SELECTED AUTHOR'S ABSTRACTS

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THE ULTRAMAFIC SUITE ASSOCIATED WITH CARBONATITES — THE CARGILL COMPLEX, ONTARIO

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The Cargill complex has been studied to elucidate the nature of the ultramafic suite that coexists with carbonatites in a unique type of carbonatite complex. The rock types are clinopyroxenites, hornblende pyroxenites and hornblendites lacking in orthopyroxene or feldspathoids and with feldspar extremely rare, yet they are feldspathoidal normative. Intrusion of the carbonatite has resulted in the production of hybridized ultramafic rocks, and the development of pervasive metasomatic phlogopite in the ultramafic rocks.

During fractional crystallization the normative whole rock chemistry changed from marginally saturated, to transitional, to decidedly alkaline and undersaturated. Olivine ranged in composition from Fo_{76} to Fo_{62}, at which point it is removed by a peritectic reaction when the composition of the coexisting pyroxene is $Ca_{46}Mg_{42}Fe_{12}$. Clinopyroxene exhibits a change in composition from $Ca_{46}Mg_{50}Fe_4$ to $Ca_{49}Mg_{36}Fe_{15}$, and with a change in buffering conditions then shows marked NaFe enrichment to $Di_{53}Hd_{20}Ac_{27}$. Titaniferous, pargasitic amphibole is present throughout the entire sequence, first as an intercumulus phase, and then as a cumulus phase, and varies from $Ca_{28}Mg_{56}Fe_{16}$ to $Ca_{27}Mg_{32}Fe_{41}$, being in apparent equilibrium with coexisting pyroxenes.

Hornblendes from the ultramafic rocks have a similar composition to olivine nephelinite. This is emphasized by a hornblende which has 13.3% normative feldspathoids. This illustrates the sub-silicic, alkalic and aluminous nature of the residual silicate magma. The high fluid pressure has stabilized hornblende rather than the olivine nepheline assemblage which would otherwise have crystallized.

CORDIERITE-HERCYNITE GRANOBLASTITES AT RAT LAKE, MANITOBA

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In a small outcrop of Fe-Al-Mg-rich granoblastites 80 miles northwest of Thompson, Manitoba, there is textural evidence of two phases of regional metamorphism. The original rock, poor in silica and calcium, may have been a regolith. The early metamorphism produced hypersthene, garnet, sillimanite (+cordierite?). A later sequence of reactions, which were quenched before they recrystallized to an equilibrium assemblage and texture, produced granoblastites having the mineralogy garnet, cordierite, hercynite, biotite, magnetite, anthophyllite (+ microcline). There were at least two periods of metamorphism in Hudsonian times, the latter with lower total pressure but higher fluid pressure (humidity) than the former.

Reaction rims and myrmekitic integrowths illustrate two reactions of Phase II, viz.:

garnet + sillimanite = cordierite + hercynite
hypersthene + spinel + H_2O = anthophyllite + clinochlore

For Phase I metamorphism, only one reaction is defined by relic minerals, viz.:

staurolite + quartz = garnet + sillimanite + water

Other reactions are required to produce the assemblage hypersthene, garnet, magnetite ± spinel.

FERROHASTINGSITE FROM CHIBOUGAMAU, QUEBEC

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A new and unusual Canadian occurrence of ferrohastingsite is recorded. The mineral is present in rocks of the Dore Lake Complex, a Bushveld-type Archean layered intrusion that has undergone greenschist metamorphism. Ferrohastingsite occurs in metamorphosed ferrogabbros and ferropyroxenites of the Layered Zone. The amphibole occurs as metamorphic pseudomorphs of primary iron-rich pyroxenes, and as rims around grains of ferroactiolite. The rims of ferrohastingsite are found most commonly at the boundaries between grains of ferroactinolite and plagioclase or altered plagioclase. $2V$ decreases with increasing Fe content, ranging from 40° to 5°. The pleochroic formula is X = straw yellow, Y = olive green, Z = deep bluish green.

Electron microprobe analyses show compositions in the following ranges: 38.6 to 45.0% SiO_2, 6.5 to 17.0% Al_2O_3, 23 to 29% total Fe (as FeO), tr to 1.47% TiO_2, 4.8 to 9.1% MgO, 9.6 to 13.0% CaO, 0.3 to 0.5% MnO, 1.03 to 2.68% Na_2O, and 0.1 to 0.4% K_2O. Some grains are zoned with Na_2O and Al_2O_3 increasing, while MgO decreases toward the edges. There is apparently no zoning of FeO and TiO_2.

ZONED CHROMITE FROM MANITOBA

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Antigorite-bearing serpentinites sub-outcropping at the SW end of the Manitoba Nickel Belt contain zoned, accessory, chromite. These consist of a dark homogeneous core, concentrically surrounded by a lighter Al- and Mg-poor chromite varying continuously in composition towards magnetite at the margin.

Zoned chromite is recorded in antigorite- and chlorite-bearing serpentinites elsewhere, but its paragenesis is uncertain. It has been variously suggested that the alteration zone formed during (i) the magmatic stage of crystallisation; (ii) regional metamorphism; or (iii) serpentinisation. Similar zoned chromite has also been observed in ultramafic nodules in basalt, used refractory bricks and some sediments. In all these environments chromite has been subjected to an elevation in temperature subsequent to initial crystallisation.

Compositional variation across the zoned chromite from Manitoba was established by electron microprobe analysis. The compositional change is shown to have been buffered by Mg and Fe^{2+} but not by Al, Cr and Fe^{3+}. The silicate mineralogy of both the serpentinites and the wall-rocks indicate metamorphism to a grade intermediate between the greenschist and amphibolite facies.

It is concluded that a magnetite rim, produced around chromite during an early serpentinisation, reacted with the chromite core during regional metamorphism to produce an intermediate zone of Mg- and Al-poor chromite.

Chromite has potential use as a metamorphic petrogenetic indicator, which is important where late serpentinisation has obscured the earlier silicate mineralogy.

MINERALOGICAL INVESTIGATIONS OF THE PLATINUM-GROUP ELEMENTS IN THE SUDBURY-AREA DEPOSITS — A PRELIMINARY REPORT

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Preliminary results of mineralogical investigations on sixteen selected samples from seven deposits and a concentrate have revealed numerous platinum-group minerals. One is a new mineral, some are reported for the first time from the Sudbury deposits, and others represent only the second occurrence since their initial discovery elsewhere. Of the platinum-group, only platinum and palladium minerals have been found so far and most of the identifications are tentative since they are based solely on optical properties and electron probe micro-analysis.

The plantinum minerals, with the number of samples in which they are found in brackets, are: sperrylite, $PtAs_2(8)$; niggliite, $PtSn(1)$; insizwaite, $PtBi_2(1)$; and moncheite, $PtTe_2(1)$. This is only the second occurrence world-wide of insizwaite and it is the first time niggliite and moncheite have been reported from Sudbury.

The palladium minerals, with the number of samples in which they were found in brackets, are: michenerite, $PdBiTe(10)$; froodite, $PdBi_2(3)$; sudburyite, $PdSb(3)$; merenskyite, $PdTe_2(3)$; polarite, $PdBi(1)$; stibiopalladinite? $Pd_5Sb_2(1)$; unnamed mineral, $Pd_8Sb_3(1)$; and unnamed mineral Pd (Bi, Sb, Te) (1). Sudburyite is a new mineral recently described, Cabri & Laflamme (1974). Merenskyite and stibiopalladinite? have not previously been reported from Sudbury and this is only the second occurrence of polarite world-wide.

Many of these minerals contain one or more minor elements, usually substituting for the anion. There is less substitution amongst the platinum metals themselves. The only mineral pair to form a continuous solid solution is merenskyite and melonite as has been reported previously by Rucklidge (1969).

MINERAL EQUILIBRIA IN MAFIC GRANULITES

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Equilibrium curves for three granulite-facies metamorphic "reactions" proposed by de Waard,

(1) hornblende + garn + qtz $\rightleftharpoons$ orthopx + anorth + alb + H_2O,
(2) hornblende + qtz $\rightleftharpoons$ orthopx + clinopx + anorth + alb + H_2O, and
(3) orthopx + anorth + alb $\rightleftharpoons$ clinopx + garnet + qtz can be shown to intersect at an invariant* point in the model system SiO_2-Al_2O_3-(Mg,Fe)O-CaO-H_2O, through which must also pass the equilibrium curves for the "reactions"
(4) hornblende + anorth + qtz $\rightleftharpoons$ clinopx + garnet + alb + H_2O, and
(5) hornblende + anorth + orthopx $\rightleftharpoons$ clinopx + garn + alb + H_2O.

Reaction (5) was proposed by Buddington as an alternative to de Waard's reaction (1). Inasmuch as any two of these reactions may be linearly combined so as to generate the other three, there seems to be no substantive disagreement between these authors.

The fact that the "univariant" assemblages are common in the granulite facies, and that even the "invariant" assemblage is rarely found, is consistent with chemical evidence that Fe and Mg are strongly partitioned between the reactant and product assemblages. Based on selected chemical data, a "reaction" has been deduced that involves quartz, plagioclase, hornblende, garnet, orthopyroxene, clinopyroxene, magnetite, and ilmenite. The configu-

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*at specified values of μH_2O and four concentrational variables.

ration of an isograd based on this reaction should be essentially a function of P, T, μH_2O, and plagioclase composition.

THE SYSTEM Na_2CO_3—K_2CO_3—$CaCO_3$ AT 1 KB AND ITS SIGNIFICANCE IN CARBONATITE PETROGENESIS

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The system Na_2CO_3—K_2CO_3—$CaCO_3$ at 1 kb is ternary: the join Na_2CO_3—$CaCO_3$ has a compound $Na_2Ca(CO_3)_2$ (nyerereite) which melts congruently at 817°C, and eutectics at $NC_{47}CC_{53}$ and 813°C, and at $NC_{78.5}CC_{21.5}$ and 725°C. The system K_2CO_3—$CaCO_3$ has a compound $K_2Ca(CO_3)_2$ (fairchildite) which melts congruently at 809°C and a compound $K_2Ca_2(CO_3)_3$ (phase A) which melts incongruently at 810°C with a reaction point at $KC_{42}CC_{58}$. There are eutectics at $KC_{54}CC_{46}$ and 790°C, and at $KC_{76.5}CC_{23.5}$ and 735°C. Maximum solid solution of CC in NC is 16 wt% and in KC is about 11 wt%. Nyerereite has a lower stability limit of 400°C; shortite has an upper stability limit of 335°C with excess NC and of 400°C without excess NC. Fairchildite is stable from its melting point down to 547°C where it inverts to buetschliite. Phase A is stable between 810°C and 512°C. NC—KC appears to be a solid solution series. In the ternary system, the cotectic between (NC—KC—FC) and $(\text{Ny—FC})_{ss}$ has a minimum at 665°C. The cotectic between $(\text{Ny—FC})_{ss}$ and CC and between $(\text{Ny—FC})_{ss}$ and phase A has a reaction point at $NC_7KC_{42.5}CC_{50.5}$ and 795°C and a minimum at $NC_4KC_{47}CC_{49}$ and 785°C.

The crystallization of natrocarbonatite lavas in Tanzania is interpreted in terms of the ternary system. It is concluded that the lavas have probably separated immiscibly from a nephelinitic magma.

It is suggested that alkali carbonatite liquid can develop only if the silica activity is too low for the development of silicates and the magma is dry. In wet magmas alkalis not bound as silicates are lost in the hydrous fluid phase. Alkali carbonatite magmas are probably common but most lose their alkalis and leave a residual melt that crystallizes as the common calcitic, dolomitic and ankeritic carbonatites. Fenitizing fluids can be derived from both carbonatitic and ijolitic (nephelinitic) magmas.

A MATHEMATICAL TECHNIQUE FOR THE ANALYSIS OF MINERAL ASSEMBLAGE DATA

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Using an equilibrium model, conditions of metamorphism or ore deposition may be determined if enough data exist to solve equations of the form:

$$\ln K = A/T + B + CP/T$$

where A, B, C are thermodynamic constants; P and T are pressure and temperature; and $\ln K$ is a function of compositions of coexisting minerals.

For any given mineral assemblage, determination of the form of the functions K is a prerequisite to the thermodynamic analysis. By setting up a matrix of end-member compositions of the various minerals in any assemblage it is possible to rapidly determine all possible functions K for that assemblage. This information may then be used to answer the following questions:

1) Can this assemblage be used to determine pressure and temperature?
2) What thermodynamic data are required?
3) What chemical analyses should be performed?

Application of this technique to assemblage data can help optimize the use of scarce analytical facilities as well as demonstrate those thermodynamic properties most useful to students of phase equilibria in geology.

THE RATE OF CRYSTALLIZATION OF MINERALS IN ROCKS

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An expression for the rate of crystallization of minerals in rocks may be obtained by combining an equation for the rate of crystal growth, obtained from data on compositional zoning, with an equation for the rate of nucleation, obtained from the crystal-size distribution.

Several models have been constructed by combining different growth and nucleation equations, and most of these give rise to a crystallization rate that is acceleratory. These models are in harmony with present knowledge concerning the crystallization behaviour of minerals of variable composition, and with models concerned with the heating and cooling of rock bodies in the Earth's crust.

COEXISTING CALCIFEROUS AMPHIBOLES FROM THE DELORO PLUTON, MADOC, ONTARIO

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An intrusive suite of syenitic to granitic rocks, characterized by calcic amphibole, comprises an early intrusive series of the Deloro pluton. Several phases have formed a complex breccia zone, the first member represented by diabasic xenoliths and the last by hastingsite-bearing, hypersolvus granite. The multiple intrusive nature of this suite has led to the thermal metamorphism of all but the last phase. These metamorphosed varieties may be distinguished by the presence of biotite, patchy replacement perthite, zoisitized plagioclase and two or more coexisting calcic amphiboles.

A wide range of chemistry is displayed by these amphiboles, including ferro-actinolite—ferro-hornblende, ferro-hornblende — ferro-hornblende, and ferro-hornblende—hastingsite pairs.

Texturally, one amphibole may rim another, the two types may occur independently or both may form a complex, fine-grained aggregate; there is no evidence of exsolution of one phase from another, and zoning is rare. The general regularity in composition of each type suggests that equilibrium prevailed, but as many as four distinct compositional varieties may be present in a single specimen.

Ferro-actinolite—ferro-hornblende pairs define the only consistent miscibility gap. Regular immiscibility is obscured between "hornblendic" amphiboles and the parameter determining the compositions of the wide variety of coexisting hornblendes may have been temperature; bulk rock chemistry does not seem to have played a major role. Between any two coexisting amphiboles, the type higher in $(Na + K)$ almost invariably has higher $Fe/Fe{+}Mg$ and a higher Al/Si, consistent with actinolite—hornblende pairs formed in rocks of medium-grade metamorphic terranes. Alkali-alumina, and Fe-rich metasomatizing fluids may have been responsible for the observed assemblages, but sharp grain boundaries nonetheless imply the existence of hornblende—hornblende immiscibility.

COMPOSITION VARIATIONS IN A Ni-Co-As ASSEMBLAGE

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A Ni-Co-As assemblage from Cobalt, Ontario consisting of plumose rosettes of rammelsbergite enclosing large axial crystals of pararammelsbergite and rimmed by cobaltite and safflorite has been examined in some detail by electron microprobe analysis for Co, Ni, Fe, As, S and Sb. Approximate, average metal compositions for these phases are pararammelsbergite, larger axial crystals, $Ni_{.965}Co_{.03}Fe_{.005}$, axial crystals in smaller lateral rosettes, $Ni_{.920}Co_{.078}Fe_{.002}$; rammelsbergite, $Ni_{.67}Co_{.30}Fe_{.03}$; cobaltite, $Ni_{.26}Co_{.66}Fe_{.08}$; and safflorite, inner zone, $Ni_{.2}Co_{.6}Fe_{.2}$, outer zone, $Ni_{.32}Co_{.32}Fe_{.36}$. The rammelsbergite is relatively homogeneous but there are significant zonal variations within the cobaltite. Ni decreases progressively outward and Fe and S distributions across the cobaltite layer have fairly pronounced M-shaped profiles, both being relatively enriched toward the inner and outer margins.

Although pararammelsbergite appears to have formed by inversion of rammelsbergite, the Co released in this process has migrated away from pararammelsbergite and must have been redistributed within the remaining rammelsbergite and, probably, within the cobaltite. Also, the M-shaped Fe and S profiles across the cobaltite are inconsistent with sequential, primary deposition from the ore-forming fluid. Thus, whilst the gross chemical zoning may be primary, other features in these rosettes appear to be the result of later chemical readjustments through solid state diffusion.

MINERALOGICAL CHARACTERISTICS OF THE ZGOUNDER SILVER DEPOSIT IN MOROCCO

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The Zgounder silver deposit is located in the Anti-Atlas mountains about 200 kilometers east of Agadir, Morocco. It consists of veins and disseminated grains of ore minerals in fractured Precambrian sedimentary rocks and in diabase. Three types of mineralization are present in the veins. One consists of silver associated with pyrite, another of sphalerite and galena with local enrichments of chalcopyrite and/or tennantite, and the third of silver and a variety of silver sulphides including acanthite, stephanite, polybasite, and pyrargyrite. The disseminated ore minerals which occur in the sedimentary rocks are very fine-grained, consisting of mixtures of the minerals represented by the three types of mineralization. The disseminated minerals in the diabase only occur adjacent to the veins, are coarser grained, and consist of the minerals that are present in the specific veins. This difference in the mode of occurrence of the disseminated grains in sedimentary rocks and diabase suggests that the deposit is sedimentary and that the ore minerals were remobilized, concentrated, and injected as veins by the intrusion of the diabase.

DISTRIBUTION OF ROCK ALTERATION MINERALS AT BRUNSWICK TIN MINES LTD.

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The deposits being explored and developed by Brunswick Tin Mines Ltd. consist of polymetallic zinc-copper-tin and molybdenum-tungsten-bismuth mineralizations in fractured, silicified and greisenized sub-volcanic felsic intrusions.

Approximately 160 samples from drill holes in section 406N across the Fire Tower zone were studied by diffractometer methods. Detection limits of the methods used range from 0.5 to 2% for the various minerals.

Primary feldspars in the rocks overlying and adjoining the deposit have been altered to chlorite and mica; the rocks underlying the mineralized body contain detectable amounts of alkali feldspars. Silicification is most important in a zone extending vertically upwards from the mineralized body; intense silicification coincides with high topaz content. Small amounts of fluorite (up to 5%) are present in most specimens; the mineral forms a broad halo around the mineralized body. Topaz may reach concentrations as high as 23% and is restricted to a vertical zone overlying the mineralized body. Chlorite, mica and kaolinite seldom account for more than 10% of the specimens. Micas and chlorite are virtually absent in the rocks from within and overlying the mineralized body; the minerals occur principally along the boundary of the mineralized zone and extend outward into the country rocks.

ON THE CRYSTAL STRUCTURE OF VESUVIANITE

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Vesuvianite crystals from two Canadian localities have been studied by x-ray single crystal techniques, and the crystal structures investigated. Results show that four additional oxygen atoms per cell are required to be included in the conventionally accepted formula. Beryllium, present in small amounts in both samples, probably is randomly distributed over tetrahedral voids, and may serve to provide charge balance. An order-disorder situation exists on the 4-axis where 4 positions are occupied by 2 Ca atoms. The variations in detail of the distribution of these two atoms over the 4 positions are responsible for the space group modifications previously noted in the vesuvianite structure.

PHASE CONTRAST AND OTHER SPECIAL MICROSCOPY APPLIED TO FINE CRYSTALLIZATIONS

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Phase-contrast microscopy of liquid-immersed powders in transmitted light has been found helpful in discerning sequences of phase associations and microtextures in fine-grained crystallizations. Dark-field and interference microscopy have been useful supplementary methods.

The foregoing is demonstrated chiefly by a study of ceramic specimens in the system lithia-alumina-silica. Here a paragenetic sequence advances with heat treatment through a series of constitutions at first glassy and later holocrystalline, and displaying the development of mullite and the transformation of quartz-type crystallizations into crystallizations of beta-spodumene type.