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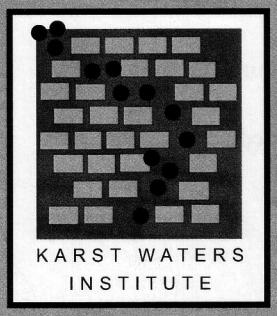


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# Hypogene Speleogenesis within the Central Basin Platform: Karst Porosity in the Yates Field, Pecos County, Texas, U.S.A.

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## INTRODUCTION

The Yates Unit Oil Field is located on the southeastern tip of the Central Basin Platform in eastern Pecos County, Texas (Figure 1). It produces from Middle Permian (Guadalupian) strata, primarily the upper San Andres Formation. Locally, the productive upper San Andres Formation is comprised of successively vertically stacked progradational shelf carbonates. On the east and southeastern sides of the field, the San Andres Formation was deposited on the seaward margins of the Central Basin Platform where facies exhibit the highest carbonate grain packing. On the western side of the Yates Field, facies are predominantly carbonate mud rich with evaporites, indicating deposition in a low energy shelf to supratidal environment. Stratigraphically overlying the Yates Field reservoir, the Toborg Field produces from the uppermost Triassic and Cretaceous units (Figure 2). Both fields are bounded on the north and east sides by the Pecos River, which has remained entrenched in its current location since the early Tertiary (Thomas, 1972). Structurally, the Yates Field is a combination stratigraphic structural high with a horseshoe-shaped anticlinal trap, as well as being characterized by conjugate fracture sets oriented at N50°W and N40°E (Tinker and Mruk, 1995). As mapped, the top of the San Andres Formation is an unconformity representing erosional topography that does not truly reflect the subsurface structural configuration.

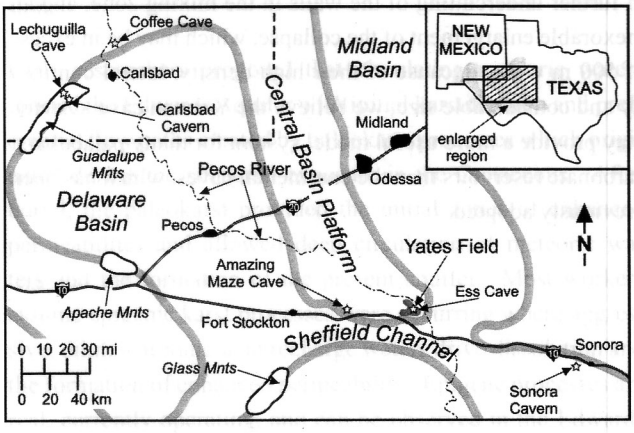


Figure 1. Location of Yates Field, showing relationship to the Central Basin Platform, Delaware Basin, Midland Basin and Sheffield Channel. Other features of significance include Carlsbad Cavern, Lechuguilla Cave, Amazing Maze Cave, Ess Cave and Sonora Cavern.

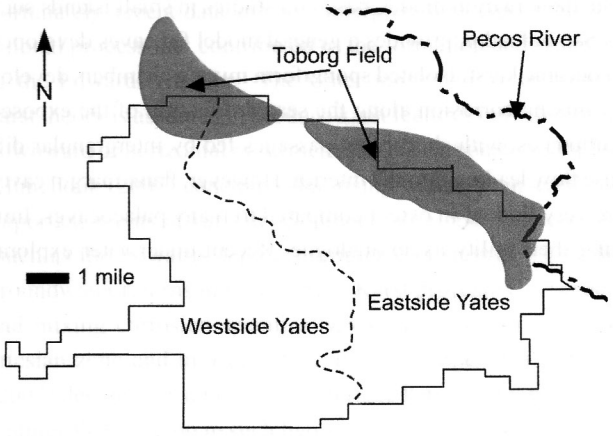


Figure 2. Map of Yates Field showing relationship between overlying Toborg Field and entrenched Pecos River. Note that the dashed line separates Eastside Yates, which is dominated by grain rich facies, and Westside Yates, which is dominated by mud-rich facies.

The Yates Field is well known as a karstic reservoir, which was recognized early in the field's production history (Hennen and Metcalf, 1929). Since the first well drilled in 1926, drilling within the Yates Field has commonly intercepted cavernous porosity and intensively fractured collapse breccias often characterized by bit drops and sustained very high flow rates. Coring efforts since the 1970s have confirmed the karstic nature of the Yates Field by documenting zones of cavernous porosity, voids containing sediment fills, collapse breccias and extensive secondary mineralization including both speleothems and spar fabrics. Craig (1988), Tinker and Mruk (1995) and Tinker et al. (1995) characterized the karst development as meteoric paleokarst associated with eogenetic, coastal speleogenesis because cavernous porosity and highly productive oil flow rates were associated with major increases in carbonate grain packing in the San Andres, which they interpreted as subaerially exposed grain rich shoals.

Since Kinder Morgan acquired Marathon Oil Company's operational interest in the Yates Field in 2003, studies have been initiated to reevaluate field reservoir characterization for improved tertiary recovery associated with $CO_2$ injection assisted gravity drainage. With recent advances in karst science, this includes a reinterpretation of the predominant speleogenesis associated with cavernous porosity, collapse fracture trends and secondary mineralization within the field. Our new model for the Yates Field proposes hypogene origins for the overwhelming majority of the karst development and karst fabrics described by Loucks and Mescher (2001) and Loucks, Mescher and McMechan (2004) within the Yates Field reservoir, which is consistent with karst development documented in many of the caves throughout the region.

## YATES FIELD KARST

Karst development within the Yates Field can be subdivided into porosity and permeability enhancement and secondary deposits, both of which provide valuable insight into the speleogenesis of the region. Karst porosity and permeability enhancement includes open caves, fracturing and brecciation of overlying strata as the cave roof collapsed, while secondary deposits include both clastic sediment fill and precipitated minerals.

Secondary porosity and enhanced permeability are commonly associated with open cavern voids and extensively fractured collapsed zones identified through bit drops within Yates Field, which range in height from 1 foot (0.3 m) to 21 feet (6.4 m),

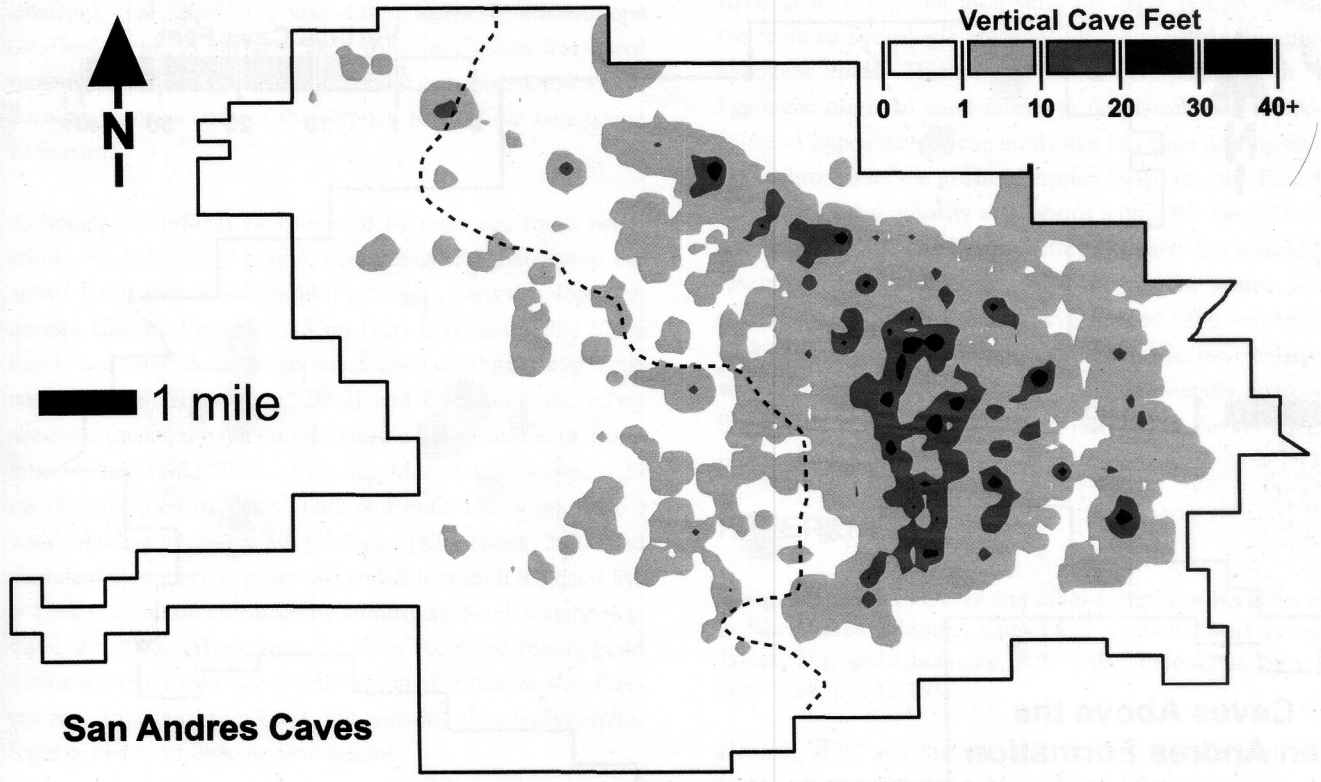


Figure 3. Spatial distribution of cavernous porosity within the San Andres Formation based on petrophysical analyses. Note that the most intense karst development occurs along the structural crest of the horseshoe-shaped anticline that dominates the eastern portion of the field.

but average 2.8 feet (0.8 m) (Craig, 1988). Similarly, zones of cavernous porosity and enhanced permeability, including both open voids and collapse breccias, can be identified through petrophysical analyses where low densities or significant caliper divergences indicate zones of intense solutional porosity. Analyses of petrophysical data for the Yates Field connected with the present study identified 1566 such occurrences with an average height of 3.9 feet (1.2 m). The resulting data indicate that porosity and permeability development within the Yates Field are highly clustered with the most intense development located along the present crest of the mapped structural high on the top of the San Andres Formation (Figure 3). Porosity development and permeability enhancement are not limited to the eastern portion of the Yates Field where grain-rich facies occur, nor are they limited to the San Andres Formation. Instead, the petrophysical data and bit drops within the Yates Field extend both into the western portion of the field (Figure 3) and into the overlying Grayburg, Queen and Seven Rivers formations (Figure 4).

Voids within the San Andres Formation in the Yates Field are commonly clastic sediment filled or filled to lined with secondary mineral deposits. Clastic sediments with the same composition of the overlying Grayburg or the overlying portions of the San Andres formations are often found as laminated sediments filling the bottoms of vugs and solutional fractures within the San Andres Formation. Throughout the Yates Field, carbonate, speleothem-like fabrics and calcite spar frequently line or completely fill solutional voids. Isotopic analyses ($\delta^{13}C$ PDB and $\delta^{18}O$ PDB) of secondary carbonate minerals indicate that carbonate speleothems are depleted in $\delta^{13}C$ relative to the host rock, while calcite spar is depleted in both $\delta^{13}C$ and $\delta^{18}O$ relative to the host rock, suggesting that the associated depositional fluids are compositionally different (Figure 5). Additionally, more exotic secondary minerals are found scattered throughout the San Andres Formation, including native sulfur, albite, galena and sphalerite, as well as uranium enrichment along vertical breccia pipes.

## CAVES OF PERMIAN BASIN REGION

While cavernous porosity and karst fabrics within the Yates Field can only be studied remotely through petrophysical and core analyses, cave and karst development within the greater Permian Basin region of West Texas and southeastern New Mexico provide clues to the dominant speleogenetic processes which have affected the region. The world famous caves of the Guadalupe Mountains (e.g., Carlsbad Caverns and Lechuguilla Cave) have traditionally been associated with sulfuric acid dissolution (Hill, 1990), but recently they have been more

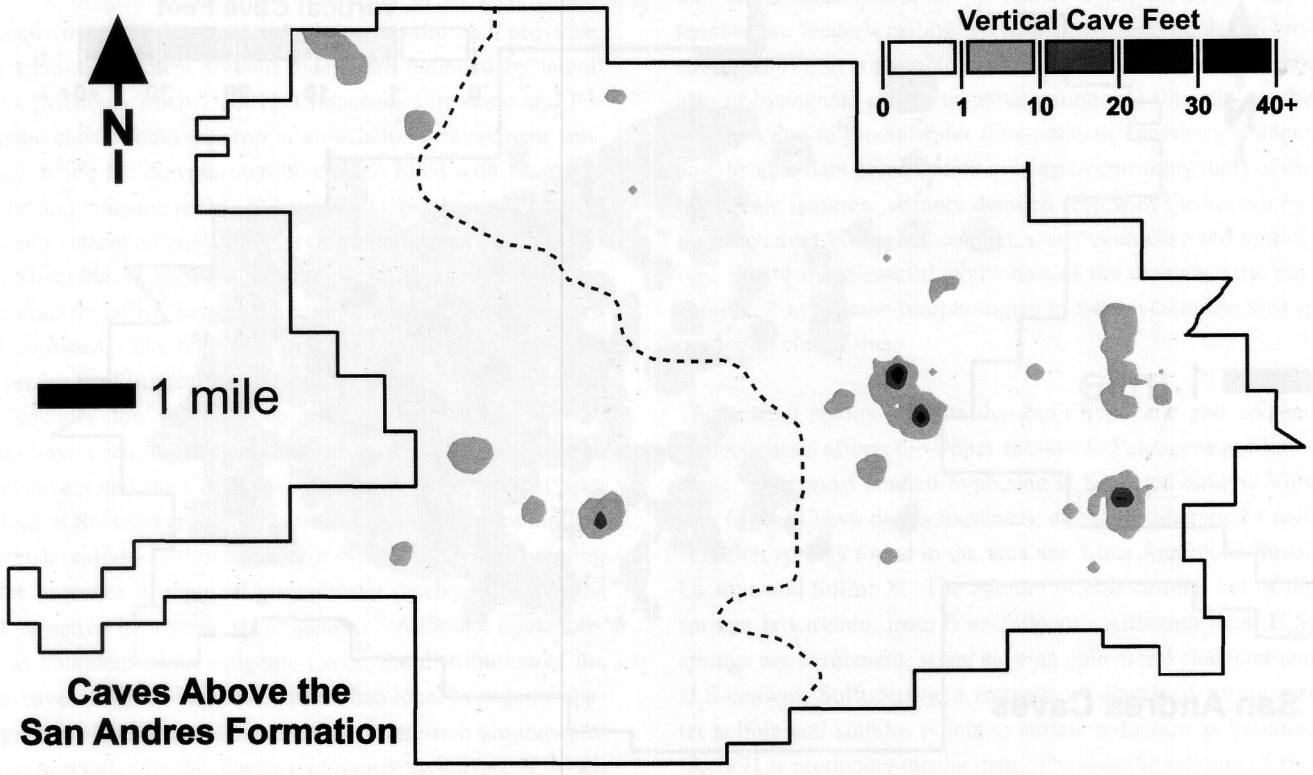


Figure 4. Spatial distribution of cavernous porosity within the Grayburg, Queen and Seven Rivers Formations based on petrophysical analyses. Note the highly clustered distribution of cavernous porosity.

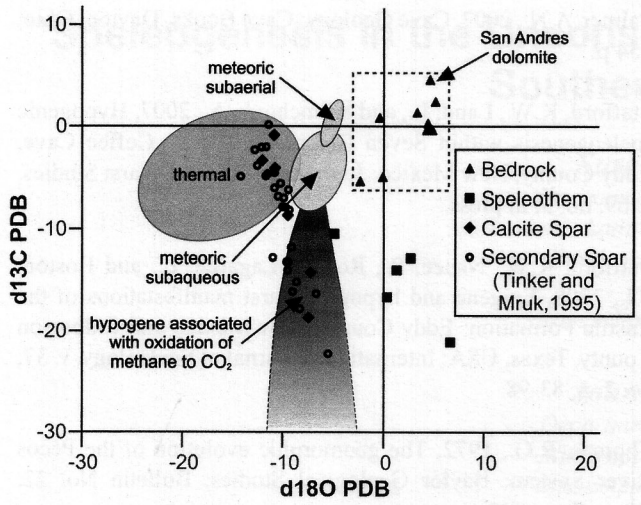


Figure 5. $\delta^{13}C$ (PDB) and $\delta^{18}O$ (PDB) isotopic analyses of dolomite bedrock, banded carbonate "speleothems", calcite spar and secondary calcite spar reported by Tinker and Mruk (1995). Note that no secondary mineralization falls within the range of meteoric mineralization. Shaded regions represent secondary carbonate mineralization associated with speleogenesis in the western United States as defined by Palmer (2007).

specifically classified as hypogene caves where confined dissolution within the Capitan Reef was enhanced by upwardly migrating sulfuric acid-rich waters (Palmer, 2006; Klimchouk, 2007). Similarly, recent work within the evaporitic backreef (Stafford, et al., 2007) and basin-filling facies surface outcrops (Stafford, et al., 2008) associated with the Capitan Reef have identified the widespread occurrence of hypogene karst within Permian strata outside of the Capitan Reef of the Guadalupe Mountains.

Although no surficial exposures of Permian age rocks occur within the Yates Field region, Cretaceous carbonates crop out across the region, which exhibit extensive karst development. Sonora Cavern, located ~ 75 mi (120 km) east of the Yates Field, is a three dimensional maze cave exhibiting hypogene morphologies (Klimchouk, 2007) and containing secondary minerals (metatyuyamunite) diagnostic of sulfuric acid dissolution (Onac et al., 2001). Amazing Maze Cave, located ~ 25 mi (40 km) west of Yates Field, is a multi-storey maze cave with abundant hypogene morphologies (Klimchouk, 2007) and abundant secondary gypsum and endellite, which indicates hypogene dissolution enhanced by sulfuric acid-rich waters. Ess Cave, directly overlying both the Yates Field and Toborg Field within the study area, is considerably smaller than Sonora Cavern and Amazing Maze Cave, but contains abundant morphologic evidence of its hypogene origins.

## CONCLUSIONS

Our proposed hypogene model for cave development and formation of karst fabrics offers an alternative to the prevailing North American paleokarst reservoir emphasis upon meteoric or eogenetic processes. Our proposal offers a different mechanism other than subaerial exposure and infiltration of meteoric fluids or freshwater / saltwater mixing to form caves and karst fabrics. These karst fabrics were described most recently by Loucks and Mescher (2001) and Loucks, Mescher and McMechan (2004), but attributed solely to eogenetic speleogenesis. However, our current research on the Yates Field indicates that cavernous porosity, enhanced permeability due to collapse fabrics and secondary mineralization within the upper San Andres reservoir are overwhelmingly due to hypogene speleogenesis. The spatial distribution of caves defined earlier within the Yates Field exhibits clustering and intense development along lithologic and structural boundaries, which is typical of hypogene dominated systems. Isotopic analyses of secondary carbonate minerals and the presence of unique secondary minerals suggests that multiple episodes of hypogene fluids of differing compositions are associated with the Yates Field, including both thermal and sulfuric acid-rich fluids. The location of the Yates Field and overlying Toborg Field in relation to the nearby Pecos River suggests that continuous downcutting of the Pecos River at its current location since the early Tertiary provided the regional hydrologic potential for the upward migration of hypogene fluids. This new model for cavernous porosity and hypogene origin of karst fabrics is consistent with the dominance of hypogene speleogenesis that has been documented in caves throughout the greater Permian Basin region. Based on our model, karst porosity and fabrics within the Yates Field do not represent meteoric or eogenetic paleokarst, but instead represents the continued evolution of a hypogene system where solutionally aggressive fluids have formed cave systems, including some that are still open and others that have collapsed, which display karst breccia fabrics. Solutionally aggressive fluids have been replaced by hydrocarbons as the system continues to evolve.

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