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Equilibrium in Sulfide Deposits, I—Concepts

Results of experimental investigations of sulfide minerals are finding increasing application in the study of the genesis of ores. Apart from the experimental problems, there are two large areas of uncertainty in applying experimental data to mineral assemblages: (1) What was the state of the system at the time of deposition? (2) To what extent has the original state been preserved?

Regarding the conditions at deposition, several variations are possible. Equilibrium may in principle be maintained throughout the system during mineralization under constant physiochemical conditions, so that each phase is homogeneous. Alternatively, if conditions change during deposition, and provided that solid-state diffusion rates are slow compared to the rate of crystal growth, zoned crystals may grow; equilibrium then exists only between simultaneously deposited zones. When dealing with such zoned equilibria, the necessity of sampling individual growth zones is obvious, though analysis may be difficult and inter-mineral correlation of zones tenuous. One mineral may grow while others neither grow nor are dissolved appreciably, so that the growing mineral is in equilibrium with only the surfaces of the earlier minerals; this is probably the most common and hence the most useful case. Finally, one or all of the minerals may be deposited metastably.

Re-equilibration (as by metamorphism), will tend to mask the original assemblage and to replace it with another that is stable under the new conditions. It is possible during re-equilibration for each isolated growth-zoned crystal to homogenize independently without reacting further with its environment; the product may be distinguished from that obtained from complete equilibrium at deposition only by the fact that different crystals may have different bulk compositions. In any event, such compositions have no significance in terms of phase equilibria. Zoned crystals are excellent evidence that complete re-equilibration has not occurred.

Some minerals (*e.g.*, sphalerite, pyrite, arsenopyrite, iron oxides, and many silicates) appear to be highly resistant to solid-state re-equilibration in usual hydrothermal environments, whereas others (*e.g.*, galena and the copper and silver sulfides) are suspect. Because many, if not most, solution-crystal reactions and homogeneous reactions within the depositing solution equilibrate more rapidly than solid-state reactions within the body of a crystal, it is likely that the surfaces of all crystals exposed simultaneously to the same solution are approximately in equilibrium, though the interiors of the crystals may be effectively isolated from the solution and from one another.

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Equilibrium in Sulfide Deposits, II—Natural Assemblages

Detailed examination of ore mineral suites from fissure veins with transmitted as well as reflected light has revealed three features of particular interest in dealing with the problem of equilibrium in sulfide deposits: (1) Periods of hydrothermal leaching have temporarily interrupted the growth of crystals, showing that the overall process of ore deposition was reversed. (2) Very fine growth banding in crystals (commonly observed as color banding due to variations of iron content in sphalerite) probably reflects a delicate adjustment of precipitate composition to minor changes in the solution. "Unconformities" due to leaching occur within the sequence of finely banded material, suggesting that even during leaching, solution and crystal were not far out of equilibrium. (3) Certain growth zones observed in sphalerite may be recognized to have precipitated from appreciably supersaturated solutions because of a heterogeneous distribution of iron within individual growth zones. Presumbably, even higher degrees of supersaturation would have produced colloidal precipitates. Consistent with observations (1) and (2), leaching is not closely associated in time with this type of deposition.

The idea that crystal surfaces may commonly be in approximate equilibrium with the solution from which they are being deposited and that strong departures from equilibrium may be recognized has important implications. Provided that we deal only with assemblages formed near equilibrium conditions and preserved without modification, laboratory phase studies may be applied to the mineral assemblages to determine the physiochemical environment of ore deposition. If evidence of a sequence of environments is preserved, as by growth zoning, the change in physiochemical conditions can provide information about the mechanisms by which the deposits form.

Near-equilibrium processes of ore deposition would preclude a supersaturated or colloidal solution as an important mechanism of ore transport. Though the rates of processes equilibrating solution and crystals may locally be slow enough to permit metastable solutions to exist, they would be only transitory, intermediate stages in precipitation.

Finally, in the case where the solubility of an ore mineral decreases as the solution moves from source to surface, the maintenance of near-equilibrium conditions will mean that leaching of a mineral can occur only on the inflow side of the ore body and that leaching may thus provide a useful criterion for the impending bottoming of the ore.

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Sur les Constituants Phosphates des Minerais de Fer Oolithiques de France

Les minerais de fer oolithiques sont constitués en grande partie par des minéraux cristallisés, reconnaissables au microscope en lumière transmise ou en lumière réfléchie. Leur identification est aisée lorsqu'ils sont assez largement développés. Ce n'est pas le cas des minéraux phosphatés qui sont relativement rares et se présentent en général en petits cristaux.

Il a été néanmoins possible de déterminer dans de nombreaux minerais le minéral responsable de la teneur en phosphore, il s'agit toujours de phosphates de calcium.

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Structure and Rock Sequences of the Critical Zone of the Eastern Bushveld Complex

Investigations of the critical zone of the eastern part of the Bushveld Complex during 1952–55 and 1961 indicate that the zone is divisible into three sectors along its strike. In the northern sector the zone is poorly exposed; the sequence of rock units (gross layers) within it is poorly indicated. In the central and southern sectors the zone is divisible into an upper anorthosite series and a lower pyroxenite series. Throughout the central sector, a remarkably consistent sequence of major units is present in the pyroxenite series. The anorthosite series consists of units of anorthosite and closely related rocks, with three to four felspathic pyroxenite units. In the southern sector, the zone is grossly the same as in the central sector, but the pyroxenite series varies along strike both in sequence and thickness of units. Thick anorthosite units appear locally in the lower part. Chromitite seams in the series in this sector differ in number and position from those of the central sector and change markedly along strike. Variations are in part related to structural features of the floor.

The investigations indicate that the evolution of the critical zone must be studied not only in terms of chemical and mineralogical variation, but in terms of the structural evolution of rock sequences in the various sectors. A wealth of internal structures bears on this problem. Disconformities, flow banding, compaction structures, slump features, and other structures suggest evolution by fractional crystallization and mechanical sedimentation in a magma at least intermittently in motion and periodically subjected to structural disturbance.

COOMBS, D. S., *Geology Department, University of Otago, Dunedin, New Zealand*

Basalt Relationships Illustrated by the Plagioclase-Ferroan Diopside-Olivine-Silica Tetrahedron

The major normative components of basalts can be accommodated in the tetrahedra plagioclase-ferroan diopside-olivine-quartz or nepheline. Average compositions of magma batches from basaltic provinces project from the plagioclase point as a broad band extending across the base of the tetrahedra. At one extreme are types in which an "indicator ratio"

$$\frac{\text{Hy} + 2\text{Q}}{\text{Hy} + 2(\text{Q} + \text{Di})} = 0.85 - 0.65,$$

and from which early precipitation of hypersthene is common. Differentiation leads to granophyric products. Where the indicator ratio is less than 0.65, hypersthene, if present, tends to follow augite. Hypersthene is rarely found where the ratio is less than 0.50. For typical tholeiites, the indicator ratio is 0.65 ± 0.20. In the range 0.40 to 0.00 is a rather heterogeneous group including the high-alumina basalts of Medicine Lake Highlands as well as mildly alkaline suites such as Ascension Island, Easter Island and Reunion. The latter examples tend to show a pantelleritic differentiation trend. Averages for the more typical alkaline suites have normative nepheline instead of hypersthene and have trachytic and phonolitic associates. Analyses of pyroxenes from alkaline basalts contain normative Ne; those from tholeiites commonly contain normative Di, Ol, Hy. Separation of such pyroxenes from their parent magma in general accentuates the undersaturated or oversaturated nature of the magma with respect to the plagioclase-diopside-olivine plane. Consideration of crystallization trends allows the approximate location of a five-phase "point" (olivine, augite, hypersthene, plagioclase, liquid) and interpretation of reaction relationships. Clustering of analyses of typical tholeiites around this point suggests that they have originated as liquids coexisting with the four solid phases mentioned.

EL BAZ, FAROUK, AND G. C. AMSTUTZ, *Missouri School of Mines and Metallurgy, Rolla, Missouri.*

A Statistical Study of Bravoite Zoning

This study is based on a systematic record of some 300 individual grains of zoned and zone-free bravoite from the National Lead mine at Fredericktown, Missouri. Here the bravoite occurs in the sulfide rich transition facies between the Cambrian Lamotte sandstone and the Bonneterre dolomite. The associated sulfides are galena, marcasite and pyrite, siegenite and chalcopyrite, and small amounts of sphalerite and wurtzite. Both the enclosing sediments and the associated sulfides are very similar to the deposits of Maubach-Mechernich, except for the lack of folding and metamorphism.

Six distinct types of zoning are recognized. Some of these types show a definite relationship with such environmental parameters as the type of sulfides and the type of host rock surrounding the specific bravoite grain.

The following internal regularities were also observed:

1) a unidirectional composition change of all gradational zones,
2) regularities with regard to gaps and steps in the range of reflectivities, and thus of composition,
3) the occurrence of empty layers (holes) at definite compositional boundaries and within certain definite zones,
4) a relationship between type of zoning and crystal habit.

Since these observed geometric regularities are essentially a function of lattice and crystallization properties, it should be possible to ultimately derive some conclusions on certain characteristics of the phase diagram(s) of FeS_2-NiS_2-CoS_2. A few preliminary steps in this direction are reported.

EMELEUS, C. H., *Department of Geology, University of Durham, Durham, England*

Structural and Petrographic Observations on Layered Granites from S. W. Greenland

Fluorite-bearing granites cut Precambrian gneisses to the north of Tigssalug Fjord, S.W. Greenland. Mineral layering, consisting of unusual concentrations of biotite, opaque minerals and accessories, is found in the upper and marginal parts of two granite stocks. The structures include well-developed rhythmically repeated layering, gravity-stratified bands, indications of trough-banding, and distorted banding resembling sedimentary slump structures.

The normal unbanded parts of the granites contain quartz, plagioclase, microcline perthites and small amounts (total usually under 5 per cent by volume) of biotite, opaque minerals, sphene, orthite, apatite, zircon and fluorite. The western granite of the pair contains abundant microcline perthite phenocrysts. The banded structures consist essentially of concentrations of biotite, opaque minerals and the accessories found throughout the granites, the total modal proportions amounting to between 30 and 40 per cent (vol.), rising in extreme instance to over 80 per cent (*e.g.:* biotite 48 per cent, opaque minerals 13 per cent, allanite 10 per cent, sphene 10 per cent, apatite+zircon 1 per cent). The mafic bands are generally of finer-grained rock (to 2 mm+) than the normal granite (5 mm+).

Texturally, the mafic bands consist of euhedral biotite, sphene, orthite, apatite and zircon, poikilitically enclosed by quartz, plagioclase, microcline perthite and fluorite. Opaque minerals are often euhedral but are invariably studded with small crystals of apatite. Well-formed crystals of microcline perthite and plagioclase are sometimes present, the latter showing normal and faint oscillatory zoning. These plagioclase crystals are more anorthite-rich (to An 25+) than poikilitic plagioclase (*ca.* An 5) from the same specimen. The textures of the mafic bands resemble orthocumulates with biotite, orthite, etc., as cumulus crystals and quartz, plagioclase, microcline perthites and fluorite in an intercumulus role, although small amounts of both feldspars may appear with the cumulus phases.

The structural and textural features of the banded granites are closely comparable with those found in many basic intrusions. It is suggested that bottom accumulation of early-formed minerals, aided by crystal sorting in magmatic currents, operated during the latter stages in the crystallization of unusually fluid granite magmas.

FERGUSON, J., AND T. C. R. PULVERTAFT, *Geological Survey of Greenland, Copenhagen, Denmark*

Contrasted Styles of Igneous Layering in the Gardar Province of S. Greenland

Igneous layering is developed in nearly all the larger Gardar intrusions of South Greenland in rocks varying from gabbro to granite in composition. In this account the layering in each rock type will be dealt with in turn, special emphasis being placed on the Nunarssuit syenite and the Ilímaussaq alkaline intrusion which present many contrasting features.

Layering comprising olivine-rich bands in more felspathic gabbro forms synclinal structures in the large (over 200 m. thick) gabbro dykes.

Layering of the Skaergaard type is pronounced in the pyroxene-fayalite syenites of Nunarssuit, Kûngnât and Ilímaussaq. Cumulus clinopyroxene and fayalite have been concentrated into bands as a result of gravity sorting under the influence of currents. Evidence of current action and turbulence is particularly striking in the Nunarssuit syenite, in which sedimentary structures such as cross-bedding, outwash channels and slump breccias have been observed. In the petrographically similar syenite of the Klokken intrusion the bands are concentrations of mafic minerals from a few meters to tens of meters thick. The banding and concordant feldspar lamination form a rather perfect saucer-shaped structure.

In the Ilímaussaq batholith the pulaskite and quartz syenite show mafic banding on rather a fine scale, while in the foyaite the banding is coarser, with pegmatitic feldspars arranged normal to the banding. Of the layered agpaitic rocks the kakortokites are by far the most striking, with rhythmic color banding and lamination developed through a vertical thickness of 400 m. The bands are gently undulating and very persistent. The black, red and white bands correspond to arfvedsonite/aegirine, eudialyte and alkali feldspar concentrations, respectively. The white bands have an average thickness of 10 m while those of black and red kakortokite average 1.5 m thick. The sequence black-red-white is never varied though the red bands may be inconspicuous. Tranquil conditions prevailed during the formation of this layering.

Banding due to compositional and textural variations, or to textural variations alone, is locally developed in the naujaite. The lujavrite of Ilímaussaq has lenticular color banding due to the alternation of aegirine (green) and arfvedsonite (black) concentrations. Part of the nepheline syenite of the Grønnedal intrusion is characterized by extreme feldspar lamination. Elsewhere there is occasionally marked mineral layering.

Mineral layering is locally conspicuous in the Helene granite where mafic minerals (including fayalite and clinopyroxene) are concentrated into layers as a result of gravity sorting assisted by magmatic currents.

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Study of Distorted Pyrite Crystals Fuente Valoria (Soria, from Spain)

In Fuente Valoria, district of Arnejun, in the province of Soria (Spain) medium-size crystals of pyrite with a pronouncedly distorted cubic habit occur in calcareous rocks that are mined for ornamental use. The distortion of these crystals seems to result from homogeneous deformation, which could be attributed to pressures on them. The variations of the cube angles have been measured, showing that the distortion is rather uniform. A qualitative spectrographic analysis as well as *x*-ray study of the powder and of a single crystal have been carried out. The faces show a characteristic striation; using reflected light a microscopical study has been made of these surfaces in the natural state and after they have been attacked with acid.

GHOSE, SUBRATA, *Crystallography Laboratory, University of Pittsburgh, Pittsburgh, Pennsylvania*[1]

The Crystal Structure of Pseudomalachite

Pseudomalachite—$Cu_5(PO_4)_2(OH)_4$—is monoclinic with $a=4.49$, $b=5.76$, $c=17.06$ Å, $\beta=91°02'$; space group $P\ 2_1/c$, $Z=2$. The interpretation of sharpened Patterson projections on (100) and (010) yielded the three independent copper and one phosphorus positions. Successive structure factor calculations and Fourier summations brought out the six oxygen atoms.

The structure consists of the two types of Cu-octahedral chains running parallel to b. The first type of chain is composed of one Cu_1- and two Cu_2-octahedra and is similar to the chain found in lindgrenite and azurite. The second chain is composed of Cu_3-octahedra sharing square edges. These two types of chains are bonded together to form sheets parallel to bc; these sheets again are tightly bonded to each other by means of isolated (PO_4) groups. As a result there is no distinct cleavage in the mineral. Erinite is isostructural with pseudomalachite.

GLASSER, L. S. DENT, F. P. GLASSER, AND H. F. W. TAYLOR, *Dept. of Chemistry, University of Aberdeen, Aberdeen, Scotland*

The Role of Oriented Transformations in Mineralogy

Transformations occurring in rock-forming minerals in the solid phase vary from those involving only small atomic displacements (*e.g.* the α-β quartz inversion) to those in which the structure is completely disrupted.

Laboratory experiments in recent years have demonstrated that many minerals undergo a type of reaction in which the product has a structure more or less related to that of the starting material and is formed from it, not randomly, but in one, or at the most several, definite orientations. This type of reaction takes place in three dimensions throughout the starting material, and has been described as topotactic; it is to be distinguished from epitaxy or oriented overgrowths.

Examples which have been studied in this and other laboratories are the dehydration of amphiboles to pyroxenes, and of brucite to periclase; the decomposition of dolomite; and the transformation of rhodonite to wollastonite solid solutions. Recent studies on iddingsite show that the hydration of olivine to yield hematite and other products occurs in an ordered way, demonstrating that this type of oriented reaction plays at least some part in geologic processes. It is suggested that this part may be more important than has hitherto been realized, and that many already known textural relationships may be reinterpreted in the light of these concepts and correlated with their history.

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The Crystal Structure of Dachiardite

Structural work on mordenite suggested a possible structure for dachiardite—a rare zeolite with the composition $(Na_2,Ca)_2Al_4Si_{20}O_{28}\cdot 12H_2O$. This trial structure has been con-

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firmed by 2-dimensional Fourier syntheses. Further refinement of the principal projections is presently under way.

The crystals are monoclinic with space group $C\ 2/m$. The framework structure of dachiardite is closely related to the mordenite structure. There are comparatively wide channels along both the *b*- and *c*-axies. The observed twinning of dachiardite can be explained readily on the basis of the aluminosilicate framework.

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Differentiation in Ferrar Dolerites, Antarctica

The Ferrar dolerites occur as sills, sheets, bosses and dikes in the basement complex and overlying Beacon sandstone throughout 60,000 square miles of Victoria Land. Related lavas overlie the Beacon sandstone. Chilled margins of different sills range in composition from 53.4 to 55.5 per cent SiO_2 and 6.6 to 4.2 per cent MgO. Sills less than about 600 ft. thick are essentially undifferentiated; their pyroxenes are augite and pigeonite. The same minerals have also crystallized from thicker sills in which the ratio

$$\frac{\mathrm{MgO} \times 100}{\mathrm{MgO} + \mathrm{FeO} + \mathrm{MnO}}$$

is less than 47, *e.g.* Peneplain sill at Solitary Rocks. This sill is relatively undifferentiated, though small coarse-grained pegmatoids are found in the upper parts. Hypersthene has crystallized in large quantity from thick sills in which the above ratio is greater than 47, *e.g.* Basement sill in the Kukri Hills and Mt. Edgerton sill. Accumulation of hypersthene by gravitational settling has had an effect on differentiation comparable to that of olivine in less siliceous rocks. The chilled margin of the Mt. Edgerton sill has 53 per cent SiO_2, 6 per cent MgO, 11 per cent CaO; 45 per cent pyroxene, 40 per cent plagioclase and 11 per cent mesostasis. Within such sills hypersthene accumulation gives a band a few hundred feet thick with 17–21 per cent MgO and up to 70 per cent hypersthene (Mg 83-70) and subordinate augite, and 30 per cent plagioclase (An 80). Near both the upper and lower limits of hypersthene accumulation, hypersthenes are commonly rimmed by hypersthene (Mg 70–62) formed by inversion of pigeonite which in turn may be rimmed by more ferriferous uninverted pigeonite. Anorthosite lenses within this layer may have 85 per cent plagioclase (An 83) and 16 per cent CaO. Upward migration of residual liquids forms pegmatoid lenses and bands of granophyre (63–67 per cent SiO_2, 1 per cent MgO) with about 7–10 per cent ferroaugite, 10 per cent plagioclase (An 45–An 10), 65 per cent micropegmatite, plentiful hornblende and iron ores. In large dike-like bodies such as the Detour Nunatak dike, such granophyres may be several hundred feet thick.

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Light Extinction and Scattering by Suspensions of Finely-divided Minerals

The true total extinction, and the absolute angular distribution of scattered intensity from 0 to 90 degrees, have been measured for aqueous suspensions of quartz, flint, diamond, ilmenite, and coal as size-graded fractions in the diameter-range ½ to 15 microns. Due to the irregular shape and spread in size of the particles, their behaviour differs from that of mono-disperse spheres on the Mie Theory. The extinction coefficient shows a constant value 2 down to 1 or 2 microns particle-size, the precise lower limit depending on refractive index and absorption coefficient. The angular scattering coefficient is more or less independent of particle-size within the same size-range, for angles outside the forward diffraction lobe, and agrees well with the scattering calculated from geometrical optics. The measurements were made to ascertain the conditions under which extinction and scattering could be used to estimate the surface-area concentration and composition of airborne dust causing pneumoconiosis, but the results are of general application.

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Cell Parameters of Orthopyroxenes

The cell parameters have been determined for forty analyzed orthopyroxenes from metamorphic rocks, the majority of them from the charnockite series or from related rock types in the granulite facies. In general the cell dimensions are each smaller than those for igneous orthopyroxenes of equivalent composition as determined by Hess. The a and b dimensions may be considerably less: they are both apparently affected by the Al, Fe^{3+}, Ti and Ca content of the mineral, those richest in Al (7 to 9% Al_2O_3) having particularly low b dimensions. The c dimension is relatively less affected by these ionic substitutions and may be used to give an approximate value for the Fe^{2+}:Mg ratio; the b dimension may then be used to give some indication of the alumina content of the orthopyroxene. It is suggested that the departure from linearity of the cell dimensions of various orthopyroxenes reported by Ramberg and De Vore and taken as evidence of the non-ideal nature of the orthopyroxene mixed crystal series, may be interpreted also in terms of the variation in paragenesis of the orthopyroxenes studied.

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Layered Basic Intrusive Rocks of the Wichita Mountains, S.W. Oklahoma

Basic igneous rocks crop out along the axis of the Wichita Mountains of southeastern Oklahoma. Five stratigraphic units have been distinguished on the basis of mineralogical and textural features. The three lower units which have been mapped at a scale of 1 inch to 1000 feet are discussed in this paper. The lowermost unit includes alternating layers of troctolite and anorthosite with olivine gabbro at some horizons. The second unit consists predominantly of anorthosite in which poikilitic pyroxene crystals ranging from 6 inches to 3 feet in diameter are randomly distributed. Enclosed plagioclase grains are of the same size and composition and show the same degree of preferred planar orientation as the grains outside the intergrowth. Some larger grains have cores of more calcic plagioclase. The third unit comprises anorthosite, gabbro, olivine gabbro, and troctolite. Poikilitic pyroxene grains from one-quarter to two inches in diameter enclose plagioclase grains which are fine-grained and anhedral in contrast to medium-grained, subhedral plagioclase outside the intergrowth. Plagioclase within the pyroxene is randomly oriented whereas in most specimens plagioclase in the enclosing rock shows some degree of preferred planar orientation.

Textures correspond closely to examples cited in the classification proposed by Wagner, Brown, and Wadsworth in 1960. Texturally the troctolites are adcumulates to mesocumulates and the gabbro containing large poikilitic pyroxene is an extreme example of a heteradcumulate. There is some question whether adcumulus growth could have been restricted to a narrow zone at the interface between crystal mush and magma. The small poikilitic intergrowths appear to have formed by simultaneous crystallization of plagioclase and pyroxene. Later adcumulus and/or intercumulus growth enlarged some of these clusters to approach the size and texture of the intergrowths in the lower units.

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Mineralogy and Petrology of the Ultramafic Complex at Duke Island, S.E. Alaska

The Duke Island ultramafic complex crops out in two areas totaling 9 square miles. Rocks within the complex are comprised of olivine, clinopyroxene, hornblende, and ferriferous oxides and are classified as dunite, peridotite, olivine pyroxenite, and hornblende pyroxenite; all are devoid of plagioclase and orthopyroxene. Hornblende pyroxenite generally occurs as a peripheral rim. Hornblende-anorthite pegmatite is closely associated and, seemingly, a derivative of the complex, but abundant surrounding gabbroic rocks have been altered near its margins and are apparently older. Remarkable gravitational layering, showing grain-size grading, occurs intermittently in the olivine-bearing ultramafic rocks through a possible thickness of 2 miles. Counterparts of cross-bedding, slide conglomerates, and slump structures suggest accumulation under the influence of magmatic currents. A marked structural break, locally analogous to an angular unconformity with basal conglomerate, marks the contact of olivine pyroxenite and the dunite-peridotite zone and indicates at least two major intrusions of magma into the complex. The Fe/Mg ratios of olivine and clinopyroxene increase slightly in the ultramafic units in the order listed above, but cryptic layering is slight or absent. A variety of structural, mineralogic, and petrologic relations suggest that the ultramafic rocks have crystallized from an ultramafic magma. The hornblende pyroxenite and the alteration aureole seem to indicate peripheral reactions that tended to produce a sequence of zones in local equilibrium under the thermal and chemical gradients that existed between the magma and its country rock. The possible composition and temperature of the magma are discussed.

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Stratigraphic and Lateral Variation of Chromite Compositions in the Stillwater Complex

Layered concentrations of chromite occur at 13 recognizable stratigraphic horizons within the 3500-foot thick Ultramafic zone of the Stillwater Complex. Five of the chromitite layers can be recognized for 15 miles along strike, and one can be traced nearly 30 miles. Samples of chromitite from the footwalls of these layers were collected at intervals of about 2.5 miles along strike and 43 chemical analyses of clean chromite were made.

Considered individually, the major cations Cr^{3+}, Al^{3+}, Fe^{3+}, Mg^{2+}, and Fe^{2+} in the chromites show no simple stratigraphic or lateral patterns of variation. However, total iron ($Fe^{2+}+Fe^{3+}$) in the analyzed chromites decreases regularly from about 6.0 cations/unit cell in the stratigraphically lower layers to about 4.5 cations/unit cell in the middle layers, then reverses, and increases regularly to about 5.5 cations/unit cell in the stratigraphically upper layers. Lateral variations in the total iron content are small, so that isochemical lines trend parallel to the layering. The oxidation ratios ($Fe^{3+}/Fe^{2+}+Fe^{3+}$) of the chromites, on the other hand, show a strong lateral variation, decreasing from about 0.30 at the eastern and about 0.15 at the western ends to less than 0.05 in the central part of the complex. Stratigraphic variation of oxidation ratios is small and irregular so that isochemical lines trend at steep angles to the layering. Inasmuch as total numbers of trivalent and bivalent cations per unit formula of balanced chromite are fixed, this combination of constant total iron and changing oxidation ratio of chromites along any given chromitite layer accounts for the complex variations of the cations when considered individually.

The strong lateral change in oxidation ratios of the chromites suggests that a lateral oxygen partial pressure gradient persisted in the magma during crystallization and accumulation of the Ultramafic zone. The variation in total iron in the chromites suggests an early reversal in the expected trend of differentiation, followed in the upper part of the stratigraphic section by normal iron enrichment.

JAHNS, R. H., AND O. F. TUTTLE, *College of Mineral Industries, The Pennsylvania State University, University Park, Pennsylvania*

Layered Pegmatite-aplite Intrusions

Intrusive bodies of granitic pegmatite and aplite with simple or multiple layering can be grouped into four major classes:

1. Composite bodies comprising two or more separate injections with or without intervening thin screens of country rock.
2. Pegmatite bodies with marginal or interior aplite masses formed *in situ* or injected from other parts of the containing bodies.
3. Aplite bodies with marginal or central pegmatite masses generally formed *in situ.*
4. Bodies in which repeated alternations of pegmatite and aplite form thinly layered sequences.

Many of the pegmatite bodies are themselves layered, generally in thick units known as zones. Some of the aplites are faintly to distinctly flow layered, and others are featured by rhythmic layering in which adjacent thin and regular units differ from each other in composition; none of this layering is regarded as a result of crystal accumulation.

The bulk composition of the layered intrusive bodies corresponds to the thermal valley of petrogeny's residua system. This also is true of individual pegmatite and aplite masses in bodies of Class 1 and many of those in bodies of Classes 2 and 3. The pegmatites are ascribed to crystallization of magma saturated with volatile constituents, and the aplites to rapid crystallization of magma during escape of such constituents.

In contrast, other aplite masses are markedly sodic and the associated pegmatite masses are correspondingly potassic in composition. This difference is attributed to segregation of major alkalies in the presence of silicate melt and coexisting aqueous gas. Variations in distribution of the two fluid phases within a given intrusive, in distribution of alkalies between them, and in rates of diffusion of alkalies through the gas could account for the known relationships between these pegmatites and aplites.

All these types of bodies can be identified genetically with subsolvus granites and related rocks, and their common association is attributed to derivation from magmas with high water content. The amount of pegmatite and aplite associated with hypersolvus granites is trivial.

JAMBOR, J. L., AND CHARLES H. SMITH, *Geological Survey of Canada, Ottawa, Ontario, Canada*

Accurate Determination of Olivine Composition Using Standard Small Diameter *X*-ray Powder Cameras[1]

Olivine composition can be rapidly and accurately obtained by using standard (Straumanis mounting) 57.3 mm. *x*-ray powder cameras. A determinative curve based on analyzed natural olivines has been constructed by plotting the mol per cent Fo against the spacing of a $k\alpha_1$ back-reflection line which has been variously indexed as (0.10.0) and (450). The new graph deviates from the generally accepted straight line relationship of *d*-spacing versus

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[1] Published by permission of the Director, Geological Survey of Canada.

composition, but corresponds instead to the slightly curved graphs derived from specific gravity measurements by Bloss, and from *x*-ray powder measurements by Eliseev.

The powder camera technique was developed for use with the small amounts of olivine normally found in thin sections of altered ultramafic rocks, thereby avoiding the task of preparing concentrates as is generally required in the diffractometer method. Olivine composition determinations can be made where only one or two grains are present in a thin section and the method can therefore be applied to rocks which are almost completely serpentinized, to olivine-bearing gabbros, meteorites, and other rocks with a low olivine content.

The camera method has been successfully utilized in outlining the pattern of olivine variation in the Mount Albert ultramafic pluton, Gaspé, Quebec, and is now being applied to the study of olivines from the Muskox intrusion, Northwest Territories, by Smith. On the basis of 125 determinations, a range in composition of approximately Fo_{60} to Fo_{90} has been established. All determinations were made on material removed from thin sections.

JENSEN, MEAD LEROY, *Dept. of Geology, Yale University, New Haven, Connecticut*

Sulfur Isotope Mineralogy of Sulfides

Sulfur from the troilite phase in meteorites exhibits a remarkably uniform S^{32}/S^{34} composition of 22.21±0.02, which value is taken as a reference standard for δS^{34} measurements. Primordial sulfur is identical or at least very near this composition; nevertheless, sulfide minerals, even juxtaposed sulfides of the same species, are known to vary by more than 5 per cent from this value although no evidence has yet been found to indicate that specific sulfide species are characterized by specific isotopic compositions, even though sulfates are generally enriched in S^{34}. Information, therefore, on the processes by which this isotopic fractionation occurs is of assistance in determining the genesis of the sulfur in sulfide minerals.

For example, a large δS^{34} variation for sulfides in one deposit is more indicative of a biogenic rather than a magmatic hydrothermal origin for the sulfur in the sulfides. Biogenic sulfur is derived from hydrogen sulfide gas evolved from anaerobic bacteria of the *Desulfovibrio* genus. Sulfides in concretions, "red beds" copper deposits, and sandstone-type uranium deposits exhibit broad δS^{34} variations, suggesting that they contain sulfur derived almost entirely from this biogenic process. The sulfur in magmatic hydrothermal sulfides, on the other hand, is quite uniform in its δS^{34} composition. It is suggested that the reason for such is that as magmatic hydrothermal solutions become more and more concentrated in a cupola zone during progressive crystallization of their host or parent magma, the solutions become well mixed, resulting in a homogenization of what isotopic variations there may have been.

Further δS^{34} studies corroborate the inference that one mechanism of sulfide replacement and exsolution is by diffusion of the smaller cations through the framework of the larger sulfur anions because the replacing sulfide exhibits the same original isotopic composition of the replaced sulfide. Even supergene sulfides form by this same mechanism of replacement, as indicated by δS^{34} analyses plus the additional realization that sulfates are reduced to sulfides only at temperatures of several hundred degrees C. in the presence of an effective reducing agent such as carbon. Enrichment of S^{34} (a common feature of sulfates) in sulfides, which has been noted for a few sulfide deposits, in correlation with geologic data is rather suggestive of this source of sulfur.

Mass spectrometric measurements of the stable sulfur isotopic composition of sulfide minerals is an additional important mineralogical step in determining the composition and variation in composition of sulfide minerals.

LOOMIS, A. A., *Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California*

Noritic Anorthosite Bodies in the Sierra Nevada Batholith

A group of small intrusive noritic plutons preceded emplacement of the immediately surrounding granitic rocks in a part of the composite Sierra Nevada batholith near Lake Tahoe. The norite and noritic anorthosite bodies are similar to some larger stratiform bodies in that (1) iron was strongly concentrated during the intrusive sequence, and (2) both Willow Lake type and normal cumulative layering are present. Pyroxenes are more ferrous in rocks late in the sequence, although most of the iron is in late magnetite which replaces pyroxenes. Cumulative layering is present but rare; Willow Lake layering is common and was formed early.

The Sierran rocks differ from those in stratiform plutons in that (1) the average bulk composition of all rocks is noritic anorthosite in which typical rocks contain 21 per cent Al_2O_3, and (2) differentiation of both orthopyroxene and plagioclase produced a smooth progressive sequence of mineral compositions. A plot of modal An vs. En for all the rocks in the sequence from early Willow Lake type layers to late norite dikes defines a smooth trend from An_{88}-En_{76} to An_{44}-En_{59}. The ratio An/Ab decreased faster than En/Of until the assemblage An_{55}-En_{70} was reached and En/Of began to decrease more rapidly.

Similar plots for large stratiform bodies show too much scatter to define single curves. In the Sierran rocks, minerals which are found together crystallized together, and remained together during final emplacement. Large stratiform bodies contain early, cumulative mineral assemblages which, because of extensive convection or other mass movement, did not crystallize together. The stratiform bodies probably cooled more slowly but contained pressure, temperature, and concentration gradients which caused the apparent disequilibrium cumulative assemblages.

MANDARINO, J. A., *Royal Ontario Museum, Toronto, Canada,* S. J. WILLIAMS, *Scott Williams Mineral Co., Inc., Scottsdale, Ariz.,* AND R. S. MITCHELL, *University of Virginia, Charlottesville, Virginia*

Spiroffite, a New Tellurite Mineral from Mexico

Spiroffite, $(Mn,Zn)_2Te_3O_8$, discovered near Moctezuma, Sonora, occurs as small cleavable masses and has a hardness of about $3\frac{1}{2}$. The luster is adamantine and the color varies from red to purple. The density is 5.01 ± 0.02. Spiroffite is biaxial positive with $2V = 55° \pm 5°$, $\alpha = 1.85 \pm 0.01$, $\beta = 1.91 \pm 0.01$, $\gamma > 2.10$.

X-ray investigations show that the mineral is monoclinic with space group *Cc* or *C*2/*c*. Unit cell values are: $a = 13.00$ Å, $b = 5.38$, $c = 12.12$, $\beta = 98°$, with Z=4. Strongest *x*-ray spacings are: 4.98 Å (strong+), 3.00 (strong+), 4.06 (strong), 3.31 (strong), and 1.63 (medium strong).

A chemical analysis of 500 mg yielded the following data: TeO_2 75.93%, MnO 14.13%, ZnO 9.32%, CaO 0.15%, remainder 0.53%, total=100.06%. The remainder includes: insoluble 0.22%, CdO 0.07%, PbO 0.05%, MgO 0.02%, Bi_2O_3 0.08%, Sb_2O_3 0.02%, Al_2O_3 0.02%, CoO 0.02%, and H_2O 0.03%. The empirical formula derived from these data is: $(Mn_{1.26}Zn_{0.72}Ca_{0.02})\ Te_{3.01}O_{8.02}$.

Spiroffite is associated with tellurite, paratellurite, native tellurium, and several other new tellurites. The mineral is named in honor of Kiril Spiroff, Professor of Mineralogy at the Michigan College of Mining and Technology, Houghton, Michigan.

MORIMOTO, NOBUO, *Mineralogical Institute, Tokyo University, Tokyo, Japan*

On the Transition of Bornite

Three polymorphs were confirmed for synthetic and natural bornites: a high-temperature form with a cubic cell of $a=5.50$ Å, a metastable form with a cubic cell of $a=10.94$ Å, and a low-temperature form with a tetragonal cell of $a=10.94$ Å and $c=21.88$ Å. The high-temperature form is not quenchable. When it is cooled rapidly to temperatures below 230° C. the metastable form appears, and this slowly changes to the low-temperature form.

The crystal structures of the high-temperature form and the metastable form were studied by x-ray single crystal methods in order to elucidate the transition mechanisms of bornite.

The high-temperature form belongs to the space group $Fd3m$. Each metal atom is distributed statistically in 24 positions, each within a tetrahedron of sulfur atoms, which lie at the nodes of a face-centered cubic lattice. This result suggests that the metal atoms behave like an interstitial liquid in the sulfur lattice.

The metastable form shows a superstructure with reflections only of indices $(4m\pm l, 4n\pm l, l)$. This superstructure was interpreted to be composed of domains in twin relation. The structure was determined on the basis of the fundamental rhombohedral cell with $a_r=6.71$ Å and $\alpha=33°32'$. The unit cell contains $(Cu, Fe)_3S_2$. The space group is $R3m$. Although the sulfur atoms lie at the nodes of the cubic lattice, as in the high-temperature form, the metal atoms have an ordered distribution, forming a layer-structure parallel to $(111)_r$.

Thus, the transition of bornite from the high-temperature form to the metastable form takes place by an ordering of the metal atoms. A single crystal with its metal atoms in a mobile state changes to many small domains with low symmetry, without changing the face-centered lattice of the sulfur atoms. These domains are in twin relation and collectively give a diffraction aspect of higher symmetry. The transition from the metastable form to the low-temperature form is now under investigation.

MORIMOTO, N., F. MARUMO, AND R. SADANAGA, *Mineralogical Institute, Tokyo University, Tokyo, Japan*

New Interpretation of Systematic "Extra Extinctions"

Systematic absences other than space group absences in the reciprocal lattice (systematic extra extinctions), can be divided into the following two categories depending on their origin: (1) structural extinctions and (2) twinning extinctions. It has not always been possible, however, to elucidate the characteristics of patterns in direct space which cause the extra extinctions. To obtain systematically maximum information on the patterns in direct space from the extra extinctions, especially from the structural extinctions, a new method based on the Fourier transform of convolution has been developed.

We divide the reflections into two groups: (a) basic reflections building a super-lattice in reciprocal space which give only the space group extinctions, and (b) additional reflections that are regarded as satellites of the basic reflections and which give the extra extinctions. First, consider a crystal with only the basic reflections. The weighted reciprocal lattice of the crystal, A(s), is written as the product of two functions; a lattice function, $\Sigma\delta(s-s_{hkl})$, and a modulation function, $F_0(s)$, which is the Fourier transform of the electron density in the unit cell, $\rho_0(r)$:

$$A(s) = \Sigma\delta(s - s_{hkl})F_0(s).$$

Then consider a change in this crystal so that the additional reflections take place. The lattice function can be regarded as the convolution of two functions; the original lattice function, and a function, G(s), accounting for the additional reflections which are regarded as satellites of each basic reflection. Thus, we can write, for the weighted reciprocal lattice, A′(s):

$$A'(s) = [\Sigma\delta(s - s_{hkl})*G(s)]F_0(s).$$

The electron density of the crystal, $\rho(r)$, is the Fourier transform of A′(s) and given as:

$$\rho(r) = [\Sigma\delta(r - r'_{lmn})g(r)]*\rho_0(r)$$

Because G(s) is determined by the extra extinctions, its Fourier transform g(r) can be obtained easily. This is the maximum information we can expect from the extra extinctions without any knowledge of reflection intensities. This approach through the convolution principle is, therefore, very useful in interpreting not only the extra extinctions but also the extra symmetries in reciprocal space. Examples are given with wollastonite, pyroxenes and some sulfides. Twinning extinctions are also explained as a special case of this method. Examples are given.

NAIDU, R. P. J., *Department of Geology, University of Madras, Madras, India*

A Layered Complex in Sittampundi, Madras State, India

A. P. Subramaniam regards the rocks of this area as a thoroughly metamorphosed and reconstituted layered complex of anorthositic rocks with associated gabbroic and chromitic facies.

The present author holds the opinion that this is not a layered complex of igneous rocks, but that it is a complex of thermally metamorphosed calcareous sediments which were earlier intruded by peridotites and the so-called eclogites. This conclusion is based on field evidence which points to the whole Tiruchengode-Sankaridrug granite mass as having domed up the sediments and transformed them into rock assemblages consisting of calcium- and alumina-rich minerals—viz. tremolite and wollastonite marbles, anorthite gneisses with grossularite and epidote, amphibolites with edenite and pargasite, and skarn with fassaites, etc., all minerals formed at limestone contact with granites.

NAIDU, R. P. J., *Department of Geology, University of Madras, Madras, India*

Crystallization of Leucite-Nepheline-Sanidine in Ultrabasic Differentiates from a Peridotite

A peridotite mass in Salem, Madras State, India, is intrusive into a country rock of Peninsular gneiss, charnockite, magnetite-quartzites, and other sedimentaries of Archaean age. The peridotite mass itself is changed to form the largest deposits of magnesites in India. The peridotite mass, while giving minor differentiates of pyroxenites, etc., has sent into the surrounding country almost concentrically several dykes, which have the mineral assemblage: leucite-pyroxene-olivine, nepheline-pyroxene-olivine, nepheline-sanidine-pyroxene-olivine, sanidine-pyroxene-olivine, or orthoclase and microline perthites-olivine-pyroxene-biotite. In all the rock types sanidine is the last mineral to crystallize interstitially. The nepheline-sanidine intergrowths do not have the outline of leucites. There is no suggestion of the presence of pseudoleucite. It is therefore held that leucite and nepheline crystallized in a peridotite magma which was differentiating to a potassic residuum, and were fractionated before leucite reacted with the residuum to form orthoclase. There is no plagioclase in any of the differentiates.

OMORI, KEIICHI, *Tohoku University, Sendai, Japan,* AND PAUL F. KERR, *Columbia University, New York, N. Y.*

Infrared Study of Sulfate Minerals

The cations Na, K, NH_4, Ca, Mg, Mn and at times, Ba, Sr and Pb combine with the anion

SO_4 to form some 58 mineral species, which may be considered as belonging to six groups, as follows.

Group I. Anhydrous sulfates with Na, K, NH_4, Ca, Pb, Sr or Ba—thenardite, aphthitalite, mascagnite, glauberite, langbeinite, palmierite, anhydrite, celestite and barite.

Group II. Alkali hydrous sulfates with Na, K, NH_4, Ca, Mg, Cu or Fe—kroenkite, bloedite, ferrinatrite, syngenite, picromerite, polyhalite, kalinite, voltaite, and tschermigite.

Group III. Hydrous sulfates with Ca, Cu, Fe, Co, Mg, Zn or Al—gypsum, epsomite, goslarite, siderotil, melanterite, coquimbite, pisanite, chalcanthite, bieberite, alunogen, halotrichite and pickeringite.

Group IV. Sulfates with (OH), or (F, Cl) and oxysulfates—natroalunite, alunite, natrojarosite, zincalunite, jarosite, raimondite, plumbojarosite, beaverite, sulfohalite, antlerite, brochantite, linarite and dolerophanite.

Group V. Hydrous sulfates with (OH) or (F, Cl)—sideronatrite, natrochalcite, metavoltine, kainite, botryogen, copiapite, fibroferrite, langite, ettringite, aluminite, johannite, zippeite and uranopilite.

Group VI. Alkali sulfates to carbonates—burkeite, hanksite, leadhillite and calcite.

Infrared adsorption spectra of most of these species have been obtained with a split beam infrared spectrophotometer. The identity of each species examined has been verified optically and by means of X-ray diffraction for further confirmation.

Examination of the spectra indicates that the sulfates yield infrared curves that fall naturally into several groups. These groups have been outlined, and the relative ranges in absorption characteristics are given for each.

PILLER, HORST, *Carl Zeiss, Oberkochen, West Germany*

Study of Translucent Tiny Grains Using the Interference Microscope

Special measures have to be taken to carry out microscopic examination of fine-grained material in order to make the particles visible with sufficient contrast. For that purpose, the author proposed the phase contrast method and he found that by combining this method with the well-known embedding methods the accuracy of the determination of refractive indices is increased. Furthermore, this showed that by using suitable embedding media with very high dispersion properties transparent particles of a certain refractive index could be imaged with characteristic colors and were thus differentiated from other particles of different refractive index. On the basis of a newly developed supplementary device for the polarizing microscope it is now possible to examine transparent particles by means of interference microscopy. As in the case of phase contrast microscopy, here too contrast is increased; however with the difference that it can be adjusted to an optimum extent depending on the optical thickness of the particle. The simple relation between the image contrast and the difference of the optical thickness of the object to that of its surrounding can be used to ascertain refractive indices and thicknesses in the microscopic specimen. The following possibilities are observed:

1. Determination of the refractive indices of smallest particles by means of a compensator and using but one (in some cases a second) embedding liquid. Therefore, repeated embedding as is necessary in the case of conventional immersion methods is not needed. 2. Determination of refractive indices exceeding that of the embedding media; this is of special importance when examining heavy minerals. 3. Ascertainment of the thickness of each individual particle present in the embedding media. 4. Possibility of application of interference phenomena combined with dispersion staining methods for routine identification of individual components in mineral complexes.

A big advantage of interference microscopy is that continuously changing optical thicknesses, as for instance with a change in concentration or in the cross section of a crystal "weathering" from its external surfaces, can be made visible and the corresponding refractive indices measured at any position.

POUS, J. MONTORIOL, A. SAN MIGUEL, AND M. FONT-ALTABA, *Laboratorio de Mineralogía, Universidad de Barcelona, Barcelona, Spain*

Spectrographic Study of a Spanish Fluorite Deposit

As a contribution to the study of the fluorite deposit of the Berta mine in San Cugat del Valles (Barcelona, Spain), a spectrographic qualitative analysis of some specimens was carried out.

The fluorite in this deposit occurs as discontinuous ore shoots preferentially vertically developed, with granite as the wall rock. Although fluorite, galena and sphalerite have been the only minerals mined, the deposit has a very complex mineralogy with, so far, 24 different mineral species identified.

Twenty-five samples were used for the spectrographic analysis: 10 belonging to the white or greyish fluorites, 10 to the green ones, and 5 to the pinkish ones. In general there is no violet fluorite in this deposit. All of the samples carry Ca, Mg, Al, V, Si, Fe (traces) and Cu. In addition, Pb and Ba appear in an irregular way, their existence having no connection at all with the color of the sample. Thus we conclude that the color of the fluorite of the Berta mine does not depend on the minor elements that we have detected spectrographically.

The presence of Cu as a minor element in all the samples is of special interest. This seems to indicate but a single mineralization, the fluorite and the primary copper minerals having the same origin.

PREWITT, C. T., AND M. J. BUERGER, *Crystallographic Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts*

A Comparison of the Crystal Structures of Wollastonite and Pectolite.

Wollastonite and pectolite have similar triclinic cells; because of this and their analogous chemical composition they have long been regarded as belonging to the same family. Recent investigations have permitted this relation to be examined more closely. It turns out that although the structures are both based upon metasilicate chains, they are not as closely isotypic as had been supposed.

If isotypism is sought in the conventional orientation, then all corresponding atoms only fall roughly in similar sites. But the structural correspondence is not very close; for example, a bend in the configuration of the silicate chain is reversed in the two structures. If, to bring the configuration of the chains into conformity, the *a* and *c* axes of one structure are interchanged, all atoms except the large cations fall into approximate coincidence. When this is done, the large cations occupy different interstices between oxygen atoms in the two structures. Since the silica frameworks are similar, this orientation is very convenient for showing relations between wollastonite and pectolite, and should be useful in studying other related compounds.

PROUVOST, JEAN, *Laboratoire de la Faculté des Sciences de Lille (Nord) France*

Quelques Aspects des Déplacements Atomiques dans les Sulfures Métalliques

Les expériences que nous avons entreprises ces dernières années sur les sulfures métalliques conduisent à penser que les éléments constitutifs, malgré un réseau parfaitement déterminé, pouvaient se déplacer. Il est facile de mettre en évidence ces phénomènes parfois par une simple observation. C'est ce qu'il est facile de voir, par example, dans la bornite, où des regroupements ont lieu à des températures assez basses, amenant des figures comparables à celles de Widmannstätten. Mais c'est surtout par des expériences que nous pouvons provoquer des déplacements. L'apport de métaux, que ce soit par électrolyse ou par élévation de température, amène à des transformations qui nécessitent des déplacements assez importants. L'étude des échantillons expérimentaux à l'aide de la microsonde de Castaing permet, sur la section polie, de suivre l'évolution des concentrations des divers éléments. Elle apporte, par consequent, une somme d'observations nouvelles qui permettent d'étudier de plus près la diffusion.

RIMSAITE, J., *Geological Survey of Canada, Ottawa, Ontario, Canada*

Studies of Rock-forming Micas[1]

An extensive age determination program by isotopic dating of micas at the Geological Survey of Canada has made available for mineralogical study several hundred concentrates of micas from rocks of diverse age, origin and history. The present study is concerned with determining the homogeneity of each mica concentrate, establishing the type or types of micas present, and correlating physical and chemical properties of the micas with their mode of occurrence in rocks. The study is confined largely to unaltered micas.

Spectrochemical and *x*-ray spectrographic analyses and complete chemical analyses have been made on about 20 selected samples of micas. Chemical formulas, negative and positive charges of tetrahedral and octahedral layers, and occupancy of the octahedral layer have been calculated. These data are discussed in relation to the following experimental data: (1) intensities of (001) reflections in *x*-ray diffractometer patterns; (2) optical properties—color, refractive indices, 2V; (3) specific gravity; (4) behavior on heating from 20° C. to 1200° C. in air, in argon and in vacuum; (5) loss of weight on heating to 1400° C.; (6) trace element content.

As a result of these studies, interesting relationships have been found between the varieties of micas and the types of their host rocks. Furthermore, in rocks containing two or more generations of trioctahedral micas, the difference in composition between an early and a late mica has been established and confirmed by different content of trace elements in these micas.

ROEDDER, EDWIN, *U. S. Geological Survey, Washington, D. C.*

The Composition of Quartz-forming Fluids in Nature

A microscope freezing stage has been developed with which qualitative and semiquantitative data may be obtained on the composition of individual fluid inclusions as small as ten microns. Although the technique can be used to obtain a variety of geologically useful data, the major application has been in the determination, under equilibrium conditions, of the depression of the freezing point of the fluid; in ordinary water solutions, this depression varies directly with the total concentration of salts. Both primary and secondary inclusions in quartz crystals that formed in a variety of geological environments have been examined. The freezing temperatures obtained range from −20° to 0° C., although most samples from alpine-type veins, and from pegmatites, range only from −8.5° to −2.5° C. Large and consistent differences are found between different genetic groups of inclusions in single samples, indicating gross changes in the composition of the fluids that have bathed the samples during their growth and at subsequent stages in their history.

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ROSS, MALCOLM, AND HOWARD T. EVANS, JR., *U. S. Geological Survey, Washington, D. C.*

The Crystal Structures and Crystal Chemistry of Various Members of the Metatorbernite Group

A large number of minerals and synthetic compounds belonging to the torbernite and metatorbernite mineral group can be represented by the formula $A^{+z}(UO_2XO_4)_z \cdot nH_2O$, where A may be almost any monovalent or divalent cation and $X = P$ or As. In order to learn more of the crystal chemistry of these phases, detailed crystal-structure studies of (I), $K(UO_2AsO_4) \cdot 3H_2O$ (abernathyite); (II), $NH_4(UO_2AsO_4) \cdot 3H_2O$; (III), $K(H_3O)(UO_2AsO_4)_2 \cdot 6H_2O$; and (IV), $Cu(UO_2PO_4)_2 \cdot 8H_2O$ (metatorbernite) have been carried out. The structures were refined by two- and three-dimensional least-squares analysis of intensity data measured on Buerger precession photographs made with MoKα radiation. The well-known waffle-like $(UO_2XO_4)_n^{-n}$ sheet structure proposed by Beintema is confirmed, and details of the interlayer structure are also revealed through a complete resolution of all except the hydrogen atoms in the electron density maps. In all four structures studied, the positions of the interlayer water molecules are based on an ideal arrangement in which four molecules are hydrogen-bonded together to form squares about the four-fold rotation axes, lying between the uranyl ions of successive layers. In Phases I and II, K^+ and NH_4^+ substitute randomly for one out of four water molecules and in Phase III, K^+ and H_3O^+ substitute randomly for two out of eight water molecules. An isomorphous series probably exists between the end members $K(UO_2AsO_4) \cdot 3H_2O$ (abernathyite) and $H_3O(UO_2AsO_4) \cdot 3H_2O$ (troegerite) and also between $NH_4(UO_2AsO_4) \cdot 3H_2O$ and troegerite. The ratio of cation (including hydronium) to water of 1:3 required by the cation replacement of water found in these structures has been confirmed by careful chemical analysis.

In metatorbernite (IV) cation substitution of water does not occur, but rather Cu^{2+} occupies special positions at the center of half of the square groups of water molecules, thus giving a cation-water ratio of 1:8.

In all four structures each water molecule of a square group is also hydrogen-bonded in a nearly tetrahedral manner to a water molecule in an adjacent square, and to an arsenate or phosphate oxygen atom. The latter bond causes a slight distortion of the $(UO_2XO_4)_n^{-n}$ sheet from ideal symmetry and accounts for the doubling of the ideal one-layer *c* axis.

SCANLON, WAYNE W., *Applied Physics Department, U. S. Naval Ordnance Laboratory, White Oak, Silver Spring, Maryland*

The Physical Properties of Semi-Conducting Sulfides, Selenides and Tellurides

The solid state physicist has available several very sensitive methods for determining the detailed chemical composition of compounds within the narrow range of stoichiometric deviations permitted in a given crystal. These methods are applied to a group of sulfides consisting of PbS, PbSe and PbTe. The studies reveal the maximum limit of solubility of the component elements in crystals of the compound as well as their solubility as a function of the solid-vapor equilibrium condition. The rate of precipitation of excess atoms in supersaturated crystals will also be discussed.

SMITH, C. H., AND H. E. KAPP, *Geological Survey of Canada, Ottawa, Ontario, Canada*

The Muskox Intrusion, a Newly Discovered Layered Intrusion in the Coppermine River Area, N.W. Territories, Canada

The Muskox intrusion is a Precambrian layered basic pluton, 74 miles in length, which is dike-like in plan and funnel-shaped in cross-section. Its internal structure is divided into four principal units—a feeder, marginal zones, a central layered series and an upper border group. The feeder outcrops for 37 miles along strike, varies from 500 to 1800 feet in width, and contains bronzite gabbro and picrite in zones parallel to the nearly vertical walls. The marginal zones parallel the walls of the intrusion which dip inward at angles of 23 to 57°. They are 200 to 1200 feet thick, and grade inward from bronzite gabbro at the contact through picrite and feldspathic peridotite, to peridotite and in places dunite. The central layered series is 8500 feet thick and contains 38 main layers of dunite, peridotite, pyroxenites and gabbros which vary in thickness from 10 to 1800 feet. These layers are nearly flat-lying and discordant to the marginal zones. The upper border group is 200 feet thick and is characterized by an upward gradation from granophyre-bearing gabbro to granophyre. Granophyre forms 8 per cent of the volume of the intrusion.

Nickel copper sulfide deposits occur along the walls of the intrusion, and a Merensky-reef type deposit, containing disseminated chromite, copper-nickel sulfides and platinum group metals, occurs in a pyroxenite horizon.

Preliminary results on variations in mineral and chemical compositions between the principal units will be described.

SMITH, J. V., *Department of Geophysical Sciences, University of Chicago, Chicago, Illinois*

Structural Classification of Zeolites

In the past ten years the structures of chabazite, dachiardite, erionite, faujasite, gmelinite, harmotome, levyne, mordenite, phillipsite and Linde A have been determined. In addition, proposals have been made for NaPl, heulandite and gismondite. Although many structures remain undetermined, it is possible to extend the structural classification started by W. L. Bragg in "Atomic Structure of Minerals" on the basis of the determinations of analcite and the natrolite group.

The zeolites chabazite, gmelinite, erionite and levyne are based on different ways of linking together parallel six-membered rings. Harmotome, phillipsite, NaPl (and perhaps gismondite) are based on parallel four-membered rings, and are related structurally to feldspar and paracelsian. The structures of faujasite and Linde A are both based on tetrahedra lying at the corners of cubo-octahedra linked by other polyhedra, and are thus related to sodalite. The columns of linked five-membered rings in mordenite and dachiardite may also form the basis of other zeolites with a 7.5 Å repeat distance (ferrierite, heulandite, laumontite and brewsterite).

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Layered Picrite-anorthositic Gabbro Sheet, West Humboldt Range, Nevada

A stratiform intrusive sheet of hornblende picrite and anorthositic hornblende gabbro is exposed over a half square mile in the West Humboldt Range, northwestern Nevada. The stratification consists of two layers: (1) a 300-foot thick basal picritic stratum of color index from 100 to 70, and (2) an overlying anorthositic layer of color index from 5 to 45. The anorthositic layer is quite eroded, and the present maximum thickness is 100 feet. The contact between the two layers is apparently sharp. Modes in vertical sections in each of the layers do not vary appreciably. The stratified sheet lies on deformed marbles and metasiltstones of the albite-epidote hornfels facies. The igneous sheet has been folded to a north-plunging anticline.

The layered body is part of a large complex of gabbro, picrite, keratophyre, dolerite, and minor anorthosite of probable Jurassic age which occurs in the adjacent, northerlytrending West Humboldt, Stillwater, and Clan Alpine Ranges of northwestern Nevada. The stratified body occurs along the western margin of the complex and is separated from other coarse-grained gabbroic rocks by later dolerites. The layered body is the earliest of the sequential intrusions forming the complex in the West Humboldt Range, and its emplacement apparently preceded deformation of the sedimentary terrane.

Both the picrite and the anorthositic gabbro in the stratiform body contain two sequential mineral assemblages. The earlier assemblage in the picrite is forsterite-labradorite-diopsidic augite-bronzite and in the overlying anorthositic gabbro is labradorite-diopsidic augite. The late assemblage in both rock types is kaersutite-magnetite-apatite. The labradorite in both layers is platy and forms a strong planar fabric. The foliation was apparently formed in a benign manner as protoclastic or cataclastic textures are absent. The attitude of the foliation in the two layers is similar and is nearly perpendicular to the interface between the two layers.

The stratified body crystallized from a basaltic melt. Settling of olivine was almost complete before crystallization of labradorite and clinopyroxene began, as clinopyroxene is only slightly concentrated in the basal layer. Differentiation proceeded in a ferrogabbro trend. The plagioclase foliation was formed prior to crystallization of the late, iron-rich assemblage. Near-coincidence of maxima of the poles of the igneous foliation and the bedding of the intruded isoclinially-folded sediments suggests that the foliation is an axial plane fabric formed during folding. The late kaersutite occurs in poikilitic nets enveloping the earlier mafic minerals and the foliate plagioclase.

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Studies of Crystal Surfaces

Studies of surface structures of crystal faces by means of phase contrast microscopy and multiple-beam interferometry offer a wide variety of information concerning the mechanism of crystal growth, etching, twin formation, behavior of dislocations, as well as physico-chemical conditions of crystal formation, etc. Since surface features down to a few Angstroms in size can be detected by these methods, it is possible to consider the above mentioned factors in terms of the unit cell. Evidence which contradicts the general belief concerning the nature of crystals, crystal growth, etching or twin formation has been observed. The following two considerations will be emphasized in this discussion:

1) Are "single" crystals really single? Evidence has been observed on SiC and hematite that some morphologically and structurally single crystals consist of several different polytypes, and that some contain small twinned portions which have a thickness of only a few tens of Å. The formation of such crystals will be discussed.

2) Dynamic movement during crystal growth. The movement and concentration of dislocations, folding, bending and actual breaking up of the surface, slipping, faulting, etc. take place on the surface and in the crystal while it is growing. These movements are caused mainly by external and internal stresses, the latter due in part to uneven distribution of impurities in the crystal.

THAYER, T. P., *U. S. Geological Survey, Washington, D. C.*

Flow Layering in Alpine-type Peridotite-Gabbro Complexes

Most alpine-type peridotite and gabbro masses are layered to some degree, and many show prominent compositional layers that range in thickness from a few millimeters to many meters. Single layers may consist of olivine, orthopyroxene, clinopyroxene, plagioclase, and chromite, or almost any combination of them, and may be sharply bounded or gradational. In these respects the layers in alpine-type and stratiform complexes are similar, but in most other aspects they differ widely.

The layering believed to have been formed by flowage in alpine-type complexes is not nearly as regular and persistent as that formed by crystal settling in the stratiform complexes, and adjoining layers may show much greater compositional contrast. Textures due to crystal settling have been observed only as rare relicts in chromitite, and poikilitic texture is not common. Tectonite fabrics have been described in alpine-type dunites from many localities, and gneissic structures are common in related gabbroic rocks. Foliation and lineation are closely related to layering and generally parallel it, but in places they cross it. Boudinage in mafic layers and related structures in chromitite bodies provide evidence of stretching. Relict structures show that early-formed layers have been largely obliterated by later flowage.

The foliation, lineation, and layering in alpine-type complexes are directly comparable to those seen in high-grade metamorphic rocks. Layering and foliation across the boundaries between rocks of such different composition as chromitite, dunite, harzburgite, and gabbro cannot be attributed to crystal settling and must have been formed by flowage of largely crystalline magma during the later stages of emplacement. Several lines of evidence show that the flowage features could not have been imposed on solid rock by regional deformation. The layers, therefore, are believed to have been formed during the later stages of magma emplacement by processes analogous to those that produce metamorphic differentiation in banded gneisses.

TOULMIN, PRIESTLEY, 3RD, AND PAUL B. BARTON, JR., *U. S. Geological Survey’ Washington, D. C.*

Thermodynamic Study of Pyrrhotite and Pyrite

Through the use of the electrum tarnish method the following equation has been found to interrelate the composition of pyrrhotite, fugacity of sulfur, and temperature:

$$\log_{10} f_{S_2} = (70.03 - 85.83N)\left(\frac{1000}{T} - 1\right) + 39.301\sqrt{1 - 0.99808N} - 11.9113. \qquad (1)$$

In this equation f_{S_2} is the fugacity of sulfur relative to the ideal diatomic gas at 1 atm, N is the mole fraction of FeS in pyrrhotite (in the system FeS-S_2), and T the absolute temperature. The experimental uncertainty in the equation is 0.002 in N. Substituting equation 1 into the Gibbs-Duhem equation and integrating leads to the following expression for the activity of FeS (a_{FeS}) relative to the pure substance at the temperature of consideration:

$$\log_{10} a_{FeS} = 85.83\left(\frac{1000}{T} - 1\right)(1 - N + \ln N) + 39.301\sqrt{1 - 0.99808N}$$
$$- 39.226 \tanh^{-1}\sqrt{1 - 0.99808N} - 0.0024. \qquad (2)$$

The electrum tarnish method has permitted us to determine the f_{S_2} vs T curve for the univariant assemblage pyrrhotite-pyrite-vapor from 743° to 325° C. (a considerably greater range than previously studied). The curve passes through the points indicated in the table below. Our determinations of the composition of pyrrhotite are in excellent agreement with the results of Arnold. The activity of FeS in pyrite-saturated pyrrhotite is very different from unity (see table), a fact that greatly influences the interpretation of some other phase equilibrium studies involving pyrrhotite and their application to sulfide mineral assemblages, but has little effect on the more general calculations of composition of hydrothermal or magmatic fluids.

Points along the pyrite-pyrrhotite curve

t° C.	N_{FeS}	log f_{S_2}	a_{FeS}
743	0.8993	+ 0.76	0.375
599	0.9202	− 2.00	0.455
514	0.9298	− 4.00	0.496
410	0.9395	− 7.00	0.536
354	0.9440	− 9.00	0.554
325	0.9462	−10.17	0.564

Combining these data with the well-known standard free-energy of the reaction Fe(α) $+1/2\ S_2$ (g, 1 atm) = FeS (pyrrhotite), we calculate the standard free-energy of formation of pyrite from the elements (Fe, S_2) at 1 atm:

$$\Delta G^\circ = -71{,}260 + 47.09T \text{ cal (T in degrees K)} \qquad (3)$$

The temperature coefficient of equation (3) is in excellent agreement with calorimetric data.

WADSWORTH, W. J., *Department of Geology, University of Edinburgh, Edinburgh, Scotland*

The Kapalagulu Layered Intrusion of Western Tanganyika

The Kapalagulu intrusion, first described in detail by van Zyl, is approximately 4000 ft. thick, with near-vertical contacts and layering. The contacts appear to be tectonic, and there is no trace of a chilled margin. The intrusion comprises a basal zone, 300 ft. thick (olivine cumulates, with local sulfide and chromite concentrations); an intermediate zone, 700 ft. thick (plagioclase, 2-pyroxene, olivine cumulates); and a main zone, 3000 ft. thick (2-pyroxene, plagioclase cumulates, with a 300 ft. anorthosite band in the lower part, and local concentrations of magnetite-bearing and pegmatitic facies near the top).

Rhythmic layering is pronounced in the intermediate zone and in the lower part of the main zone, and igneous lamination is also locally well developed. The over-all cryptic layering is slight ($An_{85\to80}$, $En_{82\to65}$), but there is evidence of more marked fractionation of the intercumulus liquid. Interstitial micropegmatite occurs throughout the main zone, increasing in abundance upwards, and reaching 20–30 per cent of the pegmatitic patches. A later suite of dolerite dykes is also characterized by a relatively large amount of acid mesostasis.

The age of the intrusion is uncertain, but it is probably post Karagwe-Ankolean, and possibly post-Bukoban (just pre-Karroo). It is believed to have formed by gravitative accumulation, and to have suffered subsequent tilting to a vertical position, as well as faulting or shearing-out of the original contacts.

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The Mechanism of Deposition and Solidification of the Skaergaard Layered Series, East Greenland

If we accept that the common feature of layered rocks is the bottom accumulation of crystals separating from a large body of magma, then there are three stages to be distinguished: (1) initial deposition of the cumulus crystals, (2) growth of the cumulus crystals while forming the top surface of the pile, (3) crystallization of trapped intercumulus liquid.

In the case of the Skaergaard intrusion the highly variable rhythmic layering is the result of the precipitation of different proportions of the possible cumulate phases. Convection currents, sometimes intermittent as Hess has postulated for the Stillwater, and sometimes continuous, though of variable velocity, account for many features of the rhythmic layering and igneous lamination.

Enlargement of the cumulus crystals during the brief time they formed the top surface of the precipitate is required to explain features of Rhum, Bushveld, Stillwater and, to a lesser extent, the Skaergaard layered series. In the latter case the amount of P_2O_5 in the rocks provides an indirect measure of the amount of adcumulus growth, and confirms the textural evidence. It is believed that the removal of heat to allow adcumulus crystallization cannot be downwards through the already deposited layered rocks but into the overlying magma which is, at certain times and places, supercooled. It is postulated that nucleation in the descending current probably occurred only after 5 or 10° C. of supercooling, that relatively few nuclei formed, and these grew slowly because of the slowness of diffusion. The crystal nuclei were probably so sporadically distributed that, during the time the magma was flowing over crystals on the floor, it did not become uniform but was at the equilibrium temperature in the neighborhood of the growing crystals, while away from these it was supercooled.

The amount of trapped liquid depends largely on the extent of adcumulus growth; in the Skaergaard there was between 5 and 40 per cent, and its crystallization, giving lower temperature phases and zones, must have continued for many thousands of years.

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Internal Structure of a Differentiated Teschenite Intrusion, Prospect Hill, New South Wales

Internal structures of a 350-ft. thick, dish-shaped teschenite intrusion are of four main types: (1) lineation, parallel to contacts, of minerals in the basalt margins, in picrite within 100 ft. of the lower contact, and in dolerite and olivine-rich dolerite within 80 to 120 ft. of the upper contact; (2) flow layers, which differ in mineral proportions and fabric, in the basalt margins and picrites within 80 ft. of the lower contact; (3) rhythmic layering of felsic and mafic rocks inclined to abrupt changes in slope of the basalt-shale contact and to internal contacts between different rock types; and (4) deformation of pegmatite and other schlieren by slip along subsequently healed fractures at a high angle to basalt-shale contacts or by slip along planes parallel to the schlieren.

Progressive decrease in perfection of lineation away from contacts and occurrence of lineations in "complementary" (dolerite) as well as "cumulative" (picrite) rock types indicates an origin by viscous flow. Flow layers are considered to have formed by mechanical concentration of olivine during viscous flow and accompanying fabric variations by volatile redistribution over pressure gradients formed by slip along laminar flow planes. Rhythmically layered units are considered to result from tension fracturing accompanied by concentration of vapor-rich magma and reciprocal diffusion between layers. Deformation of schlieren was caused by initial injection processes because schlieren over and under a deformed one are undisturbed.

Response to viscous flow of material making up 40 to 60 per cent of the intrusion and of rock types representing the most acid differentiates indicates that the rate of intrusion was slow relative to the rate of differentiation.

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A New Occurrence of Sapphirine and the Significance of Sapphirine in the Granulite Terrains of Western Australia

Several new analyses of sapphirine ($(Mg,Fe)_4Al_{10}Si_2O_{23}$), spinel, bronzite, and phlogopite

have been made from a restricted Archaean area 10 miles south of Quairading which is 100 miles east of Perth, Western Australia. A normal "parent rock" is phlogopite-spinel-bronzite. Spinel (and also phlogopite and bronzite) are replaced by sapphirine. In rocks rich in cordierite, spinel is always separated from cordierite by a reaction rim of sapphirine. Chemical analyses indicate that the formation of sapphirine is favored by replacement (in reducing conditions) of Al, Fe, Mg and Ca by Si, K, P and rare earths. The spinel-bronzitites and associated cordierite gneisses and pyroxene-plagioclase granulites form mappable bands and boudins in a biotite-microcline gneissose granite. The sapphirine, cordierite, and phlogopite have no preferred orientation, and in many rocks the "parent" spinel and bronzite are likewise in random orientation, thus suggesting growth in a non-shear environment. A survey of the regional geology suggests that these sapphirine-bearing rocks form a zone (2620×10^6 years old) in an immense area which is dominated by rocks of granulite facies and of granites. These granulites show preferred orientation of the two pyroxenes and plagioclase, and are the result of regional metamorphism in which shearing was important.

It appears that sapphirine can form only in areas of granulite facies and as the result of release of pressure and granitization of massive rocks rich in Mg and Al and deficient in Si. However, "granulite facies-granitization" of such rocks is common, yet in most cases without the formation of the rare mineral sapphirine. A granitization process in which there is an abnormally low partial pressure of oxygen together with a plentiful supply of rare earths may be necessary for its formation.

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Regressions of Physical Properties on Chemical Composition of Amphiboles

Linear regression coefficients for five physical properties (refractive indices, α, β, γ; extinction angle Z:c; and density G) on 24 variables of chemical composition $(K,Na,Ca)_w$ $(K, Na, Ca, Mn, Fe^{2+}, Mg)_2(Ca, Mn, Fe^{2+}, Mg, Ti, Fe^{3+}, Al)_5(Ti, Fe^{3+}, Al, Si)_8O_{22}(O, OH, F, H_2O)_2$ have been calculated by least-squares methods from data on about 400 analyses selected from the literature. These regressions yield high values for their coefficients of determination R^2 and variance ratios F, showing that they do empirically account for most of the variance.

Direct application of the present equations leads to preliminary predictions of the properties of a few interesting compositions in the clinoamphibole system, as follows: For tremolite $CaMg_5Si_8O_{22}(OH)_2$, $\alpha=1.6005\pm.0012$, $\beta=1.6146\pm.0015$, $\gamma=1.6266\pm.0017$, $Z\wedge c=16.3°\pm1.7°$, $G=2.974\pm.014$. For tschermakite $Ca_2Mg_3Al_2Si_6Al_2O_{22}(OH)_2$ the same properties are 1.6259, 1.6362, 1.6460, 0.7°, and 3.068. For pargasite $NaCa_2Mg_4AlSi_6Al_2O_{22}(OH)_2$, they are 1.6253, 1.6319, 1.6408, 14.0°, 3.086. For hastingsite $NaCa_2Fe''_4Fe'''Si_6Al_2O_{22}(OH)_2$, they are 1.7033, 1.7181, 1.7113, 30.1°, and 3.496. For glaucophane $Na_2Mg_3Al_2Si_8O_{22}(OH)_2$ they are 1.6083, 1.6064 [sic], 1.6086, 35.1°, 3.042. The value of "α" is here the lowest index predicted for sections ||010, and "β" is the predicted value for light vibrating parallel to the symmetry axis *b*. For cummingtonite, $Fe_2Mg_4Fe''Si_8O_{22}(OH)_2$, they are 1.6349, 1.6500, 1.6689, 13.5° and 3.239.

Special tests are being made to determine whether non-linear regressions may be required for some of the chemical variables, especially for the regression of extinction angle on composition. Full tables of regression coefficients, predicted values for end-members, and residual errors of prediction for nearly 800 analyzed specimens, will be displayed during the meetings.

Indirect uses for such regressions include the discussion of order-disorder problems, temperature of formation, etc.

WONES, DAVID R. AND DANIEL E. APPLEMAN, *U. S. Geological Survey, Washington, D. C.*

Iron-feldspar Polymorphs in the System K_2O-FeO-Fe_2O_3-SiO_2-H_2O

Potassium-iron feldspar, $KFe^{3+}Si_3O_8$, has been synthesized hydrothermally in two distinct polymorphs. The form stable at low temperatures, analogous to microcline, was synthesized directly from a mixture of crystallized $K_2O \cdot 6SiO_2$ glass and Fe_2O_3 at gas pressures of 1000 to 2000 bars and temperatures below 690° C.; above 710° C., a form analogous to high-sanidine was synthesized. At 600° C. and 2000 bars gas pressure iron-sanidine was completely converted to iron-microcline, whereas at 770° C. and 1000 bars gas pressure iron-microcline was completely converted to iron-sanidine. No "intermediate" states were observed in hydrothermal experiments.

Iron-microcline is triclinic, $C\bar{1}$; $a=8 \cdot 69$ Å, $b=13.11$, $c=7.33$ (all$\pm 0.15\%$); $\alpha=90°36'$, $\beta=116°02'$, $\gamma=86°30'$ (all$\pm 10'$); optical orientation $X \approx b$, $Z \wedge c=20° \pm 5°$. Iron-sanidine is monoclinic, $C2/m$; $a=8.69$ Å, $b=13.12$, $c=7.32$ (all$\pm 0.15\%$); $\beta=116°06' \pm 05'$, optical orientation $Y=b$, $Z \wedge c=16° \pm 4.°$

The relationship between the $KFeSi_3O_8$ polymorphs is strikingly similar to that between the $KAlSi_3O_8$ polymorphs. This increases the probability that crystal-structure studies of the Fe-Si distribution in $KFeSi_3O_8$ will elucidate the crystal-chemical and phase-equilibria behavior related to Al-Si distribution in the natural potassium feldspars.

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The Crystal Structure of Chalcocite, Cu_2S

The crystal structures of both the high-temperature hexagonal form and low-temperature orthorhombic form of Bristol, Connecticut, chalcocite have been investigated using three-dimensional intensity data. Orthorhombic chalcocite intensities were obtained using an equi-inclination counter diffractometer. Hexagonal chalcocite intensities were obtained photographically at 125° C. using a new type of integrating precession camera. The structure of the high-temperature form will be described in detail. Its relation to the orthorhombic structure will also be discussed.

WUENSCH, B. J. AND M. J. BUERGER, *Crystallographic Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts*

The Crystal Stucture of Pyrrhotite, Fe_7S_8

The crystal structure of pyrrhotite, Fe_7S_8, has been investigated by means of three-dimensional intensity data. A small sphere ground from a twinned natural crystal was used, and data were obtained photographically with the aid of a new type of integrating precession camera. Single-crystal diffraction patterns obtained at temperatures up to 200° C. all indicate the presence of a superstructure. It has been found that the twin law previously proposed does not adequately explain the "strange" extinctions. An alternate twin law is given, and a new structure based on an ordering of iron vacancies will be described in detail.

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Liquidus and Solidus Paths in Multicomponent Systems and their Effect on Mineral Zoning

A silicate melt follows a liquidus path giving the rate of change of liquid composition with temperature, and each mineral precipitated follows a similar solidus path. In the systems anorthite-albite and forsterite-fayalite the gradients of liquidus and solidus paths change continuously from one component to the other. However, in multicomponent systems they may exhibit steep slopes (small temperature changes cause little composition change) separated by shelves (small temperature changes cause large composition changes). When plagioclase crystallizes alone from a ternary liquid in the system diopside-anorthite-albite, liquidus and solidus paths are steeper than in the system anorthite-albite, but when plagioclase is joined by diopside the paths become much less steep than in the binary system. Similar changes occur for olivines crystallizing in the system CaO-MgO-FeO-SiO_2. Changes in liquidus slope may help to explain the relative proportions of igneous rocks in different petrological associations, and the slopes of solidus paths affect mineral zoning. The solidus paths of plagioclase or olivine crystallizing from basic magmas may be characterized by steep slopes followed by shelves. Continuous crystallization could then lead to the appearance of two generations of crystals, the phenocrysts having cores of fairly constant composition with narrow marginal zones. The problem of oscillatory zoning in plagioclase feldspars is somewhat simplified if the solidus path crosses a shelf in the appropriate composition range.