

Radiocarbon-age estimates indicate these impressive piles of coral rubble and sediment have accumulated in the past 9,000 yr (giving a minimum accumulation rate of 1.4 m/1,000 yr) and illustrate the potential for significant carbonate buildups without the need for early lithification.

WHITE, BRIAN, Smith College, Northampton, MA, KAREN A. KURKJY, Univ. Miami, Miami, FL, and H. ALLEN CURRAN, Smith College, Northampton, MA

Diagenesis and Sea Level Change in a Pleistocene Coral Reef, San Salvador, Bahamas

Near the Cockburn Town reef (dated 125,000 yr B.P.), precisely surveyed bench marks are related to accurately measured mean sea level, and they provide a convenient datum plane. This coral reef developed during a sea level highstand of no more than 10,000 yr, which was insufficient time for significant subsidence; however, subsidence of approximately 3 m may have occurred since the formation of the reef. Sea level changes were caused by fluctuations in glacial-ice volume. The upper beach to dune transition, which is in the calcarenites overlying the reef, is at +4 m. A minimum highstand of +7 m is indicated when corrected for subsidence.

Below +2.5 m, marine aragonite cement occurs within the intragranular pore space of the following: *Halimeda* plates, benthic foraminifera, *Favreina* (Callianassid fecal pellets), gastropods, and corals. Marine aragonite cement also occurs as intergranular isopachous rims on matrix grains of coral rubblestone. Remaining pore space was partly to completely occluded by freshwater vadose calcite cements, which occur without marine cements in the overlying shallow subtidal, beach, and dune calcarenites. No unequivocal freshwater phreatic cements have been found, although syntaxial overgrowths and irregular calcite rims about grains do occur in finer grained sediments where local patches of freshwater saturation occurred within the vadose zone. Later calcification, which affected all facies, is characterized by alveolar texture, whisker calcite, microsparite, rare bladed calcite spar, *Microcodium*, and thizocretions.

WHITICAR, M. J., E. FABER, and M. SCHOELL, Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover, Federal Republic of Germany

Hydrogen and Carbon Isotopes of C_1 to C_5 Alkanes in Natural Gases

A technique has been developed to determine C^{12}/C^{13} and D/H isotopic ratios on small quantities of methane through pentane hydrocarbons and has been applied to natural gases from various genetic sources (i.e., early-diagenetic, oil-associated, late-catagenic and mixed-gas sources).

Carbon isotopes measured from 27 natural gases have $\delta^{13}C$ range of 23, 15, and 20‰ for the C_1 to C_3 alkanes and maximum $\delta^{13}C$ values of -35.1, -26.8, and -20.8‰ respectively. With a smaller sample base, butane and pentane vary within 16 and 4‰, respectively, for those samples with the most positive $\delta^{13}C = -26.5$ and -26.9 ‰.

Deuterium isotopes exhibit greater isotopic variation than the corresponding carbon values. D/H variations clearly decrease toward the higher homologues with δD ranges of 182, 110, 75, 43, and 29‰ for C_1 through C_5 . Most negative D/H measurements also decrease with carbon number from $\delta D = -311$ ‰ for methane to -128 ‰ for pentane.

These relative changes in carbon and hydrogen isotopic contents for the higher homologues are useful in the classification of natural gases, particularly those of mixed origin.

WHITICAR, MICHAEL J., ECKHARD FABER, and WOLFGANG STAHL, Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover, Federal Republic of Germany

Sorbed vs. Free Sediment Gases—Differentiation of Thermogenic and Biogenic Gas Sources

The unique phenomenon of hydrocarbon gas sorption on mineral and organic matter surfaces provides the basis of a novel aid for geochemical petroleum exploration. A refined vacuum sediment degassing procedure permits separate analysis of sorbed and free gas fractions. Hydrocarbon gases from both individual fractions can be genetically classified (e.g., diagenetic, thermogenic, catagenic) by their molecular and ^{13}C and 2H isotopic compositions.

In contrast to the normal bulk or free gas fractions, where the composition is frequently influenced by alteration effects such as bacterial gas generation or oxidation, comparative analyses indicate the sorbed gas fraction can retain its unaltered genetic signature. Exchange between the sorbed and free gas fractions is severely restricted by surface sorption energies and perhaps by structure water, which may assist in the partitioning of gas fractions with different genetic characters. Gas transport within the sorbed fraction is probably a surface-controlled "handshake" diffusion process that minimizes contact with the free gases.

Examples of this phenomenon are provided by Gulf Coast and California surface sediment cores, which display strong biogenic methane formation and oxidation effects in the free gas fraction. In contrast, the corresponding character of the sorbed gas fractions is clearly distinguished as thermogenic and originating in subsurface. Evidence of thermogenic hydrocarbons is obscured during routine bulk analysis by the biogenic free gas component.

This sorption phenomenon has good potential for the identification of subtle geochemical hydrocarbon anomalies previously masked through bulk analysis.

WIGGINS, WILLIAM D., and PAUL M. HARRIS, Gulf Research and Development, Houston, TX

Burial Diagenesis of Allochthonous Carbonates from a Permian Slope Setting, Southeastern New Mexico

The Bone Spring formation (Permian-Leonardian) from 3-km (9,850-ft) deep conventional cores in the northern Delaware basin is a laminated, black, mixed terrigenous-carbonate mudstone with thin intervals of gray, coarse carbonate-debris flows. All carbonates have been pervasively dolomitized, and porosity and permeability were reduced to 3-8% and 1 md, respectively, during several diagenetic events related to burial history.

Three dolomite generations are defined by fluorescence and cathodoluminescence microscopy and electron microprobe, and are further characterized by means of microsampling for carbon and oxygen isotopes. Over a range of 2‰ (PDB), $\delta^{13}C$ decreases steadily from the first to last dolomite generation, reflecting constant mixing of rock carbon and organic carbon as hydrocarbons were evolving in the Bone Spring muds. The first dolomite generation was introduced during the time interval between early postdeposition and burial to approximately 1 km (3,280 ft). Dewatering and compaction of the Bone Spring muds accompanied matrix dolomitization, leaching of metastable grains, fracturing, and silicification of carbonate components. The mean $\delta^{18}O$ of the high-strontium, matrix dolomite is -2.1 ± 0.4 ‰ (PDB). A second dolomite generation may have been late Ochoan; by this time an additional 1.2 km (3,925 ft) of Guadalupian-Ochoan carbonates and evaporites had been deposited. This fluorescent, nearly stoichiometric dolomite cement has a mean $\delta^{18}O$ of -3.0 ± 0.3 ‰ (PDB), and was coeval with hydrocarbon generation in the Bone Spring. It precipitated from fluids that interacted with the overlying evaporites. Hydrocarbon inclusions are contained in this dolomite, which is succeeded by a generation of anhydrite cement. Sulfur isotopes strongly suggest that remobilized Guadalupian anhydrite-sulfur formed this cement.

The last two diagenetic phases, including the third dolomite generation, crystallized at about present burial depth. Coarsely crystalline, luminescent, pore-filling calcian dolomite, containing hydrocarbon inclusions, has a mean $\delta^{18}O$ of -5.4 ± 0.6 ‰ (PDB). Depleted poikilotopic calcite cement ($\delta^{18}O = -10.3$ ‰, PDB) records the input of Tertiary water.

WILBER, R. JUDE, Sea Education Assoc., Woods Hole, MA, ALBERT C. HINE, Univ. South Florida, St. Petersburg, FL, and A. CONRAD NEUMANN, Univ. North Carolina, Chapel Hill, NC

Multiple Submarine-Cemented Grainstone Sequences Along Leeward Carbonate Margins: Examples from Late Quaternary of Little and Great Bahama Banks

Coarse-grained, leeward-margin sand shoals, developed during the late Quaternary along the western edges of Little and Great Bahama Bank, have been deposited and preserved in response to regional sediment-transport processes and local physicochemical conditions. These sand bodies are fundamental depositional sequences, chronostratigraphically bounded by subaerial exposure crusts, and thus are of major importance in determining rates of bank-margin growth and in understanding the dynamics of carbonate margin buildup. In the Holocene sediments, these sand bodies are 1-2 km wide, up to 35 m thick, and are present along 400

km of the western Bahamas. Surficial sediment is composed of coarse sand and granules dominated by composite-oid grains. Submarine cementation is active and has led to the development of coarser grain sizes during the depositional interval. Fine to medium-sized grains are cemented with fibrous aragonite and surficially coated at the tidally active margin. The resultant composite-oid sediment is more hydrodynamically stable and is rapidly cemented into hardgrounds characterized by a smooth (tidally abraded) upper surface. Lithification is gradational through a thickness of 50-100 mm to an irregular lower boundary transitional with uncemented material. These hardgrounds are submarine discontinuity surfaces developed during inter-storm conditions of winnowing and bypass sedimentation along a depositional profile of equilibrium. Rock cores into the Pleistocene section have recovered sediments and submarine discontinuity surfaces identical to those in the Holocene. These are present in the two latest Pleistocene sequences representing the last major interglacial intervals. Both the Holocene and Pleistocene sequences have one or two cemented zones per meter in the upper section. The presence of these deposits throughout the preserved stratigraphic package indicates the persistence of characteristic leeward depositional processes during the late Quaternary and their importance in bank-margin growth. A combination of characteristics including typical microfacies, cements, and discontinuity surfaces (if seen in the ancient) should be good indicators of leeward-margin settings.

WILLIAMS, BRIAN P. J., South Australian Oil & Gas Corp., North Adelaide, South Australia

Point-Bar Deposits and Analysis of Subsurface Reservoir Dimensions, Toolachee Formation, Southern Cooper Basin, South Australia

Point-bar deposits occur ubiquitously within the lowest facies association of the Upper Permian Toolachee Formation (+500 ft thick). The association represents deposition in a moderate to high-sinuosity, mixed-load, fluvial channel system in which lateral bar deposits constitute major hydrocarbon sandstone reservoirs. Bars may be simple or punctuated in their upward-fining, vertical facies transitions, but heterolithic lateral accretion surfaces of upper point bars may occasionally be preserved in cores.

Detailed facies studies of Association 1 in 17 cored wells reveal that pebbly thalweg lags locally include chaotic bank-collapse conglomerates. These basal point-bar deposits fine upward into cross-bedded sandstones. Ripple bedding is common in upper bar sequences. The bars are associated with a variety of abandonment fills, levees, and crevasse splays, backswamp deposits, and autochthonous coals.

Paleohydraulic studies of point bars in the Moomba field demonstrate an average bankfull depth of the Toolachee channels of 14 ft and bankfull width of 320 ft. Empirical relationships indicate a maximum meander loop diameter of 1,650 ft with meander belt width at 3,650 ft. These parameters allow an evaluation of reservoir geometry, storage potential, and permeability barriers. The latter, generated by clay-plug abandonment fills, can restrict fluid migration within the field and produce overestimation of hydrocarbon reserves. Conversely, avulsive channel events may locally increase point-bar reservoir dimensions by partially, or totally, removing preexisting abandonment fills.

WILLIAMSON, P. E., C. J. PIGRAM, A. S. SCHERL, K. L. LOCKWOOD, M. A. ETHERIDGE, and J. C. BRANSON, Bur. of Mineral Resources, Canberra, Australia

New Deeper Exploration Frontiers in Bass Basin

The Bass basin is the sister basin to the Gippsland. Both are extensional basins in southeast Australia between Tasmania and the mainland, and both occupy areas in excess of 60,000 km². The Bass and Gippsland basins were resurveyed seismically by the Bureau of Mineral Resources to provide regional correlation and to penetrate seismic energy barriers caused by Eocene coals.

Analyses of these recent good quality deep seismic data, existing seismic data, and well information including thermal maturity, source rock richness, porosity, and permeability suggest that the Bass basin is not fully analogous to the Gippsland basin. Though stratigraphy is similar, there is a paucity of significant secondary faulting in Bass basin to act as paths for migration of hydrocarbons to thermally immature levels, as is the case in the Gippsland basin. Consequently, in spite of minor oil and gas in the thermally immature section, the hydrocarbon potential of Bass basin could be substantially limited to thermally mature levels.

Reservoir, seal, and source appear to be present in the Bass at thermally mature but rarely drilled levels within the deeper lower Tertiary and Upper Cretaceous lower Eastern View coal measures and in the rifted Lower Cretaceous Otway Group. Hydrocarbon leads at these levels are predicted from structural analysis, with synsedimentary transverse faults that developed during the extensional phase of the basin providing an important trapping component. Such leads are defined at drillable depths by seismic mapping. The Bass basin could thus ultimately emerge as a deeper hydrocarbon province.

WIMAN, STEPHEN K., Resource Enterprises, Inc., Grand Junction, CO, and GREGORY J. BELL, Gas Research Inst., Chicago, IL

Red Mountain Unit, Piceance Basin, Colorado: Field Laboratory for Research and Development in Coal Bed Methane Production

The coal bed methane resource of the Piceance basin has been estimated to exceed 60 tcf. Two wells have been drilled in Red Mountain unit, Mesa County, Colorado, to develop and improve the technology required to produce gas from deeply buried coal seams via vertical wells. The objective at Red Mountain is the Cameo coal member, Williams Fork Formation, Upper Cretaceous Mesaverde Group, at depths of about 5,500 ft. The 1 Deep Seam was drilled with the objective of coring and evaluating reservoir properties of both the coal and bounding sandstones. A continuous section of more than 200 ft of 3-in. core was recovered. Pressure transient tests were conducted in the 20-ft thick coal seam and in the overlying sandstone unit. The 2 Deep Seam was drilled underbalanced with an air/foam mixture, resulting in minimal formation damage and excellent recovery of coal cuttings. Extensive reservoir and production testing has been performed for the purpose of designing artificial stimulation procedures. Subsequent drilling and production testing at Red Mountain may require five additional years and may include as many as 20 additional wells.

WINN, ROBERT D., JR., MICHELE G. BISHOP, and PAUL S. GARDNER, Marathon Oil Co., Littleton, CO

Lewis Shale Reservoirs, Southern Wyoming: Turbidite Sandstones Deposited in Delta-Toe Settings

Depositional history of the Lewis Shale, Maestrichtian, south-central Wyoming, consists of a transgressive period followed by an interval of delta infill. Clastics are up to 760 m thick. The Lewis sea transgressed westward to areas of the Rock Springs and Wind River uplifts and opened eastward into the main part of the Interior Seaway. Transgressive shales are black, high in organic material, relatively silt-poor, and totally bioturbated. Depositional setting was a shallow, well-oxygenated shelf. Lewis clastics above the transgressive shale are coarser and are related mostly to deltas that entered the basin first from the northeast and later from the south. Sediments were deposited in delta-front, prodelta, deep-basin, and interdistributary areas. Lewis sandstones produce at Wamsutter and Hay Reservoir fields in addition to other areas. Wamsutter and Hay Reservoir sandstones were deposited beneath storm wave base by sediment gravity flows at the toe of the northern delta system. Sandstones may be thickly bedded and are commonly massive. Presence of fluid escape structures indicates that many thick beds underwent liquefaction during the final stages of deposition. Thinner sandstones are graded and many show Bouma sequences. Interbedded shales are unburrowed or are slightly burrowed by restricted faunas, indicating anaerobic to dysaerobic conditions and water depths of 150-200 m or more at times.

WOODWARD, LEE A., Univ. New Mexico, Albuquerque, NM

Potential Hydrocarbon Traps Along Growth Faults of Rio Grande Rift, New Mexico

Major tectonic boundaries along the Rio Grande rift are mostly listric normal faults that controlled late Cenozoic sedimentation in the rift. Potential hydrocarbon source and reservoir rocks occur in Cretaceous, Jurassic, and Pennsylvanian units beneath presumably barren upper Cenozoic continental sediments. Largest of the grabens and half-grabens comprising the rift is the Albuquerque basin, which was explored during the last decade with several deep tests. Upper Cenozoic strata generally dip gently toward the basin center except near bounding faults where "reverse drag" has beds on the downthrown block dipping toward the growth faults marking the basin margins. Most bounding faults are covered with surficial sediments, but at a few localities with good, deep expo-