ART. XXXIV.—*On the Igneous Rocks of the Sweet Grass Hills, Montana;* by W. H. WEED and L. V. PIRSSON.

IN northern Montana, the broad expanse of the great plains that lie east of the Rocky Mountain Cordillera is interrupted by a group of peaks, rising abruptly from the general level near the Canadian boundary line. These peaks, forming three isolated mountain masses, are known as the Sweet Grass Hills, or Three Buttes. Their sharp outlines and isolated position attract attention from every point of view, while recent discoveries of copper leads and ores of the precious metals, together with the excellence of the coal beds upon their flanks, have caused an influx of prospectors from the mining regions of the state.

The locality is now easily reached, as a tri-weekly stage runs from Shelby junction, where the Great Falls and Canada road crosses the Great Northern Railway, to the settlements on Birch Creek. The East and West Buttes are twenty miles apart, the Middle Butte lying to the south about midway between. The summits reach a height of 3,000 feet above the plains, and each butte is the center of a small mountain area whose verdure-clad slopes, copious springs and flowing streams are in strong and pleasing contrast to the desolate monotony of "Lonesome" prairie to the south. Through the kindness of Dr. G. M. Dawson, Assistant Director of the Canadian Geological Survey, who is the only geologist that has explored the Hills, the authors have been allowed to examine a number of specimens of the volcanic rocks constituting the central cores of these interesting mountain masses. The general geology of the Sweet Grass Hills has been described by Dr. Dawson,* from whose report the following notes have been taken.

The three buttes constituting the Sweet Grass Hills occur in the center of a broad and low anticlinal uplift that stretches for many miles parallel to the Rocky Mountain front, from which it is separated by a broad, shallow, synclinal basin. Each mountain mass consists of a core of igneous rock surrounded by Cretaceous beds uptilted at high angles, whose inclination gradually becomes less and less away from the eruptive rock, merging into the horizontal strata of the plains.

The igneous rocks forming the central masses of these mountains, though very dense and compact, are seldom seen in solid masses, since they break readily into irregular, angular fragments from a few inches to two feet across, forming debris

* Report Canadian Geol. Survey, 1882–4, C, pp. 16, 45. "Report upon country in vicinity of the Bow and Belly rivers, Northwest Territory."

piles that obscure all exposures. Dikes are occasionally found in the foot-hills or surrounding plains country, and appear to have a direction radiant from the higher peaks.

The East Butte, whose highest peak reaches an elevation of 6,200 feet above the sea, consists of four main points arranged in an irregular square. The conical northwestern peak is the most prominent; it is connected by a high ridge with the round-topped southwestern peak. The sedimentary rocks consist of yellowish and gray sandstones and black shales of Colorado Cretaceous, or Belly River (Montana?) age, the latter rocks being carved along the valleys into castellated shapes whose fluted surfaces, balcony ledges and intricate fret work, form most picturesque and attractive forms. These sedimentary rocks dip away from the Butte in all directions; the harder strata form more or less continuous ridges separated by depressions carved in the shales, and encircling the mountain. Near the igneous rocks the beds are much hardened and altered by contact metamorphism.

The dike rock described herein* occurs as a broken wall, traversing the horizontal sandstones and clays ten miles north of the summit of the East Butte. Its course is east and west.

The West Butte is the largest of the three, and rises to a height of 6,500 feet. It forms a mountainous area with numerous round-topped peaks and ridges separated by deep, precipitous valleys. The highest point is a large, blunt-topped summit with vertical rocky cliffs forming the eastern face. The sedimentary strata, dipping away from the peaks of igneous rock, show considerable contact metamorphism, and large areas of these altered rocks occur in the central portion of the mountain.

The structure here described corresponds closely with that observed in the mountain groups to the south of the Sweet Grass Hills. The Moccasin mountains, two isolated mountain masses, rising above the plains south of the Missouri, near the Judith mountains, consist of igneous cores whose rocks closely resemble those of this region, and are clearly laccolitic in character. Similar laccolites occur in the northeastern part of the Little Belt range, and the eruptive rocks of the outlying mountain groups, the Bear Paw, Little Rocky and Judith ranges, are also, in part at least, laccolitic. At most of the localities, however, the Paleozoic rocks are exposed, the intrusion having occurred in the shales forming the base of the Paleozoic series, whereas the Sweet Grass rocks are all of late Cretaceous age.

The igneous rocks here described are of similar types and correspond closely to those forming the laccolitic mountains just mentioned.

* See description by Dr. Dawson, loc. cit., p. 45.

Quartz Diorite Porphyrite.

This rock is represented by two specimens from West Butte. It is dense, of a dark gray color and thickly spotted with white feldspar phenocrysts. They are generally equidimensional and about 2^{mm} across, but in one specimen examples of twice this size occur. At times they are somewhat elongated and are then arranged in flowage planes showing fluid movements. Occasional small crystals of hornblende up to 4^{mm} in length can be seen. The rock weathers with a brownish crust.

Microscopically the following minerals are observed to be present: Apatite, hornblende, iron ore, plagioclase, orthoclase and quartz.

Plagioclase. As indicated in the hand specimens, this is very abundant as a phenocryst. The crystals are generally well formed and tabular on *b*(010). They are twinned according to the albite and Carlsbad laws. They are usually zonally built and the more basic inner portion shows a perceptible dispersion of the optic axes. They vary in composition from a basic labradorite to a medium acid oligoclase; thus a section in the zone *a*(100) on *c*(001) gave extinctions on either side of the albite twinning line of 26°, while the Carlsbad twin gave 12°, thus showing a basic labradorite approaching bytownite—a determination confirmed on other sections. In these sections the zonal growth is greatly marked and steadily becomes more acid towards the periphery. In another specimen the feldspars are more acid and even approach acid oligoclase.

The hornblende is pretty common in short, stout, ill-formed crystals and is nearly always changed to masses of opacite and chlorite and other decomposition products. It is the usual dark green variety. Twins at times on *a*(100).

The groundmass in which the above minerals lie is a very fine-grained, patchy or micro-poikilitic mixture of quartz and feldspar, the latter usually too much altered or kaolinized for identification but certainly composed in part of orthoclase. The quartz occurs also at times in irregular grains, which rise to the position of small phenocrysts. A greenish-yellowish mineral of the chlorite group occurs very often in cavities arranged in vermicular growths.

Quartz Syenite Porphyry.

This rock is represented by two specimens from East Butte. It is tough and compact, of a pale brown color which changes to a pale green gray on weathered surfaces. This groundmass is very thickly crowded with phenocrysts of feldspar which vary very greatly in size from examples 11^{mm} by 6^{mm} down to some only 0·5^{mm} across. They have the common flesh color of

orthoclase. There are also many little crystals of black augite smaller than the smallest feldspar phenocrysts.

The microscope shows the following minerals present: Zircon, iron ore, apatite, ægerine-augite, oligoclase, orthoclase, anorthoclase and quartz.

The zircon is rare and appears in very small stout columnar crystals. The iron ore is not abundant, but there is a moderate amount of it. The augite is in short, very thick little prisms about 0·5^{mm} long. Prisms and pinacoids are present. It generally contains a pale green diopside core which rapidly passes into a bright green ægirite-augite mantle; often the diopside core is wanting and the crystal passes into deep green ægirite on the exterior, the optical properties suffering a corresponding change. Some examples are changed exteriorly to ferruginous products by alteration. The oligoclase appears in the form of idiomorphic phenocrysts of tabular form or somewhat columnar on the ă axis about 1^{mm} long. Both the Carlsbad and albite twinnings are present. It is a rather common phenocryst. Much more abundant, however, are larger, ill-formed orthoclase crystals which present no unusual features. They commonly show the Carlsbad twin, but a Baveno twin was seen in one case. The anorthoclase is also quite abundant and is frequently intergrown with orthoclase. It contains successive rows or sets of short, excessively fine lamellæ of albite, twinned according to the albite law. It is sharply differentiated from the oligoclase both by the difference in double refraction and by its method of twinning. All three of these feldspars are apt to be collected together into grouped masses. They are slightly kaolinized.

The above phenocrysts lie scattered in a rather fine groundmass composed of allotriomorphic feldspar and quartz. The structure is micro-granitic and the amount of quartz is considerable. The feldspar is mostly alkali feldspar, unstriated, but a certain amount of oligoclase is present in the second generation. Small microlites of a mineral of strong refraction are present which may be of augite.

The systematic position of this rock type is rather peculiar; it is clearly of high silica, alumina and alkalies, and of these latter soda is very largely present. It contains considerable iron, while lime and especially magnesia play but an inconspicuous role. It is closely allied to the granite porphyries by the large amount of quartz in the groundmass, but it does not contain any quartz phenocrysts. On the other hand, the amount of plagioclase present, while not sufficient to throw the rock out of the alkali group, shows tendencies towards diorite porphyrite. Under these conditions it seems most closely allied to the syenitic group of rocks and the name of quartz syenite porphyry is given it.

Minette.

This is shown by a specimen from a dike north of East Butte. It is a dull, dark stone-gray color, filled with phenocrysts of biotite which have a maximum diameter of 5^{mm}. They are very common, and being arranged in an approximately parallel position, they give the rock a facility for cleavage in that plane. The lens shows a pale yellowish augite to be also present.

Under the microscope the following minerals are seen: Apatite, iron ore, biotite, augite, orthoclase and calcite.

The biotite is of a very pale leather-brown color and feebly pleochroic. It has a zonal structure, being invariably bordered by a narrow deep brown rim. The axial angle is extremely small and the axial plane is parallel to an edge of the hexagonal section; it is thus a meroxene. The large plates are greatly embayed and irregular and frequently composed of smaller individuals in parallel position. It thus corresponds precisely to the biotite characteristic of minettes as described by Rosenbusch.* Apatite is not very common. It presents nothing unusual. The iron ore is entirely in the second generation. The augite is in rather large, stout, ill-formed crystals, colorless and with here and there patches of alteration into carbonates. The groundmass in which the phenocrysts lie is composed of a mixture of very fine biotite leaves and shreds, small grains and rods of augite, grains of iron ore and laths of an untwinned feldspar which appears to be orthoclase. The orthoclase laths are at times arranged in rude spherulitic forms. Often among the augite prisms are some that are deep green and strongly pleochroic and extended in an optically negative direction. They must therefore be of ægirite. Between the feldspar laths there frequently appears small formless patches of a colorless isotropic substance that is believed to be glass.

The rock has a porphyritic structure and it is a very typical minette. It is also quite fresh, there being no alteration except in the augite. It contains some fragments of calcite that appear to be foreign to it, as if brought up from rocks below as an inclusion. In it the dark minerals play a preponderating role, the feldspars being present but in comparatively small amount in the groundmass. Its petrological affinities ally it with the syenite-porphyry of East Butte, with which it probably stands in geological relation. From this point of view it is interesting to note the occurrence of the ægirite both in the porphyry and in the minette.

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* Mass. Gesteine, p. 310, 1887.