## XXXVIII. THE "BURIED HILLS" AS A STRUCTURAL AGENCY

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Perhaps no area of similar size in the United States or for that matter on the entire earth's surface offers a more interesting problem to the geologists than the State of Oklahoma offers through the wealth of material which has been made available by the activities of oil companies in this area since the discovery of oil.

The records of more than 100,000 wells which have been drilled in search of oil or gas, together with the detailed structural maps of the surface geology of hundreds of townships, offers sources of information which are wonderfully attractive even though partially inacessible on account of private ownership. Within the last 15 years there has seldom been a month that less than 100 men with geological training have not been engaged in field work in this State. Much of the time the number has been three or four hundred. As a result of their work the geological profession is today in possession of much detailed information regarding isolated areas of the State and many attempts have been made to correlate such data in an effort to solve some of the broader geologic problems.

One of the outstanding problems which has attracted the attention of many members of the geologic profession is the correct explanation of the origin of the more or less isolated structures which are productive of oil throughout the central portion of the State of Oklahoma. These structures have many points in common. They are usually irregular in outline although a major axis may be present. They are marked by very gentle dips. They occasionally show faulting and they seem to have somewhat definite alignment into more or less parallel northeast-southwest lines or zones. Furthermore they seem to be continuous with or related to similar folds to the northward in Kansas. Among the explanations which have been offered to account for such folds, Powers [1] listed the following:

1st. Tangential compression. 2nd. Rock flowage. 3rd. Warping during deposition. 4th. Tortional faulting. 5th. Condensation of sediments.

Some of these explanations have been rejected from consideration by practically all the geologists, while other have been combined in order to arrive at satisfactory explanations. The most

recent explanations which have been offered are those of Powers [3], Heald [5], and Rubey [4]. Consideration of these three hypotheses with regard to their application to Oklahoma structures is the purpose of this paper.

The physiographic map of the State of Oklahoma shows the existence of four mountain uplifts lying wholly or partially within the borders of the State. The Ozark Mountains to the northeast, the Ouachitas to the southeast, the Arbuckles in the south central and the Wichitas in the southwest. The north central and western part of Oklahoma is remarkably free from such relatively uplifted portions.

These mountain areas are evidences to the geologists of profound crustal movements affecting the outer shell of sedimentary rocks for a considerable distance in each direction from the uplifts. It was natural therefore that geologists should first turn to these mountain uplifts when in search of the cause for the rock folds of the oil field area. Another structural feature of considerable importance although of no marked topographic expression is to be found in the Nemaha Mountains and Amarillo Mountains of Kansas and Texas, respectively.

These mountains consist of more or less continuous ridges of granite and other igneous rocks which were completely covered by deposition of sediments over them, until they have been buried in some points to a depth of more than 4000 feet. In addition to these so-called "Buried Mountains" the presence of numerous peaks and ridges roughly parallel to the Nemaha Mountains of Kansas has been postulated from the large number of wells that have encountered granite at various points of Oklahoma and Kansas.

The importance of this system of buried topography on the structure of the overlying rocks has been the subject of much discussion and papers by Blackwelder [2], Mehl [6], Powers (location cited), Monnett [7], Johnson [8], Faith [9], and Rubey [4], have appeared within the last few years calling attention to the probable effect of this old topography upon the attitude of the overlying rocks. In addition to these well known occurrences of buried granite hills there are numerous subsurface irregularities of lesser size which were developed by the erosion of the Ordovician after its deposition and later uplift and before the deposition of the younger rocks.

We are dealing therefore with the following conditions and any effort to explain these structures of central and northern Oklahoma must take into consideration these facts: first, there was a Pre-Paleozoic topography consisting of a granite area which may

have been fairly low and level except for the presence of numerous monadnocks and resistant ridges represented today by the Nemaha and Amarillo and the isolated peaks already referred to: second, upon this crystalline floor was deposited a series of sediment layers varying in thickness according to distance from land areas and consisting largely of limestone rocks in that portion of Oklahoma under discussion: third, the uplift and resultant erosion of these limestone sediments in the course of Ordovician time developing a topography which was far from being a smooth level surface in some places, but approaching peneplanation on others: fourth, a renewed deposition of sediment, first of limestones and later of shales and sandstones with some interruption, but no marked erosion interval continued until the close of Paleozoic times.

These sediments then which formed the upper part of the geologic section in central and western Oklahoma were accumulated on two floors of irregularity. They have been subject to diastrophic forces from the beginning of their deposition until the present time They have been subject to such changes in volume and position as consolidation and compaction would bring about.

It is difficult, if not impossible, to arrive at a correct evaluation of the relative importance of dynamic forces and the changes brought about by consolidation. A few facts are self-evident: first, loose sediment only partially cemented together such as those which form the most of the Permian and Pennsylvanian section in Oklahoma are not capable of transmitting thrusts very far from the point of origin of such movement; second, the underlying Cambrian and Ordovician limestones and particularly the basal granite are far more capable of transmitting forces acting upon them; third, any movements occurring in the underlying rigid rocks must affect the overlying looser sediment although the expression of such movements may be totally different; fourth, the existence of deep-seated faulting and the increase in degree of folding with depth are matters of common knowledge.

Powers (location cited) takes into consideration these four facts and calls attention to the fact in a recent paper that there is no connection between degrees of folding and distance from mountain uplifts, and that successive relative uplifts of the consolidated floor and especially relative elevations of portions of it are necessary to an explanation of the types of folding. His explanation, in brief, is that; first, the relative condensation of sediments on irregular topography; second, the uniform compression of large segments of basal rock taking place at considerable depths below the Paleozoic

sediments would cause relative uplifts of the buried hills, thereby accentuating them; third, the isostatic adjustments, likewise tend to accentuate the structures.

Powers' explanation of the origin of the folds postulates that the underlying basement rocks are capable of transmitting thrust and yet plastic enough to arch up without the development of prominent faults. Furthermore he assumes that the uplifts will be localized at the points of major elevations of the basement rocks *or in other words where the crystalline rocks are thickest and strongest.*

This is contrary to our conception of the behavior of sediment filled basins between higher rocks.

K. C. Heald believes that buried hills represent the upthrow side of faults which cut the granite of the Pre-Cambrian floor. Recurrent movements along these faults, either vertical or obliquely upward, has resulted in intermittent uplifting of the overlying sediments.

The older sediments are probably faulted while the younger ones are bent and stretched. The steepest side of the anticline must dip toward the downthrow side of the fault. According to Heald the structures are due almost entirely to deepseated fault movements occurring during and after the deposition of the younger sediments, these faults passing into folds vertically. Such an explanation does not properly evaluate the effects of sedimentary accumulation and consolidation upon surface developed as a result of earlier periods of faulting.

Rubey's (location cited) explanation of similar structure in Russell County, Kansas is that it originated by consolidation of sediments over buried fault scarps. Block faulting occurring after the deposition of Ordovician-Mississippian limestone along old fault lines. Later stream erosion accentuated the relief and furnished the irregularities of the topography upon which the later sediments were deposited and which gave to them their present attitude by consolidation.

It may not be true that all of the pronounced folds of the area under discussion overlie buried hills but it is certainly true of many of them. The connection is undoubtedly more than a coincidence. Rubey's explanation of the Russell County, Kansas fold permits of no effects of fault movement during or after the deposition of the later sediments. It is also open to serious doubt that stream erosion would accentuate a fault block topography.

The writer's conclusion regarding the origin of the "struc-

tures" may be summarized as follows:

1. The buried granite hills and mountain ranges were probably due in large part to faulting that followed the partial peneplantion of the crystalline rock area. That they are not purely erosional remnants is indicated by their distribution and form.

2. The buried hills of Ordovician and Cambrian limestones probably are in large part erosional but may have been largely localized by repeated faulting along the old shear zones.

3. The structures of the younger Paleozoic rocks are due principally to differential consolidation on the older irregular surfaces but may have been intensified by later fault movements along the old zones of faulting occurring simultaneously with the deposition and consolidation.

4. The fault movements themselves were in part due to stresses originating in the area of mountain uplifts and transmitted through the deepseated crystalline rocks and in part due to local stresses originating through isostatic adjustment as a result of rapid sedimentation.

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