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FORM OF DIABASE SHEETS IN SOUTHEASTERN PENNSYLVANIA*

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ABSTRACT. Ringlike outcrop patterns are characteristic of diabase intrusions of Triassic age in southeastern Pennsylvania. Drill-hole and geophysical data indicate that the diabase of these rings has the form of generally discordant curved sheets. Pre-existing fractures or potential lines of weakness may have controlled the sheetlike form, or pressure may have forced the diabase magma to spread laterally rather than to rise vertically.

INTRODUCTION

OVAL and elliptical outcrop patterns are characteristic of diabase bodies in the Triassic belt of southeastern Pennsylvania. The Geologic map of Pennsylvania (Stose and Ljungstedt, 1931) from which figure 1 was taken shows a belt of several elliptical rings of diabase in the northwestern part of the Triassic basin beginning south of Reading and extending northeast to the Delaware River. Another series of smaller and less well-defined rings of diabase extends southwest from Cornwall to Dillsburg. A single small almost circular ring of diabase is found just north of the Pennsylvania-Maryland boundary southwest of Gettysburg.

Most of the intrusions in the Triassic belt have heretofore been interpreted as conventional sills and steeply dipping, dikelike discordant bodies with concordant sill-like and basin-like offshoots (Stose and Lewis, 1916, p. 628; Stose and Bascom, 1929, pp. 11-12; Stose and Jonas, 1933, p. 42; Stose and Jonas, 1939, pp. 125-126; Stose, G. W., 1949, pp. 533-535). In 1908 Spencer (1908, pp. 44-45) suggested that the chain of ringlike diabase intrusions in the northeastern part of the belt was the surface expression of a "practically unbroken sheet." Drill-hole explorations at Dillsburg (Hotz, 1950, pp. 11-13) and elsewhere, and a gravity survey near Quakertown (Hersey, 1944, p. 439) have confirmed Spencer's interpretation and justify the conclusion that a sheetlike habit is characteristic of most of the diabase masses that have oval or ringlike outcrop patterns.

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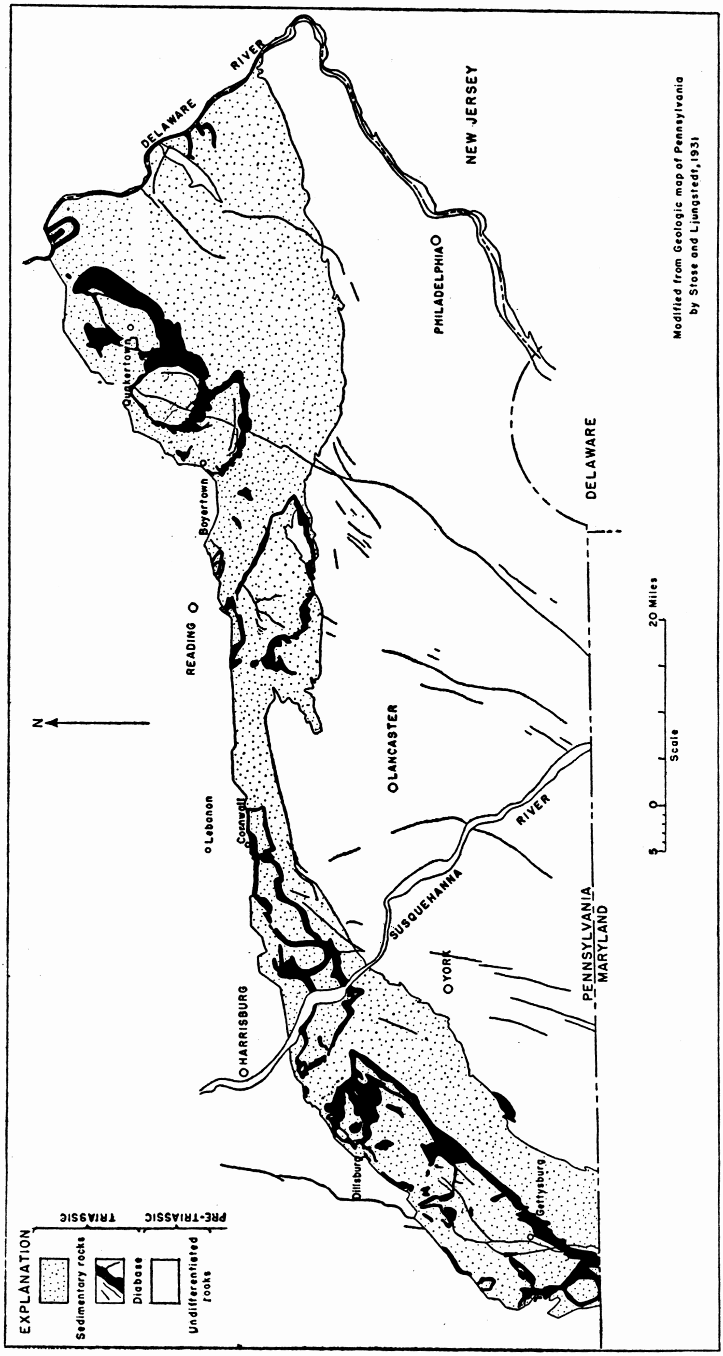

Fig. 1. Map of southeastern Pennsylvania showing distribution of Triassic diabase intrusions.

STRUCTURAL HISTORY OF THE TRIASSIC BASIN

The Triassic belt of southeastern Pennsylvania represents a continental basin in which terrestrial sediments were deposited. During deposition of the sedimentary rocks the basin gradually sank, owing to downward flexing or faulting along its northwest edge (Stose and Jonas, 1939, pp. 107-108, 119). The northwest border is marked by a fault boundary in many places, whereas the southeast limit is nearly everywhere an unconformable depositional contact on older rocks. Fracturing of the basin provided vents for the upward movement of magma, which intruded the sedimentary rocks and solidified as diabase. The sedimentary rocks were metamorphosed to quartzite and hornfels near the diabase intrusions. Diastrophic activity virtually ceased in this Triassic basin before or at the time of diabase intrusion.

The Dillsburg District.—At Dillsburg an area of Triassic sedimentary rocks about 6 miles long and 3 miles wide is nearly surrounded by diabase (fig. 2). The diabase is an offshoot from the large westward-dipping sill that extends northeast from Gettysburg, Pennsylvania. A small oval patch of diabase that is separate from the surrounding body lies near the western end of the central area of sedimentary rocks. Beneath this small body of diabase are small replacement bodies of magnetite in lenses of limestone conglomerate within the sedimentary rocks (Hotz, 1950, pp. 13-25).

The average strike of the sedimentary rocks is east-northeast and the average dip is about 30° NW. In places the rocks are gently flexed, but the regional structure is generally homoclinal and has a gentle northwest dip.

Over much of its extent the diabase surrounding the central area at Dillsburg is discordant with the structure of the sedimentary rocks, though part of the southern and southeastern contact appears to be concordant.

Spencer (1908, pp. 71-72) interpreted the oval body of diabase overlying the magnetite deposits at Dillsburg as in part discordant, though in his description of the mines he assumed concordant relations in most places. Harder (1910, p. 601) interpreted this same body of diabase as a sheet that ". . . apparently lies on the sediments with a rolling uneven contact, while the outlying smaller masses appear to be erosion remnants lying in troughs on the surface of the sediments. The sediments underneath the diabase are continuous with those surrounding them and have the same prevailing dip . . ."

Diamond drilling (Hotz, 1950, pp. 11-13) has proved Harder's concept of the structure to be correct. In each drill hole a cap of diabase 60 to 100 feet or more thick was penetrated above the metamorphosed sedimentary rocks. From

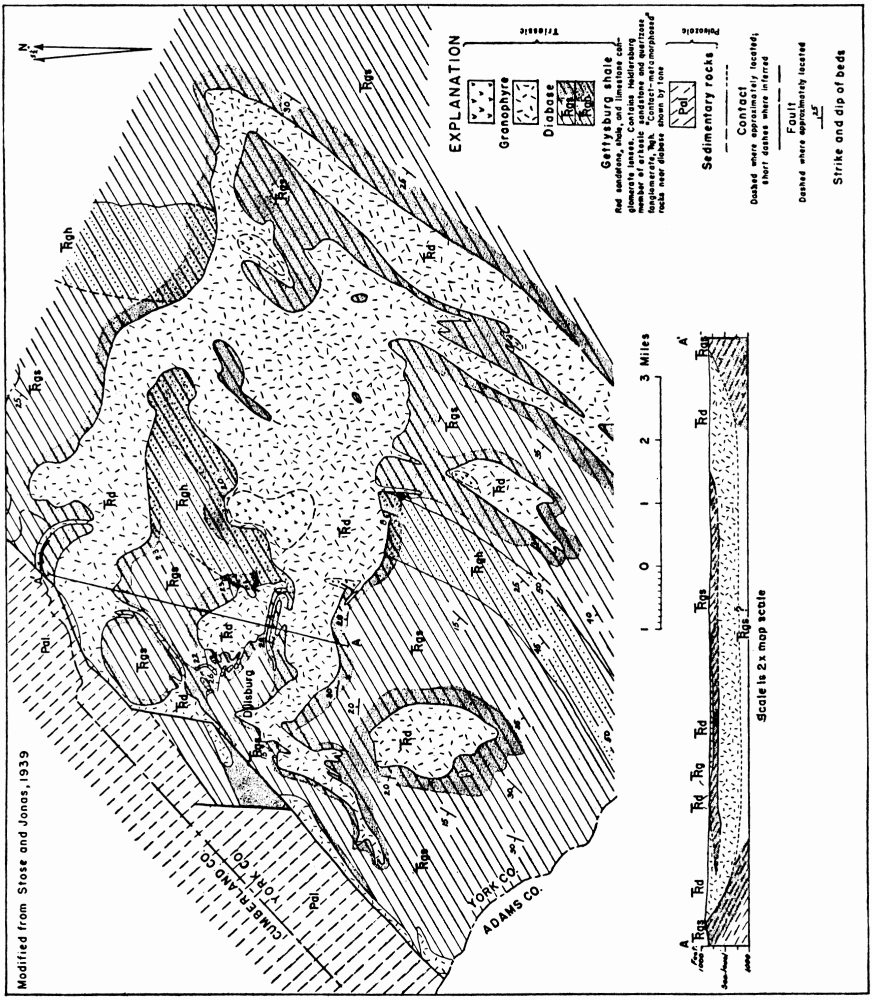

Fig. 2. Geologic map and section of northwestern York County, Pennsylvania.

the structure section exposed by the drill holes (fig. 3) it is evident that the contact of the diabase with the underlying sedimentary rocks is discordant and essentially flat.

Several drill holes encountered a second body of diabase below the sedimentary rocks. This lower intrusive body was not known prior to the drill-hole exploration. Its upper surface, at least within the drilled area, is a discordant, gently undulating surface. One drill hole disclosed granophyre beneath the upper chilled zone of the lower diabase. Similar bodies of granophyre are known to occupy the higher parts of other thick diabase masses in York County and elsewhere in Pennsylvania. It is inferred that this diabase, which is beneath the ore deposits, may be 1,000 feet or more thick.

The upper diabase sheet is almost continuous at its south extremity with the main body of diabase; two narrow strips have been removed by erosion (fig. 3). The diabase sheet overlying the ore deposits undoubtedly was formerly continuous with the body to the south and constituted a minor offshoot. Drill-hole exploration has clearly shown that the lower diabase and the body that crops out to the south are also one and the same (see sec. A-A', fig. 3). Thus, at Dillsburg there is a plate of sedimentary rocks 100 to 500 feet thick between two flat-lying sheets of diabase. The bedding within the plate of sedimentary rocks is discordant with the surfaces of contact of the two diabase sheets.

The structural interpretation favored by the writer is that the diabase beneath the Dillsburg area is part of the same body that surrounds the district and is an offshoot of the Gettysburg sill to the east. It is a broadly concave, platter-like sheet that truncates the gently-dipping sedimentary rocks (sec. A-A', fig. 2).

In the Dillsburg area the sedimentary rocks have been disturbed by intrusion of the diabase. Uplift of the sedimentary rocks above the lower diabase sheet has caused an apparent horizontal displacement of the Heidlersburg member of the Gettysburg shale (fig. 2). A continuous belt of the Heidlersburg member is interrupted by the diabase, and a displaced segment is found in the nearly isolated plate of sedimentary rocks east of Dillsburg. The change of strike of the bedding east and southeast of Dillsburg may also be the result of tilting of the rocks above and adjacent to the intrusion.

The Cornwall District.—The magnetite deposits at Cornwall are situated on the north side of a small ring of diabase 7 miles south of Lebanon, Pa. (fig. 4). The deposits are in a wedge of limestone of Paleozoic age between Triassic sedimentary rocks on the south and diabase on the north. The diabase on the north has been interpreted by Spencer (1908, pp. 19-20) and others as a more or less vertical dike with a thin sill-like offshoot that comes to the surface at the south.

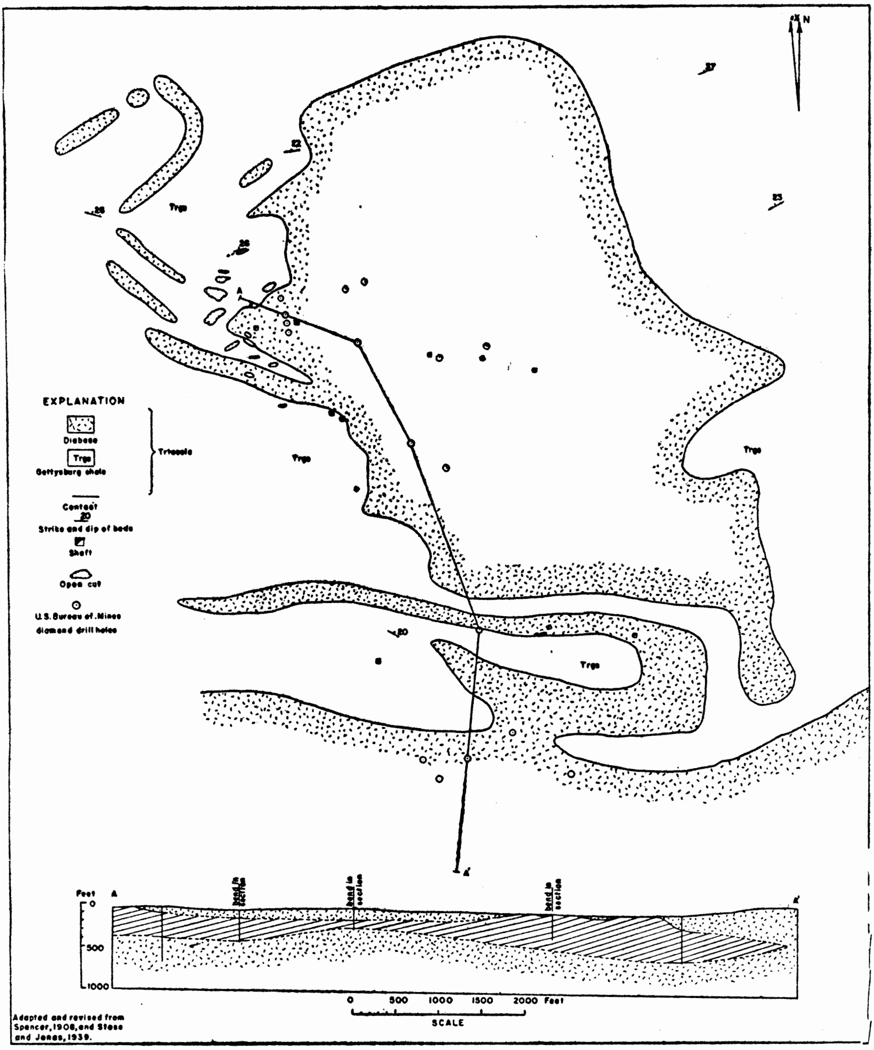

Fig. 3. Geologic map and section of the Dillsburg district, Pennsylvania.

As shown by diamond drilling, the diabase is a sheet about 1,000 feet thick that dips gently south (sec. A-A', fig. 4). Drilling toward the south and the center of the ring, which is occupied by Triassic sedimentary rocks, has shown that the diabase extends beneath the area, and becomes a nearly flat-lying body. The diabase is interpreted as a continuous shallow basinlike structure that is only locally concordant with the structure of the sedimentary rocks.

The Quakertown District.—At Quakertown, about 12 miles southwest of the Delaware River, there is an elliptical body of diabase whose long axis strikes northeast (fig. 5). A gravity survey was made in this area by Hersey (1944). Although at the surface Triassic sedimentary rocks occupy the center of the ellipse of diabase, a gravitational high over the area indicates the presence of diabase beneath a thin layer of sedimentary rocks. The gravitational pattern is symmetrical and conforms to the outcrop pattern of the diabase. The anomaly, according to Hersey, suggests a thickening of the diabase toward the central axis of the structure. Hersey states (1944, p. 439) that "the gravity anomaly could be caused by an intrusive roughly 100 feet thick near its edges and about

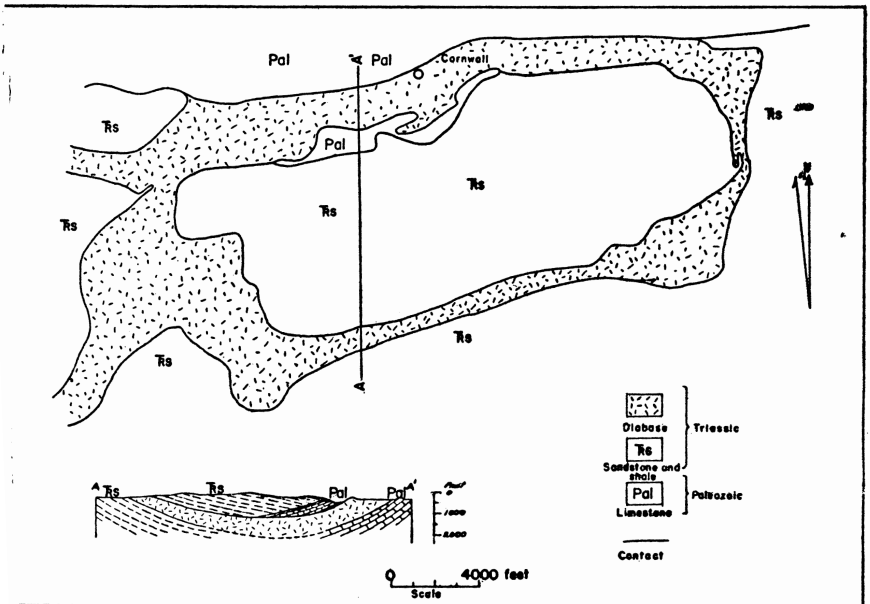

Fig. 4. Geologic map and section of the Cornwall district, Pennsylvania.

1,800 feet thick along its axis." Sections A-A' and B-B', figure 5, illustrate the possible structure of the diabase body as modified from a diagram by Hersey.

The Boyertown District.—The Boyertown magnetite deposits are at the western end of an elliptical ring of diabase,

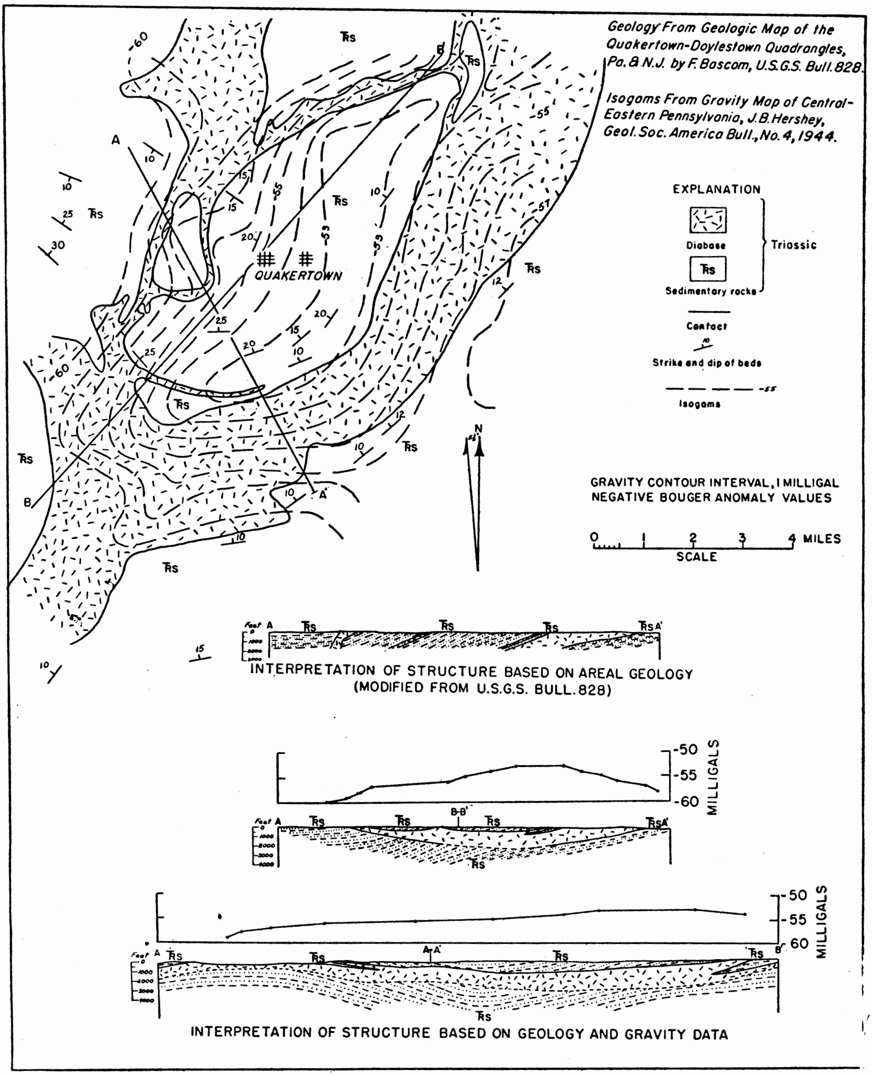

Fig. 5. Geologic map and sections of the Quakertown district, Pennsylvania.

as shown in figure 6. The following discussion is based on an unpublished description by A. F. Buddington and H. E. Hawkes, who studied the deposits and mapped the western part of the elliptical structure.

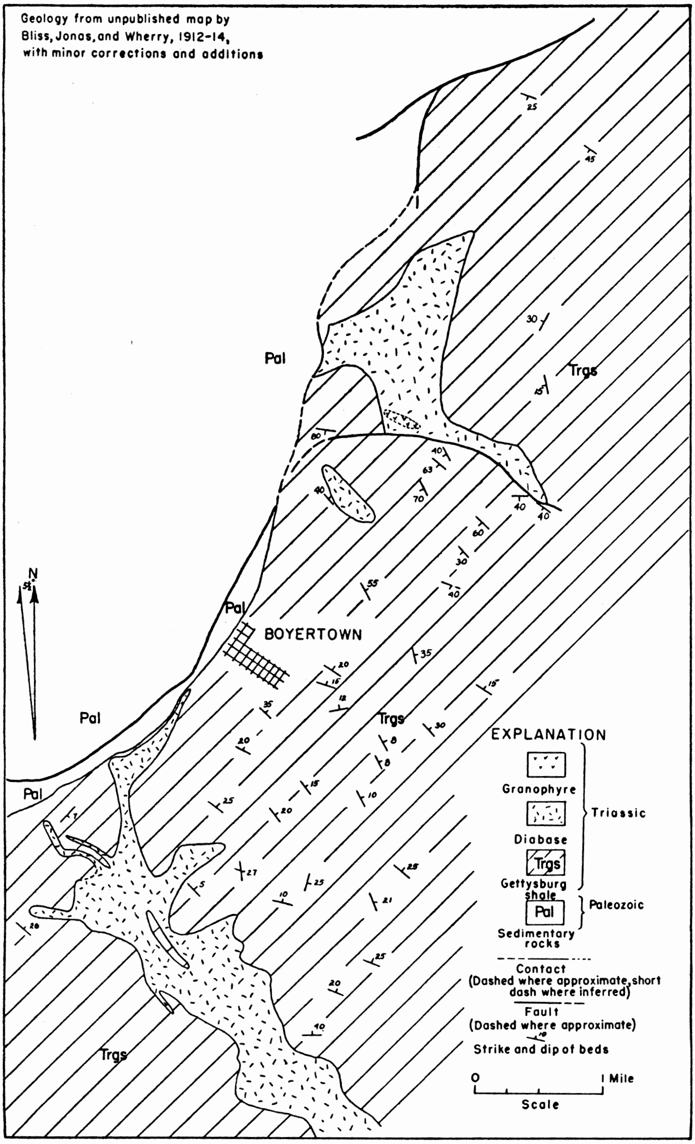

Fig. 6. Geologic map of the Boyertown district, Pennsylvania.

At least the western end, and possibly all, of the diabase ellipse occupies the flanks of a synclinal structure in the Triassic sedimentary rocks. The syncline in the vicinity of Boyertown is asymmetrical, for it dips more steeply on the north limb than on the south limb. The western end of the syncline apparently abuts discordantly against the contact between the Triassic sedimentary rocks and Paleozoic limestones. This contact, where it has been mapped in the couse of mining and exploration of the Boyertown ore bodies, dips 30° to 45° ESE.

The main diabase outcrop is interrupted in two places, leaving a large isolated area of diabase about 2 miles north of Boyertown. It may be reasonably inferred that this diabase body connects at depth with the diabase that crops out to the south and east (figs. 1 and 6) and is an integral part of the major igneous structure. Local exposures of granophyre similar to the exposure at Dillsburg were found near the southwest edge of the isolated body (fig. 6). The position of the granophyre suggests that it is in the upper part of a thick sheet of diabase dipping moderately to the south.

COMPARISON WITH DOLERITE SHEETS OF SOUTH AFRICA

Du Toit (1920), Scholtz (1936), and Walker and Poldervaart (1949) have described dolerite intrusions in the Karroo system of South Africa that are remarkably similar in form to the diabase bodies of southeastern Pennsylvania. Most of the sill-like intrusions are curved sheets whose ". . . outcrops . . . determined chains of hills snaking across the country" (Du Toit, 1920, p. 7). Figure 7, taken from Du Toit's paper, shows the irregular ringlike plan of the outcrop of these intrusions. Almost the exact counterpart is found in figure 1, which shows in plan the diabase bodies of southeastern Pennsylvania. The sheets of East Griqualand and Pondoland studied by Scholtz (1936) are well known because of their associated nickeliferous ore deposits. According to Scholtz many of the sheets are rudely circular in plan and have a basinlike structure with diameters up to 10 miles and thicknesses ranging from 1,000 feet or less to 3,000 feet or more. The sheets have rudely parallel, but markedly undulatory, upper and lower surfaces. Walker and Poldervaart (1949, pp. 605, 608) describe and illustrate undulating dolerite sheets that have pronounced anticlinal rolls as well as syn-

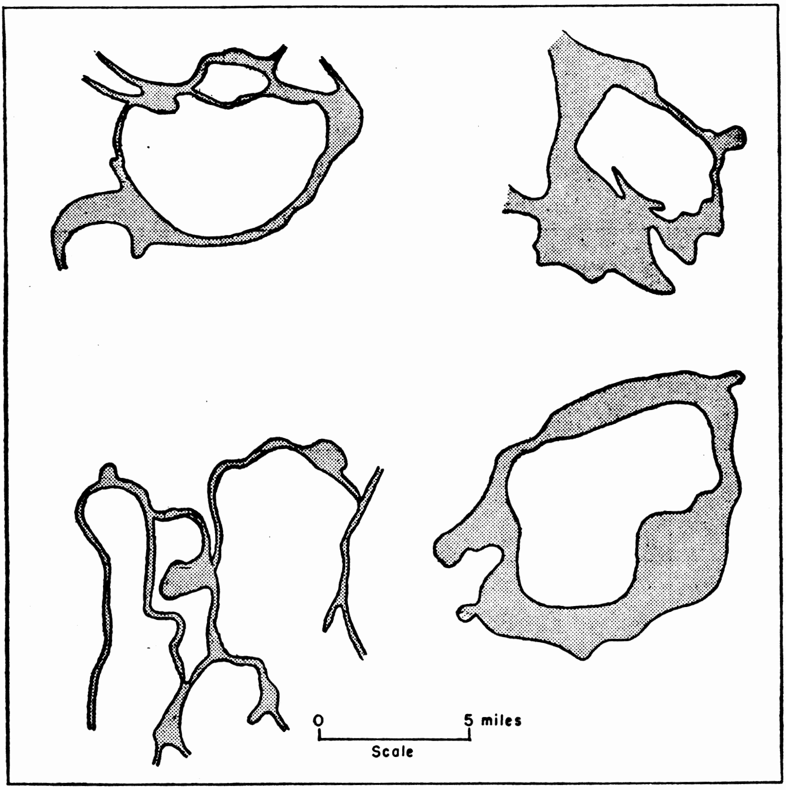

Fig. 7. Types of curved intrusive sheets of Karroo dolerite (stippled) in plan.

clinal or basinlike forms. No real anticlinal structures have been recognized in the diabase sheets in Pennsylvania.

The South African dolerite sheets are discordant intrusions; but, unlike the bodies in Pennsylvania that intruded generally westward-dipping, locally gently folded beds, the sheets in South Africa intruded essentially horizontal rocks.

ORIGIN OF THE DIABASE SHEETS

In this part of Pennsylvania there are few true sills in the usual meaning of the term. The sill east and northeast of Gettysburg apparently fulfills the requirements of the definition, for in most places it is a gently inclined concordant body. The many other bodies of diabase with their elliptical or circular outcrop patterns are in part concordant with the bedding of the enclosing sedimentary rocks but in many places they are discordant. Although the data are not yet complete the information presented above indicates that many if not all of these diabase bodies are continuous beneath a cover of Triassic sedimentary rocks and are basin-shaped. It should be emphasized, however, that in contrast to some of the dolerite sheets described from South Africa no true well-developed anticlinal rolls are found among the diabase sheets in Pennsylvania. The succession of a series of shallow, basin-like bodies suggests that in places, as for example south of Quakertown, the diabase is a continuous sheet because of the intersection of platter-shaped bodies. Erosion has removed some of the cover of sedimentary rocks so that the high parts of the sheet are exposed, giving the effect at the surface of a series of connected links in a chain.

The only form in which diabase intrusions occur in the older rocks that border the Triassic basin of Pennsylvania is as dikes. Perhaps the older rocks with their complex structures were more resistant to the intrusion of the diabase magma, and they restricted its course to a few well-defined, predetermined vertical fractures. In the Triassic sedimentary rocks the invading magma was able to spread laterally and raise its roof.

Diabase dikes occur throughout the Triassic belt as well as in the older rocks of adjoining areas. Some of these dikes may have been the avenues through which magma was fed to the sheets. Some of the sheets may be in part offshoots from larger intrusions. For example, the large body of diabase east of Dillsburg and the sheet beneath the magnetite deposits appear to be offshoots from the Gettysburg sill. Some of the diabase may have risen along fault zones at the northwest border of the Triassic basin.

The mechanism that controlled the basinlike form assumed by these intrusions is not clearly understood. The curved form of the diabase sheets might be interpreted as being due in part to the development of nearly horizontal to gently undulating fractures in the Triassic sediments. These fractures were subsequently filled with magma that crystallized as diabase. Where these fractures were joined, the filling of diabase was continuous. Du Toit (1920, p. 29) suggested that the curving form in the Karroo dolerites ". . . may have been partly or wholly determined under the stresses set up through thermal expansion." Steep fractures, formed during the tilting of the Pennsylvania Triassic basin, probably served as conduits through which the diabase magma rose into the accumulated sedimentary rocks. Perhaps relatively horizontal or basin-shaped fractures were also formed at this time.

Scholtz (1936, p. 202), discussing the mechanism of intrusion of the Karroo dolerites, postulates that the initial stages of magmatic activity resulted in ". . . the extrusion of great quantities of lava at the surface, which eventually consolidated and acted as an effective barrier to the escape of the rising magma, which now penetrated potential lines of weakness developed in the still subsiding sediments." So far as is known there was no thick overburden of lava in the Pennsylvania Triassic basin.

Scholtz pictures ". . . the injection [of magma as sheets] . . . as being of the nature of a mutual exchange of place between the settling sedimentary formations and a concomitant hydrostatically elevated quantum of magma . . ." without causing any arching of the roof. Du Toit (1920, p. 28), on the other hand, considers that introduction of the Karroo sills must have ". . . produced vertical uplift of the overlying strata amounting to the thickness of the intrusion at that point measured vertically." As we have seen in the intrusion at Dillsburg, there is evidence of uplift and disturbance of the overlying sedimentary formation (p. 379).

Probably no actual fractures were necessary for the magma to assume a sheetlike form. It may have been easier for the magma to spread laterally than to rise to higher levels. Under these circumstances the magma could probably make its own way by starting with initial irregularities in the conduit walls or by following potential planes of weakness brought about by tension in the block of subsiding sediments. According to Anderson (1942, pp. 23, 142) the thin edge of an advancing magma sheet has a powerful wedging effect by means of which it is able to advance itself. Du Toit (1920, p. 5) has also suggested that lateral spread may be aided by water vapor released from the sediments as they are heated by the magma.

ACKNOWLEDGMENTS

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