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Uranium in Igneous Rocks of Central Davis Mountains, West Texas

The central Davis Mountains are remnants of a Tertiary eruptive center composed of layered extrusives and a few shallow intrusions. Rock types range from basalts to trachyandesites, latites, trachytes, syenites, and rhyolites.

Delayed-neutron counting was used to determine uranium abundance in 102 rock samples representative of all rock types. Thin sections of 72 samples, 30 with fission-track data, were analyzed for petrography, mineralogy, and uranium distribution and mode of occurrence. Major-element analyses for 23 samples were obtained for comparison with trends in uranium abundance.

Uranium abundance increases in general with $SiO_2$ and $K_2O$ content, and ranges from a mean of 1 ppm in basalts and andesites to 7 ppm in rhyolites. Uranium is most abundant in welded tuffs, in contrast to lava flows and shallow intrusions. Hydrothermal alteration redistributes uranium; unaltered rocks have significantly more uranium than altered rocks of all types. Glassy rocks contain up to one-third more uranium than their crystalline counterparts. In a vertical section through three rhyolitic-welded tuff units, uranium increases progressively from the oldest unit to the youngest; within each of two of these units, uranium also increases upsection. Further, rhyolitic-welded tuffs from the southwest part of the area contain 50% more uranium than those from the east; the eruptive source, however, has not been located.

Within a given rock type, uranium occurs preferentially in accessory minerals, in areas surrounding hydrothermally leached zones, and in vein fillings. Coarse-grained rocks have more localized concentrations of uranium than aphanitic or glassy rocks.

Ground-water leaching of uranium from igneous rocks of the central Davis Mountains is not considered an effective mechanism for uranium redistribution and enrichment because of the low permeability of the rocks and the nature of occurrence of uranium. Therefore, the probability of occurrence of large secondary uranium deposits in the area is not high.

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Stratigraphic and Paleo-Oceanographic Setting of Organic Carbon-Rich Strata Deposited During Cenomanian-Turonian "Oceanic Anoxic Event"

At, or very close to, the Cenomanian-Turonian boundary, strata from several basins bear the imprint of a global, short-lived "oceanic anoxic event" during which large amounts of organic carbon were sequestered in marine sediments. These strata are characterized by one or more of the following features. (1) The presence of a layer, up to 1 m (3.3 ft) thick, of black, laminated shale with total organic carbon contents of up to 23%. The general lack of bioturbation in these shales indicates an absence of benthic metazoan in fauna; the organic carbon is largely of marine planktonic origin. (2) The limestones, with or without an associated black shale horizon, at the Cenomanian-Turonian boundary level, have $\delta^{13}C$ values of +4.0 to +4.3 ‰ as contrasted to $\delta^{13}C$ values of +2.0 to +3.0 ‰ exhibited by limestones immediately above and below the boundary horizon. (3) Benthic foraminiferal faunas are lacking or consist of depauperate agglutinate faunas whereas radiolarians are locally very abundant as are diverse planktonic foraminiferal faunas.

These features are interpreted as indicating deposition in many areas within a water mass that was essentially depleted of oxygen. The high $\delta^{13}C$ values are taken to indicate enrichment of the global ocean in $\delta^{13}C$ as a result of the preferential extraction of $^{12}C$ by marine plankton whose organic components were not recycled into the oceanic waters.

The basal and upper contacts between the black shales and the enclosing limestones are generally sharp or gradational over a distance of several centimeters indicating a rapid onset and equally rapid disappearance of deoxygenated waters. Sedimentation rate arguments lead to the conclusion that the Cenomanian-Turonian "oceanic anoxic event" occurred over a time span of approximately 350,000 to 700,000 years.

Paleobathymetric interpretation of strata from European and African shelf sequences and sections in the U.S. Western Interior basin show that shallow embayments, flooded by the rapid Cenomanian-Turonian transgression were particularly hospitable to deposition of anoxic sediments as were the neighboring shelves and cratonic shallow seaways. The distribution of the black shale unit indicates that the upper surface of the Cenomanian-Turonian oceanic oxygen-minimum zone was 200 to 300 m (650 to 985 ft) below the sea surface analogous to that of today.

The widespread distribution of anoxic sediments deposited synchronously during such a short-lived event indicates that such sediments were not the product of local climatic or local basinal water mass characteristics but were the product of a global expansion and intensification of the Cenomanian-Turonian oxygen-minimum zone. In some regions this was accompanied by increased biological productivity in surface waters.

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Development of Diagenetic Seals in Carbonates and Sandstones

Diagenetic seals effectively block the movement of reservoir hydrocarbons in many sandstone and carbonate rock units. Diagenetic processes that create these trapping seals include (1) chemical compaction through pressure-solution of silicate and carbonate minerals, (2) concentration of insoluble clay minerals and organic matter during chemical compaction, (3) cementation by authigenic minerals, (4) volume increase of rock constituents resulting from hydration or replacement, (5) coalescive recrystallization, (6) mechanical deformation of ductile constituents, and (7) implacement of immobile organic residue derived from crude oil and natural gas. Sealing cements include silica minerals, clays, zeolites, carbonates, sulfates, chlorides and, subordinately, several other mineral groups. The sealing capacity of the rocks is related to (1) the amount of residual porosity, (2) the pore geometry, (3) the modulus of elasticity, (4) the resealing capacity, and (5) the phases and physical properties of pore-filling media.

Diagenetic seals develop in a wide array of diagenetic environments during eodiagenesis (before burial), mesodiagenesis (during burial), and telodiagenesis (after burial). Diagenesis can convert any sandstone or carbonate lithology into a sealing rock. The direct factors that control the formation of diagenetic seals include (1) textural and mineralogical composition, (2) degree of lithification, (3) burial history, (4) fluid regime and history of chemical composition, pressure, and migration of pore-filling media, (5) thermal history, and (6) tectonic stress. These direct factors are, in turn, controlled by other parameters such as the lithology of intercalated sediments, tectonic history, structural position, and spatial relationship to unconformities or faults.

Diagenetic seals in sandstones and carbonate rocks encase reservoir rocks with either depositional or diagenetic porosity. Diagenetic reservoir porosity may originate before or after the establishment of an effective diagenetic seal. Hydrocarbon traps with diagenetic seals may conform in their geometry as well to structure or stratigraphy as to diagenetic facies. Therefore, some structural and stratigraphic traps may, in part or entirely, depend on diagenetic seals.

An example of such sealing is the Recinus Cardium "A" pool. In this field, lateral, top, and bottom sands have formed as a result of mesogenetic cementation at the margins of the sand body. The limiting injection pressure in these seals is approximately 550 psi (3,790 kPa) (mercury against air), which translates to a pore throat radius of 0.195 microns. This seal could effectively withstand a hydrocarbon-water injection pressure of 51 psi (352 kPa), which represents a trapped hydrocarbon column of between 200 and 500 ft (61 and 92 m). This clearly indicates that diagenetic seals can be tremendously effective.

Detailed analysis of diagenetic seals in sandstones and carbonate rocks can considerably improve our ability to predict their occurrence and to recognize their spatial and temporal relationship to reservoir rocks and hydrocarbon migration.

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## Genetic Characterization of Natural Gases

An empirical model is presented in which the origin of most natural gases can be deduced from compositional variations in the gases.

The genetic characterization is performed using the $C_{2+}$ composition of the gases, the $^{13}C$ concentration in methane ($\delta^{13}C_1$) and ethane ($\delta^{13}C_2$), as well as the deuterium concentration in methane $\delta D$. Three diagrams are designed in which $C_{2+}$, $\delta^{13}D$, and $\delta^{13}C_2$ are plotted versus $\delta^{13}C_1$. In these three diagrams, compositional fields can be defined for primary gases, i.e., those gases for which compositional changes are due to processes occurring during their formation (biogenic and thermogenic associated and nonassociated gases, respectively). Secondary gases result from mixing processes after formation of gases. The variability of natural gases can be described by (and reduced to) predominantly various mixing processes of primary gases. Two types of migration of gases can be recognized: shallow migration where thermogenic gases are stripped of $C_{2+}$ or become mixed with biogenic gases, and deep migration where deep dry gases become mixed with gases from more immature sources. Case histories will be presented to demonstrate the applicability of the model.

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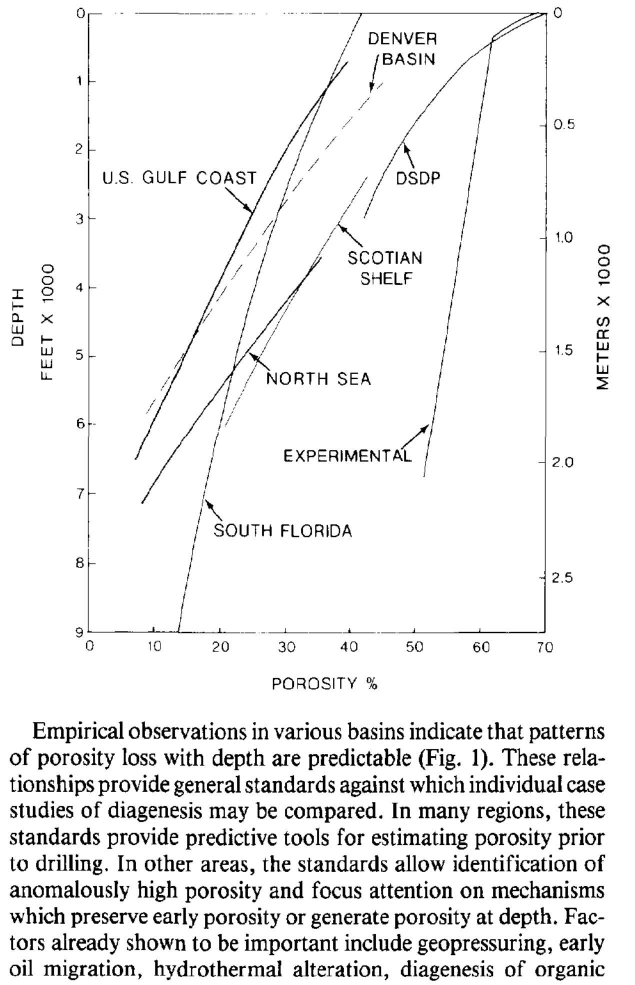
## Burial Diagenesis in Carbonate Rocks

Burial diagenesis, those changes in rock composition, mineralogy, and texture which occur below the zone of near-surface water circulation, generally becomes the dominant control on rock porosity at depths below a few hundred meters. Experimental, observational, and geochemical data show that porosity loss through burial diagenesis results from both physical and chemical compaction. In near-surface sections, dewatering, grain reorientation, grain breakage, and other mechanical processes lead to sediment/rock porosities as low as 30%. Continued porosity loss requires a combination of mechanical compaction, chemical dissolution at grain contacts and along solution seams, and reprecipitation as intergranular cement. Through these mechanisms carbonate rock porosity may be reduced to values near zero in "semi-closed" systems without significant introduction of allochthonous cementing material. Therefore, cementation may occur in systems where the only fluid movement is water expulsion.

Significant rates of noncompactional fluid flow increase the likelihood of cementation and make the identification of cements more complex. Such cements may be deposited by hydrothermal, artesian, or thermally convective fluids. Current research suggests that a combination of geochemical and petrographic criteria may eventually serve to distinguish cements of various origins.




Empirical observations in various basins indicate that patterns of porosity loss with depth are predictable (Fig. 1). These relationships provide general standards against which individual case studies of diagenesis may be compared. In many regions, these standards provide predictive tools for estimating porosity prior to drilling. In other areas, the standards allow identification of anomalously high porosity and focus attention on mechanisms which preserve early porosity or generate porosity at depth. Factors already shown to be important include geopressuring, early oil migration, hydrothermal alteration, diagenesis of organic matter, and dolomitization. Comparisions of oil field porosities with standard curves allow us to refine our basic understanding of diagenesis as well as our ability to predict reservoir quality.

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## Current Research in Geological Applications of Remote Sensing Techniques and Implications for Petroleum Geology

Exploration geologists have made extensive use of aerial photography and orbital Landsat imagery, primarily for purposes of structural mapping. The Landsat 4 spacecraft launched in July 1982 is carrying a new imaging instrument called the Thematic Mapper which represents a significant advance over earlier Landsat sensors. The Thematic Mapper possesses improved