sand bodies, and large expanses of lagoonal sediment. The reefs have only a few meters of relief and are commonly draped with lagoonal sediment of unknown age relative to the reefs. The sand bodies are especially common adjacent to the northwest rim and in the southwest lagoon. Drilling has revealed one marine sand body in the northwest, and another, possibly eolian, in the southwest. Lagoonal deposits cover large areas between reefs and sand bodies, and in the northeast, almost the entire area inside the rim.

Recent reefs are founded on a variety of substrates. Close to shore they locally fringe the Pleistocene ridges. Over Pleistocene sand bodies in the northwest and southwest, there are prominent reef and sediment shoals. On the rim, reefs encrust whatever Pleistocene rim lies below. However, many lagoon reefs are founded not on topographic highs but on nearly level lagoonal-sediment surfaces, some of which are the lagoonal drapes over Pleistocene reefs. In a few places, recent reefs occur over broad shallow depressions in Pleistocene surfaces. All recent reefs have far greater relief (5 to 20 m) than the buried Pleistocene reefs.

Few of the associations and features predicted by the karst origin of atolls hypothesis are present. For example: (1) the rim seems to have built up from the basal reflecting surface, rather than being a solutional modification of it; (2) stacked lagoonal sequences, where slow sedimentation perpetuates a steep-sided solutional depression, are uncommon, and most are present in the enclosed sounds and harbors; (3) many reefs are founded on flat surfaces, not on solutional pinnacles; and (4) deep sink holes are very rare. In general, Bermuda lacks clear signs of being a reef-encrusted paleokarst feature.

GARRISON, R. E., Univ. California, Santa Cruz, Calif., E. ESPIRITU, Bur. Mines, Manila, Philippines, and L. J. HORAN and L. E. MACK, Univ. California, Santa Cruz, Calif.

Petrology, Sedimentology, and Petroleum Potential of Early Cenozoic Back-Arc Limestone-Tuff Sequence, Central Luzon, Philippines

The Aksitero Formation of central Luzon is an upper Eocene to lower Oligocene sequence of evenly bedded hemipelagic limestones with a few thin interlayers of tuffaceous turbidites. The limestones consist chiefly of planktonic Foraminifera and calcareous nannofossils, but include up to 30% noncarbonate components which are mainly volcaniclastic debris. The tuff layers are graded beds comprising glass shards, pumice fragments, crystals, and fine-grained volcanic rock fragments. Hydrocarbons migrated into the pores of the tuffaceous layers at a relatively early stage during diagenesis. However, subsequent flushing has left only a bitumen residue, chiefly as thin coatings on grains and within pumice vesicles. During later stages of burial diagenesis, zeolites (mordenite and clinoptilolite), and secondary calcite preferentially replaced glass shards and pumice fragments. The zeolite assemblage suggests maximum burial temperatures of 55 to 90°C.

Deposition of the Aksitero Formation apparently occurred at water depths of at least 1,000 m in a subsiding back-arc basin lying west of an east-facing early Cenozoic island-arc system. Pelagic carbonate skeletal material was the main sediment source, but submarine ash eruptions of silicic composition generated volcaniclastic turbidity currents whose distal edges occasionally reached the basin floor. The thicker and coarser, more proximal facies of these volcaniclastic deposits may be prospective for hydrocarbons.

GAUDETTE, HENRI E., Univ. New Hampshire, Durham, N.H., PATRICK M. HURLEY, Massachusetts Inst. Technology, Cambridge, Mass., and T. LAJMI, Tunisian Geol. Service, Tunis, Tunisia

Provenance Studies in Tunisia by U-Pb Ages of Detrital Zircons

In recent years, with increasing availability of radiometric age determinations, age provinces in continental areas have become more clearly defined. Thus the possibility of establishing source areas for extensive sedimentary sequences by means of radiometric age determination of included detrital minerals is enhanced. With this objective, samples in northern and central Tunisia of detritus in river channels draining Oligocene–early Miocene sandstones, and rock samples of the Oligocene–early Miocene Numidian flysch, and Chercheri-Fortuna sandstones were obtained. Permian and Triassic sandstone outcrops and Ordovician sandstone cores from exploratory wells in southern Tunisia were also sampled. Zircons were separated from the detritus and the sandstones, and U-Pb isotopic compositions of the zircons were determined. Analytic results are interpreted on Concordia plots.

The results of zircon analyses of detrital sands in drainages from northern and central Tunisia indicate a primary intercept age of $1,750 \pm 100$ m.y. Analyses of the zircons from the Oligocene-Miocene sandstones cropping out in the drainage areas yield an age of $1,706 \pm 50$ m.y., strongly suggesting that the zircons in the drainage channel sands represent the population of zircons in the rocks themselves, and that the detrital zircon may provide a useful indicator of provenance. F. C. Wezel has shown a predominant transport direction of south to north for the Oligocene-Miocene sedimentary units of Tunisia. A southern source for the sedimentary sequences in northern Tunisia was sought in the Permian-Triassic and Ordovician sandstones of the Medenine area. Zircons from the Permian and Triassic sandstones give an intercept age of $1,650 \pm 60$ m.y. The U-Pb age of zircons from the Ordovician sandstone core samples is $1,871 \pm 26$ m.y. Thus, we find a coherence, within analytical error, of all the zircon separates from rocks of widely differing stratigraphic ages and geographic locations. This does not preclude the possibility of mixed populations; however, on the basis of our analytical methods, it is strongly suggested that the zircon populations appear homogeneous, and that their U-Pb isotopic ages do represent the primary age (i.e., the source age) of the zircons regardless of stratigraphic setting.

GAUTIER, DONALD L., U.S. Geol. Survey, Denver, Colo., and Univ. Colorado, Boulder, Colo.

Authigenic Tourmaline Crystals in Pore Spaces of Upper Cretaceous Gas-Productive Sandstone, North-Central Montana

Authigenic, euhedral tourmaline crystals are present in a core from a productive shallow gas reservoir in the Upper Cretaceous Eagle Sandstone of the Tiger Ridge field, north-central Montana. Detrital tourmaline is a common constituent of sands and sandstones, and although overgrowths on detrital grains have been reported elsewhere, discrete euhedral crystals of authigenic tourmaline formed in an unmetamorphosed sandstone have not been described. The tourmaline occurs as acicular or prismatic crystals of dravite which are 10 to 20 μ in length and 1 to 5 μ in diameter. The dravites usually occur in intergranular pore spaces and exhibit typical tourmaline crystal habit. An authigenic origin for these crystals is suggested by their (1) delicately euhedral morphology, (2) unabraded appearance, (3) occurrence in growth positions, (4) similarity to dravite overgrowths within the same rock, and (5) close association with other authigenic phases.

The presence of igneous rocks in the vicinity of the well, combined with the absence of tourmaline in several wells not associated with igneous rocks at Tiger Ridge field, suggests that Eocene volcanism in the Bearpaw Mountains was the source for boron, which facilitated tourmalinization. This interpretation has implications relative to the timing of gas emplacement in the Eagle Sandstone at Tiger Ridge. The gas was generated by bacteria during Late Cretaceous time; then adjacent Eocene volcanism caused tourmalinization. The gas was then remigrated into gravity-slide fault blocks in response to the Bearpaw Mountains intrusion and uplift.

GEBELEIN, CONRAD D., deceased, formerly Univ. California, Santa Barbara, Calif., RANDOLPH P. STEINEN, Univ. Connecticut, Storrs, Conn., EMILY J. HOFFMAN, Boston Univ., Boston, Mass., PETER GARRETT, and J. MICHAEL QUEEN, Univ. California, Santa Barbara, Calif.

Mixing Zone Dolomite in Tidal-Flat Sediments of Central-West Andros Island, Bahamas

The central-west coast of Andros Island is a complex carbonate facies mosaic, deposited at or near mean sea level. The shore has prograded intermittently during the past 3,000 years to produce a seaward-thickening wedge of sediments up to 25 km wide and about 4 m thick beneath the present shoreline. Old channel levees and beach ridges have been preserved during progradation as topographically high ridges which allow the development of freshwater lenses beneath. These lenses show considerable seasonal variation, both in geometry and pore-water chemistry. Mixing zones, extending laterally a few hundred meters around the lenses and down to Pleistocene bedrock, separate the fresh waters of the lenses (with high alkalinity and low ionic concentration), from adjacent saline and hypersaline waters (with low alkalinity and high ionic concentration).

Fresh waters are generally undersaturated with aragonite, calcite, and dolomite, but calcite saturation may occur locally. The ends of aragonite needles, skeletal grains, and pellets are commonly corroded, although low-magnesian calcite crystals may locally enclose and replace aragonite by dissolution-reprecipitation.

Water in the mixing zone, between 2,500 and 15,000 ppm Cl^-, is undersaturated with respect to aragonite and low-magnesian calcite, but supersaturated with respect to calcium magnesium carbonates. X-ray diffraction (XRD) studies indicate small amounts ($<6\%$) of protodolomite (38 to 44 mole % $MgCO_3$) distributed in patches across whichever sedimentary facies are intersected by the mixing zone. The mixing-zone origin of the protodolomite is however equivocal, as similar compositions occur more rarely with saline pore waters not associated with present or past mixing zones. SEM reveals 1μm euhedral rhombic protodolomite crystals between and engulfing aragonite needles. The needles may later dissolve.

Chemical data from mixing zones indicate precipitation of a magnesium-rich phase frequently in excess of observed protodolomite concentrations; a huntite phase is indicated by considerations of stability, but is unsupported by XRD results.

GEORGE, C. J., Exxon Co., U.S.A., Midland, Tex.

Porosity Examples from IAB Field, Coke County, Texas

IAB field produces oil from an Upper Pennsylvanian (Cisco-Canyon) carbonate buildup situated on the western edge of the Eastern shelf. The reservoir is approximately 6 mi (9 km) long, 2 mi (3 km) wide, and 300 to 1,000 ft (100 to 300 m) thick. The upper surface of this buildup is irregular with several pinnacles, probably caused by subaerial erosion that occurred during drops in sea level.

From examination of cores, 10 lithofacies have been identified and divided according to texture, sediment types, fossils, and mineralogic composition. Facies recognized are subtidal normal-marine deposits, ranging from relatively quiet-water skeletal wackestones to relatively high-energy, shallow-water oolitic grainstones.

Porosity consists of both primary and secondary types and is controlled by depositional fabric, dolomitization, and freshwater diagenesis. Five main porosity types are (1) primary interparticle and (2) primary intraparticle porosity, both in grain carbonate rocks, (3) secondary leached grain and moldic porosity in grain carbonate rocks, created during a drop in sea level, (4) secondary vug porosity in muddy or very fine-grained carbonate rocks, also created during a drop in sea level, and (5) secondary intercrystalline and vug porosity in dolomites.

Muddy carbonate beds had low initial effective porosities because of poor sorting, whereas grain-rich carbonate beds had high initial effective porosities owing to good sorting. Following deposition, sea level probably dropped, and the buildup was exposed to freshwater vadose and phreatic diagenesis. Solution of various grains and simultaneous precipitation of equant calcite cements produced secondary leached porosity and reduced primary interparticle and intraparticle porosity. Porosity preserved during this period of subaerial exposure and freshwater diagenesis was probably later reduced during deeper burial by additional cementation and compaction.