STRUCTURE OF LICK MOUNTAINS, VIRGINIA.

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ABSTRACT. The Lick Mountains are an anticlinal uplift exposing thick resistant Lower Cambrian quartzites in parallel south-dipping plates which are up-thrust on their north sides. A possible solution is suggested.

LICK Mountains are a small isolated group of mountains in the Appalachian Valley that lie about 8 miles north of the main front range of the Appalachian Mountains. The Lick Mountains are 14 miles long and 5 miles wide and are south of Wytheville in Wythe County, Virginia (see Fig. 1). They consist of a mountain mass, called Lick Mountain, and several smaller parallel ridges lying south of the main mountain. The northern part of Lick Mountain culminates near its west end in High Rocks, 3,640 feet in altitude. The southern part of the mountain has a similar high peak 3,543 feet in altitude. Swecker Mountain, which lies south of the higher part of Lick Mountain, has a maximum altitude of about 3,000 feet. Henley Mountain, west of Swecker Mountain, has an altitude of about 3,300 feet, and Sand Mountain, a lower ridge southwest of the west end of Lick Mountain, is about 3,000 feet. These mountains rise 1,000 feet above the surrounding valley, which is part of the Great Valley of Virginia and has a general altitude of 2,400 to 2,500 feet.

General geology.—The rocks of the area are quartzose and carbonate sedimentary rocks of Lower Cambrian age, which are closely folded and faulted. The oldest rocks are quartzites and shales, which are exposed in anticlines and form the mountains. Lick Mountain, the main uplift, is a double anticline divided by a longitudinal synclinal valley. Several ridges that lie south of Lick Mountain are minor anticlines that also expose quartzite. The younger rocks are dolomite, limestone, and shale, which underlie the valley.

The Lick Mountains are part of the Pulaski overthrust block, a great fault slice which is so thin that large windows have been eroded in it, exposing the underlying, much younger rocks. The Pulaski overthrust comes to the surface about five miles north of the Lick Mountains, but a large window in the over-

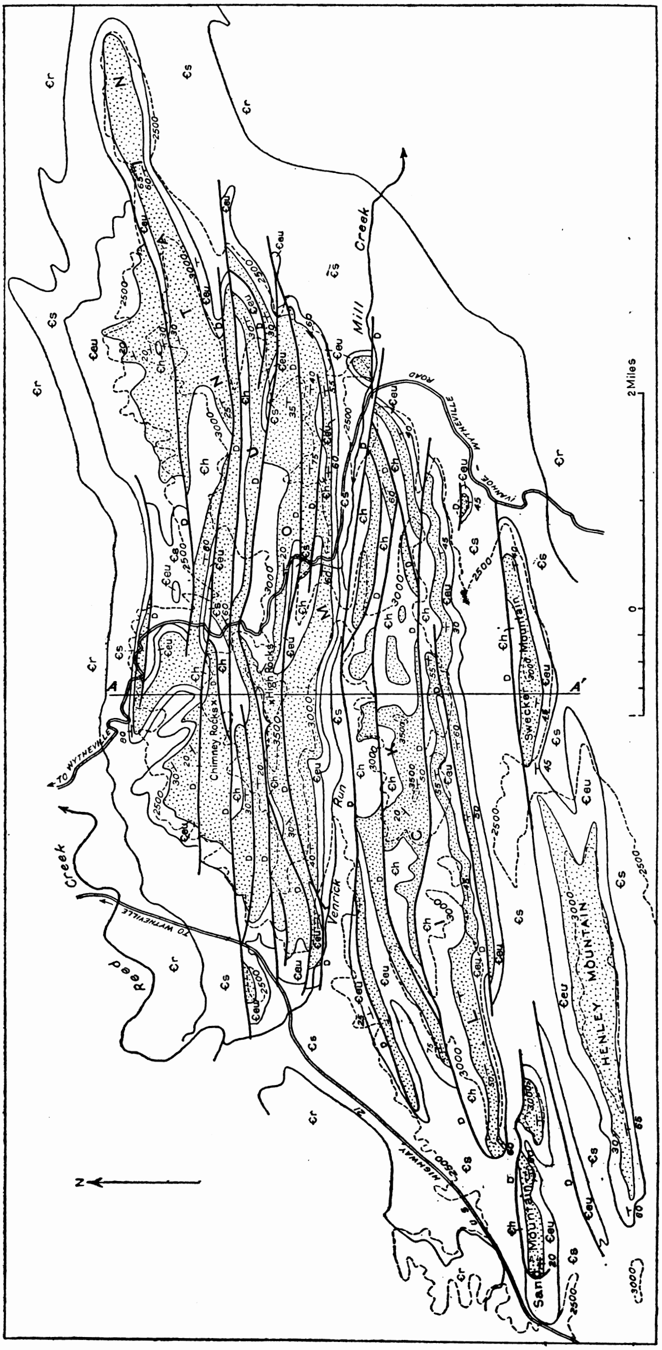

Fig. 1. Geological map of the Lick Mountains, Virginia. Єr, Rome formation. Єs, **Shady** dolomite. Єeu, Upper part of the Erwin quartzite; massive quartzite, stipple pattern. Єh, Hampton shale. Heavy lines, faults; D, downthrow. (From colored geologic map, with minor revision, Pl. 1, Bull. 59, Va. Geol. Surv., 1943.)

thrust is not more than two miles distant, so the thickness of the thrust plate beneath the Lick Mountains cannot be great. The Poplar Camp-Holston Mountain overthrust at the north foot of the front range of the Appalachian Mountains is eight miles south of the Lick Mountains, and other associated thrust faults are only two miles distant. These overthrusts are an indication of the intensity of the compressive force that produced the Lick Mountains uplift.

The formations present in the Lick Mountain area are listed and briefly described in the following table, and their distribution at the surface is shown in Fig. 1.

Sedimentary rocks in the Lick Mountain District.

Age	Formation	Thickness (feet)	Character
	Rome formation	1,000±	Upper member red shales and sandstones. Middle member calcareous shale, blue limestone, siliceous limestone, massive dolomite. Lower member red shale and sandstone, some green shale, and some dolomite.
	Shady dolomite	1,000±	Upper (saccharoidal) member: massive white to light-gray, coarsely crystalline, very pure dolomite. Lower member (Patterson member): dark-blue to dark-gray, banded to knotty dolomite, with blebs of white crystalline calcite.
Lower Cambrian		50-100	Ferruginous laminated fossiliferous coarsely granular to conglomeratic quartzite at top; thin rusty micaceous quartzite and shale below.
	Erwin quartzite	350±	Ridge-making or cliff-making white, vitreous to granular quartzite, generally *Scolithus* bearing; medial bed with fewer *Scolithus* weathers laminated and pitted.
		50±	Thin interbedded quartzite and shale with 5-foot conglomerate bed at base.
	Hampton shale	500+ (Base not exposed)	Argillaceous shale, generally light gray to buff at surface, dark gray when fresh; weathers to buff and rusty shale fragments. Includes some thin scattered quartzite beds and some arenaceous shales. Considerable iron content in upper portion.

The oldest formation exposed in the higher anticlines is the Hampton shale. It is softer and less resistant than the overlying Erwin quartzite and therefore generally occurs on the slopes of quartzite ridges or forms valleys within the mountains. Its outcrops on the steep slopes are largely concealed by quartzite talus and wash. The Erwin quartzite, the most resistant rock in the area, forms most of the mountains. The main part of the formation consists of a very resistant thick-bedded quartzite about 350 feet thick, which crops out in long lines of rocky ledges with prominent cliffs, generally on the north side. The overlying Shady dolomite is readily soluble and forms lowlands around the mountains and narrow valleys within the mountains. Its outcrops near the mountains are largely weathered to yellow or red clay and are mostly concealed by quartzite wash.

The Erwin quartzite is the most important formation in the study of the structure of the area. The main body of the formation is a massive resistant quartzite about 350 feet thick, which acted as a unit and is the competent bed that transmitted the thrust during compression. It is a nearly pure silica rock, some beds of which are so free from impurities that they have been used in the production of silicon metal in electric furnaces. The analyses of selected beds 60 to 80 feet thick, quarried for this purpose by the Sand Mountain Sand Corporation, have the following range in composition.

Analyses of quartzite, Lick Mountain

SiO_2	97.63 – 99.25
Al_2O_3	1.25 – 0.22
Fe_2O_3	.29 – .22
TiO_2	.23 – .13

The geology of the Lick Mountains was surveyed by the writer and Frank Stead of the U. S. Geological Survey during the study of the manganese deposits, and the geologic map, with sections, has been published by the Virginia Geological Survey.*

General structure.—The Lick Mountains are essentially an anticlinal uplift which exposes Erwin quartzite and underlying Hampton shale. The uplift consists of several folds which trend nearly due east and pitch east and west away from the center of the uplift. The main uplift, which forms Lick Moun-

* Stead, Frank, and Stose, G. W.: 1943. Manganese deposits of Lick Mountain, Virginia: Va. Geol. Surv. Bull. 59.

tain, is divided into two parts by a medial synclinal valley which is followed by east-flowing Mill Creek and west-flowing Venrick Run. The northern anticline of the main Lick Mountain uplift is broken by longitudinal faults into many long blocks, each of which is composed chiefly of south-dipping massive quartzite of the Erwin. The Hampton shale is exposed beneath the Erwin on the north side of many of these blocks, and in some of them Shady dolomite, or clay residual from the weathered dolomite, overlies the quartzite on its south side. In the most typical or complete fault blocks the fault separates south-dipping Hampton shale and overlying Erwin quartzite of the block south of the fault from south-dipping Shady dolomite and underlying Erwin quartzite in the block north of the fault. The vertical displacement on these faults is greatest in the center of the uplift and diminishes eastward and westward in the direction of the pitch of the uplift. The faults pass to the east and west into minor folds in the Shady dolomite which borders the uplift. The southern anticline of the main Lick Mountain is broken by fewer longitudinal faults which have similar displacement, and the quartzite in the blocks similarly dips south.

South of Lick Mountain proper, four minor anticlines expose Erwin quartzite, and in places Hampton shale, in Sand, Henley, and Swecker Mountains, and in an unnamed low hill. The quartzites in all of these minor folds, except the Henley Mountain anticline, dip south and are broken on their north sides by longitudinal faults.

The striking structural feature of the Lick Mountain uplift is the repetition of longitudinal blocks of south-dipping Erwin quartzite (see Fig. 2). The quartzite in these blocks dips generally 30° to 60° S., producing south-dipping plates with north-facing cliffs. These long, parallel white quartzite ledges are a striking feature in the landscape. The bounding fault planes are nowhere exposed, but a zone of quartzite breccia marks the fault at many places. Much of the breccia is cemented by manganese oxide (Pl. 4 and Fig. 3, Va. Geol. Surv. Bull. 59) which is the source of most of the manganese ore mined in the area. Slaty iron ore is present in the Hampton shale near fault contacts. The trace of the faults is straight, and the faults are evidently steep, probably nearly vertical, which suggests that they may be normal or tension faults. The Lick Mountain uplift, however, is known to be the result of compression, which produced the broad anticlinorium, with many minor folds at its plunging ends. The longitudinal faults pass into these minor folds and are intimately related to them. The faults were undoubtedly formed at the time of uplift, during the period of compression, and not after the uplift under conditions of tension. Minor folding has been observed in the thinner-bedded quartzites in the upper part of the Erwin,

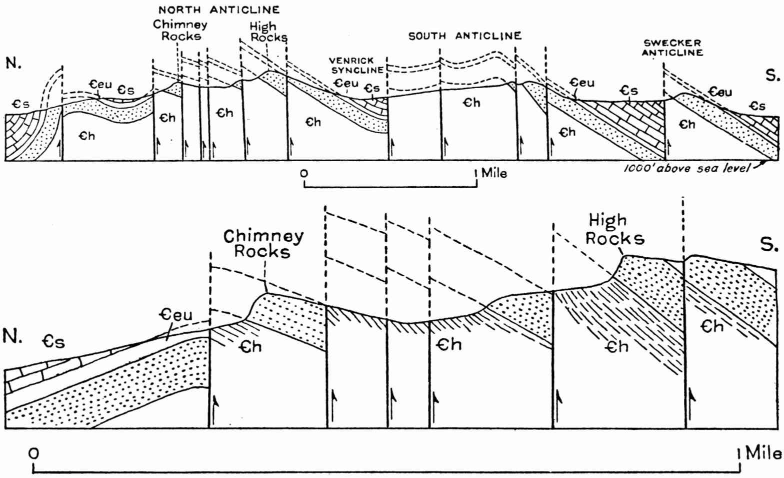

Fig. 2. Vertical sections across the Lick Mountains, Va.
Upper section along line A-A′ on figure 1.
Lower section through Chimney Rocks on larger scale.
Symbols same as those on fig. 1.

but the thick massive quartzite composing most of the Erwin rarely shows folding. The fault blocks are tilted monoclinal plates. The massive quartzite beds seem to have resisted folding and yielded to compression by breaking along nearly vertical planes into longitudinal blocks which were displaced in the doming process. The study of the nature of the faulting and of the mechanics of their structural feature is the chief purpose of this paper.

An examination of the map (Fig. 1) shows that the northern anticline of Lick Mountain has four axes of uplift along which the Hampton shale is exposed. All of these shale areas are broken on their north sides by faults, but the shale exposed on the Wytheville-Ivanhoe road east of High Rocks clearly shows anticlinal structure. The cross section of the mountain (Fig. 2) shows that the fault blocks consist chiefly of south-dipping monoclinal plates of massive Erwin quartzite.

The vertical displacement on the faults between the blocks is greatest near the center of the uplift and diminishes eastward and westward away from the maximum uplift. At the margins of the plunging uplift the softer upper beds of the Erwin quartzite dip gently beneath the overlying Shady dolomite, and have curving strikes, representing minor anticlines. This is best shown at the west-plunging end of the northern anticline of the main uplift, north of Venrick Run (Fig. 3). Here the

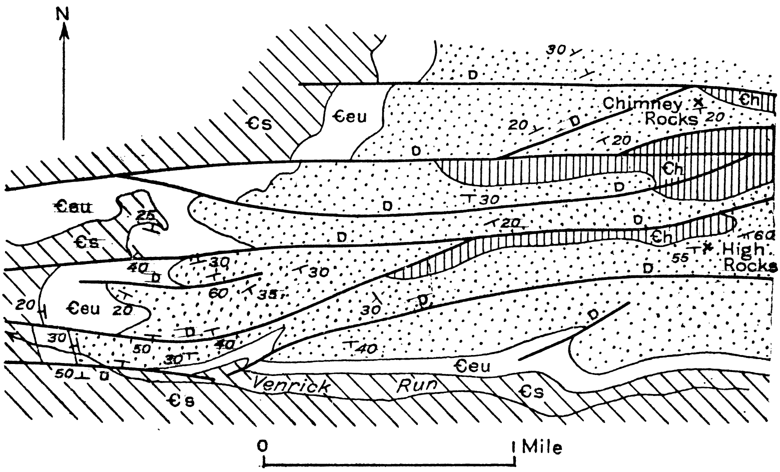

Fig. 3. Map of plunging west end of Lick Mountain, showing dip of beds and faults. Symbols same as on fig. 1.

upper softer beds of the Erwin dip 27°-30° SW. and W. beneath the Shady dolomite in minor folds, which are only slightly displaced by the waning faults. These minor folds die out in the Shady dolomite and do not affect the overlying Rome formation.

The simplest fold in the whole uplift is the Henley Mountain anticline, which is apparently unbroken by faults. The quartzite on the south limb of the fold dips 55° S., and on the north limb 30° N. Eastward the fold is double, and Swecker Mountain is the eastward extension of the northern fold of Henley Mountain. Here the quartzite on the south limb of the fold dips 45° S., and the crest and north limb of the fold are cut out by a fault. The Hampton shale in the center of the uplift is thrust against Shady dolomite to the north. The thick resistant south-dipping quartzite evidently acted as a strut which transmitted the thrust of the compressive force from the south. The steeper the bed is inclined, the greater is the vertical component of the stress. The thick resistant quartzite

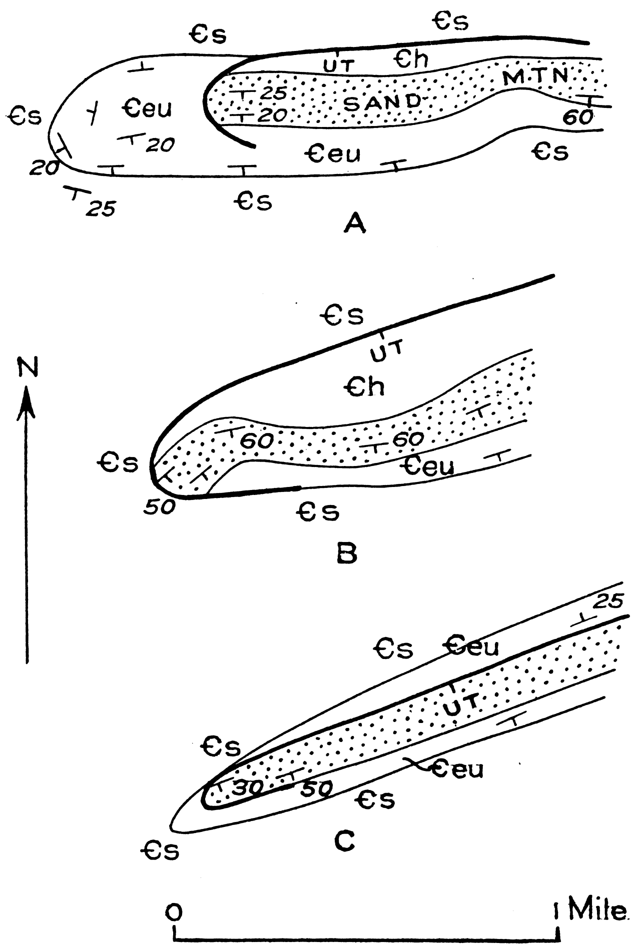

Fig. 4. Detailed geology of plunging west ends of folds.
A. Sand Mountain.
B. Southern ridge of Lick Mountain.
C. Low ridge north of B.
Symbols same as on fig. 1.

yielded to the vertical component of the stress by upthrusting, and the crest and north limb of the anticline are cut out by the fault. This seems to be the typical structure of the numerous fault blocks of the whole uplift.

Detailed structure.—The detailed character of the faulting is best shown at the west end of several of the minor anticlines. In Sand Mountain (Fig. 4A) the massive quartzite of the Erwin which forms the crest of the ridge strikes due west and dips 20°- 60° S. This strike and south dip are maintained to the west end of the mountain, where the massive quartzite is abruptly terminated. The Hampton shale, which is exposed below the quartzite, is faulted against the Shady dolomite in the lowland north of the mountain. At the west end of the mountain this fault swings southward, bevels the Hampton shale, cuts off the massive quartzite across its strike, and ends in the softer upper quartzites of the Erwin. West of the curving end of the fault, the upper softer beds of the Erwin have a curving strike and dip south, west, and northwest, normally beneath the Shady dolomite, forming a symmetrical anticline (Fig. 4A). The Shady dolomite and underlying softer beds of the Erwin were folded into a west-pitching anticline, but the massive quartzite of the Erwin did not fold; these south-dipping hard beds broke on their north side and were thrust upward and northward, breaking through the overlying beds, as is clearly shown at the west end of the fold.

Similar relations may be observed at the west end of the southern anticline of the main Lick Mountain uplift, except that Shady dolomite surrounds the fault at its south-curving west end (Fig. 4B). The massive quartzites which form the crest of the ridge strike west and dips 60° S. At their west end, where the strike of the beds bends southwest, these hard beds are abruptly terminated by the fault. The Hampton shale exposed beneath the quartzite is faulted against the Shady dolomite to the north. The fault curves southward around the west end of the fold where the massive quartzites end abruptly and the fault dies out in the softer beds of Erwin on the south. Again it is seen that the south-dipping massive quartzite was thrust upward on its north side and at its west end. The Shady dolomite which lies west of the curving fault is not exposed and its attitude cannot be determined, but it may be assumed to be anticlinal, for the upper beds of the Erwin on the south side of the uplift dip south beneath the dolomite in normal relation.

Another west-plunging anticline of the Lick Mountain uplift, which lies just north of the one just described, shows similar relations at its west end (Fig. 4C). Here the massive quartzite, which strikes southwest and dips 30°- 50° SE. is cut off

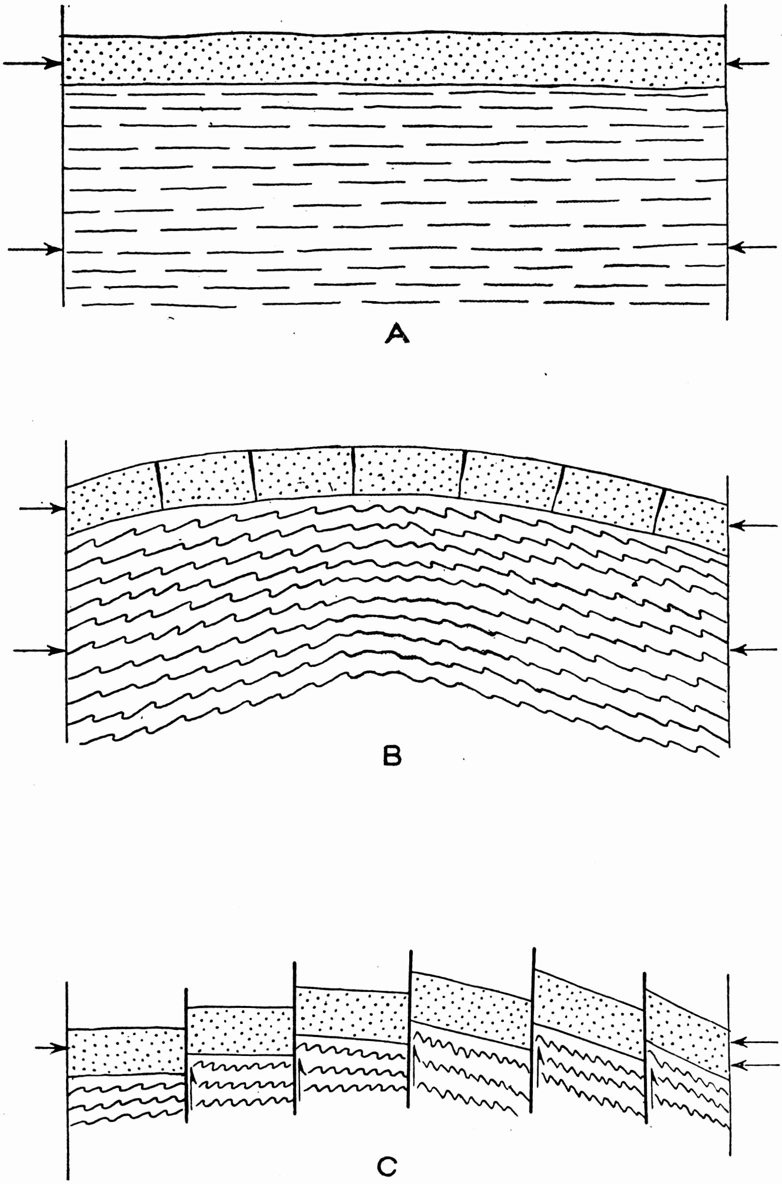

Fig. 5. Diagram showing possible mode of development of upthrusts.
A. Unfolded rocks.
B. Incipient anticline develops tension cracks in upper part of massive quartzite of the Erwin (dot pattern).
C. Tension cracks develop into upthrusts between blocks under pressure from the right.

abruptly at its west end by a curving fault. Hampton shale is not exposed in the uplift, and the displacement is not so great. The south-dipping massive quartzite is thrust over upper beds of the Erwin which dips north beneath the Shady dolomite. At the west curving end of the fault, the upper beds of the Erwin apparently dip normally beneath Shady dolomite in an anticline. Again, the south-dipping massive quartzites in the anticline are thrust upward through the overlying softer beds.

Conclusion.—From a study of the relations shown in the exposures just described, it is evident that the south-dipping massive quartzite beds of the Erwin have been broken on their north sides and have been punched upward through the overlying softer quartzite and Shady dolomite. The movement seems to have been an upthrust on a nearly vertical plane. It is suggested that the process of faulting may have resulted in the following manner.

The rocks of the area yielded to compression by folding, and the massive quartzites at first rose in broad gentle anticlines. Tension developed in the upper beds of the thick massive quartzites on the crests of the anticlines and tension cracks formed at right angles to the direction of stretching and parallel to the axis of uplift (see Fig. 5). These cracks eventually broke the mass into great linear blocks parallel to the axes of the folds. The thick massive quartzites resisted close folding and yielded to further compression by movement of the blocks along these fractures produced by tension. The dominating pressure from the south was transmitted along the inclined resistant bed, and the vertical component of this force caused the north side of the block to rise, increasing the southward dip of the bed and upthrusting the tilted plate of quartzite through the overlying softer beds (Fig. 5). The displacement on these faults was greatest in the center of the uplift and diminished away from the center, and these faults passed into pitching folds in the overlying softer quartzite and Shady dolomite on the margins of the uplift.

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