tified by kerogen typing, is essential to establish oil source rock character. Kerogen type is mainly dependent on the origin of the precursor plant remains (whether planktonic or terrestrial) and on the oxidizing (oxic) or reducing (anoxic) character of the early depositional environment.

Oxygen depletion, sufficient to arrest or minimize bioturbation at the benthic boundary, enhances oil source bed deposition, because it leads to almost entirely anaerobic microbial reworking of planktonic remains. This type of bacterial reworking favors the preservation and concentration of lipids in the residual OM, leading to the formation of "oil-prone" koergens (types I and II).

Marine oil source bed deposition and occurrence are controlled mainly by factors relevant to qualitative organic matter preservation during early sedimentation, rather than by planktonic productivity in the shallow euphotic zone. Many areas of high planktonic productivity, today, do *not* correspond with zones of high organic enrichment in bottom sediments (e.g., Grand Banks of Newfoundland, Antarctica, Australia, Northwest Shelf, Northeast Brazilian Shelf) because of oxic conditions, commonly in combination with low sedimentation rates. Conversely, whenever zones of high productivity, such as those present in some coastal upwellings, are underlain by anoxic water layers, then prolific oil source bed deposition does occur.

Zones where deep ventilation and thus oxic conditions prevail at sea bottom are much more common than zones of oxygen depletion. Persistent oxic conditions at the benthic boundary lead to deposition of "gas-prone," "type III," to "non-source," "type IV" organic facies, depending on sedimentation rate and amount of terrestrial organic matter input. Such unfavorable organic facies, resulting from past oxic conditions, have been commonly recognized as stratigraphically widespread under continental margins and in cratonic basins, regardless of past water depth. Thus, prolific oil source beds, in terms of relative rock volumes, are the exception in most sedimentary basins.

These observations are compatible with the functioning of the carbon cycle: efficient organic matter recycling through mineralization, rather than enhanced preservation, is the most common and most probable fate of dead organic matter in the environment.

Geochemical-sedimentologic evidence suggests that potential oil source beds are and have been deposited in the geologic past in four main anoxic settings as follows:

1. *Large anoxic lakes*—Permanent stratification promotes development of anoxic bottom water, particularly in large lakes which are not subject to seasonal overturn, such as Lake Tanganyika. Warm equable climatic conditions favor lacustrine anoxia and nonmarine oil source bed deposition.

2. *Anoxic silled basins*—Only those landlocked silled basins with positive water balance tend to become anoxic. The Baltic and Black Seas are examples. In arid-region seas (Red and Mediterranean Seas), evaporation exceeds river inflow, causing negative water balance and well-oxygenated bottom waters. Silled basins should be prone to oil source bed deposition at times of worldwide transgression, at high and low paleolatitudes. Silled-basin geometry, however, does not automatically imply the presence of oil source beds.

3. *Anoxic layers caused by upwelling*—These develop only when the oxygen supply in deep water cannot match demand owing to high surface biologic productivity. Examples are the Benguela Current and Peru coastal upwelling. No systematic correlation exists between upwelling and anoxic conditions because deep oxygen supply is commonly sufficient to match strongest demand. Oil source beds and phosphorites resulting from upwelling are present preferentially at low paleolatitudes and at times of worldwide transgression.

4. *Open-ocean anoxic layers*—These are present in the oxygen-minimum layers of the northeastern Pacific and northern Indian Oceans, far from deep, oxygenated polar water sources. They are analogous, on a smaller scale, to worldwide "oceanic anoxic events" which occurred at global climatic warmups and major transgressions, as in Late Jurassic and middle Cretaceous times. Known marine oil source bed systems are not randomly distributed in time but tend to coincide with periods of worldwide transgression and oceanic anoxia.

Recognition of the proposed anoxic models in ancient sedimentary basins helps in regional stratigraphic mapping of oil shale and oil source beds. Furthermore, explanation and prediction of the most favorable zones for widespread and prolific oil source bed occurrence can be achieved by paleogeographic reconstructions (plate tectonics, paleoclimate, and paleo-oceanography) conducted in conjunction with seismic stratigraphy and regional geochemical studies.

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Evolution of Carbonate Porosity During Burial—Bahamas, Florida, and Gulf Coast: Holocene to Jurassic

Modern carbonate sediments are deposited with large amounts of porosity; commonly they contain more pore space than grain volume. In contrast, ancient carbonate rocks usually retain only a few percent porosity. Although the details of porosity loss may be complex, estimates of porosity in large samples on the scale of aquifers and reservoirs reveal several relations that may be obscured by the detail of petrographic and geochemical studies.

Early diagenesis in carbonate sediments, with the exception of marine cementation, does not significantly reduce porosity. Examples from the Quaternary and Tertiary of the Bahamas and Florida demonstrate that porosity reduction by early freshwater diagenesis at shallow depths, less than 1,500 ft (500 m) for example, is quite inefficient. Although freshwater alteration efficiently stabilizes carbonate mineralogy and drastically alters permeability patterns, it leaves total porosity relatively unaffected. Thus large volumes of carbonate pore space are carried deeper into the subsurface during continued burial.

In the South Florida basin, carbonate porosity decreases persistently with depth from 0 to 18,000 ft (0 to 5,500 m) in rocks ranging in age from Pleistocene to Jurassic(?). Although this decrease is irregular in detail, on a broad scale both the average porosity and the range of measured porosity at any interval decrease with depth. A porosity basement (below which porosity is 5% or less) is encountered at about 14,000 ft (4,300 m). A south Florida standard curve defining porosity decrease with depth helps define an optimal exploration window bounded by thermal maturation criteria at the top and porosity criteria at the bottom.

Upper Jurassic hydrocarbon reservoirs in the Smackover Formation of southern Arkansas and northern Louisiana occur at depths ranging from 4,500 to 11,000 ft (1,400 to 3,350 m), and average porosity values for these reservoirs closely approximate the south Florida standard curve for the same depth range. In contrast, deeper Smackover reservoirs in Mississippi, Alabama, and Florida, which occur between 11,000 ft (3,350 m) and 22,000 ft (6,700 m), have considerably higher porosity than would be expected for their depth. Although these occurrences of porosity at considerable depth are poorly understood, this porosity development is in part the result of interactions of reservoir rocks with acidic brines, the occurrence of late secondary porosity, and the presence of fluid pressures in excess of normal hydrostatic pressure. Physical, geochemical, and lithologic parameters associated with these deep, highly porous reservoirs should be monitored during deep exploratory drilling in other areas. Overpressuring, abundant CO_2 and H_2S, and the development of late secondary porosity may indicate the presence of unexpected carbonate reservoir rocks deep in sedimentary basins.

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Deep Tuscaloosa Gas Trend of South Louisiana

The deep Tuscaloosa gas trend of south Louisiana is one of the most significant exploration plays in the United States in recent years. This trend, productive from an expanded Tuscaloosa sand-shale sequence of Upper Cretaceous age, covers a band approximately 30 mi (48 km) wide and 200 mi (322 km) long, from the Texas line on the west and extending past Lake Pontchartrain on the east.

Regional studies begun by Chevron in 1964 demonstrated the probability of an unexplored sedimentary section lying just south of the Lower Cretaceous carbonate bank edge which crosses south Louisiana. Improved regional seismic data later verified the presence of such a unit, termed "the wedge," located between reflectors identified as Upper Cretaceous chalk and Lower Cretaceous carbonates.

The discovery well of the Tuscaloosa wedge was drilled in the False River area in May 1975, when Chevron tested 20 MMCFG/D from a sand at 19,800 ft (6,035 m) in the 1 Alma Plantation, 15 mi (24 km) northwest of Baton Rouge. Chevron confirmed the trend with a discovery in December 1975 at Rigolets field, 125 mi (201 km) southeast of False River field.

The productive section of the Tuscaloosa is interpreted to be a shallow-water deposit built by progradation southward across the Lower Cretaceous carbonate bank edge. Down-to-the-south faulting in this expanded section, together with deep salt movement, has produced most of the structural features that are now productive from the Tuscaloosa.

One hundred and fifteen exploratory wells have been completed along the Tuscaloosa trend, resulting in the discovery of 19 fields. Several apparent discoveries are currently being tested. Proved plus potential reserves discovered through May 1981 are estimated to be approximately 5 TCF. This reserve estimate should increase significantly with continued drilling.

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Abnormal Pressures Produced by Hydrocarbon Generation and Maturation and Their Relation to Processes of Migration and Accumulation

Abnormally high pore-fluid pressures may be produced as a result of hydrocarbon generation from organic matter (kerogen) contained in "source rocks." Contributing processes include: (1) collapse of rock matrix as overburden-supporting solid kerogen is converted to non-expelled fluid hydrocarbons and (2) volume increases produced by the conversion of kerogen to hydrocarbons. Overpressures may also be created by volume increases associated with the thermally progressive conversion of oil to wet gas/condensate and to dry gas within the pores of either the source rock or associated isolated hydrocarbon-saturated nonsource rocks. Generation-type overpressures may be reinforced or maintained by (1) fluid-volume expansions caused by higher temperatures associated with further burial and by (2) capillary entry pressure phenomena associated with expulsion/migration. The occurrence, maintenance, and degree of fluid overpressuring appear to be dependent on time, temperature, volume of kerogen/hydrocarbons undergoing transformation, and the relative isolation of the rocks with respect to regionally extensive high-permeability rocks.

Regions of hydrocarbon-generation overpressure have been documented in several basins. They are present as vertically and laterally restricted "cells" or "pods" centering around actively generating source-rock units in basin-bottom positions. Hydrocarbons in most places appear to be the overpressuring fluid and the only initially producible fluid species present.

Actively generating source rocks within the pressure cells may be characterized by (1) abnormally high electrical resistivities and abnormally low sound velocities. Resistivity increases may be caused by the replacement of conductive pore water with nonconductive hydrocarbons. Low sound velocities may be caused by (1) the replacement of higher velocity pore water with lower velocity hydrocarbons and (2) the effects of abnormal pressure on porosity enhancement or preservation through dilation or undercompaction.

Overpressures produced by hydrocarbon generation are the primary motivating forces causing primary expulsion from source rocks to conventional reservoir rocks. These overpressures may cause the spontaneous hydraulic fracturing of a source rock. The process facilitates fluid expulsion and may also create an associated "in-situ" fracture-type reservoir. The process may also create far-reaching fractures which propagate upward or downward from the source rocks and control vertical migration through great thicknesses of seemingly impermeable confining strata.

After active high-rate hydrocarbon generation has ceased in a basin, owing either to (1) decreases in temperature produced by uplift or lower heat flow or to (2) loss of generation capacity due to "over-maturity," the associated pod of *abnormally high* pressures may be replaced by a pod of *abnormally low* pressures associated with closed apparent minimum potential energy ("potentiometric") "sinks." This stage of pressure evolution is controlled by the imbibition of water into the initially overpressured area of high hydrocarbon saturation. Contributing processes may include (1) the volume contraction of pore-fluid hydrocarbons caused by decreases in temperature, (2) the establishment of topographically introduced hydrodynamic conditions, (3) the solution-diffusion of hydrocarbons (primarily methane) outward from the system, and (4) the capillary imbibition of water.

Significant accumulation of hydrocarbons in highly unconventional basin-bottom positions may occur in either the overpressured or underpressured stages of basin hydrocarbon generation-migration evolution.

When water is imbibed into the original site of hydrocarbon generation and overpressure, and the associated unstable localization of hydrocarbon saturation has been dissipated and destroyed during an associated stage of underpressure, pore pressure conditions will eventually return to near normal states.

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Stratigraphic Evolution of North American Cordillera

Much of the North American Cordillera is a tectonic collage of allochthonous crustal fragments accreted to the western margin of the craton from middle Paleozoic time onward. This