ORES, MAGMATIC EMANATIONS AND MODES OF
IGNEOUS INTRUSION.¹

DISCUSSION OF PAPER BY B. S. BUTLER.

Professor Daly's discussion of Mr. Butler's paper² is of special interest to me, who was associated with Professor Daly at Boston from 1907 to 1912, and spent most of the field seasons of 1911, 1912, and 1913 studying the ore deposits of Utah in cooperation with Mr. Butler. Of the several mining districts and I visited, those of the Cottonwood-American Fork region and the Tintic district offered the best opportunities to study methods of igneous intrusion.

*Cottonwood-American Fork Region.*³—Conditions in the Cottonwood-American Fork region are well expressed by Mr. Butler's statement (page 116) that "the space occupied by the igneous material constituting the stocks was formed in large part by the pushing aside and doming of the earlier rocks." Professor Daly notes that Mr. Butler's "elaborate section" expressing the latter's idea of the underground relations for three hypothetical stocks "clearly shows that the country rocks were *not* pushed aside" and therefore "squarely contradicts the text." It is evident to me, from my personal acquaintance with the region, that Mr. Butler's section was drawn solely to show the relations of ore bodies to slightly and deeply eroded masses of igneous rock, and did not pretend to indicate the complicated structural details near the igneous contacts. Mr. Butler, with the genesis of the ore deposits uppermost in mind, evidently neglected the accurate representation of intrusion processes; Professor Daly, with the genesis of igneous rocks engrossing his attention, naturally looked especially for data on methods of intrusion.

Adequate representation of the complex structures around the igneous stocks in either the Cottonwood-American Fork region

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² Vol. X., No. 2, pp. 101-122.

³ A short report on this region by Mr. Butler and G. F. Loughlin has just been published as a part of Bull. U. S. Geol. Survey, No. 620 (contributions to ECONOMIC GEOLOGY, 1915, Part I.).

or the Tintic district is impossible in a single section; only an elaborate stereogram or model could serve the purpose properly. In the Cottonwood-American Fork region pre-Cambrian and Paleozoic sediments are irregularly domed around a stock of granodiorite. The dips of the pre-Cambrian slates and quartzites in Big Cottonwood Canyon, on the north side of the stock are northward, away from the stock, and in places the beds are very steep and even contorted. Along the eastern border of the stock the dips of upper pre-Cambrian and lower and middle Cambrian strata are also away from it, and the formations are broken by steep reverse faults along which the blocks adjacent to the stock moved upward about normal to the igneous contact. Along the southern boundary of the stock only Paleozoic limestones, metamorphosed and dipping away from it, are exposed. Comparison of the southern with the eastern and southeastern boundaries suggests strongly that the great series of quartzites that formerly occupied the position of the present stock were up-faulted above the level of the present surface by the upward thrust of the intrusion and have since been eroded. To one observing only the western and southern boundaries, however, the idea of up-faulting and erosion of quartzite would not occur so readily, but the doming of the limestone would still be an important feature.

The impression gained from the evidence expressed at the present surface is that the granodiorite magma made room for itself by pushing upward or doming a great thickness of pre-Cambrian and Paleozoic rocks; and that along the eastern and southern boundaries the shearing strength of these rocks was overcome and doming gave way to faulting. The method of intrusion at greater depths, where the resistance of the overlying rocks was too great to permit doming, is open to speculation. The magma must have made room for itself in some way, and as its thrusting power was inadequate, some process of stoping appears most plausible.

Study of the upper contact of the stock proves that many small apophyses of the granodiorite cut across the bedding of the quartzitic rocks and send branches along the bedding. In other words they represent the arrested process of the stoping of rock that had already been domed. Inclusions of these roof rocks in the grano-

diorite however are very scarce, although the granodiorite along Little Cottonwood Canyon is exposed to a maximum depth of 5,000 feet. Inclusions of dark dioritic rock are abundant, but their composition is such that they can not be regarded as recrystallized roof rock. The granite itself is very uniform in mineral and chemical composition. This evidence tends to indicate that after the up-thrusting force of the magma had subsided some stoping took place; but that very little rock was displaced by this process and that very few of the stoped blocks sank for appreciable distances in the viscous magma.

Tintic District.—Evidence around the principal monzonite stock in the Tintic mining district, though somewhat different from that just discussed, leads to the same general conclusion. Here the sequence of sedimentary rocks is generally the same as in the Wasatch Mountains. The monzonite was intruded near the axis of a great syncline whose western limb is about vertical. It did not cause any doming, but a number of faults have been found that were produced wholly or in part by the intrusion. These faults are considered in detail in a report which has just been completed.⁴ The diverging character of the vertical strata north of the monzonite contact suggests that the monzonite may have made room for itself to some extent by prying them apart. Evidence of stoping is much more prominent than in the Cottonwood-American Fork region, but stoping as a means of making room for the monzonite stock appears to be secondary in importance to faulting. The following is a very summary account of the intrusion faulting.

One fault of relatively small displacement extending northward through the Apex and Centennial Eureka mines is of special interest in showing the time of its formation. It faults a dike of rhyolite porphyry whose intrusion was a little earlier than that of the monzonite but is older than the ore bodies whose deposition followed closely after the monzonite intrusion. The only fissures formed between the time of monzonite consolidation and ore depo-

⁴ Lindgren, Waldemar, and Loughlin, G. F., "Geology and Ore Deposits of the Tintic Mining District, Utah." To be published as a Professional Paper of the U. S. Geol. Survey.

sition are characterized by little or no displacement, but the fault in question is a compression fault with a displacement of 300 feet or more, the east wall moving northward and upward away from the monzonite. Another fault similar in general character and magnitude of displacement extends east of north through the Emerald and Grand Central mines. Neither of these faults offset the monzonite contact. The lateral thrust of the monzonite magma was the only force to which these faults can be reasonably attributed.

Faults of so small displacement can not have contributed materially to the space occupied by the monzonite stock, the main exposed part of which covers more than a square mile, but other faults related to the intrusion are much greater. The best exposed of these extends eastward from near the Mammoth to the Northern Spy mine. Its horizontal component of movement is unknown though not great, but its vertical component is as much as 1,500 feet. Other east-west faults attributed to other causes are abundant in the district, but their total amounts of displacement are small and predominatingly in a horizontal direction.

Other faults caused by the intrusion are indicated by the distribution of limestone and quartzite inclusions in the monzonite, together with the offset position of a part of the rhyolite porphyry intrusion that borders the monzonite on the west. This combined evidence indicates that a large block was pushed upward and westward above the northwestern part of the monzonite, and was later largely obliterated by stoping. The amount of movement was great and may have been as much as 3,000 feet. Quartzite inclusions south and southwest of the Martha Washington mine suggest that a second block was thrust upward here as much as 2,000 feet higher than the up-thrust block noted in the preceding paragraph, and has since been completely demolished by stoping and erosion.

It is impossible to present adequately the evidence of this intrusion faulting followed by stoping without much detailed description and consideration of many points dealing with the stratigraphy and structure of the district. Let it suffice to state here that the evidence in part is clear and in part obscure. It shows,

however, that the northern part of the monzonite magma made the last few thousand feet of its upward progress largely by the faulting upward and outward of the sedimentary rocks, and that some farther progress was made by the stoping of the up-faulted blocks. Horizontal distribution of the large inclusions stoped from these blocks is abundant and such as to indicate that many of them have not moved far from their original position. The low relief of the monzonite area and absence of deep mine workings in that part of the district prevents study of the vertical range of the inclusions.

This evidence, which is limited to the northern part of the monzonite area, suggests that the whole monzonite mass may have made room for itself largely by faulting, but nothing approaching actual proof of this generalization can be offered. So far as it goes, the evidence in the Tintic district leads to the same general conclusion as that in the Cottonwood-American Fork region: that the intrusion at great depths, where the cover could successfully resist faulting, may have worked its way upward by stoping; that at some less depth, amounting at least to 2,500 or 3,000, and perhaps to many more, feet below the present monzonite surface, it forced its way upward mainly by faulting; that after the faulting had practically ceased some farther progress was made by stoping. So far as available evidence on the present surface is concerned, the faulting was of more importance as a method of intrusion than was the stoping that followed it.

As this stoping took place during the latest stage of the intrusion, it can hardly be supposed that any significant amount of "resurgent" waters or gases was derived from the sedimentary rocks at this time. Whether any "resurgent" waters or gases were derived in the early stages of intrusion, at depths below which the intrusion faulting took place, is, like the method of intrusion at those depths, a matter of speculation.

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