and geophysicists which inhibit effective analysis of data as well as development of sound exploration philosophy. Understanding of the nature of the basement and its relation to and influence on sedimentary basins is the first step back to geological health.

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Radiometric Dating of the Bearpaw Sea

Sampling of the bentonites included in the Upper Cretaceous Bearpaw formation of southern Alberta and adjacent areas has provided material for a geochronological investigation of this marine sequence of strata. K-Ar dating of biotite and sanidine included in the bentonites has indicated that the Bearpaw sea invaded most of the southern Alberta Plains 72–73 million years ago. The transgression of the sea was probably rapid and the base of the formation may be isochronous over most of the area, with the possible exception of areas in southern Saskatchewan and northern Montana where the sea might have transgressed somewhat earlier. The regressive upper boundary of the Bearpaw formation is set at 68 million years in the westernmost plains and at 66 million years farther east in the Cypress Hills region. The geochronological picture is compatible with the paleogeography of the Bearpaw.

The bentonites intercalated with the normal sediments represent ashfalls produced by relatively remote volcanic eruptions. Study of the phenocrysts in the sand-size fraction, provided that contamination by detrital material has been negligible, has indicated that most of the bentonites are remarkably uniform in petrologic type and are dominantly andesitic. A source area is suggested in the eastern Cordilleran belt of northern Montana, where strong volcanism throughout most of the Late Cretaceous accompanied the gradual emplacement of the Boulder batholith. The andesitic nature of the Bearpaw bentonites is compatible with granodioritic magmatism in the postulated source area.

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Some Aspects of Recrystallization of Ancient Limestones

Conditions and criteria for "grain growth" in metals are not followed in diagenesis of most sedimentary carbonates; thus the concept should not supersede "recrystallization" as first documented by H. C. Sorby for both petrographers and metallographers. An inclusive term, "neomorphism," is herein proposed to embrace the following isocompositional and replacive processes: inversion, recrystallization (calcite calcite), and strain-recrystallization. Neomorphism and its daughter processes may be aggrading or degrading; the former may be prophyroid (a few crystals growing to replace a passive groundmass) or coalescive (nearly all crystals are consuming or being consumed). In these processes driving forces and physical conditions (porosity, solutions, etc.) vary considerably.

Diagenetic calcite has the following attributes: (1) origin—porefill (P), displacive (D), or neomorphic (N); (2) shape—equant (E), bladed (B), or fibrous (F); (3) dimensions—aphanocrystalline (1) to extremely coarsely crystalline (7); (4) foundation—syntaxial overgrowth (O), crust (C), or random (R). Numerous combinations are possible, expressed symbolically as, for example, $P.E_3$ (porefill, finely crystalline equant spar), or $N.B_5O$ (neomorphic coarsely bladed overgrowth on a trilobite, replacing micrite).

Three phases of neomorphism are discussed. All micritic limestones have undergone porphyroid neomorphism (?), probably from 2μ needles or plates to 2μ subequant polyhedral blocks of calcite (electron microscope work of R. Shoji), involving digestion of the vast majority of original mud particles of similar length but much more slender than the polyhedra.

In some limestones, neomorphism bursts through the "micrite curtain" to form microspar. Normal micrite measures $1\frac{1}{2}$–2μ; a saddle exists at 3–4μ, before another peak frequency at 5–6μ (microsparite). This volumetrically very important type of neomorphism is probably specifically produced by coalescive recrystallization; it results in *uniformly*-sized grains, usually of *simple* loafish form, and is most frequent in limestones with shale interbeds, probably not in brackish environments as has been claimed.

In freakish limestones, diagenesis may go still further, producing pseudospar or fibers largely by porphyroid neomorphism. These may mimic closely the appearance of normal porefill calcite; criteria of grain shape, orientation, uniformity and boundaries are equivocal. The only firmly diagnostic criteria are those based on grosser fabric relations such as transection of allochems, occupation of large areas unsupported by allochems, or presence of undigested inclusions.

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Current Computer Usage by Exploration Geologists

Many geologists are beginning to use the computer to aid in solving some exploration problems.

Key micropaleontological data from several thousand wells penetrating portions of the Tertiary in the Louisiana-Texas Gulf Coast area are stored on magnetic tape for computer usage. Data retrieval programs select wells encountering specified paleo markers and process associated environmental data for preparation of maps showing paleogeography, shorelines, and attitude of ancient seafloors. Too much time is required to justify such map preparation manually.

Correlative tops from electric logs and sample logs are recorded on punched cards or magnetic tape to allow rapid map preparation using the computer in combination with automatic plotting equipment. Current programs include ability to accept normal fault data and restore section on isopachous maps. Fault patterns, combinations of isopach and structure data, and isoliths of sands and combinations of sands can be mapped. Truncation, onlap, shale-out, etc., are indicated on printed results and plotted maps to aid interpretation and contouring.

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Time-Trend Analysis in Paleoecology

Changes in the physical attributes of the rock are compared with differences in the relative abundance of certain fossil species within a vertical sequence of limestone and shale layers. Minor variations in the texture and composition of the rock reflect subtle changes in the depositional environment which had a direct influence on the organization of the faunal community. To plot these relationships, a continuous series of beds within the Richmond group (Upper Ordovician) were quantitatively studied in the field and in thin section.

The major sedimentation trends exhibited by the field and laboratory data are separated from local fluctuations by using two smoothing formulas. A 21-term formula which loses ten observations at each end of the series is used to accentuate the long-period trends, and a 5-term formula losing only two observations at each end is used for the short-period changes. The IBM 7090 has been programmed to compute simultaneously both smoothed curves for 11 variables from a continuous series containing up to 500 units.

The smoothed curves for several lithologic characteristics including thickness, and percentages of calcite, dolomite, micrite, and sparite, are compared with curves based on the condition, size, orientation, and relative abundance of several fossil species. The influx of new species and the decline of others can be related to physical changes in the rock, which are the result of differences in the depositional environment.

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CALCITE ARAGONITE PROBLEM

The fundamental stability relations of calcite and aragonite are considered in the light of: (a) calorimetric data, (b) solubility measurements, (c) direct studies of phase changes. New data of Crawford and Fyfe suggest slightly lower pressures for aragonite formation than have been formerly proposed. The difference in free energies of calcite and aragonite are small, and the effect on stability of grain size, non-hydrostatic stress, and impurities are evaluated and may be as large as ΔG°.

Consideration of precipitation reactions involving nucleation and growth indicates that there need be no direct relationship between fundamental stability and the order of appearance of possible phases. Ostwald's law of stages implies an inverse correlation. Data on the effects of temperature and solution composition indicate that the form of calcium carbonate precipitated may frequently reflect favorable kinetics of aragonite nucleation enhanced by calcite growth inhibition.

A basic problem in carbonate sedimentation involves the rate at which metastable aragonite undergoes transformation to calcite. Data on this reaction in the dry state are compared with similar processes in nitrates. It is suggested from study of single crystals that the dry process is essentially zero order, but a combination of structure and habit sensitivity may lead to other apparent rate laws. Nucleation normally takes place in the prism zone and proceeds via a linear boundary migration parallel to the c axis. A lack of reactivity of (001) also appears in aqueous reactions. In general, dry rates must be of no significance at the temperatures normally encountered in diagenesis unless deformation is extensive.

In aqueous solution the problem is more complex. The rate is a function of volume, pH, P_{CO_2}, salt catalysis (general) and salt inhibition (specific), and organic protection as in some fossil aragonite, and aggregate fabric (as in fossils). It is suggested that the formation of calcite from aragonite in aqueous solutions involves homogeneous nucleation and that this is the slow rate step and is controlled by some function involving Ca^{++} and/or HCO_3^- activities. Specific inhibition appears to involve inhibition of growth and several explanations are possible, but the size of the inhibiting cation appears to be critical.

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STROMATOPOROIDEA OF THE DEVONIAN SOURIS RIVER FORMATION FROM THE SUBSURFACE OF SASKATCHEWAN

The Souris River formation is a Devonian subsurface formation, presently tilted southwestward, which is encountered in southern and central Saskatchewan in wells drilled for oil, potash, and helium at depths ranging from a maximum of 6,142 feet below sea-level near the international boundary to a minimum of 821 feet below sea-level near the Souris River subcrop edge in central Saskatchewan.

Stromatoporoids were recovered from cores 2–4 inches in diameter in fragmental dolomitic limestone of the lower Souris River formation. The wells are widely spaced over a belt more than 250 miles long in southern Saskatchewan.

The stromatoporoid faunas are represented by *Atelodictyon* and *Stictostroma* of the family Clathrodictyidae; *Actinostroma* and *Trupetostroma* of the Actinostromatidae; *Amphipora*, *Idiostroma*, and *Stachyodes* of the Idiostromatidae; and *Ferestromatopora*, *Stromatopora*, *Parallelopora*, and *Synthetostroma* of the Stromatoporidae. The faunas most closely resemble those described from the lower Upper Devonian Moberly member of the Waterways formation of northeastern Alberta. Members of the family Idiostromatidae are the most common in numbers of specimens if not bulk. The Stromatoporidae is the second most important family. *Trupetostroma* stands out among the Actinostromatidae.

Most of the stromatoporoid coenostea are whole, especially the massive forms. Thin bands of matrix material around most specimens are dark brown organic lutitic limestone. The hemispherical coenostea appear to have been rolled around and show no preferred orientation. These coenostea may have been transported a short distance and deposited outside of their normal habitat. The elongate coenostea of members of the Idiostromatidae are oriented parallel with bedding surfaces and show a slight but inconclusive suggestion of polarity. The lithologic character of the described matrix material is common in association with *Amphipora* and *Stachyodes* wherever they are found. These genera are likely not oriented in their position of growth. The absence of any suggestion of a base of attachment in *Amphipora* is puzzling.

The internal preservation of the stromatoporoid coenostea is good considering the nature of the over-all lithologic character of the stratigraphic unit. Gallery spaces are mostly infiltrated by calcium carbonate.

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PRINCIPLES AND LIMITATIONS OF PRECAMBRIAN STRATIGRAPHY

Detailed studies of the Precambrian basement complex, initiated mainly for economic reasons, have now shown that the record is in part decipherable; that considered as a whole, it is indeed complex; and that it represents a large part of the history of the earth. However, the geological histories of many individual parts are no more complicated than those of areas of comparable size in younger mountain-built belts.

The processes affecting the outer crust in Precambrian time differed but little from those now active. Differences in proportions of rocks of different types that make up the record of the Precambrian, in contrast