and mid-fan facies associations are common within the Yager; however, outer-fan depositional-lobe sequences are both rare and poorly developed, and basin-plain deposits are absent. Sandy mid-fan deposits typically grade into thin-bedded and poorly cyclic fan-fringe turbidites. It is likely that "normal" distal-fan facies associations failed to develop because of restricted basin geometries. (2) The regional distribution of turbidite facies and facies associations indicates that basin-fill sequences generally maintain good continuity along strike (northwest-southeast); the facies changes occur along transverse sections, and are, at least in part, temporally controlled. Thus, the basin-fill sequences appear to be elongate in a northwest-southeast direction, parallel with the dominant structural grain. (3) Thick sections of complexly folded mudrock are common within the Yager. These fine-grained strata, which include both hemipelagic shales and silty or muddy turbidites, are interpreted as slope deposits and are typically cut by lenses of coarse-grained, thick-bedded channel fill. The slope and channel sequences are nearly as prevalent as the sandy basin-fill sequences, which suggests that the Yager basins were not only restricted in size, but probably perched on an inclined, mud-covered slope.

Analogs for the Yager formation can be found along many modern subduction zones, where small, elongate basins typically form on the lower trench slope behind thrust-bounded or anticlinal ridges. Uplift of the ridges causes sediment-transport conduits (submarine canyons and slope channels) to become blocked; coarse detritus is thus trapped behind the ridges in a manner somewhat comparable to the salt diapirs which confine intraslope basins in the Gulf of Mexico.

Mean vitirinite-reflectance values for Yager shales near Garberville, California, are as high as 0.79%. Burial depths of as much as 6,000 m (19,700 ft) are indicated, using a geothermal gradient of 2°C/100 m. However, the depositional overburden associated with Neogene shallow-marine sediments of the Wildcat Group is estimated to be only about one-third the amount required. The additional overburden apparently resulted from mid-Tertiary thrusting along the Garberville thrust, a fault which marks the tectonic contact between Yager strata and melange of the Franciscan central belt terrane.

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Research Trends in Biostratigraphy

Paleontology, as applied in biostratigraphy, has long been an indispensable part of petroleum exploration. However, rapidly improving technology in many disciplines and the limitations of traditional biostratigraphy based on tops and zones dictate the need for an improved technology. In response to this need new approaches have been suggested, including probabilistic stratigraphy, geohistory diagrams, no-space graphs, isotopic and fission track dating, radiometric geochronology, tephrochronology, magnetostratigraphy, paleo-oceanographic geochemistry, and graphic correlation utilizing composite standards.

One example of a research program for the 1990s and beyond includes the development of a paleontologic composite standards and the interactive capability for their use by graphic correlation; the development of computer data bases for morphologic, taxonomic, paleoecologic and paleogeographic research and the interactive capability for synthesis, analysis and display; and, the development of time-based primary sedimentary models for prediction of geologic conditions ahead of the drill. Refined and stable taxonomic data supplied by highly capable paleontologists are a prerequisite for success. Such a program clearly requires management commitment of manpower and resources necessary to develop the technology, and it requires the development of effective technology transfer mechanisms to implement the results in exploration programs. The reward for success will be multifold improvement in our understanding of geologic conditions and history.

As with all exploration sciences, the present and future of biostratigraphy is the intelligent application of good paleontology to the solution of increasingly difficult geologic problems by constantly improving technology.

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Diagenetic Components Within Woodbine Formation, East Texas

The Upper Cretaceous Woodbine Formation contains diagenetic components in the form of cements and clays which can cause problems in drilling, completing, and stimulating a well. These diagenetic components are present in pore systems of the rocks deposited within various Woodbine depositional systems ranging from fluvial to deep marine. Fluvial environments were present in the northeast area of the East Texas basin, and changed to deltaic-marine systems to the south and southwest. Deeper marine sediments are represented by a thickening clastic wedge deposited over the Edwards reef trend as channels, interchannels, and submarine fans. It is necessary to identify mineral types, crystal morphologies, and modes of occurrence of the diagenetic components within pore systems of rocks formed in these various depositional settings so that proper drilling, completing, stimulating, and/or acidizing programs can be conducted.

Calcite, dolomite, ankerite, and quartz are important cements which reduce porosity and affect reservoir quality of the Woodbine Formation. Carbonate minerals occur as isolated patches or extensive cement within the intergranular network. Quartz cement is commonly observed in the form of euhedral overgrowths. The storage capacity of the reservoir and productivity of a well can be hindered where these cements reduce and isolate primary and secondary pores. During completion, stimulation, and possibly acidization, calcite may cause further problems through reaction with hydrofluoric acid and precipitation of formation-damaging calcium fluoride. Iron hydroxide precipitates may also form when iron-rich calcite, dolomite, and ankerite are contacted by HCl, HF, and HCl/HF acids. These precipitated gels can block pores and reduce production.

Important clay components found within the pore network of the Woodbine Formation are kaolinite and chlorite. Kaolinite commonly displays a pseudohexagonal "book" and platelet morphology. It is relatively stable with respect to acids; therefore, acidization should have minimal effect on the kaolinite. A problem of migration of fine particles can arise when these "books" and platelets are loosened from framework grain surfaces. Turbulence within pore networks, caused by fluid movement during stimulation and production, especially near the wellbore or a fracture face, can cause the kaolinite fines to move and block pore throats. This could result in formation damage. Chlorite occurs as well to moderately crystalline platelets which reduce porosity by lining and filling pore areas. If the chlorite is iron-rich and contacted by HCl, HF, and HCl/HF acids, a problem of iron hydroxide precipitation can occur.

Other clays within the Woodbine Formation include illite and smectite. Authigenic illite is found as incipient growths on chlorite platelets. The smectite has a honeycomb morphology and occurs as a grain coating. These components can cause problems if present in significant amounts within Woodbine reservoirs. If relatively fresh water is allowed to contact the formation, illite can "mush" and the smectite can swell, both damaging the formation.

Drilling, completing, stimulating, and acidizing programs can be designed to minimize problems caused by diagenetic components. Well production can even be increased when proper procedures are designed using information on potential formation damaging diagenetic minerals that are present within pore systems of Woodbine reservoir rocks.

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Supraglacial Diamictons at Continental Ice Margins: Pleistocene Alluvial Fan-Flow Till Deposition in Southeastern Michigan

Glacial sediments more than 50 m (165 ft) thick were laid down over southeastern Michigan during retreat of the late Wisconsinan continental ice sheet. As a result, the topography of the region is now dominated by recessional moraines composed of thick sequences of outwash sand and gravel, which are in turn capped by up to 7 m (23 ft) of glacial diamicton. Sedimentary structures exposed in many gravel pits in the Fort Wayne moraine suggest that outwash sequences were deposited as proglacial alluvial fan systems which were partially overridden during short periods of ice readvance. Several features, including abruptly truncated trough cross-bedding in gravels and truncated large clasts of previously ice-cemented sand at outwash-till contacts, require shearing at outwash surfaces either prior to or during till emplacement. Such outwash till contacts suggest that some of the diamicton was deposited in subglacial settings as lodgement till. Other exposures, however, exhibit gradational outwash till contacts, fluidized mixtures of thin outwash and till layers, and till draped over large sand clasts. Such features require that much of the diamicton was emplaced without truncation at the outwash surface, and suggest that deposition occurred in supraglacial settings as flow till.

The distribution of lodgement till and flow till in this region indicates that lodgement tills predominate on proximal (iceward) portions of moraine slopes and that flow tills predominate on distal slopes. This distribution suggests that during outwash till deposition, the front of the continental ice sheet had readvanced only to the moraine crest, and that a single depositional episode gave rise to the entire outwash till sequence.

Similar features are typical of other moraines in the region and suggest that, in general, the crests of gravel-cored Pleistocene moraines coincide with the maximum limits of ice readvance and delineate areas of lodgement till deposition on proximal slopes and areas of flow till deposition on distal slopes.

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Paleomagnetic Applications in Hydrocarbon Exploration and Drilling Operations

A new generation of high-sensitivity cryogenic magnetometers permits paleomagnetic applications in weakly magnetized sedimentary rocks. One of the most useful paleomagnetic applications is drill-core orientation, which is important for determining fracture orientations, for stress analysis, and for determining sediment transport directions. A 2-year study involving ~600 core plug samples from five wells in three Rocky Mountain basins yielded paleomagnetic orientations that agree with those obtained using the conventional photographic "multishot" technique. The strongest paleomagnetic signal in these rocks points toward the late Cenozoic paleomagnetic pole and probably represents a secondary magnetization imposed by thermal effects associated with the late Cenozoic uplift and tectonism in this region.

Weaker paleomagnetic signals, reflecting earlier thermal, diagenetic, or depositional magnetizations are also commonly preserved in sedimentary rocks and can also be used to orient core. For example, lower Paleozoic rocks of the southern Great Basin contain three secondary magnetizations acquired during the Late Permian (time of deepest burial), the Late Cretaceous (Sevier orogeny), and the Late Cenozoic (recent weathering). Although many different magnetizations commonly reside in the same rock sample, these magnetizations can be routinely separated by subjecting the samples to partial demagnetization, using alternating-field, thermal, or chemical "cleaning" techniques. The components of magnetization are destroyed at vastly different rates depending on whether they reside, for example, in trace amounts of magnetite, hematite, or goethite.

In paleomagnetic core orienting, the most precise orientations are obtained from fine-grained rocks, and the method requires some prior knowledge of the region to establish the reference magnetization direction. However, paleomagnetic core orienting requires no special downhole equipment and can selectively orient only those intervals of core that are of interest after visual inspection. The paleomagnetic core orienting technique has been successfully tested against the multishot technique in several regions of the United States and internationally.

Other paleomagnetic applications can be derived from the same plugs used for orienting drill core. Some of these applications use the "primary" magnetization acquired penecontemporaneously with deposition. For example, establishing the geomagnetic polarity reversal pattern in a sedimentary sequence elucidates the sedimentation rate (by thickening or thinning of the polarity stratigraphy) and the duration of hiatuses in deposition (by absence of segments of the reversal history). The reversal stratigraphy also provides timelines that are independent of the biostratigraphy and lithostratigraphy and that are useful in correlating beds from well to well. Other paleomagnetic applications use one or more secondary magnetizations reflecting later diagenetic and thermal events. These secondary magnetizations can have important implications regarding both permeability and thermal maturity. Finally, changes in rock magnetic properties, such as bulk magnetic susceptibility, can be used to detect mineralogic alteration associated with hydrocarbon migration.

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Mineral Reactions and Controls on Zeolite Facies Alteration in Sandstone of Central Transantarctic Mountains, Antarctica

Volcanic sandstones of the Fremouw and Falla formations, like many volcanic sandstones in productive and nonproductive circum-Pacific basins, contain abundant zeolite-facies authigenic minerals. Mineral and chemical patterns in Fremouw and Falla sandstone suggest that porosity and authigenic mineralogy were controlled by parent material composition, fluid chemistry, permeability, and temperature. Mineral patterns suggest simple rock-fluid reactions in which unstable volcanic rock fragments and plagioclase grains were altered to clay, heulandite, albite, laumontite, and/or prehnite. Chemical patterns suggest that significant mass transfer of Na^{+}, Ca^{+2}, and Si^{+4} occurred in the sandstone during alteration, whereas Al^{+3} mobility was restricted to migration from reaction sites to nearby pore space where Al^{+3} was incorporated into clay and/or zeolite cements. These cements typically reduced primary porosity to a few percent; however, some secondary porosity was created by the dissolution of detrital plagioclase grains. An examination of albitization and laumontization reactions involving detrital plagioclase suggests that porosity loss resulting from these reactions is directly proportional to the anorthite content of the grains undergoing alteration. Chemical and mineral patterns also suggest that clay mineral diagenesis in mudstone units supplied at least some of the ions required by reactions in neighboring sandstone.