

SUMMARY OF  
SIGNIFICANT  
RESULTS IN—

Mineral resources

Water resources

Engineering geology

and hydrology

Regional geology

Principles and processes

Laboratory and

field methods

Topographic surveys

and mapping

Management of resources

on public lands

Investigations in

other countries

LISTS OF—

Investigations in

progress

Reports published

in fiscal year 1971

Cooperating agencies

Geological Survey offices

# GEOLOGICAL SURVEY RESEARCH 1971

## Chapter A



immersed in solutions of this compound. Furthermore, radioactive gold solubilized by an extract from flax plants that contained hydrogen cyanide derived by enzymatic action on the natural glycoside was absorbed in large amounts by the experimental plants. These experiments show that if gold is present in the soil where cyanogenic plants are rooted, a mechanism exists for introducing gold into the biogeochemical cycle.

## MINERALOGIC STUDIES IN CRYSTAL CHEMISTRY

### CRYSTAL CHEMISTRY OF ROCK-FORMING SILICATES

#### Site occupancies in synthetic (Ca,Fe)SiO<sub>3</sub>

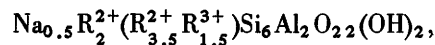
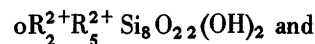
Assignments and area ratios for the *M1* and *M2* sites have been determined by Eric Dowty and D. H. Lindsley<sup>108</sup> for both room- and liquid-nitrogen temperature Mössbauer spectra of a series of synthetic hedenbergite-ferrosilite pyroxenes quenched from 950°C and 20 kb. Variations in quadrupole splitting for the *M2* site illustrate the crystal chemical basis for some of the phase relations of pyroxenes. Quadrupole splitting for *M2* decreases to a minimum at about  $\text{Fs}_{83}\text{Wo}_{17}$ , indicating maximum distortion (and highest energy) of the immediate environment of the site at this composition. In fact, the curve of isomer shift versus composition is suggestive of an inverted solvus. Area ratios for liquid-nitrogen temperature spectra are fairly precise and show a slight excess of iron in the *M1* site for compositions other than  $\text{Fs}_{100}$ , indicating that a small amount of calcium (a maximum of about 0.04 atoms) may be found in the *M1* site. The area ratios from the room-temperature spectra are anomalous although the hyperfine parameters seem to be consistent with those of the liquid-nitrogen spectra. Areas of the *M2* doublet for relatively calcic compositions, such as  $\text{Fs}_{70}\text{Wo}_{30}$ , remain almost equal to the areas of the *M1* doublet although they should be much smaller. The cause of this anomaly is not fully understood, but it is apparent that site distributions of calcic pyroxenes determined from room-temperature spectra may be seriously in error.

#### The anthophyllite-gedrite and actinolite-hornblende solid-solution series

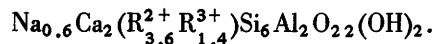
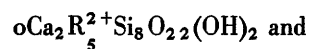
Evaluation of available chemical analyses by Peter Robinson (University of Massachusetts), Malcolm Ross (USGS), H. W. Jaffe (University of Massachusetts), and Cornelis Klein (Harvard University)<sup>109</sup> indicates the anthophyllite-gedrite series is a solid solution between two end members

<sup>108</sup>Dowty, Eric, and Lindsley, D. H., 1971, Mössbauer spectroscopy of synthetic Ca-Fe pyroxenes: Carnegie Inst. Washington Year Book, v. 69, p. 190–193.

<sup>109</sup>Robinson, Peter, Ross, Malcolm, Jaffe, H. W., and Klein, C., 1971, Composition of the anthophyllite-gedrite series, comparison of gedrite and hornblende, and the anthophyllite-gedrite solvus: Am. Mineralogist, v. 56, p. 1005–1041.



where  $\text{R}^{2+} = \text{Mg}, \text{Fe}^{2+}, \text{Mn}^{2+}, \text{Ca}$ ;  $\text{R}^{3+} = \text{Al}, \text{Fe}^{3+}, (\text{Fe}_{1/2}^{2+}\text{Ti}_{1/2}^{4+})$ ; and o=vacant *A* site. A similar evaluation of calcic amphiboles suggests that a high proportion fall in an actinolite-hornblende series between two analogous end members



Calcic amphiboles between actinolite and ideal edenite, tschermakite, or pargasite are rare. The apparent coupling of the two coupled substitutions, one, *A*-site Na and Al(IV) for the *A*-site vacancy and Si(IV); and two,  $\text{R}^{3+}$ (VI) and Al(IV) for  $\text{R}^{2+}$ (VI) and Si(IV), and the half-occupied *A* site implied by the ideal gedrite and hornblende formulas are not readily explained by determined gedrite and hornblende structures.

There is apparently complete solid solution in the anthophyllite-gedrite series at high temperature as demonstrated in specimens from the sillimanite zone of southwestern New Hampshire and Massachusetts. On cooling, members with intermediate Al and Na content exsolved to an anthophyllite-gedrite intergrowth as shown by X-ray single crystal photographs. Some of the intergrowths are coarse enough so that (010) lamellae of anthophyllite (0.2μ thick) and gedrite (0.8μ thick) are visible under the petrographic microscope. Other intergrowths are optically homogeneous but show a strong blue, green, or yellow Schiller effect believed to be due to submicroscopic exsolution. Exsolved anthophyllite and gedrite lamellae in the New Hampshire and Massachusetts intergrowths are estimated to contain approximately 0.2 and 1.6 tetrahedral Al, respectively. The Fe-Mg ratio is believed to have little influence on the width of the solvus in the composition range of the specimens studied. Under conditions of primary crystallization below the crest of the solvus, as reported by Stout<sup>110</sup> from Southern Norway, anthophyllite and gedrite, with tetrahedral Al contents in the ranges 0.29 to 0.47 and 1.13 to 1.50, respectively, formed together as two physically separable phases which subsequently underwent no fine-scale exsolution.

The composition limits of the anthophyllite-gedrite field under given metamorphic conditions are set both by the crystal chemistry and free energy of the orthoamphiboles, and the relative free energies of competing phases. The appearance of a primary anthophyllite-gedrite solvus further complicates an already complex set of metamorphic facies types.

### CRYSTAL CHEMISTRY OF TITANIAN GARNETS

The question of whether titanium replaces silicon in garnets

<sup>110</sup>Stout, J. H., 1971, Four coexisting amphiboles from Telemark, Norway: Am. Mineralogist, v. 56, p. 212–224.

has been debatable despite much recent work in the literature. It is impossible to determine the site distribution of cations in titanian garnet by any single method because there are too many chemical variables; site distributions of Fe, Al and Ti are all unknown. Eric Dowty (r0490) and D. E. Appleman have combined data from X-ray structure refinement and Mössbauer spectroscopy, enabling the site distribution of most of the titanium to be pinned down. There seems to be very little, if any, tetrahedral titanium. A result of Mössbauer study has been the apparent confirmation of a small amount of ferrous iron replacing silicon. Replacement of silicon by a large ion like  $\text{Fe}^{2+}$  is astonishing.

An analysis of a high zirconium, high titanium garnet from Magnet Cove, Ark., by J. J. Fahey has helped to delineate bulk chemical variation in Ti-Zr garnets. Although data are still very scarce for Zr garnets, there seem to be two series: one between andradite and end-member schorlomite (about  $\text{Ca}_3\text{TiFe}^{3+}(\text{Fe}^{3+}, \text{Al})\text{Si}_2\text{O}_{12}$ ), and one between schorlomite and kimzeyite ( $\text{Ca}_3\text{Zr}_2(\text{Al}, \text{Fe}^{3+})\text{Si}_2\text{O}_{12}$ ).

#### POTASSIUM-RICH MICROCLINES FROM THE WET MOUNTAINS, COLO.

Eight microcline samples, each representing a more or less distinct paragenetic type, collected from zones of potassic fenitization in the Wet Mountains, Colo., were studied by George Phair using recently developed X-ray diffraction procedures developed by P. M. Orville, by T. L. Wright, and by T. L. Wright and D. B. Stewart. Five of the samples had been chemically analyzed. Orville's heating method using  $(\bar{2}01)$ , together with Orville's curves as refined especially for K-rich microcline, determined Or contents closest to those of the chemically analyzed samples. Following in order of decreasing accuracy were Or contents as determined by (1) cell parameter,  $a$ , (2) cell parameters  $V$ , and (3)  $(\bar{2}01)$  unheated. In no determination was the difference found to be greater than 4.5 percent Or.

The six samples for which full data are available are all excellent maximum microcline. All samples appeared normal when using Wright's criterion,  $2\theta(\bar{2}01)_{\text{theor.}} - 2\theta(\bar{2}01)_{\text{meas.}} < 0.1^\circ 2\theta$ ; one of the six appears slightly anomalous when using Wright and Stewart's criterion for normality:  $a_{\text{theor.}} - a_{\text{meas.}} < 0.02 \text{ \AA}$ . The measured "triclinicities" ( $\Delta$ ) of the six samples using Laves' relationship,  $\Delta = 12.5[2\theta(1\bar{3}1) - 2\theta(131)]$  closely fit a smooth curve when plotted against the difference between axial angles  $\alpha$  and  $\gamma$ . The "triclinicity" decreases from 0.97 in the naturally heat treated but chemically unaltered granite to 0.93 in residual microcline from the fenite zone, to 0.87 in the newly formed replacement microcline in the fenite zone, and finally to 0.85 in the tabular microcline found in open spaces in the central "vein." The differences in "triclinicity" indicate progressively increasing structural disorder. A low, but distinct, temperature gradient increasing from the wallrocks through the emplacement zone into the central vein is indicated. The large size and

semieuhedral morphology of the most disordered crystals is incompatible with rapid deposition as the cause of disorder. The nearly complete lack of Ab+An component in the microcline, the very low thermal state, and the lack of gridiron twinning shown by the microcline, all indicate that unusually low temperatures prevailed during mineral formation throughout the potassic fenite zone.

#### NEW MINERAL DATA FOR HYDRATED PHOSPHATES AND SULFATES

Chemical and X-ray crystallographic studies by M. E. Mrose have demonstrated that the mineral dittmarite, previously assigned the formula  $(\text{NH}_4)\text{Mg}_5\text{H}_4(\text{PO}_4)_5 \cdot 8\text{H}_2\text{O}$ , is actually  $(\text{NH}_4)\text{MgPO}_4 \cdot \text{H}_2\text{O}$ , orthorhombic,  $Pmn2_1$ ,  $a$  5.606,  $b$  8.758,  $c$  4.788 Å, cell volume 235.1 Å<sup>3</sup>, cell contents  $2[(\text{NH}_4)\text{MgPO}_4 \cdot \text{H}_2\text{O}]$ , density (calc.) 2.19 g/cm<sup>3</sup>. Supposed "hannayite" is found to be a mixture of two phases: newberyite,  $\text{MgHPO}_4 \cdot 3\text{H}_2\text{O}$ , and dittmarite. Crystals of struvite,  $(\text{NH}_4)\text{MgPO}_4 \cdot 6\text{H}_2\text{O}$ , a mineral associated with newberyite and dittmarite, are found to alter when held in mother liquor for several weeks at about 55°C, producing first dittmarite and then newberyite. The reaction is reversible, and newberyite crystals kept over  $\text{NH}_4\text{OH}$  in a closed system for several months alter to struvite. These results explain the mineral associations and account for the previous confusion about this system.

The first known occurrence in the United States of the rare mineral, wagnerite,  $\text{Mg}_2\text{PO}_4\text{F}$ , is at Santa Fe Mountain, near Idaho Springs, Colo. X-ray diffraction studies of the crystals by M. E. Mrose show that the mineral is monoclinic,  $P2_1/a$ ,  $a$  11.929±0.005,  $b$  12.698±0.008,  $c$  9.633±0.004 Å,  $\beta$  108°12'±3', cell volume 1,386 Å<sup>3</sup>, cell contents  $16[\text{Mg}_2\text{PO}_4\text{F}]$ , density (obs.) 3.13 g/cm<sup>3</sup>, (calc.) 3.12 g/cm<sup>3</sup>. The mineral has a strong subcell with  $I2/a$  symmetry and the same  $a$ ,  $c$ , and  $\beta$  values as the true cell but with  $b$  one-half of the true cell. Ferroan wagnerite,  $(\text{Mg}, \text{Fe}, \text{Mn})_2\text{PO}_4(\text{F}, \text{OH})$  and magniotriplite,  $(\text{Mg}, \text{Fe}, \text{Mn})_2\text{PO}_4\text{F}$ , have the same  $I2/a$  space-group as does triplite,  $(\text{Mn}, \text{Fe}, \text{Mg}, \text{Ca})_2\text{PO}_4(\text{F}, \text{OH})$ . The cell dimensions for ferroan wagnerite are  $a$  11.971,  $b$  6.381,  $c$  9.714 Å,  $\beta$  108°15', and for magniotriplite,  $a$  12.015,  $b$  6.415,  $c$  9.787 Å,  $\beta$  108°10'. The close agreement of the cell constants and the triplite-like space-group symmetry indicate that the name, ferroan wagnerite, should be relegated to synonymy, and magniotriplite should be used instead.

Type trudellite from the Cerro Pintados, 80 km southeast of Iquique, Tarapaca province, Chile, originally assigned the formula  $\text{Al}_{10}\text{Cl}_{12}(\text{OH})_{12}(\text{SO}_4)_3 \cdot 30\text{H}_2\text{O}$  (?), has been shown by X-ray and chemical studies (M. E. Mrose) to be a mixture of two phases, natroalunite,  $\text{NaAl}_3(\text{SO}_4)_2(\text{OH})_6$ , and chloraluminite,  $\text{AlCl}_3 \cdot 6\text{H}_2\text{O}$ . The latter mineral has previously been found only in acid fumaroles on Vesuvius, Italy, during the eruptions of 1872 and 1906. The present work thus discredits the species trudellite and establishes a new occurrence for chloraluminite.

### CRYSTAL CHEMISTRY OF DAWSONITE, OF A NEW VANADIUM SILICATE, AND OF GOWERITE

The crystal structure of dawsonite,  $\text{NaAl}(\text{CO}_3)(\text{OH})_2$ , was redetermined by D. E. Appleman and M. E. Mrose using the symbolic addition procedure on data obtained from a crystal from Green River cores. Least-squares refinement of the very accurate data confirms the preliminary structure found by Frueh and Golightly,<sup>111</sup> and in addition, reveals the hydrogen-bonding scheme. The hydrogen atom was resolved and its position refined.

An orthorhombic dimorph of the new mineral cavansite,  $\text{Ca}(\text{VO})(\text{Si}_4\text{O}_{10}) \cdot 4\text{H}_2\text{O}$ , has been discovered by H. T. Evans, Jr. (r0492), in specimens collected by Professor Lloyd Staples (University of Oregon) at Owyhee, Oreg. The new phase forms blue-green prismatic crystals hardly distinguishable from cavansite except that they are invariably twinned, often in fivelings with striking star-shaped cross sections. The structure of this phase has been solved and found to be a layer silicate structure like cavansite, whose structure determination was previously reported in Prof. Paper 700-A (U.S. Geol. Survey, r0632, p. A118). The essential difference is that, while the cavansite silicate sheet consists of a network of 4-fold and 8-fold rings of linked  $\text{SiO}_4$  tetrahedra, the net in the new phase consists entirely of 6-fold rings. The latter has a simpler geometry which permits the layer to be folded at an angle of  $72^\circ 40'$  so that a 5-fold repetition of this process results in a nearly perfect prismatic structure corresponding to the 5 members of the multiple twin. No such mechanism can be imagined for cavansite, and, in fact, no twins are found.

The discovery of different borate polyanions in members of a series of borates having similar oxide formulas has been reported by J. A. Konnert, J. R. Clark, and C. L. Christ. The structures of macallisterite,<sup>112</sup>  $\text{MgO} \cdot 3\text{B}_2\text{O}_3 \cdot 7.5\text{H}_2\text{O}$ , of aksaite<sup>113</sup>,  $\text{MgO} \cdot 3\text{B}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$ , and of tunellite<sup>114</sup>,  $\text{SrO} \cdot 3\text{B}_2\text{O}_3 \cdot 4\text{H}_2\text{O}$  (by analogy, nobleite,  $\text{CaO} \cdot 3\text{B}_2\text{O}_3 \cdot 4\text{H}_2\text{O}$ ), all contain a polyanion which, in isolated form as in macallisterite and aksaite, has the formula  $[\text{B}_6\text{O}_7(\text{OH})_6]^{2-}$ . These polyanions share corners following Christ's fourth rule<sup>115</sup> to form the  $[\text{B}_6\text{O}_9(\text{OH})_2]^{2-}$  sheets of tunellite and nobleite. However, the structure of gowerite,  $\text{CaO} \cdot 3\text{B}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$ , contains  $[\text{B}_5\text{O}_8(\text{OH})]^{2-}$  sheets plus isolated  $\text{B}(\text{OH})_3$  groups similar to those found in veatchite<sup>116</sup> and *p*-

veatchite<sup>117</sup> both of which have the formula  $4\text{SrO} \cdot 11\text{B}_2\text{O}_3 \cdot 7\text{H}_2\text{O}$ . This discovery raises further questions about the chemical conditions that govern the crystallization of these various borates. Precise definition of these conditions might provide valuable information on the conditions causing formation of borate deposits.

## VOLCANIC ROCKS AND PROCESSES

### Intrusive activity postdating the Mt. Aetna volcanic subsidence, Colorado

Field mapping by Priestley Toulmin III has shown that the Mount Antero Granite, known for its rich suite of beryllium minerals and miarolytic and pegmatitic segregations, postdates the volcanic subsidence structure centered around Mt. Aetna, Chaffee Co., Colo. A newly recognized stock of the granite apparently cuts through a dike that injects the boundary fault of the subsidence structure on the south flank of Mt. Aetna and is associated with molybdenite-bearing veins.

### Middle Cenozoic andesitic volcanism of the western conterminous United States related to plate tectonics

Middle Cenozoic andesitic volcanism that predates initiation of basin-range structure in the Western United States has been interpreted by P. W. Lipman, H. J. Prostka, and R. L. Christiansen as indicating that until late Cenozoic time a spreading ridge system (the East Pacific Rise) was continuous west of North America, and a subduction zone was continuous along the western continental margin. Lower to middle Cenozoic andesitic and related rocks form two parallel belts in which the ratio  $\text{K}_2\text{O}:\text{SiO}_2$  increases eastward. These belts are separated by a discontinuity from the northern Rocky Mountains to the western margin of the Colorado Plateau, but converge near the Canadian and Mexican borders. Analogy with Dickinson-Hatherton  $\text{K}_2\text{O}$  plots for modern island arcs suggests that early and middle Cenozoic subduction beneath the Western United States was along two subparallel imbricate zones that dipped about  $20^\circ\text{E}$ . The western zone emerged at the continental margin, but the eastern zone was entirely beneath the continental plate, partly coupled to the western zone below the low-velocity layer. These zones remained active in the southwestern United States through Oligocene time until disrupted by the late Cenozoic transform system; in the northwest the imbricate zones were replaced in early Oligocene time by a single steeply inclined zone that remained active until the late Quaternary.

<sup>111</sup>Frueh, A. J., Jr., and Golightly, J. P., 1967, The crystal structure of dawsonite,  $\text{NaAl}(\text{CO}_3)(\text{OH})_2$ : Canadian Mineralogist, v. 9, p. 51–56.

<sup>112</sup>Dal Negro, Alberto, Sabelli, Cesare, and Ungaretti, Luciano, 1969, The crystal structure of macallisterite,  $\text{Mg}_2[\text{B}_6\text{O}_7(\text{OH})_6]_2 \cdot 9\text{H}_2\text{O}$ : Accad. Naz. Lincei Atti, Cl. Sci. Fis. Mat. e Nat. Rend., v. 47, p. 353–364.

<sup>113</sup>Dal Negro, Alberto, Ungaretti, Luciano, and Sabelli, Cesare, 1971, The crystal structure of aksaite: Am. Mineralogist. [In press]

<sup>114</sup>Clark, J. R., 1964, The crystal structure of tunellite,  $\text{SrB}_6\text{O}_9(\text{OH})_2 \cdot 3\text{H}_2\text{O}$ : Am. Mineralogist, v. 49, p. 1549–1568.

<sup>115</sup>Christ, C. L., 1960, Crystal chemistry and systematic classification of hydrated borate minerals: Am. Mineralogist, v. 45, p. 334–340.

<sup>116</sup>Clark, J. R., and Christ, C. L., 1968, Crystal structure of veatchite: Naturwissenschaften, v. 12, p. 648.

<sup>117</sup>Gandymov, O., Rumanova, I. M., and Belov, N. V., 1968, Crystal structure of *p*-veatchite,  $4\text{SrO} \cdot 11\text{B}_2\text{O}_3 \cdot 7\text{H}_2\text{O} = \text{Sr}_4\text{B}_{22}\text{O}_{34} \cdot 7\text{H}_2\text{O} = 2\text{Sr}_2[\text{B}_5\text{O}_8(\text{OH})]_2 \cdot \text{B}(\text{OH})_3 \cdot \text{H}_2\text{O}$  [in Russian]: Akad. Nauk SSSR Doklady, v. 180, p. 1216–1219.