one twentieth as intense; also, the band at 6.62 μ is about one fifth as intense as the band at 6.54 μ. So it is likely that calcium is made up of isotopes with atomic weights of 39, 40 and 44 and of quantities in the ratio of one fifth, one, one twentieth, respectively. The atomic weights given would have the approximate separation as found for the bands and these atomic weights with the quantities named would give a mean atomic weight about 40.

It is interesting to note that calcium has been studied for isotopes by Dempster,[1] Aston[2] and G. P. Thomson.[3] Dempster found points which correspond to 40 and 44 and another set of points which correspond to atomic weight 39. However, he considered the 39 as due to potassium, which likely occurred as an impurity. Aston also studied calcium, but due to the fact that it did not produce anode rays easily, he did not find a line for calcium of atomic weight 44. Aston carefully excluded potassium from the mixture, but the line corresponding to atomic weight 39 was more intense than the 40 line. So the line at 39 was possibly a mixture of potassium and calcium. G. P. Thomson's work on calcium gives a broad line at 40 which was not resolved by his instrument. However, he states that there must be another line at 39 or 41 making calcium an isobar with potassium. So it is likely that calcium has an isotope of atomic weight 39. In addition to the above facts it appears that it would have been very difficult to detect the isotope of atomic weight 44 if the intensity were only one seventieth of that of atomic weight 40. It could not have been observed by the method of band spectra used by the writer. It seems probable, therefore, that the isotope Ca^{44} is present to a greater extent than one seventieth and that a mean atomic weight of 40.07 is made possible by the presence of Ca^{39}.

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[1] *Physical Rev.*, 18, 421, 1921.

[2] Aston, ''Isotopes,'' p. 101.

[3] *Phil. Mag.*, 42, 857, 1921.

A PRE-CHATTANOOGA SINK HOLE[1]

THE Chattanooga shale is locally five to seven times the thickness generally observed in the region of the Gainesboro, Tennessee, quadrangle. This fifteen-minute quadrangle, ten miles south of the Tennessee-Kentucky line, was mapped by the Topographical Branch of the United States Geological Survey in 1925. Through it the Cumberland River swings in entrenched meanders four hundred feet below the level of the dissected Highland Rim Plateau.[2] The Fort Payne formation of lower Mississippian age is at the surface of the plateau throughout the area. Beneath the Fort Payne a green shale, varying in thickness from a few inches to one or two score feet, lies upon the Chattanooga shale. The Leipers, Catheys and Cannon strata of Ordovician age, together four hundred feet thick, are separated from the Chattanooga shale by a disconformity. The rocks of the region are gently arched in a northeastern extension of the Nashville Dome.

The writer spent three and a half months of the 1926 field season mapping the areal geology and structure of the Gainesboro quadrangle for the State Geological Survey of Tennessee. An interesting result of the summer's work was the discovery of an extraordinary local thickness of the Chattanooga shale. This body of shale is generally ten to fifty feet thick in the Nashville Basin and adjacent areas. According to general observation, the thickness does not vary more than five or ten feet in many miles.[3] The writer found the thickness to exceed 149 feet on Flynn Creek, five miles south of Gainesboro. The shale is exposed in several places in the vicinity with seventy-five or ninety feet of strata visible in a continuous outcrop. It lies in an irregular closed depression or series of depressions in a limestone conglomerate-breccia which is at the same altitude as Leipers, Catheys and Cannon strata. The actual contact of the breccia with formations other than the shale was not seen. Some of the blocks in the breccia contain fossils common to the Leipers and Catheys, but the fossils do not determine with certainty the formations from which the blocks were derived. Some of the blocks differ in lithology from the pre-Chattanooga strata heretofore observed in this general area. It is possible that a detailed and thorough study of all the blocks might yield information which would partially close the hiatus between the Leipers and Chattanooga deposits. The breccia is more than one hundred feet thick in some places.

[1] Printed with the permission of the state geologist of Tennessee.

[2] Purdue, A. H., ''General Oil and Gas Conditions of the Highland Rim Area in Tennessee,'' Resources of Tenn., Vol. 7, No. 4, pp. 220–228. 1917.

[3] Butts, Chas., ''Geology and Oil Possibilities of the Northern Part of Overton County, Tennessee, and of Adjoining Parts of Clay, Pickett and Fentress Counties,'' Tenn. State Geol. Survey Bull., 24, pt. 2-A. 1919. Hayes, C. Willard, and Ulrich, O., U. S. Geol. Survey Geol. Atlas, Columbia folio (No. 95). 1903. Mather, Kirtley F., ''Oil and Gas Resources of the Northeastern Part of Sumner County, Tennessee,'' Tenn. State Geol. Surv. Bull. 24, pt. 2-B. 1920. Miser, Hugh D., ''Mineral Resources of the Waynesboro Quadrangle, Tennessee,'' Tenn. State Geol. Survey Bull. 26. 1921.

The extent of the increased thickness of the Chattanooga shale and the presence of the conglomerate-breccia coincide in an irregular area about two miles in diameter with outcrops visible in the valley of Flynn Creek and its tributaries, Rush Fork, Cub Hollow, Lacey Hollow and Steam Mill Hollow, where they join that stream. Outside this area the Chattanooga shale is about twenty feet thick and rests disconformably upon the Leipers limestone. Gentle dips obtain throughout all but this part of the Gainesboro quadrangle. Here the Ordovician limestone strata dip at 15°, 20°, and even higher angles. On the south, east and north the dips for short distances are toward the area. On the west there may be surficial faulting of the Ordovician. The top of the shale is at a lower altitude where it rests upon the brecciated limestone than at adjacent outcrops, in general being lowest where the shale is thickest. This difference in the altitude of the top of the shale amounts to more than one hundred feet as determined by stadia and telescopic alidade. Where the shale is nearest its normal altitude, it is thin and lies upon hills of the conglomerate-breccia.

Several hypotheses were considered at the time the writer was investigating and mapping this peculiar feature. The figure obtained for the thickness was questioned, for in landslides strata that are high on the sides of a valley may slump to the bottom of the valley with their attitude practically unchanged. But the shale is completely exposed in sections up to ninety feet thick in single outcrops, and it crops out practically continuously in the bed of Flynn Creek and tributaries with the same system of joints throughout.

The question arose as to the possibility of post-Chattanooga diastrophism restricted to this small area. There might have been subsidence, or perhaps uplift followed by subsidence which deformed the shale so that at this one place it is exposed in the bed of Flynn Creek, whereas, both upstream and downstream from this locality, its base is high on the sides of the valley. The diastrophism might have proceeded in such a way as to produce the brecciation and high dips in the limestone. Bucher has described a circular area of intense folding and faulting in Adams County, Ohio, and refers it to the class of "crypto-volcanic" structures.[4] However, the thickness of the shale and the absence of folding or brecciation of the shale and overlying beds, which are structurally conformable, indicate that the Chattanooga shale and later formations could not have been affected by such diastrophism. Moreover, the actual exposure of the contact of the shale and breccia shows an irregular erosion surface which is not paralleled by the contact of the Chattanooga shale with the overlying green shale at the base of the Fort Payne chert. The conglomeratic nature of the breccia and the absence of veins or dikes of possible igneous origin discourage the view that sub-surface vulcanism may have been the cause of the diastrophism, either before or after Chattanooga time.

From the observed facts noted above, it is clear that at the inception of the deposition of the Chattanooga shale there must have been a depression with an irregular outline and an uneven floor. In the bottom of the depression and along the walls there were considerable thicknesses of slightly rounded fragments of limestone derived in part from the Ordovician limestones still represented in the surrounding area. Possibly there were also fragments from still higher strata, now eroded and entirely removed except at this one place where they are thus represented.

A depression of this sort could be formed by the collapse of the roof of an irregular branching cavern or series of caverns. The fragmentation induced by collapse, together with the slope wash of talus towards the lines of collapse, would form the conglomerate-breccia.

The Chattanooga shale was deposited in this depression when the general area was receiving carbonaceous mud in the latest Devonian or earliest Mississippian time. With the loading of the region by later sediments, the mud was compacted by the squeezing out of its fluids. The fissility was produced by the orientation of mineral flakes during this process of dehydration. The fissibility is observed to be parallel to the bedding except where it conforms to ancient hillslopes. Here true bedding was not found, but since the fissility is inclined as much as 30°, it is to be doubted if the newly deposited layers stood at that high angle. The average altitude of the top of the shale is generally less in this area because in so thick a body of shale the total amount of compacting was proportionately greater, although part of the difference in elevation may be accounted for by the gentle folding of the region.

It is doubtful if this is the only feature of the sort; others exist but have remained unnoted. The existence of a sinkhole with a depth of nearly two hundred feet indicates that in pre-Chattanooga time the altitude of this part of the continent was probably at least two hundred feet above sea-level long enough for sinkholes to be formed of the general size of many of the present depressions in the area of the Standingstone quadrangle, Tennessee.

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[4] Bucher, Walter H., "Crypto-volcanic Structure in Ohio of the Type of the Steinheim Basin" (abstract): Geol. Soc. Amer. Bull., Vol. 32, no. 1, pp. 74–75. 1921.