Mountains where a zone of imbricated thrusts follows the southern margin of the eastward-trending Helena embayment of the Belt basin.

Movements along major thrusts north and south of this east-trending zone are nearly pure dip-slip. Movements within the zone are demonstrably oblique with nearly equal components of dextral and reverse slip. This suggests that the fault zone may be described as being one of tear-thrusting.

Accumulated net slip along the tear-thrust zone may be estimated by summing estimates of net slip along the individual faults which comprise the zone and by examining displaced isopach lines for rocks deposited prior to faulting. Summing net-slip estimates for individual faults along several sections though the fault zone indicates that the horizontal components of net slip is between 15 and 30 km. Right separation of isopach lines for a limestone member of the Kootenai Formation (Cretaceous) indicates a horizontal displacement which is somewhat larger (between 30 and 60 km). Displacements of this magnitude cannot be accounted for by folding and minor thrusting in the rocks north of the tear-thrust zone and strongly suggests one or more zones of detachment within the section above Archean basement rocks.

Estimates of net horizontal displacement along this fault zone can be very useful in interpreting anomalous isopach trends such as those seen in the Flathead Sandstone (Cambrian) and Maywood Formation (Devonian).

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Depositional Environment of Dry Hollow Member, Upper Cretaceous Frontier Formation, Southwestern Wyoming

The Dry Hollow Member of the Frontier Formation in southwestern Wyoming consists of alluvial deposits that accumulated along part of the western margin of the Western Interior Cretaceous seaway. Typically, the lower part of the Dry Hollow Member contains sandstone bodies 4 to 15 m thick that fine upward and possess basal conglomeratic lenses. These units are interpreted as channel deposits of meandering streams, with the conglomerates having formed as channel-lag deposits. Commonly, silicified wood, plant fragments, freshwater gastropods, and intraformational shale clasts are present in these deposits. Medium-scale trough cross-stratification is dominant and indicates a general west to east paleocurrent direction.

The upper part of the Dry Hollow Member is dominated by interbedded shales, coals, and thin (0.2 to 1 m) fine-grained sandstones. The shales contain abundant carbonaceous plant material, silicified wood, and lignitic layers. Root horizons are commonly preserved within large (0.3 to 1 m) concretions that formed in the shales. The interbedded fine-grained sandstones are typically small-scale trough cross-stratified and contain abundant plant material. These sandstones are interpreted as near-channel overbank deposits that accumulated during periods of stream flooding, while the shales and coals represent vertical accretion deposits of interchannel swamps and lowlands that accumulated farther from the stream channels.

Analysis of these deposits suggests that a wet, poorly-drained fluvial lowland dominated by meandering streams and coal swamps existed along the Western Interior Cretaceous seaway during deposition of the bulk of the Dry Hollow Member of the Frontier Formation.

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Cenozoic Deep-Water Benthic Foraminifers

Cenozoic deep water deposits have yielded rich and diversified faunas of benthic formaminifers. From still limited data, it is clear than these faunas were depth stratified and that most species were cosmopolitan in distribution. The wide distribution and species richness, together with faunal turnover, which in places was very abrupt, points to great biostratigraphic potential. High turnovers delineate distinct Paleocene, Eocene, and Oligocene-early Miocene faunas. A gradual but profound wave of extinction and speciation occurred during the middle Miocene and by late Micene had created the modern deep water faunas.

Superimposed upon these evolutionary developments are strong changes in depth preference, particularly among those species that persist across the turnover periods. During the Paleocene-Eocene transition some species became restricted to the bathyal realm while others preferred the abyss. During the Eocene-Oligocene transition a net downward depth range extension of bathyal species occurred. During the late Miocene the periodic vertical migrations of bathyal and abyssal faunas that so strongly characterize the Quaternary began to appear. In the North Atlantic, such depth range excursions may extend over more than 1,500 m.

The evolutionary and bathymetric changes of benthic faunas are their response to the evolution of the deep water environment, particularly the establishment of the cold water sphere during the late Eocene, and the addition of the North Atlantic as a source of cold water during the middle Miocene. The late Cenozoic depth changes are indicative of periodic rearrangements of the deep ocean circulation in response to climatic change at the earth's surface.

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Surface Features and Geology of Selected Cores from Elizabeth Reef, Tasman Sea, Australia

Elizabeth reef is one of the southernmost coral reefs in the world. Located at approximately 30°S latitude in the Tasman Sea, this atoll is situated near the southern limit of environmental tolerance for reef formation. The atoll has a well-developed outer reef flat encrusted with calcareous red algae and a lagoon consisting of patch reefs, sand flats, and a central mesh reef complex. A relatively small number or coral species occur, and significant coral growth is restricted to the lagoon. Offshore there is a well-developed erosional spur and groove zone (0 to 8 m), a deeper buttress zone (9 to 30 m), and a carbonate sand flat (30 to 40 m) before the steep seaward drop-off. Detailed evaluation of eleven rotary cores from the Elizabeth reef flat indicates that a period of more active coral growth existed in the past. C^{14} age dates on scleractinian corals from the cores indicate a maximum age of about 7,000 years B.P. in the upper 3 to 4 m of the reef flat with maximum accumulation rates of approximately 90 cm per 1,000 years. The atoll has reached equilibrium with sea level, and it is now influenced more by erosion than growth.

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Prediction of Caprock Seal Capacity

Caprock seal capacity is a function of pore size, rock integrity, regional continuity, and thickness. Calculations of the oil or gas the pore system of a rock can seal can be made by Smith's 1966 formula:

$$H = \frac{PdB - PdR}{(pw\text{-}ph) \times 0.433}$$

Data necessary to make these calculations are: pore size, oil and water density, oil-water interfacial tension, and wettability.

Rock integrity, or lack of open fractures, controls whether or not the pore system of the rock will be dominant in controlling seal capacity or of minor importance. Rock integrity is a function of mechanical properties, structural stress and fluid pressures in the subsurface. Mechanical properties can be measured in the laboratory and qualitatively used to estimate rock integrity when incorporated with subsurface stress conditions.

Samples from seals for 27 reservoirs were collected and analyzed for detailed lithology, pore size, and rock mechanical properties. On the basis of this sampling, all major rock types can act as local caprock seals for hydrocarbons. Evaporites and ductile clay shales are the most likely rock types to act as regional caprock seals because of their small pore size and ductile mechanical properties. Limestones, dolomites, siltstones, and sandstones can act as local caprock seals based on this sampling.

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Prediction of Lateral Seal Capacity from Core Data

Mystery Reef field produces oil from a porous stromatoporoid, limestone reef buildup. Only a small part of the total reef porosity is filled with oil. The maximum oil column in the field is 120 ft (37 m). The upper half of the column is sealed by marine shales that filled in depositional topography. The lower half of the oil column is sealed by the reservoir-equivalent fore-reef facies.

Lateral seal capacity, in terms of vertical oil column, were calculated from capillary pressure curves for five wells updip from the field. The seal capacity for the lowest displacement pressure rock in each well ranged from 10 to 150 ft (3 to 46 m). This spread of values for the updip reservoir equivalent facies at Mystery Reef field suggests that the prediction of lateral seals from core samples can provide only a very rough approximation of seal capacity in heterogenous carbonate rocks.

Two of the five wells studied updip from the field were oil stained in the reservoir equivalent horizon. Calculations of the minimum oil column necessary to explain the oil shows in these rocks range from 10 to 84 ft (3 to 26 m). Seal capacity of the higher displacement pressure oil stained rocks ranges from 60 to 84 ft (18 to 26 m). These values are similar to the oil column known to be trapped by the sampled fore-reef facies. Estimates of lateral seal capacity from core data should put the greatest emphasis on the oil stained samples with the highest seal capacity.

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Core and Log Analysis for Subtle Trap: Cotton Valley Tight Gas Sand

Several Cotton Valley zones that appear wet from standard log calculations have proven to be gas productive in recent months. In an attempt to understand this phenomenon, a case study was performed in conjunction with Champlin Petroleum Co. on cores from the Carthage field, east Texas. The zone studied was of low resistivity (less than 2Ωm) which, when combined with porosity (16%), calculates very high water saturation (>60%) using the standard Archie equation and m = n = 2.

Geologic studies indicate the low resistivity zone was deposited as a middle to upper bar sequence exhibiting massive and laminated bedding while a normal resistivity zone (~8Ωm) immediately below exhibits both a dense characterless section and a lower bioturbated facies with marine trace fossils.

Examination of the pore system using an SEM shows authigenic illite (identified by XRD) lining the pores and pore throats in both zones. Authigenic clay precipitation was subsequent to the development of quartz overgrowths and prevented complete occlusion of the pore system by the quartz. Secondary intergranular porosity is developed where feldspar grains have undergone dissolution.

The total porosity of the low resistivity interval (16%) is twice that of the normal resistivity zone (8%). Permeability is low throughout the interval (< 20 md), but somewhat higher in the low resistivity zone. Cation exchange and surface area measurements indicate that the authigenic clay is of equal volume in each zone. However, electrical measurements suggest greater rock conductivity and lower m and n Archie parameters in the low resistivity zone. The petrophysical and geologic data collected on the Cotton Valley provided more realistic petrophysical parameters for water saturation calculations, and led to a better understanding of the pore network and origin of the low resistivity interval.

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Evaporitive Limestone: Its Generation and Diagenesis

The Calcare-di-base is the only significant carbonate facies of the upper Miocene evaporites of Sicily. It was deposited within an exceedingly saline but marine water body adjacent to older, exposed carbonate terranes which surround the depositional basin. This somewhat dolomitic limestone is commonly cavernous or brecciated at outcrop and contains numerous zones of evident halite dissolution. It also interfingers with thin gypsum stringers in many areas and overlies diatomites of variable thickness. Based on petrographic and isotopic studies, it appears that this limestone was produced by diagenetic processes from an origininal aragonitic mud containing displacive halite hoppers and massive halite zones. Regional variation in carbon-13 (δC^{13} from 0 to 49 ppt PDB) and oxygen-18 (δO^{18} from +6 to −5 ppt PDB) can be tied to variations in the mineral content of the original sediment and to later diagenetic waters and their organic content. The very negative carbon-13 values and the presence of native sulfur are indicative of the calcitization of gypsum, the by-product of the life processes of sulfate-reducing bacteria. These bacteria utilize part of the available and commonly copious organic matter associated with both the carbonate and with the diatomite. Inversion of the original aragonite to calcite has resulted in expulsion of strontium from the carbonate crystal lattice and the formation of celestite ($SrSO_4$) which now fills the voids left by the dissolution of halite, and the associated pore spaces.

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