tion of mud probably provided most of the pore water which liquefied intercalated sand. The exceptional wavy dikes apparently were intruded earlier and compacted later with their wall rock. Sill-like masses are more problematical; some evidence clearly indicates liquefaction after burial, but others of these masses could have formed at the depositional interface. Certain strata were liquefied in place after burial and are not true intrusions, although they strongly resemble sills. Some synsedimentary folds can be distinguished from tectonic ones where sandstone dikes cut through them and prove an early, soft-sediment origin. Dikes along slaty cleavage have been cited as evidence of early formation of such cleavage. Some intrusions are useful in determining dates of migration and deposition of ores or fluids. Dikes may show close relations with regional structures, but many do not. Though more common in tectonically mobile regions, they also occur in stable ones. They most probably originated by shocks from earthquakes or from sudden loading. They are more common than is generally realized and their usefulness to the geologist has not been appreciated fully.

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Distribution of Late Cretaceous Rotaliporidae and Globotruncanidae in California and Northwestern Mexico

A study of planktonic Foraminifera from the Upper Cretaceous of California and northwestern Mexico forms a basis for erecting a preliminary biostratigraphic zonation.

The *Praeglobotruncana stephani* assemblage zone, of late Cenomanian age, is characterized by species of Rotaliporidae.

Strata of early Turonian age are recognized by the first appearance of bi-keeled globotruncanids which characterize the *Globotruncana imbricata* assemblage zone. Within this zone occur *Praeglobotruncana helvetica, G. kuepperi,* and several undescribed species. The *Globotruncana coronata-G. inornata* assemblage zone includes rocks of late Turonian to early Senonian age and contains distinct species of *Globotruncana, Clavihedbergella,* and *Hedbergella.*

The *Globotruncana arca* assemblage zone, of late Senonian age, contains several important stratigraphic markers, *e.g., Globotruncana ventricosa, G. havanensis, G. elevata,* and *Rugoglobigerina rugosa.* These indicate a Campanian to early Maestrichtian age. The planktonic Foraminifera which define the late Maestrichtian in other parts of North America are unrecorded in the eastern Pacific.

The stratigraphic and geographic distributions of selected species of *Praeglobotruncana, Globotruncana,* and *Rugoglobigerina* are compared with those from the Atlantic Coast and Gulf-Caribbean area. This comparison suggests that *Globotruncana arca, G. linneiana, G. fornicata,* and several other species were cosmopolitan, whereas such species as *G. calcarata* were latitudinally restricted during the Late Cretaceous. The genera *Abathomphalus* and *Plummerita* are found exclusively in the Tethyan region. *Globotruncana gagnebini, G. subcircumnodifer,* and others are reported only from the western margin of the Atlantic Ocean; *G. kuepperi, G. churchi,* and *G. putahensis* are unknown outside of the Pacific basin.

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Late Cretaceous-Paleocene Phytoplankton, Upper Moreno Formation, California

Dinoflagellates and acritarchs are abundant in the upper Moreno Formation (Late Cretaceous-Paleocene) in Escarpado Canyon, California, the type area for the members of the Moreno Formation. Samples of the Marca Shale and the overlying Dos Palos Shale Members were studied from a subsurface cored section. The age of these units is well established by use of criteria independent of palynology, such as ammonites and foraminifers. The Cretaceous-Tertiary boundary usually has been placed somewhat arbitrarily at the contact of the Marca and Dos Palos Shales, but by the use of palynological evidence is placed in the Dos Palos Shale about 20 feet above the top of the Marca Shale. The phytoplankton assemblages exhibit marked changes at this level and further changes are evident higher up in the Dos Palos Shale.

The Maestrichtian is characterized by *Gymnodinium nelsonense* Cookson, *Deflandrea cretacea* Cookson, and a distinctive new species of *Hystrichosphaera.* The Danian is characterized by new species of *Areoligera, Hystrichosphaeridium, Cannosphaeropsis, Deflandrea,* and *Palmnickia.* A new species of *Palaeostomocystis,* and *Membranosphaera maestrichtica* Samoilovitch are abundant in the Danian but occur rarely in the Maestrichtian. Forms restricted to the lower Danian of the Dos Palos Shale include *Peridinium* and a new genus of Deflandreaceae. Forms restricted to the upper part of the Dos Palos Shale include *Cordosphaeridium inodes* Klumpp, *Deflandrea speciosa* Alberti, and *Glyphanodinium facetum* Drugg. Pollen and spores are present also in large numbers in the upper Moreno Formation. With a few exceptions, they are generally inferior to the phytoplankton for purposes of age-dating and zonation. There is good reason to believe that the phytoplankton eventually will prove to be as useful as planktonic foraminifers for correlation purposes.

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Diagenetic Modification of Recent Sediments Associated with a Limestone Island

Recent carbonate sediments on Ambergris Cay, British Honduras, occur as a thin veneer of supratidal and intra-island lagoonal deposits, incompletely mantling an irregular Pleistocene limestone surface. Both sediments and rock exhibit different degrees of diagenetic modification. The supratidal mud flats usually adjoin very shallow hypersaline ponds, where sediments are subjected to extremes of chemical and physical environmental conditions; the raised rims of the mud flats prevent rapid drainage after periods of heavy rainfall or sea-water flooding.

Etching by rainwater and boring by algae tend to destroy or comminute sediment particles on the mud flats. Furthermore, extensive blue-green algal mats commonly are associated with a near-surface crust of dolomitized sediment. Degree of induration of this crust is related to the degree of dolomitization. Low pinnacles of Pleistocene limestone, where exposed near the dolomite crust, also have been partly dolomitized. Recent sediment particles commonly are recrystallized to cryptocrystalline carbonate, without mineralogic change, prior to burial.

Storm-tossed sand and cobbles on windward beach ridges show other diagenetic effects, including disintegration caused by decay of organic matrices and by solution of particles below the fresh-water table. Conversely, cementation and pore filling in some beach-ridge sands represent incipient lithification.

The extensive outcrops of Pleistocene limestone afford a study of post-lithification diagenesis affecting lithofacies which are analogous with nearby Recent sedimentary facies. Replacement of most of the component grains of this rock by low-magnesium calcite, a change not seen in Recent sediments, tends to obliterate boundaries of recognizable grains. Boring by various organisms, leaching by percolating water, and filling of pores further modify the rock's texture; however, its primary fabric remains readily recognizable.

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ALBION-SCIPIO TREND: MICHIGAN'S SYNCLINE OIL FIELDS

The Albion-Scipio trend is a remarkable series of synclinal oil and gas traps formed in rocks of Middle Ordovician age. Except for Silurian reefs, most of Michigan's oil and gas traps are related to anticlines—many to fracture systems on their flanks. The Albion-Scipio trend is a conspicuous exception because oil and gas occur only in synclines between low-relief anticlines. Nearly 59 million barrels of oil, 3.5 million barrels of L.P.G., and 50 billion cubic feet of gas have been produced since its discovery in 1956. Cumulative oil production alone exceeds 70 times the total produced from all other Middle Ordovician reservoirs discovered in Michigan prior to 1956.

The Albion-Scipio trend is not a single, simple syncline. It consists of several coalescing, linear, and narrow oil fields, each less than a mile wide. Development drilling has resulted in the merging of several fields into a narrow productive area nearly 24 miles long. Several small fields, not yet joined to the central reservoir area, extend the full length of the trend, nearly 35 miles. More than 550 producing wells and 400 dry holes have now been drilled on 20-acre and 10-acre drilling units. Closely spaced wells provide excellent control for geologic investigations. Oil reservoirs are found in fractured and dolomitized limestone in the Trenton Limestone and Black River Group. Individual synclines are offset but are joined together by narrow, fractured, and dolomitized productive areas which curve around the ends of the anticline, thus forming a nearly continuous oil reservoir. The Trenton Limestone is overlain by thick shale units. Except for a few very thin shale units, the Trenton and Black River consist only of carbonate rock.

Most wells are completed as flowing wells with potentials of several hundred barrels of oil per day, but are prorated to 110 barrels per day. Porosity and permeability differ considerably from well to well, and in different parts of the trend. Most porosity is intercrystalline, but large vugs and open fissures also are present. Original bottom-hole pressure averaged about 2,050 psi. at the northern end of the trend and about 1,600 psi. at the southern end. Most of this difference is related to the difference in depth.

Many Trenton tests drilled on the southern edge of the Michigan basin, west of the Washtenaw anticlinorium, have not revealed definite Trenton anticlinal structures such as those found in the anticlinorium. Total differences in relief west of the anticlinorium are of about the same magnitude as in the trend. Studies suggest that the Trenton surface in this region is one of many low-relief flexures having about the same magnitude of relief as those found along the trend. In this region, one other field with characteristics similar to those of the trend has been found. It is the Hanover field, about 6 miles northeast of the trend. Discovered in 1959, Hanover has produced nearly a million barrels of oil from nine wells. Other reservoirs probably exist in this region, but they will be hard to find.

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DIAGENETIC PHASES

Diagenesis, interpreted as all those changes that may occur in or to a sediment after deposition—short of dynamic or high-temperature metamorphism—is a major process of the geocycle, potentially leading to sedimentary lithogenesis. However, this process may be subdivided into distinctive geochemical phases, each of which tends toward an equilibrium condition, only to be upset by the introduction of a new set of environmental parameters. An intermediate phase may be bypassed or reinstated repeatedly.

From the moment of deposition of a sediment grain to the eventual exposure to weathering and erosion, there are ideally three principal phases.

(a) *Syndiagenesis* (term proposed by Bissell, 1959) is the "bacterial phase," during which the sediment's organic matter provides the nutrient for vigorous bacterial metabolism and various "in-fauna." In an oxygenated basin there is a secondary subdivision into the following: (1) an upper oxygenated layer, where CO_2 is the principal organic waste product and the pH will be 7 or less; carbonate shells tend to dissolve unless present in overwhelming numbers; and (2) a lower layer beneath a boundary marked by zero redox potential ($Eh = 0$); here there is no free O_2 and the principal bacterial flora utilize CO_4^{--} ions of the connate sea water, leading to sulfite and sulfide production, and commonly the formation of pyrite nodules. In barred basins the $Eh = 0$ boundary is above the sediment-water interface and the upper layer is eliminated. Other modifications occur in fresh-water and supersaline basins.

(b) *Anadiagenesis* (writer's term) is the "compaction and cementing phase," during which the progressive new sediment accumulation and loading of the buried sediment lead to closer packing of grains and the slow expulsion of connate water. Organic geochemistry is replaced by inorganic reactions. By molecular filtration, clay adsorption, base exchange, *etc.*, the connate residual solutions become progressively stronger, commonly until brines evolve. Important authigenic minerals are formed. Mg-rich brines favor dolomite metasomatism. Complete cementation leads to connate-water entrapment, but diaclastic revival during further subsidence or tectonics may remobilize the circulation. In some basins igneous activity leads to introduction of juvenile water and elements, including metallic ions. It is postulated that at times in the past these have joined the ascending connate fluids, emanating in submarine springs to enrich bottom waters, with which "raw materials" it has been possible for syndiagenetic bac-