Geology of Magnesite Deposits in Northern Okanogan County Washington— A Preliminary Report

GEOLOGICAL SURVEY BULLETIN 1272-B

Prepared in cooperation with the Washington Division of Mines and Geology

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By KENNETH F. FOX, JR., *and* C. DEAN RINEHART

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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A study of magnesite-bearing rock that crops out as irregularly shaped lenses, 50 by 1,000 feet in maximum dimension, within a narrow stratigraphic zone at the base of a Triassic (?) sequence at its contact with Permian rock

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CONTENTS

ILLUSTRATION

TABLES

CONTRIBUTIONS TO ECONOMIC GEOLOGY

GEOLOGY OF MAGNESITE DEPOSITS IN NORTHERN OKANOGAN COUNTY, WASHINGTON—A PRELIMINARY REPORT

By KENNETH F. FOX, Jr., and C. DEAN RINEHART

ABSTRACT

Magnesite-bearing rock crops out as irregularly shaped lenses ranging in maximum thickness from 5 to 50 feet and in outcrop length from 100 to 1,100 feet within a narrow stratigraphic zone at the base of the Kobau Group of H. S. Bostock, a Triassic(?) eugeosynclinal sequence of greenstone and metachert at its unconformable contact with the subjacent Anarchist Series of R. A. Daly, a weakly metamorphosed sequence of Permian chert-conglomerate, graywacke, siltstone, and limestone. The magnesitic rock consists of varying proportions of magnesite, quartz, and dolomite, and its magnesia content ranges from about 22 to 34 percent. Several deposits have been located within the 23-mile span of the contact so far reconnoitered, and the existence of additional deposits in the area is likely. The deposits are probably sedimentary, although the magnesite is now recrystallized and perhaps locally is hydrothermally redistributed within the zone.

INTRODUCTION

This report summarizes the geology of a group of previously unreported magnesite deposits located in northern Okanogan County, Wash. This investigation, sponsored jointly by the U.S. Geological Survey, and the Washington Division of Mines and Geology, is part of a broader study of the geology and mineral resources of part of Okanogan County. J. Casey Moore very ably assisted the authors in the field, and R. G. Yates and R. A. Gulbransen reviewed the manuscript.

The deposits herein described lie approximately 80 miles northwest of the magnesite deposits of Stevens County, Wash., the source of virtually all previous production of magnesite in the State, although other magnesite occurrences within the State have been reported (Bennett and others, 1966, p. 227, 230). Indeed, the Stevens County deposits, along with deposits near Gabbs, Nye County, Nev., presently account for the bulk of domestic magnesite production.

Magnesite ore is generally mined by open-pit methods, and after the ore is crushed, undesired silicates are removed by flotation and other carbonates by heavy-media sink-float methods. The magnesite is then calcined by heating to not more than 1,650°F to produce "caustic calcined magnesia" or by heating above 2,640°F to produce "dead-burned" or refractory magnesia (Williams, 1965, p. 542). The magnesia is then either sold to other processors or further processed into other products.

Although domestic consumption of magnesia increased 48 percent from 1959 to 1963, the amount supplied from magnesite declined (Williams, 1965, p. 547), presumably because of competition from other sources of magnesia, notably sea water, bitterns, and well brines. The geographic, economic, and technological features of the industry have recently been summarized in a review by Comstock (1963).

The topography of northern Okanogan County is characterized by rolling, rocky hills and ridges which rise from the broad alluviated valley of the Okanogan River, at an elevation near 1,000 feet, to rounded, pine-clad summits at elevations of 4,000 to 5,000 feet. The climate is semiarid and mild. Principal occupations in the area are fruit growing, ranching, and lumbering. A branch line of the Great Northern Railway crosses the western part of the area, and in British Columbia the Canadian Pacific Railway serves Osoyoos, 7 miles north of Oroville, and Midway, 9 miles northeast of Chesaw.

GEOLOGIC SETTING

The area of northern Okanogan County included on plate 1 is chiefly underlain by weakly metamorphosed eugeosynclinal rocks of Permian and Triassic(?) age, gneissic granodiorite of the Colville batholith of probable Cretaceous age, and epiclastic sedimentary rocks and dacitic or andesitic extrusives and hypabyssal instrusives of Eocene age.

The low-grade metamorphic rocks are mostly those of Daly's (1912) Anarchist Series and Bostock's (1940) Kobau Group. The Anarchist consists of a thick sequence of interbedded and interfingering weakly metamorphosed chert-conglomerate, graywacke, siltstone, and limestone. The Kobau consists of a thick sequence of weakly metamorphosed lavas, pyroclastics, tuffaceous sediments, massive cherts, and locally carbonate rocks. In the Loomis quadrangle, which joins the map area on the west, the Kobau is at least 12,000 feet thick, and the Anarchist it at least 15,000 feet thick (U.S. Geol. Survey, 1965, p. A96). The Kobau overlies the Anarchist along an angular unconformity. Fossils from the Anarchist were considered "* * * most likely Permian * * *" by G. H. Girty (in Waters and

Krauskopf, 1941, p. 1364). Other collections have recently been studied by J. T. Dutro, Jr. (U.S. Geol. Survey, 1965, p. A96), who confirmed the Permian age. The Kobau is provisionally correlated with the rocks of the "lime belt" west of Riverside, which is probably Lower Triassic, based on determinations by J. B. Reeside (in Waters and Krauskopf, 1941, p. 1366).

The metamorphic rocks are intruded by the Colville batholith and several lesser plutons within the map area. The Colville batholith is a large mass containing gneissose-porphyritic granodiorite in the interior and grading to nonfoliated-nonporphyritic rock in the eastern part and to layered paragneiss along its western contact. The foliation and layering typically undulate from horizontal to dips of about 15°, and the rock generally exhibits a pervasive west-northwest lineation. Although the origin of the mass is not without controversy, Waters and Krauskopf (1941) showed that it was emplaced forcefully as a semisolid mass, and Snook (1965) demonstrated that the layered gneisses were of metamorphic origin.

The Osoyoos pluton is an oblong, northwest-trending body of gneissic granodiorite lying athwart the international boundary. The fact that the Osoyoos, although separated from the Colville by a thin septum of metamorphic rock, exhibits cataclastic textures, which increase in intensity toward the Colville, suggests that the Osoyoos is the older. The Colville also cuts the Whisky Mountain stock, an oblong body of porphyritic granodiorite 5 miles south of Oroville and trending, like the Osoyoos, northwest. The Whisky Mountain stock likewise shows a progressive increase in cataclasis toward its contact with the Colville.

Other igneous bodies of pre-Tertiary age range in size from thin dikes and sills to small stocks and intrude the metamorphic rocks. Most are felsic to mafic in composition, but a few ultramafic bodies—dunites, serpentinites, and peridotites—are known. Two serpentinites, too small to show cartographically, were found within the map area. One is located within the septum of metamorphic rocks north of Tonasket Creek (sec. 21, T. 40 N., R. 28 E.), and the other is located alongside a magnesite deposit south of Chesaw (pl. 1, loc. K). The largest ultramafic bodies near the map area include a narrow, 2½-mile-long serpentinite on Mount Chopaka (13 miles west of Oroville, secs. 29 and 32, T. 40 N., R. 25 E.), several nearby serpentinized peridotite masses, and a cluster of irregularly shaped masses 2 miles southwest of the map area.

The metamorphic and plutonic rocks just described are unconformably overlain by Tertiary conglomerates, arkoses, graywackes, and tuffs, which are capped by or interbedded with andesitic to dacitic lavas or are cut by small andesitic to dacitic stocks. Potassium-argon dating by Mathews (1964) of correlative igneous rocks of southern British Columbia indicates that they were emplaced during a single, rather narrow period of the middle Eocene, although rocks of a younger intrusive episode were present to the north in central British Columbia.

The Permian and Triassic(?) eugeosynclinal sedimentary rocks of the map area are variously folded, faulted, and metamorphosed—the cumulative result of strong deformation and metamorphism during the Triassic Cassiar orogeny (White, 1959); later deformation occurred during or before the Cretaceous. Faults, fold axes, and axes of elongate plutons of the Cassiar orogeny strike predominantly northwest, imparting a pronounced northwest grain to the regional geologic maps. The plutonism which began during the Triassic continued intermittently without a well-defined maximum into the Tertiary. The Eocene clastic and volcanic rocks, as well as the older rocks, were mildly warped and faulted during the Tertiary.

The area was overridden by a large piedmont glacier during the Pleistocene, and the present topography owes much of its character to erosion by ice and melt water. Glacial drift and terrace gravels mantle a large area, particularly east of long 119°15′ W., but these deposits are not portrayed on the map (pl. 1).

MAGNESITE

DEPOSITS

Magnesite-bearing rock crops out as irregularly shaped lenses ranging in maximum thickness from 5 to 50 feet and in outcrop length from 100 to 1,100 feet within a stratigraphic zone above but close to the unconformity between the Kobau Group and the Anarchist Series. A cluster of such lenses occurs 2 miles northwest of Oroville (pl. 1), and another cluster is near Chesaw, 18 miles east of Oroville (pl. 1). A single magnesite lens is near Teal Lake, 3 miles southeast of Molson (pl. 1), and another is within an outlier of the Kobau, 4 miles west of Tonasket (pl. 1). The main features of the known deposits are summarized in table 1.

TABLE 1.—*Summary of magnesite occurrences*

Locality (shown on pl. 1)	Description	Samples
A	Magnesite, phyllitic, dolomitic, siliceous; containing several interbeds 3–12 ft thick of quartzite in zone 80 ft thick. Overlain by 50 ft of grayish-green phyllite containing 2- to 4-ft-thick magnesite beds. Faulted against limestone at base. Beds strike N. 60° W., dip (overturned) about 75° S., folded in lower part.	
B	Magnesite, massive, dolomitic, siliceous. Dolomite ranges from less than 5 percent to over 40 percent. Locally phyllitic. Contains sparse quartz veinlets. Bedding, erratic, generally striking about N. 50° W., dipping about 75° SW. Cut by small vertical faults trending N. 15° W. Crops out discontinuously on strike for 600 ft.	O–332B.
C	Tunnel driven to southwest near edge of river. Portal in Kobau greenstone. Considerable phyllitic magnesite on dump.	
D	Magnesite, massive, dolomitic, siliceous. Dolomite varies from trace to over 60 percent. Locally thin bedded. Bed forms discontinuously exposed, 950-ft-long, dip slope, dipping gently south, with abundant minor folds and crenulations. Locally contains quartz veinlets and pods.	
E	Magnesite, massive, dolomitic, siliceous. Grades from nondolomitic siliceous magnesite in northern part to nonmagnesitic siliceous dolomite in southern part. Bed trends generally north-northeast and dips steeply to east but is tightly folded on small scale. Numerous anastomosing quartz veinlets, flecked with fuchsite (chrome mica).	O–334F.
F	Magnesite, siliceous, locally dolomitic, thin-bedded to thinly laminated. Crops out poorly in beds at least 5 ft thick beneath thin discontinuous cover of glacial drift in zone 1,100 ft in length and 150 ft in width. Probably interbedded with green slate, grayish-green phyllite, light-gray limestone. Beds in southern part of belt strike N. 25° E., and dip 20°–40° NW., but the strike swings to northwest and the dip to southwest in the northern part of the belt. Locally crumpled.	O–7A, O–91B, O–91C, and O–91D.
G	Magnesite, massive, phyllitic, siliceous. Schistosity strikes N. 35° E., dips 50° NW., grossly parallel to trend of outcrop. Apparent thickness about 50 ft, outcrop length 500 ft.	O–92A, O–92C.
H	Magnesite, phyllitic, siliceous, probably dolomitic. Schistosity strikes N. 65° E., dips 55° SE. Very poor exposure. Probably fault sliver.	
I	Magnesite, massive, siliceous. Massive ledge, at least 15 ft thick, crops out in area 100 by 100 ft surrounded by glacial drift. Probably dips gently to the northeast along axis of northeast-plunging fold, forming dip slope. Outcrop ribboned with anastomosing quartz veinlets speckled with fuchsite (chrome mica).	O–284A, O–284B.

321–750—68——2

TABLE 1.—*Summary of magnesite occurrences*—Continued

Locality (shown on pl. 1)	Description	Samples
J	Magnesite, massive to thinly laminated, dolomitic, siliceous. Crops out in rubbly, discontinuous exposure for 300 feet; dips gently north. Probably 5–10 ft thick. Overlain upslope by greenstone; underlain by black slate and limestone.	O–279A, O–279B, O–279C, O–279D, O–298C, O–298D, and O–298E.
K	Magnesite, massive, dolomitic, siliceous. Grades to serpentinite or is intruded by serpentinite at south end of outcrop. Bedding not seen, but attitude probably nearly horizontal, possibly dipping shallowly to east. At least 30 ft thick, and crops out for 480 ft along strike, excluding serpentinite to south. Veined by quartz. Shallow tunnel driven in area of abundant quartz veinlets.	
L	Magnesite, massive, slightly dolomitic, siliceous, locally very siliceous. Becomes phyllitic to south. Overlain by greenstone, and underlain by interbedded marble, greenstone, and metachert-pebble conglomerate. Attitude probably nearly horizontal. Magnesite bed is 15 to 40 ft thick, crops out discontinuously on strike for 1,100 ft. May be continuous, under cover, with magnesite at locality J.	O–299B, O–299C, O–299D, and O–299E.
M	Magnesite, massive, dolomitic, siliceous. Outcrop belt trends northwest and dips moderately to the southeast. Magnesite appears to be about 25 ft thick, and crops out on strike for 400 ft. Samples O–274A, B, and C show compositional range of this part of deposit. An outcrop of massive dolomite (sample O–275) about 1,200 ft to the southwest probably represents an extension of same bed.	O–274A, O–274B, O–274C, and O–275.
N	Magnesite, massive, siliceous. Bed crops out on the crest of low ridge and probably forms dip slope to northeast. Appears to strike about N. 65° W., and dip 20°–30° NE. Outcrop area 400 ft long and 75 ft wide, and magnesite bed probably at least 25 ft thick. Locally magnesite laced with irregular anastomosing quartz veins, some up to 4 ft thick.	O–276A, O–276B.
O	"Carbonate-antigorite schist," reported by Phetteplace (1954) at these locations, probably correlative with magnesite-bearing zone. Not visited.	
P	Magnesite, massive, siliceous, dolomitic. Grade ranges from trace to 60 percent magnesite. Sporadic, irregular patches in massive bluish-gray dolomite bed bounded above and below by phyllitic siltstone. Magnesite sporadically distributed along minimum strike length of 1,000 ft. In two places, magnesite replaces host dolomite along fractures.	C–140C, C–140D.

DESCRIPTION OF THE MAGNESITIC OUTCROPS

The magnesitic beds weather to irregular, moderate-reddish-orange to pale-reddish-brown masses, possessing a rough elephant-hide surface. The contrast of the orange cast of the weathered magnesite rock with the more somber green and gray hues of the surrounding rocks permits easy recognition even from a distance. On fresh surface the magnesite-bearing rock is commonly moderate orange pink to pinkish gray and is either hard, massive, and irregularly mottled or banded, particularly at localities I and N (pl. 1), or medium light gray with phyllitic or schistose interlaminae, as in the Oroville area (pl. 1). The magnesite rock is generally flecked with a brilliant-green, chromium-bearing mica, assumed to be fuchsite, superficially resembling malachite or the nickeliferous mineral, garnierite. Although the magnesite rocks generally will not effervesce in dilute hydrochloric acid (5 percent, cold), locally a very weak effervescence was noted, reflecting the presence of small admixtures of calcite. Dolomite is commonly present but could not be distinguished from magnesite without recourse to staining methods. Most outcrops of the magnesite rock are ribboned by a ramifying or anastomosing network of quartz veinlets, which apparently do not extend into the adjacent country rock.

Part of the magnesite-bearing zone is exposed in a narrow gully at locality A (pl. 1). There the beds, which belong to the Kobau Group of Bostock (1940), strike N. 60° W., are assumed to be overturned, and dip about 75° S. A stratigraphic thickness of about 130 feet is exposed, the upper 50 feet of which consists of crumpled, grayish-green phyllite, weathering grayish orange and containing 2- to 4-foot-thick interbeds of impure phyllitic magnesite and ¼- to ½-foot-thick interbeds of dark-gray graphitic quartzite (metachert?). The lower 80 feet is composed of impure phyllitic magnesite containing several 3- to 12-foot-thick interbeds of light- to dark-gray, subbrecciated quartzite. It is folded in the lower part and is faulted at the base against limestone of the Anarchist. The magnesitic zone within the area shown on plate 1 is probably best represented by rocks exposed at locality A where the zone is rather thick, containing beds of impure magnesite interbedded with other rocks. The character of the zone may be different to the east at localities I through O. There the magnesite crops out in single, rather massive ledges without suggestion of interbedding with other rocks.

PETROGRAPHY

The magnesitic rock is typically a fine- to medium-grained granoblastic aggregate of magnesite, dolomite, and quartz, and contains accessory or trace amounts of calcite, chlorite, mica, magnetite, and pyrite. The magnesite is quite variable in grain size even in a single thin section, the grains commonly ranging from ¼ to 4 millimeters across. The magnesite is probably ferroan, judging by the iron content of the rock (table 2) which is too high to be entirely accommodated

TABLE 2.—*Chemical, spectrographic, and modal analyses of magnesitic rocks in northern Okanogan County, Wash.*

[Chemical analyses (by rapid method of Shapiro and Brannock, 1956) by P. L. D. Elmore, S. D. Botts, Lowell Artis, J. L. Glenn, G. W. Chloe, Hezekiah Smith, James Kelsey. Spectrographic analyses by Chris Heropoulos; results are reported in percent to the nearest number in the series, 1, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, and so forth, which represent approximate midpoints of interval data on a geometric scale. The assigned interval will include the quantitative value about 30 percent of the time. Tr, trace. Looked for but not found: Ag, As, B, Be, Bi, Cd, Ce, Ga, Ge, Hf, Hg, In, La, Li, Mo, Nb, P, Pb, Pd, Pt, Re, Sb, Sn, Ta, Te, Th, Tl, U, W, Y, Yb, Zn, Zr]

Locality	B	F	I	L	N	P
Specimen [1]	O-332-B	O-91-B	O-284-A	O-299-B	O-276-A	C-140-C
Lab. No	M104507W	M104503W	M104505W	M104506W	M104504W	M104508W
Chemical analyses						
SiO_2	32.5	34.0	27.2	19.8	31.8	14.7
Al_2O_3	.36	.09	.04	.00	.09	.00
Fe_2O_3	.59	1.0	1.0	1.7	.77	1.9
FeO	4.1	4.9	5.1	3.7	4.3	5.4
MgO	22.1	24.4	30.4	34.2	28.1	33.2
CaO	7.6	3.6	.06	.18	.71	3.0
Na_2O	.02	.00	.03	.02	.02	.03
K_2O	.03	.03	.00	.02	.03	.00
H_2O-	.05	.08	.04	.10	.03	.13
H_2O+	.51	.56	.41	.43	.63	.62
TiO_2	.02	.00	.00	.00	.00	.02
P_2O_5	.02	.02	.02	.02	.02	.03
MnO	.13	.09	.11	.13	.11	.14
CO_2	31.8	31.2	35.4	39.2	33.4	40.5
Total	99.83	99.97	99.81	99.50	100.01	99.67
Spectrographic analyses for minor elements						
Ba	0.0007	0.0005	0.0005	0.0015	0.0003	0.003
Co	.005	.007	.007	.007	.007	.007
Cr	.1	.15	.15	.15	.15	.15
Cu	.002	.001	.0015	.0015	.002	.002
Ni	.15	.2	.2	.2	.2	.15
Sc	.0007	.0005	.0005	.0003	.0007	.0003
Sr	.03	.02	0	.002	.002	.03
V	.002	.003	.003	.0015	.002	.0015
Modal analyses						
Magnesite	35	49	72	82	68	61
Dolomite	29	17	0	Tr	2	23
Quartz and leucocratic silicates	36	34	27	16	28	16
Calcite and opaque minerals	Tr	Tr	1	2	2	Tr
Total	100	100	100	100	100	100

[1] Locations of specimens: O-332-B, NW¼ sec. 19, T. 40 N., R. 27 E.; O-91-B, SW¼ sec. 7, T. 40 N., R. 27 E.; O-284-A, NW¼ sec. 21, T. 40 N., R. 29 E.; O-299-B, SW¼ sec. 28, T. 40 N., R. 30 E.; O-276-A, NE¼ sec. 3, T. 40 N., R. 30 E.; C-140-C, SE¼ sec. 11, T. 37 N., R. 26 E.

in the small amounts of opaque and silicate minerals present. The magnesite from locality F has an index of refraction, $n_0 \approx 1.715$, indicating that the composition of the magnesite is about 92 percent $MgCO_3$ and 8 percent $FeCO_3$. The dolomite is also ferroan, judging by its color when stained with potassium ferricyanide. The dolomite exhibits a range in grain size comparable to that of the magnesite, although the coarsest occurs only in veinlets. The veinlets, which range in size from filaments to 2 mm across, typically form networks erratically crosscutting the magnesite. Fine-grained dolomite is interlaminated with magnesite at several localities. Quartz occurs as dispersed, very fine serrate grains or as aggregates of grains, and as reticulate veinlets. The veinlets range from filament size up to elongate pods 2 feet across and form anastomosing and trellislike networks, crosscutting earlier dolomite veins and magnesite.

COMPOSITION

The modal composition of selected, characteristic specimens was determined by point counting of stained slabs (table 3). Unfortunately,

TABLE 3.—*Modal analyses*

[Composition in volume percent; Tr, trace]

Locality (Shown on pl. 1)	Specimen	Magnesite	Dolomite	Quartz and silicates	Calcite and opaques
B	O–332B	35	29	36	Tr
E	O–334F	61	9	30	Tr
F	O–7A	72	3	25	Tr
	O–91B	49	17	34	Tr
	O–91C	64	3	33	Tr
	O–91D	16	57	32	Tr
G	O–92A	67	1	32	Tr
	O–92C	53	2	45	Tr
I	O–284A	72	----------	27	1
	O–284B	72	----------	28	Tr
J	O–279A	16	45	39	Tr
	O–279B	68	2	29	1
	O–279C	36	34	29	1
	O–279D	50	26	23	1
K	O–298C	27	25	45	3
	O–298D	44	41	14	1
	O–298E	23	44	31	2
L	O–299B	82	Tr	16	2
	O–299C	43	3	53	1
	O–299D	32	3	65	Tr
	O–299E	58	7	35	Tr
M	O–274A	30	62	8	Tr
	O–274B	56	27	15	2
	O–274C	47	22	29	2
	O–275	Tr	96	3	1
N	O–276A	68	2	28	2
	O–276B	66	Tr	32	2
P	C–140C	61	23	16	Tr
	C–140D	58	4	38	Tr

no staining procedure could be found which permitted reliable discrimination between all the major constituents simultaneously. The following procedure was therefore adopted:

1. Percentage of calcite was visually estimated, after staining red with Alizarine Red-S in 2 percent HCl in accordance with the method of Friedman (1959).
2. Percentage of dolomite was determined by point counting, after staining red with amaranth according to the method of Laniz, Stevens, and Norman (1964), or dark blue with potassium ferricyanide according to the method of Warne (1962).
3. Percentages of quartz, silicate minerals, and opaque minerals were determined by point counting, after staining dolomite and magnesite purple with Alizarine Red-S in 30 percent NaOH in accordance with the method of Friedman (1959).
4. Percentage of magnesite was determined by taking the difference between 100 percent and the sum of the other minerals.

Specimens, selected to represent the range in modal composition, were analyzed chemically and spectrographically (table 2). The magnesia content, ranging from 22 to 34 percent, is less than that in the better grade magnesite rock in the deposits in Stevens County, Wash., or Gabbs, Nev. (table 4), and doubtless must be considered low grade. Silica, present mainly as quartz, is the chief impurity and apparently exceeds the amount commonly present in other deposits. Calcium content is highly variable even within an individual deposit but is probably within acceptable limits in the better grade rock.

The composition is somewhat similar to that of the nickel ledge of the Mount Stuart quadrangle (table 4, analysis 11), and an external resemblance to the nickel-ledge rock was noted by Marshall T. Huntting (Washington Div. Mines and Geology, oral commun., 1967).

The spectrographic analyses (table 2) show, for a carbonate rock, unusually high concentrations of the trace elements chromium, nickel, and copper. Comparable values were noted in nonmagnesitic carbonate rocks in the general vicinity.

TABLE 4.—*Chemical analyses of selected magnesitic rocks*

[Source: Bennett (1941, p. 23–25) for analyses 1–6, quoted in Bennett and others (1966, p. 229); Vitaliano and Callaghan (1956) for analyses 7–8; Longwell (1928, p. 80) for analysis 9; Gale (1914, p. 514) for analysis 10; Smith (1904, p. 4) for analysis 11]

Analysis No.	Locality	Ignition loss	SiO_2	Al_2O_3, Fe_2O_3, FeO	CaO	MgO (experimental)	MgO (calculated)
1.	Woodbury deposit; NE¼ sec. 1, T. 31 N., R. 39 E., Washington	47.9	2.6	1.9	3.6	41.4	43.9
2.	Woodbury deposit; average of four analyses	46.7	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 nine 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.	U.S. Magnesite quarry; N¼ cor. sec. 10, T. 30 N., R. 38 E.; average of six analyses	49.4	3.8	1.1	1.2	43.4	44.3
6.	U.S. Magnesite quarry; average of 13 analyses	40.6	11.0	2.2	15.2	26.9	27.7
7.	June 2 quarry; Basic Magnesium, Inc.; sec. 26, T. 12 N., R. 36 E., near Gabbs, Nev.; fine-grained magnesite	51.48	.46	[1] .41	1.05	46.87	------
8.	Greenstone Addition claim; near Gabbs, Nev.; record of part of diamond drill core DG-K 27-g[2] Depth in feet:						
	82.8–86.0		[3] .8	[4] .5	19.2	-------	------
	86.0–91.5		1.9	.4	12.5	-------	------
	91.5–97.7		1.5	.4	3.8	-------	------
9.	Muddy Valley, Nev.; sample 1 of cuttings from 10 ft of best material in Magnesite Wash	44.15	11.12	.98	5.36	-------	36.72
10.	Bissell, Calif.; sample [5] 1 cut across face, 3 ft 8 in. wide excluding 1 in. of interbedded clay	[6] 40.70	9.64	2.46	4.25	-------	37.19
11.	Mount Stuart quadrangle, Washington; nickel ledge of Pehastin Formation [7]	[6] 31.04	32.12	6.37	1.81	26.73	------

[1] Includes TiO_2.
[2] Partial analyses only. Fuller description and additional analyses in source.
[3] Insoluble.
[4] R_2O_3.
[5] Undetermined: 5.76 percent.
[6] CO_2.
[7] Na_2O, K_2O, H_2O, Cr_2O_3, NiO, MnO total 1.96 percent.

SERPENTINITE

The small outcrop of serpentinite at locality L is the only occurrence of serpentinite in close proximity to magnesite in the entire belt, though small, sparse veinlets of serpentine minerals were recognized in nearby magnesite outcrops. The serpentinite is dark gray, fine grained, and massive with a characteristic dark-yellowish-brown to pale-olive rind on weathered surfaces. Although only a few feet from the nearest outcrop of magnesite, contacts are not exposed but are doubtless abrupt. It was not possible to ascertain from field relations whether the serpentinite is intrusive into the magnesite, whether it is a product of serpentinization of the magnesite, or whether the magnesite is an alteration product of the serpentine. Brief study of thin sections yielded conflicting evidence. For example, magnesite is locally cut and replaced by serpentine minerals, whereas, the serpentinite is locally cut by magnesite veinlets. These circumstances suggest at least a reaction relation between the serpentine (dominantly antigorite) and the magnesite, the reaction proceeding in either direction depending on the requisite availability of SiO_2, CO_2, and H_2O.

ORIGIN

Modes of origin commonly ascribed to magnesite deposits are: (1) syngenetic or sedimentary, in which magnesian minerals are precipitated from surface waters rich in magnesia, and (2) epigenetic, including those in which carbonate rocks, generally dolomite, are replaced by magnesite through the agency of magnesia-rich hydrothermal solutions, or others in which magnesian silicate rocks, generally serpentinite, are replaced by magnesite through the agency of hydrothermal solutions rich in carbon dioxide. It is doubtful that the Okanogan County deposits originated through replacement of magnesian silicate rocks, because, except for the small serpentinite body at locality K, none were observed in association with the magnesite over the entire length of the belt. The hydrothermal replacement of a dolomitic bed or beds at the base of the Kobau cannot be ruled out, particularly in view of the textural indications of replacement exemplified by the deposit at locality O, but the source of the magnesian fluids and the manner of their distribution and circulation in the subsurface over such a large area pose difficult problems.

We conclude that, notwithstanding certain contradictions, the sedimentary hypothesis best accounts for the wide geographic distribution of the Okanogan County magnesite deposits, their restriction to a narrow stratigraphic horizon, and their interlayering with metasedimentary rocks. The deposits probably formed as thinly interbedded siliceous magnesite and dolomite, with thicker interbeds of chert and pyroclastics and locally occurring limestone, deposited in shallow seas ponded on an erosion surface that beveled rocks of the Anarchist Series. Their origin is thus considered roughly analogous to that ascribed to the less recrystallized sedimentary magnesite deposits near Mojave, Kern County, Calif. (Gale, 1914, p. 512–516) and to those of the Muddy Mountains, Nev. (Longwell, 1928, p. 82–85).

The stability diagram of mestastable and stable carbonates by A. B. Carpenter (in Garrels and Christ, 1965, p. 376) indicates that for carbon dioxide pressures obtaining in the atmosphere, hydromagnesite and huntite are the metastable phases and magnesite is the stable phase in the presence of aqueous solutions with a high ratio of Mg^{+2} to Ca^{+2}. Dolomite is stable at intermediate ratios of Mg^{+2} to Ca^{+2}. The primary precipitates thus may have been hydromagnesite and huntite, which subsequently altered to various intermixtures of dolomite and magnesite.

The magnesite, dolomite, and quartz of the magnesitic beds have evidently undergone not only the same deformation and weak metamorphism as the enclosing rocks of the Kobau, but judging by textural evidence of recrystallization and mutual veining, they have also been extensively mobilized and replaced. Nevertheless, replacement features noted at some of the Okanogan County deposits, particularly at locality O, probably result from local hydrothermal redistribution of primary sedimentary magnesite.

CONCLUSIONS

Exposed dimensions of individual deposits described herein are not sufficient to establish an individual deposit large enough to be of economic consequence. Much of the area adjacent to the magnesite outcrops, however, is covered by glacial drift and alluvium which probably conceals extensions of the deposits on strike. Furthermore, if the deposits originated as primary sedimentary magnesite as hypothesized, or through secondary replacement of dolomite, they might reasonably extend downdip for distances as great as their strike length. If these assumptions are correct, the potential volume of magnesite present is considerable.

The analyses in table 2 compared with those of other deposits in table 4 suggest that the deposits are low grade and that the principal impurity is silica. Production of a commercially competitive product would undoubtedly require beneficiation.

The reconnaissance of the Anarchist-Kobau contact has necessarily been brief, and the existence of additional deposits in the area, some no doubt concealed by glacial drift, is likely.

REFERENCES CITED

Bennett, W. A. G., 1941, Preliminary report on magnesite deposits of Stevens County, Washington: Washington Div. Geology Rept. Inv. 5, 25 p.

Bennett, W. A. G., Weiss, P. L., and Weissenborn, A. E., 1966, Magnesite, *in* Mineral and water resources of Washington: U.S. 89th Cong., 2d sess., Comm. Rept., p. 224–231.

Bostock, H. S., 1940, Keremeos, Similkameen district, British Columbia: Canada Geol. Survey, map 341A, scale 1: 63,360.

Comstock, H. B., 1963, Magnesium and magnesium compounds, a materials survey: U.S. Bur. Mines Inf. Circ. 8201, 128 p.

Daly, R. A., 1912, Geology of the North American Cordillera at the forty-ninth parallel: Canada Geol. Survey Mem. 38, pts. 1–3, 857 p.

Friedman, G. M., 1959, Identification of carbonate minerals by staining methods: Jour. Sed. Petrology, v. 29, no. 1, p. 88–97.

Gale, H. S., 1914, Late developments of magnesite deposits in California and Nevada: U.S. Geol. Survey Bull. 540–S, p. 483–520.

Garrels, R. M., and Christ, C. L., 1965, Solutions, minerals, and equilibria: New York, Harper and Row, 450 p.

Huntting, M. T., Bennett, W. A. G., Livingston, V. E., Jr., and Moen, W. S., compilers, 1961, Geologic map of Washington: Washington Div. Mines and Geology, scale 1: 500,000.

Laniz, R. V., Stevens, R. E., and Norman, M. B., 1964. Staining of plagioclase feldspar and other minerals with F. D. and C. Red No. 2, *in* Geological Survey research, 1964: U.S. Geol. Survey Prof. Paper 501–B, p. B152–B153.

Longwell, C. R., 1928, Geology of the Muddy Mountains, Nevada, with a section through the Virgin Range to the Grand Wash Cliffs, Arizona: U.S. Geol. Survey Bull. 798, 152 p.

Mathews, W. H., 1964, Potassium-argon age determinations of Cenozoic volcanic rocks from British Columbia: Geol. Soc. America Bull., v. 75, no. 5, p. 465–468.

Phetteplace, T. M., 1954. Geology of the Chesau area, Okanogan County, Washton: Seattle, Washington Univ., M.S. thesis.

Shapiro, Leonard, and Brannock, W. W., 1956, Rapid analysis of silicate rocks: U.S. Geol. Survey Bull. 1036–C, p. 19–56.

Smith, G. O., 1904, Description of the Mount Stuart quadrangle [Washington]: U.S. Geol. Survey Geol. Atlas, Folio 106, 10 p.

Snook, J. R., 1965, Metamorphic and structural history of "Colville Batholith" gneisses, north-central Washington: Geol. Soc. America Bull., v. 76, no. 7, p. 759–776.

Umpleby, J. B., 1911, Geology and ore deposits of the Oroville-Nighthawk mining district: Washington Geol. Survey Bull. 5, p. 53–107.

U.S. Geological Survey, 1965, Pacific Coast region, *in* Geological research, 1965: U.S. Geol. Survey Prof. Paper 525–A, p. A96–A100.

Vitaliano, C. J., and Callaghan, Eugene, 1956, Geologic map of the Gabbs magnesite and brucite deposits, Nye County, Nevada: U.S. Geol. Survey Mineral Inv. Field Studies Map MF–35, scale 1: 2,400.

Warne, S. St. J., 1962, A quick field or laboratory staining scheme for the differentiation of the major carbonate minerals: Jour. Sed. Petrology, v. 32, no. 1, p. 29–38.

Waters, A. C., and Krauskopf, K. B., 1941, Protoclastic border of the Colville batholith [Washington]: Geol. Soc. America Bull., v. 52, no. 9, p. 1355–1417.

White, W. H., 1959, Cordilleran tectonics in British Columbia: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 1, p. 60–100.

Williams, L. R., 1965, Magnesium and magnesium compounds, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 630, p. 537–551.