volcanic rocks. Economic deposits are within the competent members of any rock type.

Nickel-bearing sulphides are directly related to ultrabasic and basic intrusive rocks. The sulphide deposits occur at the bottom of sills or in structural traps in the underlying rocks.

Molybdenum, bismuth, and lithium mineralization is spatially related to late granites. Iron formations containing magnetite have potential economic value and are stratiform, sedimentary deposits.

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DIGITAL SEISMIC SYSTEM IN PETROLEUM EXPLORATION

Digital seismic instrumentation and techniques have been developed as components of a broad petroleum exploration system. The objective of this system is to lower the cost of oil-finding through greatly increased reliability of seismic data. Characteristics of the system include defining the exploration objective, identifying associated problems, optimizing field procedures, applying a series of pertinent data-enhancement techniques, and interpreting the results in terms of the specified objective. Digital seismic instrumentation and techniques permit the explorationist to apply the system on a more scientific and less empirical basis.

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LATTICE PARAMETER STUDIES OF SYNTHETIC NEPHELINE SOLID SOLUTIONS AND OTHER TRIDYMITE-TYPE STRUCTURES

Lattice parameter determinations of pure sodium nephelines, crystallized from gels and glasses at 1,000 $Kg/cm^2$ water vapour pressure, show that the parameters of this mineral are very variable and that they can not be correlated either with their crystallization temperatures or with the length of the experiments, unlike the parameters of albite (MacKenzie, 1957). In contrast, the lattice parameters of nephelines of composition $Na_3KAl_4Si_4O_{16}$, which more closely approach those of natural nephelines and of pure kalsilites, do not vary with their crystallization temperatures. Investigation of the lattice parameters of nepheline solid solutions in the systems $NaAlSiO_4$—$NaAlSi_3O_8$—$H_2O$, and $NaAlSiO_4$—$CaAl_2Si_2O_8$—$H_2O$ indicates that the addition of very small amounts of both the $NaAlSi_3O_8$ and $CaAl_2Si_2O_8$ molecules produces an increase in the $c$ parameter and also stabilizes both the $a$ and $c$ parameters of the nepheline solid solutions. No change in nepheline solid-solution lattice parameters was found in the system $Na_3KAl_4Si_4O_{16}$—$CaAl_2Si_2O_8$—$H_2O$. These results are discussed in terms of three hypotheses proposed by Smith and Tuttle (1957), and it is concluded that the main factor causing the variability in pure nepheline parameters is the collapse of the framework structure about the small sodium atom, although the substitution of hydroxyl ions for oxygen atoms and variations in the starting materials in these experimental studies may also contribute to these variations.

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GEOCHRONOLOGY APPLIED TO EXPLORATION PROBLEMS

The present facilities for isotope age measurements at the Shell Development Company, Exploration and Production Research Division Laboratory, permit measurement by all of the well established age methods—potassium-argon, rubidium-strontium, uranium-lead, and thorium-lead. This gives us the advantage of a wide choice of minerals, and at least among the igneous and metamorphic rocks some age data can usually be obtained by at least one of the methods mentioned. Age measurements are often used to determine the age of igneous rocks encountered in wells. This enables the geologist to judge whether additional sedimentary reservoirs could be expected. In some places the age might suggest that "true igneous basement" has been reached and that no further sedimentary section can be reasonably expected. In other places, the presence of igneous sills and dikes, or volcanic layers is suggested, below which additional reservoirs could be expected. Samples of bottom-hole rocks from wells drilled prior to the general use of age determination methods have now been examined with the same objective. In general the results of these measurements on wells in different parts of the United States can be shown to fall in line with the suggested basement periods (G. R. Tilton and S. R. Hart, *Science*, vol. 140, p. 357, 1963).

Frequently age determinations are used to determine time and influence of igneous activities in new exploration areas. In this case surface samples are used. This type of information helps to unravel the structural evolution of an area. This is important background for any study of the hydrocarbon potential of a new exploration province.

The use of glauconite for potassium-argon and rubidium-strontium dating of sediments has been common for many years in oil exploration for obvious reasons. The use of the minerals in bentonite to date sediments is the subject of another paper in this symposium (R. E. Folinsbee, H. Baadsgaard, G. L. Cumming, and J. Nascimbene, Radiometric Dating of the Bearpaw Sea). The first dates on both biotite and zircon in bentonites were those measured at the Shell laboratory.

Recently we have been measuring the age of detrital minerals in sediments as an aid in determining the source of conglomerates and micaceous sandstones, and this work is continuing.

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RELATIONSHIP OF MINERALIZATION TO THE PRECAMBRIAN VOLCANIC-SEDIMENTARY COMPLEXES IN THE PORCUPINE AND RED LAKE AREAS, ONTARIO

The early Precambrian rock sequences at both localities consist of three major types, metabasalt, acidic welded tuff, and sediments. At Red Lake the Keewatin sediments are graywacke and argillite with conglomerate beds high in the sequence. In the Porcupine area the Keewatin sediments are mainly argillite which is unconformably overlain by Timiskaming conglomerate, graywacke, quartzite and argillite. The intrusive rock suites are also generally similar and range in composition from early basic and ultrabasic rock to later intermediate and acid rocks.

New information has been added on the type, thickness, persistence and relative ages of the major units of country rocks. Similar rock types in a similar sequence indicate a rhythmic volcanic-sedimentary cycle.

Known copper mineralization of economic grade is restricted to the Pearl Lake porphyry in the Porcupine area. Gold orebodies occur in a variety of rock types but some particular types are restricted to individual beds.

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BASEMENT: NOT THE BOTTOM BUT THE BEGINNING

Borehole myopia, isotropism, and symmetresis are occupational geological diseases of petroleum geologists

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 2$\mu$ needles or plates to 2$\mu$ 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 1½–2$\mu$; a saddle exists at 3–4$\mu$, before another peak frequency at 5–6$\mu$ (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