UNITED STATES DEPARTMENT OF THE INTERIOR
Douglas McKay, Secretary

GEOLOGICAL SURVEY
W. E. Wrather, Director

GEOLOGICAL SURVEY CIRCULAR 252

POTENTIAL ALASKAN MINERAL RESOURCES FOR PROPOSED ELECTROCHEMICAL AND ELECTROMETALLURGICAL INDUSTRIES IN THE UPPER LYNN CANAL AREA, ALASKA

By W. S. Twenhofel

Washington, D. C., 1953

Free on application to the Geological Survey, Washington 25, D. C.

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ABSTRACT

Diversion of the headwaters of the Yukon River through the Coast Range into the Taiya River valley would make available about one million horsepower of electric energy. The only foreseeable use for any substantial block of this power is by electrochemical and electrometallurgical industries. This report discusses the raw materials needed by such industries and possible Alaskan sources of some of the materials.

The industries considered as potential consumers of Yukon-Taiya power, in decreasing order as potential power claimants, are as follows: Nonferrous metals (including aluminum, magnesium, copper, zinc, and nickel), ferroalloys (including ferrosilicon, ferrochromium, ferromanganese, and ferrotungsten), calcium carbide, artificial abrasives, nitrogen compounds, chlorine and caustic soda, iron and steel, carbon and graphitized products, and phosphorus and phosphorus compounds.

Some of the ores and other raw materials required for such industries might be obtained in Alaska. The bulk of the materials, however, for large operations must be imported. The usual aluminum ores are not known and not likely to be found in Alaska. Possible Alaskan sources of magnesium are sea water, dolomite, and olivine, although there are no data on the magnesium content of Alaskan sea water or dolomite. Unlimited resources of high-magnesium olivine are available whenever magnesium production from olivine becomes economically feasible. The known copper resources of Alaska are limited and most of the reserves are in marginal or submarginal deposits potentially of interest also for their iron or nickel content. Copper mineralization, however, is widespread and copper production from Alaska has been second only to gold. Known Alaskan zinc resources are small although occurrences are widespread and numerous. Because there are no zinc smelters on the Pacific coast, interest in development of Alaskan zinc deposits has been minor. Alaskan

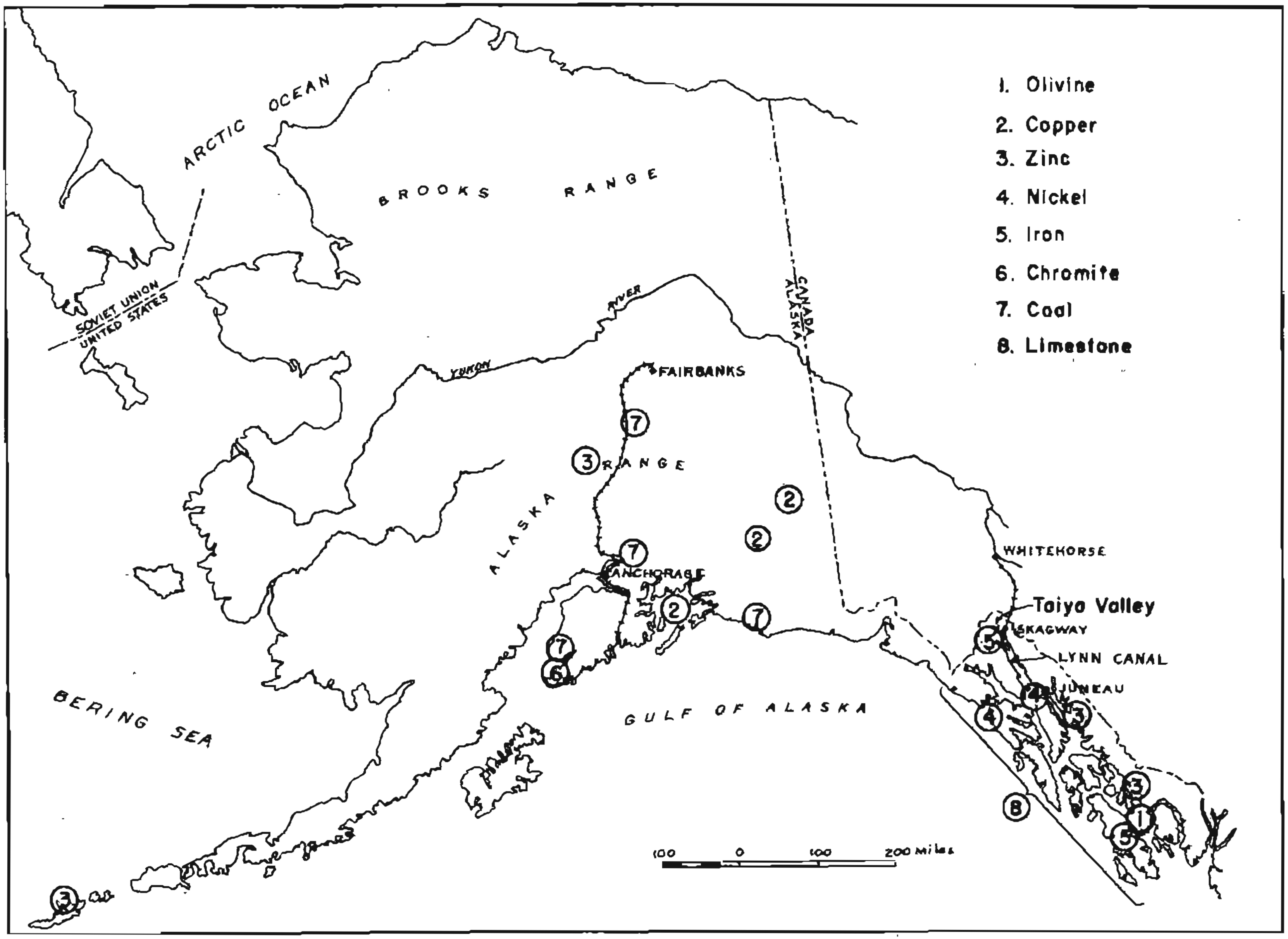

Figure 1, --Map of Alaska.

nickel deposits are large, but known deposits are low-grade. Of the raw materials necessary for ferroalloy manufacture, Alaska could supply only limited quantities of tungsten, nickel, chromite, iron, and coal. Suitable manganese and silicon dioxide deposits are not known. Alaskan iron deposits of 50 percent or better grade are relatively small; the largest deposits probably do not exceed 20 percent of recoverable iron. Alaskan coal deposits are enormous and are mainly lignitic to bituminous. Enormous quantities of limestone are present in southeastern Alaska. Thus Alaska might contribute the following raw materials to electrochemical and electrometallurgical industries in the upper Lynn Canal area: sea water, olivine, dolomite, copper, zinc, nickel, tin, tungsten, iron, chromite, coal, and limestone. Of these only coal, limestone, and minor amounts of byproduct zinc are produced at the present time.

INTRODUCTION

One of the largest undeveloped sources of hydroelectric power in North America is in the area between Skagway, Alaska, and Whitehorse, Yukon Territory, Canada. For several years both government and private engineers have been studying the feasibility of damming the Yukon River at Miles Canyon near Whitehorse and diverting the headwaters of the Yukon River drainage system from Lindeman Lake into an 11-mile tunnel through the Coast Range into the Taiya River valley of Alaska. (See fig. 1.) Such a plan envisions a storage area of about 300,000 acres at about 2,000 feet altitude, all in Yukon Territory and British Columbia. Two power plants in the Taiya valley, one at 1,000 feet and the other near sea level, if fully developed, could produce an estimated one million horsepower of electric energy.

At present no market exists in Canada or Alaska for any substantial portion of the estimated potential of one million horsepower and the only forseeable market for the power is electrochemical or electrometallurgical industries. No industries of this type are within transmission limits of the Taiya valley. If such industries may be attracted to the area because of the inexpensive power available, an appraisal should be made of the local and reasonably accessible raw materials that would be available for the use of such industries. It is the purpose of this report to assemble the pertinent facts and information concerning mineral raw materials in Alaska that might be treated or processed with electric energy from the Yukon-Taiya area.

The information in this report is restricted to those mineral raw materials that require large amounts of electric energy to treat and process, and to those materials in which electric energy is essential in the treatment process regardless of the amount of energy used.

ACKNOWLEDGMENTS

The basic sources for almost all the factual material and much of the interpretive material of this report are found in publications of the U. S. Geological Survey, U. S. Bureau of Mines, and the Territorial Department of Mines. A list of the publications would comprise well over 200 items. The references in this report are listed in the selected bibliography to which the reader may refer for additional information.

The writer is particularly indebted to Paul M. Tyler, formerly of the U. S. Bureau of Mines. His unpublished report on the potential power markets to use Yukon-Taiya power provided the outline upon which this report is based.

S. H. Lorain, Alaska Regional Director of the U. S. Bureau of Mines, has critically reviewed this report, suggested corrections and additions, and in many instances has contributed information and material.

The writer has used freely an unpublished Geological Survey manuscript report entitled "Mineral resources of Alaska," with contributions by many Survey geologists including Fred H. Moffit on copper, H. Richard Gault on zinc, L. A. Warner on iron, G. O. Gates on chromite, and Clyde Wahrhaftig and F. F. Barnes on coal. In some places the writer has quoted directly from this report, but has not so indicated. This was done solely in the interest of avoiding footnotes and references to an unpublished report that cannot be generally consulted. The writer gratefully acknowledges the use of the material without which this report would not be complete.

NONFERROUS METALS

Aluminum

Electric energy is a most essential commodity in the reduction of aluminum ore to aluminum metal. The commercial practice consists of two steps: (1) the preparation of alumina from bauxite, and (2) the electrolysis of alumina in a liquid bath of cryolite and other added salts. Because of the large quantity of electricity needed (about 10 kilowatt-hours per pound of metal) the universal practice of the aluminum industry is to transport the ore to the source of electric power. The proximity of proposed power plants on the Taiya River to ocean transportation is particularly attractive for development of an aluminum-processing industry.

Alaska has no known deposits of the usual ores of aluminum. The principal ore of aluminum is bauxite ($Al_2O_3 \cdot 3H_2O$), a product of rock decay, commonly of acidic igneous rocks, under conditions of tropical climate. No deposits of bauxite have been found in Alaska, and it is unlikely that any will be found, as our present knowledge of past climates indicates that tropical conditions did not prevail in Alaska.

Cryolite (Na_3AlF_6) is used in the electrolytic process for extraction of aluminum and generally is prepared artificially. Fluorite, one of the essential ingredients used in preparing cryolite, is present in large low-grade deposits in the Lost River area of Seward Peninsula. These deposits have not been mined and because of their isolated position it is doubtful that they can be profitably mined under present conditions.

If an aluminum-processing plant is established in connection with the Yukon-Taiya power, the ores must be imported from the States or foreign sources.

Magnesium

The commercial practices for production of magnesium have varied in the past, but they may be classified into two general types: (1) the electrolytic process, and (2) the ferrosilicon process. The former involves the conversion of magnesium ore into relatively pure magnesium chloride, followed by the electrolysis of the magnesium chloride. The latter involves the direct reduction of dolomite into the metallic state. The electrolytic method requires large amounts of electricity, (reportedly 8 to 13 kilowatt-hours per pound of metal), whereas the ferrosilicon method uses less electric power but is more costly.

The Dow Chemical Company operates a large magnesium plant at Freeport, Texas and a second plant, Government owned, at Velasco, Texas, that use sea water as a source of magnesium chloride, which, in turn, is reduced to the metallic state by electrolysis.

In addition to sea water and dolomite, other potential raw material sources are magnesite ($MgCO_3$), brucite ($Mg(OH)_2$), salt water bitterns, dolomite ($CaCO_3 \cdot MgCO_3$), olivine ($(Mg, Fe)_2SiO_4$), and serpentine ($3(Mg, Fe)O \cdot 2SiO_2 \cdot 2 H_2O$).

Apparently the only Alaskan sources of magnesium are sea water, dolomite, and olivine or serpentine. None of the other magnesium ores are known to exist in Alaska.

The writer has been unable to find any analysis of the ocean waters of southeastern Alaska, but the search of the literature has by no means been exhaustive. It can be logically argued that the sea water of the Haines-Skagway area is deficient in salts, compared with most sea water, because of the large inflow of fresh water from streams, the excessive rainfall, and the limited amount of evaporation. Nevertheless, in the absence of any specific data on salt content (specifically magnesium content), it is recommended that consideration be given to studies of the salt content of the sea water of upper Lynn Canal.

Limestone and dolomite are widespread in southeastern Alaska, extending almost continuously through Prince of Wales, Kuiu, and Chichagof Islands, into Glacier Bay and extending into Canada in the vicinity of Pleasant Camp at mile 41 of the Haines Cut-off. Discussion of limestone and dolomite in southeastern Alaska is deferred to a later section of this report.

Large masses of ultramafic rocks containing virtually unlimited quantities of olivine are known in southeastern Alaska and Kenai peninsula. Rocks composed dominantly of olivine, known as dunites, weather reddish and yellowish, and produce a soil that will support little vegetation; consequently, these rock masses are conspicuous because of their bare reddish outcrop.

On the Blashke Islands, about 75 miles northwest of Ketchikan between Kashevarof Passage and Clarence Strait, is a large mass of ultrabasic rock composed of a central core of dunite surrounded by more or less concentric rings of other ultrabasic-rock types with outwardly decreasing amounts of magnesium minerals and outwardly increasing amounts of iron, silica, and aluminum minerals. The dunite core is composed of equal proportions of olivine and serpentine derived from olivine. Kennedy and Walton (1946)[1] studied these rocks and by optical methods determined that the olivine contains about 93 percent of the Mg_2SiO_4 molecule and about 7 percent of the Fe_2SiO_4 molecule. Presumably, the serpentine, an alteration product of the olivine, contains the same relative proportion of magnesium to iron.

At Mount Burnett on the northwest side of Cleveland Peninsula about 35 miles northwest of Ketchikan, is a large body of ultramafic rock dominantly composed of dunite in the eastern part and pyroxenite in the western part. On the basis of optical criteria, Kennedy and Walton (1946) concluded that the olivine is composed of approximately 92 percent of the Mg_2SiO_4 molecule and 8 percent of the Fe_2SiO_4 molecule. Much of the olivine at Mount Burnett is altered to serpentine, although some is very fresh and unaltered.

At Red Bluff Bay, on the east side of Baranof Island, Guild and Balsley (1942) have studied the ultramafic rocks and their associated chromite deposits. There are large areas of olivine rock at Red Bluff Bay, most of which has been altered to serpentine except near the center of the mass where the olivine is very fresh. Optical studies by Guild and Balsley (1942) indicate that the olivine is composed of about 95 percent of the Mg_2SiO_4 molecule and 5 percent of the Fe_2SiO_4 molecule. Presumably, the magnesium-iron ratio of the serpentine is the same as that of the olivine from which it was derived.

Other ultramafic rock bodies in Alaska that are known to contain sizeable quantities of dunite are at Kane Peak on Kupreanof Island, a small hill near the northeast end of the runway on the Annette Island Airfield, and at Claim Point and Red Mountain on the southwest tip of the Kenai Peninsula. No data are available on the magnesium content of the olivine at the first two localities. The Bureau of Mines reports a partial analysis of the partially serpentinized dunite at the Kenai Peninsula locality to be about 45 percent of magnesium oxide, 8 percent of iron, 1 percent of chromic oxide, and 0.25 percent of nickel.

The present insufficient data pertaining to the Alaskan dunites as sources of magnesium ore barely indicate the potentialities of their worth. However, should consideration ever be given to establishing a magnesium plant in Alaska or the Pacific Northwest using olivine as an ore, the Alaskan deposits would be particularly attractive. The tonnages of olivine are enormous, and some of the deposits are at or near tidewater.

[1] See selected bibliography.

Copper

The present commercial practice for the conversion of copper ore to metallic copper consists of three essential steps: (1) smelting of the ore in a fuel-fired furnace to produce a copper-rich matte; (2) treatment of the matte in converters to eliminate sulfur and iron and produce "blister" copper, and (3) electrolytic refining of the blister copper to produce the pure metal. The latter step is the only process requiring electricity, about 0.18 kilowatt-hour per pound of metallic copper. This requirement, of course, is much less than the amount of electricity for refining aluminum or magnesium. Because electric energy plays such a minor role in copper refining, such refining plants will not be established in Alaska merely because large blocks of cheap power are available.

Although in the past Alaska has been a fabulous producer of copper ores from the Kennecott mine, there are no known similarly large copper deposits in the Territory. Copper occurrences are widespread, however, and in view of the large unprospected and unexplored areas it is quite possible that profitable copper deposits will be found.

The more promising copper deposits of Alaska are in the following regions: southeastern Alaska, Prince William Sound, Copper River-Yukon region, Iliamna Lake, Kobuk-Noatak River, and the region around the upper White River valley near the Canadian border. Of these, only the first three have been sufficiently prospected and explored to offer much hope for immediate development.

Southeastern Alaska. --Southeastern Alaska has produced more than 27,000,000 pounds of copper metal from Prince of Wales Island in the Ketchikan district, essentially all of it during the period 1906-18. The Salt Chuck mine near the head of Kasaan Bay on Prince of Wales Island contains bornite and chalcopyrite disseminated in an intrusive complex of gabbro and pyroxenite, and has produced more than 5,000,000 pounds of copper metal and an important amount of palladium. Mines on Kasaan Peninsula and Copper Mountain, and to a lesser extent mines elsewhere on Prince of Wales Island, have produced about 22,000,000 pounds of copper metal. With the notable exception of the Salt Chuck mine and one or two other small mines, the most abundant copper-bearing material in many of the deposits on Prince of Wales Island is actually a magnetite ore. Gold and silver are present locally in recoverable quantities. The magnetite replaces beds of limestone, and, to a lesser extent, greenstone. It also occurs as fissure fillings and replacement bodies in fault and shear zones.

In the northwestern part of southeastern Alaska on Yakobi Island, at Mirror Harbor on Chichagof Chichagof Island, and at Funter Bay on Admiralty Island, deposits of nickel- and copper-bearing pyrrhotite, pentlandite, and chalcopyrite are associated with intrusive bodies of norite, amphibolite, pyroxenite, and olivine gabbro. These are more fully discussed under nickel in a later section of this report.

The Geological Survey has estimated that in southeastern Alaska there are about 18,000,000 tons of indicated and inferred reserves of copper ore most of which contains less than 0.50 percent of copper.

Prince William Sound. -- For many years a large proportion of the copper mined in Alaska came from the deposits at Latouche and Ellamar. No mining has been done at either place since 1930 when operations ceased because of depletion of ore then considered recoverable at a profit. Substantial quantities of low-grade ore are said to still exist at these properties. Elsewhere in Prince William Sound many copper prospects have not been sufficiently explored to determine their extent or grade.

The copper deposits of Prince William Sound occur in or near areas in which basic lava flows are interbedded with slate and graywacke. Chalcopyrite is the principal copper mineral and is commonly associated with pyrrhotite, pyrite, and other sulfide minerals, in shear zones. Locally recoverable amounts of gold and silver are present in the copper ores.

The Geological Survey has estimated that in Prince William Sound there are about 1,500,000 tons of indicated reserves of copper ore containing slightly more than 1 percent of copper, and about 5,000,000 tons of inferred reserves of copper ore averaging slightly less than 1 percent of copper.

Copper River-Yukon region. --The bulk of the Alaskan copper ore was produced from the fabulous Kennecott mines in the Nizina district during the years 1911-38. The known deposits are depleted and mining operations have ceased. The copper ores are associated with two formations, a thick series of basaltic greenstone flows and an overlying sequence of limestone beds about 3,000 feet thick. Occurrences of copper are abundant in the greenstone but the major deposits of copper are in the basal part of the limestone. Chalcocite is the most abundant copper mineral in the limestone beds; bornite and chalcopyrite are most abundant in the greenstone. The deposits at Kennecott were replacement bodies controlled by fracture and bedding planes in limestone.

A large deposit of copper-bearing material is located at Orange Hill on the northeast side of the Wrangell Mountains near the foot of the Nabesna Glacier. Here metamorphosed sedimentary rocks, including thick limestone beds with interbedded lava flows, have been intruded by a mass of quartz diorite. Copper occurs in the quartz diorite as disseminated grains of chalcopyrite and as veinlets containing chalcopyrite, pyrite, and molybdenite, together with a little gold and silver. The Geological Survey estimates that the Orange Hill deposit contains 200,000,000 tons of indicated ore averaging 0.4 percent of copper as well as associated values in molybdenum, gold, and silver.

The Orange Hill deposit offers promise as a significant potential source of Alaskan copper ore. However, because of its isolated position and low grade, it is considered submarginal under present conditions.

Selected references to publications on copper are Capps and Johnson (1915); Gault and Wahrhaftig (1943);

Holt and others (1948); Johnson (1918); Martin (1918); Martin and Katz (1912a); Miller (1946); Moffitt (1938); Stefansson and Moxham (1946); Van Alstine and Black (1946); Warner, Ray, and Flint (1944); and Wright (1915). Also see references listed under the sections on Nickel and Iron and steel.

Zinc and cadmium

Zinc metal is recovered from its ores by two general methods: the pyrometallurgical method involves roasting to convert sphalerite (ZnS) to the oxide and reduction of the oxide by carbon and carbon monoxide to the metal. The hydrometallurgical method involves roasting of sphalerite to the oxide and leaching of the oxide by sulphuric acid to produce soluble zinc sulphate which is then treated either chemically or electrically to produce metallic zinc. Electrolytic treatment is rapidly gaining favor in commercial practice because of better recovery of accessory metals and because a more nearly pure zinc product is obtained than with either chemical treatment or pyrometallurgical methods. About 1.85 kilowatt-hours of electric energy are required per pound of zinc in the electrolytic process, an amount considerably less than that required for either aluminum or magnesium.

Cadmium is obtained solely as a byproduct of the metallurgical recovery of zinc. No ores are mined for cadmium alone nor are there any ores in which cadmium is the most valuable constituent. Virtually nothing is known of the cadmium content of Alaskan sphalerites. One sample of hand-picked sphalerite from Groundhog Basin contained 0.46 percent of cadmium. The writer is not aware of the existence of other cadmuim analyses of Alaskan sphalerite.

Although deposits of zinc are widespread in Alaska and have been known for many years, it was not until 1947 that zinc ores were mined in Alaska. These were produced at the Mahoney mine on Revillagigedo Island, 15 miles northeast of Ketchikan. Total production for 1947-48 amounted to about 100 tons of concentrate containing 2 ounces of gold, 347 ounces of silver, 214 pounds of copper, 42,086 pounds of lead, and 74,819 pounds of zinc. Insofar as known to the writer this mine has not produced since 1948, although some byproduct zinc is recovered from concentrates of the Riverside mine in the Hyder district.

It should be emphasized that our present knowledge of Alaskan zinc deposits is far from complete and because of the absence of a zinc smelter on the Pacific coast there has been little incentive to search for or explore Alaskan zinc deposits. Because of the fairly widespread occurrence and considerable number of zinc deposits in Alaska, the Territory may become a more regular and substantial producer of zinc in the future.

The only zinc-reduction works available to Alaskan zinc ores are at Kellogg, Idaho; Trail, British Columbia; and Great Falls and Anaconda, Mont. This factor, necessitating transportation by boat from Alaska to either Seattle, Wash., or Vancouver, British Columbia, and transportation by rail from the coast, coupled with the fact that most of the zinc ores of Alaska are of the sphalerite variety marmatite (containing up to 20 percent of iron), has been a deterrent to zinc mining in Alaska. Similarly, the lead-zinc-silver mines at Keno Hill and Mayo, Yukon Territory have been severely handicapped by the expensive freight charges from the mine to the zinc-reduction plant. Zinc mining in Alaska would undoubtedly be stimulated if a zinc-reduction plant were constructed in Alaska or elsewhere on the Pacific coast of North America, and if and when an economic method is devised of recovering zinc from marmatite.

Zinc deposits are best known in three regions in Alaska: (1) southeastern Alaska; (2) Kantishna district; and (3) eastern end of the Aleutian chain.

Southeastern Alaska. --The principal zinc deposits in southeastern Alaska are in the Wrangell-Revillagigedo belt of metamorphic rocks along the southwestern margin of the Coast Range batholith. Some of these deposits contain appreciable quantities of lead whereas others contain appreciable quantities of copper, in addition to zinc. The deposits at Groundhog, Glacier, and Berg Basins, east of Wrangell, and at Mahoney Creek on Revillagigedo Island belong to the lead-zinc group, whereas the deposits at Tracy Arm and Moth Bay belong to the copper-zinc group. The sulfide minerals are sphalerite, pyrite, pyrrhotite, chalcopyrite, and galena which have replaced certain beds in the gneiss and schist sequence of Wrangell-Revillagigedo belt of rocks. The ore beds are steeply dipping. The deposits are low-grade (about 8 percent or less of zinc) and the sphalerite is the variety marmatite, having an Fe: Zn ratio of 1:4 or 1:3.5, and an iron content about 12 to 15 percent.

The Groundhog Basin lead-zinc deposits are the largest known in Alaska. The Geological Survey has estimated that the Groundhog Basin deposit contains about 550,000 tons of indicated and inferred ore containing 8 percent of zinc and 1.5 percent of lead, as well as about 500,000 tons containing 2.5 percent of zinc and 1 percent of lead. The limits of the deposit are not known at depth nor to the northwest, and it is quite possible that further exploration will increase the known reserves considerably.

The Tracy Arm deposit has been estimated by the Geological Survey to contain about 125,000 tons of ore containing 4.5 to 5.8 percent of zinc and 2 to 3 percent of copper. Its limits are not known at depth.

The other four or five known zinc deposits in southeastern Alaska appear to be either smaller or lower grade than the two mentioned above.

Kantishna district. -- The Mount Eielson deposit in the Kantishna district is a contact-metamorphic deposit containing sphalerite, galena, and chalcopyrite that replaces limestone. The Geological Survey has estimated this deposit to comprise about 200,000 tons of ore containing 5 percent of zinc, 3 to 5 percent of lead, and 0.2 to 0.3 percent of copper.

Aleutian Islands. -- A little-explored zinc-lead deposit on Sedanka Island, one of the small islands near Dutch Harbor, shows considerable promise. Sampling and trenching by the U. S. Bureau of Mines disclosed that this deposit ranges from 5 to 15 feet in width and is at least 120 feet long. The 19 samples within these limits averaged about 9 percent of zinc, about 0.5 percent of copper, and 0.25 percent of lead. This deposit has not been sufficiently explored to estimate reserves, but it probably shows enough promise to merit further exploratory work.

Selected references to publications on zinc are Gault (1944); Gault, Rossman, and Flint (1944); Muir, Thomas, and Sanford (1947); Reed (1933); Robinson (1944); Wahrhaftig (1944); and Webber, Moss, and Rutledge (1946).

Nickel

Nickel ores consist of two general types, the iron-rich sulfide ores of Sudbury, Ontario, and the silicate ores of New Caledonia. The latter type is not found in Alaska and will not be considered further in this report. Ninety percent of the world's production of nickel is produced from mines of the Sudbury district, Ontario. The ore consists of pyrrhotite (Fe_8S_9), pentlandite ($(NiFe)_{11}S_{10}$), and chalcopyrite ($CuFeS_2$), disseminated in a "granitic" and noritic gangue rock; the sulfides comprise from 15 to 50 percent of the ore mined and the ore values range from 1 to 3 percent of nickel and 0.75 to 1.5 percent of copper.

The metallurgical treatment of the iron-rich sulfide ores of the Sudbury district involves: (1) smelting of ore to a low-grade matte, which is treated in basic converters to remove the iron; the resulting matte is then (2) treated to remove the copper, and the residue (containing the nickel) is (3) cast into anodes for electrolytic refining.

Electric energy plays only a subsidiary role in the metallurgy of nickel ores and consequently it is unlikely that large blocks of low-cost power will, alone, attract nickel-ore processing plants to Alaska. However, there are large deposits of low-grade nickel-bearing material in Alaska that may eventually be mined if the Sudbury ores become depleted or if metal prices increase substantially. If either condition prevails, then Alaskan metallurgical industries may be developed utilizing Alaskan nickel ores and electric energy.

The Alaskan nickel deposits constitute a substantial proportion of the nickel reserves of the United States and are similar to the Sudbury ores except that they are lower in grade. Virtually all the known deposits are in southeastern Alaska, principally in and near Bohemia Basin on Yakobi Island about 75 miles west of Juneau. Other nickel deposits are those at Funter Bay on Admiralty Island, at Mirror Harbor on the west side of Chichagof Island, at Snipe Bay on Baranof Island about 45 miles south of Sitka, and near Spirit Mountain in the Copper River region. All the nickel deposits are sulfide-bearing parts of bodies of norite or related basic rocks. Those in southeastern Alaska are in the noritic parts of composite stocks or sills of basic rocks. The deposits at Spirit Mountain are in a disconnected sill of altered basic rock.

The metallic minerals in the Alaskan deposits are pyrrhotite, pentlandite, chalcopyrite, and magnetite. These minerals are disseminated throughout the parts of the basic-rock bodies that constitute the deposits. The best explored and most promising deposits are on Yakobi Island, a small island off the northwest shore of Chichagof Island in southeastern Alaska. All the deposits are situated in or on the edge of a topographic basin known as Bohemia Basin. Exploratory drilling by the Bureau of Mines has indicated that some, if not all, of the deposits are parts of a large trough- or bowl-shaped deposit formed by the sulfide minerals near the bottom of a norite mass. They have not been explored sufficiently to determine if the sulfide zone is continuous throughout the bowl-like depression in the bottom of the norite body. The sulfide zone, in places, attains a thickness of 150 feet. The Geological Survey has estimated that the deposits at Bohemia Basin contain almost 20 million tons of material that averages about 0.32 percent of nickel and 0.20 percent of copper. Of this amount $6\frac{1}{2}$ million tons is estimated to average 0.51 percent of nickel and 0.27 percent of copper.

The second largest known Alaskan nickel deposit is at Funter Bay on the north end of Admiralty Island. This deposit has been explored by an adit (crosscut) and several drill holes. It is probably a sill and is composed of feldspar and olivine, with disseminated pyrrhotite, pentlandite, and chalcopyrite. Its grade is about 0.45 percent of nickel and 0.40 percent of copper, with insignificant values in gold and silver, and very little cobalt. It is estimated by the Geological Survey to contain at least 500,000 tons of this type of material.

Present knowledge indicates that none of the other known Alaskan nickel deposits are nearly as large as the two mentioned above, although those at Mirror Harbor on Chichagof Island and at Spirit Mountain in the Copper River region have small tonnages of material two or three times as rich in nickel.

No nickel has ever been produced from Alaska. The outlook for nickel mining in Alaska in the immediate future is not good. Sooner or later, as world political and economic conditions may dictate, the deposits probably will be mined. The known deposits of any appreciable size are much lower in grade than those at Sudbury. A concentrate equal in grade to that of the Sudbury ore undoubtedly could be made. However, there are no nickel smelters nearer than eastern Canada and the nickel market is almost entirely east of the Mississippi River.

Selected references to publications on nickel are Holt and Moss (1946); Kennedy and Walton, Jr., (1946); Kingston and Miller (1945); Pecora (1942); Pierce (1946); Reed (1942); Reed and Dorr 2d (1942); and U. S. Bureau of Mines (1944).

Miscellaneous metals

Electric energy is an essential commodity in the treatment and refining of beryllium, lithium, titanium, zirconium, cerium, calcium,and some of its alloys, and sodium. Of these only sodium is consumed commercially in large enough amounts to require a substantial quantity of electricity. It has been estimated that 5.2 kilowatt-hours of electrical energy are required to produce a pound of sodium metal, and in view of the increasing use of sodium and its compounds it is possible that industry might consider an Alaskan location if cheap power were available.

None of the ores of beryllium, lithium, titanium, zirconium, cerium, and sodium are known to exist in commercial quantities in Alaska. However, the major interest in Alaska has been centered on gold, copper, or coal and there has been little incentive for the search for such ores. Both limestone ($CaCO_3$) and gypsum ($CaSO_4 \cdot 2H_2O$) are known in Alaska and could possibly be used as ores of calcium, although such use is considered unlikely.

FERROALLOYS

Ferrosilicon

Ferrosilicon is an alloy of iron and silicon, ranging in proportion from 10 percent of silicon and 90 percent of iron to 95 percent of silicon and 5 percent of iron. It is used in the manufacture of certain iron alloys, in which silicon is a desired constituent, and for other purposes. Ferrosilicon containing less than about 15 percent of silicon is made in blast furnaces, whereas ferrosilicon containing larger amounts of silicon is produced in the electric-arc furnace. Power requirements for ferrosilicon are approximately 2 to 3 kilowatt-hours per pound of product. The general practice requires a furnace feed of silicon in the form of quartzite, iron in the form of scrap or iron ore, and reducing-coke.

The supply of coke (coal) and iron ore in Alaska is discussed elsewhere in this report. Siliceous rocks such as quartzite, sandstone, or chert are extremely rare in the parts of Alaska within reasonable shipping distance of upper Lynn Canal. Siliceous rocks suitable for ferrosilicon feed must be as near to pure silicon dioxide as possible, must be uniform in composition and well consolidated. In all of southeastern Alaska there are no known clean quartzose sandstones or quartzites except possibly small quantities at some of the isolated Eocene localities, but these rocks are typically unmetamorphosed and virtually unconsolidated. The complete sequence of rocks for southeastern Alaska is little known and there is a slight possibility that relatively pure quartzose rocks may exist.

Ferrochromium

Ferrochromium is an alloy of iron and chromium with varying amounts of carbon (usually less than 8 percent) depending on the use of the product. The chromium content is generally 60 to 70 percent. Ferrochromium is produced in an electric furnace by adding iron ore, chrome ore, and coal or coke, and, if necessary, lime, fluorspar, or quartz to produce a suitable slag. Power requirements are about 3 to 4 kilowatt hours per pound of product.

The Alaskan supplies of coal, iron ore, and chromite are discussed elsewhere in this report. There is a distinct possibility that Alaskan raw materials could be utilized to manufacture ferrochromium. Good metallurgical-grade chromite is available on the Kenai Peninsula; suitable coal is available in the Matanuska Valley; and high-quality iron ore could be obtained from southeastern Alaska. All these materials are close to water or rail transportation.

Ferromanganese

Ferromanganese is an alloy of iron, carbon, and manganese, generally containing about 80 percent of manganese, less than 7.5 percent of carbon, and about 15 percent of iron. Much of the ferromanganese produced in the United States is made in blast furnaces, but it is also produced in electric furnaces in this country and abroad. The highest grades of ferromanganese are produced in the electric furnace. The furnace feed is a blend of manganese and iron ores with coal or coke.

There are no known commercial manganese deposits in Alaska and from our present knowledge of the geology of Alaska it appears that conditions are not favorable for the existence of extensive manganese deposits.

Ferrotungsten

Ferrotungsten is an alloy of iron and tungsten generally containing about 70 to 85 percent of tungsten and about 15 to 30 percent of iron. It is produced in an electric furnace and the usual furnace feed is a high-grade concentrate of wolframite and reducing carbon with small amounts of lime and fluorspar to act as a flux. Scheelite is not used to produce ferrotungsten.

The only occurrences of wolframite in Alaska that are sufficiently known to offer immediate possibility of development are the deposits at the Lost River tin mine on western Seward Peninsula (Heide, 1946). At Lost River the deposits are valuable chiefly for their tin content, although wolframite concentrates would be a byproduct.

General consideration of ferroalloys

The establishment of ferroalloy industries in Alaska involves a number of factors. Dependable supplies of high-quality low-cost fuel, including coke or its equivalent, would have to be developed. High-grade limestone for metallurgical flux should present no special problem, as there are extensive deposits on tidewater. No sources of metallurgical-grade silica are known in Alaska, and the geology of the region is not believed to be encouraging for their occurrence. Known deposits of iron ore, chromite, and tungsten could contribute to ferroalloy industries based primarily on imported ores, but potential Alaskan resources of these ores are not believed to be large enough to support industries by themselves. With cheap power, cheap transportation to large centers of population and established markets, and solution of the other problems indicated, ferroalloy industries in Alaska would be favorably situated to treat chrome, tungsten, and manganese ores from Alaskan and Asiatic sources.

CALCIUM CARBIDE

Calcium carbide (CaC_2) is produced from high-grade lime, petroleum coke, and bituminous coal or coke in an electric furnace of the same type used to make ferrosilicon or other ferroalloys. The principal cost in making calcium carbide is the cost of the lime, which constitutes from 35 to 40 percent of the total cost. Energy requirements are about 1½ kilowatt-hours per pound of product.

If a calcium carbide plant were to be established in connection with development of Yukon-Taiya power it would be favorably situated with regard to supplies of high-grade lime. As described elsewhere in this report there are extensive high-grade limestone deposits in southeastern Alaska. Petroleum, coke, and coal (or coke) would have to be imported, but these items constitute a relatively small proportion of the total cost of calcium carbide as compared with the cost of the limestone.

Limestone for use in manufacturing calcium carbide should be with the following limits:

	Percent
$CaCO_3$	0.97 or more
MgO	.5 -1.5
SiO_2	.5 -2.0
Al_2O_3	.5 -1.0
Fe_2O_3	.035 -0.5
$SiO_2 + Al_2O_3 + Fe_2O_3$	1.0 -3.0
P	.0004 -0.01
S	Tr. -0.1
TiO_2	Tr.

ARTIFICIAL ABRASIVES

The principal artificial abrasives are silicon carbide (SiC) and fused alumina (Al_2O_3), both of which are made only in the electric furnace. Energy requirements are between 4 and 5 kilowatt-hours for silicon carbide and between 1¼ and 1½ kilowatt-hours for fused alumina per pound of product.

The raw materials for manufacturing silicon carbide are silica sand, coal or coke, sawdust, and salt. Coal and sawdust are available in Alaska, but silica sand and salt are not.

Fused alumina is made from bauxite and there are no bauxite deposits in Alaska.

NITROGEN COMPOUNDS

The manufacture of nitrogen compounds requires a substantial quantity of electric energy and is considered by some who have studied the problem to offer a possibility as an ultimate consumer of Yukon-Taiya power. The raw materials needed are a large supply of water (about 100,000 gallons per ton of ammonia) and a cheap supply of coking coal. The nitrogen, of course, is obtained from air; hydrogen is obtained from coke, and the two are combined under pressure and heat to produce ammonia. Electricity is used for compressing and pumping, and not directly in the process. However, electrolytic hydrogen can be produced, and in view of the present lack of available coking coal in Alaska it might be feasible to produce electrolytic hydrogen. The ammonia plant at Trail, British Columbia, obtains its hydrogen electrolytically.

CHLORINE AND CAUSTIC SODA

Caustic soda ($NaOH$) is manufactured by the lime-soda process and by the electrolysis of common salt. The former method involves the reaction of slaked lime ($Ca(OH)_2$) and soda (Na_2CO_3) to produce lime ($CaCO_3$) and sodium hydroxide ($NaOH$). The latter method involves the electrolysis of a solution of common salt, ($NaCl$) to produce sodium hydroxide, chlorine, and hydrogen.

Both caustic soda and chlorine are essential commodities in the manufacture of pulp and paper products, and in view of the probability of the eventual development of a large industry of this type in southeastern Alaska, it is considered possible that a caustic soda and chlorine plant could be established in connection with development of Yukon-Taiya power. There are no known deposits of common salt in Alaska and it would have to be imported, probably from the nearest source of supply in California.

IRON AND STEEL

Iron ore is smelted in electric furnaces in various parts of the world where there is high-grade iron ore and cheap electricity but but little or no solid fuel. The most notable localities where this situation prevails are in northern Scandinavia, northern Italy, and Japan. There has been much speculation, but very little study, of the possibility of establishing an iron industry in Alaska, using Alaskan iron ores and electric energy to smelt them. Limestone and carbonaceous fuel are needed in addition to iron ore to charge the electric furnace. The usual ratio of iron ore (containing 60 percent of iron), to carbonaceous fuel, and to limestone is 33:7:4. The requirement of carbonaceous fuel is about one-half that required for the ordinary blast furnace and a much lower grade of coal or coke can be used than in a blast furnace.

The availability of Alaskan supplies of limestone and coal is discussed elsewhere in this report.

Iron deposits are known at several localities in Alaska, but only those in southeastern Alaska offer any immediate possibility of development. Occurrences of iron ore are known elsewhere in Alaska in the Yukon region, near Lake Iliamna in southwestern Alaska, north of Eagle in eastern Alaska, and in the vicinity of the Shungnak Hills and Sinuk River in western and northwestern Alaska. Extensive pyrite and pyrrhotite deposits are present in southeastern Alaska and in Prince William Sound.

The southeastern Alaska iron deposits are classified either as (1) pyrometasomatic deposits of magnetite with a small content of copper, gold, and silver; or (2) concentrations of magnetite in basic igneous or metamorphic rocks. The first type is represented by the deposits on Kasaan Peninsula and at Copper Mountain on Prince of Wales Island. These average 45 to 60 percent of iron and are high in sulfur (1 to 5 percent) as pyrite and chalcopyrite are conspicuous accessory minerals disseminated in the magnetite. All the known iron deposits of this type have been mined or prospected in the past for their copper content. The second type includes the deposits at Klukwan, Haines, and at Port Snettisham. These are titaniferous and contain appreciable amounts of phosphorus. The average magnetic-iron content of this second type is not yet determined but on the basis of a few random samples it appears that the recoverable iron content will be somewhat less than 20 percent.

The pyrometasomatic magnetite deposits characteristically are small (in terms of iron ore), irregular, and contain so much barren rock that selective mining would be required. The largest deposit of this type, the Mount Andrew-Mamie on Kasaan Peninsula, was estimated by the Geological Survey to contain about 3,500,000 tons of ore, and the other smaller deposits are estimated to contain about 2,000,000 tons.

The basic-rock type of magnetite deposit is large; the deposit at Klukwan contains at least several billion tons of magnetite-bearing rock.

The copper deposits of Prince William Sound contain, in addition to chalcopyrite, very large quantities of pyrite and/or pyrrhotite which is essentially a waste product. However, if a market existed in Alaska for sulfuric acid or for iron ore, such as might be created by ferroalloy manufacturing plants, this iron sulfide product conceivably could be produced at a profit.

All other occurrences of Alaskan iron ores are so little known and so far removed from easy transportation to the upper Lynn Canal area that they are not considered further in this report.

Selected references to publications on iron are Erickson (1948); Goddard, Warner, and Walton (1944); Holt and Sanford (1946); Warner and Ray (1944); Warner and Walton (1944); and Wright and Fosse (1946).

CARBON AND GRAPHITIZED PRODUCTS

Electrometallurgical and electrochemical industries require a considerable quantity of electrodes for delivering energy into furnaces and certain types of electrolytic cells. The raw material used for making carbon and graphitized products is either petroleum coke or high-grade, low ash, anthracite, neither of which is at present available in Alaska. Because of the lack of local raw materials for the manufacture of electrodes it would be necessary for any industrial enterprise that might be established in connection with the Yukon-Taiya power either to purchase its needed electrodes from the States or to import the necessary coal and coke to manufacture its own electrodes.

PHOSPHORUS AND PHOSPHORUS COMPOUNDS

Phosphorus and its compounds are principally used in fertilizer and for military purposes. Superphosphate, a constituent of some fertilizer, is produced by the action of sulphuric acid on high-grade phosphate rock. Elemental phosphorus is produced in an electric furnace by smelting phosphate with coke and silica; the phosphorus is volatilized and recovered as white phosphorus or converted to the pentoxide (P_2O_5). A variety of phosphorus compounds are produced from the pentoxide and are used for varied purposes.

The only known occurrences of phosphate rock in Alaska are in the Brooks Range. It is doubtful if deposits of phosphate rock in such an inaccessible area could be utilized in connection with the development of Yukon-Taiya power.

CHROMITE

Chromite ($FeO \cdot Cr_2O_3$) is used in the manufacture of ferrochrome, as a refractory in metallurgical plants, and in the chemical industry for such products as chromates and pigments. Its use in ferrochrome has been mentioned previously. As a refractory considerable amounts might be required in certain metallurgical plants that might be established in connection with the development of Yukon-Taiya power.

The only known Alaskan chromite deposits of any significant size are those on the southwest tip of the Kenai Peninsula (Guild, 1942) in the Cook Inlet region. Though small in comparison with deposits of similar grade elsewhere in the world, these deposits constitute the largest known reserves of high-grade chromite in the United States and its territories. Deposits are known in two localities: (1) an area of about 1 square mile at Claim Point; and (2) an area of about 14 square miles at Red Mountain (Rutledge, 1946).

The deposits constitute parts of dunite and serpentine bodies in which chromite grains are concentrated in amounts ranging from a few to more than 50 percent of Cr_2O_3. The ore bodies generally are banded and tabular in shape; they range in size from small stringers to bodies of more than 50,000 tons. Analyses of relatively pure chromite mineral from these deposits reveal that it contains 54 to 59 percent of Cr_2O_3 and has a Cr:Fe ratio of 3:1.

Most of the known chromite ore at Claim Point is in a single, banded, and disseminated deposit that has been estimated by the Geological Survey to contain about 250,000 tons of indicated ore averaging

17 to 18 percent of Cr_2O_3, and about 2,000 tons of inferred ore that averages 42 percent of Cr_2O_3.

At Red Mountain there are 31 known deposits of which 11 contain nearly all the chromite ore in the area. Two of the deposits contain most of the high-grade ore (containing 40 or more percent of Cr_2O_3). The Geological Survey has estimated that these two chromite deposits at Red Mountain contain 18,000 tons of indicated ore averaging 40 to 45 percent of Cr_2O_3 and 13,000 tons of indicated ore averaging 25 percent of Cr_2O_3, about 12,000 tons of inferred ore averaging 40 percent of Cr_2O_3, and 64,000 tons of inferred ore containing 20 percent of Cr_2O_3. The remaining 9 of the 11 deposits are estimated to contain a few thousand tons of inferred ore averaging 40 to 45 percent of Cr_2O_3, and as much as 100,000 tons of inferred ore containing 15 to 25 percent of Cr_2O_3.

More than half of the ultramafic body above sea level at Claim Point is covered with moraine and soil. At Red Mountain, areas of exposed bedrock are scattered through much larger areas of talus. It is possible that deposits of chromite comparable in size and grade with those known may exist beneath the covered areas and might be discovered by geophysical methods.

Other occurrences of chromite are known along the northwest flank of the Chugach Mountains near the head of Cook Inlet, near Livengood in the Yukon region, at Red Bluff Bay on Baranof Island, and at Mount Burnett on Cleveland Peninsula near Ketchikan. All of these occurrences are considered to be too small to be of economic importance.

Many areas containing ultramafic rocks are known in Alaska and certain of these, such as east of Fairbanks to the International boundary, near Platinum in southwestern Alaska, and east of Lituya Bay in southern Alaska, include geologic environments favorable for the occurrence of chromite.

COAL

Coal, especially anthracite and coking coal, is an essential commodity in several of the metallurgical processes previously described in this report. Although there are vast coal deposits in Alaska, the only known anthracite coal and coking-coal deposits are in the Matanuska Valley and Bering River fields.

Coal of Carboniferous age is found at Cape Lisburne, on the Arctic coast of northwestern Alaska, and at the mouth of the Nation River on the upper Yukon River. Coal of Cretaceous age is found chiefly in northwestern and west-central Alaska north of the Yukon River, and in small deposits along the Alaska Peninsula. Tertiary coal beds occur on the north flank of the Alaska Range both east and west of the Nenana River, in the Matanuska Valley, on the west side of the Kenai Peninsula, and near Bering River northeast of Katalla.

Bering River. --The Bering River coal field is 12 miles northeast of Katalla at the foot of the St. Elias Range. The nearest harbor at Controller Bay is about 10 miles away but it does not provide safe anchorage for large vessels. To connect the coal field with Cordova, the nearest deep-water harbor, would require 60 miles of low-level railroad and crossing of the Copper River delta. The coal ranges in rank from semibituminous to anthracite and is in part of coking quality. The coal beds are from 3 to slightly more than 25 feet thick and are highly folded, faulted, and crushed. In spite of its high quality, no coal has been produced commercially from the Bering River field. The complex structure of the beds and the difficulty of bringing the coal to tidewater are deterrents to exploitation of the field.

Cook Inlet Lowland. -- The better known coal deposits of this region are on the western part of the Kenai Peninsula north of Kachemak Bay. Coal is being produced for local use from beds that crop out a short distance west of Homer. The coal beds have been only slightly folded and faulted, and range from 3 to 6 feet thick. The coal is subbituminous and lignitic. Minable reserves are large and are near tidewater.

Matanuska Valley. --The Matanuska Valley coal field has the largest production of any field in Alaska. The lower part of the field is readily accessible by a branch line of the Alaska Railroad and by several auto roads from the south and east. The principal mines have been the Evan Jones and Eska mines. The Evan Jones mine has a daily capacity of more than 500 tons and is the only mine in Alaska producing bituminous coal. The government-owned Eska mine ceased operations in 1946.

The coal occurs in the Chickaloon formation of Tertiary age, a series of argillaceous and sandy sediments more than 5,000 feet in total thickness, that is locally overlain by several thousand feet of conglomerate. In the western part of the field the beds are moderately folded and faulted, whereas toward the eastern part of the field the beds are complexly folded, faulted and crushed, and penetrated by an increasing number of igneous intrusives. There are at least 12 coal beds in the western part of the field, generally from 2 to 6 feet thick but locally as much as 20 feet thick. Because of their complex structure the coal beds are less accurately known in the eastern part of the field. The coal of the Western Matanuska Valley is bituminous and is noncoking; that of the eastern part is mainly high-rank bituminous, at least in part of coking quality, and includes some anthracite.

Undeveloped reserves in the Matanuska Valley are large, especially in the Wishbone Hill district between Eska and Moose Creeks. Many faults increase mining costs and necessitate expert supervision of development and mining for profitable operation.

Susitna River basin. -- Coal-bearing strata are exposed in many scattered areas of the Susitna Basin and probably extend over much larger areas beneath the mantle of glacial and stream gravels that covers the basin. Some coal has been produced from the Dunkle mine on Costello Creek, and from the mines at Houston and near Broad Pass. The coal is lignitic and subbituminous and occurs in beds 4 to 8 feet thick and of limited extent. Coal from the Susitna Basin, because of its poorer quality, limited known reserves, and difficulty of access, is in an inferior competitive position with respect to Matanuska Valley coal.

Nenana coal field. --The Tertiary coal beds of the Nenana field extend in a broad, nearly continuous belt along the north flank of the Alaska Range between the Toklat River and Jarvis Creek. The central part of the field is crossed by the Alaska Railroad and the eastern end of the Richardson Highway. The Suntrana mine, the second largest coal mine in Alaska, is in this field. Its annual production is about 100,000 tons.

The coal is lignitic and subbituminous, and occurs in beds ranging from a few feet to more than 50 feet in thickness. Enormous reserves are present in many parts of the field, in both steeply and gently dipping beds.

Other coal fields. --Most of the other Alaskan coal fields are so far removed from transportation facilities and possible markets that they are little known and little developed. The other known coal fields are: northwestern Alaska, Kobuk River, Seward Peninsula, Yukon River basin, Chignik Bay, Herendeen Bay, Unga Island, and Kootznahoo Inlet. The Geological Survey has studied parts of these fields and considerable information about them has been published. They are not considered further in this report because of their remoteness, low quality, or limited size.

Selected references to publications on coal are Barnes (1949); Barnes and Byers (1945); Capps (1927); Cobb (1950); Geer and Yancey (1946); Martin (1908, 1919); Martin and Katz (1912b); Martin, Johnson, and Grant (1915); Payne and Hopkins (1945); Rutledge (1948); Tuck (1937); U. S. Bureau of Mines (1946); Wahrhaftig (1944); Wahrhaftig and Freedman (1945); and Waring (1936).

LIMESTONE

Southeastern Alaska has vast quantities of limestone and marble. Pacific Coast States are deficient in good limestone and marble and such materials must be imported from southeastern Alaska or from east of the Sierra Nevada and Cascade Mountains. In the early part of this century six or more marble quarries operated in southeastern Alaska, and Alaskan stone has been used in the United States in more than a hundred buildings as well as for statuary and monumental purposes. Since the early part of this century the use of building stone has lost favor and Alaskan marble quarries have not been in production for many years. Burchard (1920) gives a comprehensive description of marble in southeastern Alaska.

Lime rock has been produced from the quarry at View Cove on Dall Island since 1928. The quarry was operated for many years by the Portland Superior Cement Co. which shipped the rock to its plant at Portland. The operators ship the rock in their own vessels and are said to be able to place it at the dock in Puget Sound at a cost of about $2.25 per ton. In 1946-47, Alcoa planned to develop a quarry site for lime rock at Edna Bay on Kosciusko Island and has done considerable diamond drilling. However, their plans were temporarily recessed in the latter part of 1947 because, the company was not yet ready to operate its plant in Oregon for the recovery of aluminum and iron from Oregon laterites. It was intended that the limestone would be used in this plant and would also be sold on the open market.

Most of the limestones of southeastern Alaska are confined to the Paleozoic system and are most prevalent in pre-Silurian, Silurian, and Devonian rocks. These rocks extend through Prince of Wales Island, Kuiu Island, Kupreanof Island, the south end of Admiralty Island, the east side of Chichagof Island, and through Glacier Bay and northward into Canada. The eastern border of this belt crosses the Haines Cut-off in Alaska about a mile from the international boundary.

The pre-Silurian limestones have been little studied, although it is known that there are beds as much as 1,000 feet thick on Prince of Wales Island near Hetta Inlet and Cholmondeley Sound. At the few places where these rocks have been analyzed they are dolomitic.

The Silurian rocks comprise vast areas of limestone and are uniformly of high purity ranging from 95 to 100 percent calcium carbonate. The limestones occur as beds of enormous thickness and countless suitable quarry sites could be selected near tidewater, particularly on Prince of Wales Island. Roehm (1946) has described a few of the Silurian limestone localities in southeastern Alaska.

Limestone of Devonian age occurs in beds as much as 600 feet thick on the east coast of Prince of Wales Island and on Kupreanof Island. Little is known of the quality of Devonian limestones, although they appear to be of high quality.

Limestone is known in the upper Lynn Canal area at mile 41 on the Haines Cut-off on the Alaskan side of the international boundary. Thick beds of massive white limestone crop out adjacent to the highway and in high, steep bluffs above road level. Two samples, probably representative of the entire limestone mass, were collected in 1950 by E. C. Robertson of the Geological Survey. Listed below are the analyses of the samples (analyses by Harry M. Hyman of the Geological Survey).

	50ARn-162	50ARn-163
SiO_2	0.12	0.13
Al_2O_3	.14	.03
Fe_2O_3	.00	.07
FeO	.08	.03
MgO	2.02	2.54
CaO	53.75	53.09
Na_2O	.00	.00
K_2O	.02	.02
$H_2O(-)$	.02	.02
$H_2O(+)$	.06	.08
TiO_2	.00	.00
CO_2	44.07	44.16
P_2O_5	.01	.01
MnO	.01	.01
	100.28	100.19

CONCLUSIONS AND RECOMMENDATIONS

Alaska has some of the ores and raw materials required by potential electrochemical and electrometallurgical industries that might be attracted to the upper Lynn Canal area should Yukon-Taiya power be developed. These are sea water, olivine, copper, zinc, nickel, iron, chromite, coal, and limestone. Of these coal, limestone, and byproduct zinc are produced in Alaska at present and the producing sources are so situated that boat transportation is required to bring the materials to upper Lynn Canal. The other possible Alaskan ores are not developed to the extent necessary for a final appraisal of their ultimate worth as contributors to the proposed electrochemical and electrometallurgical industries.

The aluminum industry is considered the most likely claimant of Yukon-Taiya power; there are no known Alaskan ores of aluminum.

To further appraise Alaska's raw material resources as possible supplies for Yukon-Taiya industries, the following investigations are recommended:

1. Sampling and analysis of the sea water of upper Lynn Canal to determine magnesium content.

2. Exploration and appraisal of Alaskan zinc deposits.

3. Economic studies of cost of mining, treating, and marketing Alaskan zinc ores.

4. Exploration and development of the copper-bearing pyrite ore bodies in the Prince William Sound area.

5. Studies of costs and means of concentrating and marketing Alaskan nickel-copper ores and magnetite-copper ores.

6. Further sampling and appraisal of limestone deposits in southeastern Alaska.

SELECTED BIBLIOGRAPHY

Bain, H. F., 1946, Alaska's minerals as a basis for industry: U. S. Bur. Mines, Inf. Circ. 7379.

Barnes, F. F., 1949, Coal investigations on the southern margin of the Homer district, Kenai coal field, in 1947-48: U. S. Geol. Survey. [Mimeographed report.]

__________ 1951, A review of the geology and coal resources of the Bering River coal field, Alaska: U. S. Geol. Circ. 146

Barnes, F. F., and Byers, F. M., Jr., 1945, Geology and coal resources of the eastern part of the lower Matanuska Valley coal field, Alaska: U. S. Geol. Survey. [Mimeographed report.]

Buddington, A. F., and Chapin, Theodore, 1929, Geology and mineral deposits of southeastern Alaska: U. S. Geol. Survey Bull. 800.

Burchard, E. F., 1920, Marble resources of southeastern Alaska: U. S. Geol. Survey Bull. 682.

Capps, S. R., 1927, Geology of the upper Matanuska Valley, Alaska: U. S. Geol. Bull. 791.

Capps, S. R., and Johnson, B. L., 1915, The Ellamar district, Alaska: U. S. Geol. Bull. 605.

Cobb, E. H., 1950, Coal investigations on the southwest margin of the Homer district, Kenai coal field, Alaska: U. S. Geol. Survey. [Mimeographed report.]

Erickson, A. W., 1948, Investigation of Tolstoi Mountain iron deposits, Kasaan Peninsula, Prince of Wales Island, southeastern Alaska: U. S. Bur. Mines, Rept. of Inv. 4373.

Gault, H. R., 1944, Zinc deposits of Groundhog Basin, Wrangell district, southeastern Alaska: U. S. Geol. Survey. [Mimeographed report.]

Gault, H. R., Rossman, D. L., and Flint, G. M., Jr., 1944, Geology and mineral deposits of Glacier Basin and vicinity, Wrangell district, southeastern Alaska: U. S. Geol. Survey. [Mimeographed report.]

Gault, H. R., and Wahrhaftig, Clyde, 1943, The Salt Chuck copper-palladium mine, Prince of Wales Island, southeastern Alaska: U. S. Geol. Survey. [Mimeographed report.]

Geer, M. R., and Yancey, H. F., 1946, Washability characteristics and washing of coals from the Matanuska field of Alaska: U. S. Bur. Mines, Rept. of Inv. 3840.

Goddard, E. N., Warner, L. A., and Walton, M. S., Jr., 1944, Copper-bearing iron deposits of the Mount Andrew-Mamie area, Kasaan Peninsula, Prince of Wales Island, Southeastern Alaska: U. S. Geol. Survey. [Mimeographed report.]

Guild, P. W., 1942, Chromite deposits of Kenai Peninsula, Alaska: U. S. Geol. Survey Bull. 931-G, pp. 139-175

Guild, P. W., and Balsley, J. R., 1942, Chromite deposits of Red Bluff Bay and vicinity, Baranof Island, Alaska: U. S. Geol. Survey Bull. 936-G, pp. 171-187.

Heide, H. E., 1946, Investigation of the Lost River tin deposit, Seward Peninsula, Alaska: U. S. Bur. Mines, Rept. of Inv. 3902.

Holt, S. P., and others, 1948, Diamond drilling at Rush and Brown copper mine, Kasaan Bay, Prince of Wales Island, southeastern Alaska: U. S. Bur. Mines, Rept. of Inv. 4358.

__________ 1948, Investigation of the Salt Chuck copper mine, Kasaan Peninsula, Prince of Wales Island, southeastern Alaska: U. S. Geol. Survey Bull. 862-C, pp. 193-220.

Holt, S. P., and Moss, J. M., 1946, Exploration of a nickel-copper-cobalt deposit at Funter Bay, Admiralty Island, Alaska: U. S. Bur. Mines, Rept. of Inv. 3950.

Holt, S. P., and Sanford, R. S., 1946, Exploration of Poor Man iron deposit, Kasaan Peninsula, Prince of Wales Island, southeastern Alaska: U. S. Bur. Mines, Rept. of Inv. 3956.

Johnson, B. L., 1918, Copper deposits of the Latouche and Knight Island districts, Prince William Sound, (Alaska): U. S. Geol. Survey Bull. 662-C, pp. 193-220.

Kennedy, G. C., and Walton, M. S., Jr., 1946, Geology and associated mineral deposits of some ultrabasic rock bodies in southeastern Alaska: U. S. Geol. Survey Bull. 947-D, pp. 65-84.

__________ 1946, Nickel investigations in southeastern Alaska: U. S. Geol. Survey Bull. 947-C, pp. 39-64.

Kingston, Jack, and Miller, D. J., 1945, Nickel-copper prospect near Spirit Mountain, Copper River region, Alaska: U. S. Geol. Survey Bull. 943-C, pp. 49-57.

Martin, G. C., 1908, Geology and mineral resources of the Controller Bay region, Alaska: U. S. Geol. Survey Bull. 335.

__________ 1919, The Nenana coal field, Alaska: U. S. Geol. Survey Bull. 664.

Martin, G. C., Johnson, B. L., and Grant, U. S., 1915, Geology and mineral resources of Kenai Peninsula, Alaska: U. S. Geol. Survey Bull. 587.

Martin, G. C., and Katz, F. J., 1912a, A geologic reconnaissance of the Iliamna region, Alaska: U. S. Geol. Survey Bull. 485.

__________ 1912b, Geology and coal fields of the lower Matanuska Valley, Alaska: U. S. Geol. Survey Bull. 500.

Miller, D. J., 1946, Copper deposits of the Nizina district, Alaska: U. S. Geol. Survey Bull 947-F, pp. 93-120.

Moffit, F. H., 1938, Geology of the Chitina Valley and adjacent area, Alaska: U. S. Geol. Survey Bull. 894.

Muir, N. M., Thomas, B. I., and Sanford, R. S., 1947, Investigation of the Mount Eielson zinc-lead deposits, Mount McKinley National Park, Alaska: U. S. Bur. Mines, Rept. of Inv. 4121.

Payne, T. G., and Hopkins, D. M., 1945, Geology and coal resources of the western part of the lower Matanuska Valley coal field, Alaska: U. S. Geol. Survey. [Mimeographed report.]

Pecora, W. T., 1942, Nickel-copper deposits on the west coast of Chichagof Island, Alaska: U. S. Geol. Survey Bull.936-I, pp. 221-243.

Pierce, H. C., 1946, Exploration of Spirit Mountain nickel prospect, Canyon Creek, lower Copper River region, Alaska: U. S. Bur. Mines, Rept. of Inv. 3913.

Reed, J. C., and Dorr, J. V. N. 2d, 1942, Nickel deposits of Bohemia Basin and vicinity, Yakobi Island, Alaska: U. S. Geol. Survey Bull. 931-F, pp. 105-138.

Robinson, G. D., 1944, The zinc-copper deposits near Moth Bay, Revillagigedo Island, southeastern Alaska: U. S. Geol. Survey. [Mimeographed report.]

Roehm, J. C., 1946, Some high calcium limestone deposits in southeastern Alaska: Terr. Dept. Mines, Pamph. no. 6.

Rutledge, F. A., 1946, Exploration of Red Mountain chromite deposits, Kenai Peninsula, Alaska: U. S. Bur. Mines, Rept. of Inv. 3885.

__________ 1948, Investigation of the W. E. Dunkle coal mine, Costello Creek, Chulitna district, Alaska: U. S. Bur. Mines, Rept. of Inv. 4360.

Smith, P. S., 1939, Areal geology of Alaska: U. S. Geol. Survey Prof. Paper 192.

Stefansson, Karl, and Moxham, R. M., 1946, Copper Bullion claims, Rua Cove, Knight Island, Alaska: U. S. Geol. Survey Bull. 947-G, pp. 121-141.

Tuck, Ralph, 1937, The Eska Creek coal deposits, Matanuska Valley, (Alaska): U. S. Geol. Survey Bull. 880-D, pp. 185-214.

U. S. Bureau of Mines, 1944, Mirror Harbor, Chicagof Island, Alaska: War Minerals Rept. 333.

__________ 1944, Yakobi Island, Sitka mining district, Alaska: War Minerals Rept. 174.

__________ 1946, Analyses of Alaska coals: Tech. Paper 682.

Van Alstine, R. E., and Black, R. F., 1946, Copper deposits of the Kotsina-Kuskulana district, Alaska: U. S. Geol. Survey Bull. 947-G, pp. 121-141.

Wahrhaftig, Clyde, 1944, Coal deposits of the Costello Creek Basin, Alaska: U. S. Geol. Survey. [Mimeographed report.]

__________ 1944, Zinc deposits of Mount Eielson district, Alaska: U. S. Geol. Survey. [Mimeographed report.]

Wahrhaftig, Clyde, and Freedman, Jacob, 1945, Coal deposits in the valley of the Healy River, Alaska: U. S. Geol. Survey. [Mimeographed report.]

Waring, G. A., 1936, Geology of the Anthracite Ridge coal district, Alaska: U. S. Geol. Survey Bull. 861.

Warner, L. A., and Ray, R. G., 1944, Iron and copper deposits at the Haida mine and Copper Center prospect, Kasaan Peninsula, Prince of Wales Island, southeastern Alaska: U. S. Geol Survey. [Mimeographed report.]

Warner, L. A., and Walton, M. S., Jr., 1944, The Poor Man iron deposit, Kasaan Peninsula, Prince of Wales Island, southeastern Alaska: U. S. Geol. Survey. [Mimeographed report.]

Warner, L. A., Ray, R. G., and Flint, G. M., Jr., 1944, Copper deposits at the Rush and Brown mine and Venus prospect, Prince of Wales Island, southeastern Alaska: U. S. Geol. Survey. [Mimeographed report.]

Webber, B. S., Moss, J. M., and Rutledge, F. A., 1946, Exploration of Sedanka zinc deposits, Sedanka Island, Alaska: U. S. Bur. Mines, Rept. of Inv. 3967.

Wright, C. W., 1915, Geology and ore deposits of Copper Mountain and Kasaan Peninsula, Alaska: U. S. Geol. Survey Prof. Paper 87.

Wright, W. S., and Fosse, E. L., 1946, Exploration of the Jumbo Basin iron deposits, Prince of Wales Island, southeastern Alaska: U. S. Bur. Mines, Rept. of Inv. 3952.

INT.-DUP. SEC., WASH., D.C. 36633