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WASHINGTON

INTRODUCTION AND SUMMARY

This report describes the mineral and water resources of Washington. Its purpose is to bring together in summary form authentic and up-to-date information on the State's resources of minerals and water. The report is based principally on published data on the geology and mineral and water resources of Washington but has been supplemented by information in the files of the United States Geological Survey and the Washington Division of Mines and Geology. It contains, in addition, information derived from the personal observations of many of the authors of individual sections of the report and, consequently, includes considerable information not previously available in published form. It is hoped that the material herein presented will be useful to the professional as well as to the nonprofessional who is, for one reason or another, interested in the State's resources.

In introductory chapters the geology of Washington is summarized, and a brief résumé is given of the mineral industry and its relative importance in the economy of the State. In succeeding chapters all the mineral resources known to occur in the State in commercial or near-commercial quantities are discussed. The use, manner of occurrence, distribution, and outlook for each of these resources are considered. Where available, production statistics are included.

A second part of the report deals with the State's very important resources of water. The quantity, quality, and distribution of surface and ground water resources and their use for municipal water supply are considered. In a separate chapter, developed and potential resources of hydroelectric power are discussed. A final chapter is concerned with water resource development exclusive of that dealing with hydroelectric power and municipal water supply.

This report is a joint effort of the United States Geological Survey, the Washington Division of Mines and Geology, and the United States Bureau of Reclamation, with important contributions from the Bonneville Power Administration and the Washington State Department of Highways. A. E. Weissenborn, United States Geological Survey, served as editor, assembled the various sections of the report, and coordinated the efforts of the many authors who contributed to the report. Marshall T. Huntting, Supervisor of the State Division of Mines and Geology, arranged for the participation of the various authors from State agencies. L. B. Laird, United States Geological Survey, coordinated the preparation of that part of the report concerned with water resources, and Gilbert V. Schirk, United States Bureau of Reclamation, was responsible for the preparation of the chapter on water resources development.

SECTION I

GEOLOGY AND MINERAL RESOURCES

GEOLOGY

INTRODUCTION

(By A. E. Weissenborn, U.S. Geological Survey, Spokane, Wash.)

Washington is familiarly known as the Evergreen State, but it might as aptly be termed the Land of Contrast. Within the State, rainfall varies from more than 200 inches annually in the Olympic Mountains to less than 10 inches in parts of eastern Washington. The lush forests of northern and western Washington contrast sharply with the barren, forbidding scablands of central Washington and the treeless wheat fields of the Palouse Hills; the towering, rugged Cascades contrast with the coulees and flat, basalt-covered mesas of central Washington and the level farmlands in the Puget Lowlands north of Seattle; the snow-capped volcanoes that crown the Cascades contrast with the magnificent beaches that stretch for miles along the Pacific Coast.

Washington's 68,192 square miles fall into seven distinct physiographic divisions. These are the Okanogan Highlands, the Columbia Basin, the Blue Mountains, the Cascade Mountains, the Puget Lowlands, the Olympic Mountains, and the Willapa Hills (fig. 1). Each of these areas differs from the others in climate, topography, and the natural resources that are available within it. These differences profoundly influence the economic life of the more than 2.8 million people who live within the boundaries of the State. These differences, in turn, are in very large part but a reflection of differences in the geology of each area. Natural resources and geology walk hand in hand. Therefore this volume, which discusses the mineral and water resources of Washington, begins with a summary of the geology of the State.

Our knowledge of the geology of Washington is derived from the findings of many geologists working over a period of many years, beginning back in the 1880's when Washington was still frontier country. Some of the early work of the U.S. Geological Survey was done in Washington, and geological mapping by this organization is still going on in many places in the State. The State of Washington Division of Mines and Geology—and its predecessor, the Washington Geological Survey—has actively been engaged in studying the geology and mineral resources of the State since the early 1900's and has produced a wealth of knowledge. Work done under the auspices of the University of Washington, Washington State University, and other universities has made important contributions to the knowledge of the geology, particularly in the Cascade Mountains.

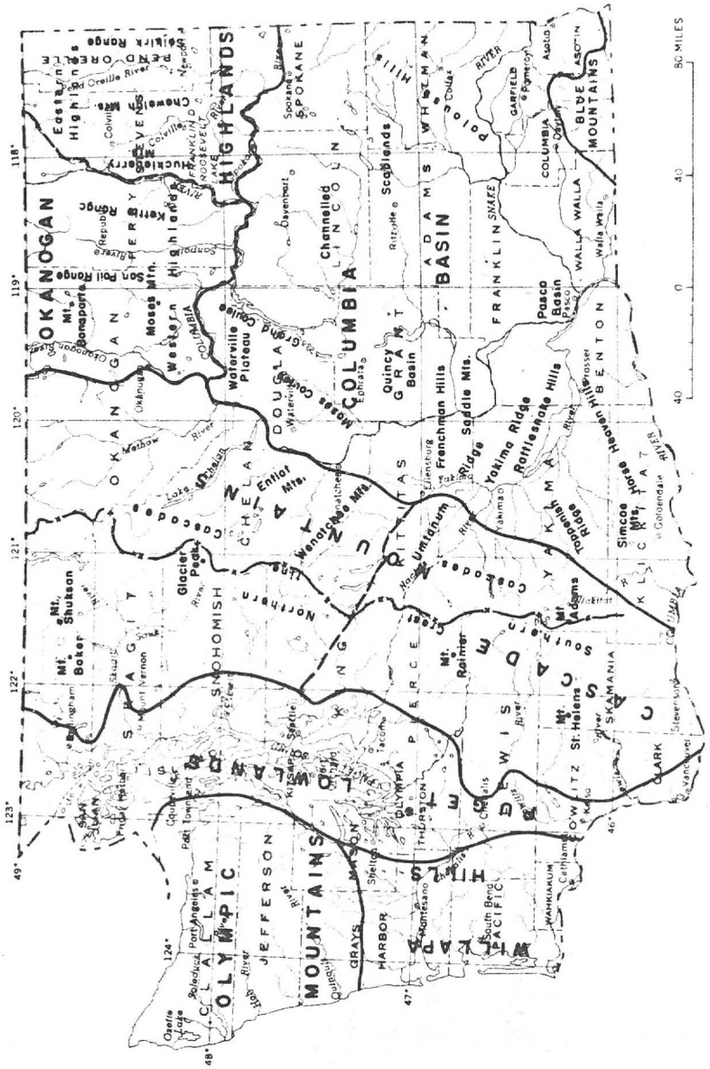

FIGURE 1.—Physiographic divisions of Washington.

Geologists from industry, searching for metallic and nonmetallic minerals as well as petroleum and natural gas, have likewise made many contributions to our knowledge of the geology of the State. Figure 2 shows the areas in the State covered by published geological maps from all sources. A number of other areas have been mapped geologically. Figure 2, however, includes only published geological mapping and does not include a considerable amount of work that has not yet been published.

Although there are a few critical areas where geological information is almost completely lacking, figure 2 indicates that the greater part of the State has been mapped geologically. However, published maps, on what by modern standards would be considered an adequate scale, are available only for the much smaller stippled areas of figure 2. Clearly, much remains to be done before it can be considered that the geology of the State is adequately known—or even as adequately known as that of its neighboring States.

Topographic maps are essential for many purposes such as recreational, industrial, and highway construction but are especially essential as bases on which to plot the geology and other data. Figure 3 shows the areas in the State which have been mapped topographically. Some critical areas from the standpoint of mineral and water resources still lack topographic maps, but because of intensive work during the past few years topographic map coverage for most parts of the State is well advanced—far ahead of the geologic mapping.

The following discussion of the geology of Washington is divided into four sections: northeastern Washington; the Columbia Basin, including the Blue Mountains; the Cascade Mountains; and western Washington. The geology of each of these sections is summarized with the intent of providing a background for the remainder of the report. As with other sections, bibliographic references are given for the benefit of those readers who wish more detailed information than can be included in these necessarily brief accounts. As an aid in following the geological discussion, the reader is referred to figure 4, a highly generalized map of the geology of Washington.

NORTHEASTERN WASHINGTON

(By R. G. Yates, U.S. Geological Survey, Menlo Park, Calif.)

Northeastern Washington, as defined here, includes Pend Oreille, Stevens, Ferry, eastern Okanogan, and northern Spokane Counties. It comprises less than 15 percent of the State's area, but from its mines comes over 90 percent of the State's metal production. It is, therefore, not surprising that the geologic setting of this part of the State is uniquely different from that of the remainder. Mountainous in character, it contrasts sharply with the smooth undulations of the Columbia Plateau to the south, but much less sharply with the higher and more rugged Cascade Mountains, which lie to the west. Likewise, its geology merges with the geology of the Cascades, but contrasts strongly with that of the Columbia Plateau.

This area, which lies east of the Okanogan River and north of the west-flowing stretch of the Columbia and its tributary, the Spokane,

in places rises as much as 5,000 feet above the surface of the plateau. The area is commonly known as the Okanogan Highlands (fig. 1). In a general way, the Columbia River divides the Highlands into two geographic parts: east of the river are the Selkirk, Chewelah, and Huckleberry Mountains; west of the river are the Kettle, Sanpoil, and other ranges. The mountains, however, lack any orderly arrangement that would make it possible to separate them into a system of ranges and valleys. They appear to be crowded together, with little room for the narrow, south-trending valleys of the Columbia, Okanogan, Sanpoil, and Pend Oreille Rivers that drain northeastern Washington.

All the drainage from the area reaches the Pacific Ocean via the Columbia River, but some tributaries follow rather devious courses to reach the master stream. The Okanogan and Sanpoil Rivers behave as normal, orderly streams and flow directly south to join the Columbia in the shortest possible distance. But not so with the Pend Oreille and Kettle Rivers. The Pend Oreille swings northward in a wide arc to join the Columbia in British Columbia; the Kettle also selects a very circuitous route; as if it were making great—but futile—efforts to avoid a junction with the Columbia. Such irregularities reflect, in part, changes in the drainage pattern brought about by the great ice sheets that advanced southward during the Pleistocene epoch. The ice moved down the river valleys in great lobes that grew and coalesced to form a thick sheet that covered almost the entire area. As the climate warmed, the ice retreated northward, and lakes formed in the valleys of the Columbia and Pend Oreille Rivers and their tributaries. The melt waters of the swollen rivers, milky with suspended clay and fine silt, swept southward the sand and gravel that had been left by the ice, to deposit it and the suspended clay and silt in the slack waters of the lakes. Deposits of horizontal-layered silt, clay, and sand on the lower slopes of the valleys preserve the outlines of these ancient lakes. Near the International Boundary, terrace features indicate that the last high level of the lake in this valley was at an elevation of about 2,000 feet. The numerous steplike terraces along the valley walls of the Columbia River represent successive lower levels of the lake or lakelike river that succeeded the lake. The higher slopes and even the peaks near the Canadian border likewise were covered with the wastes of the glaciers; even today, deposits of gravel and sand, from a few to several hundred feet thick, and stray exotic boulders cover more than half the area of the mountain slopes. This extensive cover of ice-transported material greatly handicaps the interpretation of the bedrock geology, as well as increasing the difficulty of the discovery of mineral deposits.

Enough bedrock does extend through this mantle to demonstrate clearly that the sedimentary rocks in the eastern Okanogan Highlands record a different geologic history from those in the western Highlands.[1] The difference is not only in the age of the rocks, but in the conditions under which they accumulated. The oldest rocks in the State with well-established ages are east of the Columbia River. Most of these can be demonstrated to lie below the rocks that contain

[1] This division of two different groups of rocks, one in the eastern and the other in the western Okanogan Highlands, is only a broad generalization. The boundary between the two groups only approximates the course of the Columbia River. From the mouth of the Spokane River to Evans it is a few miles east of the river; from Evans to Northport it is west of the river; and from Northport to the International Boundary it is again east of the river.

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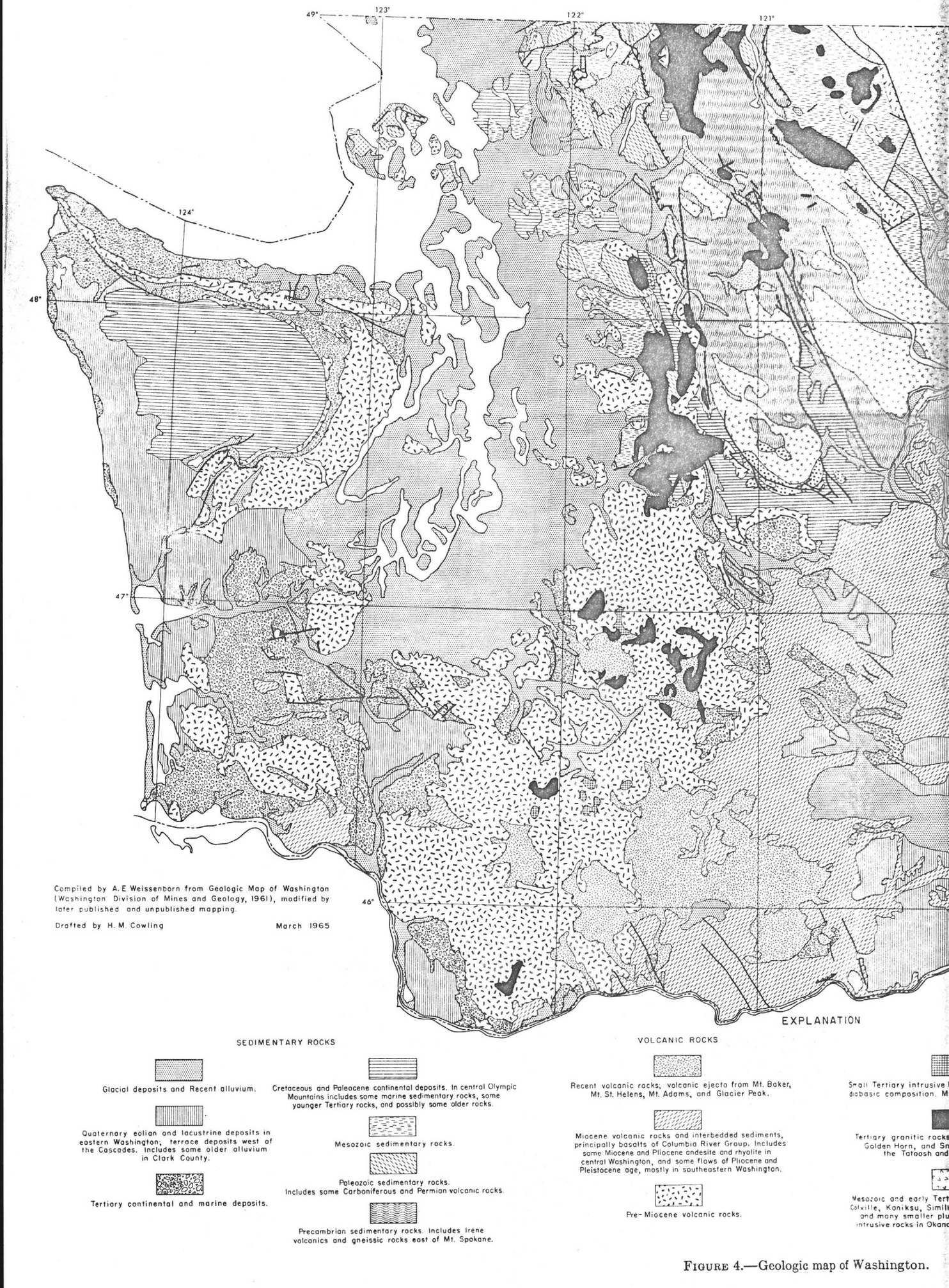
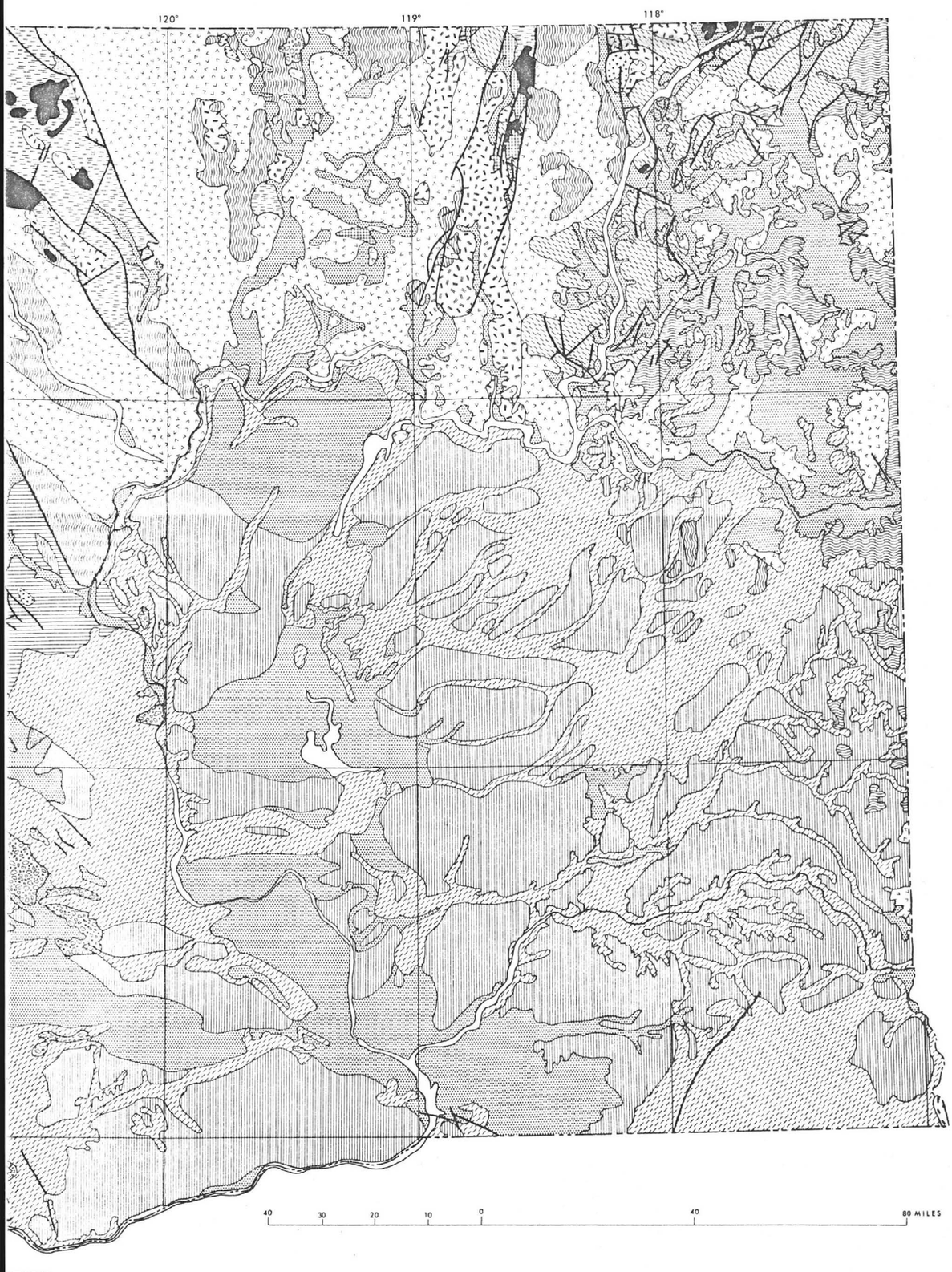


FIGURE 4.—Geologic map of Washington.



ATION

CRYSTALLINE ROCKS

Small Tertiary intrusive bodies, mostly of andesitic and diabasic composition. Many small bodies not shown.

Tertiary granitic rocks. Includes the Chilliwack, Golden Horn, and Snoqualmie batholiths, and the Tatoosh and other small plutons.

Mesozoic and early Tertiary granitic rocks. Includes the Colville, Kaniksu, Similkameen, and Mt. Stuart batholiths and many smaller plutons. Also includes alkaline intrusive rocks in Okanogan and Stevens Counties.

Tertiary and pre-Tertiary mafic and ultramafic intrusive rocks.

Pre-Devonian granitic rocks. Restricted to Cascade Mountains and San Juan Islands.

Metamorphic rocks, mostly pre-Jurassic but includes some rocks of probable later age.

Fault

Thrust fault, saw-teeth on upper plate.

of Washington.

	OLYMPIC MOUNTAINS		PUGET LOWLAND	
	Western	Northern	Central	Eastern edge
Middle(?) and late Pleistocene	Queets Beds of Glover (1940)	Vashon Drift	Vashon Drift	Vashon Drift
			Kitsap Fm.	Evans Creek Drift
		?——?		
		Alpine drift	Salmon Springs Drift	Wingate Hill Drift
		?——?		
Early(?) and middle Pleistocene			Puyallup Fm.	Lily Creek Fm. upper part
			Stuck Drift	
			Alderton Fm.	lower part
	Taholah Fm. of Glover (1940)	Older drift(?)	Orting Drift	Logan Hill Fm.

FIGURE 11.—Pleistocene stratigraphy of western Washington.

In late Pleistocene time, ice lobes from the Canadian ice sheet again extended southward beyond Olympia in the Puget Lowland and westward through the Juan de Fuca Strait to the Pacific Ocean. Streams flowing out of the mountains were dammed by these thick lobes, lakes formed, and lacustrine sediments many hundreds of feet thick accumulated before the climate again changed and the Ice Age came to a close. As the ice lobes retreated, thick deposits of glaciofluvial outwash and till remained in their wake along the north coastal area of the Olympic Mountains and in the Puget Lowland (Vashon Drift, fig. 11). Simultaneously, glaciofluvial deposits accumulated locally west of the Olympic Mountains (Queets Beds of Glover, 1940, fig. 11).

Marine sediments at Seattle provide evidence that, as Pleistocene time ended and the Recent Epoch began, waters from the Pacific Ocean flooded part of the Puget Lowland. The climate became somewhat warmer than at present (Crandell, 1963, p. 9), streams with headwaters in the higher mountains carried much silt and sand to the adjacent lowlands, and great mudflows swept masses of volcanic boulders and ashy silt into the southern part of the Puget Lowland. Worldwide melting of the continental ice sheets, and resultant rise in sea level, brought marine waters to their present position in the glacier-cut troughs of Puget Sound.

MINERAL RESOURCES

The Mineral Industry of Washington

(By A. E. Weissenborn, U.S. Geological Survey, Spokane, Wash.)

In 1963 Washington's mineral production was $71.4 million, placing it 35th among the States with respect to the value of its mineral output. The State produced about 32 different mineral products. It led the United States in the production of olivine and was second in the production of magnesite, third in the production of diatomite, and sixth in the production of talc and soapstone, and sixth in the production of uranium. It ranked sixth among the States in the production of lead, twelfth in the production of zinc, and about sixth in the production of gold. In the Knob Hill mine at Republic and the Gold King mine at Wenatchee, it has two of the leading lode gold mines in the United States, and its Pend Oreille mine at Metaline in 1963 was the country's 12th ranking producer of both lead and zinc.

Washington's production of minerals compares favorably with that of her sister states of Idaho and Alaska, both probably in popular estimation better known as mining states. In 1963 Idaho's mineral production was $82.8 million, or 0.42 percent of the United States production; Alaska's was $67.8 million, or 0.35 percent of domestic production (D'Amico, 1964).

Only a relatively small percentage of the State's labor force is employed in mining. According to the Washington State Department of Employment Security, in 1963 approximately 224,000 were engaged in manufacturing, 76,500 in farming, 1,500 in commercial fishing, 11,100 in logging, and 1,900 in mining and quarrying. Manufacturing, which in 1963 had an annual payroll of $1.5 billion and produced $2.9 billion worth of goods, greatly overshadows mining, which in the same year had an annual payroll of $12.8 million and produced metals and nonmetallic minerals valued at $71.4 million. Cash received for farm products in 1963 amounted to nearly $600 million, about eight times the value of the raw minerals produced in the State. These figures, however, do not indicate the real importance of the mineral industry to the economy of Washington, for although only 1,900 persons were employed in mines and quarries, an additional 26,600 with an annual payroll of about $200 million were employed in processing the minerals, including smelting, refining, and casting of metals; manufacture of stone, clay, and glass products; petroleum refining, and the industrial chemical industry, including the Hanford atomic plant. Some of these processing plants treat principally raw materials that have been brought into the State, but nearly all draw on local sources for at least some of their raw materials. Some depend heavily on these local sources and could not operate without them; others use local materials exclusively. The State's resources of metallic and nonmetallic minerals contribute vital support to an important segment of its economy.

Coal and gold were the first minerals to be produced commercially in Washington. According to Glover (1954), coal was first discovered in 1833 in what was to become Washington Territory and was produced commercially for local use as early as 1853. Numerous other discoveries of coal soon followed, and by 1870 all the major coal fields in the State had been found. With the coming of the railroads and the rapid growth of the population, coal soon became the State's leading mineral product, a position it maintained for many years.

Gold also was discovered early in the history of Washington. In 1853 a party under Captain George B. McClellan searching for a railroad route across the Cascades is reported to have found placer gold in the Yakima Valley. Other placer gold localities were found in the same year between the Cascades and the Columbia River (Huntting, 1955). By 1855 placer gold was being mined along the Columbia and some of its tributaries in the vicinity of Fort Colville. Discovery of placers on the Similkameen River in 1859 brought a rush of miners to the area. Prospectors ranged through the country and others were found. Huntting (1955, p. 33) estimates that $9 million in placer gold was mined prior to 1866. The influx of miners to northeastern Washington was deeply resented by the Indian tribes and was one of the causes of the Indian wars that followed. The end result was the restriction of the Indian population to a few reservations and the opening of the State to settlement By 1900 most of the gold placers in Washington that had been found had been largely worked out.

The early history of lode mining has been described by Patty (1921). Lode mining did not begin until the early 1870's. The first known lode discovery was made near Mount Chopaka in Okanogan County in 1871 (Glover, 1954, p. 13). Locations were made on Silver Creek in the Index district in 1874. The Blewett area also was active in 1874, and the first stamp mill in the State was installed here in 1878. The first claims in the Monte Cristo district were located in 1889. The district was an important producer in the early days of mining in Washington, and a railroad was built into the district to serve the mines—the only railroad in the State constructed solely for mining purposes (Patty, 1921, p. 21).

The Lone Jack mine, the first important lode mine in the Mount Baker district, was discovered in 1897, but the district's placers were worked much earlier and occasioned a brief but lively gold rush when first discovered.

Lead-silver ore was found in Stevens County in 1893 near the present site of Colville, and rich ore from the Old Dominion mine was transported to Spokane by pack train. Impetus was given to mining by the building of a railroad into Stevens County, and numerous other discoveries of lode deposits were made in the Chewelah, Deer Trail, Northport, and other districts. The opening to prospecting of the north half of the Colville Indian Reservation in 1896 gave another impetus to mining in eastern Washington. Discovery of the important Republic district soon followed. Additional discoveries were made when the southern half of the reservation was opened to location in 1898. By 1900 most of the metal mining districts in the State were known, although it would be many years before some of them would be brought into production.

Figure 12 shows the growth of Washington's mineral production since 1900, when reliable records of production first became available. The lower curve gives the reported value in dollars. Because the value of the dollar has fluctuated widely, a more accurate measure of the magnitude of production is shown in the upper curve where the values are expressed in "constant dollars." In this curve the value of the dollar from 1957 to 1959, based on the wholesale price index, is taken as 100. The adjusted curve shows a steady increase in Washington's mineral production interrupted by some periods of low production, with the peak of production occurring at the start of World War II. If the current demand for the minerals Washington produces continues, the next few years should see production reach a new peak.

In contrast to some of the other western States, Washington is predominantly a producer of nonmetallic minerals. Of the estimated $1.8 billion worth of minerals mined or quarried from the State since 1866, 80.7 percent has come from nonmetallic minerals and only 19.3 percent was from metallic ores. This ratio still holds true; in 1963 81.6 percent of the value of the State's mineral production came from nonmetallic minerals and only 18.4 percent from metallic ores (fig. 13). In terms of total production and value of the product, coal, sand and gravel, and stone (including limestone for portland cement) are by far the most important mineral commodities produced in the State. Zinc, gold, lead, copper, uranium, and silver are the next most important commodities produced, but the total value of all these metals combined does not equal the value of the coal (fig. 13).

Coal production reached a peak about 1918. Since then it has declined drastically owing chiefly to the increased use of oil as a fuel, to the availability of cheap hydroelectric power throughout the Pacific Northwest, and to competition from Utah and Wyoming coal. Conversion of the railroads to diesel or electric power was a nearly fatal blow. The decline of coal as a factor in the mineral economy of the State is illustrated graphically in figure 13, which shows that, whereas coal has accounted for nearly 25 percent of the value of all minerals produced in Washington since the beginning of records, in 1963 it accounted for less than 2 percent of the mineral production. The efficiency of steam generating plants has increased markedly in recent years, and the more favorable hydroelectric power sites in the Northwest are rapidly being preempted. In addition, research may develop new uses for coal. Although no immediate improvement can be anticipated, Washington's substantial resources of coal should in the coming years once again become an important segment of the State's mineral industry.

The production of metallic minerals has shown a healthy growth in spite of low prices for lead and zinc which have been in effect from the early 1950's until recently, and despite the fact that some ore bodies have been mined out and are now abandoned. Among the outstanding events of the last 10 years or so have been the mechanization—and consequent increase in production—of the Metaline district, the development of the Gold King mine at Wenatchee into a major gold and silver producer, important developments in the Republic district, and the discovery of a highly profitable uranium mine on the Spokane Indian Reservation. The successful operation of the Van Stone mine and, more recently, the bringing in of the Calhoun mine

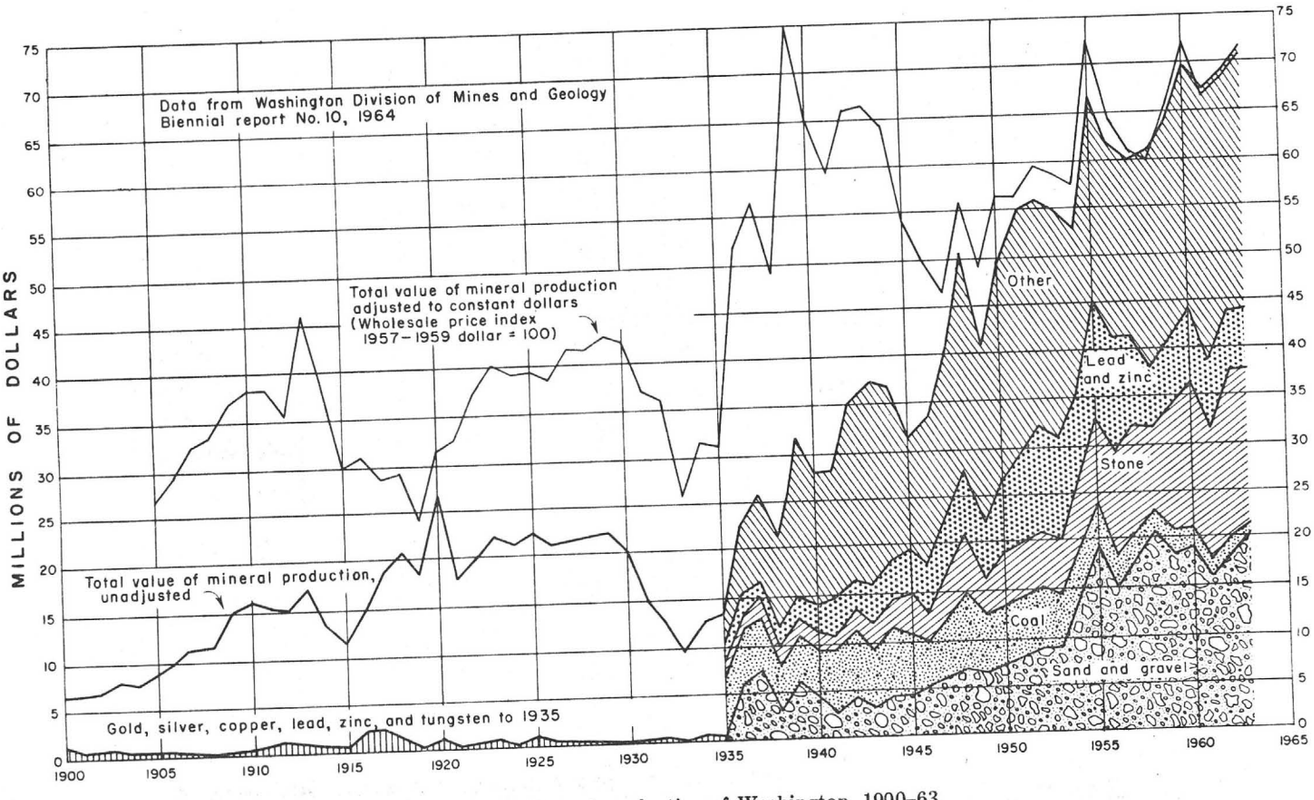


FIGURE 12.—Mineral production of Washington, 1900–63.

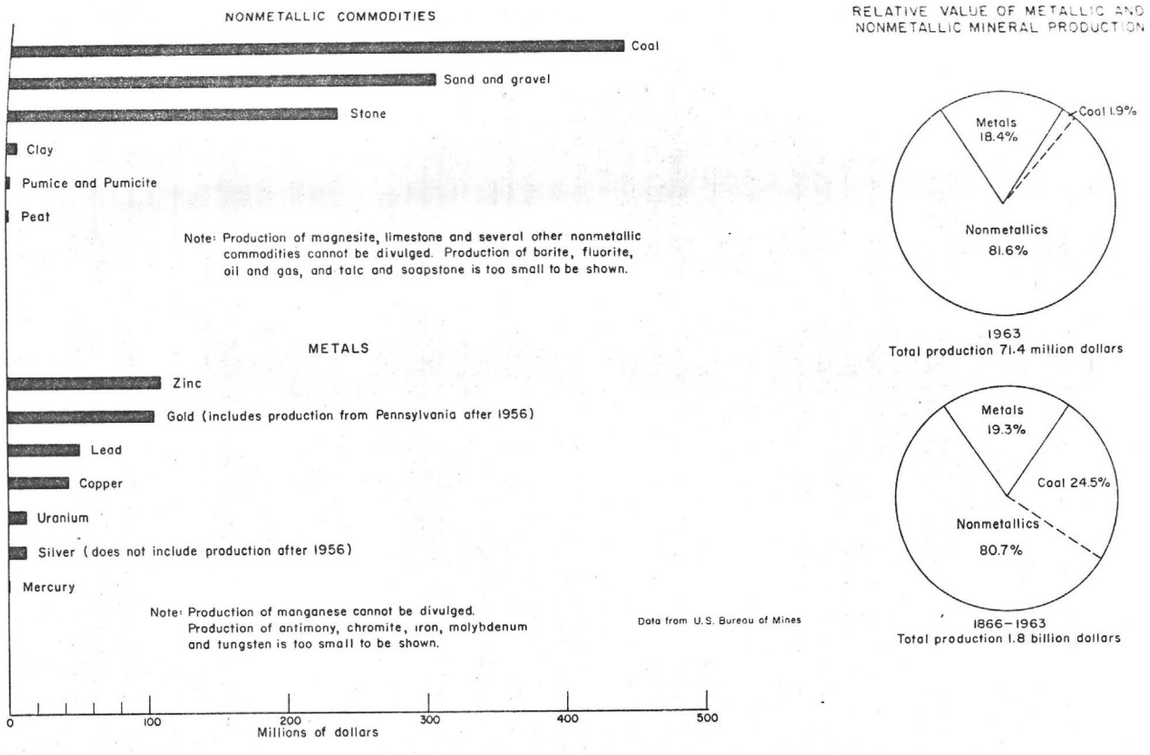


FIGURE 13.—Washington's mineral production by commodities.

have shown that mining in Stevens County need not be confined to the high-grade ore bodies from which most of the past production has come. These developments also show that even though most areas in northeastern Washington and in many parts of the Cascades have been thoroughly combed by prospectors during several periods of prospecting, application of new techniques of exploration, and mining and of new concepts of geology can discover new ore bodies. With price levels that will encourage exploration, discoveries should be made that will permit the continued growth of Washington's metal mining industry.

Nonmetallic mining has long been an important segment of Washington's mineral industry. With the continued growth of the State and its increasing industrialization, there will be an increased demand for nonmetallic minerals. Production of sand and gravel, cement, and other materials for the construction industry will increase. Production of olivine has increased rapidly in the last few years and should continue to grow. As the population increases, there will probably be a demand for other products which the State does not now produce or produces in small amounts.

Exploration in Washington for petroleum and natural gas has met with indifferent success up to now, although gas fields in Benton and Whatcom Counties and oil production in Grays Harbor and Jefferson Counties have proven that sources of petroleum and natural gas are present. Only about 100 wells have been located on sites selected as a result of sound geological investigations, and these provide inadequate coverage of the State's potential petroleum areas. Only further test drilling can determine whether oil and gas in commercial quantities occur in Washington.

Metallic Mineral Resources

ANTIMONY

(By D. R. MacLaren, U.S. Geological Survey Spokane, Wash.)

Antimony is a silvery white, soft, brittle metal chemically similar to arsenic and bismuth. It possesses three somewhat peculiar properties that strongly influence its uses; it expands on solidifying from a melt, it relatively strongly repells a magnetic field (a property called diamagnetism) and its electric conductivity varies markedly with changes in temperature. Antimony is most commonly used as an alloy, principally with lead for type metal, storage battery plates, sheeting and pipes used in the chemical industry, cable covering, castings, and ammunition. Other common alloys are with lead and tin for solder and machine bearings, and with copper and zinc for brass and brass products. Besides its use as an alloy, antimony is used in pharmaceuticals, laboratory chemicals, ceramics, and plastics.

There are many minerals that contain antimony, but the only important ore minerals are stibnite, Sb_2S_3, and to a lesser extent tetrahedrite ($Cu_{12}Sb_4S_{13}$), which is primarily an ore mineral of copper. Sometimes silver replaces part of the copper in tetrahedrite, which may then become an important ore mineral of silver. Whether it is a copper or silver ore mineral, the antimony is usually only a detriment to its value. A notable exception is the tetrahedrite silver ore of the

Sunshine mine in Idaho, from which the antimony is recovered by an electrolytic process.

The United States has been mostly dependent on foreign sources of antimony. In the past, Mexico, China, and Bolivia were the principal foreign sources (Purdy, 1951, p. 15), but during 1951 China ceased exporting antimony to the United States. In 1963, the principal imports of antimony were 4,337 short tons from Mexico, 4,010 short tons from the Republic of South Africa, and 988 short tons from Bolivia (Moulds, 1964, p. 241).

Nearly two-thirds of the antimony produced domestically is obtained from reclaiming antimonial scrap. Most of the rest is antimony or antimonial lead obtained at primary smelters as a by-product of treating imported antimonial ores. In 1963, only 645 tons of antimony was produced from domestic mines, nearly all of which was recovered from the treatment of the tetrahedrite ore by the Sunshine Mining Company at Kellogg, Idaho.

The total recorded production from Washington has been a little more than 3,300 tons of antimony ore, of which 2,300 tons was produced during World War I (Huntting, 1956). The last recorded production from the State was from the Bales property in 1952 (Huntting, 1956).

The first discovery of antimony in Washington was made in 1892 at the Great Republic mine in King County. Since that year, numerous occurrences of antimony have been reported. Huntting (1956) lists 275 mines and prospects where antimony minerals occur, but antimony production has been recorded from only 9 mines. Of these, only the Antimony Bell (fig. 14, No. 14), Antimony Queen (No. 13), Bales (No. 10), and Lucky Knock (No. 9) mines in Okanogan County were primarily producers of stibnite. Grand Central (No. 18) and Great Republic (No. 21) were primarily gold mines from which stibnite was recovered. The other mines from which antimony production has been reported and many of the reported occurrences of antimony contain tetrahedrite rather than stibnite, and their ores or potential ores are principally valuable for silver, gold, copper, or lead. Only those properties from which production of antimony has been reported and several of the reported occurrences containing stibnite are shown on figure 14.

Stibnite forms at relatively low temperature and pressure and is therefore usually deposited at or near the surface, with no apparent affinity for any particular rock type. In Washington, it is found in rocks of various types and ages, as a description of a few of its occurrences will illustrate.

At the Antimony Queen mine (fig. 14, No. 13) the rocks are irregularly interbedded argillite and graywacke of Triassic or Jurassic(?) age. Stibnite ore shoots, up to 2 feet wide and 40 feet long, occur in quartz veins and breccia zones in the argillite. From 1907 through 1941, the mine has produced more than 1,100 tons of ore (Huntting, 1956). Purdy (1951, p. 109) indicates that 1,000 tons of stibnite ore and several hundred tons of antimony oxide, prepared at a small plant near the mine, were shipped in 1916 and 33 tons of stibnite ore was shipped in 1941.

At the Lucky Knock mine (fig. 14, No. 9) irregular pockets of stibnite intermittently replace metamorphosed limestone of the Anarchist Series of Daly (1912) of late Paleozoic age. This is the

barren. The kyanite crystals are as much as 2 inches long in pegmatitic zones, but the average length is probably less than half an inch (Wash. Div. Mines and Geology field notes).

An occurrence of "massive crystalline kyanite" has been reported in NW¼ sec. 16, T. 27 N., R. 18 E., Chelan County. It is stated to be in Mad River canyon (No. 13) on the east side of Maverick Peak (Valentine, 1960).

Skamania County.—Although the two Washington occurrences of dumortierite are apparently small, their proximity to each other might be indicative of a "province" worth further exploration. Both are associated with small Tertiary granodiorite masses. The occurrence mentioned at the head of the North Fork of the Washougal River (No. 15) (Schaller, 1905, p. 102) is probably on what is now known as the West Fork. In this deposit, dumortierite crystals are reported to occur as radiating clusters up to 3 mm in diameter. Specimens contain about 2 percent dumortierite and 35 percent andalusite, but the extent and overall grade of the deposit is unknown.

The Saturday Rock dumortierite deposit (No. 14) is in the SE¼ sec. 2, T. 4 N., R. 5 E., probably 5 or 6 miles north of the deposit mentioned above. In the Saturday Rock occurrence, dumortierite has apparently formed by hydrothermal alteration of disseminated tourmaline along joints. The dumortierite is erratically exposed for about a hundred yards along a road cut and may locally constitute up to an estimated 5 percent of the rock.

The andalusite deposits of Stevens and Pend Oreille Counties are probably the only known mullite-forming mineral deposits in Washington that might be considered a potential resource. While they are fairly extensive, their relative low grade and the impurity-intergrown character of the crystals would necessitate extensive beneficiation. In addition, the limited thickness and steep dip of most deposits would make large-scale mining difficult and expensive, and their distance from major users would necessitate relatively high transportation costs.

MAGNESITE

(By W. A. G. Bennett, Washington Division of Mines and Geology, Olympia, Wash.; P. L. Weis and A. E. Weissenborn, U.S. Geological Survey, Spokane, Wash.)

Magnesium carbonate ($MgCO_3$) occurs in relatively pure form in nature as the mineral magnesite. Its theoretical composition is 47.8 percent MgO and 52.9 percent CO_2, but iron can substitute for magnesium in any amount, and most natural magnesite mined contains a small amount of iron.

Two varieties of magnesite are known. A cryptocrystalline type, sometimes known as "bone magnesite," has an earthy luster and conchoidal fracture. It is formed by alteration of magnesium silicate rocks such as serpentinite or dunite. Crystalline magnesite, with vitreous luster and perfect cleavage on individual mineral grains, is usually found associated with dolomite, although a few deposits are in limestone. The deposits were formed by alteration of dolomite or limestone, or were laid down as original sedimentary beds (Ladoo and Myers, 1951, p. 298; Comstock, 1963, p. 27). Although the cryptocrystalline deposits occur in more places, the crystalline variety generally forms the larger deposits. Both types have a specific gravity from 3.0 to about 3.1, depending on the percentage of iron, and both types

have a hardness of 3.5 to 4.5. Colors are generally white, light shades of off-white, gray, red, or brown, but magnesite has been found with a wide range of colors.

Magnesite is used chiefly as a source of magnesium oxide, or magnesia (MgO). Magnesite and, to a lesser extent, brucite ($Mg(OH)_2$) formerly were nearly the only sources of the world's magnesia, but since about 1937 they have shared this distinction with dolomite and natural and artificial brines, including sea water. Properly speaking, the term "magnesite" should be restricted to the mineral, but in the trade magnesium oxide, properly termed "magnesia," is commonly referred to as "magnesite." Two major types of magnesia are marketed. Dead-burned magnesite of commerce is the product obtained by heating magnesite or other substances convertible to magnesia to temperatures higher than 1,450° C. for a long enough time to form weather-stable granules suitable for use in refractories. Caustic calcined magnesite of commerce is the product obtained by heating magnesite or other substances convertible to magnesia to such a degree that less than 10 percent ignition loss remains and the magnesia displays absorptive capacity or activity (Wicken, 1960, p. 534).

Caustic calcined magnesite is used in the manufacture of oxychloride cements, rayon, fertilizer, insulation, rubber, and a variety of chemical compounds that contain magnesium. It is also one of several possible sources of magnesium metal (Comstock, 1963, p. 4). A little more than 10 percent of the annual consumption of magnesium oxide is in the form of dead-burned magnesite mostly for refractory use (Comstock, 1960, p. 487). Most of the magnesite mined in Washington is used to make dead-burned magnesite, principally to make refractory brick used as liners in steel-making furnaces and kilns.

World production of crude magnesite in 1963 was 9,050,000 short tons. The three largest producers were the U.S.S.R., Austria, and China, with 32 percent, 16 percent, and 11 percent of the world total, respectively. The United States produced about 528,000 short tons of crude magnesite in 1963; all of it came from two States, Nevada and Washington. Domestic production of refractory magnesia in 1963 was 713,000 short tons. About 21 percent, or 149,730 tons, was made from ores; the rest was from well brines and sea water (Williams and Stamper, 1964a, pp. 767–775). Production of magnesia and other magnesium compounds from brines has increased rapidly in the last 10 years, and as technology improves and treatment cost are lowered, production from brines can be expected to continue to grow and become increasingly competitive with crude magnesite ore.

Magnesite production in Washington began about 1916. By the end of 1932, the total production, partly estimated, amounted to 1,362,629 tons valued at $9,421,970 (Glover, 1936a, p. 63). Subsequent production figures cannot be disclosed, but the U.S. Bureau of Mines Minerals Yearbook reports that in 1962, output of magnesite from the Red Marble quarry supplied the largest part of the $3,938,000 of nonmetallic minerals produced in Stevens County. Since World War II, Washington, Nevada, and California have produced most of the crude magnesite mined in the United States, and for the past several years, Washington has been the largest producer.

Magnesite was first recognized in Stevens County, Washington, by Shedd in 1902 in the course of a survey of building stone quarries

(Shedd, 1903, p. 91). Attention was also called to the occurrence by Darton (1909, p. 23) and again by Shedd (1913, p. 126). The Finch and Allen-Moss quarries, the former worked first for limestone, were the first to produce magnesite. Because of the demand for magnesite during World War I, the Northwest Magnesite Co. and the American Mineral Production Co. were organized to quarry the deposits. The latter company through a subsidiary built a railroad from Valley to the Allen-Moss deposit. As World War I came to a close, the demand for magnesite declined, and the American Mineral Production Co. eventually went out of business. The Northwest Magnesite Co. continued operations as conditions improved and eventually gained control of the larger and more important deposits of the area (Whitwell and Patty, 1921, pp. 16–23).

The Stevens County magnesite is found as massive lenses in the Precambrian Stensgar Dolomite. Distribution within the Stensgar Dolomite is variable both in place and amount. The deposits are entirely restricted to this formation. Although there has been some controversy about the origin of the deposits, most geologists believe that they are the result of hydrothermal replacement of the dolomite by magnesium-rich solutions which may possibly have originated in nearby granitic intrusives and have obtained their magnesium from leaching of dolomite beds at depth (Campbell and Loofbourow, 1962, p. 38).

About 15 occurrences of magnesite have been found in the belt of outcrops of the Stensgar Dolomite in Stevens County (fig. 46). This has a length of about 27 miles, extending from the Colville Valley on the northeast to the Spokane Valley on the southwest. The Stensgar Dolomite has a maximum thickness of 730 feet on the northeast but averages 300 to 400 feet. Only 5 percent is exposed in outcrops (Campbell and Loofbourow, 1962, p. F–17). Stratigraphically, it lies near the top of the Deer Trail Group, which is overlain by the Huckleberry Formation, also of Precambrian age. This in turn is overlain by the Addy Quartzite of Cambrian age. Underlying units in descending order are the McHale Slate, the units of dolomite, slate, and quartzite of the Edna Dolomite, and the Togo Formation. The Precambrian formations have been compressed into many small folds and some large ones, and these have been cut by several longitudinal or strike faults. The effect has been to repeat the Stensgar Dolomite three times in the north central part of the belt and to fault it out in several places along the strike in the southwestern half of the belt (Campbell and Raup, 1962). The westernmost fault segment of the Stensgar Dolomite, 4 miles long, contains the Black Bear (No. 12), Davis (No. 11), and Midnight (No. 8) deposits (fig. 46), which are undeveloped and probably relatively small. The Red Marble segment, about 3 miles long, includes the Red Marble deposit (No. 13) and the small, early-worked Crosby deposit (No. 10) on the north. The easternmost segment of the Stensgar Dolomite begins half a mile east of the Red Marble quarry and continues for 4 miles. It includes the Double Eagle and Keystone deposits (Nos. 7 and 9), the former on the axis of a northward-plunging anticline and the latter on the west limb of a syncline. These folds and the folded fault plane that brought up the Red Marble segment presumably account for the repetition of the small isolated occurrence of the Stensgar at the Nogue deposit (No. 6).

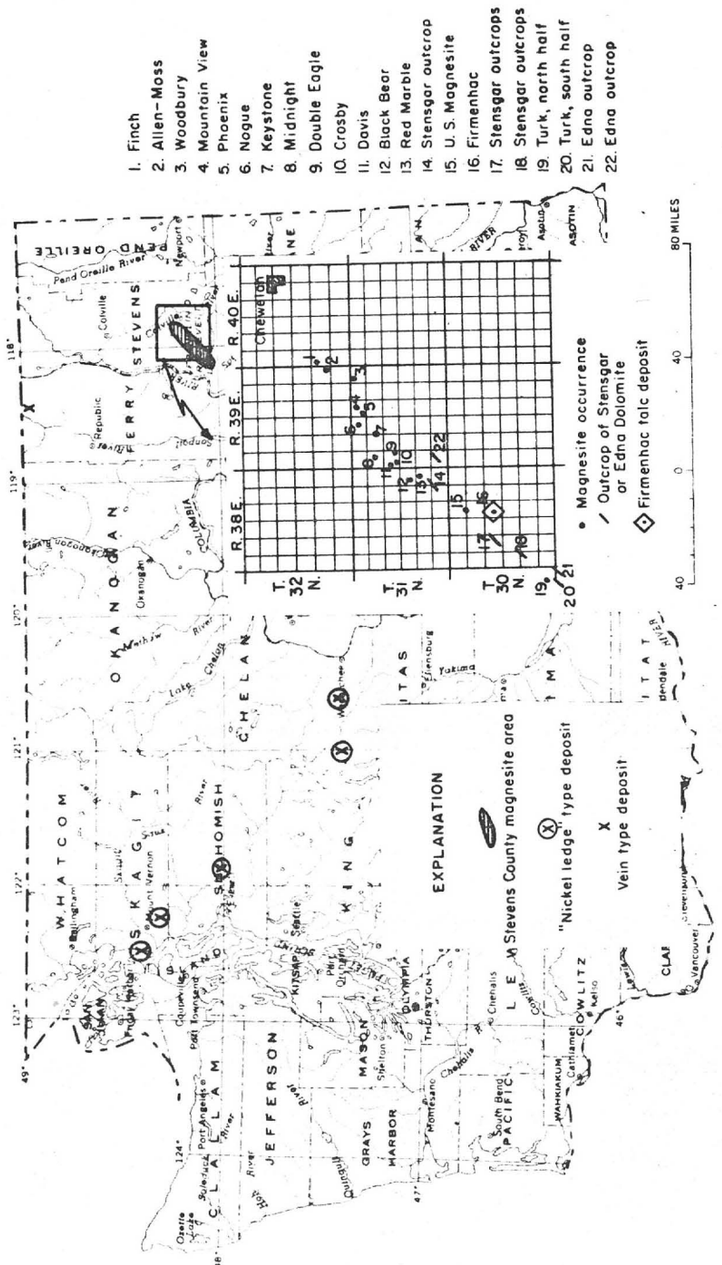


FIGURE 46.—Magnesite deposits of Washington.

Between the Red Marble (No. 13) and the Turk (Nos. 19 and 20), the last important deposit on the southwest, there are no known magnesite occurrences except for the early-worked U.S. Magnesite deposit (No. 15), although there are occurrences of magnesitic dolomite.

The Finch deposit (No. 1), now probably nearly worked out, originally extended to the overlying slate on the west and ended against siliceous dolomite on the east. The dimensions of the deposit were about 700 feet east to west by about 500 feet north to south. It contained blocks of dolomite or low-grade magnesite in places and dipped moderately steeply to the west. The vertical dimension was 330 feet, or 70 feet below the level of operation (Hodge, 1938c). Hodge reports that CaO averaged 2.3 percent across the ore body and SiO_2 averaged 4.82 percent.

The northern part of the Allen-Moss deposit (No. 2) had a low dip to the west. It was about 300 feet wide and had a vertical dimension of 160 feet. It averaged 3.0 percent CaO and 3.9 percent SiO_2. The southern part had relatively thin high-grade layers alternating with high CaO and siliceous layers. Its overall vertical dimension was about 200 feet.

The Woodbury deposit (No. 3) was worked on a small scale during the early part of World War I. Analyses taken across a 30-foot face indicate low grade, mostly because the rather coarsely crystalline magnesite lies along bedding planes as irregular replacements in the dolomite.

The Phoenix deposit (No. 5) shows a small body of coarsely crystalline magnesite at the southwestern end of a Stensgar outcrop about 1,000 feet long and 300 feet wide. The Nogue (No. 6) shows only patches of magnesite.

The Keystone (No. 7) has been extensively worked, and the amount of ore that remains is not known. Presumably, operations reached a point where impure ore and waste caused the transfer of operations to the Red Marble deposit. As has been mentioned, before magnesite was recognized here this quarry was worked for building stone. The width of outcrop before the more recent operations was 1,100 feet between the overlying lower slate member of the Buffalo Hump Formation and mafic intrusive bodies on the southeast. The Stensgar Dolomite here was replaced by magnesite, mostly in the upper part next to the overlying Buffalo Hump Formation. Much of the rock on the southeast is brucite. What is probably the largest hydromagnesite body in the United States (Eugene Callaghan, 1942, personal communication) occurs in a shear zone mentioned by Shedd (1903) that cuts across the magnesite.

The Double Eagle deposit (No. 9) includes two outcrops, of which the larger is 1,500 feet east and 100 feet above the other. The area between outcrops is not well exposed but probably is dolomite. The old quarry, 60 feet wide, extends 100 feet north into the hillside, where the face shows magnesite and magnesitic dolomite. The west deposit is an opening 70 by 50 feet with a 20-foot face at the back, which shows massive magnesite for half the width.

The Crosby deposit (No. 10) crops out in an area 400 feet by 125 feet. Development consists of several trenches opened in pink to red finely crystalline magnesite that analysed 43.6 percent MgO.

The Red Marble deposit (No. 13) has a total length of about 4,000 feet and a width of 450 feet. It crops out at an altitude of 3,500 feet on the north, rises to 4,000 feet at the old quarry, then descends into a shallow ravine on the south. Much of the deposit is coarsely to finely crystalline, reddish to pinkish, and white magnesite. Banding is indicated in places by color differences as well as grain size. Samples taken before present operations began (table 18, Nos. 2, 3, and 4) average 45.6 percent magnesium oxide and range from 0 to 1.4 percent calcium oxide. The depth of the ore body is not known.

The easternmost segment of the Stensgar Dolomite, half a mile east of the Red Marble quarry, is a potential source of magnesite. Shedd (1913, App. A, No. 66) reports that a sample from there contained 45.76 percent MgO.

TABLE 18.—*Analyses of carbonate rocks from Stevens County magnesite belt* [1]

No.		Ignition loss	SiO_2	Al_2O_3, Fe_2O_3	CaO	Experimental MgO	Calculated MgO
1	Woodbury deposit; NE¼ sec. 1, T. 31 N., R. 39 E.; magnesite	47.9	2.6	1.9	3.6	41.4	43.9
2	Woodbury deposit, average of 4 analyses	46.6	1.9	1.7	24.2	24.8	25.4
3	Red Marble quarry; SE¼ sec. 24, NE¼ sec. 25, T. 31 N., R. 38 E., average of 9 analyses	50.1	2.8	.9	.5	44.5	45.8
4	Red Marble quarry, magnesitic dolomite	45.3	.9	.8	20.9	--------	24.7
5	Red Marble quarry, dolomite	45.1	3.9	.9	29.3	22.0	20.8
6	Stensgar Dolomite; NE¼ sec. 35, T. 31 N., R. 38 E.; average of 6 analyses	46.0	4.4	1.5	28.6	--------	21.3
7	Stensgar Dolomite; magnesitic dolomite	45.4	3.3	1.4	25.5	--------	24.4
8	U. S. Magnesite quarry; N¼ cor. sec. 10, T. 30 N., R. 38 E.; average of 6 analyses	49.4	3.8	1.1	1.2	43.4	44.3
9	U. S. Magnesite quarry; average of 13 analyses	40.6	11.0	2.2	15.2	26.9	27.7
10	Stensgar Dolomite; SE¼ sec. 17, T. 30 N., R. 38 E.; probably magnesitic	45.9	2.5	1.0	26.2	23.8	24.4
11	Stensgar Dolomite; secs. 19, 20, and 30, T. 30 N., R. 38 E; probably magnesitic	47.5	.5	1.2	25.7	24.7	25.1
12	Stensgar Dolomite; probably magnesitic	47.6	2.0	1.1	14.9	33.2	35.0
13	do	46.5	1.4	1.4	21.9	25.3	28.8
14	do	45.2	3.6	.4	21.9	20.2	21.7
15	Turk deposit, North end; SW¼ sec. 36, T. 30 N., R. 37 E.; average of 4 analyses	44.3	6.5	2.1	1.4	45.1	45.5
16	Turk deposit, South end; NW¼ sec. 1, T. 29 N., R. 37 E., magnesite, average of 2 analyses	46.4	4.8	.9	.7	45.8	47.1
17	"Nickel ledge," siliceous "dolomitic rock"	31.04	32.12	6.37	1.81	26.73	--------
18	Magnesite, collected by Stone, Red Marble quarry(?) 17 miles west of Valley, Wash	[3] 49.51	4.27	[2] .78	1.07	45.02	--------
19	Magnesite, collected by Stone, U.S. Magnesite quarry(?)	[3] 47.81	8.83	[2] .85	7.39	38.41	--------
20	do	[3] 46.03	5.60	[2] .88	6.88	40.90	--------
21	Magnesite, collected by Stone, Allen quarry	[3] 50.32	.46	[2] 1.01	.31	46.23	--------
22	Brucite(?), collected by Stone, Allen quarry	[3] 5.23	1.20	[4] 2.36	.92	90.59	--------
23	Edna Dolomite, sec. 31, T. 31 N., R. 39 E	29.9	31.2	3.7	14.6	--------	20.6
24	Firmenhac talc, SW¼ sec. 15, T. 30 N., R. 38 E	47.7	1.5	1.2	18.8	29.4	30.8
25	Edna Dolomite, NW¼NE¼ sec. 1, T. 29 N., R. 37 E	39.3	8.1	1.6	17.5	--------	33.5
26	do	43.5	6.3	2.2	1.4	45.1	46.6
27	do	32.5	21.1	2.5	41.7	.6	22.2

[1] Source: Bennett (1941, pp. 23–25) for analyses Nos. 1 to 16 and 23 to 27; Wells (1937, p. 62) for analyses Nos. 18 to 22; Smith (1904, p. 4) for analyses No. 17.
[2] FeO.
[3] CO_2.
[4] Fe_2O_3.

The U.S. Magnesite deposit (fig. 46, No. 15), worked during World War I, includes an area 125 by 100 feet near the base of the Stensgar. Yale and Stone (1921, p. 151) report 38.41 percent MgO in the upper 40 feet and 40.90 percent in the middle 18 feet of the quarry. Other analyses are shown in table 18, Nos. 8 and 9. Some good grade

magnesite occurs here, but much of it is intimately intermixed with dolomite, and quartz veins cut across the rock in places. The deposit is at the northeast end of a 2-mile long faulted segment of the Stensgar Dolomite (Campbell and Loofbourow, 1962).

The north half of the Turk deposit (fig. 46, No. 19) consists of two masses that were outlined by drilling in 1942. Each part is roughly 200 feet square and extends to a depth of about 220 feet (Bennett, 1941, pp. 21–23; 1943, 22 pages). The outcrop of the north part lies between valley level and 100 feet above on the west, and the south part lies between 100 and 200 feet above. On the basis of the drilling and about 450 analyses of most of the cores from 19 drill holes, as well as adit and surface samples, reserves of a little more than 2 million tons of magnesite have been calculated for the north part of the Turk deposit.

Analyses made by the U.S. Bureau of Mines (Bennett, 1941, p. 23–25) show magnesitic dolomite in the Stensgar Dolomite southwest of the Red Marble deposit as follows: NW¼ sec. 36, NE¼ sec. 35, T. 31 N., R. 38 E. (fig. 46, No. 14; table 18, No. 7), and secs. 19, 20, and 30, T. 30 N., R. 38 E. (fig. 46, No. 18; table 18, Nos. 11–14). The Edna Dolomite, which is unusually siliceous in secs. 30 and 31, T. 31 N., R. 39 E. (fig. 46, No. 22; table 18, No. 23), appears to be magnesitic at the Firmenhac talc deposit in the SW¼ sec. 15, T. 30 N., R. 38 E. (fig. 46, No. 16; table 18, No. 24). In the vicinity of the Turk magnesite deposit, the formation grades from limestone through limey magnesite to high-grade magnesite (fig. 46, No. 21; table 18, Nos. 25–27)

The operations of the Northwest Magnesite Co. have been carried on almost continuously for nearly half a century. The Finch deposit was the first to be explored and was worked later in conjunction with the Allen-Moss. It seems probable that these deposits are essentially worked out. Hodge (1938, p. 41) reported 387,000 tons reserves in the Finch and 201,250 in the Allen-Moss quarries, and 100,000 tons "of fair grade" in the south Turk deposit in the NW¼ sec. 1, T. 29 N., R. 37 E. (fig. 46, No. 20; table 18, No. 16). Operations were started in 1944 at the Keystone deposit, which was connected with the Finch quarry by a tramline. Another tramline completed in 1954 extended from the Finch to the Red Marble quarry. Beneficiation of magnesite by flotation was started in 1942 or 1943 and by sink-float process in 1945.

Other occurrences of magnesite are known in Washington, two in Skagit County and one each in Ferry, Okanogan, Snohomish, Kittitas, and Chelan Counties (Gildersleeve, 1962, and fig. 46). None offer much promise. The deposits in Skagit, Snohomish, Kittitas, and Chelan Counties are large but low grade. They are the so-called "nickel ledges" and are intimate mixtures of silica and carbonate minerals, including magnesite (Smith, 1904, pp. 3–4; Hobbs and Pecora, 1941). The Okanogan deposit is a narrow vein of magnesite in serpentine. At the Ferry County deposit, one-fourth inch veinlets of hydromagnesite are found cutting serpentine (Valentine, 1949).

The production of magnesite in Stevens County probably will continue for some years, but it would seem unlikely that operations would continue beyond the resources at the Red Marble deposit unless other deposits that do not crop out are found. The competition of magnesia produced from sea water and bitterns as well as from other materials such as dolomite is strong and has been increasing

for the past 10 years. The prospects do not appear to be very bright for the discovery of economic deposits of magnesite in areas outside Stevens County.

OLIVINE, SERPENTINE, AND ASBESTOS

(By J. S. Vhay, U.S. Geological Survey, Spokane, Wash.)

Olivine, serpentine, and asbestos are considered together in this report because all three occur principally in ultramafic rocks. Exceptions to this are the olivine in basalt, the serpentine in silicated dolomite, and some types of amphibole asbestos. The first two are of geologic interest only; the last constitutes only 5 percent of the world's supply of asbestos. In a few places—Arizona, for example—minable chrysotile asbestos does occur in dolomite metamporhosed by diabase sills.

Olivine consists of magnesium and iron silicate ($(Mg, Fe)_2SiO_4$), and the olivine in dunite is close to the magnesium end of the series. An olivine from the Twin Sisters mass shows 50.1 percent MgO and 8.28 percent FeO (Ross and others, 1954). Serpentine is a hydrous silicate of magnesium ($H_4Mg_3Si_2O_9$), which contains about 44 percent MgO. Both olivine and serpentine are used mainly as refractories. They have also been used as sources of magnesium metal and salts, but at present, sea water and brines are used as the sources for the metal and salts of magnesium. The greatest use of olivine is as a molding sand by foundries and glass plants. This is because of olivine's refractoriness (forsterite, the pure magnesium type of olivine, has a melting point of 3461° F.), its strength at high temperatures, and its resistance to corrosion by most compounds except acid slags (Clark and McDowell, 1960, pp. 704, 707). Refractory forsterite bricks are made by adding magnesia to olivine and bonding them either chemically or by firing. Its use as a blasting sand has developed recently. For this use, as well as for use as foundry sand, olivine has the advantage that it does not cause silicosis, as silica sand may. It has been used also as an ingredient in the manufacture of fertilizers. Additional uses of serpentine are as a base for some special paints, in insecticides, and, especially formerly, as a decorative stone—"verde antique."

In recent years, Washington and North Carolina have produced most of the olivine consumed in the United States. The mining and use of olivine in Washington have increased spectacularly in recent years; the following percentage increases of production took place: from 1957 to 1958, 110 percent; 1958 to 1959, 44 percent; 1959 to 1960, 44 percent; 1960 to 1961, 50 percent; and 1961 to 1962, 34 percent. The present annual production in the State is approximately 25,000 tons. Nearly all this production has been from the Twin Sisters dunite mass, Skagit and Whatcom Counties; some has been from a mass on Cypress Island, Skagit County. The Twin Sisters dunite mass is the largest known in the United States and is unusual, and valuable, in that the olivine in it is almost completely unaltered. Only around its edges is the olivine serpentinized (Ragan, 1963). This is true of most of the younger (middle Tertiary(?)) masses of dunite in the State. The older ultramafic rocks, on the other hand, are now mostly serpentine. Figure 47 shows the locations of the larger masses of ultramafic rocks. They are also shown on figure 4, the geologic map of Washington.