occur at or a short distance below the sediment-water interface; post-depositional effects result largely from solution alteration accompanying subaerial exposure and (or) increasing lithostatic pressure. The thinness of Recent carbonate accumulations precludes solution alteration due to lithostatic pressure; consequently the present discussion is confined to the remaining diagenetic processes.

Within the marine environment pene-depositional diagenesis affects both sedimentary structures and grain textures. The most obvious, and perhaps most important, structural change is the destruction of stratification in carbonate mud deposits by a vagile infauna. Indeed, this absence of stratification is so commonplace that the occasional occurrence of laminated carbonate mud deposits heralds unusual environmental conditions.

The most important change in grain texture results from the recrystallization of various grain types, both skeletal and non-skeletal, to cryptocrystalline carbonate. Recrystallization is effected by the replacement of aragonite by aragonite or by the replacement of high magnesium calcite by high magnesium calcite. The only obvious change accompanying this replacement is the obliteration of the pre-existing crystal fabric of the affected grain. In fact, there seems to be no decrease in solubility accompanying the replacement. These data coupled with the observed replacement of organic matter by cryptocrystalline carbonate suggest that decomposition of the contained organic matter in certain carbonate grain types may indirectly effect recrystallization to cryptocrystalline carbonate.

Subaerial exposure of unconsolidated carbonate deposits results in carbonate solution, replacement, and precipitation in that order. High magnesium calcite and aragonite are dissolved preferentially by meteoric water until the percolating solutions become saturated with respect to low magnesium calcite. At this point the more soluble high magnesium calcite and aragonite constituents are replaced by less soluble low magnesium calcite. Pore space precipitation of low magnesium calcite occurs when calcite saturated solutions lose water or carbon dioxide. Precipitation and (or) replacement transform the unconsolidated carbonate deposit into a limestone.

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DIAGENESIS IN JURASSIC-CRETACEOUS CLASTIC ROCKS IN SOUTHWESTERN ALBERTA AND THE INTERPRETATION OF SEDIMENTARY ENVIRONMENTS

Coarse-grained clastic rocks at the top of the Kootenay formation and the base of the Blairmore group are transitional between the Jurassic and Cretaceous systems in the westerly regions of the area.

The subsurface equivalents in the easterly regions of the area occur at the base of the Blairmore or Mannville groups and are known locally as the Basal quartz, Ellerslie, Sunburst, Cutbank and Dina sands, respectively; all are generally considered Cretaceous in age and overlay either the Paleozoic surface or members of the Jurassic Ellis group. Where the Cretaceous overlies the Paleozoic, a residual or detrital bed commonly occurs and is known as the Deville member of the Mannville group.

Petrographic examination of the transitional or basal Cretaceous clastic rocks indicates that there are three main authigenic mineral facies developed largely irrespective of rock type in "residual beds," shales, siltstones, sandstones, and (or) conglomerates.

The three diagnostic authigenic minerals are hematite, siderite, and pyrite; other significant authigenic minerals present are magnetite, iron-rich dolomite, calcite, kaolinite, silica chlorite, and glauconite.

The presence of these authigenic minerals, together with various physical features of the sedimentary rocks, assists in elucidating the intricate paleographic pattern of estuaries, rivers, lakes, and land surfaces.

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INTRUSIVE CARBONATE IN THE ICE RIVER COMPLEX, BRITISH COLUMBIA

The Ice River valley is situated in Yoho National Park in the westerly ranges of the southern Rocky Mountains, British Columbia. The region is the site of a nepheline syenite-ijolite-jacupirangite complex which is intruded into Cambro-Ordovician sediments and is dated (potassium-argon method with biotite) as Devonian in age.

Associated with the ijolite-jacupirangite differentiates is a mass of brown-weathering carbonate (dominantly iron carbonate with calcite and iron oxide) at least 2 miles long and 900 feet across. This mass was originally described as a "stoped block or roof pendant" but recent field observation indicates that the carbonate is intrusive. Two traverses are described.

The carbonate is succeeded by an intensely fractured and brecciated ferruginous zone, which merges into carbonatized aegirine-feldspar gneisses which in turn merge into and alternate with ijolite or the aegirine-feldspar pegmatite dykes that cut the ijolite. Augen of unaltered to partly altered pegmatite occur commonly in the gneiss. Pods and lenses of carbonate (similar in composition to that of the main mass and as much as 500 feet from it) are associated with the gneiss.

A 10-foot zenolith of aegirine-feldspar pegmatite occurs in the main mass of carbonate. Toward the periphery of the zenolith the pegmatite merges into gneiss, then gneiss with carbonate and finally carbonate.

The carbonate mass may be termed carbonatite.

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SILURIAN CONODONTS FROM CENTRAL KENTUCKY AND THEIR RELATION TO EUROPEAN ZONES*

The Brassfield limestone and the overlying Crab Orchard formation of Madison and Estill Counties, central Kentucky, represent a nearly continuous sequence of strata of Llandovery and early Wenlock age. The conodont sequence very closely parallels that of Europe, and zones I and II (Llandovery in age) and zone III (early Wenlock(?) in age), as recognized by Otto Walliser, are found here.

The Brassfield limestone and the Plum Creek clay, Oldham limestone, Lulbegrud clay, and Waco limestone members of the Crab Orchard contain conodonts of zone I for which *Icriodina* is the most important guide. Zone II conodonts are found in a thin zone transitional between the Waco and the Estill clay member, and the lower part of the Estill contains new genus A and *Bryantodus?* sp., which are characteristic of European zone III. Zone III conodonts have been considered to be early Wenlock in age, but exact correspondence with the graptolite zones is uncertain.

Northward in Ohio and west of the Cincinnati arch in Indiana and Kentucky, the Brassfield also contains a zone I fauna. As the Crab Orchard formation is traced

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northward, the part below the position of zone II conodonts becomes progressively thinner, and only a thin wedge of the lower part extends into southernmost Ohio. Here this lower unit is overlain by the Dayton limestone, which underlies a shale sequence called the Alger formation in Ohio. The Alger is a northern extension of the Estill clay.

Zone I is represented in the Kankakee limestone of northern Illinois, and zone III conodonts have been obtained from the Joliet limestone of northern Illinois and the basal few inches of the Osgood formation of southern Indiana. Insufficient work in other areas of the United States precludes precise correlation. The close resemblance of the European and central Kentucky conodont faunas, together with the other known occurrences, shows the potential value of these fossils for stratigraphic work in this part of the column.

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Experimental Consolidation of Carbonate Mud†

About 200 compression and heating experiments simulating diagenesis and low-grade metamorphism have been performed on samples of $CaCO_3$ sediment obtained from the banks west of Andros Island in the Bahamas; the mud consists mainly of aragonite needles, 0.1μ by 1μ, and ovoid pellets, about 100μ across. The ranges of conditions and the precisions of the experiments were as follows: pressure P, 1–3,000 bars, $\pm 10\%$; temperature T, 25°–400° C., $\pm 10\%$; and time t, 3 hours to 2 months, $\pm 1\%$. The chemical compositions of the sea water in the mud and the vapor driven off were not determined.

Consolidation is effected by compaction of grains, recrystallization, and by increase of integranular bonding. Pressure of 30 bars causes a compaction of about 20% for a given temperature; at $T = 25°$ C. the density increases from that of the initial mud, 1.7 g/cm^3, to a final 2.0 g/cm^3; essentially, some of the interstitial water is squeezed out. Heating at T between 100° and 200° C., under $P < 30$ bars, causes an apparently anomalous decrease in density because of an exchange of air for water in the void spaces, and the products remain friable.

Heating at $T = 400°$ C. under low pressure, $P < 100$ bars, for $t > 1$ day, lithifies the mud, apparently during inversion of aragonite to calcite; electron micrographs show coalescence, increasing with time, of the original needles to rounded grains and then to a subhedral, interlocking texture; the product has a compressive strength > 100 bars. Higher pressure, $P > 100$ bars, causes increasing breakage of the aragonite needles.

About 30 experiments on aragonitic mud from Kapingamarangi Atoll in the Caroline Islands produced results similar to those obtained on the Bahamas mud. However, in none of 6 experiments performed on deep-sea, coccolithic, calcite ooze from near the Hawaiian Islands could the sample be lithified, even at $T = 400°$ C., $P = 1,000$ bars, $t = 11$ days; apparently consolidation of calcite sediment requires the circulation of dissolving water.

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Relation of Mineralization to Precambrian Stratigraphy, Blind River Area, Ontario

The study is a result of a continuing surface-mapping program that was begun in 1953, with additional data provided by the drilling and underground activities of mining companies. The Archean rocks are Keewatin greenstones intruded by Algoman granites, for which the geological age has been determined as about 2,500 million years. These granitic rocks consist of gneissic granodiorites and massive, slightly radioactive quartz monzonite. The Archean complex was eroded to a peneplain with valleys in the less resistant rock types. The Lower Huronian formations are a sequence containing a great variety of sedimentary rocks such as conglomerate, arenites, argillite, siltstone, greywacke, limestone, and quartzite. Thickness and facies changes indicate a northwesterly source, northerly overlap, and deposition in shallow water controlled by basement topography. The Lower Huronian formations unconformably overlie the Archean rocks and in turn are unconformably overlain by the Middle Huronian formations. The Middle Huronian rocks consist of the Gowganda and Lorrain formations of conglomerate, greywacke, quartzite, and arkose.

Age-dating methods give the age of the Nipissing diabase as 1,950 million years and of the granite at Cutler as 1,750 million years (Penokean orogeny). A few dikes of Keweenawan olivine diabase have been tentatively dated at 1,000 million years.

Copper mineralization is associated with the Nipissing diabase. Uranium ores in oligomictic conglomerates are post-Archean placers modified at a later date. Uranium production to the end of 1962 consisted of 44,937,871 tons of ore grading approximately 0.1% U_3O_8, valued at $944,373,250.

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Early and Middle Pennsylvanian Fusulinids from Horquilla Limestone, Southeastern Arizona

The lower 1,000 feet of the Horquilla limestone of southeast Arizona contain abundant early and middle Pennsylvanian fusulinids. Unconformities lie at the base of the Horquilla and at the top of the zone of *Fusulina* about 1,000 feet above the base of the formation. The lowest fusulinid zones, the zones of *Millerella* and *Profusulinella*, are relatively thin and in combined thickness make up about 100 feet of strata. The overlying zone of *Fusulinella* varies from about 100 to nearly 400 feet thick and has a diverse fusulinid fauna which is divisible into three subzones. The evolution of species of *Fusulinella* from early into later fusulinid groups is remarkably complete. Above this the zone of *Fusulina* reaching 600 feet in thickness is divisible into four subzones.

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Basement Studies in Midwestern United States

As the midwestern United States is covered largely by Paleozoic sedimentary rocks, geologic studies of the basement complex are based primarily upon extrapolation of trends from the Laurentian shield and samples from approximately 50 basement wells in Illinois, Indiana, Ohio, and Michigan. Age determinations and lithologic studies of samples from these basement tests suggest an extension of the Grenville province from Ontario into the area of the Indiana-Ohio platform. Geophysical surveys also have revealed structural and lithologic patterns in the basement complex that can be

† Approved for publication by director of the U. S. Geological Survey.