freshwater phreatic environment. This intepretation is consistent with the vadose origin ascribed to features observed within other parts of the complex.

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Deduction of Past Geothermal Gradients in Neogene Siliceous Rocks in Circum-Pacific Region

Zones of diagenetic silica record past geothermal gradients in Neogene diatomaceous sediments and siliceous rocks in the Circum-Pacific region and are useful in evaluating the petroleum potential of these important source rocks. In many areas burial diagenesis has produced the well-known lithologic and mineralogic progression: diatomite (opal-A) → chert and porcelanite (opal-CT) → chert and porcelanite (quartz). Temperature is an important control of these transformations. The range in temperature for the conversion of opal-A to opal-CT, calculated from measured values of heat flow and thermal conductivity, is 25 to 56°C. Opal-CT transforms to quartz in the range 43 to 81°C. Similar ranges of temperatures are calculated from oxygen isotopes of opal-CT and quartz from cherts and porcelanites using the experimental fractionation for quartz and water, assuming the transformations occurred in isotopic equilibrium with water whose oxygen isotopic composition differed only slightly from standard mean ocean water. Taking the top and base of the opal-CT zone as approximate isotherms, the past geothermal gradient for any area equals the difference between these isotherms divided by the thickness of the opal-CT zone. In addition, both the thickness and the depth (reconstructed maximum overburden) to the top of this zone decrease with increasing geothermal gradient. Because depth and thickness are related by a simple linear expression, either may be used to estimate past geothermal gradients in Neogene siliceous rocks.

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Important Stratigraphic Breaks in COST GE-1 Well, Southeast Georgia Embayment

A foraminiferal analysis of the recently completed Continental Offshore Stratigraphic Test (COST) GE-1 well reveals that ~1,000 m of Cenozoic, ~700 m of Upper Cretaceous, and ~1,600 m of Lower Cretaceous sedimentary rocks lie above Devonian metamorphic basement in this part of the Southeast Georgia embayment. Seven regional hiatuses interrupt the depositional record and correspond to times of low global sea level. The hiatuses are between Albian and Turonian rocks; upper Maestrichtian and upper Paleocene; upper Paleocene and lower Eocene; upper Eocene and lower Oligocene; middle Oligocene and middle Miocene; middle Miocene and upper Pliocene; and upper Pliocene and lower Pleistocene. The depositional environments represented in the GE-1 well range from terrestrial nonfossiliferous biotopes to ocean depths equivalent to those of a modern continental slope. Most of the Cenozoic and Upper Cretaceous rocks accumulated in continental-shelf biotopes, but the Lower Cretaceous rocks are largely nonmarine and marginal-marine deposits. The sequence of paleo-environments can be correlated with the supercycles of global sea-level change outlined by P. Vail et al. Sediment-accumulation rates were highest (5.0 to 6.4 cm/1,000 years) during the Albian through Santonian interval, the middle and late Eocene, and the middle Miocene. Lowest rates (1.3 to 2.5 cm/1,000 years) prevailed during the Campanian and Maestrichtian, the early and middle Oligocene, and the Pleistocene. Subsidence calculations reveal that Cretaceous subsidence was more rapid than that of the Cenozoic, that most of the major paleobathymetric changes were caused by eustatic sea-level fluctuations, and that subsidence rate of the embayment was sensitive to sediment loading and unloading.

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Temporal and Spatial Distribution of Ice-Rafted Mineral Grains in Pliocene Sediments of North Atlantic

An important find of Deep Sea Drilling Project (DSDP) Leg 12 was ice-rafted mineral grains in Pliocene sediments of the Labrador Sea and the Hatton-Rockall Basin. The oldest (first) occurrence of ice-rafted mineral grains in these sediments is associated with the evolutionary first appearance of the planktonic foraminifer *Globorotalia inflata* (d'Orbigny) and the extinction of the coccolith *Reticulofenestra pseudoumbilica* Gartner. This association yields a paleontologic age estimate of 3.0 m.y.B.P. for the start of low-elevation Northern Hemisphere glaciation extensive enough to produce icebergs in the North Atlantic. Results from subsequent drilling in the North Atlantic (DSDP Legs 37, 48, and 49) confirm that the first occurrence of ice-rafted mineral grains in North Atlantic sediments is at about 3.0 m.y.B.P. and further show that, during the Pliocene, icebergs penetrated as far south as 45°N lat. (DSDP hole 410) but not as far south as 37°N lat. (DSDP holes 333 and 335).

The estimated age of 3.0 m.y.B.P. for the onset of Northern Hemisphere low-elevation glaciation derived from the North Atlantic is compatible with, although slightly younger than, the 3.2 m.y.B.P. estimate suggested by paleomagnetically controlled isotopic data from the Equatorial Pacific.

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Diagenesis in Hygiene and Terry Sandstones (Upper Cretaceous), Spindle Field, Colorado

Recent research in the field of sandstone diagenesis suggests a relation between depositional fabric and the observed pore-filling sequence. An ordered paragenetic sequence representing an ordered decrease in energy-of-formation ($\Delta G°_f$) values is reported for fine-grained, poorly sorted sandstones. Coarser grained, better sorted sandstones from the same depositional environment show unordered diagenesis with respect to $\Delta G°_f$, perhaps related to higher fluid flow and less influence of rock composition. A relation may also exist between diagenetic sequence and depositional environment;

chlorite is common as initial pore filling in marine rocks, whereas kaolinite and illite initiate pore filling in nonmarine rocks.

Spindle field, second largest oil field in Colorado, produces oil and gas from Hygiene and Terry sandstones deposited as offshore marine bars. Upward-coarsening lithofacies in both sandstones are: (1) bioturbated muddy sandstones (shelf and interbar); (2) very fine-grained, poorly sorted, weakly cross-stratified sandstone (bar margin); (3) fine-grained to medium-grained, moderately sorted, cross-stratified sandstone (central bar).

On the basis of known fabrics and environments, Hygiene and Terry sandstones were predicted by use of the reported diagenesis model to show a $\Delta G°_f$-related diagenesis in interbar and bar-margin facies, and an initial chlorite diagenesis in the central-bar facies. Preliminary thin-section and SEM investigations tend to confirm the prediction for the finer grained facies. The origin of kaolinite-rich pore filling in the central-bar facies is not clearly understood, but it may be related to abundant argillaceous clasts which provide in-situ material for continuous alteration of pore-fluid composition during diagenesis.

Modification of predicted diagenesis in the coarser grained facies provides an additional basis for anticipation of diagenetic sequences in other offshore-bar deposits.

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Resource Appraisal Predictions and Exploration Performance—Case Studies for Onshore United States

Geologic estimates of undiscovered recoverable oil and gas resources in the United States were published in U.S. Geological Survey Circular 725 in mid-1975, based on data through 1974. In the 1975 study, 47 onshore provinces included within 11 regions, were evaluated. Three of these geologic provinces, (1) West Texas–Eastern New Mexico, (2) North Slope, Alaska, and (3) the Overthrust belt of Idaho-Utah-Wyoming, were selected as case studies to show the relation between the 1975 resource assessments and subsequent exploration results.

U.S. Geological Survey resource estimates for the maturely explored West Texas–Eastern New Mexico province range from 4 to 14.4 billion bbl of oil and 35 to 100 Tcf of gas, based on the 95 and 5% probability percentiles. Exploration wildcat drilling from 1974 through 1977 resulted in more than 840 oil and gas discoveries, mainly of small field or pool size. Exploration results in this province, based on finding rates and the amounts of oil and gas discovered, do not appear to have met the resource predictions.

Resource estimates for the immaturely drilled North Slope province range from 3 to 10 billion bbl of oil and 7 to 25 Tcf of gas. About 40 wildcats were drilled from 1974 through 1977, resulting in 15 successful oil wells and 1 gas well. Two of the oil discoveries appear to be in the >50 million-bbl field size ("A" class). Resource predictions appear to have been met, or exceeded for the North Slope, based on this recent exploration performance.

Estimates of resources for the Overthrust belt, the most recently successful of the three provinces, range from 0 to 0.2 billion bbl of oil and 0 to 1.1 Tcf of gas. Three gas and five oil fields were discovered out of 89 total wildcats drilled from 1974 through 1977, at least four of which are estimated to be of "A" field-size class or greater. Exploratory performance to date has exceeded the earlier resource estimates in the Overthrust belt.

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Palo Duro Basin Analysis

A comprehensive stratigraphic analysis of the Palo Duro basin, emphasizing facies and depositional systems, provides a framework for resource analysis and exploration. A pre-Pennsylvanian section consists of thin, basal, Cambrian sandstone overlain by Ordovician and Mississippian shallow-shelf carbonate rocks. Pennsylvanian and Lower Permian rocks consist of 1,000 m of basin and slope shales, massive shelf-margin carbonate rocks, and deltaic sandstones. Facies distributions define a major episode of basin subsidence and transgression (Pennsylvanian) with shelf-margin retreat, followed by regression (southward), and basin filling (Early Permian). In Late Permian time, the basin was an extensive sabkha-shelf platform on which salt (upper sabkha), anhydrite-gypsum (lower sabkha), dolomite (subtidal to intertidal shelf), and red beds were deposited. Two continuous 1,220-m cores drilled to the base of the evaporites provide a unique opportunity for calibration of well logs with petrographic studies, and for resource evaluation (fluid tests, uranium and copper analyses, etc).

The subsurface analysis has been coordinated with geomorphic and hydrologic studies in the same area (climate, slope, stream, and eolian process monitoring and field surveys of selected drainage basins) to demonstrate surface and subsurface interrelations. For example, locations of salt solution zones in the evaporite section coincide with surface erosional features, suggesting control of solution rate and position by drainage. High solute loads of area streams are probably derived from subsurface evaporite solution and result from regional surface discharge of groundwater circulation systems.

Lack of proven oil and gas reserves in the basin may be attributable to a limited volume of thermally mature source rocks.

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Upper Permian Evaporites and Red Beds of Palo Duro Basin, Texas—Facies Patterns Through Time

Subsurface facies analysis of Upper Permian evaporites and red beds of the Palo Duro basin, Texas, provides information important in evaluations for potential hydrocarbons, uranium, copper, and evaporite minerals. Cores, cuttings, and well logs were used for analysis. Stratigraphic units include the Clear Fork Group, Glorieta and San Andres Formations, and post-San Andres Guadalupian and Ochoan strata.

Evaporites and associated carbonate rocks show ba-