State of Arizona
Oil and Gas Conservation Commission

1110 W. Washington Street, Phoenix, AZ 85007
602-771-4501
www.azogcc.az.gov
Chris Schmidt, Oil and Gas Administrator

Katie Hobbs
Governor

NOTICE OF COMBINED PUBLIC MEETING AND POSSIBLE EXECUTIVE SESSION ARIZONA OIL AND GAS CONSERVATION COMMISSION

Pursuant to A.R.S. § 38-431.02, notice is hereby given to the members of the Arizona Oil and Gas Conservation Commission (AZOGCC) and to the general public that the AZOGCC will hold an open public meeting:

Friday, March 1, 2024

10:00 A.M.

via Zoom using the link below:

https://us02web.zoom.us/j/82978670131?pwd=NTVNeFYyU05SSTl1SVIxV1QzMHNQQT09

Dial in:

+1 669 444 9171 US

Meeting ID:

829 7867 0131

Passcode:

289955

Please join a few minutes early to avoid technical difficulties and keep all microphones muted except when speaking. This virtual meeting will be recorded. If you experience difficulties logging into the meeting please contact Andrew Foss, Oil and Gas Project Manager, at foss.andrew@azdeq.gov or (602) 618-3588 for technical assistance.

Executive Session: Pursuant to A.R.S. § 38-431.03(A)(3), the AZOGCC may vote to go into executive session, which will not be open to the public for the purposes of obtaining legal advice on any item on the Agenda.

CALL TO ORDER

1. Establish a quorum and conflicts of interests.

AGENDA ITEMS FOR DISCUSSION, CONSIDERATION, AND POSSIBLE ACTION:

2. **Administrator Updates - Chris Schmidt:**
    a. **Permit Applications (Attachment A)**
        i. Vote on Applications to Drill

1. Pinta South Operating LLC
    a. Well ID: PS 22-1 SD State
    b. Well ID: PS 22-13 SD State
    c. Well ID: PS 14-9 SD State
2. Ranger Development LLC
    a. Well ID: Ranger 5-11 NS
    b. Well ID: Ranger 6-13 NS
    c. Well ID: Ranger 27-1 SH NS
    d. Well ID: Ranger 27-8 NS
    e. Well ID: Ranger 28-1 SH NS
    f. Well ID: Ranger 28-8 NS
    g. Well ID: Ranger 28-10 NS
    h. Well ID: Ranger 33-13 NS
    i. Well ID: Ranger 31-7 NS
3. Pinta Dome Operating LLC
    a. Well ID: PD 10-1 State

b. Permit Extensions

i. Vote on Pinta Dome Operating LLC Permit Extensions
    1. Well IDs: 10-1PR, 12-1PR, 14-1PR, 14-1 State, 16-1

c. Well Plug and Abandonment Application

i. Desert Eagle Operating LLC Well ID: DEO 13-4

d. Spacing or Other Exception Requests

i. Vote on Pinta Dome Operating LLC Spacing Exception Well ID: 10-1 State (Attachments B&C)

ii. Vote on Ranger Development LLC Location and Increased Density Exceptions for Well ID: Ranger 31-7 NS

3. Presentation by Brian Gootee (Arizona Geological Survey)

4. AZOGCC Chairman Frank Thorwald Report

a. CO2 Sequestration/Pore Space Update

b. Commissioner Stephen Cooper Resignation effective March 31, 2024

5. Call to the Public:

Members of the public may address the AZOGCC during this Call to the Public. In the interest of maintaining an orderly meeting, comments shall not exceed three minutes per speaker. For any specific issues, the total comment period shall not exceed ten minutes per side. If a member of the public wishes to speak, they may unmute their telephone by pressing *6.

Pursuant to A.R.S. § 38-431.01(H), the AZOGCC members shall not discuss or take legal action on matters raised during an open call to the public unless the matters are properly noticed for discussion and legal action. As a result of public comment, the AZOGCC members may respond to criticism, may direct staff to review a matter, or may ask that a matter be placed on a future agenda.

6. **AZOGCC Requests for Future Agenda Items**
7. **Announcements**
8. **Adjournment of the AZOGCC**

For additional information about this meeting, contact Chris Schmidt, Oil and Gas Program Administrator, azogcc@azdeq.gov or (602) 771-4501. At least 24 hours prior to any meeting, a copy of the agenda will be available for public inspection at the Arizona Department of Environmental Quality (ADEQ), 1110 W. Washington Street, Phoenix, AZ 85007, or online at http://www.azdeq.gov/ogcc-notices. A copy of material provided to AZOGCC (with exception to material relating to possible executive sessions) are available for public inspection upon request by contacting the ADEQ Records Center at (602) 771-4380 or (800) 234-5677.

ADEQ will take reasonable measures to provide access to department services to individuals with limited ability to speak, write or understand English and/or to those with disabilities. Requests for language translation, ASL interpretation, CART captioning services or disability accommodations must be made at least 48 hours in advance by contacting the Title VI Nondiscrimination Coordinator at 602-771-2215 or Communications@azdeq.gov. For a TTY or other device, Telecommunications Relay Services are available by calling 711.

ADEQ tomará las medidas razonables para proveer acceso a los servicios del departamento a personas con capacidad limitada para hablar, escribir o entender inglés y/o para personas con discapacidades. Las solicitudes de servicios de traducción de idiomas, interpretación ASL (lengua de signos americano), subtitulado de CART, o adaptaciones por discapacidad deben realizarse con al menos 48 horas de anticipación comunicándose con el Coordinador de Anti-Discriminación del Título VI al 602-771-2215 o Communications@azdeq.gov. Para un TTY u otro dispositivo, los servicios de retransmisión de telecomunicaciones están disponible llamando al 711.

ATTACHMENT A

APPLICATION TO DRILL WELL DETAILS SUMMARY

PERMIT #	ORGANIZATION	WELL NAME	WELL TYPE	COUNTY	ELEVATION (GROUND, FT)	S/T/R	EST. TOTAL DEPTH (FT)	TARGET FORMATION
TBD*	Pinta South Operating LLC	PS 22-1 SD State	Helium	Apache	5791	SEC 22, T19N, R26E	950	Chinle, Shinarump
TBD*	Pinta South Operating LLC	PS 22-13 SD State	Helium	Apache	5695	Sec 22, T19N, R26E	900	Chinle, Shinarump
TBD*	Pinta South Operating LLC	PS 14-9 SD State	Helium	Apache	5750		920	Chinle, Shinarump
TBD*	Ranger Development LLC	5-11 NS	Gas/Helium	Apache	5804	Sec. 5, T19N, R26E	1085	Coconino
TBD*	Ranger Development LLC	6-13 NS	Gas/Helium	Apache	5770	Sec. 6, T19N, R27E	985	Shinarump
TBD*	Ranger Development LLC	27-1 SH NS	Gas/Helium	Apache	5777	Sec. 27, T20N, R27E	985	Shinarump
TBD*	Ranger Development LLC	27-8 NS	Gas/Helium	Apache	5762	Sec. 27, T20N, R27E	985	Shinarump
TBD*	Ranger Development LLC	28-1 SH NS	Gas/Helium	Apache	5806	Sec. 28, T20N, R27E	985	Shinarump
TBD*	Ranger Development LLC	28-8 NS	Gas/Helium	Apache	5788	Sec. 28, T20N, R27E	985	Shinarump
TBD*	Ranger Development LLC	28-10 NS	Gas/Helium	Apache	5722	Sec. 28, T20N, R27E	985	Shinarump
TBD*	Ranger Development LLC	31-7 NS	Gas/Helium	Apache	5760	Sec. 31, T20N, R27E	1085	Coconino
TBD*	Ranger Development LLC	33-13 NS	Gas/Helium	Apache	5728	Sec. 33, T20N, R27E	829	Shinarump
TBD*	Pinta Dome Operating LLC	10-1 State	Oil/Gas	Navajo	5374	Sec. 10, T16N, R21E	4500	Precambrian

TBD = To Be Determined

S/T/R = Section, Township, Range

*Permit Number Issued Upon approval by the AZOGCC

ATTACHMENT B

CAZ EXPLORATION, LLC

To: Arizona Oil & Gas Conservation Commission

From: Adrian O. Garcia, President/Geologist, CAZ Exploration, LLC

Subject: Initial proposed location, Pinta Dome Operating 10-1PR State

T16N-R21E-S10 Apache Co., AZ

2-9-2024

To Whom It May Concern,

Pinta Dome Operating LLC is seeking an exemption to the well location/spacing rule by requesting approval for a well to be drilled on its Puerco Ridge Prospect lease at 1,467' from the west section line and 1,951' from the North section line in T16N-R21E-S10 in Apache County. This location is optimally located as the primary helium trap on the section as shown by the electro-seismic surveying provided by PDO. All of the helium shows on this section were located in the far western edge of Section 10 and the point chosen was the highest point of the trap. As seen in the accompanying Structure Map on Top of the Permo-Pennsylvanian Supai Formation and Cross Sections A-A' and B-B', this specific location is located several miles to the northeast of the axis of the monocline and on its high side. We can conclude the area is in a location conducive to forming a viable trap for gas/helium. Based on Pinta Dome Operating's electro-seismic mapping results, if the location is moved farther to the east/southeast following current spacing guidelines, the PDO-10-1 would likely be outside of the limits of the helium trap identified at this position. This would create a high risk of the well being completed below the gas/water contact or being pinched out entirely. With my extensive experience in conducting electro-seismic surveying/mapping all over the U.S, I respectfully request the state grant an exemption to drill its well at a geologically optimal location.

Respectfully submitted,

Adrian O. Garcia
President/Geologist

Adrian O. Garcia
216 Alyssa Dr.
Del Rio, Texas 78830
806-440-6664
Adrian.garcia18@hotmail.com

ATTACHMENT C

Pinta Dome Operating LLC
Potential Drilling Location (Permitted)
Pinta Dome Operating (PDO) No.10-1 State
SW NE Sec.10-T16N-R21E
Navajo Co., AZ

SYNOPSIS / INTERPRETATION

This section of the Synopsis/Conclusion is to provide an analysis at the beginning of this report to emphasize the conclusions presented below. The Pinta Dome Operating (PDO)10 -1 State location is a permit in progress as of 1/20/24 [SW NE Sec.10-T16N-R21E, Navajo Co, AZ] with the permit submitted 6/24/23. The delay in the permit approval is due to the need for a spacing exemption.

The PDO 10-1 State is in Sec.10-T16N-R21E with the closest offset well being 4 miles to the south in the same township in Sec.34 [DS55 SE NW Sec.34]. The next closest offset wells are 5 miles away to the west, east, and northeast of the PDO 10-1 State. The lack of nearby offset wells [1 to 2 miles away] for direct comparison on structural position requires a different approach to obtain a relative structural position of the POD 10-1 State.

From the conclusions drawn from both the Structure Map and Cross Sections and Geological discussion, it is determined that the PDO 10-1 State location has a structurally high position locally and has a good potential for a gas trap for helium.

Structural Map on Top of the Permo-Pennsylvanian Supai Formation and Cross Sections A-A' and B-B'

Since there are no direct offset wells closer than 4 miles to the PDO 10-1 State well, it is necessary to use local geology to refine the structural position of this location. From the Structure Map on to of the Supai Formation, it can be seen that the PDO 10-1 State has an approximate structural elevation of +4600 and located on the structurally high side of the Holbrook Anticline. The Holbrook Anticline, a structurally positive feature, runs in a NW-SE orientation as shown on the map. The PDO 10-1 State is located several miles to the northeast of the axis of the Holbrook Anticline and again is on the high side of the axis. This puts the PDO 10-1 State in a structurally high position in the area and is conducive to forming a trap for gas/helium.

Again, the lack of direct well control makes the direct structural interpretation more difficult, but using local geological knowledge, one can infer this relatively higher structure position and the favorable formation of a gas trapping mechanism. Refer to the discussion below for more refinement on the regional and local structural geology affecting the PDO 10-1 State location.

Regional and Localized Structural Geological Position of the PDO 10-1 State well in reference to the Holbrook Anticline within the Holbrook Basin, Arizona

The PDO 10-1 State is in the Holbrook Basin of eastern Arizona. The Holbrook Basin is located along the southern margin of the Colorado Plateau on the Mogollan Slope. The Mogollan Shelf lies to the southeast of the Holbrook Basin, refer to Figure 1., Late Paleozoic tectonics of the southern Colorado Plateau and vicinity. Holbrook Basin is approximately 100 miles wide and 200 miles long. Within the Holbrook Basin is the Holbrook Anticline, an 80 miles long solution-collapse fold structure.

Earlier publications and geological research [prior to 1989-2019] refer to the Holbrook Anticline, as an anticline. But more recent studies, such as the included references from the 13th Sinkhole Conference in 2019, now interpret the Holbrook Anticline not as a true anticline but rather as a monocline. A publication from this conference by James T Neal, "Variations in Evaporite Karst in the Holbrook Basin, Arizona", presents the structural and geological evidence to support this most recent interpretation.

SYNOPSIS / INTERPRETATION

A **monocline** is a step-like fold in stratigraphy made up of a zone of steeper dipping layers within a horizontal or gently dipping layered sequence. The following two examples are an illustration of what a monocline looks like compared to a classic anticline. As was stated in the previous paragraph, earlier investigations labeled the Holbrook Anticline as true anticline. With more recent and in-depth studies, such as the publication by James T Neal in 2019, the Holbrook Anticline is shown to be a monocline. There are numerous studies done prior to this 2019 study by James T Neal, including publications by him leading up this more comprehensive study on the karst features of the Holbrook Basin and the Holbrook Anticline.

The primary focus of the “Variations in Evaporite….” publication is to refine the previous interpretations and conclusion as to the Holbrook Anticline being a monocline feature rather than a true anticline. For the purposes of this discussion, I will not go into depth about the direct influence and connection of the dissolution-collapse features along the axis of the Holbrook Anticline/Monocline. The pages from the “Variations in Evaporite…” that follow the structure map and two cross sections, A-A” and B-B’ are included as a brief reference from the publication to illustrate the conclusions from this publication that this feature is indeed a monocline.

The first page is a map of the location of **the Holbrook Basin** within Arzona and in relation to other structural features of the Colorado Plateau, Figure 1.

Page 177 in the Abstract section concludes that “numerous sinkholes and depressions are generally coincident with the axis of the Holbrook Anticline-in reality a **dissolution-collapse monocline**”.

Page 179 in Figure 1 has a map showing the approximate location of the Holbrook Anticline/Monocline with the many karsts and sinkholes along with geographic features such as the towns of Holbrook and Snowflake, highways/roods, the Petrified National Forest, and other local features.

Page 179 also has Figure 2, a cross section view, that shows the Holbrook Anticline/Monocline is a positive structural feature and the PDO 10-1 State is located along the top of the structure.

Page 181 gives an overview of the Initiation of Karst Development and recited historical publications ranging from 1925 to 1989 in support of the Holbrook Anticline being a monoclinal structure. This page also concludes the monocline is a solution related feature with a structural control of those dissolution effects. Figure 4 from page 181 demonstrates a clear picture of the position of the Holbrook Anticline/Monocline and its higher structural position to the surrounding topography. The PDO 10-1 State is located along the top of this structural high to the northeast of the Holbrook Anticline/Monocline.

Figure 4. Mechanism of Sinkhole Collapse

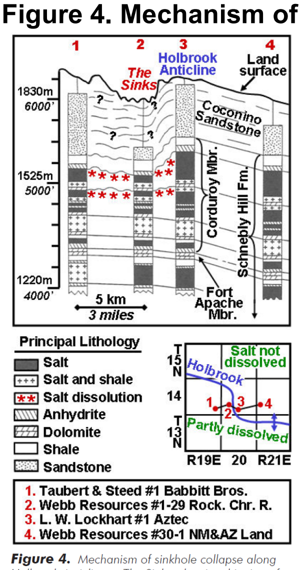


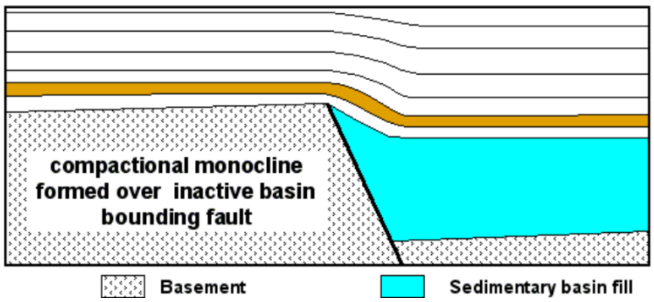
Figure 4. *Mechanism of sinkhole collapse along Holbrook Anticline at The Sinks, showing thinning of Corduroy member evaporites in well records (Dean and Johnson, 1989).*

SYNOPSIS / INTERPRETATION

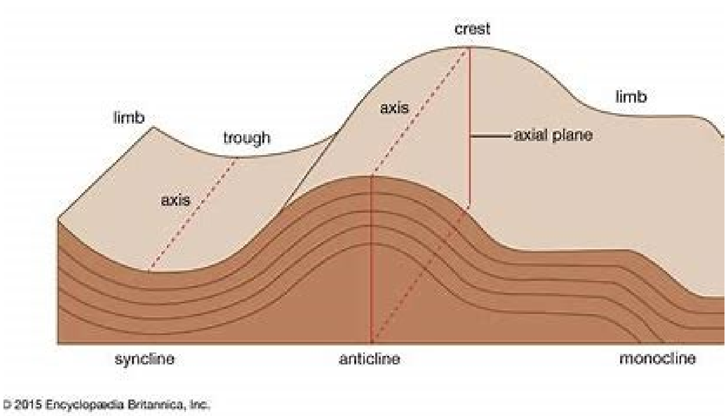
Page 182 reiterates the historical misinterpretation of the Holbrook Anticline as true anticline when if fact is a monocline. They state on this page "In fact, the ~50 m (164 feet) vertical-relief structural feature in bedrock is monoclinal and now known to result from dissolution of underlying salt beds."

The following two diagrams are basic illustrations of what a typical monocline looks like with the second diagram showing a syncline, anticline, and monocline for comparison.

Example of a Monocline Draped over a Fault



Basic examples of a syncline, anticline, and a monocline



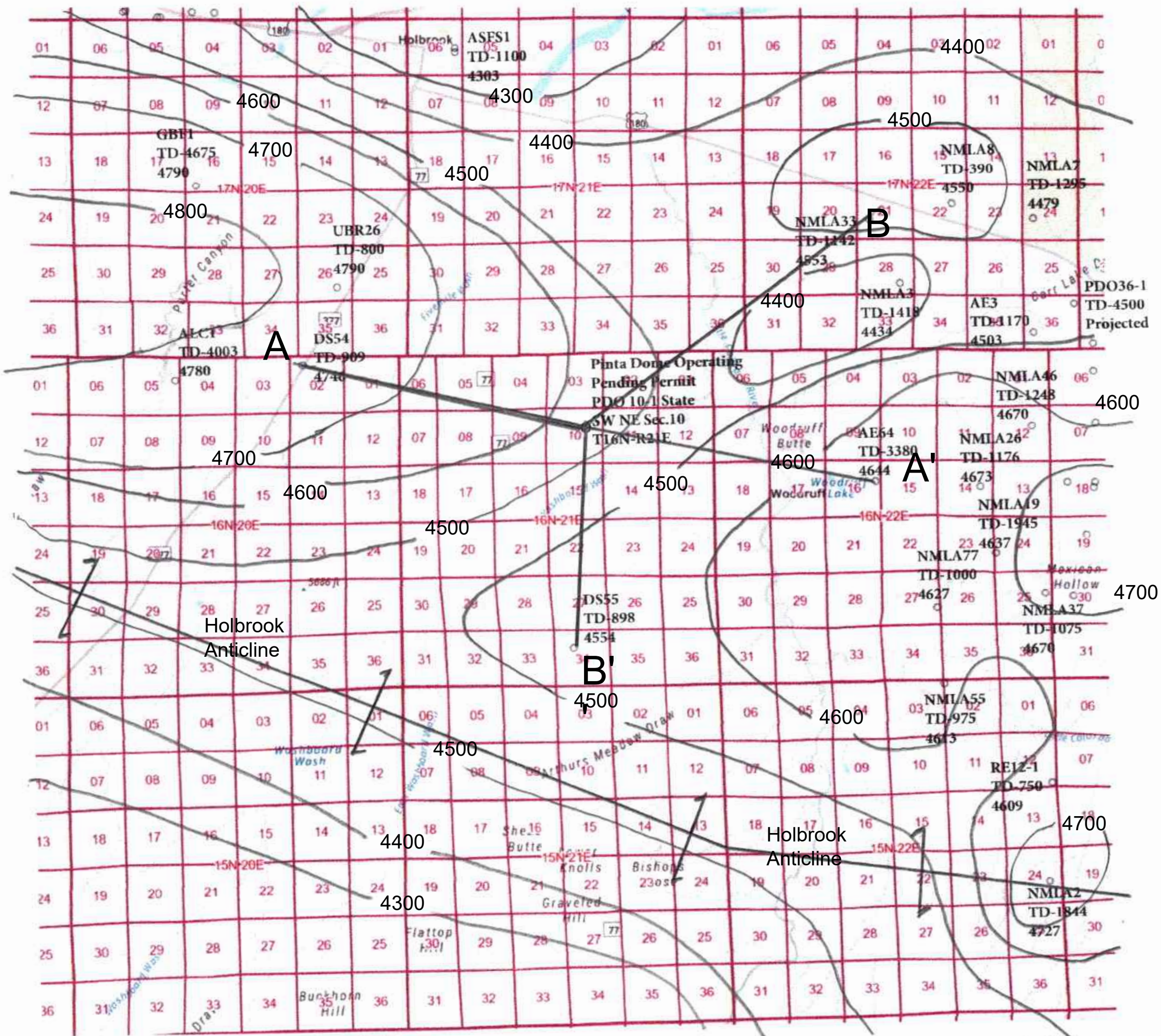
CONCLUSION

The PDO 10-1 State SW NE Sec.10-T16N-R21E Navajo Co., AZ is a "permit in progress" prospect based on seismic interpretation. The permit was submitted on 6/24/23 and has not been approved yet due to a delay from pending spacing exemption. With the closest offset/control wells 4 to 5 miles away to have a direct structural comparison to, it was necessary to reference regional/local structural geology for additional comparison.

The Structure Map on top of the Supai Formation shows the structure of the nine townships with T16N-R21E in the middle where the PDO 10-1 State is in section 10. The contours show the PDO 10-1 State to be between +4550 and +4600 elevation with the final elevation interpretation to be +4600 using the structure map and Cross Sections A-A' and B-B'.

The sections above discuss the Regional and Localized Structural Position of the PDO 10-1 State in reference to the Holbrook Anticline/Monocline. From the illustrations and accompanying discussion it is shown that the PDO 10-1 State lies on the structurally high side of the Holbrook Anticline/Monocline. This structural high position of the PDO 10-1 State indicates a good possibility of the formation of a gas trapping mechanism for helium.

Pinta Dome Operating LLC
Pinta Dome Operating 10-1 State
Permit in Progress
SW NE Sec.10-T16N-R21E
Navajo Co., AZ
Structure Map Top of Supai
Formation Permo-Pennsylvanian
Contour Interval 100 Feet

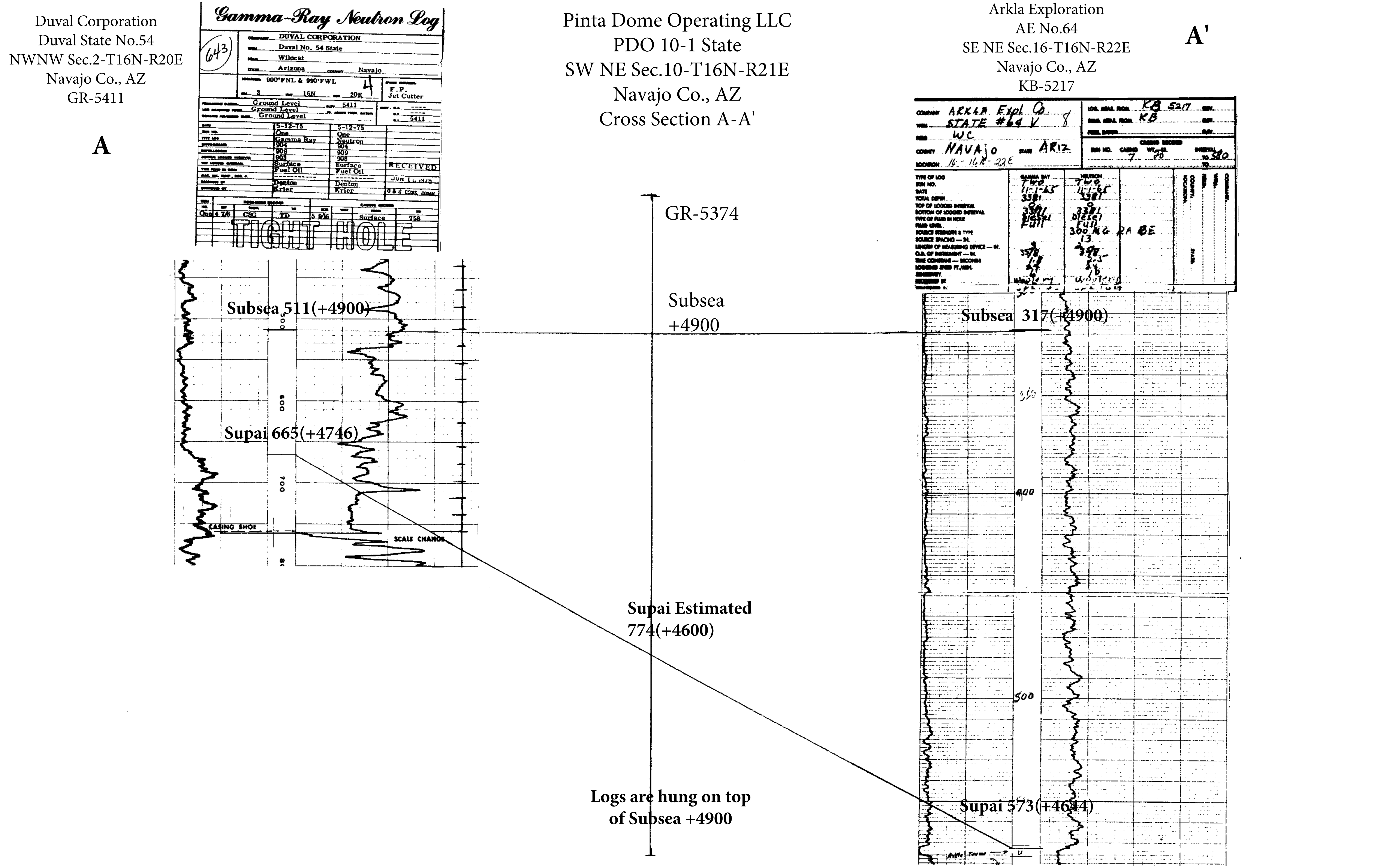


Randy Say
1/15/2024

Cross Section A-A'
DS54 (NW NW Sec.2-T16N-R20E) to
AE 64 (SE NE Sec.16-T16N-R22E)

Cross Section B-B'
NMLA33 (NW SW Sec.21-T17N-R22E) to
DS55 (SE NW Sec.34-T16N-R21E)

Pinta Dome Operating LLC
Pinta Dome Operating 10-1 State
Permit in Progress
SW NE Sec.10-T16N-R21E
Navajo Co., AZ
Structure Map Top of Supai
Formation Permo-Pennsylvanian
Contour Interval 100 Feet



Duval Corporation
Duval State No.54
NWNW Sec.2-T16N-R20E
Navajo Co., AZ
GR-5411
A
Gamma-Ray Neutron Log
DUVAL CORPORATION
Duval No. 54 State
Wildcat
Arizona
Navajo
TIGHT HOLE
Pinta Dome Operating LLC
PDO 10-1 State
SW NE Sec.10-T16N-R21E
Navajo Co., AZ
Cross Section A-A'
Arkla Exploration
AE No.64
SE NE Sec.16-T16N-R22E
Navajo Co., AZ
KB-5217
A'
GR-5374
Subsea 511(+4900)
Subsea
+4900
Subsea 317(+4900)
Supai 665(+4746)
CASING SHOE
SCALE CHANGE
Supai Estimated
774(+4600)
Supai 573(+4644)
Logs are hung on top
of Subsea +4900

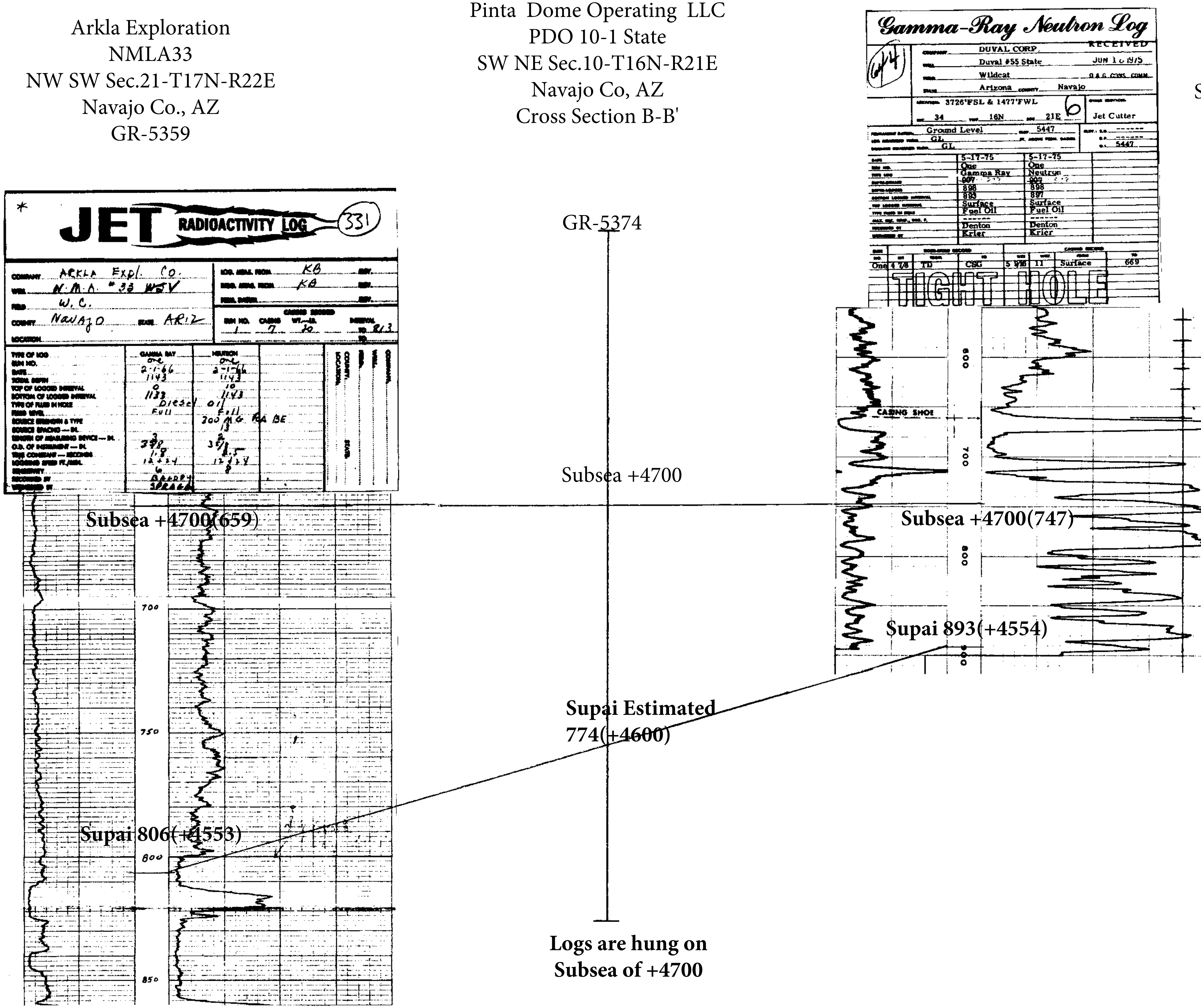
B

Arkla Exploration
NMLA33
NW SW Sec.21-T17N-R22E
Navajo Co., AZ
GR-5359

Pinta Dome Operating LLC
PDO 10-1 State
SW NE Sec.10-T16N-R21E
Navajo Co, AZ
Cross Section B-B'

Duval Corporation
DS55
SE NW Sec.34-T16N-R21E
Navajo Co., AZ
GR-5447

B'



part of the basin, and potash (sylvite) is present in the center of the basin. The interbedded anhydrite, carbonate, and sandstone sequence of the Fort Apache and Corduroy members of the Schnebly Hill Formation along the eastern margin of the basin (Wengerd and Methany, 1958) are correlative and laterally continuous with the Yeso Formation in New Mexico. Equivalent strata are not found in the Supai Group in the Grand Canyon, which explains why Blakey (1980, 1990) proposed different nomenclature for these strata. Mytton (1973) claimed this is the thickest Permian section in Arizona.

The Schnebly Hill Formation is approximately 600 m thick. The evaporite section in the Corduroy Member is more than 300 m thick (fig. 4). The Sedona Group is underlain successively by the Pennsylvanian Naco Group, Mississippian Redwall Limestone, and Devonian Martin Limestone; all units rest nonconformably on Precambrian crystalline basement.

The southern margin of evaporites is being dissolved by circulating ground water. The dissolution has produced a major subsidence and collapse zone with more than 500 dolines, depressions, fissures, and possible breccia chimneys (figs. 2–4). Salt removal apparently caused anomalously low gravity values measured within the general area of surface karst expression around The Sinks, but gravity is not anomalous in the Dry Lake Valley and McCauley Sinks areas (Lysonski and others, 1981). Peirce (1981) suspected that the regionally extensive development of these internally drained depressions occurred where salt is within about 300 m of the surface. Peirce (Arizona Geological Survey, 1994, oral communication) also suggested that the Holbrook basin may contain the largest active dissolution/collapse feature in the world, having been active since at least the Pliocene. Regional structural trends on the Mogollon slope are predominantly northwesterly. Joint systems in the study area strike about N55°W and N30°E (Kelley and Clinton, 1960); locally they vary by about 10°. These intersections are observed

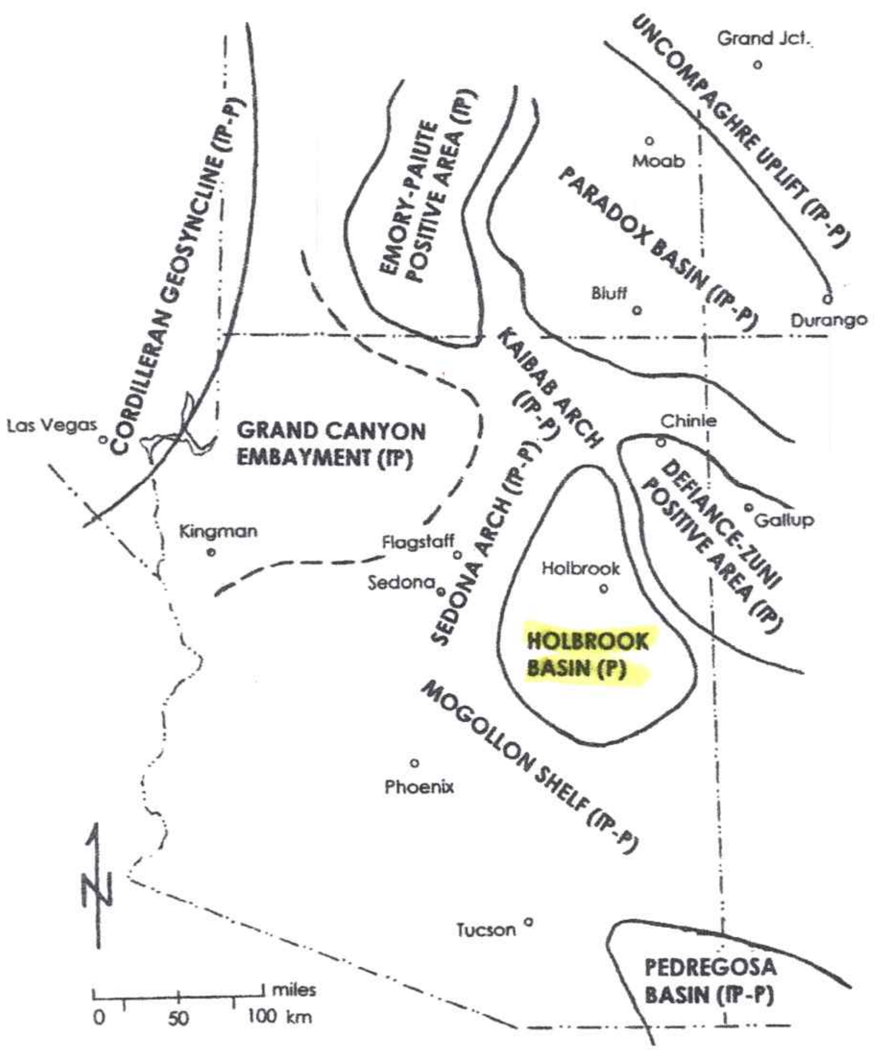


Figure 1. Late Paleozoic tectonics of the southern Colorado Plateau and vicinity showing the Sedona arch separating Holbrook basin evaporites from the Grand Canyon Supai sediment sequence (after Blakey, 1980).

VARIATIONS IN EVAPORITE KARST IN THE HOLBROOK BASIN, ARIZONA

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Abstract

At least six distinct forms of evaporite karst occur in the Holbrook Basin—depending considerably on overburden and/or bedrock type. Early Permian evaporites in the 300-m-thick Corduroy Member of the Schnebly Hill Formation include halite, sylvite, and anhydrite at depths of 215-250 m. Karst features result from collapse of overlying Permian and Triassic strata into underlying salt-dissolution cavities.

Evaporite karst occurs primarily along the 100+ km-long dissolution front on the southwestern edge of the basin, and is characterized by numerous sinkholes and depressions generally coincident with the axis of the Holbrook Anticline—in reality a dissolution-collapse monocline. "The Sinks" comprise ~ 300 individual sinks up to 200 m across and 50 m deep, the main karst features along the dissolution front. Westerly along the dissolution front, fewer discrete sinkholes occur, and several breccia pipes are believed to be forming. Numerous pull-apart fissures, graben-sinks, sinkholes, and broad collapse depressions also occur.

A newly recognized subsidence/collapse area of some 16 km^2 occurs in the western part of the basin, northward from the extension of the Holbrook "anticline." The Chimney Canyon area is some 12 km east of McCauley Sinks, a postulated breccia pipe exemplified in, and possibly manifested in at least four other closed depressions. Interferometric Synthetic Aperture Radar (InSAR) data of one depression shows active subsidence of ~4 cm/yr.

Karst formation is ongoing, as shown by repeated drainage of Dry and Twin Lakes into newly opened fissures and sinkholes. These two playa lakes were enlarged and modified in recent years into evaporation impoundments for effluent discharge from a nearby pulp mill. Four major drainage events occurred within these playa reservoirs during the past 45 years, collectively losing more than 1.23×10^7 m^3 (10,000 acre-feet) of water and playa sediment. Drainage occurs through piping into bedrock joints in Triassic Moenkopi Formation (sandstone) in the bottom and along the margins of these playas. Effluent discharge has been discontinued into these playas, although recurring precipitation can fill the basins.

Introduction

Evaporite karst in the Holbrook Basin of northeastern Arizona occurs above interstratal bedded evaporites, principally halite, in Permian sediments. The karst displays a variety of geomorphic features common to many carbonate-karst terrains (Jennings, 1985), including more than 500 sinkholes, fissures, depressions, and other features (Neal et al., 1998). The karst features are the subject of environmental concern because of increasing encroachment of residential and industrial development, and because of potential groundwater influx through surface karst openings.

Bahr (1962) was among the first to show that karst formation is still active, noting that a sinkhole visible on 1953 air photos had not existed 17 years earlier. New fissures and sinkholes have been observed many times since, with more recent activity in December 1995 on the south side of the collapse basin, and during 1996-8 in Dry Lake Valley, a major collapse depression that contains several artificially impounded playa lakes.

Local ranchers have continued to report periodic sinkholes forming when the valley floor flooded. These karst features are among the lesser known geomorphic curiosities in Arizona, but surely one of the most spectacular displays of evaporite karst in the United

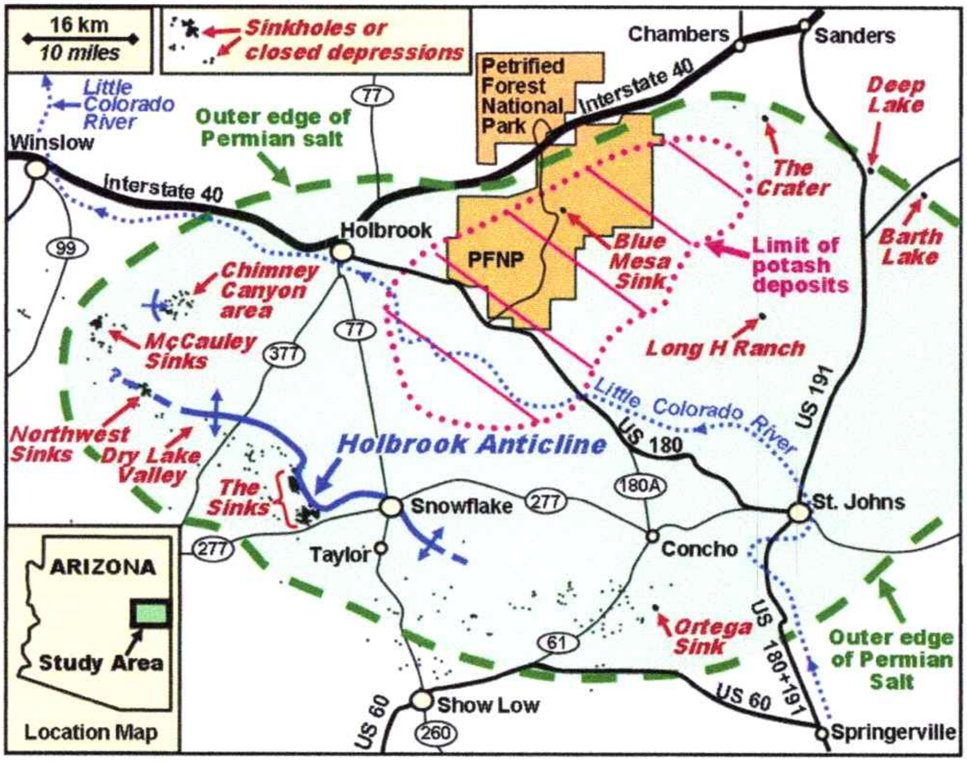

Figure 1. *Extent of Corduroy evaporite member with overlay of surface areas of karst features referenced in this article.*

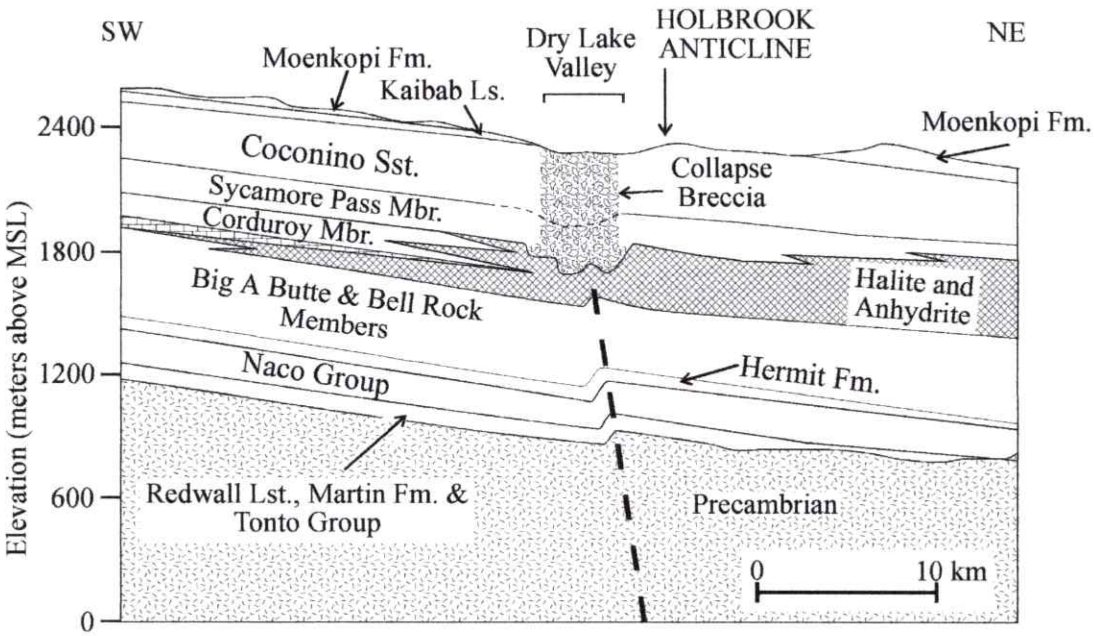

Figure 2. *Principal stratigraphic units associated with evaporite karst in the Holbrook Basin, Arizona. The Corduroy Member of the Schnebly Hill Formation (below Coconino Sandstone and above Hermit Formation) is the principal unit undergoing dissolution. Fault in Precambrian basement and pre-Corduroy Member strata is speculative.*

is self-perpetuating. Depressions and areas of possible breccia pipes conspicuously are near the outer limits of evaporites (Figure 1).

Initiation of Karst Development

Karst development required elevation of the Colorado Plateau, which began during the Late Cretaceous some 75 mya, with intensity increasing during the Neogene combined with northward movement of groundwater downslope from the Mogollon Highlands toward the integrated Colorado River drainage system.

Groundwater moved through the overlying Coconino Sandstone aquifer and began salt removal of the Corduroy evaporite member, continuing to the present. The groundwater encroachment upon evaporite beds and its consequent dissolution is particularly manifested in the southwestern part of the basin; the area of Dry Lake Valley resulted from the collapse of overlying strata into dissolution voids. The area along the Holbrook Anticline includes The Sinks, which contains 250 plus prominent sinkholes, and is perhaps the most conspicuous of karst features expressed in the Holbrook Basin.

The Holbrook Anticline, in fact a monoclinal dissolution flexure, extends northwesterly for more than 100 km from southeast of Snowflake, Arizona, nearly to Winslow, Arizona. Locally the flexure deforms the upper part of the Schnebly Hill Formation and the overlying Coconino Sandstone, Kaibab Formation (limestone), and Moenkopi Formation (Figures 2,4). The flexure produces tension along the top of the fold and compression at the bottom, creating significant open cracks at the top, and buckles at the bottom. The surface expression is locally named the Pink Cliffs, deriving its color from red beds of the Moenkopi Formation.

Originally the structure was referred to as the Holbrook Dome (Darton, 1925), and was once thought to be a combined fault and solution-related feature (Holm, 1938). Bahr (1962) suggested a non-tectonic dissolution origin for the structure and argued that the anticline apparently does not extend below the salt. He believed the structure is a flexure that resulted from dissolution and collapse of a narrow portion of the Mogollon Slope. Doeringsfeld et al. (1958) show this feature is parallel to many low-amplitude folds in the southwestern part of the Colorado Plateau. The persistence of parallel, NW-trending monoclinal structures over large areas of the Plateau (Kelley and Clinton, 1960; Wilson et al., 1960; Davis, 1978) is a compelling statement for structural control of dissolution effects. Peirce et al. (1970) also argued that the surface anticline expression is not seen in the subsurface beneath the salt, suggesting that dissolution played a major role; whether there is basement faulting at depth, as shown by Brown and Lauth (1958), is speculative. The principal sinkhole occurrences are in the Coconino Sandstone, almost exclusively on the steep, southwestern side of the flexure at six distinct locations.

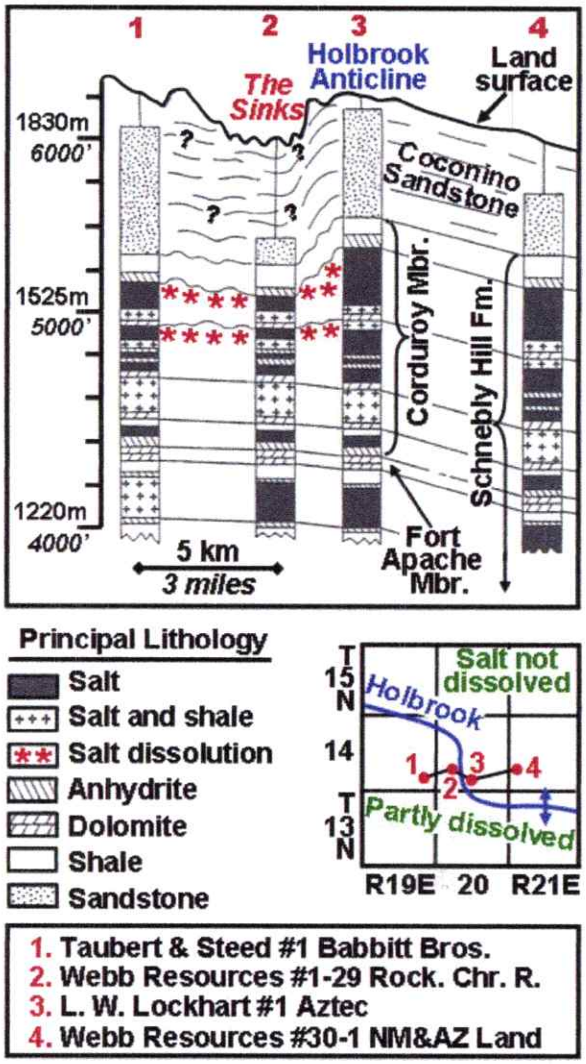

Figure 4. *Mechanism of sinkhole collapse along Holbrook Anticline at The Sinks, showing thinning of Corduroy member evaporites in well records (Dean and Johnson, 1989).*

The origin and timing of major dissolution and collapse is problematic, but sinkhole formation and collapse are ongoing, as noted previously, and probably began at least by Pliocene time. The uplift and tilting of the Colorado Plateau likely intensified the hydrogeologic environment, but the rates and timing of the orogenic processes are imperfectly known (Lucchitta, 1979). The close association of the dominant regional fractures and the Holbrook Anticline with sinkhole formation is conspicuous throughout the region, but this was not understood by early investigators. Accelerated dissolution of halite during pluvial stages of the Pleistocene seems likely, as intensified hydrogeologic processes are often noted elsewhere in the arid southwest (Smith and Street-Perrott, 1983).

Principal Varieties of Karst Expression

The Sinks and Adjacent Areas

The Sinks and adjacent areas are associated with the topographic expression of what has historically been called the Holbrook Anticline—perhaps originally named to foster interest in petroleum exploration. In fact, the ~50 m vertical-relief structural feature in bedrock is monoclinal and now known to result from dissolution of underlying salt beds. Near-orthogonal joint openings in Coconino sandstone follow a NW/NE direction common in this part of the Colorado Plateau (Kelley and Clinton, 1960). At many places along the dissolution monocline are collapse grabens that locally form incipient sinkholes, which may be the primary sinkhole-forming mechanism.

Numerous open fissures and sinkhole-growth patterns coincide with intersecting joints in the Moenkopi and Coconino Formations on the crest of the Holbrook Anticline adjacent to Dry Lake Valley (Figure 5). These fissures are up to 200 m long, 0.3-15 m wide, and as much as 30 m deep. Numerous stories surround these gaping features, some of which purportedly swallowed cattle and possibly two people, and have been described as "bottomless" by local residents. Field observations show that soil is collapsing into joint-fissures at depth, suggesting a similar mechanism for the appearance of piping features in the Dry Lake Valley drainage incidents. The crest and south flank of the Holbrook Anticline are in tension, which explains the open joint-fissures at the surface. Once open, these fissures form a conduit for ground water to penetrate to the relatively shallow (~250 m deep) salt beds below. Near the intersections of some fissure sets, joint-fissures show evidence of subsidence, suggesting how some sinkholes are initiated. The sinkholes occur less than one kilometer to the west and southwest of the monoclinal crest; one of these showed draping and overturning of beds in its collapse. Similar features in the Chimney Canyon area suggest common mechanisms of formation.

Figure 5. *Aerial view of The Sinks , looking south down monoclinal flexure toward collapsed Dry Lake Valley (see Fig. 4). Sinkhole locations are strongly influenced by joint openings and collapse grabens in Coconino Sandstone. Nearly 50 sinkholes are shown in this one view, the largest being 100m across.*

A group of 24 sinkholes, termed here "Northwest Sinks," occurs 10 km northwest of the open fissures, along the southwest-dipping crest of the Holbrook Anticline. Two particularly well developed sinkholes are conspicuously larger, deeper, and more regular than the others in this group and they may be younger. The surficial jointing that is so prominent at The Sinks is not nearly as evident here.

Playa Depressions

A series of major depressions and a playa-lake basin, called Dry Lake Valley, cover an area of more than 325 km^2 in the central and western part of the larger collapse zone. Sinkhole development and collapse are ongoing here, as attested to in local newspaper reports (Snowflake Pioneer, 1984). The artificially impounded Twin Lakes playa (reservoir) in the eastern part of Dry Lake Valley lost more than 6.8×10^5 m^3 (550 acre-feet) of water and sediment into open fissures connected to subsurface piping channels. These fissures occurred along a N 53° W trend, generally parallel to the regional structural trend (Sergent et al., 1984). The piping occurred along the reservoir margin during the first filling; presumably the newly formed surface fissures in the playa sediments, which extended for about 1.5 km in a 200-m-wide zone, overlie joint-fissures in Moenkopi redbeds that extend into the dissolution zone of the salt layers. The surface-drainage features filled with suspended sediment after

Pinta Dome/Holbrook Basin
Correlation Worksheet

	Pinta Dome Operating LLC	Offset/Control Well	
	Well Name		
	FNL FEL		
	Qtr Qtr Sec.xx-TxxN-RxxE		
	Co., AZ		
	Wildcat		
	LAT LON -		
	API No.02- GR		

TIME STRATIGRAPHIC	ROCK STRATIGRAPHIC	PROG	SMPL	KB	ELOG	KB	THICK	Elevation Difference	ELOG	KB	THICK	Generalized Lithology of Formations
Quaternary	**Quaternary Surface**											Alluvium, sand and gravel
	Unconformity											
Tertiary	**Bidahochi Formation**											Grayish-brown calcareous sandstone interbedded with silty mudstone and volcanic ash; bentonitic
	Upper Fluviatile Member											
	Middle Volcanic Member											
	Lower Lacustrine Member											
	Unconformity											
Triassic	**Chinle Formation**											Reddish-brown to grayish-blue mudstone and claystone with some silty sandstone; some limestone and gypsum in upper portion; siltstone and conglomeritic sandstone in lower portion
	Petrified Forest Member											
	Upper Part											
	Sonsela Sand											
	Lower Part											
	Lower Red Member											
	Shinarump Member											
	Shinarump Conglomerate											
	Unconformity											
	Moenkopi Formation											Brown to gray calcareous siltstone and mud-stone; slightly gypsiferous; very silty
	Holbrook Member											
	Moqui Member											
	Wupatki Member											
Not Present Pinta Dome	Kaibab Limestone											
	Unconformity											
Permian	**Coconino Sandstone**											Light gray to buff, fine- to medium-grained sandstone; loosely to firmly cemented with silica
Permo-Pensylvanian	**Supai Formation**											Reddish-brown sandstone, siltstone, and mud-stone; some dolomitic limestone; thick interbedded evaporitic sequence in upper portion
[Hermit Shale]	Corduroy Member [Evaporitic]											
	Fort Apache Member											
	Big A Butte [Basal Member]											
	Marker 1											
	Marker 2											
	Marker 3											
Dolomitic Siltstone	Amos Wash Member											
Pennsylvanian	**Naco Formation [LS]**											Limestone ltgy aphanitic crinoids chert abnt fos(bracs)
Mississippian	**Redwall Limestone**											Limestone red w/intbd SS and calc shales
Devonian	**Martin Formation**											Limestone dkgy fos occ lt-mgy w/lt pink Shales; abnt bracs & corals
	Unconformity											
Precambrian	**Precambrian**											Crystalline basement rocks
	TOTAL DEPTH-DRILLER											
	TOTAL DEPTH-STRAP											
	TOTAL DEPTH-ELOG											