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WAH CHANG STARTS ELECTRON-BEAM MELTING

By
T. C. Matthews*

A revolutionary new furnace** that works like an immense X-ray tube was installed this summer at the Wah Chang Corporation plant near Albany, Oregon. It is used to melt and refine the refractory metals columbium, tantalum, zirconium, and hafnium by electron bombardment of the metal itself. The purification of the melted ingot is accomplished by devolatilization and evaporation of the impurities in a high vacuum. Since the only material that is heated is the ingot itself, all parts of the furnace are cool and the operator may view the melting operation through a large glass window.

The 225-kw electron-beam melting furnace now installed, manufactured by Stauffer-Temescal Company, Richmond, California, will produce 4-inch diameter ingots of 160 to 200 pounds in weight. It is the first model of this new type installed in a production plant in the United States, and it will add one more important step to the integrated processing of special metals in the Willamette Valley. The present production rate is 5 tons per month for metal of average purity and a second similar unit, which has been ordered, will more than double this amount.

Operation

The concentrated columbite-tantalite ore is received at the Wah Chang plant in drums, which are valued at as much as $5000 each when the ore contains 35 percent or more tantalum oxide. After separation and processing to almost pure metal, the sponge or powder is brought to the electron-beam furnace for final refining. Traces of oxygen, hydrogen, nitrogen, and carbon, either alone or in combination with various other metals, tend to make the refractory metals so hard that adequate fabrication is impossible. Passage through the electron beam reduces these impurities, thus increasing the workability, so that these special metals may be formed into the required shapes for reactor parts or space vehicles. One melting will reduce the Brinell hardness number of columbium to 85 and remelting the same ingot will reduce the number to 50. Metal in the form of sponge, bar stock of sintered powder, or premelted ingot is charged into the furnace through an air-tight entrance lock as shown in Figure 1 on page 94. The material is fed into the bombardment area of the electron gun where it fuses and then drips into a water-cooled ingot mold. The gun or cathode is in the form of a concentric ring around the lower end of the raw ingot, and may be removed and replaced through an entrance lock, when the need arises. The molten pool into which the metal drips is intensely stirred to bring

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** Smith, H. R., Hunt, C. d'A., and Hanks, C. W., Electron-bombardment melting: Journal of Metals, February 1959.

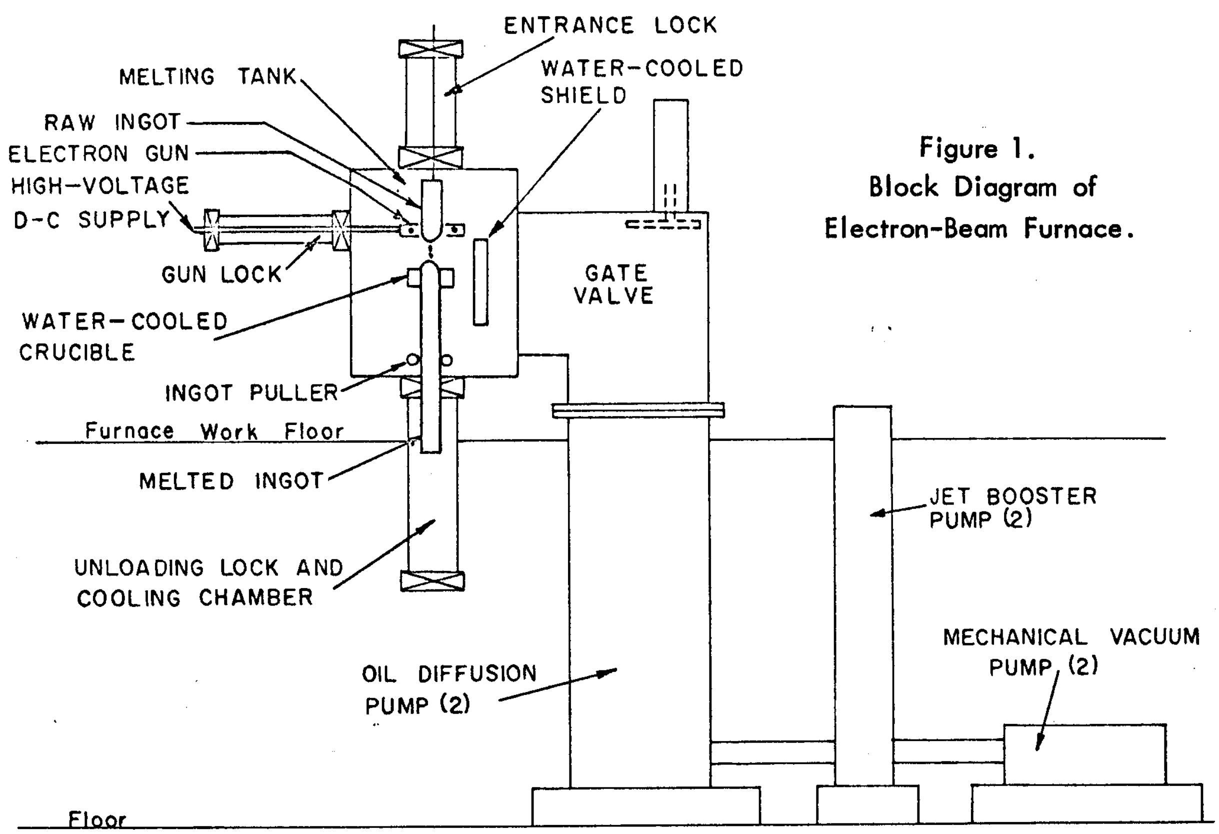

Figure 1.
Block Diagram of
Electron-Beam Furnace.

the volatile impurities to the surface rapidly. As the material solidifies, it is extracted from the mold at a selected rate to maintain a constant level in the molten pool. After a sufficient length of ingot is cast, it is dropped through a gate valve into the ingot removal lock. Here it is allowed to cool while another ingot is started in the melting chamber.

Equipment

Although the size of the melting chamber itself is only that of a 5-foot cube, its accessories fill a large room. Two mechanical vacuum pumps reduce the air pressure to approximately 1 mm Hg. Two jet booster pumps then reduce this to .025 mm Hg., or 25 microns. The two large oil diffusion pumps with a combined capacity of 60,000 liters per second are then able to evacuate the furnace down to .005 microns if left running without opening any valves. The usual melting pressure is .015 microns with a maximum allowable of .2 microns during short gas bursts. After cleaning the furnace and starting the pumps, 1½ hours are required to evacuate down to melting pressure. Thereafter changes of electron guns or raw or melted ingots are made through the air locks; so that only 15 or 20 minutes are needed to pump down after each change.

Power for melting is supplied as conventional three-phase, full-wave rectified, high-voltage direct current (Figure 2). The power requirements for general operations vary considerably, depending both on the melting point of the metal and on its evaporation rate above that melting point. Independent voltage and current controls are provided and the system is divided into three independent units, so that operations may continue even with

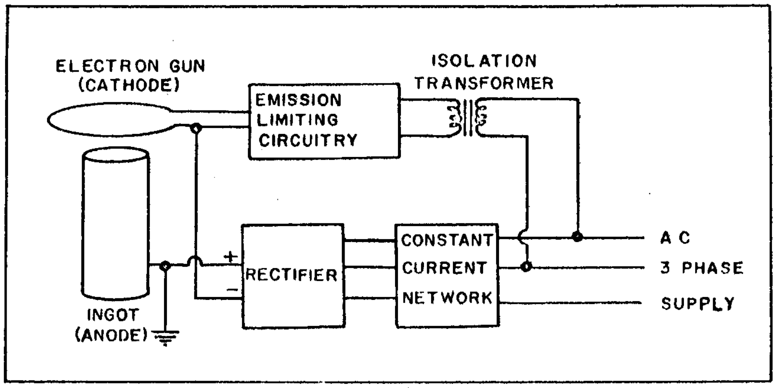

Fig. 2 - Block Diagram of Power Circuits (from Journal of Metals, Feb. 1959).

one unit out of service. The 4-inch columbium ingots being melted at present require 5 amperes at 15,000 volts. Tantalum with a melting point of 2850° C, as shown by the table below, requires about 33 percent more power.

Cooling is provided by 22 water circulating lines, each with individual control, and provided with automatic cutout features that would shut down the furnace in case of failure or drop in pressure. High-pressure air is used to empty and dry out any line which must be broken to open an air lock into the melting chamber.

High-Temperature Metals

	Specific Gravity	Melting Point	Boiling Point
Nickel	8.9	1452°C	2900°C
Cobalt	8.9	1480	2900
Chromium	7.1	1615	2200
Zirconium	6.4	1700	2900
Vanadium	5.8	1715	3400
Titanium	4.5	1800	3000
Columbium	8.4	1950	3300
Hafnium	13.3	2207	3200
Molybdenum	10.2	2620	3700
Tantalum	16.6	2850	4100
Tungsten	19.3	3370	4727

Alloy composition

Changes in the composition of metals and alloys occurring during electron-beam melting are different from changes occurring in other melting systems. This is attributed to the much higher vacuum existing at the surface of the molten pool, which causes devolatilization to proceed more rapidly. With respect to the evaporation of alloy metals from columbium, results show that vanadium and all other metals with a greater volatility than vanadium, such as chromium, iron, nickel, and aluminum, evaporate rapidly to concentrations of a few hundredths of a percent. Since the zirconium in a columbium-1 percent zirconium alloy evaporates faster than the columbium, the usual procedure in alloy work is to refine each metal to the required purity and then combine the metals for the final alloy in a vacuum-arc furnace. The vacuum-arc furnace is also used for remelting the smaller ingots into larger ones of 12 inches or more in diameter for forging large pieces. A 3,000-pound ingot may cost as much as $150,000 before entering the forging press. Besides the columbium-zirconium alloys used primarily in reactor construction, a tantalum-10 percent tungsten alloy has been run and a number of experimental alloys have been tried. It would appear that the field is very promising for the production of molybdenum and tungsten and their alloys for space vehicles.

Acknowledgment is gratefully made to Mr. Stephen Yih, Vice President and General Manager of the Albany Division, Wah Chang Corporation, for the information furnished on the equipment and expected operations. Acknowledgment is also made to Mr. James McClain, Manager of Manufacturing, for his assistance and description of the new furnace.

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ALLOY ORE IMPORTS INCREASING*

The number of foreign countries sending steel alloying elements to the United States has increased sharply in recent years. Forty-five nations sent one or more ores of alloying elements to this country in 1957, compared with 33 sources in 1947 and 26 just prior to World War II. The increase apparently is the result of a number of factors. Alloy users say that some of the new or smaller source-nations sell ores a little cheaper than sources of longer standing. The problem of obtaining shipping space for alloy ores at certain ports is another factor. Monetary exchange factors also have had an effect on ore sources.

The most important elements for the purpose of alloying are, in alphabetical order: boron, chromium, cobalt, columbium, copper, manganese, molybdenum, nickel, silicon, titanium, tungsten, vanadium, and zirconium. The United States is the world's largest producer of five of these, accounting for about 95 percent of total mine output of boron, 25 percent of all copper; 90 percent of all molybdenum; more than 35 percent of all titanium; and about 85 percent of all vanadium. Like all other countries, the United States also has large domestic supplies of silicon.

The three alloying elements used in greatest quantity by the steel industry are manganese, chromium, and nickel, for which the United States relies almost entirely on imports. In recent months domestic production of these ores has declined at such an alarming rate that our dependence on imports is approaching 100 percent.

The United States brings in manganese ore from 27 foreign nations, as against 10 in 1947. Since August 5, 1959, domestic production has essentially ceased. Russia, once the leading source of manganese ore, no longer supplies this country. India, a prime importer, is proving very difficult to do business with. Barter contracts of manganese for surplus agricultural commodities have been "in the fire" for more than a year and a half and are still not close to consummation. Present major sources of supply include Brazil, Ghana, Union of South Africa, and Mexico. All steel requires manganese in its manufacture - an average of approximately 13 pounds for each ton of steel.

Imports of chrome ore to the United States have risen threefold over the 1947 level when Russia supplied 46 percent of the total. In 1950 Russia summarily cut off all imports to the United States. The bulk of the chrome used in the United States comes from Turkey, Southern Rhodesia, Union of South Africa, and the Philippines. Since May 1958 United States production of metallurgical chrome has been shut down.

Canada remains the principal source of nickel imports in the form of ore, matte, and metal. Other possible sources are Cuba, Burma, New Caledonia, and Union of South Africa. Russian nickel, a pre-1947 source, is no longer available. The only United States production of nickel is at the Hanna Nickel Smelter, Riddle, Oregon; its 1958 production was equivalent to 15 percent of 1958 national consumption.

China, the largest source of tungsten ore and concentrates in 1947, no longer ships to the United States. China's ore was lost to us at the beginning of the Korean war, which worked severe hardship on our efforts in this conflict. Now western hemisphere sources account for more than two-thirds of total imports. Domestic production, which amounted to greater than 150 percent of the nation's needs in 1957, is completely closed down except for some by-product material.

Most of the world supply of cobalt is produced as a by-product with other metals and the two principal sources of imports are the Belgian Congo and Canada. Other producers include Australia, Federation of Rhodesia and Nyasaland, and Morocco. The United States has been producing slightly less than 50 percent of its cobalt requirements, part as a by-product but the bulk from a single mine in Idaho. The government contract with this mine terminated June 1959 and, although the price was only slightly above the world market, no steps have been taken to preserve this operation.

Imports of columbium in the past have come from eleven foreign nations, with Nigeria supplying 56 percent of the total. In 1958, Idaho produced 99 percent of the domestic columbium. Government contracts covering the Idaho production are near completion and, following the pattern of cobalt, it seems that the bulk of domestic production of this strategic mineral will soon be lost.

Australia is the largest source of zirconium ore imports. The United States is the world's second largest producer but requires 75 percent more than it mines.

Many other ores, metals, and miscellaneous products used in steel manufacture are also imported but are not considered in this article. For example, iron ore, iron and steel scrap, aluminum, tin, palm oil, and ferroalloys are not included.

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* Adapted from <u>Steel Facts</u>, August 1959.

Alloying elements, used singly or in combination, are added to molten steel either in the furnaces or in a ladle after refining. Usually they are added in the form of ferroalloys - manufactured products containing the desired element and iron.

Some of the more important properties imparted to steel through the use of alloying elements are listed below. Combinations of the elements are often used to produce entirely different properties. In addition, many of the elements listed are used in the making of alloys having useful strength at elevated temperatures. These may contain little or no iron but are manufactured largely by steel companies.

A large portion of ferroalloy production is in electric furnaces. Since the end of World War II, the Willamette Valley and Lower Columbia River area has become an important center for electroprocess materials. As long as low cost power is available, it seems likely that this form of industrial development will continue to increase in Oregon.

Boron is alloyed with steel to enhance the hardening properties of the finished product. Small amounts are enough to reduce the quantity of other hardening elements which might otherwise be required and are scarcer or more costly.

Chromium, in small amounts, is used to impart hardenability. In larger amounts, usually in conjunction with nickel, it helps impart corrosion resistance to stainless steels.

Cobalt, a somewhat magnetic element, is used with iron in making magnet steels and alloys. It is also used in high-speed tool steels where hardness at high temperatures is desirable, in addition to abrasion resistance.

Columbium is used in some stainless steels designed to be welded or used at high temperatures. The element helps prevent unwanted changes in the crystalline structure of the steel.

Copper, as an alloying element, serves to retard corrosion in some steels. The addition of copper is usually made in metallic form.

Manganese has two different functions as an alloying element. In relatively small percentages, it aids the strength and toughness of steel. In larger amounts, it increases the toughness and the resistance to wear and abrasion of steels in heavy-duty service.

Molybdenum is another of the elements used to impart hardenability to steel and to increase resistance to impact. In some alloys, it imparts high-temperature strength. It is also used in stainless, heat-resisting, and tool steels.

Nickel, like copper, is added to molten steel in metallic form. It increases toughness, strength, and ductility in steel and, in large amounts, it increases resistance to heat and acids. With chromium, it is one of the principal alloying elements used in making stainless steels.

Silicon improves the magnetic characteristics of steel, making the product desirable for some electrical equipment.

Titanium is used in steels designed for high-temperature applications to prevent unwanted changes in crystalline structure, particularly of stainless steels.

Tungsten helps impart hardness and toughness to steels at high temperatures. It is found in many high-speed tool steels.

Vanadium improves the toughness, mechanical properties and heat-treating characteristics of some steels often used in engine and motor parts.

Zirconium reacts with sulphur, nitrogen, and oxygen to cleanse the steel of certain impurities. Steels containing zirconium in various quantities are used in some tough, high-strength parts such as axles, crankshafts, and rock drills.

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UNUSUAL MINERAL EXHIBIT ON DISPLAY

The Oregon Agate and Mineral Society is displaying an unusually colorful and attractive exhibit of minerals at the Department's office in Portland. On display is a wide variety of crystals and polished slabs from various parts of the world, including agate material from Oregon. The exhibit was arranged by Mrs. Elda Hall and may be seen through December.

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STEEL IMPORTS INCREASE - EXPORTS DECREASE

Drastic changes in the import and export of iron and steel mill products during the last few years have cost Americans the equivalent of 30,000 jobs in our steel industry, according to the September issue of Steelways, a publication of the American Iron and Steel Institute. Imports of foreign steel-mill products in the United States rose to 1.7 million tons in 1958. This represented a 48-percent import increase over 1957, while domestic output in the same period dropped 24 percent. The first six months of this year continued to show the same discouraging trend. In that period imports exceeded exports by about 2 to 1, in sharp contrast with the years 1953-57 when the industry's exports exceeded imports 3 to 1. Based on 1958 investment per-ton-of-steel ingot capacity, imports last year idled about 146 million dollars' worth of production equipment.

While imports waxed, exports of steel mill products waned. From 1957 levels, exports dropped 48 percent to 2.7 million net tons in 1958. The reasons for this imbalance in trade are several and complicated, according to Steelways. The United States is the largest steel market area in the world and is essentially a free market with nominal tariffs and no trade restrictions on steel. We are the only such "free market" area in the world. Through both financial and technical assistance, we have helped rebuild, modernize, and expand the war-destroyed and outmoded production facilities of Europe and Asia. These new plants embody our own most forward advances in technology. We undertook this in large part to gain staunch allies in the face of our new antagonist, the Soviet Union, as well as in the belief that healthy economics would bring about an increase in the overall level of general world trade and well-being. As a result of our policies, a trebling of steel production has occurred since World War II in at least 20 countries. The United States' share of world steel production has dropped from 54 percent in 1946 to 35 percent in 1957, with recession-ridden 1958 dragging our share of world production down to 29 percent.

In the past, despite our higher wage rates, we have been able to manufacture at competitive total costs. We could do this because of heavy capital investment; size of market; mass production; and the technical, productive, and managerial know-how on which that is based. Now we have handed over these advantages through our aid programs and we stand in world trade on a more common technological plateau, while foreign wages continue well below our own. Average total hourly employment costs of our steel workers in 1957 stood at $3.22 against $1.01 in West Germany, 81 cents in Italy, and 46 cents in Japan. Our tax laws stretch depreciation over 20 to 25 years, by which time the original costs recovered have been far outdistanced by inflationary price increases. By contrast, Germany, for example, has a depreciation rate on new investment of 25 percent in each of the first two years, or a 50-percent recovery of original cost in the first 24 months of use. It is no wonder that our exports in 1958 are down 37 percent and our 1958 imports are up 467 percent over 1949, and the end is still not in sight.

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NOTICE TO SUBSCRIBERS OF THE ORE.-BIN

A number of complaints have been received by the Department from subscribers who have not been receiving the Ore.-Bin. The reason, in most instances, is that these people have moved and have not notified us of their change of address. The Ore.-Bin is sent by second-class mail which cannot be forwarded by the post office. Therefore, if you move, be sure to send us your new address so that you will not miss any issues.

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ANDERSON NAMED CHIEF GEOLOGIST FOR GEOLOGICAL SURVEY

Recently announced is the advancement of Dr. Charles A. Anderson from Geologist, Mineral Deposits Branch to Administrative Geologist, and Chief of the Geologic Division, United States Geological Survey. This is the position recently vacated by Dr. Wilmot H. Bradley who was appointed in 1944.

As Chief Geologist and head of the Geologic Division, Dr. Anderson will assume direction of the Survey's program for a systematic inventory of the Nation's mineral resources investigating and mapping the geologic patterns of the country; ascertaining, through research, the geochemical and geophysical relationships that determine the location of yet-undiscovered deposits of petroleum, metallic ores, and nonmetallic minerals; providing subsurface information required by civil engineers in the planning stages of construction projects; and conducting broad programs of fundamental research in the principles of geologic and related sciences and their applications to a wide variety of scientific and engineering problems.

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BUREAU OF MINES NORTHWEST REGION REORGANIZED

A reorganization of U.S. Bureau of Mines Region I, comprising Alaska, Idaho, Montana, Oregon, and Washington, has been announced. The regional office at Albany, Oregon, will retain its status with Mark L. Wright as director. Wright has been with the Bureau since 1940 and acting director of Region I since 1956. Under the reorganization plan there will be five major units:

1. Division of Administration, Albany, Oregon, will be headed by Robert W. Myers.

2. Division of Mineral Resources, headquarters at Albany, Oregon, will have Ottey M. Bishop as chief. Under this new division will be an Albany Office headed by A. J. Kauffman, Jr.; an Alaska Office at Juneau headed by J. A. Herdlick; and a Spokane Office with Richard N. Appling, Jr., in charge.

3. Spokane Office of Mining Research, formerly a field office of the old division of mineral technology, will continue under the direction of Wing G. Agnew.

4. Seattle Coal Research Laboratory, a new designation for the Northwest Experiment Station, will continue on the University of Washington campus under the direction of Dr. H. F. Yancey.

5. Albany Metallurgy Research Center, which takes over the work of the Northwest Electrodevelopment Experiment Station, will be headed by A. H. Roberson.

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NEW OIL AND GAS DRILLING PERMIT

Permit No. 37 was issued by the Department to Ross R. Mitchell, Canby, Oregon, on October 2, 1959. The site is located on the Samuel Paige ranch 1304.5 feet north and 930.8 feet west from the south $\frac{1}{4}$ corner sec. 11, T. 8 S., R. 5 W., Polk County. Mr. Mitchell abandoned drilling on the Bliven ranch before moving to the present location. The new test will be called Paige No. 1.

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SIGNS OF THE TIMES

Fluorspar Relief Denied - The Office of Civilian and Defense Mobilization denied a fluorspar industry request for relief from the depressing effects of foreign imports. OCDM, empowered by Congress to make decisions concerning effects of imports on national security, noted that imports have exceeded domestic production since 1952 and have more than doubled in volume since 1951. The report nevertheless stated definitely that it is not in the interest of national defense to change the situation.

Cobalt Plea Rejected - OCDM also rejected a plea from Calera Mining Company (a Howe Sound Company subsidiary) for protection from imports of cobalt. For several years Calera has mined cobalt at its Blackbird Mine, Cobalt, Idaho, and processed it in a Salt Lake City refinery. Leo A. Hoegh, OCDM's director, said that the increase in price necessary to keep the Calera operation on a profitable basis would mean an additional annual cost to consumers exceeding the combined payroll and taxes paid by the company. He added, concerning the vulnerability of foreign sources to political and military interference: "Cobalt sources are becoming increasingly widespread geographically and politically and denial of sources of supply is unlikely."
(From Management Digest, Utah Mining Association, October 7, 1959.)

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KENNETH HAMBLEN

Kenneth E. Hamblen, consulting mining engineer of Portland, died suddenly October 13, 1959. Mr. Hamblen, a 1922 graduate of Oregon State College in mining engineering, made his offices in Portland all of his professional life and was one of Oregon's best known engineers. He had been associated with and helped develop several important Oregon mining properties including the Oriole gold mine in Josephine County, the Blue Ridge quicksilver mine in Crook County, and the Oregon King silver mine in Jefferson County. In addition, he helped develop several nonmetallic properties in the State. Mr. Hamblen's work carried him to all parts of the North American Continent. He was a partner in the development of the Red Mountain chrome property in Alaska. For several years he was on a Federal advisory board for procurement of strategic minerals. Mr. Hamblen was a member of the Oregon Section of the American Institute of Mining, Metallurgical and Petroleum Engineers and was active in the Pacific Northwest Metals and Minerals Conference.

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GARTH THORNBURG

Dr. Garth W. Thornburg, formerly President of Lakeview Mining Company, Oregon's only uranium mine and mill, died October 18 as the result of a hunting accident near Grand Junction, Colorado. Lakeview Mining Company took over the Lucky Lass mining claims in 1955 and, under the direction of Dr. Thornburg, developed the mine and obtained a contract for construction of a uranium mill at Lakeview. The Thornburg interests also had a uranium mine and mill in Colorado. Dr. Thornburg was a member of Governor Hatfield's Mining Advisory Committee.

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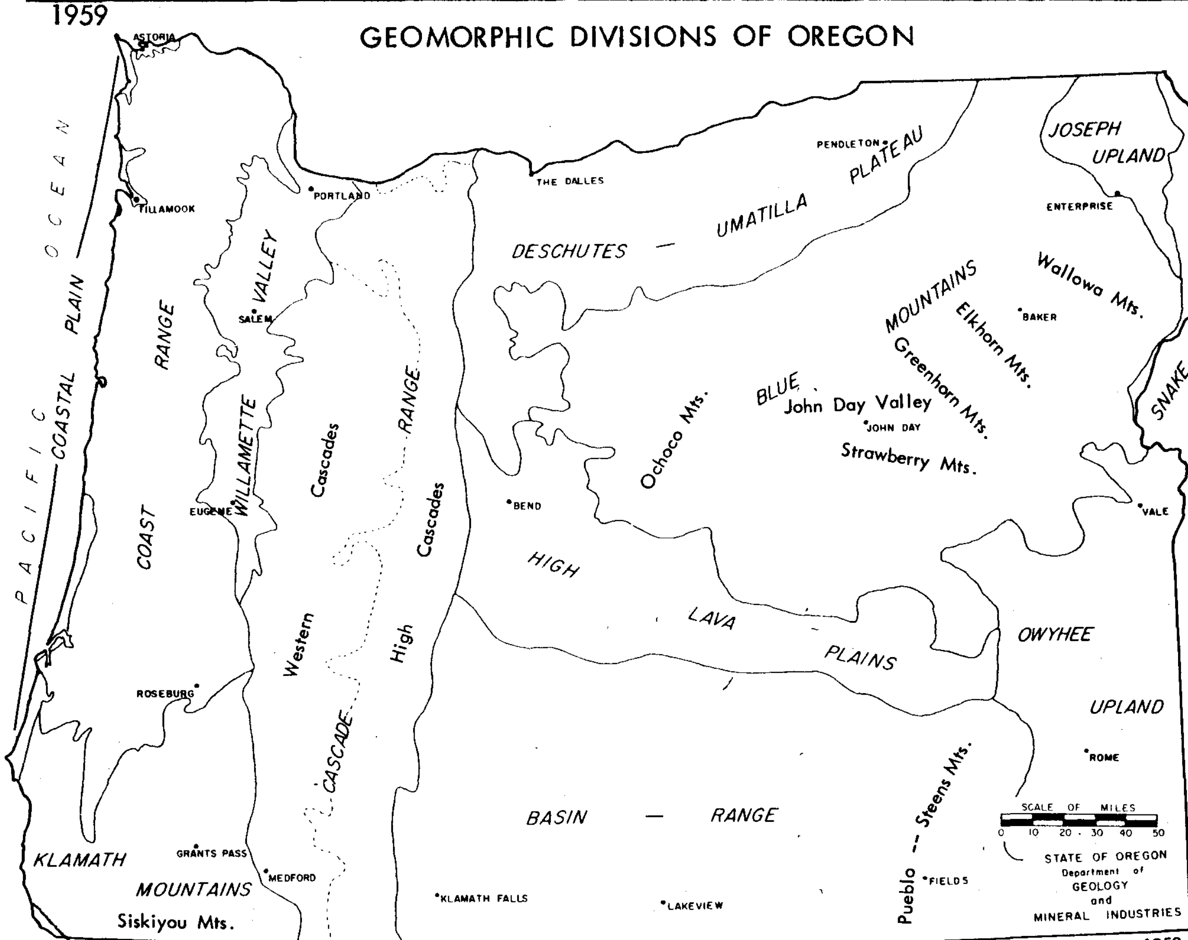
GEOMORPHIC DIVISIONS OF OREGON



Modified from Dicken, Oregon Geography, 1950.

Coastal Plain - Unconsolidated sands and gravels of Quaternary age deposited as a thin veneer on the eroded surfaces of older Coast Range rocks. Marine terraces extend along coast at elevations from a few feet to 1500 feet above sea level. They are well demonstrated between Port Orford and Coos Bay. Sand dunes cover wide areas and are especially large between the mouths of Siuslaw and Umpqua rivers. Many dormant dunes now support a heavy cover of brush and timber. Drowned valleys and exhumed drowned valleys partially filled with sediments are characteristic.

Coast Range - A structural anticlinorium which has its main north-south axis superimposed on earlier folds trending northeast to east. Northern part is composed of submarine volcanic rocks, mainly pillow lavas and palagonitic tuffs and breccias, flanked by Tertiary marine sandstones, tuffaceous shales, and mudstones. Total thickness of volcanics is at least 10,000 feet. Most of the sedimentary rocks are of Eocene and Oligocene ages. Thickness varies from a few feet to 7000 feet. Intrusive rocks are of late Oligocene to Miocene age and are mostly gabbroic sills from a few tens to 3000 feet thick with dikes from 5 to 50 feet wide. Sills and dikes of nepheline syenite and dikes of camptonite are present. Southern part of Coast Range almost entirely marine Eocene sandstones and shales. Calapooya Mountains, an east-west trending ridge and a part of Coast Range, grade into nonmarine rocks of Western Cascades. Southernmost Coast Range rocks unconformably overlie or are in fault contact with the older rocks of Klamath Mountains. Crest of Coast Range averages about 1500 feet in elevation. Marys Peak, the highest point, is 4097 feet. Topography generally rugged especially in the volcanic areas.

Klamath Mountains - A region of rugged topography with elevations from sea level to 7500 feet. Streams are numerous, canyons deep, and ridges narrow. A core of pre-Triassic schists underlies a thick sequence of interbedded marine and nonmarine Mesozoic volcanic and sedimentary rocks (Applegate group; Dothan, Rogue, and Galice formations) which are tightly folded, faulted, intruded by ultramafic to acid plutonics, and uplifted. Low-grade regional metamorphism is widespread. Schists and gneiss occur in areas of greater movement and adjacent to the larger intrusive masses. Regional structure trends northeast. Slightly deformed uppermost Jurassic and Cretaceous marine sediments occur in troughs, grabens, and along borders.

Willamette Valley - A valley flood plain with isolated hills, lying between the Cascade and Coast ranges. Underlain by marine Eocene and Oligocene sandstones and shales (Spencer and Eugene formations). Formations dip eastward from Coast Range foothills, crop out in hills within the valley, and again along parts of Cascade foothills. Miocene lavas (Columbia River basalt) cap marine sediments in northern Willamette Valley. Basic dikes and sills form buttes in southern part. In the Portland area consolidated sands and gravels of Pliocene age fill structural basin; local occurrences **of Plio-**

Geomorphic Divisions of Oregon (cont.)

Pleistocene lavas. Silts and gravels deposited by Willamette River and major tributaries have filled the valley up to several hundred feet. Terraces representing several periods of rejuvenation have been developed.

Cascade Range - Divisible into Western Cascades and High Cascades and best described as a great pile of volcanic rocks. The older Western Cascades are maturely dissected. Rocks range in age from late Eocene to possibly early Pliocene. Along western margin, formations dip gently eastward and broad open folds, sizable faults, and disconformities are present. Eocene to lower Miocene rocks are chiefly pyroclastics with interbedded lava flows and lenses of waterlaid sediments. Include tuffs, volcanic conglomerates, tuff breccias, welded tuffs, and rhyolitic to basaltic flows. Middle Miocene rocks are predominantly basaltic lavas which cap higher ridges and may be remnants of shield-type volcanoes. Younger rocks vary from pyroclastics to basalts.

The High Cascades are the majestic volcanic peaks, cinder cones, and relatively undissected lavas on east side of Range. Original constructional form of most central vent volcanoes has been severely modified by glaciation. Most peaks are Plio-Pleistocene in age; Recent flows and cinder cones are common. Lavas are dominantly basaltic andesites and olivine basalts. Some rhyolite and obsidian flows are present. Pumice blankets large areas. Intracanyon basalts of Pliocene age extend into Western Cascades from High Cascades. Highest peak is Mount Hood, 11,245 feet. Highways crossing the Range go through passes at elevations of about 5,000 feet.

Deschutes-Umatilla Plateau - A north-sloping lava plateau or monocline bounded on north by Columbia River. Elevation 600 to 3000 feet above sea level. Surface deeply dissected by youthful streams separated by broad, gently rolling interstream areas. Scabland channels eroded by glacial flood waters occur in northern part. Region underlain by thousands of feet of Miocene basalt flows (Columbia River basalt); in places gently warped into large open folds. Surface blanketed in part by Pliocene lake beds and river gravels (Dalles and Shutler formations), Pleistocene ice-rafted boulders and torrential flood-deposited alluvium, and loess.

High Lava Plains - Young, uneroded surface with few established streams; largely interior drainage. Elevation 3500 to 6000 feet above sea level. Region underlain by thick accumulation of Cenozoic volcanic rocks, dominantly Pliocene lava flows. Quaternary rocks blanket western part and consist of lavas, pumice, obsidian, and many small cinder cones. Tertiary rocks include basaltic, andesitic, and rhyolitic lavas; tuffs; welded tuffs; and minor amounts of interbedded waterlaid sediments. Region highly fractured, with dominantly northwest-trending pattern.

Basin-Range - Young fault block mountains separated by broad graben valleys with interior drainage; occasional volcanic peaks. Elevation 4000 to 9000 feet above sea level. Shallow alkaline lakes and playas in graben valleys are remnants of much larger Quaternary lakes. A thick sequence of Tertiary rhyolite, andesite, and basalt flows with interbedded tuffs and tuff breccia underlies all of the area except the Pueblo Mountains. Here a small body of pre-Tertiary schists, greenstone, and granite is exposed below the Tertiary volcanic rocks near the base of the large Pueblo-Steens escarpment. Faults of the typical Basin-Range topography trend northeast and northwest. Occasional undissected Recent volcanic cones and flows are found in the northern part.

Owyhee Upland - Moderately to highly dissected surface with few perennial streams. Elevation 2000 to 6000 feet above sea level. Region underlain by middle Tertiary to early Quaternary basalts, rhyolites, and associated pyroclastics interbedded with lake and stream deposits. Late Quaternary lavas of limited extent occur north and west of Jordan Valley. No known marine formations are exposed at the surface. Major faulting of middle Tertiary formations is generally north-south with typical fault block structures developed. Late Tertiary and early Quaternary lava flows and sedimentary rocks are only slightly deformed. Merges into the Basin-Range region to the south and west. Northern border sharply defined where it lies on the intensely deformed pre-Tertiary rocks of the southern Blue Mountains. Northern and northeastern areas dominantly terrestrial sediments associated with the late Tertiary filling of the Snake River area to the east.

Blue Mountains - A complex region of mountain ranges and mountainous areas, canyons, plateaus, and basins. Elevations range from 2,000 to 10,000 feet. High mountains glaciated. Region drained by John Day River and other streams tributary to Columbia and Snake rivers. A wide variety of rock types ranging in age from Paleozoic to Recent. In central and eastern parts: core of Cretaceous granitic rocks intrusive into folded and in places metamorphosed marine sediments, greenstones, and basic intrusives that may range in age from Devonian (?) to Cretaceous; Triassic and Jurassic marine and volcanic rocks predominate. In many places pre-Tertiary rocks occur as islands surrounded by Tertiary lavas and pyroclastics. In northern, western, and extreme southern parts: largely Tertiary pyroclastics and lavas from central vents and fissures and their associated tuffaceous sediments. Tertiary rocks warped by large, broad, probably deep-seated folds. Major faults are common and have formed basins and valleys now partially filled with late Cenozoic lake beds and alluvium.

Joseph Upland - Underlain almost exclusively by a thick succession of essentially flat-lying Miocene basalts with but few thin sedimentary interbeds. Deeply eroded by numerous streams draining for the most part northward in narrow canyons with steep gradients. Elevations on upland surface average between 3000 and 5000 feet. Creeks have cut downward to nearly 1500 feet along northern margin of area.

Snake River Canyon - The Snake River has carved a deep (5652 feet at Hat Point), narrow, V-shaped, and locally precipitous canyon with an average gradient of approximately 10 feet per mile over an airline distance of 110 miles. It has cut through basalts of Joseph Upland and on into basement rocks of Blue Mountains to reveal a narrow, ribbonlike exposure of pre-Tertiary rocks throughout nearly entire course of canyon bottom. Older formations are principally Permo-Triassic metasediments and metavolcanics. Imnaha River has cut a deep canyon exposing similar pre-Tertiary rocks but in fewer places.

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