and Trench sediment is limited because the pelagic clay units consist only of thin Quaternary veneers.

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Geology and Development of Teak Oil Field, Trinidad, West Indies

The Teak oil field is located 25 mi (40 km) off the southeastern coast of Trinidad in the eastern part of the Venezuela Tertiary basin. The Teak field structure, discovered in 1968 from seismic data, is a broad asymmetric anticline located along a compressional foldbelt between the Caribbean and South American tectonic plates. It is broken by numerous transverse antithetic and synthetic normal faults which divide the producing reservoirs into many separate pools. Production is from depths of 4,000 to 14,000 ft (1,200 to 4,200 m) subsea in 17 upper Pliocene sandstones, ranging in thickness from 20 to 500 ft (6 to 150 m). The effectiveness of the faults as barriers to communication between fault blocks is demonstrated by variations in edgewater conditions, reservoir pressures, and gas:oil ratios. At the same time, migration of oil into the Teak feature may be related to deep-seated fault conduits communicating with underlying Miocene shales.

Production from the Teak field began in 1972 and is presently in its secondary stages, including waterflooding of some oil zones. Fifty productive wells have been drilled from five platforms with an additional 3 wells recently drilled for water injection. As of June 1, 1978, the field had produced 94 billion bbl oil and 153 Bcf gas.

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Distribution and Factors Controlling Foraminiferal Associations and Assemblages on Fringing Reefs During Winter, Mombasa, Kenya

Comparison is made between the distribution patterns of live and total foraminiferal assemblages using either a variety of cluster analyses techniques or a direct intuitive analysis. The former give quick, valid results; the latter brings out nuances of distribution not obvious in routine statistical analysis. The methods are complementary.

Contrasting physio-geomorphologic environments exist in the reef, on either side of the Ras Iwa Tine promontory. Trigon diagrams of the three foraminiferal suborders confirm the assessment of an open-marine foraminiferal environment. The miliolids dominate immediately north of the promontory, but decrease northward. Their abundance is inversely related to that of the rotalines, which dominate both the biocoenose and thanatocoenose of the southern sector. Thanatocoenoses have a high diversity in the lagoon channel and a low diversity in berm and reef-entrance regions, whereas the biocoenose has the highest diversity on the outer platform and the lowest in the channel. Total abundances and standing crops as directly related to gross environmental parameters are very variable in space.

Two hundred and six species have been identified (104 of them living) in marked contrast to the 465+ species and varieties identified by Heron-Allen and Earland farther south at Kerimba. Relative percentage occurrences, abundances, and rank occurrence delimit distinct species associations. The genera *Spiroloculina, Heterostegina, Ammonia*, and *Bolivina* are common in the north, but are locally restricted. Similarly, *Planorbulina, Epistomarioides*, and *Miliolinella* characterize the south. Live and total assemblages reflect the prevailing biophysical and edophic environments.

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Natural Gas Stability in Deep Subsurface

The trend from oil to gas with increasing reservoir depth is well established, but depth limitations on the occurrence of natural gas (methane) have yet to be determined. The controlling factor at depth is the chemical stability of the methane and its reactions with water and the rock matrix. This problem has been studied using a computer program which calculates the equilibrium composition in a multiphase, multicomponent system that simulates the rock-water-gas combination in a deep reservoir. The program accepts thermodynamic data, rock mineralogy, and gas-water ratios as input data. Within these constraints all possible combinations of compounds are considered and the equilibrium composition established using minimum free energy criteria.

Methane alone has considerable thermal stability but in the natural system it occurs in a water-wet environment that decreases its stability. At 30,000 ft (9,000 m) approximately 5% of the methane is destroyed, but for high geothermal gradients this can be as much as 40%. Reservoirs that contain methane derived from the breakdown of crude oil contain a carbonaceous residue. This residue can interact with the water in clastic reservoirs and produce increased amounts of methane along with considerable amounts of carbon dioxide. However, in carbonate reservoirs (or clastic reservoirs with carbonate cement), methane is destroyed with increasing depth, although carbon dioxide remains a major component in the gas phase. Free sulfur and many sulfur compounds dramatically reduce the stability of methane and generate high concentrations of hydrogen sulfide.

Computer calculations help define the role of rock composition in controlling the stability, and therefore the distribution, of natural gas in the deep subsurface. This understanding will become more important as the average well depth increases.

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Role of Temperature and Burial Depth in Development of Subnormal and Abnormal Pressures in Gas Reservoirs

The aquathermal-pressuring concept shows that isolated, water-filled reservoirs become abnormally pressured when temperature rises owing to increasing depth of burial. When reservoirs contain free gas, the situation is more complex and abnormal or subnormal pressures may develop depending on the gas/water ratio and the initial and final depth of burial. Because zones that have nonhydrostatic pressures must be effectively isolated from their surroundings (or the pressure should be equalized), a model would be a sand lens encased in shale. Consider, for example, where isolation occurs at 4,000 ft (1,200 m) where temperature is 123°F (51°C), and subsequent burial moves it to 8,000 ft (2,400 m) at 178°F (81°C). The pressure in the gas will start at 1,860 psi (12,815 kPa) hydrostatic at 4,000 ft (1,200 m), but the temperature rise will increase it to 2,035 psi (14,021 kPa), at 8,000 ft (2,400 m). However, the hydrostatic pressure at 8,000 ft (2,400 m) is 3,720 psi (25,630 kPa), so the gas reservoir will be 1,685 psi (11,610 kPa) underpressured. Real gas reservoirs contain both gas and water. Calculations show that for trapping at 4,000 ft (1,200 m) followed by burial to 8,000 ft (2,400 m) the reservoir will show various amounts of underpressuring if it contains more than 3 vol.% gas. With less than 3 vol.% gas it will overpressure. At greater trapping depths, high percentages of gas are needed to produce underpressuring, for example, 16 vol.% at 12,000 ft (3,600 m). Temperature decrease owing to uplift and removal of overburden produces the opposite effects, and reservoirs containing high percentages of gas develop abnormally high pressures.

This theoretical model provides an explanation for the common occurrence of underpressured gas, particularly in stratigraphic traps with low water contents. It also explains the underpressured gas in the bottom of basins (such as San Juan, Wattenberg, and western Canada "Deep Basin") and shows how abnormal and subnormal pressures can be developed in adjacent gas reservoirs in a restricted geographic area (such as the Appalachians). Regional tilting may bury a formation in one area but uplift it in another leading to regional trends from subnormal to abnormal pressures. An example of this is provided by the "gas sands" of the Morrow in western Oklahoma.

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Paleotidal-Range Indicators in Carboniferous Barrier Sequences of Eastern Kentucky

When compared with their modern counterparts, the internal morphologies and external geometries of flood-tidal-delta and tidal-channel deposits in Carboniferous rocks of eastern Kentucky suggest mean tidal ranges of 1 to 2 m.

Tidal-inlet, tidal-channel, and tidal-delta deposits of modern barriers each display characteristic vertical sequences; their relative proportions within barrier lithosomes vary consistently with tidal range. Increasing tidal range is accompanied by: (1) thicker inlet sequences; (2) changes in back-barrier deposits from thin, extensive flood-tidal-delta sheets intercalated with lagoonal muds to tidal-creek channel fills intercalated with marsh sediments; and (3) the increasing predominance of ebb-tidal deltas. Stratigraphic recognition of these environments provides an estimation of paleotidal range. Moreover, if basin geometry is known, tidal-wave-propagation theory allows evaluation of relative paleotidal range on a basin-wide scale, enabling prediction of sand-body-geometry patterns along depositional strike.

Several Carboniferous exposures in eastern Kentucky are composed of well-sorted fine to medium-grained orthoquartzites arranged in linear, lenticular bodies up to 14 m thick, 1 to 2 km wide, and 40 km long. They intertongue basinward with red and green shales and carbonate rocks containing marine faunas, and landward with dark shales and siltstones bearing brackish faunas. Two thin (<4 km) lithosomes display obvious flood-tidal-delta characteristics. These erosionally based sheets compose gently landward-dipping to subhorizontal accretion surfaces that bound cosets 1 to 2 m thick of decimeter-scale cross strata with bimodal/bipolar orientations. Washed-out ripples, ladder-backs, rill marks, and bubble sand textures attest to intertidal exposure; extensive root casts typify supratidal areas. Biogenic structures are similar to those on modern flood-tidal deltas. These lithologic and stratigraphic characteristics resemble those of back-barrier components transitional between microtidal and mesotidal environments.

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Modern and Ancient Examples of Annelid Burrows as Current-Direction Indicators

Estuarine burrow patterns of the modern polychaete *Diopatra cuprae* relate to tidal currents in arrangements closely resembling trace-fossil assemblages of a Cambrian tidal sand body.

Dwelling tubes of *Diopatra* on tidal creek point bars in South Carolina reflect local hydrodynamics in four preservable ways: (1) population density is markedly higher on intertidal bar flanks than in channels; (2) burrows are sparse on parts of the bar shielded from ebb currents; (3) in intertidal areas with high population densities, tubes comprise linear rows normal to flow; and (4) tubes in intertidal areas subject to supercritical flow are ringed by asymmetrically ellipsoidal, current-parallel scour pits preferentially oriented in the ebb direction.

Associations of sedimentary textures and structures in Cambrian orthoquartzites of eastern Pennsylvania are analogous to modern upward-fining tidal-channel and point-bar deposits. Channel deposits are characterized by nonburrowed, thick sets of planar-tangential cross-strata with erosional bases and abundant mud-clast lags. Intertidal bars display higher population densities and are characterized by thin sets of planar-tabular cross-strata with bipolar orientations, herringbone cross-stratification, and reactivation surfaces. *Monocraterion* occurs as a *Skolithos* burrow top, and only in intertidal sequences; these structures are analogous to the scour pits around *Diopatra* burrows. In plan, the asymmetrical ellipses of *Monocraterion* burrows are parallel and arranged in rows. These features allow the measurement of paleocurrent directions from relatively small bedding-plane exposures.