.

The coal bearing formation consists of a sequence of interbedded lenses of poorly consolidated sandstone, siltstone, claystone, and conglomerate. Although there are numerous coal beds, those with thicknesses exceeding 2-1/2 feet are rare.

Matanuska Coal Field

Matanuska coal field is about 45 miles northeast of Anchorage on the Glenn Highway. In the Upper Matanuska Valley the coal increases in rank from high volatile A bituminous at the Castle Mountain Mine, to anthracite at the Anthractie Ridge. The coal in the Wishbone Hill District of the Lower Matanuska Valley is high volatile B bituminous. The coal seams are limited to the Chickaloon formation of Tertiary age. This formation consists of nonmarine rocks that include all gradations from coarse sandstone and conglomerate to claystone. It is concealed by a mantle of Quaternary deposits or by a capping of younger Tertiary conglomerate (8)(9).

Coal was mined extensively in this area until 1968 when the Evans Jones coal mine ceased operations.

There are two coal beds exposed at the Castle Mountain Mine (not operated since the early 1960's). The lower bed, 7.0 feet thick, was sampled (UA-107). Another coal seam was sampled at the Premier Mine (UA-108) and is from a region highly faulted and at the creek of an anticline.

Northern Alaska Coal Field

The great bulk of Alaska's cola resources lie in the northern Alaska field, north of the Brooks Range. Coal-bearing Cretaceous rocks are known or inferred to underlie about 58,000 square miles (Barnes, 10). Coal beds of potential economic significance, are confined almost entirely to the Corwin formation. The Cretaceous rocks include sandstone, conglomerate, siltstone, shale and coal. Although these rocks are mostly of marine origin, non-marine coal-bearing rocks predominate in some areas and intertongue with the marine rocks.

Wainwright

Sample No. UA-109 was from an outcrop on the east bank of the Kuk River, about 14 air miles from Wainwright. The seam is 5 feet thick and the bottom of the seam is approximately 4 feet above the river level. The stratigraphic position of this bed has not been definitely established, but according to Barnes (10) it is believed to be in rocks correlative with the Chandler formation. Coal outcrops have been de-

scribed and in fact some have been mined for a distance of 10 miles along the Kuk River. There are two principal beds exposed at the outcrops with approximately 10 feet of coal. The individual beds ranging in thickness from 2 to 6 feet with 10 to 50 feet overburden outcrop along the Kuk River (Tonges and Jolley, (11)).

Meade River

Coal out crops along the west bank of the Meade River near the village of Atkasook. Coal for shipment to Barrow has been mined during the forties and early fifties in an open trench and underground. The U.S. Bureau of Mines has done extensive drilling in this region and delineated the coal-bearing areas for mining purposes (Sanford and Pierce (12)). Four coal seams have been identified in this locality. The top No. 1 bed is 34 inches thick, the No. 2 bed is 5 to 6 feet, the lower No. 3 and No. 4 beds are approximately 12 inches and the beds are separated by 1 to 2 feet of clay (12). The seam that is sampled for this study is No. 2 bed (UA-110).

Sagwon Bluff

Rocks in the Sagavanirktok quadrangle are part of a thick sequence of submarine volcanic and non-marine carbonate rocks of Mississippian through Tertiary age. Coal has been reported in Ignek formation of Cretaceous age and Sagavanirktok formation of Tertiary age. The sampled

coal outcrop (UA-114) was from the bluffs on the Sagavanirktok River adjacent to the Trans Alaska Pipeline. The sampling location has not been mapped in detail and the age of the formation in which the coal occurs has not been determined (Cretaceous to Tertiary).

Broad Pass Coal Field

Broad Pass coal field is located near Broad Pass station, 166 miles south of the Alaska Railroad and Parks Highway. The field may be divided into two basins. The Costello Creek Basin (Wahfhaftig (13)) is on the west side of the railroad and covers about seven square miles.

Coal Creek Basin is located on the east side of the Alaska Railroad and lies in an area three miles long and one mile wide (Hopkins (14)). About 1 1/2 square miles are known to be underlain by coal-bearing rocks.

Coal was mined from the basin until the mid-1940's. The sample collected (UA-111) was from an outcrop near the former Coal Creek mine. The seam is 8 feet thick and is covered by unconsolidated sediments. Access to the locality is via an old wagon trail from the Parks Highway. The trail crosses several streams and its use is limited to four-wheel-drive vehicles.

Little Tonzona Coal Bed

Occurrences of coal near Farewell were first observed by Brooks

(15) in 1902. Capps (16) described 20-foot-thick coal beds in Tertiary non-marine sedimentary rocks south of Kantishna. The Little Tonzona coal bed, however, was first described in 1977 by Player (17) and recently by Sloan et al (18).

Coal beds occur in Tertiary non-marine sandstone, siltstone and volcanic rocks in widespread isolated exposures north and south of Farewell fault, from Big River northeast to Kantishna and beyond (Player (17). The sampled seam occurs in an isolated exposure of Tertiary non-marine sedimentary rocks on the southwest bank of the Little Tonzona River. Beds strike N60^{o}E to N70^{o}E and dip 55° to 70° northwest. The total stratigraphic thickness measured by Player is about 195 feet, and the sample (UA-112) was collected from the exposed portions of the coal seam.

Tramway Bar Coal Occurrence

Occurrence of coal near Tramway Bar was first reported by Schrader (19) in 1899 and has been mined for local use (Smith and Mertie (20) p. 316). The occurrences are at the northeastern part of the Yukon-Koyukuk Province. The province is a broad tract of Cretaceous and Tertiary rocks that stretches across west-central and south-central Alaska from the Brooks range to the Yukon River delta (Patton (21)). Tramway Bar occurrence is the westernmost outcrop of coal in the basin, and is assigned an upper Cretaceous age (Patton (21)).

Coal is exposed along the north bank of the Koyukuk River in three seams, a 3-foot seam, an 8-inch seam, and a 17-foot 6-inch seam. The top portion of the 17 foot seam was covered and was difficult to sample. The bottom 13 feet of the seam was sampled including bands of interbedded shale. The coal bed dips at 56^{0} and the sample was cut horizontally across the seam at a level six feet above the river.

Cook Inlet Sedimentary Basin

Non-marine sedimentary rocks of Cook Inlet basin exceed 18,000 feet in thickness and in some parts of the basin they may extend to 27,000 feet. The rocks outcrop as far north as Peters Hills and continue south to Homer forming a belt 200 miles long and 70 miles wide. Although these formations are known to be coal-bearing since the early 1900's, recent discoveries of petroleum and gas fields sparked intensive drilling that resulted in a greater understanding of the geology of these Tertiary rocks.

From purely geographical considerations the sedimentary basin is divided into three coal fields: a) Kenai field, b) Beluga field and c) Yentna field. The coal is of Tertiary age and is limited to the Kenai group (formerly Kenai Formation). Coal is interbedded with coarse to fine grained sandstone, siltstones and occasional conglomerates. The Kenai Group is subdivided into four formations which include (from older to younger) Hemlock Conglomerate, Tyonek, Beluga and Sterling Formations.

a. Kenai coal field. Much of the Kenai lowland is underlain by coal bearing rocks. Coal exposures are found extensively on steep bluffs along the east shore of the Cook Inlet, rising at places to 200 feet above the beach. Barnes and Cobb (22) made a detailed study of those outcrops and presented extensive sections of these exposures. The beds are not massive in thickness; Barnes, however, Barnes identified at least 30 beds ranging in thickness from 3 to 7 feet.

Coal has been mined in the Homer district since 1888. There has been no mining since 1951 when the Homer Coal Corporation ceased operations. Some residents of the Homer areas still collect coal from the beach for domestic use, particularly after a severe storm. The sample collected (UA-118) is from the Cabin Bed and the location is equivalent to locality 117 of Barnes (22). The seam is 6 feet thick and has about 5 feet overburden at the sampling location. The seam outcrops on a vertical face, and sampling was accomplished with the aid of technical rock-climbing equipment.

b. Beluga coal field. Barnes (25) defined the Beluga-Yentna region as the broad lowland west of lower Susitna River that is bounded on the north and west by the Alaska Range, and on the south by Upper Cook Inlet and the Chakachatna River. The Beluga Coal field is part of Cook Inlet sedimentary basin and is located approximately 60 miles west of Anchorage on the northwest shore of Cook Inlet. The field can be subdivided into three coal-bearing regions. Region 1, the Three Mile Creek Basin, located about 6 miles from Cook Inlet, contains approxi-

mately 22 steeply-dipping seams averaging 10 feet in thickness. Region 2, the Chuitna Basin, is located about 17 miles from Cook Inlet. There are at least two mineable coal beds, one of which exceeds 40 feet in thickness, outcropping along the Chuitna River. Region 3, the Capps Basin, lies 26 miles from Cook Inlet. This area has two seams in the Tyonek formation: the Upper Capps Bed with an average thickness of 17 feet, and the Waterfall Bed (Capps Bed of Barnes) with an aggregate thickness from 20-49 feet. The latter has an average mineable thickness of 30 feet with interburden varying from 80 to 280 feet. Sample No. (UA-113) was from this seam and represents the bottom 30 feet of the seam. The top 6 feet is dirty and will be sampled separately in future investigations.

The lower part of the Tyonek Formation is well exposed south of the Capps Glacier and the section is described by Adkison, Kelley and Newman (23). The location is about two miles north of the sample location of UA-113. These beds were designated part of the type section of the Seldovian stage by Wolff, Hopkins and Leopold (24).

c. Yentna coal field. There are numerous outcrops of the Kenai Group in the northern part of the Beluga-Yentna region. Much of the area is covered by a mantle of Quaternary deposits, Barnes (25) concludes, "outcrops of the Kenai Formation (now Kenai Group), though mostly of small extent, are so widely distributed as to leave little doubt that the formation underlies much of the lowland areas". Occurrences of coal in the Fairview Mountain area was first described by

Capps (16). An outcrop on Chicago Gulch was determined by Wolff, Hopkins and Leopold (24) to be Seldovian. Of all the coal outcrops in the region, the thickest was Locality 2 described by Barnes (25). The bed is 55 feet thick and has no visible partings. The middle part of the bed was covered with gravel and could not be reached for sampling. The part of the bed below (UA-115) and above (UA-116) were sampled separately. The sampled outcrop is approximately 23 air miles from Peters Creek and access was via helicopter. Peters Creek is about 25 miles on Peters Creek Road from the Cache Creek Station on the Parks Highway.

LABORATORY PROCEDURES

Sample Preparation

Figure 2 is a flowsheet of procedures used in the laboratory for processing samples for washability studies (Rao and Wolff (1)(2)). Washability products of 1 1/2 inches to 100 mesh materials were used in this study. Raw coal and float-sink products crushed to 20 mesh were used for petrographic analysis. Samples pulverized to 60 mesh were used for the preparation of low and high temperature ashes. High temperature ash was prepared by oxidizing pulverized coal in quartz boats at 750°C. This ash was used for the determination of all major oxides, trace and minor elements. Mineralization in coal was isolated by oxidizing pulverized coal at a temperature less than 150°C, using LFE model LTA-302 low temperature asher in excited oxygen plasma to obtain essentially

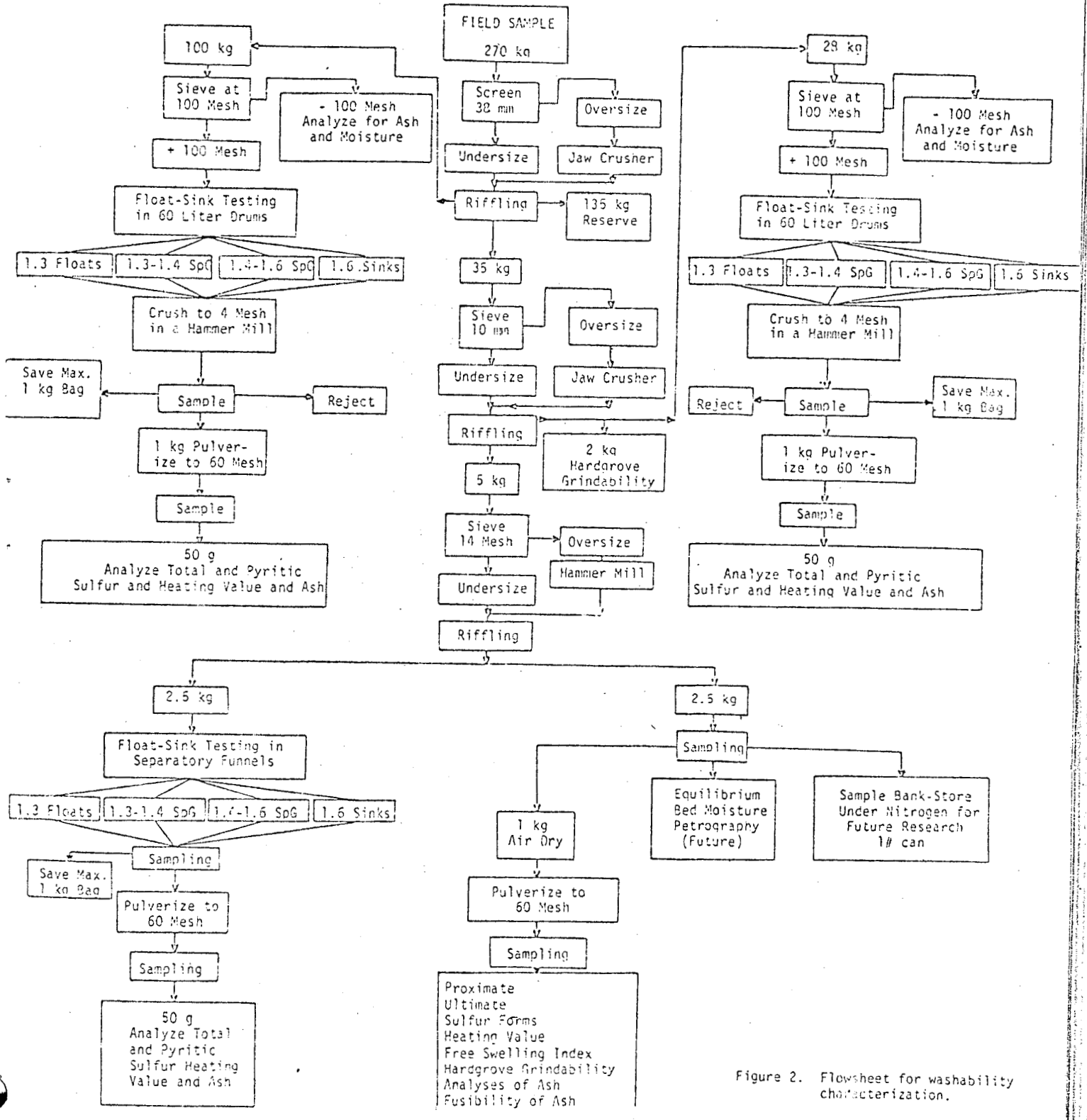


Figure 2. Flowsheet for washability characterization.

unaltered mineral components of coal. The ash was further pulverized in an agate mortar covered with alcohol, to prepare for x-ray diffraction and infrared spectrometric analyses.

COAL PETROLOGY

Procedures recommended by the American Society for Testing and Materials (ASTM), specifications D2797-72, D2798-72, D2799-72, were generally followed for petrological studies. Coal samples crushed to 20 mesh were made into 1" diameter pellets using epoxy binder under pressure. Grinding of the pellets was done on 120 micron diamond lap followed by 30 micron metal bonded diamond lap with Buehler automet for 2 minutes. Polishing was done using automet with 1 micron and 0.05 micron alumina suspensions for 2 minutes each stage, followed by one minute of polish with distilled water flooding.

A special technique was needed for preparation of thin sections of subbituminous "C" coals, since these coals dry out and crack with normal procedures. Blocks of coal with 1" x 2" face x 1" thick were ground with 30 micron diamond lap followed by 1 micron alumina and finished with .05 micron alumina. The piece was kept wet all the time (stored under water) to prevent drying and resultant cracking. A glass slide is cleaned with acetone and dried, the polished face is rinsed with a jet of acetone quickly wiped clean and glued to the face of the glass slide with a few drops of methyl methacrylate adhesive, commonly sold as super glue and other trade names, while applying heavy pressure with the

thumb. After five to ten seconds, pressure can be released and the slide covered with a wet paper towel for 10 minutes. The coal piece is cut off with a diamond saw leaving coal on the slide, one to two mm thick. The slide was held in a plastic slide holder and ground on 30 micron diamond lap while carefully applying pressure to whichever side appeared opaque. The slide could be ground down within a few minutes. Further thinning was done on 1 micron alumina. The face was finished with .05 micron alumina. The slide was cleaned (wiped with a tissue) and immediately covered with a glass slide, again using super glue.

The procedure should be completed rapidly. Long soaking in water will allow the adhesive to peel off and the coal will dry out and fracture severely while in air. From the time the block is glued to the glass slide the section should be processed to completion.

Reflectance Measurements

All polished sections were dried in a dessicator prior to measurement of reflectance. Low-rank coal particles fracture badly due to dessication. Reflectance apparatus consisted of Leitz orthoplan microscope with MPV-3 system (Figure 3), with a motorized drive for the stage. A square leaf diaphram with a 5 micron square measuring area of the specimen was used. All reflectance measurements were made using a filter to give peak transmittance at 546 nm wave length. Bausch and Lomb Company optical glasses were used as reflectance standards. Maximum reflectances were measured in oil for 100 vitrinite/ulminite particles using two pellets.

Petrological Analysis

Terminology and procedures approved by the International Committee for Coal Petrology (26) and Stach's textbook of coal petrology (27) were followed. Brown coal terminology was used for all subbituminous and lower-rank coal, and hard coal terminology was used for bituminous coals. Tables 1 and 2 summarize the macerals of brown coals and hard coals (26). A thousand points were counted between 2 pellets for petrological analysis. Point counts were made under both normal incident light and fluorescent incident light excitation (blue light) for liptinite macerals and fluorescent vitrinite. The fluorescence system consisted of Leitz SmLux microscope, ploempak fluorescence incident light illuminator and 100w mercury lamp, fitted with I2 cube (Figure 4). Figures 5, 6 and 7 show the occurrence of various macerals. Figure 8 shows fluorescence colors of liptinite macerals in fluorescence (blue light). In reflected light, examination of fluorescence of liptinite macerals makes their identification unambiguous.

Determination of Minerals by X-Ray Diffraction

An internal standard method recommended by Rao and Gluskoter (28) was used for the quantitative analysis of minerals in low temperature ash. A Phillips Norelco X-Ray diffraction system with $CuK\alpha$ Ni-filtered radiation at 40 Kv, 15 ma was used.

Mineral matter residue obtained from low temperature ashing was first ground in an agate mortar to minus 200 mesh. As an internal standard, 0.02 grams of finely powdered pure fluorite was mixed with 0.1

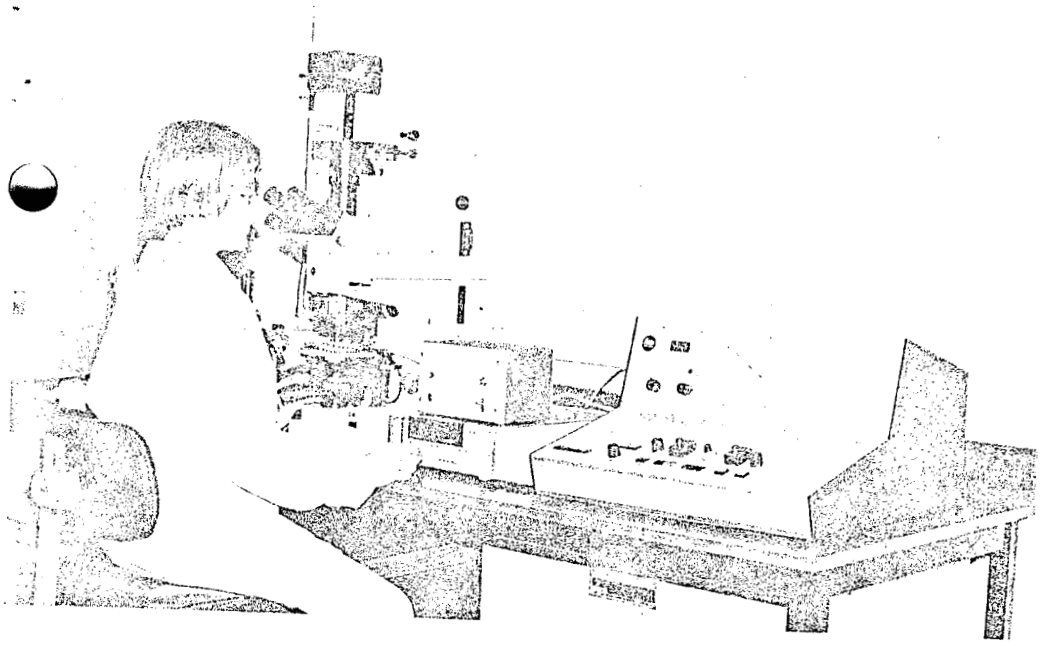


Figure 3. Leitz orthoplan microscope with MPV 3 reflectance measurement system and vario-orthomat photomicrographic camera system.

Figure 4. Leitz Sm-Lux microscope for reflected light fluorescence examination of Liptinite macerals.

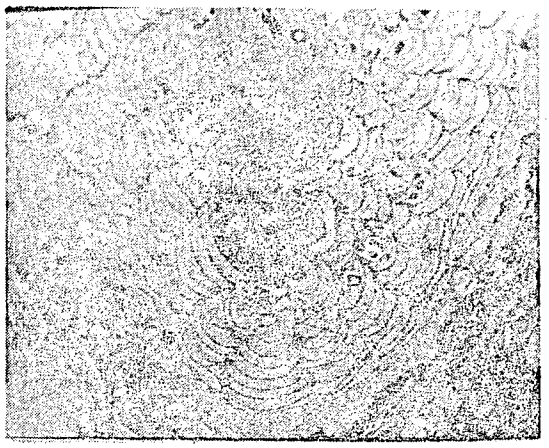
TABLE 1. Summary of the Macerals of Brown Coals (26)

Group Maceral	Maceral Subgroup	Maceral	Submaceral
Huminite	Humotelinite	Textinite	
		Ulminite	Texto-Ulminite Eu-Ulminite
	Humodetrinite	Attrinite	
		Densinite	
	Humocollinite	Gelinite	Porigelinite Levigelinite
		Corpohuminite	Phlobaphinite Pseudophlobaphinite
Liptinite		Sporinite	
		Cutinite	
		Resinite	
		Suberinite	
		Alginite	
		Liptodetrinite	
		Chlorophyllinite	
Inertinite		Fusinite	
		Semifusinite	
		Macrinite	
		Sclerotinite	
		Inertodetrinite	

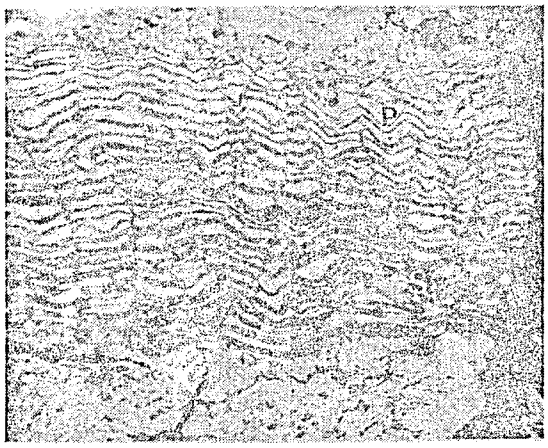
TABLE 2. Summary of the Macerals of Hard Coals (26)

Group Maceral	Maceral	Submaceral
Vitrinite	Telinite	Telinite 1 Telinite 2
	Collinite	Telocollinite Gelocollinite Desmocollinite Corpocollinite
	Vitrodetrinite	
Exinite	Sporinite	
	Cutinite	
	Resinite	
	Alginite	
	Liptodetrinite	
Inertinite	Micrinite	
	Macrinite	
	Semifusinite	
	Fusinite	Pyrofusinite Degradofusinite
	Sclerotinite	
	Inertodetrinite	

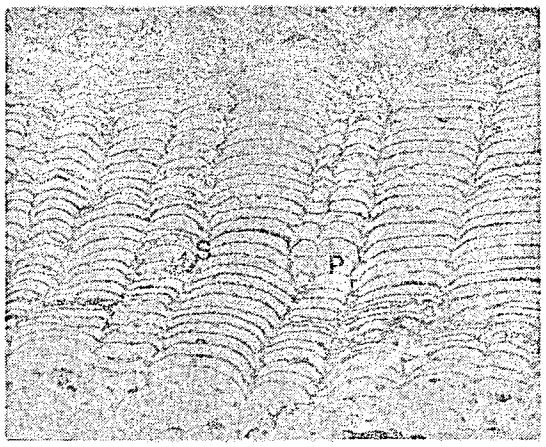
A. Corpohuminite bodies, partly dense(D) and partly porous(P) in a root section (UA-103)



B. Phlobaphinite(P) and suberinite (S) in a traverse section of root bark (UA-113)

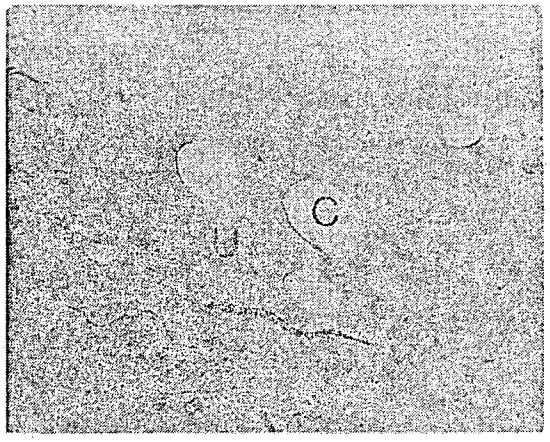


C. Pholbaphinite (P) cell fillings and thick suberinites (S) cell walls of a cortex (UA-101)



D. Phlobaphinite (P) with thin suberinite (S) cell walls (UA-103)

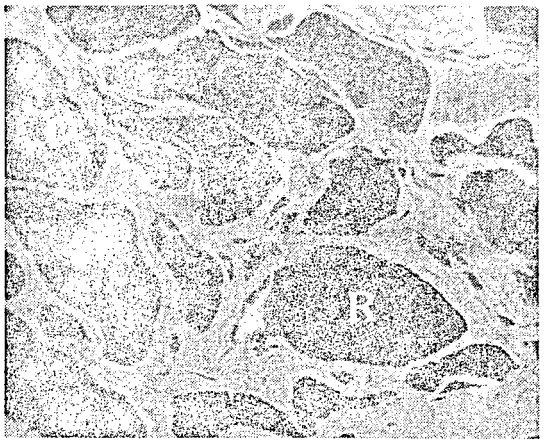
E. Large and small corpohuminites (C)(UA-113)



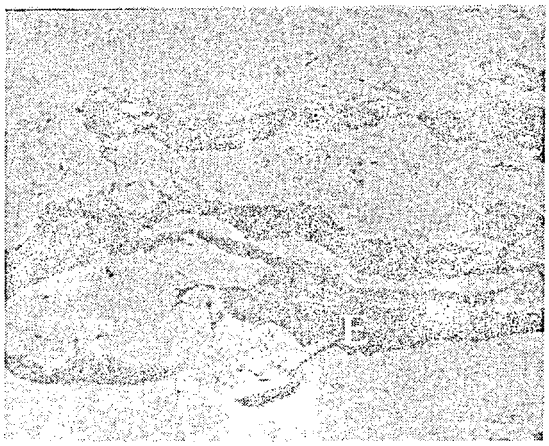
F. Corpohuminites (C) in ulminite (U)(UA-113)

Figure 5. Photomicrographs of Beluga and Nenana coals showing corpohuminites and associated macerals. Oil Immersion 500 X

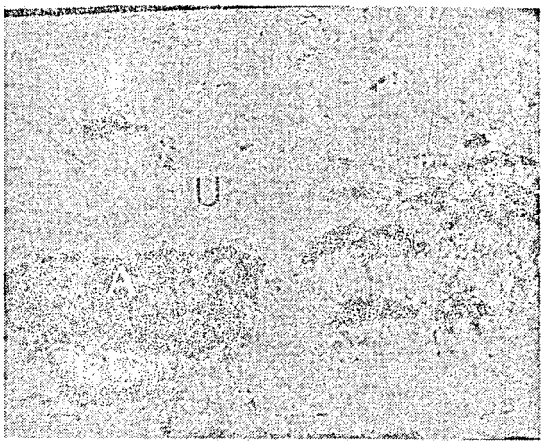
A. Autocthonous resinite (R) in cell tissue (UA-100)



B. Resinite (R) cell fillings surrounded by thin cell walls (UA-108)

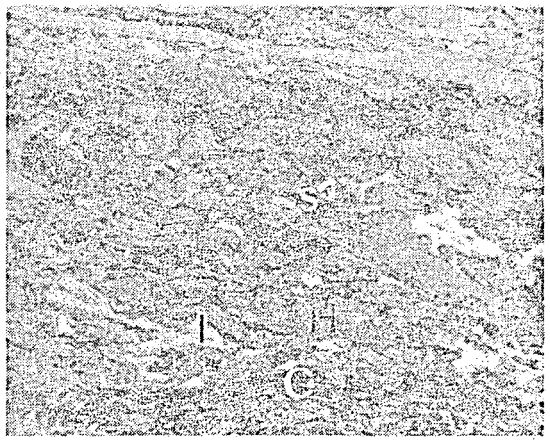


C. Exsudatinite (E) filling cracks (UA-110)



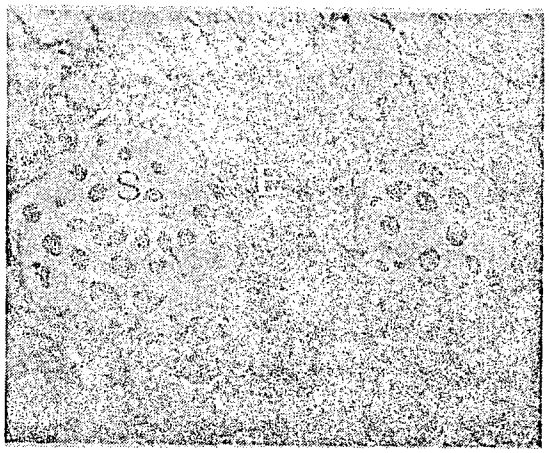
D. Alginite (A) embedded in ulminite (UA-110)

E. Alginite (A) and cutinite (C) (UA-113)

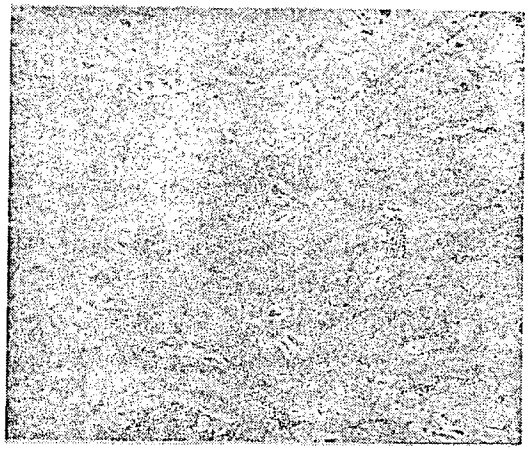


F. Sporinite (S), cutinite (C), inertodetrinite (I), in humodetrinite (H) (UA-100)

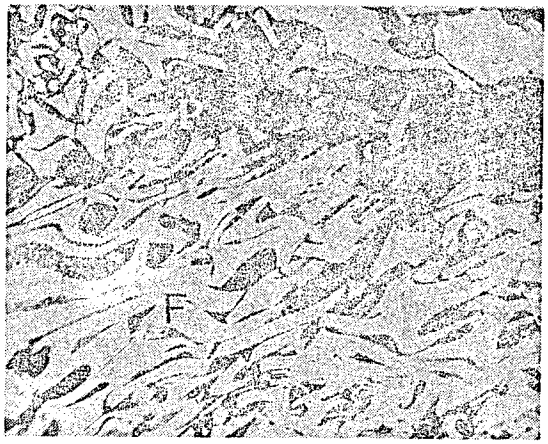
Figure 6. Photomicrographs of Beluga, Nenana, Matanuska and Northern Alaska coals showing liptinite and associated macerals. Oil Immersion 500 X



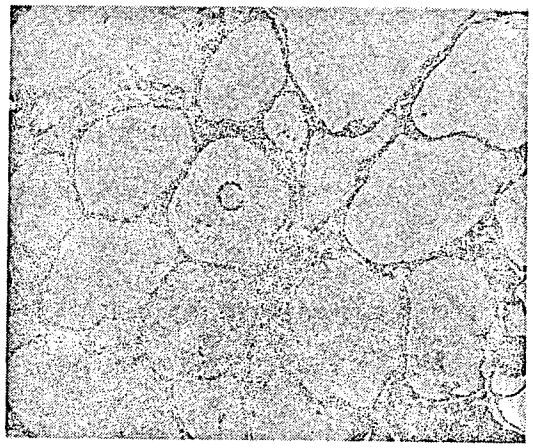
A. Sclerotinite (S) and Exinite (E)(UA-113)



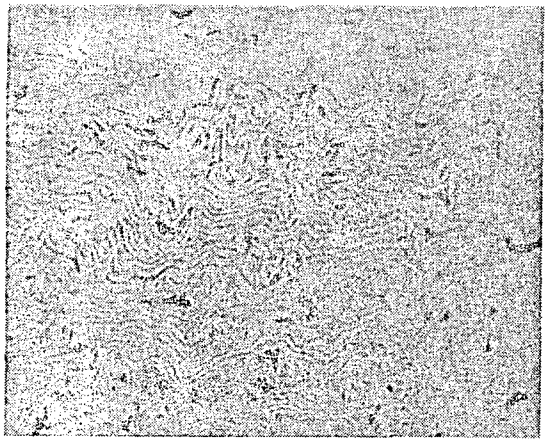
B. Increase in reflectance (↑) of ulminite tissue possibly due to fungal activity (UA-100)



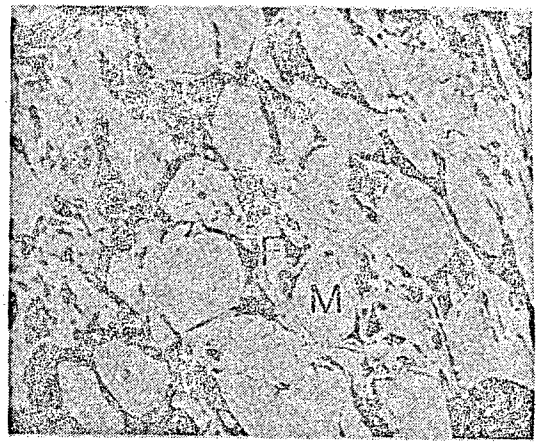
C. Porigelinite (P) filling fusinite (F) cell lumens (UA-109)



D. Corpocollinite (C) filling cell lumens (UA-113)

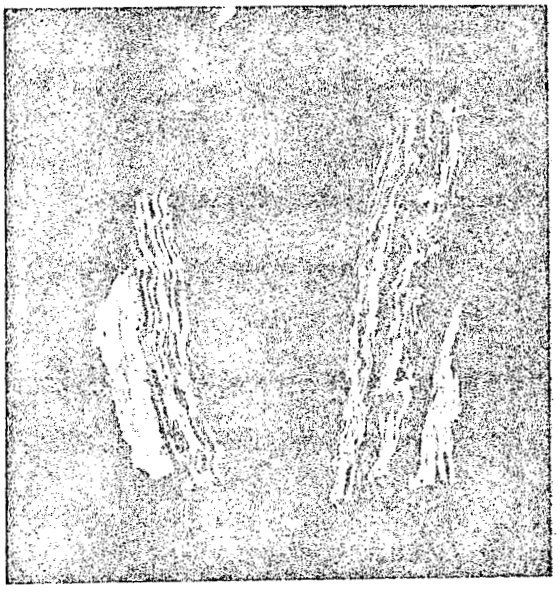


E. Typical Eu-ulminite (UA-119)



F. Macrinite (M) filling fusinite (F) cell cavities (UA-109)

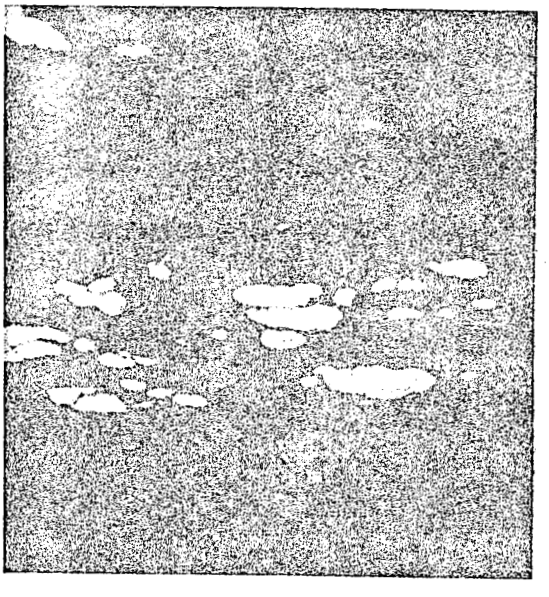
Figure 7. Photomicrographs of Beluga, Nenana and Northern Alaska coals showing various macerals. Oil Immersion 500 X



A. Suberinite

B. Resinite filling cell cavities. Same as Figure 6B.

C. Exsudatinite filling fractures. Same as Figure 6C.



D. Alginite. Same as Figure 6D.

Figure 8. Photomicrographs of liptinite macerals in fluorescence (blue light excitation) reflected light, X air.

grams of sample on a weighing paper, followed by hand mixing-grinding in an agate mortar for 25 minutes under ethanol.

The back-packed cavity mount technique described by Rao and Gluskoter (28) was used and was found effective in avoiding orientation of powdered grains along the preferred cleavage faces of minerals.

A preliminary scan of the samples from 2° to 60° revealed that the minerals in the samples were quartz, calcite, dolomite, siderite, kaolinite, illite and expandable clay.

The calibration curves of two series of standard mixes (Rao (29)) were used. The first set (Standard QCD) of standards consisted of quartz, calcite and dolomite, and the second set (Standard PSA) of plagioclase, siderite and analcime. Details of preparation of standards and standard curves were presented by Rao (29).

An internal standard of 0.2 grams of fluorite powder and a clay mixture diluent containing equal amounts of kaolinite, montmorillonite and illite were added to the series of standard mixes. The standard mixes were pulverized by an automatic mortar grinder for 120 minutes in order to obtain an optimum grain size. The mounted standards were x-rayed from 14° to 34° with a scanning speed of 1/4 degrees per minute and a chart speed of 1 inch per minute. Integrated peak-height intensities of each mineral were measured in recorded chart units with 500 counts full scale. The reflections of minerals used for peak-height measurements were quartz (101) 3.34^{o}A, calcite (104) 3.04^{o}A, dolomite (104) 2.89^{o}A, siderite (104) 3.15^{o}A and fluorite (111) 3.15^{o}A. Three

mounts were prepared for each standard mix and each mount was x-rayed twice. The average value from the six patterns was used for the calibration curves.

The calibration curves were constructed by plotting the respective peak-height intensity ratios of these minerals with fluorite as the ordinate, and grams of the respective minerals per 0.2 grams of fluorite as the abscissa.

Identical settings of x-ray diffractometer and recorder were used for samples and standards. Percentages of the minerals were obtained by referring directly to their respective calibration curves, using internal standard sample peak-height ratios (Rao (29)).

Infrared Spectrophotometric Determination of Kaolinite

Procedures described by O'Gorman and Walker (30) and Gong and Suhr (31) were used. Kaolinite used for the preparation of standards was pulverized wet in an agate mortar and the minus 2 u fraction separated by sedimentation. LTA samples were pulverized in an agate mortar wetted with ethanol. A 1 mg sample or standard was mixed with 200 mg of KBr and pelletized in an evacuated die with pressure maintained at 10 tons/sq. inch for 10 seconds. The pellets were scanned using a Perkin-Elmer model 283B double beam grating infrared spectrophotometer. Kaolinite is determined using the 910 cm -1 peak. The baseline method (O'Gorman and Walker, (30)) was used. The baseline is obtained by connecting the background lows on either side of the peak with a straight line. Stand-

ard curves were drawn of absorbance vs concentration of kaolinite, and these gave an excellent straight line relationship.

DETERMINATION OF CHEMICAL COMPOSITION OF ASH

Atomic absorption and emission spectrochemical procedures were used for the analysis. Procedures outlined by Rao (29) were generally followed and are briefly described below. For atomic absorption analysis, sample digestions were made by both lithium metaborate fusions and hydroflouric acid digestions.

Atomic Absorption Analysis

A Perkin-Elmer model 603 atomic absorption spectrophotometer was used. In the lithium metaborate fusion procedure: (Meldin, Suhr and Bodkin, (31)) 0.2 g of coal is mixed with 0.8 g of lithium metaborate and fused for 10 minutes in a graphite crucible at 950°C. The fusion is dissolved in 80 ml of 4% HNO_3 solution while stirring over a magnetic stirrer. The solutions are transferred to polyethylene bottles, capped tightly and are used for the determination of SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, TiO_2 and MnO using standard analytical procedures.

Digestion with Hydrofluoric Acid

0.5 gms of coal ash is weighed and transferred to a 3" diameter Teflon evaporating dish. The sample is moistened with 2 ml distilled water. After an addition of 4 ml perchloric acid, the dish is heated on

a hot plate until nearly dry. The dish is cooled and 1 ml perchloric acid and 10 ml HF are added and evaporated to near dryness. The dish is cooled and 1 ml $HClO_3$ and 5 ml 5% boric acid solution are added and swirled to make sure that all the sample is loosened from the bottom of the dish. Any sticking residue is loosened with a polyethylene covered rod. The dish is now heated until dense fumes evolve, without allowing the residue to dry. The dish is cooled and the residue is taken into solution with 20 ml 25% HCl and made up to 50 ml. Sodium and potassium were determined using cesium nitrate as deionizer. In addition copper and nickel were also determined with these solutions.

Emission Spectrochemical Analysis

A Jarrel-Ash, Model 78-090, 1.5 meter Wadsworth grating spectrograph with a reciprocal linear dispersion of 5.4 A^o/mm in the second order was used. The exposures were recorded in the second order between 2100 A^o and 4850 A^o using spectrum analysis No. 1 emulsion 35 mm film. The exposed films were processed for 3 minutes at 68° F in D-19 developer using a Jarrel-Ash photoprocessor. The emulsion was calibrated and attenuated using a 7-step rotating sector having a transmission ratio of 1.585 between steps.

All samples were analyzed in duplicate on separate films. Standards were burned in triplicate, spaced in between samples. Standard analyzed rocks were analyzed to check the accuracy of the procedure. Percent transmission of the lines was measured with a Jarrel-Ash micro-

photometer using a 12.5 micron slit. Background corrections were made for Pb, Ga, Mo, Sn, V, Ag and Co. No corrections were made for the background for Ba, B or Cr since the background level for these elements was very low at the step measured.

The total energy method was used in which only one exposure is needed for the determination of all elements. 20 mg of coal ash was mixed with 60 mg of graphite buffer mix (SP-2 graphite containing 20% LiF) in a wig-L-bug mixer. 20 mg of the arc mix was loaded into electrodes and packed. Duplicate exposures are made for each sample.

DISCUSSION OF RESULTS

The coals studied range in rank from lignite to high volatile 'A' bituminous. Table 3 presents proximate and ultimate analyses of 20 coal samples (Rao and Wolff (1)(2)). Table 4 shows washability analyses of 38mm x 100 mesh coals, UA-107, 113 and 119 used for the study (Rao and Wolff (1)(2)).

PETROLOGY

Vitrinite reflectance of the 20 coals studied is shown in Table 5, mean maximum reflectance varied from 0.25 to 1.04. Table 6 shows petrology of subbituminous and lignite rank coals. Total huminites in the coals range from 80% in UA100 to 96.3% in UA110. Corpohuminites include

both phlobaphinite and pseudo phlobaphinite. Humodetrinite was highest in UA100 and UA101. This is explained by the fact that these two samples are from the upper portion of No. 6 seam (the uppermost seam at the lower Lignite Creek) indicative of changes in the environment causing physical degradation of humic matter and eventually ending conditions for the formation of coal.

High concentration of flourescent huminites in UA112 might have resulted from impregnation of liptinitic material in huminite. These coals showed highest concentration of resinite. Resinite particles up to a centimeter have identified in the field. Suberinite was generally found only in Tertiary coals, and was not found in UA109 and UA110 of Cretaceous age.

Samples UA109 and UA110 from the northern Alaska coal field are the only coals where a significant amount of alginite has been identified. First petrographic work on these two coals was reported by Dutcher, Trotter and Spauckman (33). Coal samples from Lower Lignite Creek i.e., UA100, UA101, UA102 and UA119 showed the highest concentration of inertinite, in excess of 11%, and much of it as inertodetrinite.

Tables 8 and 9 show distribution of macerals in various density factions of low rank coals. Humodetrinite concentration is lowest in 1.3 specific gravity floats and increases with increasing density. This is due to the fact that processes responsible for physical degradation of humic matter also brought in detrital inorganic material that caused increase in density of coal particles.

Another observation is that suberinite is concentrated in higher density fractions. Suberinite is generally found in root tissues. The roots were coalified in place and the places roots were growing best were where there was inorganic material admixed with the original peat. Fusinite and semifusinite concentration increased for higher density fractions. The same is true for inertodetrinite. For UA119, total inertinite concentration was 3.7% for 1.3 specific gravity float and increased to 19.7% for 1.6 specific gravity sinks, showing that beneficiation can result in substantial reduction in inert macerals, thereby concentrating reactive macerals in clean coal.

Table 7 shows the petrology of bituminous coals from Matanuska Coal field. These coals are very high in vitrinoid macerals. Table 10 shows petrology of various washability products. The concentration of pseudovitrinite is highest in lowest density fraction. Pseudovitrinite occurs in a pure form, free from admixed detrital minerals, and thus explains this phenomenon. As was the case with UA113 and UA119, inertodetrinite was highest in the intermediate density fractions.

Mineral Matter

Tables 11 and 12 show distribution of mineral matter in raw coals and float-sink products. Quartz and kaolinite were the major minerals identified. Calcite and siderite were identified in a few instances. Bituminous coals UA107 and UA108 showed high concentrations of both quartz and kaolinite, showing higher degrees of crystallinity brought to

e coal by coalification processes. In the upper Lignite Creek, of the two samples UA103 and UA104, the top seam in the series, UA103, showed higher kaolinite. In the lower Lignite the lower No. 4 Seam UA119 showed only 5% kaolinite. However the No. 6 Seam (the top seam) had 31% kaolinite for the upper portion (UA100), 18% for the lowest portion (UA102) and 15% for the middle portion (UA101). Both siderite and calcite were found in UA104 and UA112. The sample UA109 had low total ash content and thus accounted for a small portion of the total mineral matter. The balance was presumably non-crystalline that could not be detected by x-ray diffraction, as well as other clay minerals. The same is true for several other samples.

The float-sink products show gradual increase in quartz with increase in density. Distribution of kaolinite is, however, different and varied with rank of coal. For bituminous coal UA107, kaolinite was highest in lowest density fraction, and decreased with increase in density. For subbituminous "C" coals UA113 and UA119, the lowest density fraction showed lowest kaolinite and is presumed to be due to the non-crystalline nature of the mineral matter in the 1.3 floats of these samples.

Composition of Coal Ash

Table 13 presents concentrations of major elements in the ash of raw coals. Samples UA115 and UA116 are lignites with very low ash and have the lowest silica. Most of the inorganic matter in these two samples consists of alumina, calcium, magnesium and iron oxides.

UA109, also a low ash coal, showed the lowest alumina. Siderite was the only significant mineral phase identified from x-ray diffraction patterns of LTA of the samples, and was also detected in the polished sections during petrographic analysis. The sample also showed anomalously high concentrations of MgO and Na_2O and very low concentrations of TiO_2. CaO is high in the ash of low rank coals, particularly lignites and subbituminous C coals. Coals of subbituminous B and higher rank showed considerably lower concentrations of CaO.

Table 14 shows concentration of major oxides calculated as percent of raw coals. Concentrations of SiO_2 and Al_2O_3 generally vary with ash content of the coal. Coals of subbituminous C and lower rank coals showed higher concentrations of CaO compared to higher rank coals. Coals from upper Lignite Creek, UA103 and UA104, showed very low concentrations on MnO compared to other coal from this field.

Tables 17, 18 and 19 show distribution of major oxides in ashes of float-sink products. Concentration of SiO_2 increases with increase in density. All three coals showed higher iron in 1.3 specific gravity float ash compared to intermediate density fractions. All the coals showed highest concentrations of CaO and MgO in 1.3 float ash; concentration decreased with increase in density. CaO in 1.6 sink ash for UA107 again increased, apparently due to the presence of CaO as carbonates. Difference in concentration of CaO in various density fractions is quite spectacular. For example, UA113 shows 34.9% of CaO for 1.3 specific gravity float ash and reduced to 2.4% for 1.6 sink ash,

indicating ash composition can be dramatically changed in beneficiation processes. On the contrary, concentrations of Na_2O and K_2O is lower in 1.3 float ash fraction (UA113 and UA119) compared to higher density fractions, indicating that these elements are not tied to the organic matter. Calcium was probably introduced into coal as calcium humate and explains such high concentrations of CaO in 1.3 specific gravity floats of low rank coals.

Tables 20, 21 and 22 show distribution of major elements expressed as percent float-sink products. With the exception of calcium, all elements showed increased concentrations with increase in density, showing that concentrations of these elements in a washed coal would be less than raw coal. Calcium, however, showed different behavior. Low rank coals UA113 and UA119 showed high CaO in the intermediate density products. Major oxides analyses, however, are more useful when evaluated as concentrations of ash, since it is what matters most in predicting the behavior of ash in combustion processes and evaluating possible uses for the ash as a by-product.

Table 15 shows the concentration of various trace elements. Anomalously high concentrations of boron were found in two seams from upper Lignite Creek, UA103 and UA104, and two cretaceous coals from Northern Alaska, UA109 and UA110. Table 16 shows concentration of trace elements as percent of raw coals. Samples from upper Lignite Creek UA103 and UA104, samples from Jarvis Creek UA106, Broad Pass UA111 and Little Tonzona UA113 showed much higher barium compared to others.

Tables 23, 24 and 25 show concentration of trace elements in various float-sink products. In general, boron, barium, cobalt, molybdenum and nickel showed higher concentration in the ash of lower density fractions.

Tables 26, 27 and 28 show concentrations of trace elements expressed as concentrations in float-sink products. All elements show increase in concentrations with increase in density, showing that beneficiation of these coals will result in partial elimination of trace elements from raw coal. This finding is in agreement with the findings of Cavallaro et. al. (24) for coals from other parts of the country.

SUMMARY

Twenty samples of Alaskan coal seams, collected under a separate U.S. Department of Energy sponsored project, were used for this study. The purpose of the investigation was to conduct a general survey of basic characteristics of Alaskan coals and to determine the change in these characteristics brought about by coal preparation processes. The characteristics presented in the report include proximate analysis, ultimate analysis, vitrinite reflectance, petrology, concentration of mineral matter obtained by low temperature ashing (LTA), major, minor and trace elements in high temperature ash (HTA). In addition, washability analysis of three coals, one each from Nenana, Beluga and Matanuska coal fields, were sink-floated at 1.3, 1.4 and 1.6 specific

gravities and the products were analyzed for petrographic composition, minerals in LTA and composition of ash (HTA).

CONCLUSIONS

The reflectance rank of the coals studied ranged from a low of 0.22 for lignite to 1.04 for high volatile A bituminous coal. Huminite macerals in the subbituminous coals and lignites ranged from 80 to 96.3%. Humodetrinite was highest in the top seam in a coal-bearing sequence. Suberinite was found in all tertiary brown coals. Float-sink products showed the lowest concentrate of inertinite and humodetrinite in 1.3 specific gravity floats and increased with increasing density. Petrology of bituminous coals showed very high concentrate of vitrinite macerals. LTA of bituminous coals showed a higher concentrate of kaolinite and quartz compared to brown coals. Concentration of major oxides in the ash float-sink products showed major differences, particularly for CaO, ranging in one instance from 34.9% in 1.3 specific gravity float ash and falling down to 2.4% in 1.6 specific gravity sink ash. Similar major differences were observed in petrology and mineralogy, indicating that total characterization of washability products (rather than raw coal alone) is necessary in evaluating the behavior of washed coal in utilization.

TABLE 3

Proximate and Ultimate Analyses of Raw Coals

Coal Field	ASTM Rank	Thickness Meters (feet)	Sample Numbers	Basis*	Moisture %	Volatile Matter,%	Fixed Carbon,%	Ash %	Heating Value BTU/lb.	C,%	H,%	N,%	O,%	Sulfur Pyritic	Sulfur Total
Nenana Poker Flat Pit No.6 Seam Top	Subbit.C	0.98 (3.2)	UA-100	1	23.61	32.80	26.54	17.05	7022	40.59	5.93	0.56	35.70	0.01	0.17
				2		42.94	34.74	22.32	9193	53.14	4.30	0.73	19.29	0.01	0.22
				3		55.28	44.72		11834	68.40	5.54	0.94	24.84	0.01	0.28
Nenana Poker Flat Pit No.6 Seam Middle	Subbit.C	5.58 (18.3)	UA-101	1	25.23	35.71	31.40	7.66	8136	46.08	6.30	0.60	39.24	0.01	0.12
				2		47.76	41.99	10.25	10882	61.64	4.65	0.80	22.50	0.01	0.16
				3		53.22	46.78		12124	68.68	5.18	0.89	25.07	0.01	0.18
Nenana Poker Flat Pit No.6 Seam Lower	Subbit.C	1.00 (3.3)	UA-102	1	25.68	34.12	29.83	10.37	7516	43.87	6.05	0.59	38.99	0.01	0.13
				2		45.91	40.14	13.95	10113	59.03	4.28	0.80	21.77	0.01	0.17
				3		53.36	46.64		11752	58.60	4.97	0.93	25.30	0.01	0.20
Nenana Moose Seam	Subbit.C	6.58 (21.6)	UA-103	1	21.42	36.02	34.88	7.68	8953	51.69	6.34	0.81	33.33	0.01	0.15
				2		45.85	44.38	9.77	11393	65.78	5.02	1.03	18.25	0.01	0.15
				3		50.81	49.19		12627	72.90	5.56	1.15	20.18	0.01	0.21
Nenana Caribou Seam	Subbit.C	5.06 (16.6)	UA-104	1	21.93	35.88	32.85	9.34	8567	49.44	6.10	0.69	34.30	0.02	0.13
				2		45.96	42.08	11.96	10973	63.33	4.67	0.88	18.99	0.02	0.17
				3		52.20	47.80		12464	71.93	5.30	1.00	21.57	0.03	0.20
Nenana No.2 Seam	Subbit.C	8.47 (27.8)	UA-105	1	26.76	33.12	32.25	7.87	7966	46.41	6.42	0.63	38.50	0.02	0.17
				2		45.23	44.03	10.74	10876	63.38	4.68	0.86	20.11	0.02	0.23
				3		50.67	49.33		12185	71.01	5.24	0.96	22.54	0.03	0.25
Jarvis Creek Ober Creek	Subbit.C	3.05 (10)	UA-106	1	20.58	36.20	34.16	9.06	8746	49.83	5.84	0.80	33.42	0.31	1.05
				2		45.58	43.01	11.41	11012	62.75	4.45	1.00	19.07	0.39	1.32
				3		51.45	48.55		12430	70.83	5.02	1.13	21.53	0.44	1.49
Matanuska Castle Mountain Mine Lower Seam	hv Ab	2.13 (7)	UA-107	1	1.78	28.23	52.20	17.78	12258	69.33	4.66	1.64	6.13	0.09	0.46
				2		28.75	53.15	18.10	12480	70.59	4.54	1.68	4.62	0.09	0.47
				3		35.10	64.90		15238	86.19	5.54	2.05	5.65	0.11	0.57
Matanuska Premier Mine	hv Bb		UA-108	1	5.87	35.73	43.96	14.44	11101	63.63	5.11	1.14	15.33	0.04	0.35
				2		37.96	46.70	15.34	11794	67.60	4.73	1.21	10.75	0.04	0.37
				3		44.84	55.16		13864	79.85	5.59	1.43	12.70	0.05	0.43

Proximate and Ultimate Analyses of Raw Coals

Coal Field	ASTM Rank	Thickness Meters (feet)	Sample Numbers	Basis*	Moisture %	Volatile Matter,%	Fixed Carbon,%	Ash %	Heating Value BTU/lb.	C,%	H,%	N,%	O,%	Sulfur Pyritic	Sulfur Total
Northern Alaska Wainwright	Subbit.B	1.5 (5)	UA-109	1	20.28	30.20	44.75	4.77	9292	54.79	5.71	1.13	33.32	0.08	0.28
				2		37.88	56.13	5.99	11655	68.73	4.31	1.42	19.20	0.10	0.35
				3		40.29	59.71		12398	73.10	4.58	1.51	20.43	0.10	0.35
Northern Alaska Meade River	Subbit.B	1.5 (5)	UA-110	1	17.88	30.30	48.22	3.60	10425	60.04	5.87	1.35	28.71	0.06	0.43
				2		36.90	58.72	4.38	12695	73.12	4.72	1.64	15.61	0.07	0.53
				3		38.59	61.41		13277	76.47	4.94	1.71	16.33	0.08	0.55
Broad Pass Coal Creek Seam	Lignite	2.4 (8)	UA-111	1	28.32	33.53	24.08	14.07	6395	38.14	6.06	0.54	41.04	0.03	0.15
				2		46.77	33.60	19.63	8921	53.21	4.04	0.75	22.16	0.04	0.21
				3		58.20	41.80		11100	66.20	5.03	0.93	27.58	0.05	0.26
Little Tonzona Coal bed	Subbit.C	38.7 (127)	UA-112	1	21.21	37.59	30.36	10.84	7663	45.02	5.80	0.64	36.59	0.06	1.11
				2		47.72	38.53	13.75	9725	57.14	4.34	0.81	22.56	0.08	1.40
				3		55.33	44.67		11277	66.25	5.03	0.94	26.15	0.09	1.63
Beluga Waterfall Seam	Subbit.C	9.1 (30)	UA-113	1	23.65	35.20	33.34	7.81	8327	47.98	6.25	0.54	37.28	0.01	0.14
				2		46.10	43.67	10.23	10907	62.84	4.71	0.71	21.33	0.01	0.18
				3		51.35	48.65		12151	70.01	5.25	0.79	23.74	0.01	0.21
Northern Alaska Sagwon Bluffs	hv Cb	2.0 (6.5)	UA-114	1	14.71	15.74	15.65	53.90	3591	20.98	3.37	0.53	21.16	0.04	0.06
				2		18.45	18.36	63.19	4210	24.60	2.02	0.62	9.50	0.05	0.07
				3		50.13	49.87		11439	66.83	5.49	1.67	25.81	0.14	0.20
Yentna Locality 2 Lower	Lignite	3.0 (10)	UA-115	1	29.80	38.26	28.61	3.33	7943	45.20	6.76	0.53	44.07	0.01	0.11
				2		54.50	40.76	4.74	11315	64.39	4.87	0.75	25.10	0.01	0.15
				3		57.21	42.79		11879	67.59	5.11	0.79	26.35	0.01	0.16
Yentna Locality 2 Upper	Lignite	3.0 (10)	UA-116	1	29.86	39.29	28.43	2.42	8017	45.48	6.89	0.49	44.67	0.01	0.05
				2		56.02	40.54	3.44	11429	64.84	5.06	0.70	25.89	0.01	0.07
				3		58.02	41.98		11837	67.16	5.24	0.73	26.79	0.01	0.08
Tramway Bar	hv B	4.0 (13)	UA-117	1	6.38	24.29	33.54	35.79	7263	42.72	3.62	0.55	17.18	0.04	0.14
				2		25.94	35.83	38.23	7758	45.64	3.10	0.59	12.29	0.04	0.15
				3		41.99	58.01		12559	73.88	5.02	0.95	19.90	0.07	0.25
Kenai Cabin Bed	Subbit.C	1.8 (6)	UA-118	1	23.01	35.63	32.71	8.65	8028	47.23	6.07	0.62	37.20	0.01	0.23
				2		46.28	42.49	11.23	10428	61.35	4.54	0.81	21.77	0.01	0.30
				3		52.13	47.87		11747	69.11	5.11	0.91	24.53	0.01	0.34
Nenana Poker Flat Pit No. 4 Seam	Subbit.C	7.3 (24)	UA-119	1	25.29	32.51	32.55	9.85	7779	45.28	6.30	1.13	37.11	0.02	0.33
				2		43.52	43.30	13.18	10412	60.61	4.64	1.51	19.62	0.02	0.44
				3		50.13	49.87		11993	69.81	5.34	1.74	22.60	0.03	0.51

* 1 is Equilibrium bed moisture basis
2 is Moisture-free basis
3 is Moisture-ash-free basis

TABLE 4. Washability Aalyses of 38mm x 100 Mesh Coals Used for the Study.

SPECIFIC GRAVITY		ACTUAL PRODUCTS					CUMULATIVE FLOAT					CUMULATIVE SINK	
					Sulfur percent					Sulfur percent			
Sink	Float	Wt. %	Ash %	Btu/lb	Pyritic	Total	Wt. %	Ash %	Btu/lb	Pyritic	Total	Wt. %	Ash %
Washability Analyses of Lower Seam (UA-107), Castle Mountain Mine, Upper Matanuska Valley, Matanuska Coal Field, Alaska													
Raw Coal Bed Moisture = 1.78%													
	1.30	46.49	5.46	14712	0.02	0.51	46.49	5.46	14712	0.02	0.50	100.00	18.63
1.30	1.40	23.95	12.14	13741	0.03	0.40	70.44	7.73	14382	0.02	0.49	53.51	30.07
1.40	1.60	13.46	27.75	11262	0.05	0.43	3.90	10.94	13801	0.03	0.48	29.56	44.60
1.60		16.10	58.71	5254	0.15	0.40	100.00	18.63	12492	0.05	0.47	16.10	58.71
Washability Analyses of Water Fall Seam (UA-113) Beluga Coal Field, Alaska													
Raw Coal Bed Moisture = 23.65													
	1.30	41.23	4.86	11652	0.01	0.15	41.23	4.86	11652	0.01	0.15	100.00	9.45
1.30	1.40	51.44	9.04	10877	0.01	0.24	92.67	7.18	11222	0.01	0.20	58.77	12.67
1.40	1.60	5.31	32.39	7029	0.01	0.24	97.98	8.55	10995	0.01	0.20	7.33	38.12
1.60		2.02	53.17	5031	0.04	0.20	100.00	9.45	10874	0.01	0.20	2.02	53.17
Washability Analyses of No. 4 Seam (UA-119) Usibelli Coal Mine, Nenana Coal Field, Healy, Alaska													
Raw Coal Bed Moisture = 25.29													
	1.30	21.50	5.54	11441	0.03	0.21	21.50	5.54	11441	0.03	0.21	100.00	11.27
1.30	1.40	71.29	10.88	10644	0.01	0.30	92.79	9.64	10829	0.01	0.28	78.50	12.85
1.40	1.60	6.99	32.24	7978	0.02	0.86	99.78	11.23	10629	0.02	0.32	7.21	32.28
	1.60	0.22	33.49	7771	0.13	0.51	100.00	11.27	10623	0.02	0.32	0.22	33.49

TABLE 5. Vitrinite Reflectance.

Sample No.	ASTM Rank	Mean Maximum Reflectance $\bar{R}_{0max}$	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}	V_{11}
UA-100	Subbit. C	0.29	4	57	23	16							
UA-101	Subbit. C	0.32	5	40	33	22							
UA-102	Subbit. C	0.33	1	31	60	8							
UA-103	Subbit. C	0.41		1	28	71							
UA-104	Subbit. C	0.42			25	74	1						
UA-105	Subbit. C	0.32	11	26	49	14							
UA-106	Subbit. C	0.39		3	51	46							
UA-107	hv Ab	1.04									20	71	9
UA-108	hv Bb	0.63				1	18	75	6				
UA-109	Subbit. B	0.57				6	59	33	2				
UA-110	Subbit. B	0.52				42	42	15	1				
UA-111	Lignite	0.28	9	63	26	8							
UA-112	Subbit. C	0.27	26	47	25	7							
UA-113	Subbit. C	0.25	3	85	11								
UA-114	hv Cb	0.54				14	74	12					
UA-115	Lignite	0.33		28	66	6							
UA-116	Lignite	0.22	46	37	14	3							
UA-117	hv Bb	0.66					14	67	19				
UA-118	Subbit. C	0.31		41	53	6							
UA-119	Subbit. C	0.25	24	58	18								

TABLE 6. Petrology of Subbituminous and Lignite Raw Coals.

Sample No.	Ulminite	Gelinite	Corpo-huminite	Humo-detrinite	Fluorescent Huminite	Total Huminite	Suberinite	Cutinite	Alginite	Sporinite	Resinite	Total Liptinite	Semi-fusinite	Fusinite	Sclero-tinite	Macrinite	Inerto-detrinite	Total Inertinite	TOTAL
UA-100	37.6	18.9	1.8	12.3	9.4	80.0	0.8	0.4	0	2.4	0.6	4.2	0.9	3.1	0.3	1.1	10.4	15.8	100.0
UA-101	49.5	12.9	1.6	13.4	6.8	84.2	0.4	0.2	0	3.6	0.4	4.6	1.0	0.7	0.2	0	9.3	11.2	100.0
UA-102	61.3	9.4	3.0	5.8	0.6	80.1	0.7	0.4	0	4.6	0.8	6.5	3.2	1.2	0	0	9.0	13.4	100.0
UA-103	80.3	11.6	0.3	2.4	0	94.6	0	0.2	0	4.2	0.4	4.8	0	0	0.6	0	0	0.6	100.0
UA-104	81.3	7.6	1.8	1.8	0.2	92.7	0	0	0	3.8	0.4	4.2	0	0.2	0.8	0	2.1	3.1	100.0
UA-105	69.7	12.4	0.9	3.8	0.2	87.0	0.4	0.1	0	4.8	0.8	6.1	1.0	0.8	0.3	0	4.8	6.9	100.0
UA-106	81.7	9.3	0.6	2.5	0	94.1	0.1	0.1	0	3.5	0.6	4.3	0	0	0.2	0	1.4	1.6	100.0
UA-109	68.7	19.0	0	1.3	0.4	89.4	0	0	0.2	1.3	0.4	1.9	1.5	6.5	0	0.7	0	8.7	100.0
UA-110	71.7	22.9	0	1.3	0.4	96.3	0	0	0.9	1.5	0.2	2.6	0.4	0.5	0	0.2	0	1.1	100.0
UA-111	29.1	35.8	0.3	8.5	17.0	90.7	0	0.5	0	4.6	0.8	5.9	0	0	0.5	0	2.9	3.4	100.0
UA-112	36.4	34.0	0.4	3.0	15.4	89.2	0.8	0.8	0	5.8	1.4	8.8	0.3	0.4	0.2	0	1.1	2.0	100.0
UA-113	65.7	18.3	2.5	3.4	0	89.9	0.4	0.3	0	3.5	0.4	4.6	0	0.5	0.7	0.1	4.2	5.5	100.0
UA-119	54.6	26.3	2.0	1.1	0	84.0	0.2	0.3	0	3.3	0.4	4.2	0.9	1.3	0	0	9.6	11.8	100.0

TABLE 7. Petrology of Bituminous Raw Coal.

Sample No.	Vitrinite	Pseudo-vitrinite	Fluorescent Vitrinite	Total Vitrinite	Culinite	Alginite	Sporinite	Resinite	Total Liptinite	Semi-Fusinite	Fusinite	Selero-tinite	Macrinite	Inerto-detrinite	Total Inertinite	TOTAL
UA-107	80.2	14.3	0.4	94.9	0	0	0.5	0.6	1.1	0.4	0.6	0	0.5	2.5	4.0	100.0
UA-108	79.5	13.2	0	92.7	1.1	0	1.2	0.7	3.0	0.3	0	0	0	4.0	4.3	100.0

TABLE 8. Washability Analyses of Sample UA-113, Crushed to 38 mm, Showing Concentrations of Macerals.

Specific Gravity Sink	Specific Gravity Float	Ulminite	Gelinite	Corpo-huminite	Humo-detrinite	Fluorescent Huminite	Total Huminite	Suberinite	Culinite	Alginite	Sporinite	Resinite	Total Liptinite	Semi-fusinite	Fusinite	Sclero-tinite	Macrinite	Inerto-detrinite	Total Inertinite	TOTAL
	1.3	75.1	17.3	0.4	0.7	0	93.5	0	0.3	0	3.6	0.7	4.6	0	0	0.2	0	1.7	1.9	100.0
1.3	1.4	71.9	14.6	3.9	3.3	0	93.7	0.8	0	0	2.1	1.3	3.2	0.5	0	0.1	0	2.5	3.1	100.0
1.4	1.6	54.3	21.2	4.6	10.2	0	90.3	0.3	0	0	4.4	1.1	5.8	0.5	0.1	0.1	0	3.2	3.9	100.0
1.6		61.9	17.9	2.8	11.3	0	93.9	0.3	0	0	2.1	0.6	3.0	0.5	1.4	0	0	1.2	3.1	100.0

TABLE 9. Washability Analyses of Sample UA-119, Crushed to 38 mm, Showing Concentrations of Macerals.

Specific Gravity Sink	Float	Ulminite	Gelinite	Corpo-huminite	Humo-detrinite	Fluorescent Huminite	Total Huminite	Suberinite	Culinite	Alginite	Sporinite	Resinite	Total Liptinite	Semi-fusinite	Fusinite	Sclero-tinite	Macrinite	Inerto-detrinite	Total Inertinite	TOTAL
	1.3	81.5	9.8	0.8	0.7	0	92.8	0	0.3	0	3.1	0.1	3.5	0.5	1.1	0.2	0	1.9	3.7	100.0
1.3	1.4	66.2	12.5	2.0	4.9	0	85.6	0.7	0.6	0	3.6	0.4	5.3	2.3	1.7	0	0	5.1	9.1	100.0
1.4	1.6	54.8	22.2	0.8	9.8	0	87.6	1.1	0.7	0	2.4	0.7	4.9	0.9	1.2	0.1	0	5.3	7.5	100.0
1.6		57.2	12.1	0.9	4.8	0	75.0	0.8	0.8	0	2.6	1.1	5.3	6.4	8.3	0.3	0	4.7	19.7	100.0

TABLE 10. Washability Analyses of Sample UA-107, Crushed to 38 mm, Showing Concentrations of Macerals.

Specific Gravity Sink	Float	Vitrinite	Pseudo-vitrinite	Fluorescent Vitrinite	Total Vitrinite	Culinite	Alginite	Sporinite	Resinite	Total Liptinite	Semi-Fusinite	Fusinite	Selero-tinite	Macrinite	Inerto-detrinite	Total Inertinite	TOTAL
	1.3	62.7	35.0	0	97.7	0	0	0.3	0.7	1.0	0	0.2	0.1	0	1.0	1.3	100.0
1.3	1.4	62.9	31.3	0	94.2	0	0	0.3	0.5	0.8	1.1	0.8	0	0	3.1	5.0	100.0
1.4	1.6	76.9	19.9	0.2	97.0	0	0	0	0.5	0.5	0.4	0.8	0	0	1.3	2.5	100.0
1.6		81.6	10.8	0.7	93.1	0	0.1	0.3	5.9	6.3	0	0.2	0	0	0.4	0.6	100.0

TABLE 11. Distribution of Minerals in Low Temperature Ash of Raw Coals and Float Sink Product.

Sample No.	Product	Quartz	Calcite	Dolomite	Siderite	Kaolinite
UA-100	Raw Coal	6	0	0	0	31
UA-101	" "	6	0	0	0	15
UA-102	" "	8	0	0	0	18
UA-103	" "	12	0	0	0	26
UA-104	" "	14	4	0	4	16
UA-105	" "	8	0	0	0	9
UA-106	" "	4	0	0	0	8
UA-107	" "	10	0	0	0	39
UA-108	" "	16	0	0	0	41
UA-109	" "	?	0	0	5	0
UA-110	" "	6	0	0	0	13
UA-112	" "	7	5	0	3	12
UA-113	" "	6	0	0	0	19
UA-119	" "	4	0	0	0	5

TABLE 12. Distribution of Minerals in Low Temperature Ash of Float-Sink Products.

Sample No.	Specific Gravity Sink	Specific Gravity Float	Quartz	Calcite	Dolomite	Siderite	Kaolinite
UA-107		1.3	2	0	0	1	39
	1.3	1.4	6	0	0	0	31
	1.4	1.6	8	0	0	0	27
	1.6		9	0	2	3	23
UA-113		1.3	3	0	0	0	5
	1.3	1.4	6	0	0	0	17
	1.4	1.6	10	0	0	0	38
	1.6		12	0	0	0	38
UA-119		1.3	4	0	0	0	5
	1.3	1.4	10	0	0	0	12
	1.4	1.6	11	0	0	0	24
	1.6		11	0	0	0	21

TABLE 13. Concentration of Major Elements in Ash of Raw Coals (percent).

Sample No.	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO
UA100	55.3	19.3	7.1	2.2	9.4	0.16	1.8	1.0	0.44
UA101	37.7	22.6	9.4	3.8	22.8	0.12	1.1	0.9	0.37
UA102	39.5	21.4	6.6	2.5	24.1	0.11	1.1	1.0	0.19
UA103	34.7	25.0	5.2	7.7	16.7	0.48	1.6	1.2	0.06
UA104	43.1	21.4	9.0	5.2	14.7	0.32	1.8	1.1	0.07
UA105	47.3	20.7	8.9	2.8	12.9	0.77	1.2	0.9	0.44
UA106	42.7	16.6	11.2	2.2	20.8	0.08	0.7	1.1	0.12
UA107	53.3	25.7	4.4	1.9	3.6	0.46	2.1	1.3	0.12
UA108	53.5	28.8	6.5	2.3	4.4	0.23	1.9	1.6	0.10
UA109	41.7	5.9	18.8	13.0	13.2	5.41	1.0	0.1	0.29
UA110	43.8	23.3	6.1	3.3	4.4	1.07	1.8	1.3	0.06
UA111	45.4	29.3	4.6	1.1	9.1	0.25	2.1	1.2	0.17
UA112	39.8	19.4	6.9	3.3	22.7	0.25	1.2	0.9	0.05
UA113	41.0	28.9	6.7	1.9	16.6	0.18	2.1	0.8	0.10
UA114	66.5	20.1	3.9	2.2	1.8	0.21	3.5	1.3	0.04
UA115	16.8	33.3	9.5	6.3	28.0	0.26	1.0	1.1	0.12
UA116	11.6	27.9	10.6	7.4	37.2	0.27	0.6	0.8	0.13
UA117	52.8	30.8	5.1	1.4	2.3	0.53	4.0	1.7	0.05
UA118	37.4	21.0	5.7	3.6	25.3	0.11	1.3	0.9	0.11
UA119	43.4	22.7	6.7	2.7	16.6	0.93	2.2	1.1	0.21

TABLE 14. Concentration of Major Elements in Raw Coals (percent), Moisture Free Basis.

Sample No.	Ash, Percent Moisture Free Basis	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO
UA-100	22.32	12.34	4.31	1.58	0.49	2.10	0.036	0.40	0.22	0.098
UA-101	10.25	3.86	2.32	0.96	0.39	2.34	0.012	0.11	0.09	0.038
UA-102	13.95	5.51	2.99	0.92	0.35	3.36	0.015	0.15	0.14	0.027
UA-103	9.77	3.39	2.44	0.51	0.75	1.63	0.047	0.16	0.12	0.0059
UA-104	11.96	5.15	2.56	1.08	0.62	1.76	0.038	0.22	0.13	0.0084
UA-105	10.74	5.08	2.22	0.96	0.30	1.39	0.083	0.13	0.10	0.047
UA-106	11.41	4.87	1.89	1.28	0.25	2.37	0.009	0.08	0.12	0.013
UA-107	18.10	9.65	4.65	0.80	0.34	0.65	0.083	0.38	0.24	0.022
UA-108	15.34	8.21	4.42	1.00	0.35	0.68	0.035	0.29	0.25	0.015
UA-109	5.99	2.50	0.352	1.13	0.78	0.79	0.32	0.062	0.006	0.017
UA-110	4.38	1.92	1.02	0.27	0.14	0.19	0.047	0.080	0.057	0.003
UA-111	19.63	8.91	5.75	0.90	0.22	1.79	0.049	0.41	0.24	0.033
UA-112	13.75	5.47	2.67	0.95	0.45	3.12	0.034	0.17	0.12	0.069
UA-113	10.23	4.19	2.96	0.69	0.19	1.70	0.018	0.21	0.08	0.010
UA-114	63.19	42.0	12.7	2.46	1.39	1.14	0.13	2.2	0.82	0.025
UA-115	4.74	0.80	1.58	0.45	0.30	1.33	0.012	0.047	0.052	0.0057
UA-116	3.44	0.40	0.962	0.36	0.25	1.28	0.009	0.021	0.028	0.0045
UA-117	38.23	20.9	11.8	1.95	0.54	0.88	0.20	1.53	0.65	0.019
UA-118	11.23	4.20	2.36	0.64	0.40	2.84	0.012	0.15	0.10	0.012
UA-119	13.18	5.72	2.99	0.88	0.36	2.19	0.12	0.290	0.15	0.028

TABLE 15. Concentration of Trace Elements in Raw Coal Ashes (parts per million).

Sample No.	Ag	B	Ba	Co	Cr	Cu(A.A.)	Ga	Mo	Ni(A.A.)	pb	Sn	V	Zn(A.A.)	Zr
UA-100	N.D	110	N.D	N.D	150	142	36	N.D	62	23	N.D	240	57	310
UA-101	N.D	160	4,300	N.D	110	152	24	N.D	111	N.D	N.D	190	61	130
UA-102	N.D	180	4,800	N.D	160	150	26	N.D	101	150	39	280	80	180
UA-103	N.D	H	18,000	49	150	215	39	N.D	200	320	N.D	300	110	440
UA-104	1.3	1,900	12,000	40	160	150	34	N.D	130	93	N.D	300	71	360
UA-105	N.D	140	4,700	N.D	120	170	21	N.D	150	N.D	N.D	250	170	280
UA-106	1.5	130	15,000	60	140	180	22	94	145	N.D	N.D	280	160	500
UA-107	N.D	110	3,400	40	110	92	52	N.D	90	25	N.D	320	99	370
UA-108	N.D	470	N.D	260	180	86	63	N.D	200	28	N.D	380	370	260
UA-109	N.D	4,100	7,900	61	N.D	46	14	N.D	102	N.D	N.D	N.D	237	470
UA-110	N.D	H	4,800	200	81	103	100	21	260	180	N.D	270	366	580
UA-111	N.D	96	11,000	71	380	157	57	N.D	124	99	27	350	110	400
UA-112	2.9	330	12,000	73	200	434	22	79	175	57	N.D	560	403	320
UA-113	N.D	130	5,200	88	230	164	52	N.D	121	110	N.D	360	182	420
UA-114	N.D	180	N.D	N.D	150	72	32	N.D	60	21	N.D	310	101	170
UA-115	1.3	320	5,700	35	160	230	47	N.D	130	42	48	220	100	480
UA-116	1.6	370	5,500	98	170	250	31	10	165	83	28	240	120	750
UA-117	N.D	670	N.D	23	160	76	46	N.D	79	59	26	320	145	330
UA-118	N.D	380	5,500	28	170	235	27	14	105	42	N.D	400	95	410
UA-119	N.D	310	5,900	90	160	300	32	17	145	29	N.D	540	50	350

TABLE 16. Concentration of Trace Elements in Raw Coals (parts per million).

Sample No.	Ash, Percent Moisture Free Basis	Ag	B	Ba	Co	Cr	Cu(A.A.)	Ga	Mo	Ni(A.A.)	pb	Sn	V	Zn(A.A.)	Zr
UA-100	22.32	N.D	25	N.D	N.D	33	32	8.0	N.D	25	5.1	N.D	54	13	69
UA-101	10.25	N.D	16	440	N.D	11	16	2.5	N.D	9.0	N.D	N.D	19	6.3	13
UA-102	13.95	N.D	25	670	N.D	22	21	3.6	N.D	12	21	5.4	39	11	25
UA-103	9.77	N.D	H	1,800	4.8	15	21	3.8	N.D	40	31	N.D	29	11	43
UA-104	11.96	0.16	230	1,400	4.8	19	18	4.1	N.D	22	11	N.D	36	8.5	43
UA-105	10.74	N.D	15	500	N.D	13	18	23	N.D	15	N.D	N.D	27	18	30
UA-106	11.41	0.17	15	1,700	6.8	16	21	2.5	11	19	N.D	N.D	32	18	57
UA-107	18.10	N.D	20	620	7.2	20	17	9.4	N.D	18	4.5	N.D	58	18	67
UA-108	15.34	N.D	72	N.D	40	28	13	9.7	N.D	58	4.3	N.D	58	57	40
UA-109	5.99	N.D	250	470	3.7	N.D	2.8	0.84	N.D	4.9	N.D	N.D	N.D	14	28
UA-110	4.38	N.D	H	210	8.8	3.5	4.5	4.4	0.92	21	7.9	N.D	12	16	25
UA-111	19.63	N.D	19	2,200	14	75	31	11	N.D	35	19	5.3	69	22	79
UA-112	13.75	0.40	45	1,700	10	28	60	3.0	11	25	7.8	N.D	77	55	44
UA-113	10.23	N.D	13	490	9.0	24	17	5.3	N.D	19	11	N.D	37	19	43
UA-114	63.19	N.D	110	N.D	N.D	95	45	20	N.D	33	13	N.D	200	64	110
UA-115	4.74	0.06	15	270	1.7	7.6	11	2.2	N.D	4.7	2.0	2.3	10	4.7	23
UA-116	3.44	0.06	12	190	3.4	5.8	8.6	1.1	0.34	5.2	2.9	0.96	8.3	4.1	26
UA-117	38.23	N.D	280	N.D	8.8	61	29	18	N.D	26	23	9.9	120	55	130
UA-118	11.23	N.D	43	520	3.1	19	26	3.0	1.6	13	4.7	N.D	45	11	46
UA-119	13.18	N.D	41	780	12	21	40	4.2	2.5	21	3.8	N.D	71	66	46

TABLE 17. Washability Analyses of Sample 107, Crushed to 38 mm Top Size, Showing Concentration of Major Elements in Ash of Products.

Specific Gravity Sink	Float	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO
	1.3	43.4	31.8	5.8	2.4	8.6	0.41	1.3	1.9	0.05
1.3	1.4	55.5	31.3	2.8	1.6	2.6	0.32	1.9	1.7	0.04
1.4	1.6	60.0	29.0	2.6	1.6	1.6	0.33	2.9	1.6	0.05
1.6		54.4	27.1	6.3	1.1	4.9	0.53	2.4	1.0	0.14
Head, calc.		54.2	28.8	4.9	1.6	4.4	0.44	2.3	1.4	0.09

TABLE 18. Washability Analyses of Sample 113, Crushed to 38 mm Top Size, Showing Concentration of Major Elements in Ash of Products.

Specific Gravity Sink	Float	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO
	1.3	20.2	25.7	9.3	2.5	34.9	0.25	0.9	0.5	0.14
1.3	1.4	36.5	27.3	6.7	2.1	22.1	0.20	2.1	0.8	0.13
1.4	1.6	56.9	26.3	3.8	1.3	5.0	0.16	2.8	1.1	0.08
1.6		66.0	21.5	3.8	1.3	2.4	0.17	2.8	1.0	.07
Head, calc.		40.1	26.1	6.4	1.9	19.5	0.20	2.1	0.8	0.12

TABLE 19. Washability Analyses of Sample 119, Crushed to 38 mm Top Size, Showing Concentration of Major Elements in Ash of Products.

Specific Gravity Sink	Float	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO
	1.3	32.2	13.5	8.7	6.0	30.3	0.08	0.4	0.7	0.17
1.3	1.4	41.4	18.0	5.5	3.3	18.4	0.09	1.2	1.0	0.09
1.4	1.6	55.9	24.3	3.2	1.8	7.4	0.11	2.8	1.0	0.03
1.6		56.4	18.4	9.6	1.5	6.4	0.19	2.1	1.0	0.09
Head, calc.		41.6	18.0	5.8	3.5	18.9	0.09	1.2	1.0	0.10

TABLE 20. Washability Analyses of Sample 107, Crushed to 38 mm Top Size, Showing Concentration of Major Elements in Products (Moisture Free Basis, Percent).

Specific Gravity Sink	Float	Ash &	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO
	1.3	5.46	2.37	1.74	0.32	0.13	0.47	0.022	0.07	0.10	0.003
1.3	1.4	12.14	6.74	3.80	0.34	0.19	0.32	0.039	0.23	0.21	0.005
1.4	1.6	27.75	16.65	8.05	0.72	0.44	0.44	0.09	0.8	0.44	0.014
1.6		58.71	31.94	15.91	3.7	0.65	2.88	0.31	1.41	0.59	0.082
Head, calc.		18.63	10.10	5.37	0.91	0.30	0.82	0.082	0.43	0.26	0.017

TABLE 21. Washability Analyses of Sample 113, Crushed to 38 mm Top Size, Showing Concentration of Major Elements in Products (Moisture Free Basis, Percent).

Specific Gravity Sink	Float	Ash &	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO
	1.3	4.86	0.98	1.25	0.45	0.12	1.7	0.012	0.04	0.02	0.007
1.3	1.4	9.04	3.3	2.468	0.606	0.19	1.998	0.018	0.190	0.072	0.012
1.4	1.6	32.39	18.43	8.52	1.231	0.421	1.62	0.052	0.907	0.35	0.03
1.6		53.17	35.09	11.43	2.02	0.69	1.28	0.09	1.49	0.53	0.04
Head, calc.		9.45	3.79	2.47	0.60	0.18	1.84	0.02	0.20	0.08	0.01

TABLE 22. Washability Analyses of Sample 119, Crushed to 38 mm Top Size, Showing Concentration of Major Elements in Products (Moisture Free Basis, Percent).

Specific Gravity Sink	Float	Ash &	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO
	1.3	5.54	1.78	0.75	0.48	0.33	1.68	0.004	0.022	0.039	0.01
1.3	1.4	10.88	4.5	1.96	0.60	0.36	2.0	0.01	0.13	0.11	0.01
1.4	1.6	32.24	18.02	7.83	1.03	0.58	2.39	0.04	0.9	0.32	0.01
1.6		33.49	18.89	6.16	3.22	0.50	2.14	0.06	0.70	0.33	0.03
Head, calc.		11.27	4.69	2.03	0.39	0.39	2.13	0.01	0.14	0.11	0.01

TABLE 23. Washability Analyses of Sample 107, Crushed to 38mm Top Size, Showing Concentration of Trace Elements in the Ash of Products.

Specific Gravity Sink	Float	Ag	B	Ba	Co	Cr	Cu(A.A.)	Ga	Mo	Ni(A.A.)	pb	Sn	V	Zn(A.A.)	Zr
	1.3	N.D	300	9,300	110	170	105	57	N.D	195	87	N.D	H	181	150
1.3	1.4	N.D	120	3,700	76	180	106	63	N.D	105	59	N.D	670	112	680
1.4	1.6	N.D	50	2,500	N.D	130	110	38	N.D	80	31	N.D	330	94	400
1.6		N.D	35	2,300	N.D	90	56	44	N.D	50	21	N.D	150	117	180
Head, calc.		N.D	87	3,500	N.D	100	81	48	N.D	84	33	N.D	N.D	120	300

TABLE 24. Washability Analyses of Sample 113, Crushed to 38mm Top Size, Showing Concentration of Trace Elements in the Ash of Products.

Specific Gravity Sink	Float	Ag	B	Ba	Co	Cr	Cu(A.A.)	Ga	Mo	Ni(A.A.)	pb	Sn	V	Zn(A.A.)	Zr
	1.3	N.D	97	13,000	220	230	133	45	69	190	210	N.D	510	278	450
1.3	1.4	1.1	110	6,000	100	200	150	42	28	118	110	N.D	360	212	450
1.4	1.6	N.D	89	N.D	N.D	190	147	58	N.D	72	64	N.D	400	117	440
1.6		N.D	97	N.D	N.D	220	130	44	N.D	74	76	N.D	360	110	310
Head, calc.		N.D	100	N.D	N.D	210	144	46	N.D	120	120	N.D	400	197	430

TABLE 25. Washability Analyses of Sample 119, Crushed to 38mm Top Size, Showing Concentration of Trace Elements in the Ash of Products.

Specific Gravity Sink	Float	Ag	B	Ba	Co	Cr	Cu(A.A.)	Ga	Mo	Ni(A.A.)	pb	Sn	V	Zn(A.A.)	Zr
	1.3	N.D	510	11,000	46	94	145	18	21	141	30	29	300	64	240
1.3	1.4	N.D	340	5,900	30	180	220	38	12	111	29	N.D	470	89	410
1.4	1.6	N.D	130	3,300	N.D	210	220	40	N.D	65	44	N.D	520	97	260
1.6		160	160	7,800	N.D	140	265	32	N.D	104	1,100	51	270	219	260
Head, calc.		N.D	340	6,400	N.D	170	210	35	N.D	111	38	N.D	450	87	370

TABLE 26. Washability Analyses of Sample 107, Crushed to 38 mm Top size, Showing Concentrating Trace Elements in Products.

Specific Gravity Sink	Float	Ash %	Ag	B	Ba	Co	Cr	Cu(A.A.)	Ga	Ge	Mo	Ni(A.A.)	pb	Sn	V	Zn(A.A.)	Zr
	1.3	5.46	N.D	16	510	6.0	11	5.7	3.1	N.D	N.D	11	4.8	N.D	H	9.9	8.2
1.3	1.4	12.14	N.D	15	450	9.2	25	13	76	N.D	N.D	13	7.2	N.D	81	14	83
1.4	1.6	27.75	N.D	14	690	N.D	47	31	11	N.D	N.D	22	8.6	N.D	92	26	110
1.6		58.71	N.D	21	1,400	N.D	120	33	26	N.D	N.D	29	12	N.D	88	69	110
Head, calc.		18.63	N.D	16	650	N.D	19	15	8.9	N.D	N.D	16	6.1	N.D	N.D	22	56

TABLE 27. Washability Analyses of Sample 113, Crushed to 38 mm Top size, Showing Concentrating Trace Elements in Products.

Specific Gravity Sink	Float	Ash %	Ag	B	Ba	Co	Cr	Cu(A.A.)	Ga	Ge	Mo	Ni(A.A.)	pb	Sn	V	Zn(A.A.)	Zr
	1.3	4.86	N.D	4.7	630	11	11	6.5	2.2	N.D	3.4	9	10	N.D	25	14	22
1.3	1.4	9.04	0.10	9.9	610	9.0	18	14	3.8	N.D	2.5	11	9.9	N.D	33	19	41
1.4	1.6	32.39	N.D	29	N.D	N.D	62	48	19	N.D	N.D	23	21	N.D	130	38	140
1.6		53.17	N.D	52	N.D	N.D	120	70	23	N.D	N.D	39	40	N.D	190	58	160
Head, calc.		9.45	N.D	9.5	N.D	N.D	20	14	4.3	N.D	N.D	11	11	N.D	38	19	41

TABLE 28. Washability Analyses of Sample 119, Crushed to 38 mm Top size, Showing Concentrating Trace Elements in Products.

Specific Gravity Sink	Float	Ash %	Ag	B	Ba	Co	Cr	Cu(A.A.)	Ga	Ge	Mo	Ni(A.A.)	pb	Sn	V	Zn(A.A.)	Zr
	1.3	5.54	N.D	28	610	2.5	5.2	8	1.0	N.D	1.2	8	2.0	1.6	17	3.5	13
1.3	1.4	10.88	N.D	37	640	3.3	20	24	4.1	N.D	1.3	12	3.2	N.D	51	9.7	45
1.4	1.6	32.24	N.D	42	1,100	N.D	58	71	13	N.D	N.D	21	14	N.D	170	31	84
1.6		33.49	54	54	2,600	N.D	47	89	11	N.D	N.D	35	370	17	90	73	87
Head, calc.		11.27	N.D	35	650	N.D	17	21	3.6	N.D	N.D	11	3.9	N.D	46	8.9	38

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