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STRUCTURE AND ORIGIN OF TWO WINDOWS EXPOSED ON THE NITTANY ARCH AT BIRMINGHAM, PENNSYLVANIA

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ABSTRACT. There are two windows located on the axis of the southern end of the Nittany arch of central Pennsylvania. The windows are named the Birmingham window and the Knarr window.

The formations exposed within the windows are overturned, and have been graben faulted. The thrust which bounds the greater part of these two windows is low angle only within the area of the windows, and terminates very rapidly southwest of the windows.

The present interpretation of the structure of the windows differs from former interpretations. It is believed that local synclinal folding and faulting were the major factors in the development of the present structure. This was later covered by a thrust of relatively small stratigraphic displacement.

INTRODUCTION

IN the area surrounding the town of Birmingham, Pennsylvania, and along the Birmingham fault, two unusual windows (fensters) are exposed. Birmingham is located within the Tyrone quadrangle of central Pennsylvania, two and one-half miles southeast of Tyrone.

The region mapped is twenty-four miles long and an average of three and one-half miles wide. The location of the area and the surrounding topographic quadrangles are shown in figure 1.

The first geological work in this region was undertaken in the summer of 1841 by Harvey B. Hall, an assistant geologist of the First Pennsylvania Survey. In the summary report of the first survey H. D. Rogers (1858, pp. 503-504) included a section along the Little Juniata River from Union Furnace northwest to the town of Birmingham. It was in this report that the presence of a fault at Birmingham was first noted.

In 1881 Franklin Platt (1881) published a report of the geology of Blair County, and in 1885 J. P. Lesley (1885) published a report on Huntingdon County. These reports represented the work of the Second Pennsylvania Survey. It was the opinion of these men that there was no major faulting at Birmingham.

No further work was done until the first decade of the twentieth century when Charles Butts mapped the Tyrone quadrangle. He realized for the first time that the rocks exposed

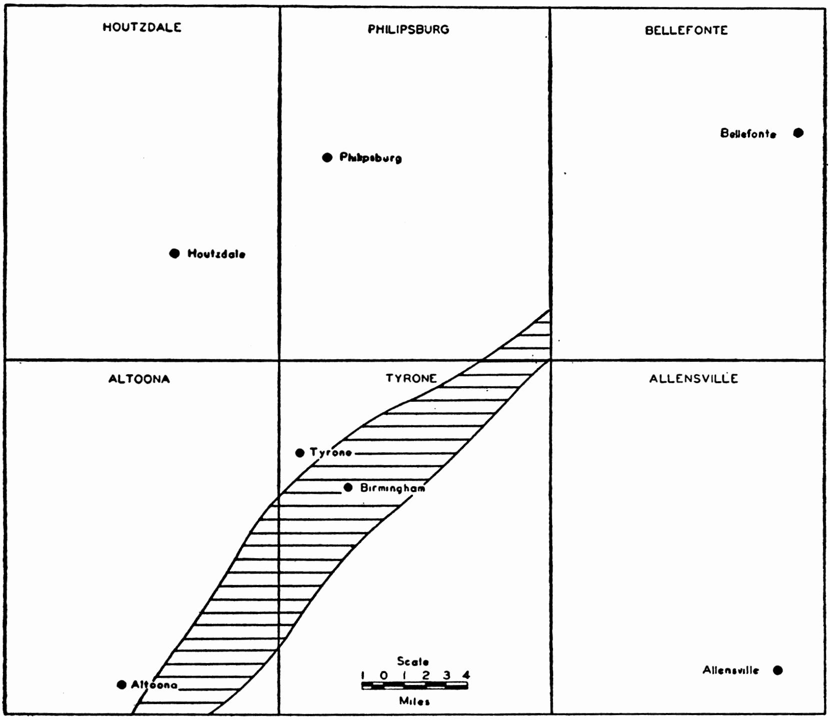

Figure 1. Area mapped (lined) in relationship to the 15′ quadrangles of central Pennsylvania.

at Birmingham were not of Cambrian age, but rather represented the Carlim- Tuscarora sequence of the upper Ordovician and lower Silurian. He (Butts, 1918) further noted that the beds at Birmingham were overturned.

It was not until Butts (1939) published his Tyrone quadrangle report that a second window, two miles northeast of Birmingham, was mentioned.

In the summer of 1947 the writer spent one week on reconnaissance of the general geology of the Birmingham region; and in the summer of 1948 eight weeks were spent in the field. Topographic maps were used as a base for mapping the area outside the two windows; but within the windows it was necessary to use a base map of a larger scale. For detailed mapping, aerial photographs on scales of one to sixteen hundred and sixty-seven and one to one thousand were used.

It is interesting to note that no windows, except the two in the Birmingham area, have been reported in the northern section of the folded Appalachian province.

STRATIGRAPHY

The first detailed stratigraphic section of the formations mapped in the Tyrone quadrangle was published by Butts (1918). This was revised in his paper on the Tyrone quadrangle (1939). Later, G. M. Kay (1944) published the results of a detailed study of the middle Ordovician of central Pennsylvania. The detailed description of the formations of these groups will not be repeated here as it is covered in the papers mentioned above.

The Chazy and Black River are undistinguishable within the windows as these beds are brecciated to such an extent that only the gross lithologic relationships can be determined. It is possible to distinguish the Trenton from the Chazy and Black River, because the Trenton is darker and thinner. The basic difference between the two sections of Butts and Kay is the position of the boundary lines (Table 1), which was largely determined by the fauna. In working out the structure of the southern end of the Nittany arch these

TABLE 1
Comparison of published sections of Chazy, Black River, and Trenton stages.

<table>
<tr><th colspan="3">Butts (1939)</th><th colspan="3">Kay (1944)</th></tr>
<tr><th>Formation</th><th>Thickness (in feet)</th><th>Stage</th><th>Formation</th><th>Thickness (in feet)</th><th>Stage</th></tr>
<tr><td rowspan="2">Reedsville</td><td rowspan="2">1100</td><td rowspan="2">Eden</td><td>Reedsville</td><td>——</td><td>Eden</td></tr>
<tr><td>Antes</td><td>400</td><td rowspan="4">Trenton</td></tr>
<tr><td rowspan="2">Trenton</td><td rowspan="2">500</td><td rowspan="2">Trenton</td><td>Coburn</td><td>300</td></tr>
<tr><td>Salona</td><td>200</td></tr>
<tr><td>Rodman</td><td>30</td><td rowspan="3">Black River</td><td>Nealmont</td><td>150</td></tr>
<tr><td rowspan="2">Lowville</td><td rowspan="2">337</td><td>Curtin</td><td>140</td><td rowspan="2">Black River</td></tr>
<tr><td>Benner</td><td>40-200</td></tr>
<tr><td rowspan="2">Carlim</td><td rowspan="2">250</td><td rowspan="2">Chazy</td><td>Hatter</td><td>70-110</td><td rowspan="2">Chazy</td></tr>
<tr><td>Loysburg</td><td>50-80</td></tr>
</table>

differences are negligible. It was found expedient, therefore, to follow Butts' classification since his formation names are used on the only published areal geological map of the Tyrone quadrangle.

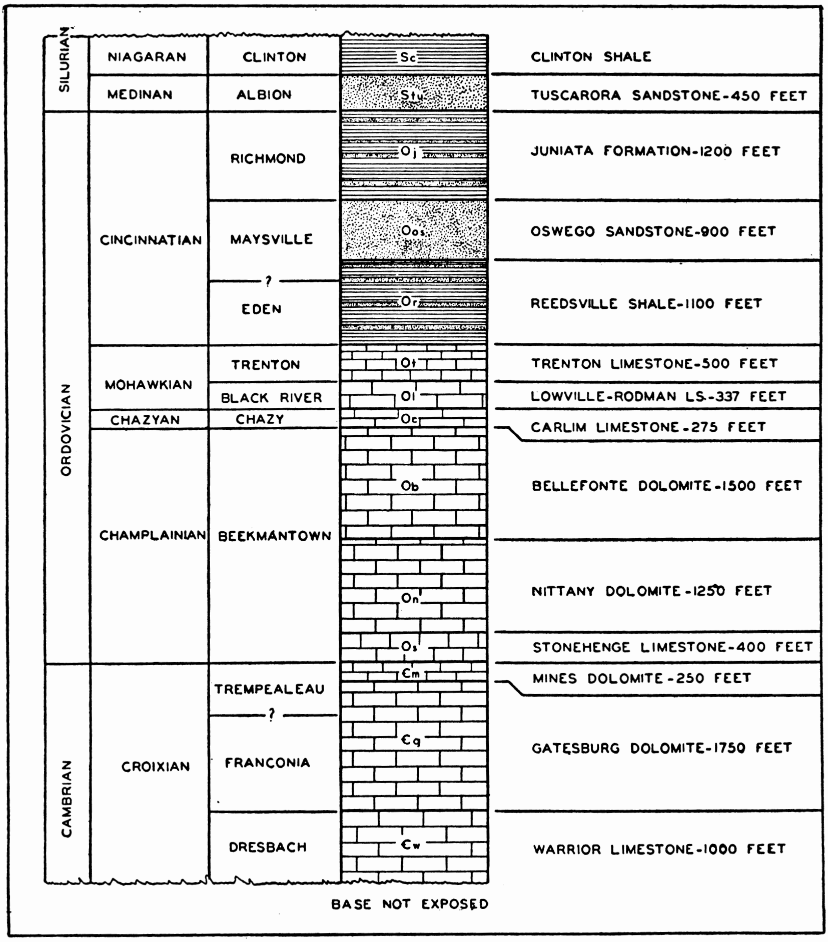

Figure 2. Stratigraphic section of rocks exposed on the south end of the Nittany arch (modified after Butts, 1938).

Figure 2 is a stratigraphic section of the formations as mapped in this paper.

STRUCTURE

The Nittany Arch. The last great westward structure of the folded Appalachians is the Nittany arch. To the northwest are the minor folds of the Allegheny plateau; and southeastward the folded Appalachians extend for fifty-three miles to the Piedmont Province. This arch, which really is an anticlinorium, extends from Altoona to Muncy, ten miles east of Williamsport, a distance of 110 miles. Across the strike it reaches from the Allegheny escarpment, northwest of Tyrone, to the Broad Top syncline southeast of Huntingdon, thus having a minimum width of twenty-six miles.

The Nittany arch has a consistent northeast-southwest strike throughout its length. Where the arch dies out by plunging to the northeast, the trend of the Appalachian folding swings through a major change of some 40° to the east. The plunging to he northeast, the trend of the Appalachian folding the Sinking Valley anticline (fig. 3). The axis may be considered to extend from north of Warriorsmark to seven miles south of Altoona, a distance of more than twenty-five miles. This anticline is asymmetrical, dips on the southeast flank averaging 25° to 35°, whereas the beds on the northwest flank are at first overturned to the southeast, then vertical, and gradually flatten out to the northwest. Along the Allegheny escarpment the dips are 15° or less to the northwest.

The Birmingham Fault. The south end of the Nittany arch is broken by the Birmingham fault. This fault lies along the axis of the arch, extending from one mile northeast of Culp to four miles southwest of Bellefonte, a distance of some thirty miles. Figure 3 shows the southern nineteen miles of this fault.

From the vicinity of Warriorsmark northward it appears to be a fairly high angle fault. Although no dip was obtained in the field, the trace of the fault plane through irregular topography indicates that it dips 40° to 50° to the southeast. North of Warriorsmark, where the upper Warrior limestone is thrust against the Stonehenge, the stratigraphic throw is about 1800 feet. At Stormstown, more than eight miles farther northeast, where the upper Warrior is thrust against the lower Nittany dolomite, the stratigraphic throw is about 2000 feet.

In the vicinity of Birmingham the fault is folded, as shown by the windows, and the dip is much lower and variable. At Birmingham the fault is exposed along a railroad cut (pl. 1, fig. 1). The local dip at this exposure is 15° to the southeast.

The fault here forms the southeast frame of the Birmingham window, and the stratigraphic throw is a minimum of 5000 feet. One and one-half miles southwest of Birmingham the Stonehenge is thrust over the lower Nittany, and the stratigraphic throw is less than 1000 feet. Beyond this point the throw decreases rapidly, and five miles south of Birmingham the fault is no longer evident.

The Birmingham Window. Along the top of the Nittany arch, an area of overturned formations at Birmingham was described by Butts (1939), and it is here named the Birmingham window. This window is about one mile long and half a mile wide (fig. 4). It is surrounded by the Gatesburg dolomite except for about 2000 feet along the northwest edge, where the Stonehenge limestone and the Nittany dolomite form the boundary.

A section along the main highway from southeast to northwest begins just southeast of the axis of the arch in the Gatesburg dolomite, which is dipping 10° to the southeast (fig. 5), section A-A^1, and fig. 4). Here the Birmingham fault (fault 4, figs. 4 and 5) has thrust the Gatesburg dolomite over the Carlim limestone, and forms the south frame of the window. The Carlim is then exposed for 1200 feet. Since it is impossible to distinguish between the Carlim, Lowville and Rodman, because of folding and shattering, all the massive limestone within the window is mapped as Carlim. The Carlim-Trenton contact appears to be normal, although the beds are upside down with the Carlim lying above the Trenton. The Trenton has been highly folded, and it is impossible to obtain a dip that has much significance throughout the 250 feet which it covers. At the most, only 125 feet of the original 500 feet of the Trenton is present. The contact between the Trenton and the Oswego sandstone is a fault contact. This fault (fault 3, figs. 4 and 5) has cut out the remaining Trenton, the Reedsville shale, and part of the Oswego: thus having a minimum stratigraphic throw of 1750 feet. There is 200 feet of Oswego sandstone exposed dipping about 45° to the southeast; thus only 140 feet of the normal thickness of 900 feet of the Oswego is present. The last twenty feet of Oswego is covered, but the contact between the Oswego and the Juniata formation must be assumed to be a fault (fault 2a, figs. 4 and 5) as the normal thickness of the Juniata is

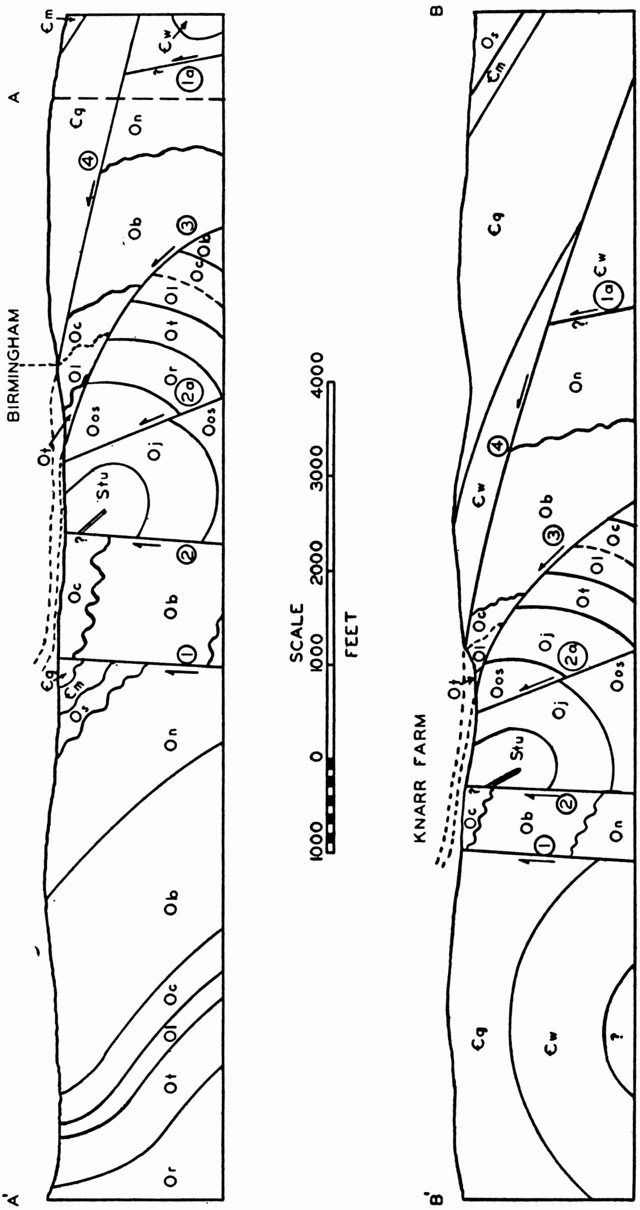

Figure 5. Geologic structure sections of Birmingham and Knarr windows, along lines A-A′ and B-B′ of figure 4. Faults numbered as in figure 4. For formational symbols see figure 2.

not present. There is 300 feet of Juniata exposed, and here the first significant dips may be taken. The Juniata dips 45° S. 40° E. Thus only 210 feet is left of the normal Juniata thickness of 1200 feet. The contact between the Juniata formation and the Tuscarora sandstone is gradational and normal. The Tuscarora dips 45° S. 40° E. The width of its outcrop is 480 feet, and, therefore, only 330 feet of the original 450 feet is exposed.

The window thus contains a sequence of overturned younger beds, all of which have been greatly reduced in thickness by shearing.

Bed rock is covered for the next 1200 feet by the flood plain of the Little Juniata River. This covered zone is terminated by outcrops of the Carlim limestone, just southeast of the Bald Eagle Water Co. pumping station. Here 50 feet of Carlim is exposed. The sequence of formations within the Knarr window, one mile to the northeast, indicates that this covered area may be underlain entirely by Carlim limestone, and it has been so mapped. If this is true the Tuscarora-Carlim contact is a fault (fault 2, figs. 4 and 5). This Carlim is the last formation within the window, and it is thrust against the upper Gatesburg.

Continuing northward along the highway, the Mines dolomite, Stonehenge limestone, and Nittany dolomite are all found in reverse sequence. The dips are to the southeast although, because of local folding, it is not possible to obtain a significant reading. The dip of the Nittany near the Nittany-Bellefonte contact is 35° S. 30° E. The Bellefonte is also overturned, and the reverse dip at about the center of the formation is 30° S. 45° E. From this point northwestward the beds slowly right themselves. The Carlim and Trenton still maintain a reversed position, the Trenton near the Reedsville contact dipping 75° S. 30° E. The Tuscarora beds are vertical at Tyrone.

Another important section through the Birmingham window is along the railroad cut of the Pennsylvania Railroad. This section is southwest of the river and roughly parallel to the main highway. Although the distance between these two sections averages only 300 feet, there is a surprising difference in the beds exposed.

The Birmingham fault appears along the railroad cut 1600

Plate 1, figure 1. Birmingham fault exposed along the main line of the Pennsylvania R. R. 1600 ft. south of Birmingham Station. The Gatesburg (dark colored) is thrust over the Carlim. View looking southwest.

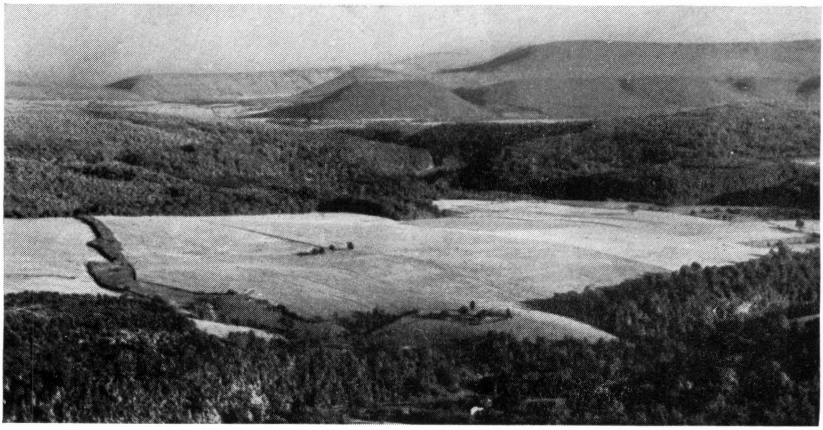

Plate 1, figure 2. The Birmingham window (center) from Bald Eagle Mountain looking across the Nittany arch to the southeast.

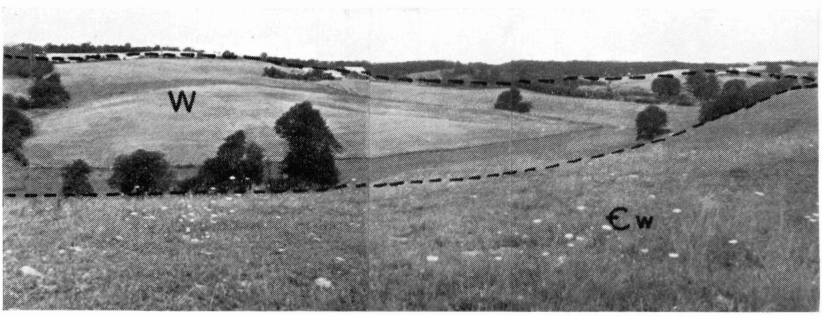

Plate 1, Figure 3. The Knarr window looking north. The Warrior limestone forms the ridge in the foreground. The dashed line is the boundary of the window.

feet southeast of Birmingham Station (pl. 1, fig. 1). Here, the lower Gatesburg is thrust over the Carlim, and the local dip of the fault plane is 15° to the southeast. Along the railroad northwest from this fault exposure there is 2850 feet of Carlim limestone. It is impossible to obtain significant dips within this distance as the Carlim has been badly folded and smashed. This Carlim cuts across the strike of the Oswego-Juniata-Tuscarora sequence observed in the section along the highway. That is, the Oswego-Juniata-Tuscarora sequence does not cross the river since it has been cut off by fault 3.

A small amount of Trenton limestone, less than 200 feet, appears before fault 3 is reached. Since the Carlim here again overlies the Trenton, it would seem that all the Carlim is overturned. The rest of the section along the railroad corresponds to the section previously described along the highway.

The Birmingham fault (fault 4) and fault 3 are flat, low angle, southeasterly dipping thrusts and are closely related in origin. An altimeter survey of the outcrops of these two faults shows that they have been folded (fig. 6). In the northeast portion of the Birmingham fault (no. 4) between eleva-

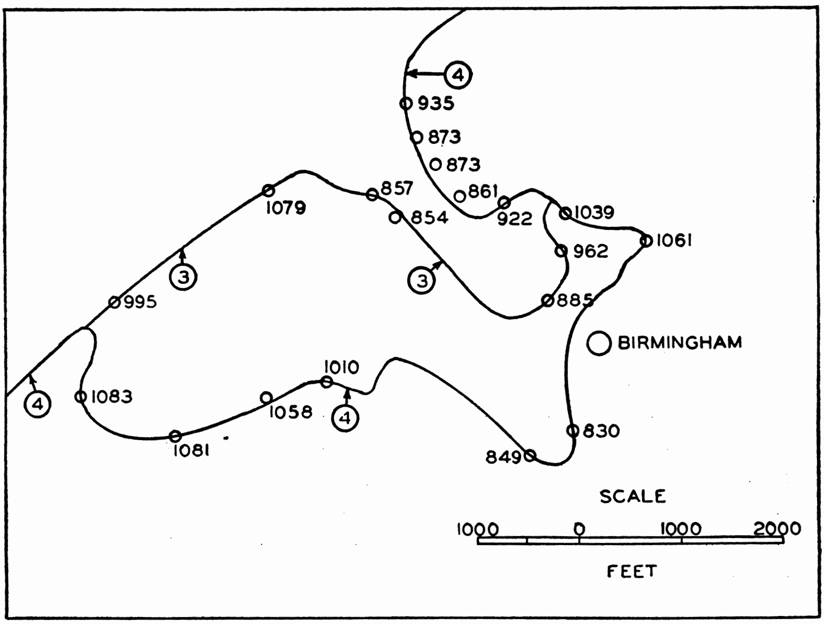

Figure 6. Elevations on the outcrops of faults 3 and 4 at Birmingham.

tions 1061 and 861 there is a reversal of the dip of the fault plane. The lower thrust (no. 3) has no complete reversal, but between elevations 855 and 857, a distance of 1900 feet, the dip of this fault is almost flat. However, between 857 and 1079, a distance of only 1100 feet, there is a marked southeast dip. Therefore, both of these thrusts have been warped by subsequent folding.

Fault 3, the lower of these thrusts, forms the greater portion of the northwestern border of the window. The rest of the window is bounded by fault 4, except for about 1000 feet bounded by fault 1. Actually the structure is a semi-window, rather than a true window, since no one fault completely surrounds it.

Faults 1, 2, and 2a are all high angle faults as shown by their outcrop patterns. Although there is no field evidence as to their direction of dip, they are thought to be high angle reverse faults.

The Knarr Window. A little over a mile northwest of Birmingham, along the axis of the Nittany arch, a smaller window is exposed. It covers an area 3800 feet long and 1900 feet wide. Since the Knarr farms lie near the center, it is here named the Knarr window (fig. 4 and pl. 1, fig. 3). The Gatesburg and Warrior formations enclose the window and the Birmingham fault (fault 4) bounds two-thirds of it. The northwest side is framed by fault 1.

The Knarr and Birmingham windows are very similar. The same sequence, and also about the same thicknesses, of formations are found in both windows. Moreover, all of the faults are present in both windows. The faults in the Knarr window are numbered the same as their counterparts in the Birmingham window (figs. 4 and 5).

Two apparent differences in the exposures of the two windows should be noted: fault 3 is exposed for only 1000 feet along the southeastern edge of the Knarr window; and much less Carlim is exposed in the Knarr window than in the Birmingham window. These apparent differences are thought to be the result of greater warping of the fault planes of the two low angle thrusts (no. 3 and no. 4) in the Birmingham window, together with a greater amount of erosion of that window. Actually, there are no basic differences between the two windows, and they are merely separate exposures of the same fundamental structure. Therefore, where field evidence was missing in one window it was supplied from better exposures of the same sequence within the other window.

ORIGIN AND DEVELOPMENT OF THE STRUCTURE OF THE SOUTHERN END OF THE NITTANY ARCH

The Nittany arch is the westernmost fold of the northern Appalachians and is one of the largest structures of this province. To the west of this arch the beds of the Allegheny plateau are only slightly disturbed by folds of an entirely different nature. Price (1931) discussed the effect of a regional inherent weakness in the geosyncline as a controlling factor in the location and development of this arch. Even though it is over one hundred miles long and better than thirty miles wide, it is an overturned fold with some of the beds on the northwest flank dipping approximately the same direction and amount as those on the southeast flank. This fact places a large overturned syncline between the axis of the Nittany arch and the Allegheny escarpment to the west.

Along the crest of the Nittany arch is the Birmingham fault. This fault, except for the complicating factors exposed within the two windows, is a rather small thrust which has broken the arch at about its axis. At Stormstown (fig. 3) the stratigraphic throw of the Birmingham fault is about 2000 feet, and at Warriorsmark it is about 1800 feet. With the exception of the exposures within the windows, the throw decreases southwest of Warriorsmark until the fault disappears in Sinking Valley, along the plunge of the fold.

Within the two windows, the throw of the Birmingham fault suddenly increases to a maximum of some 8000 feet. However, as shown above, this fault is a relatively small thrust throughout the greater part of its length. Therefore, the problem is: Why does the Birmingham fault suddenly greatly increase its throw within the windows? The causes which brought this about should probably be local.

The extent of the structure within the windows may be related to two local peculiarities in this part of the Nittany arch. The first is the change of the Birmingham fault from a high angle to a low angle thrust in the area within and between the windows. The second is a bulge of the west flank of the Nittany arch to the northwest of about a mile. This departure

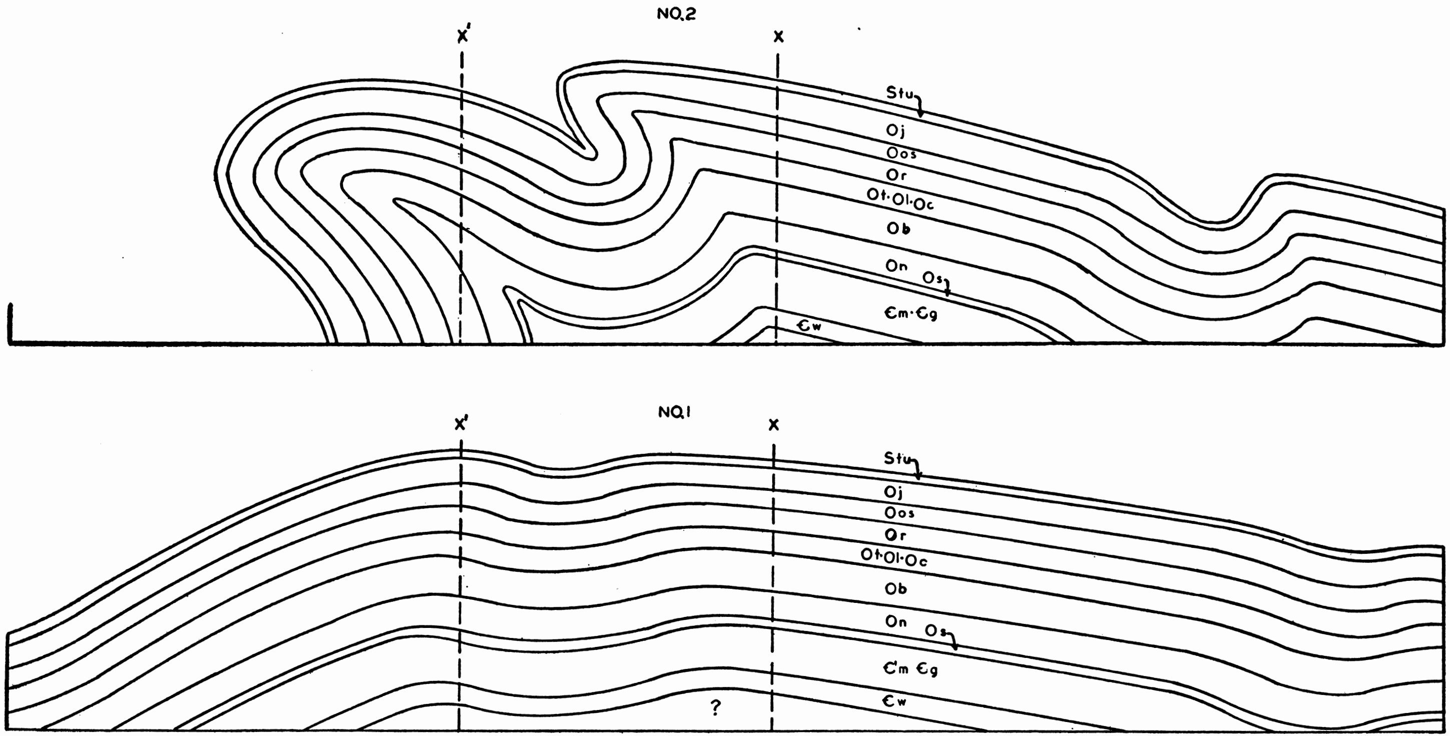

Figure 7. Schematic structure sections along line A-A′, fig. 4, showing first two stages in the development of the Birmingham and Knarr windows. For formational symbols see figure 2.

from the usual trend is partly caused by the strike slip displacement along a small transverse fault (see fig. 2). The bulge is limited to that portion of the flank opposite the windows. It would seem, therefore, that the conditions which brought about the structure exposed within the windows are of a local nature.

Development of the Windows. It is suggested that early in the development of the Nittany arch a local syncline was formed near the crest of this large arch (fig. 7, no. 1). This small syncline was overturned before it was faulted (fig. 7, no. 2), and its southeast flank is the Oswego-Juniata-Tuscarora sequence within the windows. It should be noted that the degree of overturning is the same as that of the major syncline between the axis of the Nittany arch and the Allegheny escarpment (both dip 35° to 45° S. 35° to 45° E.). Since this small syncline disappears southwest of Birmingham, it must plunge to the northeast, which is counter to the plunge of the Nittany arch. The resulting torque should have sheared and weakened the flanks. They failed, and a fault trough was formed. The bounding faults are thought to be high angle reverse faults as the graben was developed under active compression (fig. 8, fault 1 and 1a). At about the same time a smaller graben was formed within the larger graben (fig. 9, no. 4, faults 2 and 2a). Although for clarity these grabens are shown as though they developed separately, it is thought that they formed at about the same time. The faulted syncline was later overridden by two low angle thrusts (fig. 9, no. 5, faults 3 and 4). Fault 3 forms the base of a lower plate and is the older. The Birmingham thrust (fault 4) is the youngest and completely overrode the entire sequence. The thrusts were then slightly folded, and subsequent erosion has exposed the windows and uncovered the underlying structure.

Within the area of the two windows the strong rocks, the Oswego and Tuscarora sandstones, caused the Birmingham thrust to ride up and then across at a low angle. Outside this area, however, where the local syncline and infolded sandstones are not present, the sheet rode up against less interference. The change in the character of the Birmingham fault from high to low angle is paralleled by the change in trend of the west flank of the Nittany arch previously mentioned.

In lower Sinking Valley the Carlim and the Trenton forma-

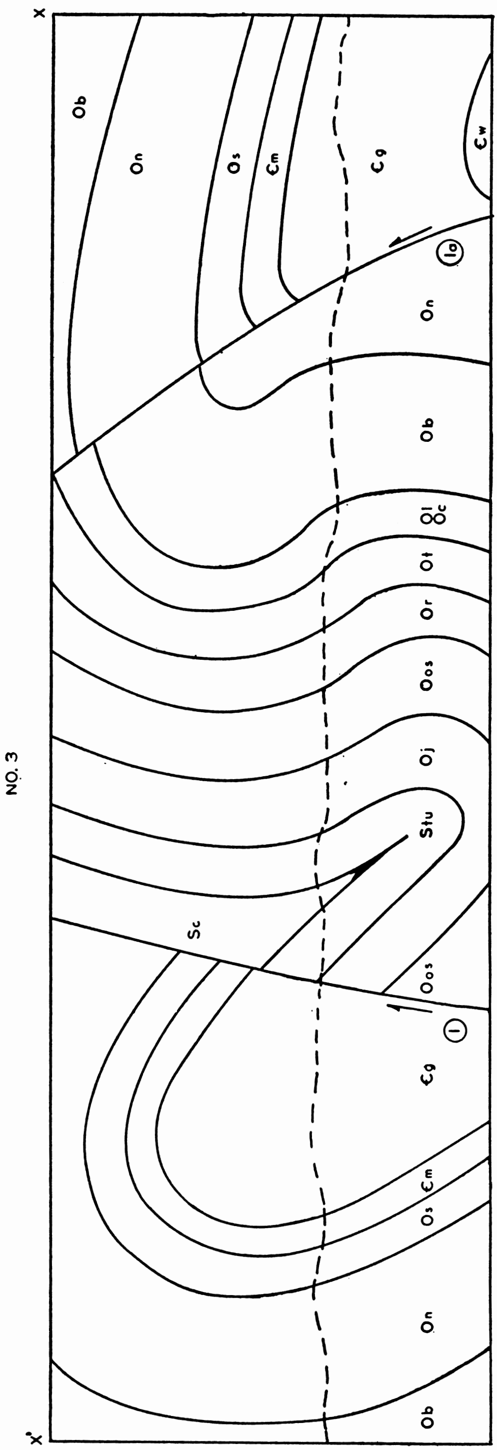

Figure 8. Schematic structure section along line A-A', figure 4, showing third stage in the development of the Birmingham and Knarr windows. Note change of scale from figure 7. For formational symbols see figure 2.

tions have been brecciated, jointed and veined, even though there is no displacement of the Carlim-Bellefonte contact. This fracturing reflects the final absorption of the major faulting present at Birmingham. Sphalerite and galena mineralization is scattered throughout lower Sinking Valley, and is also present in the fracture zones within the windows. This mineralization has been structurally controlled and reflects the effect of major faulting at depth.

Comparison of Present Interpretation with Previous Interpretations. In Butts' paper (1939) two separate interpretations are set forth. The first of these is Butts' own interpretation which includes both a discussion and a structure section (fig. 10, upper section), and the second an alternative interpretation by G. W. Stose (fig. 10, lower section). Stose's section is based upon field data furnished him by Butts. At the conclusion of his interpretation Butts (1939, p. 78) says, "no fully satisfactory explanation of the entire situation has as yet been reached."

It is difficult from the discussion in Butts' paper to determine how he thought the windows were developed. It would seem that the major differences between the origin here proposed and the suggestions of Butts and Stose are:

(a) The size and location of the syncline. Both Butts and Stose would seem to require a major syncline that has been thrust a considerable distance from where it was formed. This interpretation makes it difficult to explain the rapid termination of the faulting to the southwest.

(b) The role of the Birmingham thrust. Butts and Stose thought that this fault was very large. In Butts' interpretation this fault must have a throw of about three miles; and all the faults in Stose's section are integral parts of a low angle thrust of large displacement. Here again a fault of this nature is contrary to the field evidence of the Birmingham thrust outside the area of the windows.

It would seem that a local syncline, later block faulted, would more nearly explain the present position of the formations exposed within the windows. This structure was overridden by the Birmingham fault, which was caused by the compressive forces that formed the southern half of the Nittany arch.

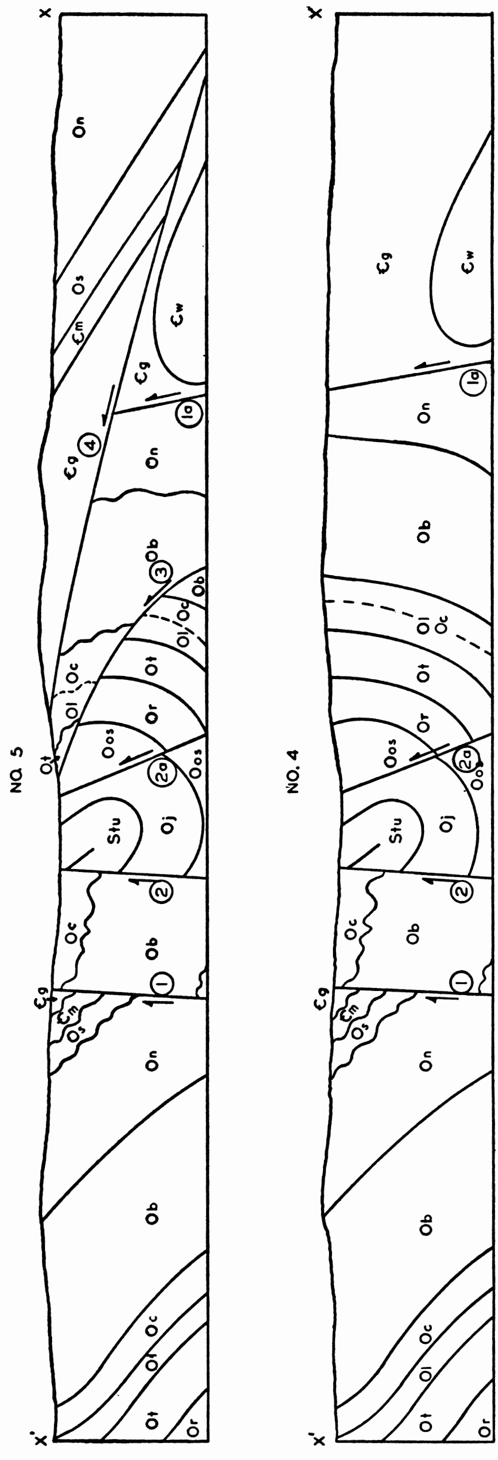

Figure 9. Schematic structure sections along line A-A', figure 4, showing last stages in the development of the Birmingham and Knarr windows. For formational symbols see figure 2.

Comparison with Windows Elsewhere in North America. Windows in major thrust sheets such as those in the Cumberland overthrust of Virginia (Butts, 1927), and the Bannock thrust sheet of Idaho (Richards and Mansfield, 1912) differ basically from the two windows here discussed. The windows of the Cumberland and Bannock thrusts are related to large low angle thrust sheets with displacements of tens of miles. However, the rocks exposed within the Birmingham and Knarr windows are not associated with such a large low angle thrust, and their present position is due to local synclinal folding and block faulting, later covered by a thrust which is low angle only within the area of the windows.

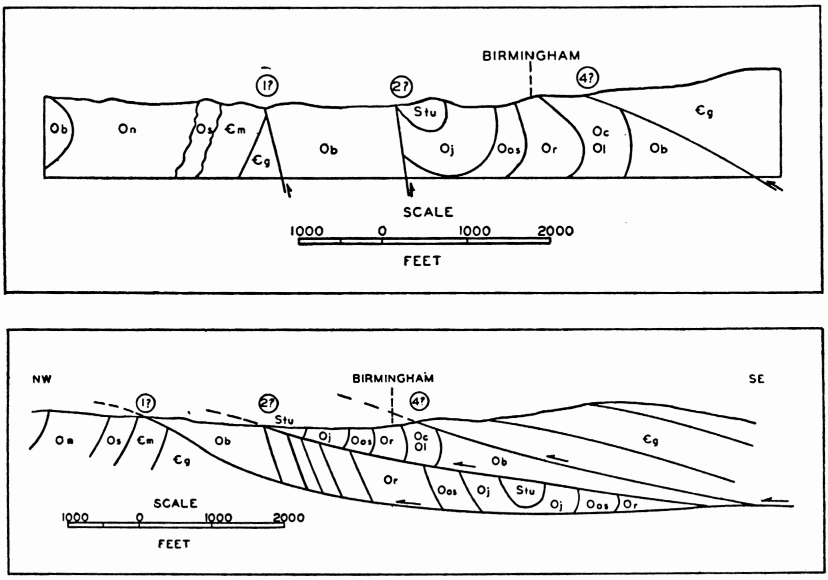

Figure 10. Structure sections across the Birmingham area, modified from Butts (1939). Upper section after Butts, lower section after Stose. For formational symbols see figure 2; for fault numbers (tentative) see figures 4 and 5.

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ERRATUM

In the paper by Harold D. Fox entitled "Structure and Origin of Two Windows Exposed on the Nittany Arch at Birmingham, Pennsylvania" (March, 1950), page 157, line 13, should read:

"plunging southwest end of the Nittany arch has been named."