An Unusually Wide Zone of Crushing in the Rocks Near Kettle Falls, Washington

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Field Relations.

The rocks described below occur in a belt about twelve miles long and two miles wide, in eastern Ferry County, Washington. The northeast end of this belt lies directly across Columbia River from the town of Kettle Falls, its further extensions to the northeast being hidden by the schists and quartzites around the Falls. The southwest end of the belt lies beneath the quartzite and schist of Onion Ridge.

This belt of crushed rocks forms the southeastern margin of the Colville batholith,[1] in this part of its range. The contact is narrow between this crushed border zone and the older metamorphic series, but disappears under the Columbia River terraces near Mink Creek, to reappear just north of Sherman Creek. In contrast to the sharp-cut outside edge of the crushed zone, the inside edge, or that facing the center of the intrusion, is gradational into the uncrushed central parts of the Colville batholith. The strain phenomena in the western areas of the batholith, away from the border, are restricted to warping but not crushing of the minerals, and cannot be seen in the field. Though the apparent width of the zone of crush effects has been stated as two miles, its true thickness is much less; for the ridge-tops mark approximately the roof of the batholith, and thus the depth of the exposed batholith is limited by the depth of the valleys to about three thousand feet. No greater thickness of the batholith shell was seen anywhere; yet even along its roof, toward the west, no effects of crushing could be found, though thin-sections show that even these rocks have been under stress at some time.

Field Appearance of the Rocks.

The crushed border zone consists of straight-foliated blue-gray gneiss in most places seen, but there are yellow-white streaks and black streaks parallel to the foliation. The main gneiss is composed of close-set rounded white feldspars of all sizes up to an inch in diameter, but most of them under an eighth-inch. These granules are separated by thin black films along which the rock can split to expose their almost metallic luster and a sprinkling of small but sparkling muscovite flakes. The gneiss is therefore quite platy, and could almost be called a schist. Its foliation runs parallel to the contact between the batholith and the wall rock: in this area, the strike is variable northeast, and the dip southeast from fifteen to forty degrees.

In addition to the platy foliation of the gneiss, there is a pronounced linear element, or grooving. The grooves are narrow parallel wrinkles in the black films, and they trend almost due east with greater constancy of direction than that of the platy foliation itself. This eastward trend of the grooving carries it obliquely down the dip of the foliation.

The same foliation and linear structure are found in the light-colored streaks as in the gray gneiss, but many of the narrow black streaks show neither, though surrounded by strongly-foliated gneiss.

Borders of the Crushed Zone.

Contacts between gneiss and adjacent quartzites are of knife-edge sharpness; and the foliation and textures of the gneiss are no different at the contact than at a distance from it. The same is true of the contact between gneiss and quartz-biotite schist. Also, the schistosity of the latter is parallel to the contact and the foliation of the gneiss, but owing to the absence of columnar minerals, no linear structure is apparent in it. These clean-cut wall-rock contacts are in contrast to the gradational inner border of the crush zone.

Structures and Composition of the Wall-Rock.

Only the part of the wall-rocks next to the border of the batholith are considered in this section, as they are quite different at a distance. They are a series of sedimentary rocks and lava flows which have suffered sufficient metamorphism to convert them into slates, greenstones and other low-grade metamorphic rocks. Next to the contact, their bedding is parallel to it. Locally these rocks and the sills included between them are folded into small overturns which lie back against the southeast-dipping contact, and pitch about 50 degrees to the southwest. Folds of similar orientation were seen in the foliation of the gneiss itself.

Two sills, larger than the rest, present a curious problem. One, about fifty feet thick, is separated from the batholith by two hundred feet of fine-grained quartz-biotite schist. The composition and foliated structure of this sill make its outcrops indistinguishable from those of the main mass. Above this sill are a hundred feet of black slate and thirty feet of fine-grained white quartzite, then the second sill. This second sill, if it really is a sill, is also fifty feet thick. Its dense black groundmass thickly sprinkled with small white feldspar crystals, makes it look a little like some sort of lava such as an andesite, but the crystals are aligned in bent and interrupted gneissic streaks, and the rock is full of tiny faults which displace these streaks a fraction of an inch or more. Thin-sections of this layer, described in more detail on another page, show apparently that it has the composition of granodiorite, and has been mashed to a remarkable degree.

At its top, this crushed layer grades into fifteen feet of dense gray flinty material containing yellow veinlets of the same texture and a little pyrite. Above this a gray limestone which accommodates itself to the blocky top of the flinty layer. The point to be noted here is that a hundred-foot layer of hard rock, some of it apparently thoroughly crushed, is sandwiched between soft rocks (a limestone and a slate).

Petrography of the Gneiss.

The main mass of the gneiss seems to be granodiorite, although estimates of the true mineral proportions are made uncertain by the fine grain of much of the rock. Much of the quartz is in irregular lenses, up to five millimeters long. The lenses are aggregates of ragged grains of quartz which will be referred to as "sutured quartz" because of the irregularity of the boundaries between grains. A few large ragged flakes of brown biotite occur by themselves, but most of the biotite forms irregular swarms of minute flakes interspersed with finely granular felsic material. Locally the biotite is partially or wholly turned to chlorite.

The gneiss shows all degrees of crush effects, from mortar structure (in which the grains are sprung apart and granulated on the edges) to advanced granulation which has reduced the feldspars to strained and rounded relics set in a mixed groundmass of fine particles, sutured quartz and one or more micas. Locally, and occurring together, are muscovite, garnet grains and apatite; and although the garnet and apatite are euhedral, the muscovite is locally bent around other mineral grains or cuts sharply across the rounded feldspars, the sutured quartz and the other micas.

White streaks in the gneiss are taken to be pegmatites or splites which have been sheared along with the enclosing rock. Their textures are now practically the same as those of the darker main mass. These light streaks lack biotite and chlorite, but contain more muscovite and garnet than the dark.

Conclusions.

From the observations listed above, it is evident that a strong directed pressure left its marks on this part of the batholith, southwest of Kettle Falls. The brecciated appearance of the rock, the slicing and displacement of the feldspars, the warping of quartz and feldspars as shown by strain shadows, and the lens-like grouping of fine particles about rounded and strained relic crystals; all these are evidence of the pressure that has acted on the Colville batholith. The presence of muscovite and garnet suggests without proving dynamic metamorphism, as these minerals may be of igneous origin.

The east-west streaking, or linear structure of the gneiss means that the deforming force acted in that direction. But the complexity of the structures in the wall rocks, as yet not wholly worked out, necessitates basing conclusions so far obtained, on the evidence of the batholith and its immediate environs.

The extreme crushing of the batholith border must have been the result either of intrusion pressure continued through final stages of crystallization, or of orogenic movements of some later date. The uniformity in direction of the streaking, over wide areas, makes the second alternative more likely. Also, if the foliation was produced by movements of the nearly solid igneous mass as it was forced into place, the folds in the adjacent wall-rocks show that the igneous material must have moved eastward and downward: a condition possible only along the top side of a tongue-shaped mass being pushed eastward as a kind of thick sill. There is no independent evidence that the batholith is of this type. While the superposed linear and platy structure and the joint sets are not out of harmony with this explanation,[2] the abundant dikes and sills to be expected in the rocks to the east, are not present. Because of this, it is thought somewhat more probable that the foliation and crushing in the batholith are due to distinctly later forces acting from outside the batholith.

Crush phenomena of the kind described above, have been found in many parts of the world,[3] including an occurrence in Washington (a short distance up Columbia River from Wenatchee).[4] The resulting rocks, called mylonites, have been formed along deep-seated thrust soles in most of these places; in very few are there any such large masses of rocks involved as in this intrusion border near Kettle Falls.

BIBLIOGRAPHY

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[3] For detailed bibliography, see Waters, A. C. and Campbell, C. D., Mylonites from the San Andreas fault zone: Am. Jour. Sci., ser. 5, vol. 29, pp. 473-503, 1935.

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