GEOLOGICAL SUMMARY OF THE HOLBROOK ANTICLINE

Apache, Navajo & Coconino Counties, Arizona

The Colorado Plateau is a stable uplift larger than the entire state of Arizona that occupies the four corners region of Arizona, New Mexico, Colorado, and Utah. Its southern fringe is marked by the outcrops at the Mogollon Rim. The volcanic activity at the perimeter of the Colorado Plateau has created a ring of fire through all four states. In fact, following the Mogollon rim to the southeast corner of Apache County encounters the vast White Mountain Volcanic Field. The southwestern portion of the ring of fire is the ore rich transition zone which cuts Arizona diagonally in half on a northwest-southeast trend. Outcrops along the escarpment of the Mogollon Rim have showed oil seeps. Some thirty miles to the north, the Mogollon slope dips into the center of the Holbrook basin. This slope is interrupted by the Holbrook Anticline. Almost all wells drilled along the Holbrook Anticline have had shows of oil. Continuing north into the center of the Holbrook basin it then climbs towards the Defiance Uplift.

Entering Arizona near the junction of the Defiance Uplift and the Holbrook Basin, Highway 40 swings to the south around the Defiance Uplift. The road from the New Mexico border crosses more than 100 miles of the Holbrook Basin. The road from Holbrook to Winslow roughly parallels the geological trends of the area. Highway 40, the Little Colorado River, the surface expression of the Holbrook Anticline, and the Mogollon Rim all trend northwest-southeast. These features mark an area of interest on the Colorado Plateau in Northeast Arizona for exploration of oil and gas.

The Holbrook Anticline may be the largest single solution-collapse fold structure in the world. The crest of this 80 mile long anticline rests on a core of quartzite flanked by basement rocks of granite. Almost all wells drilled along the sinuous backbone of this anticline have reported shows of oil and gas from numerous pay zones.

The Holbrook basin is almost 100 miles wide and over 200 miles long. During Supai time, the Holbrook Basin was a depositional basin where over 1000’ of salt-anhydrite-sylvite was deposited after the inland sea known as the Rock Point Lagoon dried up.

Rocks of the middle Permian include the Kaibab lime and the Coconino / De Chelly sandstone which carry shows of gas and produce gas with high levels of Helium from the upper part of the Coconino. The upper Triassic has a basal Shinarump member that also produces helium.

The massive Supai formation of late Permian carries a number of oil shows from both the upper and lower zones. In between the red clastics, carbonates and gypsum of the upper Supai and the interbedded orange-red brown siltstone and sandstone of the lower Supai is the dolomite of the Fort Apache. Because the Fort Apache member carries so many oil shows it is a key for exploration. It is also a popular target for drilling because of its shallow depth (1310'-1920'). It is common to core the Fort Apache. One core was 67', and 32.6' carried oil. Typically, the upper 10' is anhydritic dolomite, the middle 25' is dolomitic anhydrite and the bottom 20' is a dark brown fossiliferous limestone. A DST of the Fort Apache on the Holbrook Anticline reported a final bottom hole pressure of 945# at a depth of 1847'.

About 24 miles south of Holbrook the anticline is interrupted by the influence of the Colorado Lineament that cuts across Arizona from the SW to the NE and continues on to the Great Lakes region. On the plain just north of The Sinks four wells were drilled. All reported numerous substantial shows of oil. One well tested 250,000 cubic feet of flammable gas and was later re-entered and re-completed for 2,000,000 cubic feet of gas. Another well is rumored to have recovered 750,000 cubic feet of gas with 6% helium.

Wells drilled near the intersection of the Holbrook Anticline and the Colorado Lineament are among the highest structurally along the entire Holbrook anticline. The rate of dip in general for the Fort Apache is up to the south at 200 feet per mile. However, just 1 ½ miles northwest of these wells, a test drilled in May of 1976 found the Fort Apache 145' high and it tested tight. The PreCambrian basement was found at 3364' which was 360' high. In 1917, Adamana Oil cut a well four miles north of the 1976 test. They drilled to 3387 with the bottom 18" called 'oil sand'. During a completion attempt the pressure was so great the well unloaded a hole full of water and blew 48° oil out over the crown block of the derrick.

The upper Pennsylvanian Naco group continues the stratagraphic column for 700'-1250' under the Fort Apache. The Naco group consists of unfossiliferous red beds in the western Holbrook Basin grading into fossiliferous carbonate beds to the east and southeast part of the basin. This section resembles the Hermosa formation which is productive throughout the four corners, and the Bough formation which is productive in southeast New Mexico. In the Permian/Delaware Basin, the Bough meets the Matador Arch, and the production is found in the zone lower. A case can be made that the Naco is to the Defiance Uplift as the Bough is to the Matador Arch.

As the Holbrook Basin extends southeast to the corner of Apache County the surface expression of the Holbrook Anticline is hidden beneath the White Mountain Volcanic Field. Southeast of the volcanic field on the New Mexico border, massive fossiliferous limestone outcrops on the north flank of the Escudilla Mountain. This important discovery proves that the Pennsylvanian underlies the entire White Mountain volcanic field where volcanism may have enhanced oil and gas potential. A parallel can be drawn

to the Dineh-Be-Keyeh field, in the extreme northeast corner of Arizona, which produced an average of 547,365 Bbls oil and 188,201 MCF gas per well, because the oil produces from Tertiary age igneous material that intruded Pennsylvanian carbonate formations. It appears that the intrusive masses may have cooked the oil out of the shales, while the fractures allowed the oil to migrate into the field. A well cut south of the Volcanic Field in 1993 had oil bleeding from carbonate units, thus attesting to hydrocarbon presence at depth.

The Mississippian is referred to as the Redwall, Leadville or Escabrosa throughout regions of Arizona, and includes the Mooney Falls and Thunder Springs members. It is a fine, to coarse crystalline abundantly fossiliferous limestone. Throughout most of the Mogollon slope the Mississippian maintains 100'+ of thickness. Because 1000' of Mississippian is present in the northeast corner of the state, it is apparent that enormous erosion took place mid way through the carboniferous (pre Pennsylvanian). This massive weathering created cavernous porosity which is apparent in the outcrops along the escarpment of the Mogollon Rim. Numerous parallels can be drawn to existing oilfields of cavernous porosity where updip porosity is filled and downdip porosity is clean and thus suitable for stratagraphic trapping of hydrocarbons.

It is noteworthy that the Leadville lime has been completed with high helium concentrations on the east flank of the Butte Field (Utah border in northeast Arizona). The Mississippian has produced 6% helium bearing gas and it has produced oil north of the Defiance Uplift, especially where truncated between Devonian source rocks and Pennsylvanian overlying seals.

The Devonian/Martin formation has the Ouray limestone, Elbert formation, McCracken sandstone member, and the Aneth formation. Basal sands 10-20' thick (McCracken) are the pay zones in many wells on the north margin of the Defiance Uplift. The McCracken is one of the pay zones in the Dineh-Be-Keyeh field and has produced helium rich gas in that area. Far to the south along the Mogollon Rim, the McCracken outcrops beneath a thick sequence of dark brown petroliferous lime.

The Devonian formation rests atop the Percha shale which is a rich source rock-with a total organic carbon content well within the oil-generating-window. This places the Devonian reservoir in position to accept the first fruits of all hydrocarbons generated below.

Only recently has the presence of the Cambrian/Tonto Group rocks been recognized in the Colorado Plateau Province. In the Holbrook Basin over 160' of lower Cambrian has survived extensive weathering. The Bright Angel shale and the rich Percha shale are both favorable for the generation of hydrocarbons.

Past drilling along the supposed crest of the Holbrook anticline has recovered numerous shows of oil but no commercial production yet. In the past, workers have concluded in

error that the surface expressions, domes, anticlines, etc., would lead to oil and gas fields. This might have worked on the east side of the Defiance Uplift: It has not worked on the west side. The fact that regional gravity appears to correlate with surface topography, has reinforced this erroneous conclusion. It is postulated that the subsurface crest of the Holbrook anticline offsets the surface expression by two to five miles.

Test holes across the Holbrook Basin indicate that all major reservoir rocks from the Cambrian up through the Permian thin over the Anticline, and disappear totally to the north against the Defiance Uplift. This trend also appears as you move updip from the anticline to the south. Oil shows and seeps throughout the Basin indicate this is a Hydrocarbon rich environment.

To summarize the area of the Holbrook Basin, it is clear that there are several significant geological features that are major contributors to the numerous oil shows across the area. First of all, the Holbrook Anticline itself is a subsurface geological feature extending 80 miles northwest-southeast, that offsets by roughly five miles from its surface expression. Secondly, the Mogollon Slope from the Holbrook Anticline south to the Mogollon Rim provides favorable environment for stratagraphic traps because of truncation of zones. There is evidence that the same potential pay zones subcrop against the base of the Defiance Uplift to the north. This subcropping provides numerous possibilities for stratagraphic traps north of the Holbrook Anticline. Additionally, the transcontinental Colorado Lineament is a major influence that crosses perpendicular to the axis of the Holbrook Anticline.

Because the recent 216 sq miles of satellite work concludes that there may be a dozen fields similar in scope to the Dineh-Be-Keyeh field on trend with the Holbrook Anticline; because there are major geologic features and cross features; and because there is limited well control: it is recommended that a satellite shoot be undertaken over the entire area to properly evaluate the hydrocarbon rich region for the best and most prolific of the structural and stratagraphic traps. It is therefore strongly recommended that 16,000 square miles of satellite study be undertaken.