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THE HOLBROOK ANTICLINE, NAVAJO COUNTY, ARIZONA

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INTRODUCTION

The Holbrook anticline is by far the largest such structure exposed in the Holbrook region. In the past 45 years some 14 exploratory wells have been drilled in the vicinity of the anticline. Unverified shows of oil were reported from several of the earlier tests, and at least one well obtained verified, but apparently sub-commercial, shows. In addition, several recently completed wells were rumored to be capable of producing up to 1000 MCF/day of gas of reportedly "high" helium content.

The post-Cambrian sedimentary section on the Holbrook anticline is thin. Drill depths to basement average 3800 feet. Drilling objectives of primary interest have been the Permian Fort Apache limestone of the Supai formation, Pennsylvanian Naco formation, Mississippian Redwall limestone, and the Devonian Martin formation. Of these, the Fort Apache and Martin appear to offer the best, however limited, potential for oil production.

Solution-collapse phenomena, most notably indicated by the local development of karst topography, are a characteristic feature of the anticline, and have highly modified the appearance and extent of the surface structure. A careful examination of the relationship between the surface structure and the solution features indicates that the subsurface crest of the anticline may lie as much as 5 miles south of the surface crest — the displacement resulting from the modifying influence of solution and collapse upon the surface structure.

The drainage pattern in the vicinity of the Holbrook anticline provides perhaps the most direct of several lines of evidence of the extent to which solution phenomena have affected the surface structure. Two major drainages diverge around Dry Lake Valley, a broad sunken area of internal drainage bordering the south flank of the surface anticline. The pattern of divergence is such as to indicate that a topographically high area previously existed in the area now occupied by this valley. Because of the importance of solution-collapse structure and drainage pattern to an understanding of the evolution of the Holbrook anticline, both are discussed at some length below.

STRUCTURE

The axis of the Holbrook anticline is mappable at the surface for a distance of more than 60 miles. The trend is markedly sinuous, and locally the structure entirely disappears. Although a number of separate closures occupy this trend, there is little doubt that the anticline is essentially one continuous structural feature. The north flank of the anticline is formed by beds with a regional north dip averaging approximately 2 degrees. The north flank's having only regional dip causes the crest of the structure, as viewed from the north, to be evident only as a skyline ridge.

The south flank of the Holbrook anticline is formed by a rather sharp reversal of the regional northerly dip. Dips on the south flank range up to near vertical, but representative dips average less than 15 degrees. Even this magnitude is somewhat higher than dips associated with the majority of structures in the Holbrook region, and the prominence of this flank accounts for the early recognition of the Holbrook anticline.

The structurally highest portion of the crestal area of the Holbrook anticline extends approximately from section 33, T.18 N., R.20 E., through the south half of T.15 N., R.19 E. to the west center of T.15 N., R.17 E. Three separate local closures occupy the highest crestal area, the approximate center of each being marked by the locations of the two Union-Continental wells and the L. M. Lockhart well. Of these closures, the L. M. Lockhart area appears to be structurally highest. For the reasons presented below, the two Union-Continental wells may have been off-structure at depth, whereas the Lockhart well may have been relatively nearer the subsurface crest.

There is a close correlation between topography and surface structure in the area of the Holbrook anticline, as well as generally throughout the Holbrook region. The correlation is sufficiently close that the topography as shown on the Army Map Service Holbrook topographic sheet fairly well outlines the surface structure of the Holbrook anticline, despite its small scale.

Discussion of Solution Phenomena

The most striking single feature of the Holbrook anticline and immediate vicinity is the large number of sinks and related solution-collapse structures. The topography in several areas (as in the vicinity of the L. M. Lockhart well) is typically karst, and the south flank of the structure is pockmarked with potholes and sinks — in many places to such an extent that detailed surface structure mapping results in nothing short of a chaotic picture.

The Zeniff syncline, which occupies Dry Lake Valley, and borders the Holbrook anticline on the south, is similarly the locus of numerous sinks. Most of these are filled with alluvium and, although not obvious at the surface, show clearly on air photos. Sinks of this area have coalesced to such an extent as to suggest that much, if not all, of the Dry Lake Valley synclinal area is the result of subsurface solution and collapse. The walls of some of the open sinks in Dry Lake Valley expose alluvial-filled older sinks. That solution is a continuing factor in the structural development of the area is evidenced by the appearance of several deep sinks on air photos flown in 1953, which are absent on photos flown only 17 years earlier.

The sinks and related features are the result of solution of Permian evaporites, which, with interbedded red shales and siltstones aggregate some 1400 feet in thickness. The evaporitic section includes both anhydrite and salt and probably attained a depositional thickness of some 700 feet. The Coconino sandstone is the major aquifer of the Holbrook region, and directly overlies the evaporitic section. Juxtaposition of this aquifer and evaporites handily accounts for the development of the solution phenomena. It should be pointed out that, despite the existence of karst topography, there is nowhere, in the vicinity of maximum sink development, sufficient thickness of limestone to account for the existing topography. Indeed, as the walls of the sinks as well as logs of nearby wells attest, limestones are virtually absent either in outcrop or in the near subsurface of that area.

The close association of the various and extensive solution phenomena with anticlinal structure suggests that,

Figure 1. Holbrook anticline in vicinity of SW¼ T. 14N., R. 20 E. Note abrupt reversal of smooth northeast regional dip into sinks of Dry Lake Valley.

Figure 2. Sinks on southwest flank of Holbrook anticline, approximately 1 mile west of L. M. Lockhart well. Subsurface crest may approximately underly surface axis in right center, despite numerous sinks.

as in many other areas containing near-surface evaporites, the location of the present crest of the Holbrook anticline may be the result of the modifying influence of extensive evaporite solution on regional dip, and that either no subsurface anticlinal structure exists or, if it does, the subsurface crest may lie some distance to the south of the surface anticlinal crest. As can be seen on the photograph of Figure 1, dip directions on the south flank of the Holbrook anticline are everywhere directly into sinks. In this view it is apparent that the south flank is the result of sink encroachment upon regional northeast dip. The structure clearly lacks the appearance of a tectonic anticline.

That some sort of tectonic structural reversal must exist in the area is indicated by the fact that the elevation of the Coconino sandstone on the crest of the surface anticline is several hundred feet higher than in the area immediately south of Dry Lake Valley. In other words, the elevation of the Coconino sandstone north of the area of maximum collapse is higher than in the area immediately south. This is the reverse of the situation that should result from the superimposition of collapse structure on beds of regional dip.

It has been suggested that the south flank of the Holbrook anticline marks the present position of a regionally retreating collapse front and that this front may have originally developed near the Mogollon Rim, some 27 miles to the south, when Permian evaporites were exposed there. Such a circumstance could explain the observed structure, but there is no evidence of solution-collapse phenomena of any magnitude far south of Dry Lake Valley. It is clear that, whatever the cause of the Dry Lake Valley solution structures, it is local in nature.

Relationship Between Drainage Pattern and Structure

The accompanying drainage map (in pocket) illustrates the topographic modifications resulting from solution, and also suggests the magnitude of these effects on the location of the surface axis of the Holbrook anticline. The large area of internal drainage is evidently the result of subsurface solution. Direct evidence of this is provided by the courses of the two major external drainages bordering the collapse area on the south: Pierce Wash and Day Wash-Cottonwood Creek. Both of these northeasterly draining streams diverge abruptly, their courses becoming northwest and east, respectively, along the southern margin of the collapse area. This divergence extends for a number of miles and, being at right angles to the drainage pattern of the surrounding region, forms a prominent anomaly in that pattern.

The abruptness and extent of the divergence is all the more strikingly shown by the elevations of these streams in the area of divergence, which are more than one-hundred feet higher than the area about which they diverge. The evident conclusion is that a topographic high existed in the area of internal drainage previous to collapse. This is further emphasized by several drainages, whose earlier northeasterly direction clearly has been reversed by subsidence of the Dry Lake Valley area. There are a number of such occurrences in the area. Several are shown on the drainage map.

As noted above, there is generally a remarkable coincidence between topography and surface geologic structure throughout much of the Holbrook area. The existence of a pre-collapse topographic high further implies the presence of a pre-collapse structural prominence.

Test Drilling in Dry Lake Valley

Several lines of evidence, including some geophysical work not described, indicate that the subsurface crest of the Holbrook anticline lies beneath Dry Lake Valley, some miles south of the position of the surface axis. The California Oil Company located their "State 2516 No. 1" well late in 1961 with the intention of better defining the subsurface location of the Holbrook anticline, as well as to gain information concerning the subsurface stratigraphy.

The well was programmed as a slim-hole stratigraphic test. Unfortunately mechanical difficulties were encountered, apparently due to caving of the evaporitic section, and the well was abandoned at a total depth of 1596. A second attempt, drilled 50 feet from the first location, ran into similar difficulties and was abandoned in the Naco formation at 2862 feet. At this depth, the well appears to have been at least as high, structurally, as the wells drilled on the surface crest of the Holbrook anticline, although some 3 miles south of these wells. While

Figure 3. View looking northeast at south flank of Holbrook anticline in vicinity of Dry Lake. Dashed lines indicate margins of some of the larger sinks.

Figure 4. Sinks near L. M. Lockhart well. Note stream course interrupted by sinks.

the results of the California Oil Company wells tend to confirm the existence of a structural high beneath the Dry Lake Valley, the exact location of this feature still remains in doubt.

STRATIGRAPHY

The post-Cambrian stratigraphy and representative thicknesses of the formations present on the Holbrook anticline are briefly summarized below:

TRIASSIC

Moenkopi Formation: 0 - 200 feet
Continental red shale and siltstone, with thin gypsum beds; thin or absent over much of the Holbrook anticline.

PERMIAN

Kaibab Limestone: 0 - 200 feet
Marine limestone and sand; absent over most of northern and eastern portion of Holbrook anticline; largely sandstone and/or sandy limestone where present.

Coconino Sandstone: 600 feet
White to yellow, clean, X-bedded sandstone.

Supai Formation: 3355 feet
Upper Member: 1200 feet
Interbedded red shale, siltstone, dolomite, with major amounts of anhydrite and salt; thickness variable due to evaporite solution.
Fort Apache Member: 55 feet
Interbedded limestone, dolomite, and anhydrite.
Lower Member: 1500 feet
Interbedded red shale and siltstone; includes Pennsylvanian beds in lower part as well as Naco lithologies.

PENNSYLVANIAN

Naco Formation: 250 feet
Interbedded red and gray shale and limestone; unconformably overlies Redwall limestone.

MISSISSIPPIAN

Redwall Limestone: 0 - 100 feet
Massive, gray, fossiliferous limestone.

DEVONIAN

Martin Formation: 0 - 300 feet
Interbedded dolomite, limestone, gray and green shale, sandstone, and conglomerate.

CAMBRIAN

Tapeats Sandstone: 0 - 20 feet
Pink to buff, quartzitic sandstone.

Of these formations, the Fort Apache, Naco, Redwall and Martin are of primary economic interest.

The Fort Apache member on the Holbrook anticline is a persistent carbonate unit separating the dominantly evaporitic upper Supai formation from the dominantly clastic lower Supai. In the California Oil Company "State 2519 No. 1" well, the Fort Apache consists of an upper shaly, anhydritic dolomite approximately 10 feet thick; a middle sandy, dolomitic anhydrite approximately 25 feet thick; and a lower dark brown, "dirty", fossiliferous limestone approximately 20 feet thick. Flourescence and slight cuts were obtained from cores of both carbonate intervals. Shows of live oil are a relatively common occurrence in the Fort Apache in the Holbrook area. Some of the reported shows are summarized in the table describing the results of drilling in the Holbrook region.

The Naco formation consists of interbedded lithologies characteristic of both the Supai and Naco formations. Because of the presence of lithologies of both formations in roughly equal amounts through several hundred feet of section, it is difficult to derive a useful definition of the Naco. Although equivalent to part of the Hermosa formation of the Paradox basin and containing some of the oil-productive carbonate lithologic types,

these lithologies are thin and discontinuous. For this reason the Naco appears to offer a very limited potential for oil production on the Holbrook anticline.

The Redwall limestone consists of fine- to coarse-crystalline, locally abundantly fossiliferous limestone. Pre-Pennsylvanian erosion has resulted in carvernous porosity, as is apparent in outcrops south of the Mogollon Rim. This porosity appears to be "filled" in the subsurface of the Holbrook area, but where open, would offer an attractive drilling objective. The Redwall may be locally absent, as a result of pre-Pennsylvanian erosion, over portions of the Holbrook anticline.

The Martin formation comprises a variable assortment of lithologies ranging from conglomerate, through sand and shale to a variety of carbonate rock types. These lithologic varieties appear to be more or less regularly distributed about a series of approximately northeast-trending highs, several of which crop out south of the Mogollon Rim. Another appears to cross the Holbrook anticline in the vicinity of Dry Lake. The Martin is thin or absent on the crests of these highs. The near margins of the highs characteristically are occupied by conglomerate and sandstone, which gave way laterally to shale interbedded with thin biostromal units. The biostromal units consist of gastropod-brachiopod-coral coquinas and/or coral-stromatoporoid masses. Individual thin beds locally are composed entirely of colonial coral. Adjacent to the shale-biostromal lithologies and farther from the "highs" are interbedded shale and thicker units of dense, fine-crystalline, dark-colored dolomite. The dolomite is petroliferous in outcrop, yielding a strong odor of petroleum on fresh fractures. The petroliferous character, combined with carbonate rock types of sufficient thickness and similarity to those that are oil-productive in other areas, suggest that the Martin offers the best potential for oil production on the Holbrook anticline.

SUMMARY OF DRILLING ON THE HOLBROOK ANTICLINE

The chart below summarizes the results obtained in

WELL	LOCATION	DATE	T. D.	REMARKS
Adamana Oil Co. Adamana #1	4-14N-20E	1918-1927	3390' Miss.(?)	Blowout of 48 degree gravity oil reported @ 3387'.
Holbrook Oil Co.	23-15N-18E	1925	3775' Dev.	Gas shows reported.
Hopi Oil Co.	21-15N-19E	1927	2420' Supai	No information.
Union-Continental Aztec L. & C. #1	19-15N-18E	1943	3850' Dev.	Oil staining reported in Ft. Apache, Miss. & Dev. carbonates; 3 DST's recovered mud & mud filtrate.
Union-Continental New Mexico & Arizona Land Co. #1	34-15N-19E	1944	3609' Precamb.	Shows of oil as above; reportedly lost hole and unable to test.
L. M. Lockhart Aztec L. & C. #1	33-14N-20E	1949	3734' Precamb.	Numerous substantial shows of oil; core analysis saturations up to 41% in Dev. carbonates; Ft. Apache tested for 250 MCF/D flammable gas; mechanical difficulties prevented tests of Naco, Redwall, and Martin.
P. D. Lynch Aztec L. & C. #1	3-13N-20E	1951-1954	3140' Naco	No information.
J. A. Eisele McCauley #1	1-16N-16E	1954	4231' Precamb.	No shows reported; 2 DST's recovered salt water from Precamb. granite.
L. Johnson Aztec Trustee #1	33-14N-20E	1958	3737'(?)	Rumored to have been capable of small helium production from Ft. Apache.
Pan American New Mexico & Arizona Land Co. #B-1	25-12N-23E	1959	4497' Precamb.	Oil shows reported in Ft. Apache and Martin; DST's recovered salt water from Martin.
L. Johnson Aztec Trustee #2	33-14N-20E	1959	1750' Supai	Rumored to have made 780 MCF/D 6% helium from Ft. Apache.
L. Johnson Aztec Trustee #3	33-14N-20E	1960	185' Coco.	No information.
California Oil Co. State 2519 - #1	12-14N-18E	1961	1569' Supai	Slight shows in Ft. Apache; no tests; abandoned due to mechanical difficulties.
California Oil Co. State 2519 - #1A	12-14N-18E	1962	2947' Naco	50 ft. from #1; no shows reported; abandoned due to mechanical difficulties.

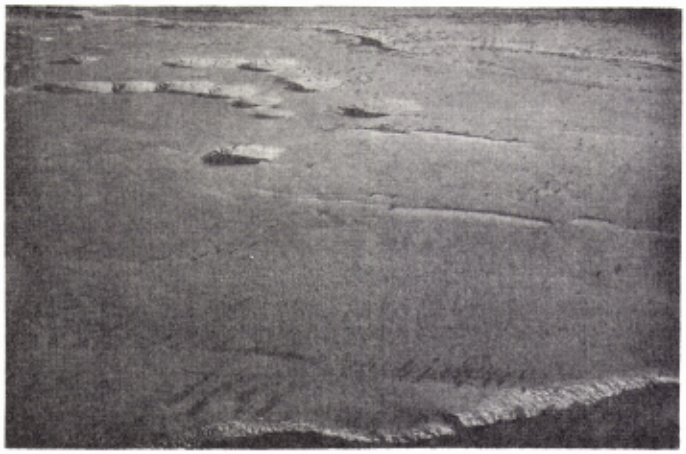

Figure 5. Sinks and pressure ridges in vicinity of Eisele "McCauley" well. Ridges are anticlinal in form, and range up to 20 feet in height.

the 14 wells drilled to date in the vicinity of the Holbrook anticline. It should be emphasized that the shows of oil noted under "Remarks" are based on reports of variable reliability. It is significant that mechanical difficulties were encountered in a surprisingly high percentage of the wells drilled in the last 18 years. These difficulties either prevented reaching the Redwall and Martin formations or prevented adequate testing. Finally, it should be noted that, if the interpretation of the structure presented above is correct, none of the deeper wells listed below tested the structurally highest portion of the Holbrook anticline.

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