THE GEOLOGICAL SURVEY OF WYOMING
HORACE D. THOMAS, State Geologist

BULLETIN NO. 43

ANORTHOSITE OF THE LARAMIE RANGE, ALBANY COUNTY, WYOMING, AS A POSSIBLE SOURCE OF ALUMINA

BY
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UNIVERSITY OF WYOMING
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ANORTHOSITE OF THE LARAMIE RANGE, ALBANY COUNTY, WYOMING, AS A POSSIBLE SOURCE OF ALUMINA*

BY

ARTHUR F. HAGNER †

ABSTRACT

The anorthosite of the Laramie Range in Wyoming is a potential source of alumina that may be of considerable importance should a national shortage become acute.

The anorthositic rocks described are in the southeastern part of Wyoming and form part of the pre-Cambrian complex of the Laramie Range. The area studied is 32 miles long and about ten to eighteen miles wide. Continuity of the anorthositic rocks has been interrupted by norite, syenite, gneisses, and granite.

The anorthositic series is made up of layers of anorthosite, noritic anorthosite, and feldspathic norite several thousand feet thick and each composed chiefly of one rock type. Lenses and layers of olivine anorthosite are present in the north-central part of the area. These rocks have the form of a folded lens or of a tabular mass. The major structure is an anticline in the eastern part of the area. This anticline trends north for 25 miles. Near its southern end the anticline is offset and trends N. 60° E.

INTRODUCTION

The alumina content of anorthosite generally is fairly high (Table 1). In Russia, nepheline syenite, a silicate rock somewhat similar to anorthosite in chemical composition, is used as a source of alumina (Strokov, 1936). During World War II the Monolith Portland Midwest Company of Laramie, Wyoming, developed a process for extracting alumina from anorthosite of the Laramie Mountains and for making a by-product usable in the manufacture of cement. Reports on the process were submitted to the War Production Board and the National Academy of Science in 1942 and 1943. Details of the process and of a test plant were given in a paper presented by Duncan Williams in November, 1944, before the Utah section of the American Institute of Mining and Metallurgical Engineers. The United States Bureau of Mines has published the results of tests on the recovery of alumina from anorthosite of the Laramie Range (Brown *et al.,* 1947). Small-scale laboratory tests and pilot-plant runs indicate that the alumina and soda in the Wyoming anorthosite can be extracted and recovered satisfactorily. A plant for this purpose was constructed a few miles south of Laramie but to date (April, 1951) has not operated.

This report presents geologic information on the anorthositic rocks in the Laramie Mountains, Wyoming, that would be of use to potential producers should this process for the production of alumina prove commercially successful, or should the anorthosite be exploited for other

* Publication authorized by the Director, U. S. Geological Survey.

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commercial uses (Bowles and Lee, 1930, pp. 5-7; Spence, 1932, pp. 131-135; Schwartz, 1937, p. 471; Grout and Schwartz, 1939, pp. 69-74).

Study of the anorthosite and associated rocks of the Laramie Range, Wyoming, was begun in 1944 by W. H. Newhouse and the writer. The investigation is a joint undertaking of the United States Geological Survey and the Geological Survey of Wyoming, and constitutes part of the geologic studies of the Laramie Range that have been carried on intermittently since 1944.

The anorthosite series was previously studied by Katherine Fowler (1930); the southern part of the area is included in the Laramie-Sherman folio (Darton *et al.,* 1910). A brief account of the structure of this series is given by Newhouse and Hagner (1945).

The writer is indebted to Dr. W. H. Newhouse of the University of Chicago, who has made many valuable suggestions during the preparation and writing of this manuscript. Mr. Max L. Troyer and Mr. George W. DeVore assisted in the field, and Dr. H. W. Fairbairn of the Massachusetts Institute of Technology and Dr. J. C. Haff of Mount Holyoke College have given advice and help with universal stage techniques. Messrs. E. W. Tooker and N. F. Sohl took the two photographs that show platy crystal structure of anorthosite. Dr. H. D. Thomas, State Geologist of Wyoming, has encouraged and supported the studies from the start, and Dr. S. H. Knight has generously provided space and the facilities of the Department of Geology, University of Wyoming. The chemical analyses of anorthositic rocks from the Laramie Range given in Table 1 were made possible by funds from the University of Wyoming.

LOCATION AND ACCESSIBILITY

The anorthositic rocks are located in the Laramie Range of southeastern Wyoming and cover a large part of Tps. 16 to 21 N., Rs. 71 and 72 W., in Albany County (Fig. 1). The Laramie Range is part of the north portion of the Southern Rocky Mountains and constitutes the eastern limb of the Rocky Mountain Front Range in the area. The western limb is the Medicine Bow Mountains and the two ranges are separated by the Laramie Basin.

Relief in the area is moderate, the maximum being about 2800 feet. Much of the region is a peneplane modified by later pediment surfaces (Fig. 2). The maximum altitude is approximately 8000 feet above sea level; the minimum 5200 feet.

Vegetation is sparse and consists principally of grasses and sagebrush; junipers and pines grow in the higher granitic areas. Vegetation is more plentiful, though limited in types, along permanent streams and in irrigated areas. The area underlain by anorthosite is devoid of timber, with the exception of deciduous trees and shrubs along streams and occasional pine trees.

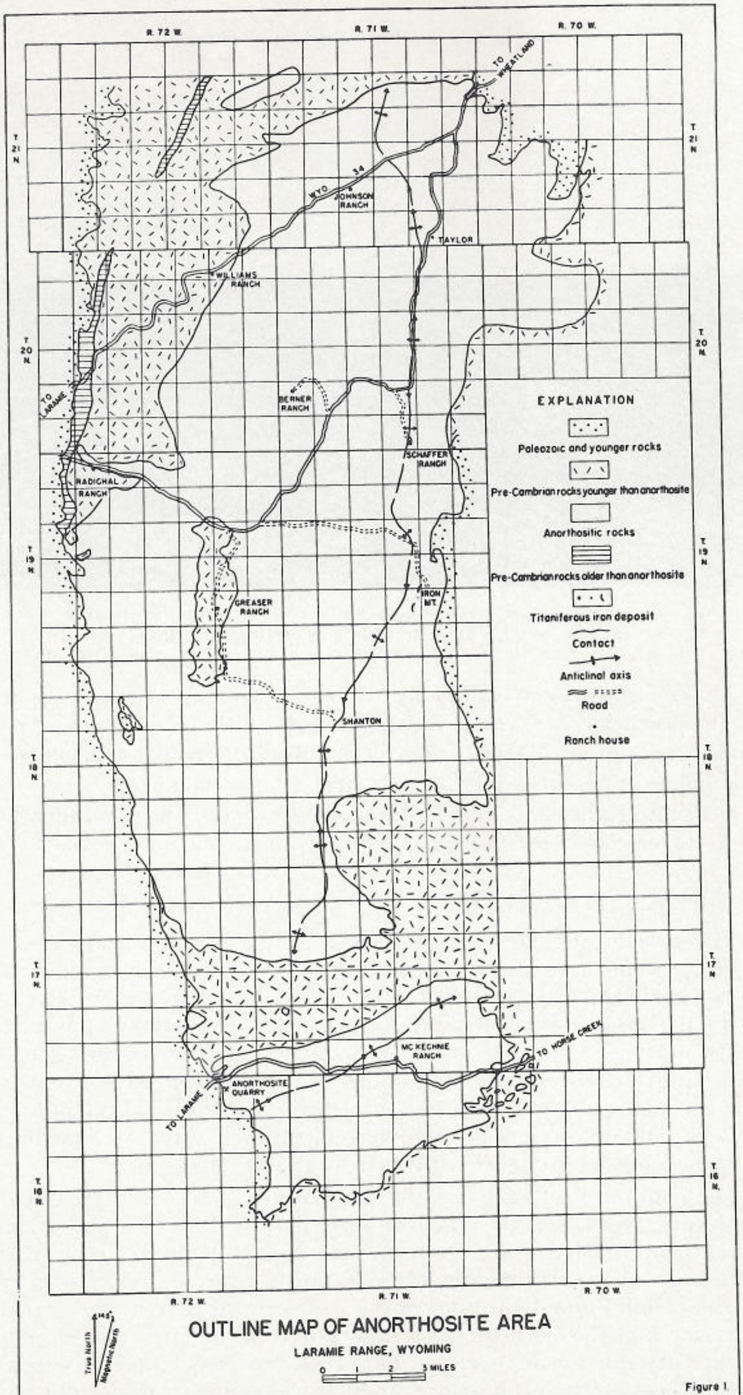

FIG. 1. Outline map of the anorthosite area, Laramie Range, Wyoming.

Fig. 2. Peneplane surface. Looking north across metanorite area (low, smooth topography) to northern anorthosite mass.

Most of the area is readily accessible. Wyoming Highway 34 traverses the northern part, and two county roads and numerous ranch roads provide access to other parts. The relatively flat terrane of much of the region makes it possible to drive a car over a large part of the area. The Union Pacific Railroad to the west and the Colorado and Southern Railroad to the east may be reached by state, county, and ranch roads.

GENERAL GEOLOGY OF PRE-CAMBRIAN ROCKS

The anorthosite and associated rocks of the Laramie Range occupy an area 32 miles long and from 10 to 18 miles wide. The oldest rocks are pre-Cambrian quartzite, dolomite, and hornblende schist. Next in age are the anorthositic rocks that have been invaded by masses and dikes of norite. After the norite crystallized, quartz syenite, gneisses, granites, and "lamprophyre" dikes formed. Following these events, the region was subjected to a long period of pre-Cambrian erosion and peneplanation. Titaniferous iron ores were introduced after the anorthosite was formed but before it was invaded by granite dikes.

The continuity of rocks of the anorthosite series is interrupted by several rock types. In the northwestern part of the area a northeast-trending band of quartz syenite from 2 to 4 miles wide has replaced the anorthosite. A north-trending band of norite from ½ to ¾ of a mile wide and 5 miles long is present in the west-central part of the anorthosite mass. Anorthosite near the southern part of the area was displaced with the introduction of norite. This rock has been much sheared to produce a metanorite. Shearing produced "openings" along which the metanorite was replaced by syenite, gneisses, and granites. Locally cordierite was deposited (Newhouse and Hagner, 1949, pp. 15-16). The introduction of norite, syenite, gneisses, and granites has divided the rocks of the anorthosite series into a large northern mass and a smaller southern mass.

ANORTHOSITIC ROCKS

Rocks of the anorthosite series have been divided into several lithologic types on the basis of percentage of dark minerals. These types include anorthosite with less than 10 percent dark minerals, noritic anorthosite with 10 to 20 percent dark minerals, and feldspathic norite with 20 to 35 percent dark minerals. These types occur in layers several thousand feet thick each composed principally of one rock. Within most of these layers there are smaller layers of other anorthositic rocks (Fig. 3). In places these smaller layers are from one to several tens of feet thick.

FIG. 3. Layering of anorthosite and noritic anorthosite. Shanton deposit.

The southern half of the northern anorthosite area contains lenses and layers of olivine anorthosite. Rarely noritic and olivine anorthosite are pegmatitic and contain much coarse - grained orthopyroxene and olivine.

Anorthosite is light- to medium-gray or blue-gray, medium- to coarse-grained, and has altered orthopyroxene as the principal mafic or dark mineral. Plagioclase, the predominant mineral, is a soda-lime feldspar with varying amounts of soda and lime. Much of the anorthosite is composed almost entirely of this feldspar with only 1 or 2 percent of orthopyroxene and magnetite-ilmenite. Grain size ranges from a small fraction of an inch across in some of the granulated anorthosite to occasional crystals that are 10 inches long and 2 inches across; most of the grains would fall between the limits of $\frac{1}{8}$ to $\frac{1}{2}$ inch across and 3/16 to 1 inch long. Outcrops are generally angular and prominent (Fig. 4). In places anorthosite grades along strike into more noritic varieties

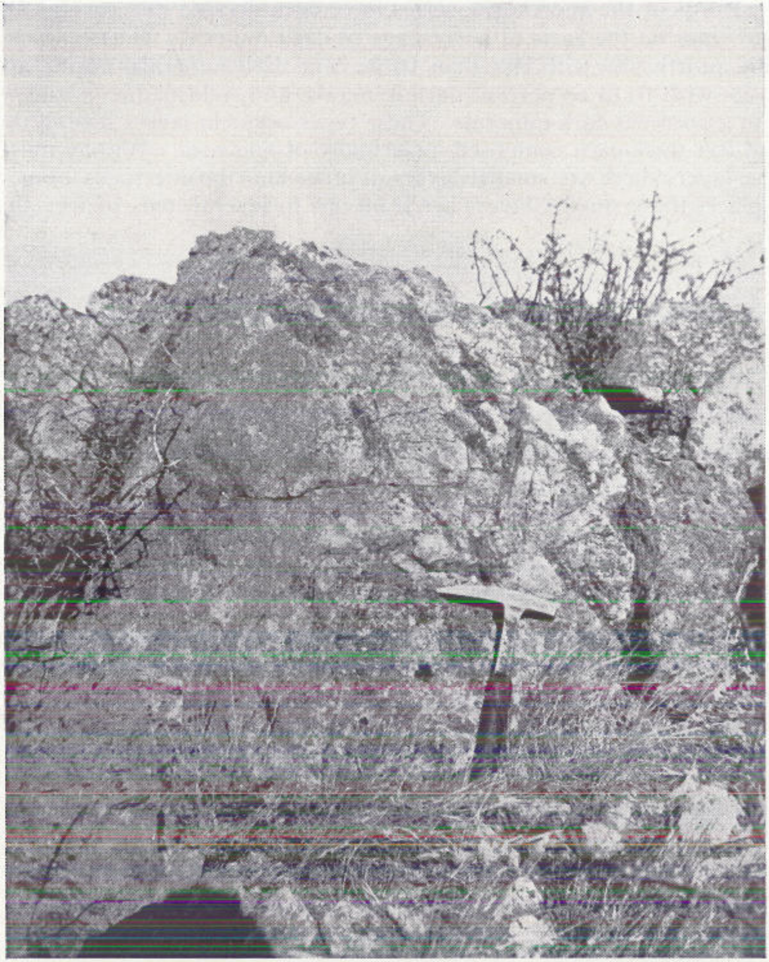

FIG. 4. Anorthosite outcrop showing angular character. Dark patches are clusters of mafic minerals developed locally. Iron Mountain.

Anorthosite commonly exhibits a well-developed parallelism of plagioclase crystals, called platy crystal structure (Figs. 5, 6). The ratio of length to width of plagioclase crystals ranges from about 2:1 in some places to as much as 15:1 elsewhere. This ratio also varies with composition, being less in the more calcic varieties. As seen under the micro-

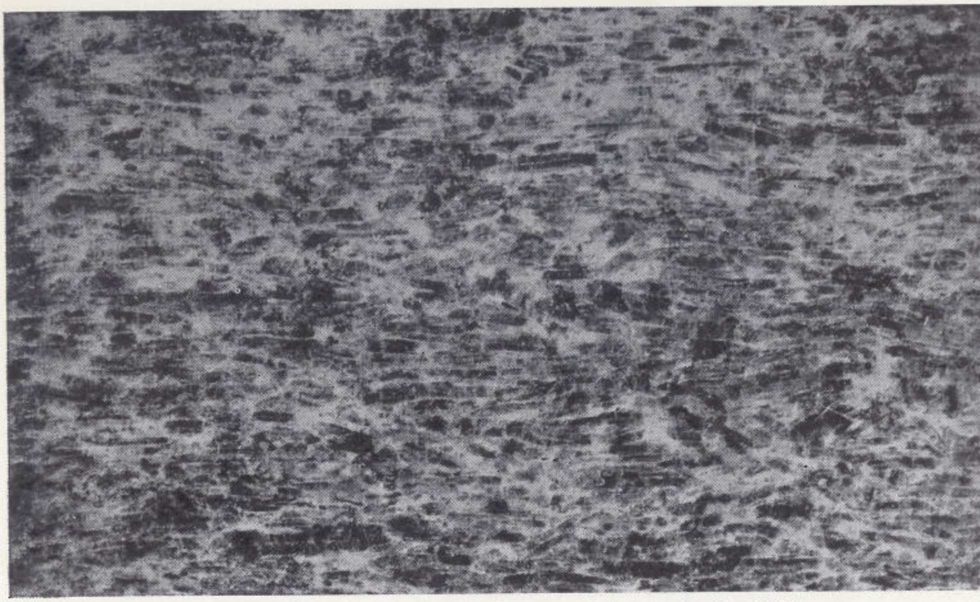

Fig. 5. Excellent platy crystal structure in anorthosite. X 2.

scope, many of the large crystals are bent and a few are micro-faulted. The orthopyroxene is largely altered to one or more of the following minerals: horneblende, actinolite, biotite, epidote, and chlorite. Most plagioclase is fresh, but some shows incipient alteration, particularly along fractures and twin lamellae, to sericite, carbonate, and clay. Magnetite-ilmenite may make up several percent of the rock and in places is partly altered to leucoxene, hematite, and limonite. Minute inclusions of rod-shaped and prismatic minerals are found in the plagioclase; these inclusions are arranged in parallel growth, and have not been identified.

Noritic anorthosite and olivine anorthosite do not show such well-developed platy crystal stucture as does anorthosite. Where the percentage of dark minerals is high, platy crystal structure may be lacking except locally. The grain size falls within the limits given for anorthosite, but in general the noritic varieties are coarser than most of the anorthosite. Outcrops are subround to round, are brown in color and weather to a coarse arkosic soil (Fig 7). Locally olivine may form up to 50 percent of the rock. The dark minerals are not as completely altered as those in anorthosite. Minor magnetite-ilmenite is generally present.

A few small veins of anorthosite are found in the more noritic varieties. In contrast with this are areas where pegmatitic norite and olivine anorthosite transgress the platy crystal structure of anorthosite. The pegmatitic varieties contain exceptionally large crystals, up to several inches across, of plagioclase, orthopyroxene, and olivine with coarse magnetite-ilmenite. These features are found in the northern anorthosite mass.

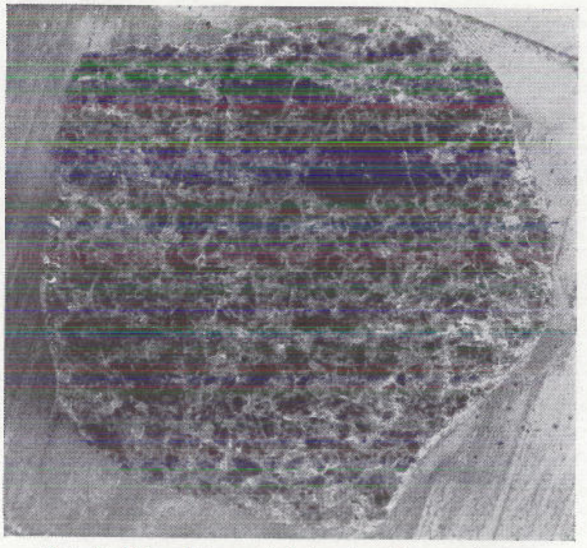

FIG. 6. Fair platy crystal structure in anorthosite.
Natural size.

FIG. 7. Noritic anorthosite outcrop showing typical subround character.
Shanton deposit.

VARIATIONS IN MINERAL PERCENTAGES

The anorthositic rocks range in mineral composition from anorthosite with almost 100 percent plagioclase to feldspathic norite with as much as 35 percent mafic minerals. Locally the dark minerals form 50 percent or more of the rock, which is then classed as a norite. In the south-central part of the northern anorthosite mass several layers of olivine anorthosite contain from 5 to approximately 50 percent olivine or olivine and combined orthopyroxene.

Several hundred determinations have been made on the composition of the plagioclase of the anorthosite, and these indicate that the anorthite content ranges from 35 to 70 percent or more. In some areas of a square mile or two, the composition is fairly uniform. In other areas of similar size the composition varies considerably. These variations appear to be related in part to the presence of dark minerals and to structural features. Anorthosite in and near the syenite mass in the northwest part of the area contains plagioclase as sodic as oligoclase. This plagioclase is up to 15 percent lower in anorthite than that in the adjoining anorthosite. In the southern anorthosite mass, in places where anorthosite is associated with quartzite, some of the plagioclase is bytownite.

In general the anorthite content of plagioclase in anorthosite is somewhat less than that in noritic or olivine anorthosite in the immediate vicinity. In the northern anorthosite mass the anorthite content increases from north to south from an average of about 41 percent to approximately 52 percent; in the southern anorthosite mass the plagioclase has a more uniform composition except in the vicinity of quartzite, where the anorthite may increase to 70 percent or more.

The original ferromagnesian silicate in the anorthosite and in the more noritic varieties was orthopyroxene. Microscopic work by DeVore (1948) indicates that the unaltered orthopyroxene of the anorthosite ranges from 17 to 54 percent orthoferrosilite. The orthoferrosilite content of the orthopyroxenes in anorthosite appears to be several percent lower than that in adjoining noritic or olivine anorthosite. Preliminary work by DeVore suggests that the orthoferrosilite content of the orthopyroxene in anorthosite shows a general decrease from north to south and a general increase westward from the anticlinal axis. The composition of the olivine in the olivine anorthosite is remarkably constant and ranges from 60 to 67 percent forsterite except near the syenite in the northwest part of the area, where it ranges from 42 to 53 percent forsterite. The forsterite content increases with distance from the syenite area (DeVore, 1948).

CHEMICAL ANALYSES OF ANORTHOSITIC ROCKS

Table 1 gives the chemical analyses of anorthosite, noritic anorthosite, feldspathic norite, and olivine anorthosite from the Laramie Range. These analyses are included to give some idea of the variation in composition of these rocks. Additional analyses of anorthosite from the Laramie Range may be found in papers by Fowler (1930, p. 390), Hague (1877, pp. 10, 13, 14, 15), Kemp (1905), and Brown *et al.* (1947, p. 6).

TABLE 1

CHEMICAL ANALYSES OF ANORTHOSITIC ROCKS, LARAMIE RANGE, WYOMING

Analyst: F. A. Gonyer

	1	2	3	4	5	6	7
SiO_2	51.91	53.50	55.60	55.14	52.25	52.44	48.88
TiO_2	1.29	0.14	0.08	0.12	0.49	0.32	0.64
Al_2O_3	25.87	28.92	27.48	27.78	25.96	24.70	21.22
Fe_2O_3	0.78	0.62	0.26	0.38	1.42	1.44	2.22
FeO	2.80	0.14	0.14	0.21	2.31	2.60	6.44
MnO	0.05	0.03	None	Trace	0.04	0.02	0.08
MgO	0.72	0.07	0.04	0.04	2.20	3.28	7.14
CaO	9.18	10.78	9.38	9.18	9.98	10.06	8.44
Na_2O	4.51	4.54	5.18	5.20	4.26	3.58	3.39
K_2O	0.78	0.62	1.01	0.98	0.64	0.51	0.46
H_2O-	0.04	0.01	0.05	0.04	0.02	0.05	0.51
H_2O+	0.94	0.39	0.59	0.60	0.42	0.52	.....
CO_2	0.82	0.02	0.13	0.41	0.02	0.21	0.32
P_2O_5	0.07	0.04	0.06	0.07	0.11	0.06	0.09
S	None	0.04	None	0.03	0.03	None	None
BaO	0.04	0.03	0.06	0.06	0.05	0.07	0.06
SrO	None	None	None	None	None	None	None
Cr_2O_3	....	....	....	....	None	....	....
	99.80	99.89	100.06	100.24	100.20	99.86	99.89

1. Anorthosite, Iron Mountain. From drill core.
2. Anorthosite, Shanton deposit.
3. Anorthosite, Taylor deposit.
4. Anorthosite, Taylor deposit.
5. Noritic anorthosite, Shanton deposit.
6. Feldspathic norite, Iron Mountain. From drill core.
7. Olivine anorthosite, 1½ miles northwest of Shanton deposit.

STRUCTURE OF THE ANORTHOSITIC ROCKS

A complete section of the anorthosite series is not exposed. The part that is exposed has the form of a folded lens or of a tabular mass. This mass consists of four major compositional layers in the northern anorthosite area and one in the southern area. Each of these layers is several thousand feet thick. Structural features are relatively simple and are outlined by compositional layering and by platy crystal structure.

The major structure of the anorthosite mass is a sharply defined anticline whose axis trends north for 25 miles through the eastern part of the area. This structure is offset in the southern anorthosite mass, where the anticline trends N. 60° E. for about 7 miles (Fig. 1). Dips of the platy crystal structure and layering of the anorthosite series on the principal, northern, anticline range from 20° to 60°, but most are from 40° to 50°. The domal part of the anticline is in the northeastern part of the anorthosite area; the anticline plunges south from this point for 17 miles and north for 8 miles. The major structure is modified locally by minor folds away from the axial areas.

ZONES OF GRANULATION AND ALTERATION

Zones of granulation and alteration are present in the northern anorthosite mass. A zone of granulated anorthosite from 1000 to 3000 feet wide and about 9 miles long is present along or near the anticlinal crest in the domal part. The anorthosite here is light-gray, granulated, and in general finer-grained than elsewhere.

The granulated anorthosite continues southward as a fractured and altered zone, nearly 8 miles long. This zone begins northeast of Iron Mountain near the anticlinal crest and trends southeast across the eastern limb of the fold. The zone localized an early period of mineralization, when widely disseminated olivine and local magnetite-ilmenite were deposited. Later it was intruded by small granite dikes, which produced widespread alteration in the broken and mineralized anorthosite. Another fractured and altered zone extends west and south of Iron Mountain for about 4 miles along the anticlinal crest.

FRIABLE ANORTHOSITE

In the southern anorthosite mass, particularly in the western part, much of the rock has weathered to a friable aggregate. The upper few feet of this coarse, loosely coherent material generally has disintegrated to unconsolidated debris. Beneath this the rock is friable to the extent that it crumbles under pick and shovel. Hard, unweathered chunks of anorthosite of varying size occur in this material. The depth to which the friable and altered zone extends is probably related to fracturing and weathering that took place before deposition of the Paleozoic rocks. It is to be expected that in places the friable zone extends to greater depths than elsewhere, and in these places much of the anorthosite could be removed by steam shovel as a pit operation. A quarry has been opened in the southern anorthosite mass in the NW 1/4 sec. 2, T. 16 N., R. 72 W. Quarry operations would be feasible throughout much of the northern and southern anorthosite masses.

CONCLUSIONS

This paper presents geologic information on the Laramie Range anorthositic rocks, their composition, mineralogic variations, and structure. Decisions on the type of anorthosite best suited for the extraction of alumina should take into account such factors as transportation costs, mining methods, alumina extraction processes and other economic and technical factors. Many millions of tons of anorthosite are readily available in the Laramie Range and provide a tremendous potential source of alumina that may prove to be of considerable importance should a national shortage develop.

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