EVALUATION OF AMPHIBOLE SYNTHESIS AND PRODUCT CHARACTERIZATION

by

Mati Raudsepp

A thesis
presented to the University of Manitoba
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy
in
Geology

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ABSTRACT

Synthesis products from a general survey of iron-free monoclinic amphibole endmembers were characterized by powder X-ray diffraction, scanning electron microscopy, infrared spectroscopy and Rietveld structure analysis. Previous amphibole syntheses were reviewed and evaluated; certain amphiboles synthesized in other studies were characterized in more detail.

Early studies usually assumed on the basis of optical microscopy and powder X-ray diffractometry that amphiboles from high-yield runs were of the nominal composition. Later studies with electron microprobe and spectroscopic analysis showed many synthetic amphiboles to be off-composition. Furthermore, although natural amphiboles are ordered, synthetic amphiboles show wide degrees of long-range and short-range order, which must be characterized for proper application of synthesis experiments.

Amphibole synthesis and characterization in this study confirm these findings. It is unlikely that any pure amphibole endmember has been synthesized. Infrared spectroscopy and Rietveld structure analysis of products too meagre or fine grained for other techniques, have shown that virtually all synthetic amphiboles deviate from the ideal compositions and show wide variation in the degree of cation ordering. These methods should be routinely used in amphibole synthesis studies for adequate characterization of run products.

ACKNOWLEDGEMENTS

It gives me pleasure to acknowledge the support and encouragement of A.C. Turnock, whose advice and patience contributed immeasurably to this work. I thank F.C. Hawthorne for suggesting the research and for invaluable discussions of amphibole crystal chemistry during the study. T.S. Ercit was responsible for modifications to the Rietveld structure analysis program and also provided helpful discussion of this part of the work. I am grateful to W.G. Ernst who generously provided alkali amphibole synthesis products for merciless scrutiny. F.C. Hawthorne, J.B. Westmore and D.R. Veblen greatly improved the manuscript by thorough and constructive examination.

SYMBOLS AND ABBREVIATIONS

ab	albite	grt	garnet
an	anorthite	ly	layer silicate
cam	clinoamphibole	mchr	magnesio-chromite
cen	clinoenstatite	mpt	monteponite
chl	chlorite	ne	nepheline
cpx	clinopyroxene	ol	olivine
crs	cristobalite	pa	pargasite
cum	magnesio-cummingtonite	pl	plagioclase
di	diopside	qtz	quartz
ed	edenite	ri	richterite
en	enstatite	spl	spinel
esk	eskolaite	tlc	talc
fl	fluorite	trd	tridymite
fo	forsterite	ts	alumino-tschermakite
fts	ferri-ferro-tschermakite	wil	willemseite
gh	gehlenite	X	unknown phase

¤	empty A-site in amphibole formula
gl	glass
v.f.g.	unidentifiable very fine-grained material
ss	solid solution

Solid oxygen buffers

NNO	Ni-NiO	IQF	$Fe-Si_2-Fe_2SiO_4$
IW	Fe-FeO	FMQ	$Fe_2SiO_4-Fe_3O_4-SiO_2$
IM	$Fe-Fe_3O_4$	CCH_4	graphite-methane
WM	$FeO-Fe_3O_4$	FFsM	$Fe_2SiO_4-FeSiO_3-Fe_3O_4$
MH	$Fe_3O_4-Fe_2O_3$	CT	Cu_2O-CuO

(mineral symbols after Kretz 1983, where appropriate)

CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter I

INTRODUCTION

Amphiboles are the most complex mineral group and occur in a wide variety of igneous and metamorphic rocks. In sedimentary rocks, amphiboles are found both as detrital and authigenic phases. Amphiboles have been described from mafic and ultramafic nodules in mafic rocks, suggesting that amphibole is a mantle phase. Rare occurrences of amphibole have been noted in meteorites and in lunar rocks. The wide chemical variations within amphiboles result from the geometry of the amphibole structure. Several crystallographically unique sites are able to accommodate virtually all major cations in the earth's crust. A comprehensive review of amphibole crystal chemistry is given by Hawthorne (1981, 1983b).

Although several synthetic amphiboles have been characterized by modern methods, the study of synthetic amphiboles has generally not kept pace with advances in structural and crystal-chemical studies. Despite a large number of experimental studies of amphibole stability (Gilbert et al. 1982) and endmember syntheses (see Chapter 2), few synthetic amphiboles have been adequately characterized by modern methods. In the studies of the late 1950's and early 1960's, run products were generally examined by optical microscopy and powder X-ray diffraction. The amphiboles were usually assumed to be of nominal composition, and additional phases were ignored or considered metastable. During the 1970's, more sophisticated techniques (electron microprobe analysis, Mössbauer spec-

troscopy, infrared spectroscopy) suggested that some synthetic amphiboles were "off-composition".

Natural and synthetic amphiboles can potentially display long-range and short-range order/disorder that must be characterized for proper interpretation of the results of synthesis experiments, particularly with regard to thermodynamic modelling and the interpretation of natural occurrence in terms of synthesis and stability experiments. Of specific importance here is cation order/disorder and chain-width order/disorder. This study was undertaken to critically assess the results of amphibole synthesis and to more adequately characterize the products. The study focussed on the characterization of synthetic, iron-free, monoclinic amphiboles with the C2/m structure because previous studies (e.g. Maresch and Czank 1983, Veblen 1981) have shown that Fe-Mg-Mn amphiboles are not only difficult to synthesize, but also are subject to short-range chain-width disorder, high densities of stacking faults and other local structural disorder. The characterization of short-range structural disorder requires high-resolution transmission electron microscopy; this technique was not available to this study but should be used to complement future work. There is presently no evidence that such local structural disorder is a major problem with syntheses of calcic, sodic-calcic and alkali amphiboles; but little work has been done. Mallinson et al. (1980) report evidence of chain-width disorder in nephrite. However, the nephrites are not typical calcic amphiboles; they occur in restricted environments and have unusual physical properties. Synthetic Mg-rich amphiboles in the system Na_2O - MgO - SiO_2 - H_2O have chain-width disorder at low synthesis temperatures (Drits et al. 1974, Drits et al. 1976, Tateyama et al. 1978).

Run products were characterized by optical and scanning electron microscopy (morphology; detection of foreign phases), X-ray diffraction (cell dimensions; detection of foreign phases), infrared spectroscopy (ordering), and Rietveld stucture analysis (ordering and site-occupancies). These results, together with a review of previous monoclinic amphibole syntheses, were used to evaluate the problems of amphibole synthesis and product characterization.

CRYSTAL CHEMISTRY

The standard amphibole formula may be written (Leake 1978) as

$$A_{0-1}B_2C_5T_8O_{22}W_2$$

where, in natural amphiboles

A = Na, K

B = Na, Li, Ca, Mn, Fe^{2+}, Mg

C = Mg, Fe^{2+}, Mn, Al, Fe^{3+}, Ti, Li

T = Si, Al

W = OH, F, Cl, O^{-2}

In this study, the following additional cation substitutions were attempted, with varying success:

B = Cd

C = Sc, V, Cr, Ni, Cu, Ga, In

The classification adopted by the I.M.A. Subcommittee on Amphiboles (Leake 1978), and the addendum to this report (Leake and Hey 1979), was used. Endmembers pertinent to this study are listed in Appendix C. Certain trivalent cation substitutions (Cr, Ga, Sc, In) in the C-group cations create new endmembers not explicitly accounted for by the classification. These compositions are named with an appropriate prefix.

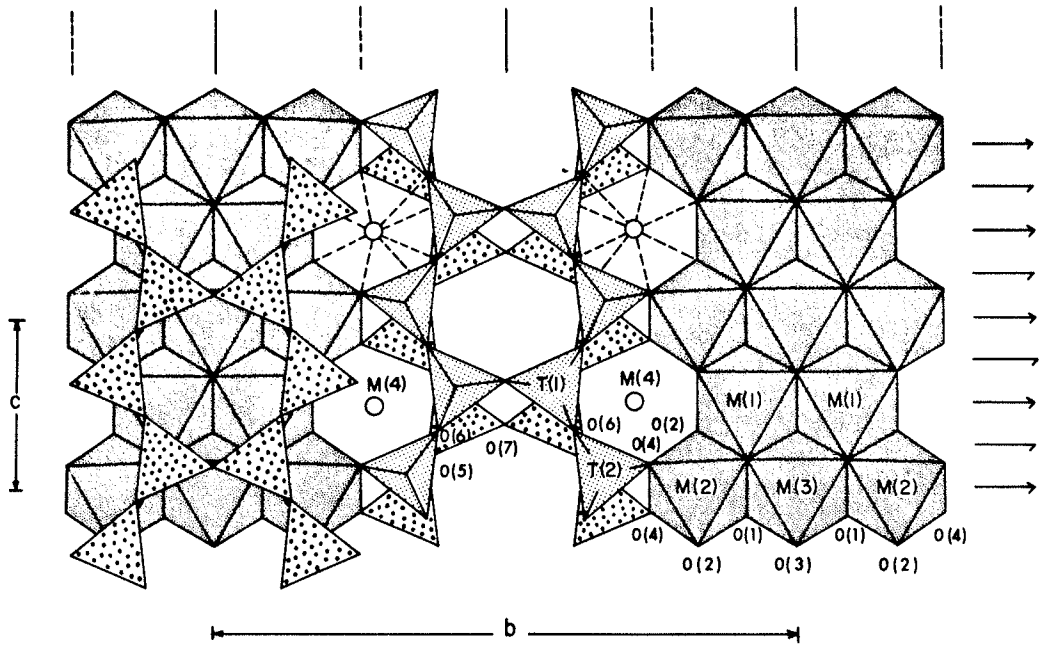

Figure 1: The C2/m amphibole structure projected onto (100). From Hawthorne (1983b).

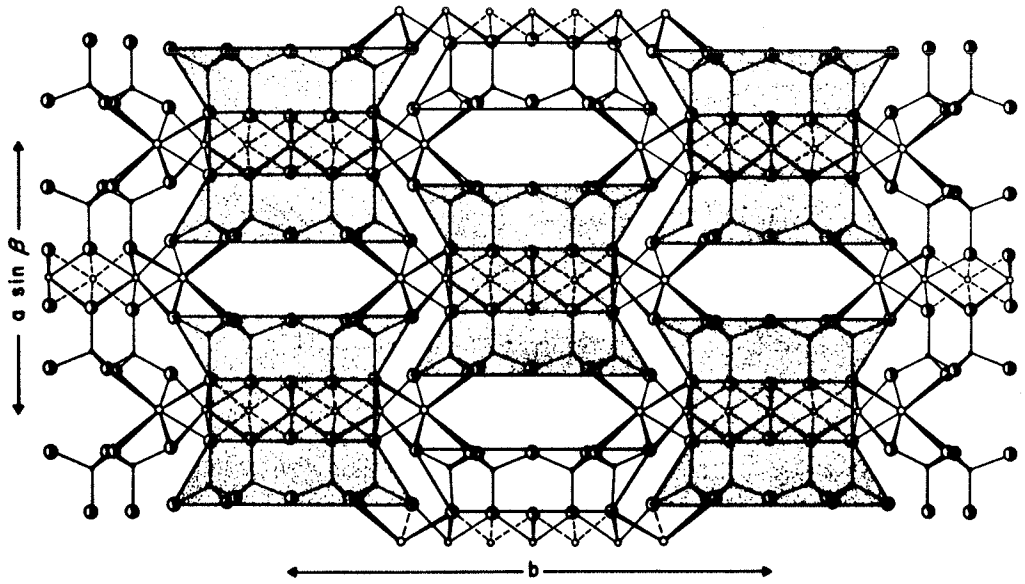

Figure 2: The C2/m amphibole structure projected down Z. From Hawthorne (1983b).

For example, in pargasite, $NaCa_2Mg_4AlSi_6Al_2O_{22}(OH)_2$, the amphibole formed by replacing all of the octahedral aluminum with scandium, $NaCa_2Mg_4ScSi_6Al_2O_{22}(OH)_2$, is named scandium-pargasite.

Naming the monoclinic synthetic amphibole $NaMgNaMg_5Si_8O_{22}(OH)_2$ requires clarification. Traditionally, this species is named "magnesio-richterite" (e.g. Gibbs et al. 1962), Gier et al. 1964). According to Leake (1978), it should be named sodian magnesio-cummingtonite (Appendix C). This amphibole is not sodic-calcic, its cell dimensions are more similar to cummingtonite than richterite (particularly β), and its structure may not have C2/m space-group symmetry (see Chapters 4 and 5); consequently the name sodian magnesio-cummingtonite is used here.

THE C2/M AMPHIBOLE STRUCTURE

The amphibole structure (Figure 1) is based on a double-chain of corner-linked tetrahedra that extends infinitely in the Z direction. Pairs of (T_4O_{11}) chains are linked by intermediate-size (0.53-0.83 Å) divalent and trivalent C-group cations to form a module with I-beam cross-section (Figure 2). The modules (I-beams) are joined in a three-dimensional array by linking divalent and trivalent cations at the edges of I-beams (Figure 2). These linkages are reinforced by B- and A-group cations at the margins of the octahedral strip and in the cavity between the back-to-back double chains.

CATION DISTRIBUTIONS IN AMPHIBOLES

The wide variety of cation coordinations in amphiboles, together with the large structural compliance of some of the sites, leads to complex site-occupancy and order-disorder relationships. Unless a synthetic amphibole has been fully characterized with respect to its site-occupancies and patterns of cation ordering, knowledge of its synthesis conditions and physical properties is of limited use in formulating models concerning the properties and parageneses of natural amphiboles. Table 1 summarizes the normal cation groupings in amphiboles. For a detailed

TABLE 1

Normal Cation Site-assignments in Amphiboles

Cation	A	M(4)	M(1),M(2),M(3)	T(1),T(2)
Si				—
Al			—	—
Fe^{3+}			—	
Ti			—	
Fe^{2+}		—	—	
Mn		—	—	
Li	–	—	—	
Ca		—		
Na	–	—		
K	–			

from Hawthorne (1983b)

review of cation ordering in amphiboles, see Hawthorne (1983b).

Chapter II

REVIEW OF PREVIOUS AMPHIBOLE SYNTHESES

Most previous amphibole syntheses have been restricted to three major areas:

1. Study of phase relations of endmembers and intermediate compositions for geological applications.
2. Synthesis of amphibole asbestos for industrial applications.
3. Synthesis of endmembers and intermediate compositions for crystal chemical studies.

Of these, phase studies are most abundant in the literature surveyed (about 50 percent). The products were generally characterized by X-ray powder methods (cell dimensions) and optical properties were usually measured. Industrial studies are next in abundance (about 30 percent). Unfortunately, these studies were generally crude, or were performed in large-scale batches under poorly controlled conditions with commercial viability as the most important consideration. Except in rare cases, the products were inadequately characterized, resulting in very little useful crystal-chemical or structural data. Syntheses of pure endmembers and well-documented miscellaneous compositions for crystal chemical studies are fewest in number (<20 percent) but are rich in fundamental data.

In this chapter, previous amphibole studies are reviewed. Those studies with detailed product characterization are discussed in more detail in Chapter 6. The review emphasizes those studies that contain either fundamental physical properties, or phase relations that are critical to the future duplication of syntheses. Selected synthesis studies not critically reviewed are included as an additional bibliography of amphibole syntheses. Cell dimensions, optical properties, and run conditions are given in Tables 5, 6 and 7.

CALCIC-AMPHIBOLES

Tremolite: $\square Ca_2Mg_5Si_8O_{22}(OH)_2$

Tuttle and England (1953) synthesized tremolite by heating mixtures of MgO, $CaCO_3$, and silica glass at 400°C and 1000 atm water vapour pressure. At 500°C and the same pressure, the mixture crystallized to talc and diopside. Experimental details and physical properties of the synthetic amphibole are not given.

Boyd (1954, 1959) determined the low-pressure stability of tremolite. In spite of its chemical simplicity and widespread occurrence as a metamorphic mineral, tremolite is difficult to nucleate and pyroxene and quartz persist metastably, even in the presence of tremolite nuclei. Boyd observed that with oxide and/or glass-bearing starting materials, the probability of obtaining a perceptible amount of amphibole is about 1 in 3, for runs at temperatures between the breakdown curve and about 50° below the curve. Improved yields of amphibole were obtained with a starting mixture of 50 percent submicroscopic tremolite and 50 percent pyroxene and quartz. This strategy, however, still yielded only 50 percent amphibole, but larger yields were occasionally obtained.

X-ray powder diffractometer patterns (Boyd 1954, 1959) show marked pyroxene and quartz peaks. No evidence is given as to whether the amphibole synthesized is of tremolite composition. The cell dimensions of this amphibole are given in Colville et al. (1966). Cell volume compares well with other synthetic tremolites (Table 5), but the remaining cell parameters vary.

Attempts to synthesize tremolite at 800°C and 10 kbar from dry mix by Gilbert (1969) produced tremolite and quartz. Reaction of this run product with excess water at 30 kbar and 800°C produces talc, orthopyroxene, and quartz; no amphibole is reported. Yields and physical properties of amphiboles are not reported.

Troll and Gilbert (1972) also experienced difficulty in synthesizing tremolite. Yields of 85 to 95 percent were achieved only by long runs with intermediate re-grinding. Two run schemes were used: (1) running for 360 h at 650°C, 1 kbar, then re-running under the same conditions for 1506 h, and (2) running for 362 h at 775°C, 4 kbar, re-grinding and running for 618 h under the same conditions. The 4 kbar runs are slightly better crystallized than the 1 kbar runs. Grain size of the largest amphibole crystals is 10 to 15 microns. Cell dimensions are given (Table 5).

Jasmund and Schäfer (1972) studied the join tremolite - alumino-tschermakite at 1,2, and 3 kbar using gel starting materials. Amphiboles grown in these experiments are only about 2 microns in size. Yields of amphibole and proportions of other phases were not given for runs in the endmember tremolite stability field. Cell dimensions were

determined for selected compositions between tremolite and tremolite$_{50}$...alumino-tschermakite$_{50}$ (alumino-magnesio-hornblende) but were not published because they do not show significant variation. Jasmund and Schäfer (1972) account for this lack of cell-parameter variation by proposing that the decrease in cation-oxygen distance, from substituting Al for Mg in the octahedral strip, is largely balanced by the increase in cation-oxygen distance from the substitution of Al for Si in the tetrahedral chains.

Westrich (1978) synthesized tremolite from gel prepared after the method of Hamilton and Henderson (1968). The mixture was seeded with about 5 percent natural tremolite, reacted for 45 h at 900°C and 4 kbar water pressure, then reground and run again for 45 h. Cell dimensions (Table 5) given for this synthetic amphibole are peculiar, especially a and c. It is probable that the X-ray powder pattern was incorrectly indexed. Impurity phases are reported to be less than 4 percent.

In his study of the tremolite-pargasite join, Oba (1980) grew fibrous or acicular tremolite crystals up to 5 microns wide and 20 microns long from dry mixes. According to his Table 1, 100 percent yields were not realized; clinopyroxene at 1 kbar, and clinopyroxene plus quartz at 5 kbar were present. He attributes the presence of these phases to metastability, the result of sluggish reaction rates, and notes that their proportions decrease with increased run length. Electron microprobe analyses are given for coexisting amphiboles on the join, but analyses of endmembers are not reported.

Jenkins (1981) suggests that synthetic tremolite is non-stoichiometric, having a Ca/(Ca+Mg) ratio of about 0.88 for cations assigned to the M(4) site. This implies that there is solid solution towards magnesiocummingtonite. Experimental details are not given.

Hoschek (1973) synthesized tremolite for use as one of the reactants investigation of the reaction:

5phlogopite+6calcite+24quartz=3tremolite+5K-feldspar+H_2O+6CO_2

Gel starting materials were prepared after Hamilton and Henderson (1968). Run conditions were 600° to 750°C, 4kbar, for 30 to 60 days. Amphibole crystals measured about 10 microns long and about 0.1 microns thick. Refractive indices are: α=1.602(3), γ=1.628(3). Non-amphibole phases comprised up to 2 percent of the run product.

Wones and Dodge (1977) reported problems with tremolite synthesis; all run products contained 1 to 2 percent quartz and diopside. Cell dimensions are given (Table 5). They note that a survey of over 1200 amphibole analyses from Deer et al. (1963) and Leake (1968) produced only nine analyses in which the calculated structural formula contains between 1.90 and 2.10 Ca, fewer than 2.10 A and B cations, and greater than 7.80 Si. Furthermore, N. Chatterjee (pers. comm. 1971 to Wones and Dodge) concludes that tremolite synthesized at 750°C contains 5 to 10 mole percent $^{x}Mg_7Si_8O_{22}(OH)_2$. Because of these data and because previous workers (Boyd 1959, Troll and Gilbert 1972) also describe difficulties in synthesizing tremolite, they suggest that stoichiometric tremolite may not be stable above 700°C.

Gilbert (1969) attempted to synthesize tremolite from a dry mix at 800°C and 10 kbar. The result is amphibole plus quartz. Gilbert states that the mix contained excess SiO_2. Neither yields nor physical properties of the amphibole are given.

Ferro-actinolite: $\square Ca_2Fe_5^{2+}Si_8O_{22}(OH)_2$

Ernst (1966) determined the stability of ferro-actinolite in conventional hydrothermal apparatus with excess water at oxygen fugacities defined by the WM, IM, FMQ, NNO, and MH buffers. Starting materials comprised reagent-grade CaO, Fe_2O_3 and SiO_2 corresponding to ferro-actinolite stoichiometry. Hematite was reduced to metallic iron by exposure to H_2 at 600°C for one-half hour before using the mix.

Ferro-actinolite is stable only at relatively low oxygen fugacities approximately defined by the FMQ and IM buffers. Yields of amphibole up to 95 percent of the charge were achieved with difficulty and only by regrinding previously crystallized lower-yield runs. Grain size averaged about 0.3 x 0.3 x 5 microns. Long runs produced more amphibole than short runs. The remainder of the products consisted of the high-temperature and/or high-oxygen fugacity assemblages of anhydrous phases designated as equivalent in bulk Ca-Fe-Si proportions to ferro-actinolite.

Cell dimensions and mean refractive indices of 10 typical ferro-actinolites grown at 406° to 537°C, 500 to 3000 bar, -23.9 to -33.6 log fO_2 are given (Table 5). According to Ernst, b decreases slightly with increasing fO_2 and decreasing temperature. He attributes this variation, if real, to the increase in Fe^{3+}/Fe^{2+} ratio of ferro-actinolite at ele-

vated oxygen fugacities and low temperatures. The decrease in ionic radius produced by the oxidation of iron could account for a transverse octahedral strip contraction in the Y axis direction.

Tremolite...Ferro-actinolite Series

Hellner and Schürmann (1966) investigated the lower thermal stability of compositions along the join $^{\square}Ca_2Mg_5Si_8O_{22}(OH)_2$ - $^{\square}Ca_2Fe_5Si_8O_{22}(OH)_2$ at about 1 kbar water pressure and 50 bars carbon dioxide pressure. Starting materials consisted of $CaCO_3$, $MgC_2O_4 \cdot 2H_2O$, $Fe_2C_2O_4 \cdot 2H_2O$ and silica gel. Although oxygen fugacity was apparently not consistently controlled during the experiments (Mueller 1967, Hellner and Schürmann 1967), it was probably close to that of the FMQ buffer.

Yields of amphibole in the amphibole stability field are not explicitly given; however, it is implied that they are close to 100 percent (Table 2, Hellner and Schürmann 1966). Cell dimensions were not determined but d-values for the (110) and (251) spacings are given for actinolites grown at 550°C. Amphiboles grown at lower temperatures did not produce X-ray powder patterns of sufficient quality.

Actinolite-Cummingtonite Series

Cameron (1971, 1975) synthesized amphiboles along the join $^{\square}Ca_2Mg_{2.5}Fe_{2.5}Si_8O_{22}(OH)_2$ - $^{\square}Mg_{3.5}Fe_{3.5}Si_8O_{22}(OH)_2$. Starting materials consisted of MgO, Fe-sponge, $CaCO_3$, Fe_2O_3 and Corning 7940 silica glass.

Actinolite formed crystals less than 5 microns long and 0.5 microns wide. Cummingtonite crystals were larger, reaching a maximum size of about 15 microns long and 3 microns wide. When both were present, they

could be distinguished optically with certainty. Cell parameters (Table 5) are given for endmembers and for several coexisting actinolites and cummingtonites. Modes of amphiboles and other phases were estimated from X-ray powder patterns. Amounts of 5 percent of a phase indicate that it is barely, but definitely detectable; one percent indicates that it is only detectable optically as scattered grains. Amphibole yields increased at the expense of anhydrous phases when charges were rerun. Some charges less calcic than than $Act_{60}Cum_{40}$ were converted to about 99 percent amphibole(s) in runs of 40 to 60 days.

Ca contents and Fe:Mg ratios of clinoamphiboles were estimated from d_{100} spacings and b cell dimensions, respectively. A linear determinative curve of Ca versus d_{100} was constructed (but not published) using data from two runs; one with 99 percent cummingtonite, the other, 99 percent actinolite. Fe contents of cummingtonite were estimated using a determinative curve of Fe content versus b-cell dimension for the series cummingtonite-grunerite (Klein and Waldbaum 1967). Fe contents of actinolites were estimated from a similar curve (also not published) using the b cell dimension data for tremolite (Boyd 1959, Colville et al. 1966), ferro-actinolite (Ernst 1966), and an actinolite from his own study with Fe:Mg = 1. Partial electron microprobe analyses, using the intensity ratio method described by Eugster et al. (1972), were also used to estimate the Ca contents and Fe-Mg ratios of two actinolites and three cummingtonites.

Because of the small grain size, precise refractive indices could not be determined for actinolite. The approximate average of α and γ indices of crystal clumps of bulk composition of 100 percent actinolite is 1.660. Refractive indices of cummingtonite are α=1.650(3), γ=1.668(3).

Fluor-tremolite: $^{\square}Ca_2Mg_5Si_8O_{22}F_2$

Ehrenberg (1932) unsuccessfully attempted to synthesize fluor-tremolite by solid-state reaction from a mixture of CaF_2, $CaCO_3$, MgO, and SiO_2. Experiments were performed at 620°, 750° and 800°C. X-ray examination of the products showed that amphibole was absent in all runs. Run products included forsterite at 620°C, and forsterite plus diopside plus fluorite at 750° and 800°C.

Grigoriev (1939) investigated the effect of 1, 3, 5, and 10 percent Al_2O_3 on the optical properties of synthetic fluor-tremolite crystallized from a melt starting at 1400°C. He claims 100 percent yields of amphibole, based on microscopic examination of the run products. The results demonstrate that an increase in Al_2O_3 causes a decrease in refractive indices and extinction angle.

Eitel (1952) noted that in the synthesis of fluor-tremolite by solid state reaction at 1000°C, the phases formed are dependent on the fluorine content of the starting mix. Increasing fluorine content from 2 to 6 atoms per formula unit increased the yield of amphibole. Diopside, although always present, decreases in abundance with increasing fluorine. Other phases, observed but not in all runs, include norbergite, tridymite, CaF_2, MgF_2, MgO, $CaSiO_3$, and $Ca_3Si_2O_7$. Specific yields are not stated, but were apparently not close to 100 percent. Higher yields were obtained by melting batches at 1400°C and cooling to 1200°C in 2 h, but close to 100 percent amphibole was not achieved. Physical properties of the amphiboles grown are not given.

Boyd (1954) synthesized fluor-tremolite by solid-state reaction at about 1000°C and 1 atm. No physical properties are given.

The first well-characterized synthetic fluor-tremolite was grown by Comeforo and Kohn (1954), also reported in Shell et al. (1958). A starting mix of MgF_2, MgO, finely-ground quartz and natural wollastonite was melted at 1450°C, maintained at this temperature for 4 h, and then lowered at a rate of $5°Ch^{-1}$ to 1100°C. Single crystals of fluor-tremolite up to 4mm long were formed; the yield is not reported. Analysis of a beneficiated sample gave the formula:

$$Na_{0.03}Ca_{1.91}Mg_{5.15}Si_{7.96}O_{22}F_2$$

The slight excess of Mg is attributed to a small amount of glass. Optical properties and density are given. Cell dimensions were calculated from (600), (0 12 0), (461), and (661) reflections.

Fluor-tremolite crystals suitable for single-crystal structure refinement were grown by Cameron (1970) and Cameron and Gibbs (1973) from a mix having the composition $CaCO_3 \cdot CaF_2 \cdot 5MgO \cdot 8SiO_2$. The charge was run for 1 week at 1150°C, 1 atm; it was converted to greater than 95 percent fluor-tremolite crystals up to 0.08 mm in size. Cell parameters were calculated from single-crystal diffractometer data.

Troll and Gilbert (1972) achieved 80 to 90 percent yields of fluor-tremolite with starting mixes prepared from $CaCO_3$, CaF_2, MgO, and Corning 7940 silica glass. Charges were reacted in sealed Pt capsules between 1090° and 1155°C at 1 atm for 20 h to 1 week with the same equipment used by Cameron (1970). Although long runs produced larger crystals than short runs, yields of amphibole were not increased. Non-

amphibole phases were clinopyroxene, fluorite, and tridymite or cristobalite.

Westrich (1978) attempted to synthesize fluor-tremolite from an anhydrous gel of tremolite composition. Dilute (5 percent by volume) HF solution was added to the gel and the mix was reacted in a sealed $Ag_{70}Pd_{30}$ tube at 900°C for 24 h. Cell dimensions of the resulting amphibole are peculiar and are not similar to any other fluor-tremolite cell parameters (Table 6). These results may reflect experimental problems with using HF as a source of fluorine, rather than the usual solid fluoride. Reaction of HF with other mix components, leading to anomalous products, is suggested (cf. Manning 1978).

Edenites: $NaCa_2Mg_5Si_7AlO_{22}(OH)_2$

Boyd (1954) synthesized edenite hydrothermally in the range 800° to 900°C and 400 to 1000 bar. Optical properties are in accord with those of corresponding natural amphiboles. No other details are given.

Colville *et al.* (1966) synthesized edenite from a dry mix reacted at 850°C, 2 kbar for 3 days. Amphibole yields and the presence of non-amphibole phases, if any, are not reported. Cell dimensions and refractive indices are given (Table 5). The *c*-dimension, 5.236(15) Å is obviously in error; it is likely that the cell dimensions were not refined correctly.

Gilbert (1969) reported edenite synthesis from oxide mix at 900°C and 20 kbar. Clinopyroxene, forsterite and traces of glass were present in the run product. No yields or physical properties are given.

Petö (1976) reacted both gels and glasses of anhydrous edenite composition with water at 0.5, 1.0 and 2.0 kbar. Certain runs after 138 to 288 h grew fine-grained, acicular crystals of amphibole presumed to be edenite, plus diopside, forsterite, and albite. Refractive indices β and γ are given. Other experiments grew abundant richteritic amphibole plus abundant diopside and forsterite. Initially, the upper stability limit of pure edenite is defined by the reaction (Petö 1976):

$$4ed = 8di + 6fo + ab + 3ne + vapour$$

However, it seems that in the presence of diopside, forsterite, albite and vapour, edenitic amphibole reacts with albite; Na+Si from albite replaces Ca+Al in edenite to form richteritic amphibole and aluminous diopside:

$$ed(ss) + ab = ri(ss) + di(ss) + fo$$

These experiments suggest that edenite is not stable at its own bulk composition.

Hinrichsen and Schürmann (1977) investigated the join edenite ($NaCa_2Mg_5Si_7AlO_{22}(OH)_2$)...potassic-edenite ($KCa_2Mg_5Si_7AlO_{22}(OH)_2$). Potassium-bearing starting mixes were prepared from $K_2O \cdot CaO \cdot 6SiO_2$ glass plus Al_2O_3 and MgO. Sodium was added as Na_2CO_3. The amount of water added to capsules was kept small, generally less than 5 percent, in order to minimize dissolution of components in the vapour phase. Runs lasted from 14 to 30 days at water pressures between 0.5 and 4.4 kbar, and temperatures between 700° and 950°C.

Hinrichsen and Schürmann (1977) claim that "unequivocally" edenites were synthesized at 750°C and 4 kbar in the range Na_{100}-$Na_{50}K_{50}$ with yields of more than 95 percent. At $Na_{25}K_{75}$ diopside and phlogopite dom-

inated and reliable identification was impossible. Pure potassic-edenite was grown from a single run at 750°C, 0.5 kbar. This amphibole was less than 5 percent of the run product, but X-ray and electron-microscope identification was "without any doubt" according to Hinrichsen and Schürmann. Cell dimensions are given for pure edenite and the intermediate member, $Na_{50}K_{50}$. A rough value is given for potassic-edenite, calculated from an "extremely bad" X-ray pattern.

Greenwood (1979) was unable to synthesize 100 percent edenite. Attempts to duplicate the results of Colville et al. (1966) failed to grow amphibole without the presence of other phases, particularly diopside and soda montmorillonite. All experiments with edenite bulk composition whether crystalline, glass, or dry mix produced only minor amphibole. Amphiboles grown from edenite bulk composition were not characterized.

Oba (1980) reported the synthesis of edenite at 800°C and 2440 bar water pressure. Amphibole was claimed as the only phase in the run product besides vapour. The upper stability of edenite was determined to be 825°C at 1 kbar. No physical properties are given.

Ferro-edenite: $NaCa_2Fe^{2+}_5Si_7AlO_{22}(OH)_2$

Colville et al. (1966) claimed to have synthesized ferro-edenite from a dry mix reacted at 600°C, 3 kbar for 31 days. Oxygen fugacity was controlled on the IW buffer. Amphibole yields, and the abundance and nature of non-amphibole phases are not reported. Cell dimensions and refractive indices are given.

Loida and Hinrichsen (1975) synthesized edenitic hornblende and pargasitic hornblende with 100 percent yields at 800°C, 4 kbar; nominal compositions were $Na_{0.5}Ca_2Mg_4AlSi_{6.5}O_{22}(OH)_2$ and $Na_{0.75}Ca_2Mg_4AlSi_{6.25}Al_{1.75}O_{22}(OH)_2$ respectively. Cell dimensions are given (Table 7)

Fluor-edenite: $NaCa_2Mg_5Si_7AlO_{22}F_2$

Eitel (1952) grew fluor-amphibole by solid-state reaction at 1000°C for 15 h from mixes of fluor-edenite composition. Diopside, forsterite and fluorite were present in minor amounts. Increasing the fluorine concentration did not improve the yield. Fluor-amphiboles were also produced by cooling a melt of fluor-edenite composition from 1400° to 1200°C in 2 h. The crystallization of fluor-amphibole was greatly improved by increasing fluorine concentration, but diopside, forsterite, fluorite, NaF, and Na-phlogopite were also produced. The amphiboles grown in these experiments were not characterized.

Boyd (1954) claimed to have synthesized fluor-edenite in sealed Pt tubes at about 1000°C and 1 atm pressure. No physical properties are given.

Kohn and Comeforo (1955), using methods and materials similar to Comeforo and Kohn (1954), achieved at least 80 percent yields of fluor-edenite. Fractions of this material were beneficiated by heavy-liquid separation until the only contaminant was about 1-2 percent clinopyroxene, and about 0.5 percent others. The beneficiated material was chemically analysed and the calculated formula (including impurities) is:

$$Na_{0.99}Ca_{1.84}Na_{0.16}Mg_{4.79}Al_{0.18}Si_{7.12}Al_{0.88}O_{22}F_{2.85}$$

Cell dimensions and optical data are given (Table 6).

Boron-edenite was synthesized and characterized in the same way. Its chemical formula (including impurities less than 4 percent of which 3 percent is forsterite):

$$Na_{0.93}Ca_{1.87}Na_{0.13}Mg_{4.92}Si_{7.16}B_{0.92}O_{22}F_{2.10}$$

Pargasite...Ferro-pargasite: $NaCa_2(Mg,Fe)_4AlSi_6Al_2O_{22}(OH)_2$

Boyd (1954, 1956, 1959) determined the high-temperature stability relations of pargasite from dry starting mixes. Optical properties and cell dimensions are given in Colville et al. (1966) and Table 5. An X-ray powder diffractogram shows a prominent peak attributed by Boyd to nepheline plus diopside.

Gilbert (1969) synthesized pargasite at 800°C, 10 kbar, and 900°C, 20 kbar from dry mix. Clinopyroxene was also present. Reaction of pargasite plus clinopyroxene at 800°C and 20 kbar apparently decreased the amount of clinopyroxene, which is indicated as being metastable in the run table. No amphibole was observed after reacting pargasite plus clinopyroxene between 28.2 and 38.7 kbar. Physical properties and yields are not reported.

Gilbert (1965, 1966) studied the stability relations of ferro-pargasite as a function of oxygen fugacity, temperature, and fluid pressure. Starting materials were either dry mixes, or minerals synthesized from these mixes. The largest crystals, 20 to 30 microns long, were obtained at temperatures of about 800°C on the IW and WM buffers. Crystals grown on the FMQ buffer at about 600°C averaged only 1 to 10 microns in length. At oxygen fugacities defined by more oxidizing buffers, and at lower temperatures, ferro-pargasite crystals were commonly full of in-

clusions of reaction products, making them difficult to characterize. Cell dimensions are given for ferro-pargasite synthesized on the IW, WM, FMQ, and NNO buffers (Table 5). X-ray powder diffraction data are given for those grown on the IW, WM, and FMQ buffers; cell dimensions were refined in this study from these data (Table 5). With increasing relative oxidation, the cell volume decreases, accompanied by decreases in a and β dimensions. The b and c cell dimensions do not show systematic variation. These changes suggest oxidation of some of the ferrous iron in the octahedral strip to smaller ferric iron.

Holloway (1973) synthesized pargasite from both dry mixes and gels. The fluid phase contained either pure H_2O, or CO_2 plus H_2O. Varying amounts of CO_2 in the system had no apparent effect on the cell parameters of pargasite. Cell dimensions are given for a pargasite grown with pure H_2O (Table 5). Amphibole yield is not stated, but pargasite was listed as the only phase present in this run product.

Holloway and Ford (1973, 1975, 1976) synthesized pargasite with 0.87 F atoms in the half-cell (43 mol percent fluorine). Fired gel plus CaF_2 were run with 10 percent by weight H_2O for 5 days at 1050°C. Amphibole yield was about 99 percent with minor clinopyroxene and spinel. Physical properties are not given.

Charles (1974a, 1980) synthesized pargasite in a study of amphiboles across the join $NaCa_2Mg_4AlSi_6Al_2O_{22}(OH)_2$ - $NaCa_2Fe_4AlSi_6Al_2O_{22}(OH)_2$ at 1 to 5 kbar. Starting mixes were of the dry type, consisting of MgO, γ-Al_2O_3, MgO, SiO_2 (cristobalite) and $Na_2Si_2O_5$. Pargasite yields varied from 60 to 99 percent but cell dimensions do not vary with yield. Non-

amphibole phases were mainly pyroxene and plagioclase. Charles (1980) suggests that either charges with low amphibole yield are non-stoichiometric pargasitic amphibole with cell dimensions fortuitously similar to those of purer charges, or more probably, the amphibole is on composition. Intermediate phases were grown on MH, FMQ, CCH_4, and IW buffers. Yields varied from 50 to 95 percent. For a given bulk composition, cell parameters are constant with pressure, temperature, and oxygen fugacity. Pyroxene and plagioclase were present in all products. Intermediate compositions did not nucleate well; amphiboles in these runs formed only as crystalline aggregates about 5 microns in diameter. Variation of unit cell parameters is linear with changing Fe/Mg ratio. Charles (1980) concludes that this indicates disorder of Mg and Fe in M(1), M(2) and M(3) sites. Ferro-pargasite crystallized with yields of 90 to 95 percent. Cell dimensions do not change with run conditions.

Droll and Seck (1976) synthesized the solid solution series pargasite - fluor-pargasite from oxide mixes at 2 kbar according to the text of the paper, but at 1 kbar according to the title. The H_2O/HF ratio was determined during long runs by means of an ion-selective F-electrode. Substitution of (OH) by F increased the a cell dimension from 9.81 to 9.88 in fluor-pargasite. This is contrary to other pargasite...fluor-pargasite pairs and to experience with the same substitution in other amphiboles, in which a decreases from the OH to the F endmember.

Hinrichsen and Schürmann (1977) attempted the synthesis of certain members in the series $NaCa_2Mg_4AlSi_6Al_2O_{22}(OH)_2$ - $KCa_2Mg_4AlSi_6Al_2O_{22}(OH)_2$ from dry mixes. Pargasites were successfully synthesized only in the composition range from $Na_{100}K_0$ to $Na_{50}K_{50}$ at temperatures from 750° to

1000°C, and pressures from 1 to 4 kbar. Yields of amphibole were greater than 95 percent. Cell dimensions are given for the compositions $Na_{100}K_0$ and $Na_{50}K_{50}$ (Tables 5 and 7). Substitution of K for Na produced a slight increase in all cell dimensions.

Braue and Seck (1977) studied the stability of solid solutions on the join pargasite - richterite at 1 kbar water vapour pressure. Dry starting mixes were used. An almost complete solid solution series on the join was synthesized at total H_2O pressure of 1 and 3 kbar and temperatures of 850° and 900°C respectively. Satisfactory synthesis of amphibole was not possible at 850° and 900°C at 1 kbar on the composition $pa_{50}ri_{50}$. Amphibole yields were close to 100 percent at 3 kbar with minor amounts of metastable diopside, clinopyroxene and forsterite. At 1 kbar, however, experiments were complicated by a smectite phase which persisted metastably to 950°C. This sheet silicate is characterized by a basal reflection at 11.6 Å which expands slowly to 14.4 Å in a hydrous atmosphere. Treatment with organic liquids do not cause further expansion. Braue and Seck (1977) conclude that this sheet silicate is a trioctahedral vermiculite. Reheating the 14.4 Å phase reproduced the 11.6 Å phase, and increasing the temperature to 750°C finally yielded a broad peak at 9 to 10 Å. Quenching immediately after initial run-up to 850°C suggests that this phase forms primarily during the heating-up period. This conclusion is reinforced by the presence of vermiculite in pressure-quenched runs. Conditions for the growth of this phase are apparently most favourable on the bulk composition $pa_{50}ri_{50}$; none was observed in richterite-rich compositions. Two different amphiboles were synthesized in this study. The first, amp I(ss), coexists with vapour

in the subsolidus region with minor metastable diopsidic clinopyroxene and forsterite. The second, amp II(ss), is produced at the solidus defined by the reaction:

amp I(ss) + vapour = amp II(ss) + cpx + fo + liquid + vapour

No feldspar or nepheline were detected either optically or by X-ray diffraction. Cell dimensions are given for endmember pargasite and richterite, as well as for intermediate amp I(ss). (Tables 5 and 7). Cell volume, a, b, and β vary smoothly but show positive deviations from linearity. Variation in c is small compared to the standard error; it decreases with increasing richterite component in the solid solution.

Westrich (1978) and Westrich and Holloway (1981) synthesized pargasite from anyhydrous gel prepared after Hamilton and Henderson (1968). The gel was crystallized hydrothermally at 1205°C and 4 kbar water vapour pressure for 72 h. Amphibole yield was greater than 96 percent; cell dimensions are given (Table 5).

Oba (1980) synthesized pargasite in study of the tremolite - pargasite join at 1 and 5 kbar in the temperature range 750° to 1150°C. Starting materials, method and results were discussed above in the tremolite section. Pargasite yields are not explicitly stated but amphibole is listed as the sole phase in the pargasite stability field. Although electron microprobe analyses are given for amphibole solid solutions, no single phase endmembers were analysed. Cell dimensions are given (Table 5).

Semet (1972, 1973) synthesized pargasite at 800°C and 2 kbar. Except for the infrared spectrum, no physical properties are reported. The

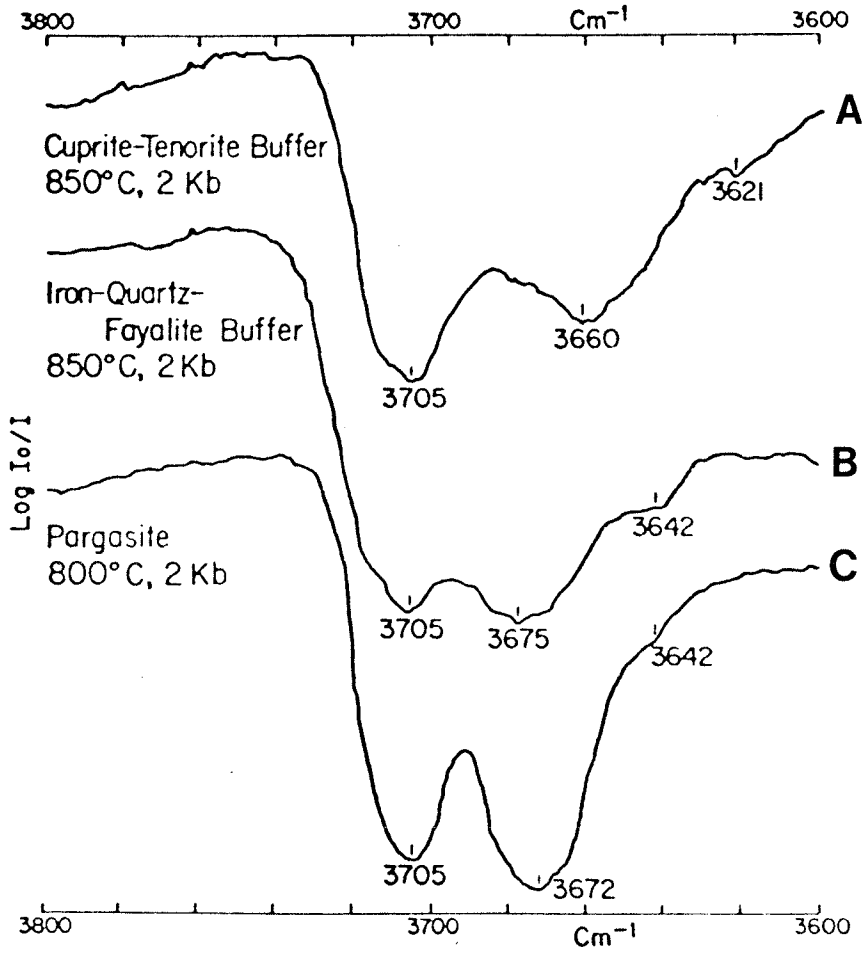

Figure 3: Infrared spectrum of synthetic magnesio-hastingsite and pargasite. A: magnesio-hastingsite. B: magnesio-hastingsite. C: pargasite. From Semet (1972).

spectrum consists of two major peaks at 3705 cm^{-1} (MgMgMg-OH) and 3672 cm^{-1} (MgMgAl-OH), and a minor peak at 3642 cm^{-1} (MgAlAl-OH) (Figure 3). Al occupancy of M(1) and M(3) calculated from this spectrum is 0.23±0.05 ions per site, indentical within error to the ideal 0.20 ions per site for completely random distribution of Mg and Al among the octahedral sites (Semet 1973).

Fluor-pargasite: $NaCa_2Mg_4AlSi_6Al_2O_{22}F_2$

Boyd (1954) reported the first synthesis of fluor-pargasite from charges sealed in Pt tubes and reacted at temperatures a little over 1000°C. Yields were not 100 percent; fluor-amphiboles grown were always mixed with other phases.

Holloway and Ford (1973, 1975, 1976) studied the phase relations of a pargasite with 43 percent of OH at the O(3) site replaced with F. F was added as CaF_2 to a fired gel. Amphibole yield was 99 percent with minor clinopyroxene and spinel. No physical properties are given.

Droll and Seck (1976) give the a-cell dimension of a fluor-pargasite grown during a study of the pargasite...fluor-pargasite join. No other data were reported.

Westrich (1978) and Westrich and Navrotsky (1981) synthesized fluor-pargasite from a gel with F added as CaF_2. The mix was reacted at 1000°C and 1 atm for 24 h. Grain size of the resulting amphibole was less than 5 microns; other phases constituted 1 to 2 percent of the run product. Cell dimensions are given (Table 6).

Alumino-magnesio-hornblende: $^{\square}Ca_2Mg_4AlSi_7AlO_{22}(OH)_2$

Boyd (1954) reported that a glass with composition midway on the tremolite...alumino-tschermakite join (alumino-magnesio-hornblende) was almost completely crystallized to amphibole at 800°C and 10 kbar pressure. No physical properties are given.

Gilbert (1969) attempted to synthesize alumino-magnesio-hornblende from glass (probably the same glass as used by Boyd 1954) at 800° and 900°C and 10 kbar. Run products were dominantly amphibole with minor clinopyroxene, orthopyroxene, and garnet. At 700°C and 20 kbar, less amphibole was produced and talc is present. No physical properties or yields are given.

Jasmund and Schäfer (1972) apparently synthesized alumino-magnesio-hornblende on the join tremolite...alumino-tschermakite. 100 percent yields are implied by symbols on the 2 and 3 kbar phase diagrams, but the 1 kbar phase diagram appears to be in error; the symbols do not appear in the key. If the symbols are what they appear to be, the alumino-magnesio-hornblende yields at 1 kbar are generally not 100 percent. No physical properties are given. X-ray diffractograms are given for compositions along the join but none are for run products in the amphibole stability regions.

Fluor-alumino-magnesio-hornblende: $^{\square}Ca_2Mg_4AlSi_7AlO_{22}F_2$

Shell et al. (1958) crystallized a melt at 1 atm with composition corresponding to fluor-alumino-magnesio-hornblende. They found that with low fluoride content, the aluminum tends to combine with calcium and silicon to form anorthite. As fluoride content increased, Ca-phlogopite grew at

the expense of amphibole. Although amphibole was apparently present, no estimates of abundance are given.

Alumino-tschermakite: $\square Ca_2Mg_3Al_2Si_6Al_2O_{22}(OH)_2$

Alumino-tschermakite synthesis was first attempted by Boyd (1954). All hydrothermal experiments at pressures less than 2 kbar failed. At 800°C and 10 kbar, however, a glass of alumino-tschermakite composition was partly crystallized to amphibole. No physical properties are reported.

Gilbert (1969) reported the synthesis of 85 to 90 percent amphibole from a glass of alumino-tschermakite composition at 800°C and 10 kbar. It was tentatively identified as tschermakite, but no supporting physical properties are given.

Jasmund and Schäfer (1972) studied the join tremolite - alumino-tschermakite (see Tremolite section). They were unable to synthesize amphibole on the composition of alumino-tschermakite at 3 kbar or less. A reconnaissance run at 10 kbar also failed to yield amphibole.

The most comprehensive survey of synthetic alumino-tschermakite is by Oba (1978), who studied the alumino-tschermakite - ferri-tschermakite join at temperatures between 750° and 1000°C at water pressures of 5 to 24 kbar. Run products were characterized by X-ray diffraction, optical examination and by microprobe analysis for two compositions in equilibrium with garnet. No endmembers were analysed. Refractive indices and cell dimensions are given. Although 100 percent amphibole yields are implied for several products in his run table, yields are not explicitly reported. The amphiboles in equilibrium with garnet are not on composi-

tion; they are deficient in octahedral aluminum and contain excess magnesium.

Fluor-alumino-tschermakite: $\square Ca_2Mg_3Al_2Si_6Al_2O_{22}F_2$

Boyd (1954) reported the synthesis of fluor-alumino-tschermakite by solid state reaction in sealed Pt tubes at 1000°C and 1 atm pressure. No physical properties are given.

Shell et al. (1958) attempted to grow fluor-alumino-tschermakite from a melt. No amphibole was obtained; the product was Ca-bearing mica and anorthite.

Hastingsite: $NaCa_2Fe^{2+}_4Fe^{3+}Si_6Al_2O_{22}(OH)_2$

Colville et al. (1966) claimed hastingsite synthesis at 600°C and 3 kbar on the FMQ buffer. Run length was 31 days. Run procedure and starting materials were the same as those of Ernst (1960). No information is presented concerning amphibole yield or the nature of the run product. Cell dimensions and refractive indices are given.

Malinovskiy (1966) reacted a dry mix of hastingsite composition plus excess iron hydroxide in a neutral 10 to 12 percent solution of sodium chloride at 500° to 600°C and about 500 atm. Clinopyroxene is the main product along with about 10 to 15 percent amphibole. More amphibole crystallized from a mix with non-stoichiometric composition, $CaO:Al_2O_3:SiO_2$ = 10:22.5:67.5. Such a mixture, reacted in NaCl solution with excess iron, produced amphibole plus magnetite. The amphibole formed intensly pleochroic, green, acicular and elongated prisms up to 1 to 1.5mm long. A powder X-ray pattern and refractive indices are given.

Chemical analyses of two of the amphiboles showed that they contain 0.86 and 0.78 percent Cl respectively. The relative error in these analyses is 15 percent. The amphibole composition corresponds to an intermediate member of the hastingsite...ferro-edenite series.

Gilbert (1969) determined that hastingsite is not stable at T >650°C at 20 kbar, or at T >700°C at 12 kbar when oxygen fugacity was controlled by the FFsM buffer. On the FMQ buffer, hastingsite is not stable above 750°C at 12 kbar. No physical properties of the synthetic amphibole are given.

Thomas (1977, 1979, 1982a, 1982b) studied the upper thermal stability of hastingsite as a function of temperature, fluid pressure and oxygen fugacity. Starting materials for synthesis runs comprised dry mixtures or gels of anhydrous hastingsite composition. Run products were characterized optically and by X-ray powder diffraction. Cell dimensions (Table 5) and Mössbauer spectra (Figure 20) are given for selected samples. Synthetic hastingsite formed acicular grains less than 10 microns long and about 1 to 4 microns wide. Amphibole yields in the IQF, IW and WM buffers were generally greater than 95 percent, but on the FMQ buffer, yields were less. Thomas (1979) is confident that the hastingsites are on composition because cell parameters are similar for all hastingsites synthesized, proportions of breakdown phases are qualitatively similar in all runs, and high yields from mixes of the proper stoichiometry should be of the nominal composition.

Charles (1978) studied the stability of the hastingsite bulk composition on the IW, CCH_4, FMQ, NNO, and MH buffers. Amphibole yields were

95 percent on the CCH_4 and FMQ buffers; impurities were clinopyroxene and plagioclase. Cell dimensions are uniform, regardless of temperature or buffer conditions.

Magnesio-hastingsite: $NaCa_2Mg_4Fe^{3+}Si_6Al_2O_{22}(OH)_2$

Semet (1970, 1972, 1973) and Semet and Ernst (1981) studied the stability relations and crystal chemistry of magnesio-hastingsite synthesized from dry mixes at 850°C and 2 kbar pressure. They measured optical properties, cell dimensions (Table 5), collected Mössbauer (Figure 21) and infrared spectra (Figure 3), and give two electron microprobe analyses of the synthetic amphibole (Table 2). Yields of 90 to 100 percent amphibole are claimed for initial syntheses. At low oxygen fugacities, however, up to 10 percent by volume of high-temperature breakdown phases of equivalent composition was present. Amphibole synthesized directly from the dry mix is very fine grained (10 x 5 x 5 microns); long runs did not produce larger crystals. Larger crystals (100 x 20 x 20 microns) were synthesized from the high-temperature assemblage of equivalent bulk composition. Semet notes a significant variation in both colour and refractive indices with oxygen fugacity, that is, with changes in the valence of iron.

Electron microprobe analyses of an amphibole grown on the CT buffer and one grown on the IQF buffer show that both amphiboles are close to theoretical magnesio-hastingsite bulk composition. Only the amphibole synthesized on the CT buffer, however, contains no ferrous iron; the others deviate markedly from the ideal composition.

TABLE 2

Electron microprobe analyses of synthetic magnesio-hastingsites

	1	2	3
SiO_2	42.08	41.8	41.2
Al_2O_3	11.90	12.1	11.6
FeO	8.39	8.4	8.5
MgO	18.32	19.1	18.5
CaO	13.09	13.2	12.9
Na_2O	3.62	3.5	3.5
H_2O	2.10	2.1†	2.1†

from Semet (1973)
1. Ideal magnesio-hastingsite, all Fe as FeO.
2. A3-11T, 850°C, 2 kbar, CT buffer.
3. A4-11C, 850°C, 2 kbar, IQF buffer.
† Ideal H_2O, column 1.

Colville et al. (1966) synthesized magnesio-hastingsite on the MH buffer at 850°C and 2 kbar. Refractive indices and cell dimensions are given (Table 5). Large standard errors in the cell dimension calculations preclude useful comparison with Semet's (1973) results for the MH buffer, although both sets of data are reasonably consistent. Because the MH buffer was used, this amphibole must contain some ferrous iron and cannot be endmember magnesio-hastingsite.

SODIC-CALCIC AMPHIBOLES

Richterite: $NaCaNaMg_5Si_8O_{22}(OH)_2$

Huebner and Papike (1970) synthesized the complete series of solid solutions along the join $NaCaNaMg_5Si_8O_{22}(OH)_2$ - $KCaNaMg_5Si_8O_{22}(OH)_2$ from dry mixes. Run conditions were between 732° and 916°C., 1 and 2 kbar.

Richterite grew euhedral crystals bounded by equant to slightly elongate stubby pinacoids up to 50 microns long. Microscopic examination showed that amphibole yields were 98 to 100 percent; when present, other phases were diopside and glass. Cell dimensions are given for all amphiboles on the join (Tables 5 and 7).

Cell dimensions of intermediate compositions on the join show little deviation from linearity between endmembers. Only runs with yields equal to or greater than 98 percent were used to calculate these data. The a, β and V parameters decrease markedly from potassium-richterite to richterite; b and c decrease only slightly.

A mix of bulk composition corresponding to potassium-ferro-richterite was reacted at 601°C., 1 kbar on the CCH_4 buffer; the amphibole yield is not given, but green and brown clinopyroxene were present. At these conditions, the oxygen fugacity is approximately intermediate to that of the FMQ and WM solid buffers. This means that Fe^{3+} must be present and the amphibole is not on composition. Cell dimensions are given (Table 5).

Makarova et al. (1971) synthesized richterite from alkaline media comprising oxides, hydroxides, carbonates, and amorphous silica. Amphibole yields were 95 to 98 percent. Refractive indices are given (Table 5). Grigor'eva et al. (1975b) give the analyzed chemical formula of this richterite as:

$$Na_{1.86}Ca_{1.05}H_{0.14}Mg_{4.90}Si_8O_{22}(OH)_2$$

Cell dimensions are also given (Table 5).

Forbes (1971) synthesized richterite hydrothermally from a mixture of Na_2CO_3, CaO, MgO, and SiO_2. He states that carbonate-free mixes do not differ in result from those with carbonate. Above 650°C., runs of 24 h duration yielded 90 to 95 percent amphibole with minor unreacted mix, forsterite and diopside; 100 percent richterite was obtained in longer runs. Cell dimensions and optical properties are given (Table 5); cell dimensions do not vary with changing pressure and temperature.

Charles (1972a,b, 1974b, 1975, 1977) grew richterite, ferro-richterite and intermediate compositions on the join between the endmembers from dry mixes. Oxygen fugacity was controlled in Fe-bearing runs on the IW, WM, CCH_4, FMQ, NNO, and MH buffers. Experiments at 800°C and 1 kbar of 2 day's duration produced 98 to 100 percent amphibole from the endmember richterite composition. Fe-bearing amphibole grew most readily on the IW buffer. 20 to 30 percent clinopyroxene was present in compositions containing more iron than Mg_3Fe_2 on buffers more oxidizing than IW. For compositions Mg_4Fe through Mg_2Fe_3, experiments on the IW buffer at 500° to 550°C produced >95 percent amphibole with minor pyroxene, olivine and glass. Amphibole with $MgFe_4$ composition was difficult to grow at less than 5 kbar. End-member ferro-richterite (Type II) grew with >95 percent yield at 500° to 550°C in long runs (22 to 30 days). Minor clinopyroxene, olivine and glass was present. Although shorter experiments (about 10 days) at higher temperatures (600° to 700°C) produced less amphibole (Type I, about 90 percent), its cell volume is much larger than that of the long-term product; it is probably less oxidized and closer to the nominal compostion.

Cell dimensions and optical properties are given for representative runs on all buffers; the parameters on the IW buffer are probably close to the nominal composition. End-member richterite apparently has a low stability limit with respect to pressure. Cell parameters trend towards tremolite with increasing pressure (Charles 1974). However, amphiboles containing iron show no variation in cell parameters. Charles (1974) examined the cell dimensions of amphiboles grown on the IW buffer most closely because this buffer produces the highest amphibole yields; thus these amphiboles are closest to the nominal compositions. Parameters $\underline{a}$, $\underline{c}$, and $\underline{a}\sin\beta$ increase almost linearly from Mg_5 to $MgFe_4$, while β decreases; the values for $\underline{b}$ are slightly below the line for Mg_4Fe, Mg_3Fe_2 and Mg_2Fe_3.

Hariya and Terada (1973) synthesized amphibole with the composition $richterite_{50}$ - $tremolite_{50}$ from quartz, MgO, $CaCO_3$, and $Na_2Si_2O_5$ at high pressures. Water content in the capsules was from 5 to 10 percent by weight. Cell dimensions are given for an amphibole grown at 900°C and 29 kbar; the run table lists amphibole as the only phase in the product. The crystals average 0.07 mm long, show no plechroism and are almost colourless.

Braue and Seck (1977) studied the stability of solid solutions on the join pargasite-richterite at 1 kbar (see pargasite section for details). Cell dimensions are given for the endmember richterite (Table 5).

Westrich (1978) claimed hydrothermal synthesis of richterite from anhydrous gel at 950°C and 4 kbar. The run product contains less than 4 percent non-amphibole phases. Cell dimensions are given (Table 5); $\underline{V}$ and $\underline{a}$ are less than those of other synthetic richterites.

Phillips and Rowbotham (1968) synthesized richterite from gels at 750° to 1000°C and 1 to 5 kbar. Crystals are prismatic, occasionally twinned, and vary in size from 20 x 50 microns to 70 x 200 microns. Cell dimensions given by Philips and Rowbotham are incorrect; they were recalculated from the X-ray pattern using CELREF (Table 5).

Potassium Richterite: $KCaNaMg_5Si_8O_{22}(OH)_2$

Heubner and Papike (1970) synthesized potassium richterite in their study of the richterite...potassium-richterite join. The results are reported in the previous section.

Fluor-richterite: $NaCaNaMg_5Si_8O_{22}F_2$

Eitel (1952) reacted a dry mix of fluor-richterite composition at 1000°C, 1 atm, and formed fluorine amphibole as the major phase with minor forsterite, MgF_2 and CaF_2. In melt crystallization, increasing fluorine concentration reduces amphibole yields and produces Na-phlogopite.

Shell et al. (1958) synthesized numerous endmembers based on the fluor-richterite bulk composition (experimental details are given in the tremolite section). In addition to synthesizing normal fluor-richterite, the following substitutions were attempted: Ba, Cd, Co, Mn, and Sr for Ca, and Co, Fe, Cu, Mn, Ni, and Zn for Mg. Amphibole grew from most of these compositions, but yields were generally low and they were not characterized. Fluor-richterite yield was about 80 percent; it was characterized by Kohn and Comeforo (1955). Beneficiated samples with less than 1 percent impurities have chemical compositions close to the

ideal. Optical properties and cell dimensions (Table 6), and powder X-ray pattern are given.

Huebner and Papike (1970) synthesized fluor-richterite and fluor-potassium-richterite endmembers at 1 atm from dry mixes sealed in Pt capsules. The charges were heated above the melting point to 1200°C and then cooled to 800°C over a period of 9 days. One charge was reacted at 818°C, 2 kbar for 39 days. Amphibole yields are not given; run products are mainly amphibole with minor glass and diopside. Cell dimensions are given (Table 6).

Cameron et al. (1973a, b) and Cameron et al. (1983) refined the crystal structures of both of these amphiboles at room and higher temperatures. Cell dimensions determined from the single-crystal structure refinements are slightly lower than those of Huebner and Papike (1970) (Table 6).

Cameron (1970) and Cameron and Gibbs (1971) synthesized fluor-richterite from a dry mix at 1 atm by cooling at $5°Ch^{-1}$ from 1170° to 1000°C. Cell dimensions are given (Table 6). They also synthesized fluor-richterite with $Mg/(Mg+Fe^{2+}) = 0.67$. The Fe-bearing fluor-richterite was cooled at $5°Ch^{-1}$ from 1050° to 880°C with a metallic iron buffer. Amphibole yield was less than 100 percent; the composition was determined by electron microprobe. Crystals were up to 4 mm in length. Cell dimensions are given (Table 7). Single-crystal structure refinements were done on both amphiboles (see Chapter 6).

Westrich (1978) claimed fluor-richterite synthesis from anhydrous gels at 1000°C and 4 kbar pressure. Fluorine was added as dilute (5

percent by volume) hydrofluoric acid. Cell dimensions of the amphibole produced, however, are very different from those of other synthetic fluor-richterites (Table 6). Fluor-tremolite cell dimensions given in this study are also peculiar. These are the only fluor-amphiboles grown with HF rather than fluoride as a fluorine source, and it is possible that the use of HF was responsible for the anomalies (see fluor-tremolite section).

Magnesio-alumino-taramite: $^{\square}NaCaNaMg_3Al_2Si_6Al_2(OH)_2$

Phillips and Rowbotham (1968) attempted magnesio-alumino-taramite synthesis from gels at temperatures between 750° to 1000°C and pressures between 1 to 5 kbar with runs 18 to 192 h long. Only anthophyllite, a talc-like mineral, and sodium-calcium montmorillonite were formed.

ALKALI AMPHIBOLES

Glaucophane: $^{\square}Na_2Mg_3Al_2Si_8O_{22}(OH)_2$

Boyd (1955) reported reconnaissance runs on glaucophane bulk composition that yielded mixtures of amphibole and albite at 750° to 825°C and 500 to 1000 bar pressure. Boyd states that this amphibole has refractive indices, X-ray pattern, and extinction angle close to natural glaucophane, but the data are not given. Forsterite and enstatite, which are expected breakdown products along with albite, were apparently absent. Thus, the amphibole cannot be glaucophane in composition.

From glaucophane bulk composition, Ernst (1957) synthesized an amphibole whose upper stability limit is 20° to 80°C lower than that of magnesio-riebeckite. High-temperature assemblages included forsterite, albite, enstatite(?), liquid and vapour.

Ernst (1958a) presents preliminary P-T stability data for amphibole grown from the bulk composition $^{\text{m}}Na_2Mg_3Al_2Si_8O_{22}(OH)_2$ up to 2000 bar vapour pressure. He concludes that glaucophane is not itself a high-pressure mineral, but can exist over a wide P-T range depending on the bulk composition. Physical properties are not given.

Ernst (1959) reports the results of reconnaissance runs on the glaucophane composition at 600° to 800°C and 20 to 30 kbar pressure. He suggests that two polymorphs of glaucophane may exist because the cell dimensions of this high-pressure phase are appreciably smaller than those of the low-pressure phase (Ernst 1958b). Amphibole grown at 700°C and 20 kbar apparently recrystallizes at 800°C and 1000 bar to the form with the larger unit cell. Cell dimensions of both phases are given (Table 5) but no other experimental results are presented.

Ernst (1961) summarized the above work and gives prevously unpublished physical properties and experimental technique. Two starting compositions were used, (1) $Na_2O \cdot 3MgO \cdot Al_2O_3 \cdot 8SiO_2$ + excess H_2O (glaucophane + vapour), and (2) $Na_2O \cdot 3MgO \cdot Al_2O_3 \cdot 10SiO_2$ + excess H_2O (quartz + glaucophane + vapour = talc + albite + vapour). Starting materials comprised dry mixes, glasses of the above two compositions, mixtures of talc and Amelia albite in proportions corresponding to composition (2) above, and synthetic enstatite and Amelia albite in the proportion $Na_2O \cdot 3MgO \cdot Al_2O_3 \cdot 9SiO_2$. Amphibole yields range from less than 1 percent of the condensed assemblage to over 70 percent; 10 to 20 percent is typical. Grain size is about 20 to 40 microns by 1 to 3 microns. Other phases are the equivalent high-temperature assemblages (metastable).

Optical properties do not vary over a wide range of temperature and pressure and amphibole grown from the equivalent high-temperature assemblage is indistinguishable from that grown from dry mix or glass. For a temperature range of 625° to 862°C and pressure range of 175 to 2500 bar, α varies between 1.594 and 1.596; γ varies between 1.618 and 1.621. The same set of cell dimensions reported in Ernst (1959) is given (Table 5). Ernst concludes that neither high pressure nor differential stress is required for the stable existence of glaucophane.

Ernst (1963) presents the variation of cell dimensions of alkali amphiboles as a function of temperature, pressure and composition. The composition of these amphiboles is not well-documented. Only part of the charge was crystallized to amphibole and variable amounts of the high-temperature anhydrous assemblages of equivalent bulk composition are present. He concluded that glaucophane occurs as two polymorphs, because amphibole grown from glaucophane bulk composition at low pressure has a unit cell volume more than two percent greater than natural glaucophane, whereas that grown at high pressure had volume comparable to that of natural glaucophane (see Chapter 6).

Carman (1974) synthesized amphibole, presumed to be glaucophane, with 90 percent yield. Run conditions were 800°C at 25 kbar. No physical properties were given.

Gilbert and Popp (1973) reported glaucophane synthesis at 750°C and 25 kbar. The cell dimensions of this amphibole are among the smallest recorded for synthetic amphiboles of presumed glaucophane composition (Table 5). They consider this to represent nearly fully ordered material.

Maresch (1973, 1974, 1977) reviewed the evolution of experimental work on glaucophane. He criticized the concept of polymorphism proposed originally by Ernst (1963) and concluded that an amphibole of glaucophane composition had never been synthesized. Maresch (1973) synthesized an amphibole with greater than 80 percent yield on the glaucophane composition; it had cell dimensions (Table 5) which at the time were closest to extrapolated natural iron-free glaucophane (Borg 1967: $\underline{a}$=9.50, $\underline{b}$=17.67, $\underline{c}$=5.29 Å, β=103.720, V=864 Å^3). However, because jadeite and quartz were always present he suggested that the amphibole composition was displaced towards anthophyllite and was not on the glaucophane composition. Koons (1982) examined the behaviour of amphibole in the system

$$Na_2O\text{-}MgO\text{-}Al_2O_3\text{-}SiO_2\text{-}H_2O$$

and its relationships with sodium mica at high pressures. He found that C2/m amphibole approaching glaucophane composition exists only in water undersaturated systems. In the pressure interval 18 to 24 kbar at 700°C, it coexists with quartz on the glaucophane composition. Thus, it must be displaced from the nominal glaucophane composition by substitution of $Na^{A}Al^{IV}$ for Si and $Mg^{M4}\ Mg^{M2}$ for $Na^{M4}\ Al^{M2}$ Koons (1982). Cell dimensions are given (Table 5). An electron microprobe analysis is given but it is of poor quality. Transmission electron microscopy on this amphibole by M. Carpenter shows the amphibole to be well-crystallized C2/m amphibole with 8.9 Å repeat spacings of the (020) planes. Rare 14 Å repeats of (020) planes were found, which are consistent with the presence of occasional, triple-chain multiplicity faults. Thus, this amphibole has many fewer stacking defects than have been reported in other synthetic amphiboles (Maresch and Czank 1981, 1983; G. Skippen, pers. comm. to P. Koons.).

Carman and Gilbert (1983) investigated glaucophane stability using gels, oxide-carbonate mixes, and various mineral mixtures. Products were examined optically, by X-ray diffraction, and certain amphiboles were analysed by electron microprobe. Grain sizes were generally less than 10 microns. Cell dimensions (Table 5) are given for four amphiboles of presumed glaucophane composition. Unfortunately, the electron microprobe analyses are unsatisfactory with totals of only 93 to 94 percent; however, high yields and chemographic reasons are given to substantiate virtually nominal compositions. The cell volumes are among the lowest obtained for any synthetic glaucophane study, and the amphiboles are probably close to glaucophane composition.

Ferro-glaucophane: $\square Na_2Fe^{2+}_3Al_2Si_8O_{22}(OH)_2$

Hoffmann (1972) synthesized amphibole of presumed ferro-glaucophane composition from seeded runs at 500°C, 5 kbar fluid pressure with oxygen fugacity defined by the WM buffer. Electron microprobe anayses are given to confirm nominal composition. They show that the synthetic amphibole is close to endmember ferro-glaucophane in composition. Because syntheses were done at oxygen fugacities corresponding to the WM buffer, there must be Fe^{3+} present. Cell dimensions (Table 7) are given.

Crossite: $\square Na_2Mg_{1.5}Fe^{2+}_{1.5}Al_{0.67}Fe^{3+}_{1.33}Si_8O_{22}(OH)_2$

Koslowski and Hinrichsen (1979) attempted to synthesize amphibole, intermediate to glaucophane and riebeckite, of the composition:

$$\square Na_2Mg_{1.5}Fe^{2+}_{1.5}Al_{0.67}Fe^{3+}_{1.33}Si_8O_{22}(OH)_2$$

Nearly 100 percent amphibole was obtained on the MH buffer at 700°C and 4 kbar H_2O pressure. Cell dimensions are given (Table 7). The amount

and distribution of Fe^{2+} and Fe^{3+} were determined by Mössbauer spectroscopy; the spectrum and details are not given.

Riebeckite: $\square Na_2Fe^{2+}_3Fe^{3+}_2Si_8O_{22}(OH)_2$

Tuttle and England (1953) report the synthesis of amphibole on the riebeckite composition at temperatures below 610°C and in runs with less than 3.9 percent water. No physical properties are given.

Ernst (1959, 1962) reports on the synthesis and stability relations of riebeckite and riebeckite-arfvedsonite solid solutions at conditions defined by the CCO, MH, NNO, FMQ, WM, IM, IW and IQF buffers. Forty-seven sets of cell dimensions (Tables 5, 7), optical properties and micrometric analyses of coexisting phases are given. He shows that as oxygen fugacity is decreased, the amphibole becomes more arfvedsonitic through progressive filling of the A-site. Cell volumes increase from about 912 $Å^3$ to about 918 $Å^3$ as the oxygen fugacity varies from conditions on the MH buffer to those prevailing near the lower limit of magnetite stability. A sharp jump in volume to about 930 $Å^3$ is noted at lower oxygen fugacities defined by the MW, IM and IW buffers. Ernst (1962) attributes this increase to the the replacement of tetrahedral Si by Fe^{3+}. This is not a plausible solution; tetrahedral Fe^{3+} has not been observed in any amphibole crystal-structure study (Hawthorne 1983b).

Magnesio-riebeckite: $^{B}Na_2Mg_3Fe^{3+}_2Si_8O_{22}(OH)_2$

Ernst (1958a, 1958b, 1960) studied the stability relations of magnesio-riebeckite at various oxygen fugacities. Cell dimensions are given for endmember magnesio-riebeckite, but the synthesis conditions are not given for the sample used (No. 125, Table 5). Refinement of the X-ray powder data given for this sample gave virtually identical results (No. 126, Table 5). Refinement of material provided by Ernst as part of the present study, however, gave markedly different results; cell volumes are consistently lower by about 9 $Å^3$ (No. 127-130, Table 5). Refinements using Lake Toxaway quartz from the original study as an internal standard, and BaF_2 from the present study, gave essentially identical results. The reason for this discrepancy is unknown. An infrared spectrum of material provided by Ernst (see Chapter 6) shows that the amphibole grown is not magnesio-riebeckite; it is probably towards magnesio-arfvedsonite in composition.

Eckermannite: $NaNa_2Mg_4AlSi_8O_{22}(OH)_2$

Phillips and Rowbotham (1968) grew an amphibole presumed to be eckermannite coexisting with a talc-like mineral from gels of eckermannite compositon at 770 to 1000°C and 1 to 5 kbar. Maximum grain size was 20x3 microns; length averages about 10 microns. Because of the presence of the talc-like mineral, they admit that the exact composition is uncertain. Cell dimensions (Table 5) of this amphibole are almost identical to those of sodian magnesio-cummingtonite. Refinement of cell dimensions from the powder X-ray data in their paper, however, gives very different results (No. 145, Table 5). It is not known whether the cell dimensions are incorrect, or whether the wrong pattern is given. Note that the same problem was noted with their richterite cell dimensions.

Nyböite: $NaNa_2Mg_3Al_2Si_7AlO_{22}(OH)_2$

Phillips and Rowbotham (1968) failed to grow amphibole on the nyböite composition at 750 to 1000°C and 1 to 5 kbar. Sodic montmorillonite was the only phase.

Carman and Gilbert (1983) synthesized amphiboles apparently near nyböite in composition with yields of about 90 percent. Syntheses were performed at 900 and 980°C, and 25 and 33.6 kbar respectively. Cell dimensions are given (Table 5); note, however, that the bulk composition of No. 147 was that of glaucophane, while that of No. 146 was nyböite.

Alkali Fluor-amphiboles

Syntheses of alkali fluor-amphiboles are rare. Eitel (1952) attempted to synthesize fluor-eckermannite in the solid state at 1000 to 1100°C, but 100 percent yields were not obtained. Crystallization from a melt also produced extraneous phases in addition to amphibole. Physical properties are not given. Shell et al. (1958) reacted a fluor-eckermannite composition in the solid state at 1010°C and obtained fluor-amphibole, forsterite, clinoenstatite, MgF_2 and glass. Physical properties of the amphibole are not given.

Fedoseev and Chigareva (1964) reacted a mix of magnesio-fluor-arfvedsonite with excess NaF and NaCl plus sawdust and obtained close to 100 percent amphibole. Optical properties are given.

IRON-MAGNESIUM-MANGANESE AMPHIBOLES

Sodian magnesio-cummingtonite, sodian hydro-magnesio-cummingtonite: $NaMgNaMg_5Si_8O_{22}(OH)_2$, $NaNa_2Mg_5Si_8O_{21}(OH)(OH)_2$

Gier et al. (1964) synthesized a variety of amphiboles based on the sodian magnesio-cummingtionite and sodian hydro-magnesio-cummingtonite compositions (Table 3). Starting materials were prepared from solutions of 1 M $MgCl_2$, 2 M Na_2SiO_3, colloidal silica, and 1 M NaF (for fluor-amphibole). Substitutions for Mg were accomplished by replacing $MgCl_2$ with $CoCl_2$ or $NiCl_2$. The resulting gels were crystallized in sealed Pt capsules. Products comprised densely intertangled fibers with diameters of 0.1 to 3 microns and lengths up to 10 cm. All products were analyzed by X-ray powder diffractometry, but only the powder pattern and cell dimensions for the sodian hydro-magnesio-cummingtonite are given (Table 5). The β-angle is the same; the other parameters are smaller and give a volume that is 1.2 percent less than that given by Gier et al. (1964). Structural studies of the Co-amphibole (No. 3, Table 3) and the sodian fluor-magnesio-cummingtonite (No. 5, Table 3) by Prewitt (1963) and Gibbs and Prewitt (1968) show that Co occupies the M(1), M(2), M(3) and M(4) sites in sample No. 3, and that both amphiboles deviate somewhat from their ideal compositions. Cell dimensions are given in Prewitt (1963) for the Co-bearing amphibole and the fluor-amphibole (Table 5).

Schreyer and Seifert (1968) synthesized amphiboles in the system Na_2O - MgO - SiO_2 - H_2O at compositions on and between the endmembers $Na_2Mg_6Si_8O_{22}(OH)_2$ and $Na_4Mg_4Si_8O_{20}(OH)_2(OH)_2$. The endmembers were not characterized except for stability. $Na_2Mg_6Si_8O_{22}(OH)_2$ melts incongruently at 965±20°C and 1 kbar water pressure to forsterite, an osumilite-type phase, and liquid, whereas solid solutions towards the Na-rich

TABLE 3

Synthetic amphiboles based on the sodian magnesio-cummingtonite and sodian hydro-magnesio-cummingtonite endmember compositions

No.	Chemical Formula	Run Conditions T(°C)	P(atm)	t(h)
1.	$Na_{2.5}H_{1.5}Mg_5Si_8O_{22}(OH)_2$	700	3000	6
2.	$Na_{2.2}H_{0.6}Mg_{0.6}Mg_5Si_8O_{22}(OH)_2$	700	3000	6
3.	$Na_{2.44}H_{0.75}Co_{0.4}Co_5Si_8O_{22}(OH)_2$	575	2000	6
4.	$Na_{2.2}H_{0.2}Mg_{3.0}Co_{2.8}Si_8O_{22}(OH)_2$	700	3000	6
5.	$Na_{1.74}H_{0.55}Mg_{0.7}Mg_5Si_8O_{22}-(F_{1.27})(OH)_{0.73}$	700	3000	6

Gier et al. (1964)

endmember melt at successively lower temperatures. At 770±10°C, the Na-rich endmember melts to less Na-rich amphiboles plus liquid. It is not likely, however, that the Na-rich endmember was actually synthesized. Four sodium atoms in the formula unit imply that a sodium atom must occupy at least one of the M(1), M(2) or M(3) sites; sodium occupancy of the octahedral strip has not been documented by structure studies (Hawthorne 1983b).

Nesterchuk et al. (1968) synthesized a Co-rich analogue of sodian magnesio-cummingtonite with formula (by chemical analysis):

$$Na_{2.65}H_{0.23}Co_{5.43}Fe^{3+}_{0.06}Si_{7.98}O_{22}(OH)_2$$

High yields (98 percent) were obtained by the co-precipitation method, in which a solution of $CoSO_4$ was added in small amounts to a solution of $Na_2SiO_3 \cdot 9H_2O$ with continuous stirring. The resulting suspension of fine, dispersed particles was placed in a platinum crucible and reacted in an autoclave at 300° to 500°C, and at pressures of about 900 atm.

Run lengths varied between 10 and 168 h. The synthetic Co-bearing amphibole formed a pink, matted, fibrous mass with individual fibers up to 4 mm long and 4 to 5 microns thick.

Fedoseev et al. (1968a) synthesized a Ni analogue of sodian magnesio-cummingtonite with formula (by chemical analysis):

$$Na_{2.58}Ni_{5.65}Si_8O_{22}(OH)_2$$

Best results were obtained from starting materials comprising NaOH, $NiCl_2$ and SiO_2 in proportion to the amphibole stoichiometry governed by the reaction:

$$14NaOH + 6NiCl_2 + 8SiO_2 = Na_2Ni_6Si_8O_{22}(OH)_2 + 12NaCl$$

Solutions of the calculated amounts of NaOH and $NiCl_2$ were mixed with finely pulverized, amorphous SiO_2, and reacted at 450° to 500°C at pressures near 900 atm. The product consisted of a green, fibrous mass of amphibole with fibers up to 4 mm long and 0.015 to 0.1 microns thick. Refractive indices were measured. Attempts to refine the cell dimensions from the given X-ray powder data as part of this study failed; the refinement did not yield reasonable values. It seems that the published powder data are in error.

Fedoseev et al. (1968b) reported synthesis of sodian magnesio-cummingtonite, and nickel and cobalt analogues using similar techniques as in Nesterchuk et al. (1968) and Fedoseev et al. (1968a). The results for the Ni- and Co-amphiboles are the same data that were reported in Nesterchuk et al. (1968) and Fedoseev et al. (1968a). X-ray powder data for the sodian magnesio-cummingtonite of formula (by chemical analysis):

$$Na_{2.52}H_{0.23}Fe^{3+}_{0.02}Mg_{5.36}Si_8O_{22}(OH)_2$$

are given.

Witte et al. (1969) synthesized sodian magnesio-cummingtonite from glass of composition $Na_2O \cdot 6MgO \cdot 8SiO_2$ at 750° to 770°C and 1 kbar water pressure. Run lengths varied from 47 to 119 h. They also grew $Na_3Mg_5Si_8O_{21}(OH)(OH)_2$ from glass of composition $Na_2O \cdot 2MgO \cdot 4SiO_2$ at 500° to 600°C at 2 kbar water pressure. Run lengths varied from 44 to 117 h. Cell dimensions are given for both endmembers (Table 5).

Makarova et al. (1971) synthesized amphiboles based on the sodian magnesio-cummingtonite formula with all or part of the Mg replaced by Co^{2+} or Ni^{2+} (Table 4). Syntheses were done in alkaline media, similar to the methods used by Nesterchuk et al. (1968) and Fedoseev et al. (1968a, b). Optical properties are given. Cell dimensions (Table 5) and more precise chemical formulae (Table 4) for these amphiboles were

TABLE 4

Synthetic amphiboles based on the sodian magnesio-cummingtonite formula

No.	Formula	Synthesis T(°C)	m.p (°)
1.	$Na_{2.52}Ca_{1.05}H_{0.14}Mg_{5.36}Si_8O_{22}(OH)_2$	770-800	1180
2.	$Na_{2.65}H_{0.23}Co^{2+}_{5.34}Fe^{3+}_{0.06}Si_{7.98}O_{22}(OH)_2$	740-760	1075
3.	$Na_{2.65}Ni^{2+}_{5.65}Si_8O_{22}(OH)_2$	800-820	1200

Makarova et al. (1971)
formulae from Grigor'eva et al. (1975)

compiled by Grigor'eva et al. (1975). Makarova et al. (1972) reported the synthesis of Mn-bearing sodian magnesio-cummingtonite with formula (by chemical analysis):

$$Na_{2.32}Mn_{1.14}Mg_{4.44}Si_8O_{22}(OH)_2$$

The other syntheses presented in this paper, sodian magnesio-cummingtonite, Ni analogue and Co analogue, are the same ones described earlier (Fedoseev et al. 1968a, b, Nesterchuk et al. 1968). No physical properties are given.

Grebenshchikov et al. (1974) synthesized sodian magnesio-cummingtonites with two different habits depending on synthesis conditions. At 450° to 550°C and pressures above 750 atm under conditions of low NaOH concentrations, long fibers were grown. At 350° to 450°C and 250 to 750 atm with higher NaOH concentrations, "aveniform" or "bundle aggregates" of amphibole were formed. Cell dimensions are given in Table 5 for the two varieties.

Witte (1976) studied the stability of the endmembers sodian magnesio-cummingtonite, $NaMgNaMg_5Si_8O_{22}(OH)_2$, and sodian hydro-magnesio-cummingtonite in the system Na_2O - MgO - SiO_2 - H_2O. The Na-poor endmember becomes stable at 750°C, 350 bar and at 850°C, 550 bar. It breaks down at 955°C, 800 bar to forsterite + $Na_2Mg_5Si_{12}O_{30}$ + melt + H_2O. Above 800 bar water pressure, it reacts to forsterite + enstatite melt + H_2O at 990°C, 1 kbar, and 1130°C, 5 kbar. The Na-rich hydro-endmember displays a significantly lower thermal stability. It becomes stable at 550°C and 150 bar; between the points 610°C, 250 bar and 613°C, 300 bar it reacts to amphibole solid solution + $Na_2Mg_2Si_6O_{15}$ + melt + H_2O, and above 300 bar only to amphibole solid solution + melt + H_2O. Sodian hydro-magnesio-cummingtonite melts at 580°C, 5 kbar water pressure.

Sodian fluor-magnesio-cummingtonite: $NaMgNaMg_5Si_8O_{22}F_2$

Gibbs et al. (1962) synthesized sodian fluor-magnesio-cummingtonite both from a melt and by pneumatolysis from batch compositions containing excess fluoride. The product contained mostly acicular amphibole; the identity of other phases is not stated. Reagent grade NaF and Na_2CO_3, technical grade MgO and MgF_2 and -200 mesh quartz (99.9 percent SiO_2) were reacted in sealed graphite or Pt crucibles at 1250°C. After 2 h, the temperature was lowered to below the solidus at $10°Ch^{-1}$. Chemical analysis of the product shows good agreement with the nominal composition; cell dimensions and optical data are given (Table 6). Single crystal data are consistent with the space group I2/m.

Fedoseev et al. (1970) and Grigor'eva et al. (1973a,b) give cell dimensions and optical properties of sodian fluor-magnesio-cummingtonites (Table 6). Other syntheses by these workers of amphiboles based on this endmember composition were not reviewed in detail; cell dimensions are given in Table 6. Miscellaneous syntheses by others of amphiboles based on this endmember composition are listed in the additional bibliography of amphibole syntheses.

TABLE 5

Cell dimensions and optical properties of previously synthesized hydroxy-amphiboles: pure endmember compositions

A. Cell Dimensions

Ref.†	a (Å)	b (Å)	c (Å)	β (°)	V (Å³)
		Calcic Amphiboles			
		Tremolite			
		□$Ca_2Mg_5Si_8O_{22}(OH)_2$			
1.	9.833(5)	18.054(9)	5.268(4)	104.52(7)	905.3(10)
2.	9.801(3)	18.07(3)	5.284(2)	104.35(3)	905.4(3)
3.	9.828(3)	18.059(6)	5.276(3)	104.70(3)	905.8(4)
4.	9.822(2)	18.055(5)	5.277(2)	104.63(2)	905.4(4)
5.	9.873(10)	18.027(6)	5.250(7)	104.30(15)	905.4(8)
6.	9.814(6)	18.063(12)	5.275(3)	104.65(5)	904.6(7)
		Ferro-actinolite			
		□$Ca_2Fe^{2+}_5Si_8O_{22}(OH)_2$			
7.	9.95(1)	18.35(2)	5.30(1)	104.4(1)	937.5(20)
8.	9.98(1)	18.31(2)	5.32(1)	104.7(1)	940.7(20)
9.	9.98(1)	18.33(2)	5.29(1)	104.6(1)	937.6(20)
10.	9.98(1)	18.31(2)	5.31(1)	104.7(1)	939.4(20)
11.	9.98(1)	18.32(2)	5.32(1)	104.7(1)	941.4(20)
12.	9.97(1)	18.39(2)	5.28(1)	104.4(1)	938.1(20)
13.	9.98(1)	18.35(2)	5.30(1)	104.6(1)	939.0(20)
14.	9.96(1)	18.36(2)	5.30(1)	104.3(1)	938.7(20)
15.	9.97(1)	18.35(2)	5.30(1)	104.5(1)	937.7(20)
16.	9.97(1)	18.34(2)	5.30(1)	104.5(1)	937.5(20)
17.	9.97(1)	18.34(2)	5.30(1)	104.5(1)	938.2(20)
		Edenite			
		$NaCa_2Mg_5Si_7AlO_{22}(OH)_2$			
18.	9.911(11)	17.951(22)	5.310(5)	105.26(9)	911.4(2)
19.	9.853(15)	18.005(11)	5.236(15)	104.40(25)	899.8(10)
		Ferro-edenite			
		$NaCa_2Fe^{2+}_5Si_7AlO_{22}(OH)_2$			
20.	9.999(10)	18.217(11)	5.314(14)	105.50(17)	932.8(30)
		Pargasite			
		$NaCa_2Mg_4AlSi_6Al_2O_{22}(OH)_2$			
21.	9.906(10)	17.986(17)	5.265(8)	105.30(14)	904.7(19)
22.	9.914(3)	17.946(5)	5.282(5)	105.67(3)	904.9(7)
23.	9.896(2)	17.94(3)	5.279(3)	105.50(5)	903.2(3)

†Ref. corresponds to references at end of table.

Ref.	a (Å)	b (Å)	c (Å)	β (°)	V (Å^3)
24.	9.905(5)	17.956(7)	5.276(1)	105.70(2)	903.4(4)
25.	9.890(2)	17.930(5)	5.274(3)	105.54(2)	901.1(4)
26.	9.81				
27.	9.874(4)	17.904(10)	5.278(3)	105.43(4)	899.4(8)
28.	9.888(5)	17.943(7)	5.280(3)	105.55(2)	902.5(5)
29.	9.891(4)	17.932(6)	5.275(4)	105.50(7)	901.5(6)
30.	9.890(3)	17.935(6)	5.277(2)	105.53(2)	901.9(4)
31.	9.891(8)	17.953(22)	5.280(10)	105.63(12)	902.8(10)
32.	9.895(2)	17.939(5)	5.280(2)	105.57(3)	902.8(3)
33.	9.887(5)	17.940(14)	5.271(6)	105.52(7)	900.9(9)
34.	9.893(2)	17.941(5)	5.276(1)	105.55(1)	902.1(2)
35.	9.899(2)	17.946(3)	5.278(1)	105.58(1)	903.1(2)
36.	9.892(1)	17.941(2)	5.277(1)	105.55(2)	902.2(3)
		Ferro-pargasite			
		$NaCa_2Fe_4^{2+}AlSi_6Al_2O_{22}(OH)_2$			
37.	9.953(5)	18.152(3)	5.330(2)	105.27(3)	928.8(4)
38.	9.958(4)	18.149(7)	5.328(2)	105.30(5)	928.8(4)
39.	9.95(1)	18.14(2)	5.33(1)	105.3(1)	928.5
40.	9.94(1)	18.13(2)	5.33(1)	105.2(1)	927.0
41.	9.90(1)	18.13(2)	5.33(1)	105.1(1)	924.7
42.	9.91(1)	18.13(2)	5.34(1)	105.1(1)	925.4
43.	9.952(2)	18.128(4)	5.326(1)	105.30(2)	926.7(2)
44.	9.938(3)	18.119(6)	5.324(2)	105.22(2)	925.1
45.	9.890(2)	18.123(4)	5.334(1)	105.08(2)	923.1(2)
		Hastingsite			
		$NaCa_2Fe_4^{2+}Fe^{3+}Si_6Al_2O_{22}(OH)_2$			
46.	9.979(27)	18.152(63)	5.325(27)	105.20(34)	930.8(60)
47.	9.990(4)	18.213(10)	5.325(3)	103.25(3)	934.8(9)
48.	10.003(2)	18.184(4)	5.321(1)	105.33(2)	933.5(2)
49.	10.001(3)	18.191(3)	5.318(1)	105.31(2)	932.8(2)
50.	10.003(2)	18.181(2)	5.322(1)	105.33(2)	933.5(2)
51.	9.957(8)	18.184(2)	5.321(1)	105.13(1)	930.1(2)
52.	9.984(2)	18.162(4)	5.334(3)	105.25(3)	934.6(5)
53.	9.996(1)	18.181(3)	5.340(3)	105.25(3)	935.4(5)
54.	9.994(1)	18.174(4)	5.325(2)	105.33(2)	933.1(3)
55.	9.965(1)	18.196(2)	5.329(1)	105.09(2)	932.7(2)
56.	9.997(2)	18.179(5)	5.323(1)	105.34(2)	932.9(3)
		Magnesio-hastingsite			
		$NaCa_2Mg_4Fe^{3+}Si_6Al_2O_{22}(OH)_2$			
57.	9.925(15)	17.982(30)	5.289(11)	105.61(12)	909.1(260)
58.	9.928(2)	18.015(9)	5.282(3)	105.43(4)	910.7(8)
59.	9.930(5)	18.025(8)	5.290(4)	105.43(4)	912.0(10)
60.	9.933(2)	18.029(4)	5.293(1)	105.43(1)	913.0(5)

Ref.	a (Å)	b (Å)	c (Å)	β (°)	V (Å^3)
61.	9.932(2)	18.015(4)	5.289(1)	105.43(2)	912.2(3)
62.	9.933(1)	18.028(3)	5.297(1)	105.44(2)	914.3(3)
63.	9.926(5)	18.029(9)	5.297(4)	105.46(5)	913.7(8)
		Tschermakite			
		$^{\square}Ca_2Mg_3Al_2Si_6Al_2O_{22}(OH)_2$			
64.	9.749(4)	17.95(1)	5.294(1)	104.93(2)	895.4(5)
65.	9.843(3)	17.90(1)	5.285(3)	105.51(2)	897.3(3)
66.	9.839(2)	17.89(1)	5.283(3)	105.43(3)	896.5(2)
67.	9.822(4)	17.87(1)	5.290(3)	105.21(4)	896.2(6)
68.	9.742(4)	17.95(1)	5.326(3)	104.96(4)	899.9(6)
		Ferri-tschermakite			
		$^{\square}Ca_2Mg_3Fe^{3+}_2Si_6Al_2O_{22}(OH)_2$			
69.	9.770(4)	18.02(1)	5.309(3)	105.14(3)	902.6(7)
		Sodic-calcic amphiboles			
		Richterites			
		$NaCaNaMg_5Si_8O_{22}(OH)_2$			
70.	9.909(1)	17.978(5)	5.268(1)	104.22(3)	909.8(2)
71.	9.899(2)	17.978(2)	5.269(1)	104.22(2)	908.6(1)
72.	9.902(1)	17.980(4)	5.269(1)	104.22(2)	909.4(3)
73.	9.901(2)	17.976(4)	5.270(1)	104.20(2)	909.4(3)
74.	9.903(1)	17.982(2)	5.267(1)	104.23(2)	909.2(1)
75.	9.884(7)	17.984(7)	5.268(3)	104.07(8)	907.7(6)
76.	9.893(3)	18.003(8)	5.268(2)	104.23(3)	909.5(4)
77.	9.896(5)	18.001(9)	5.270(3)	104.33(5)	909.6(6)
78.	9.854(4)	17.975(4)	5.266(2)	104.18(5)	904.3(6)
79.	9.907(2)	17.979(4)	5.269(1)	104.25(2)	909.6(4)
80.	9.892(5)	17.958(3)	5.263(2)	104.28(3)	906.0(10)
81.	9.901(3)	17.978(5)	5.269(1)	104.20(2)	909.3(3)
81a.	9.74(1)	18.10(1)	5.29(1)	104.12	905
		Ferro-richterite			
		$NaCaNaFe^{2+}_5Si_8O_{22}(OH)_2$			
82.	9.982(7)	18.223(6)	5.298(5)	103.73(12)	936.2(10)
83.	10.003(1)	18.238(4)	5.308(1)	103.92(2)	940.0(7)
		Potassium-richterite			
		$KCaNaMg_5Si_8O_{22}(OH)_2$			
84.	10.049(2)	17.988(3)	5.272(1)	104.80(1)	921.4(5)
		Potassium-ferro-richterite			
		$KCaNaFe^{2+}_5Si_8O_{22}(OH)_2$			
85.	10.172(3)	18.201(7)	5.290(2)	104.53(3)	948.2(4)

Ref.	a (Å)	b (Å)	c (Å)	ß (°)	V (Å^3)
		Alkali amphiboles			
		Glaucophane			
		$^{\square}Na_2Mg_3Al_2Si_8O_{22}(OH)_2$			
86.	9.71	17.92	5.27	102.5	895.3
87.	9.64	17.71	5.28	103.7	875.8
88.	9.717(2)	17.922(3)	5.271(1)	102.64(1)	895.7(2)
89.	9.619(7)	17.682(13)	5.292(5)	103.44(8)	875.4(9)
90.	9.742(1)	17.921(3)	5.269(1)	102.71(1)	897.3(1)
91.	9.703(5)	17.928(6)	5.272(2)	102.57(3)	895.0(4)
92.	9.783(5)	17.860(7)	5.274(2)	103.31(4)	896.6(4)
93.	9.73	17.91	5.27	102.8	896
94.	9.71	17.92	5.27	102.6	896
95.	9.75	17.91	5.27	102.8	898
96.	9.66	17.74	5.28	103.7	878
97.	9.78	17.82	5.29	103.6	897
98.	9.76	18.01	5.25	103.5	896
99.	9.77	17.92	5.27	103.0	898
100.	9.81	17.93	5.25	103.1	899
101.	9.74	17.83	5.28	102.6	895
102.	9.69	17.90	5.27	103.1	891
103.	9.66	17.83	5.25	103.6	878
104.	9.70	17.86	5.27	102.7	891
105.	9.67	17.83	5.26	103.0	883
106.	9.76	17.90	5.28	102.5	899
107.	9.71	17.73	5.28	103.7	883
108.	9.73	17.80	5.27	103.7	888
109.	9.69	17.74	5.28	103.7	882
110.	9.64	17.70	5.28	103.7	875
111.	9.66	17.70	5.28	103.7	877
112.	9.69	17.72	5.27	103.7	879
113.	9.61	17.75	5.29	103.6	877
114.	9.59	17.77	5.30	103.4	878
115.	9.61	17.71	5.28	103.8	873
116.	9.73	17.90	5.27	102.8	896
117.	9.72	17.98	5.25	103.4	893
118.	9.540(6)	17.694(12)	5.293(4)	103.58(7)	868.5(10)
119.	9.557(3)	17.700(5)	5.291(2)	105.50(2)	870.4(3)
a.	9.598	17.701	5.276	103.7	870.9
120.	9.540(8)	17.697(13)	5.284(5)	103.53	867.4(9)
121.	9.557(3)	17.700(5)	5.291(2)	103.50	870.4(3)
122.	9.555(3)	17.690(10)	5.290(2)	103.57	869.2(4)
123.	9.547(3)	17.694(5)	5.281(2)	103.42	867.7(6)

Ref.	a (Å)	b (Å)	c (Å)	β (°)	V (Å^3)
		Ferro-glaucophane			
		$^{\square}Na_2Fe^{2+}_3Al_2Si_8O_{22}(OH)_2$			
124.	9.686(3)	17.89(3)	5.317(3)	103.75(1)	894.9(2)
		Magnesio-riebeckite			
		$^{\square}Na_2Mg_3Fe^{3+}_2Si_8O_{22}(OH)_2$			
125.	9.79	18.02	5.28	102.8	908.6
126.	9.794(3)	18.023(6)	5.283(1)	102.93(4)	908.9(3)
127.	9.742(1)	17.945(2)	5.291(1)	103.38(2)	899.9(2)
128.	9.745(4)	17.943(7)	5.294(3)	103.40(5)	900.5(5)
129.	9.761(5)	17.928(8)	5.291(3)	103.43(6)	900.7(6)
130.	9.693(1)	17.953(2)	5.290(1)	103.19(1)	896.4(1)
		Riebeckite			
		$^{\square}Na_2Fe^{2+}_3Fe^{3+}_2Si_8O_{22}(OH)_2$			
131.	9.74	18.06	5.33	103.3	913.1
132.	9.739(6)	18.082(10)	5.331(4)	103.30(6)	913.7(7)
133.	9.73	18.07	5.33	103.2	911.7
134.	9.72	18.08	5.34	103.2	913.7
135.	9.72	18.05	5.33	103.3	910.9
136.	9.73	18.05	5.33	103.4	911.7
137.	9.71	18.06	5.34	103.2	912.1
138.	9.73	18.07	5.33	103.4	912.0
139.	9.74	18.09	5.33	103.4	913.3
140.	9.73	18.08	5.33	103.4	912.8
141.	9.73	18.04	5.34	103.5	912.3
142.	9.74	18.09	5.33	103.4	914.3
143.	9.75	18.08	5.33	103.4	914.0
		Eckermannite			
		$NaNa_2Mg_4AlSi_8O_{22}(OH)_2$			
144.	9.762(6)	17.892(11)	5.284(6)	103.17(49)	898.6(8)
145.	9.675(3)	17.889(7)	5.270(2)	102.73(3)	889.6(4)
		Nyböite			
		$NaNa_2Mg_3Al_2Si_7AlO_{22}(OH)_2$			
146.	9.652(4)	17.681(11)	5.290(3)	103.73	877.0(8)
147.	9.649(2)	17.699(2)	5.286(6)	103.73	877.0(5)
		Iron-magnesium-manganese amphiboles			
		Sodian magnesio-cummingtonite			
		$NaMgNaMg_5Si_8O_{22}(OH)_2$			
148.	9.735(7)	17.911(11)	5.279(4)	102.59(5)	898.3
149.	9.70(1)	18.01(1)	5.28(2)	103.03(8)	899(5)
150.	9.68(1)	18.06(1)	5.30(5)	104.90(17)	895(10)

Ref.	a (Å)	b (Å)	c (Å)	β (°)	V (Å^3)
		Miscellaneous compositions			
151.	9.89	18.05	5.28	103	918
152.	9.866(5)	17.997(6)	5.274(3)	103.03(4)	912.3
153.	9.832(5)	18.088(2)	5.299(5)	103.0(2)	918.2
154.	9.650(5)	17.920(2)	5.270(5)	102.9(2)	888.3

B. Optical Properties

Ref.	α	γ	av. α,γ	Z^c
1.	1.601	1.625		17
2.	1.605	1.628		
7.			1.689(3)	
8.			1.689(3)	
9.			1.688(3)	
10.			1.690(3)	
11.			1.691(3)	
12.			1.688(3)	
13.			1.689(3)	
14.			1.690(3)	
15.			1.688(3)	
16.			1.691(3)	
17.			1.689(3)	
19.	1.621(3)	1.634(3)		
20.	1.700(3)	1.726(3)		
21.	1.624	1.645		26
23.	1.617	1.636		
36.			1.624(3)	
37.				
38.			1.715(5)	
39.	1.700(2)	1.713(3)		
40.	1.698(2)	1.715(3)		
41.	1.698(2)	1.715(3)		
42.	1.699(2)	1.715(3)		
46.	1.702	1.728		
51.	1.698(3)	1.722(3)		22
52.	1.692(2)	1.712(3)		24
53.	1.692(2)	1.712(3)		27

Ref.	α	γ	av. α,γ	Z^c
54.	1.697(3)	1.723(3)		
55.	1.698(3)	1.725(3)		17
57.	1.652	1.665		
58.	1.642(4)	1.653(4)		24
60.	1.650(5)	1.662(4)		26
62.	1.654(4)	1.669(4)		25
63.	1.657(3)	1.672(4)		25
64.	1.640	1.654		
65.	1.639	1.654		
66.	1.640	1.653		
67.	1.642	1.652		
68.	1.643	1.655		
69.	1.642	1.661		
70.	1.602(2)	1.620(3)		16(2)
72.	1.604(5)	1.622(3)		
79.	1.603(2)	1.624(3)		
80.	1.602(3)	1.624(3)		15(2)
81a.	1.600	1.615		
82.	1.690(5)	1.710(4)		
84.	1.604(3)	1.629(2)		
91.	1.595	1.620		10
120.	1.602	1.620		5(2)

REFERENCES

1. Colville et al. (1966): synthesized by Boyd (1959)
2. Troll and Gilbert (1972): 650°C, 1.01 kbar, 1866 h
3. Troll and Gilbert (1972): 775°C, 4.06 kbar, 980 h
4. Oba (1980): 800°C, 1 kbar
5. Westrich (1978): 900°C, 4 kbar, 45 h, rerun 45 h
6. Wones and Dodge (1977): 770°C, 2 kbar, 166 h
7. Ernst (1966): 528°C, 3 kbar, 733 h, -log fO_2=23.9
8. Ernst (1966): 470°C, 3 kbar, 989 h, -log fO_2=26.6
9. Ernst (1966): 452°C, 1 kbar, 984 h, -log fO_2=27.5
10. Ernst (1966): 437°C, 2.98 kbar, 840 h, -log fO_2=28.3
11. Ernst (1966): 406°C, 2 kbar, 1604 h, -log fO_2=29.9
12. Ernst (1966): 537°C, 3 kbar, 475 h, -log fO_2=27.6
13. Ernst (1966): 516°C, 3 kbar,602 h, -log fO_2=28.5
14. Ernst (1966): 503°C, 2 kbar, 820 h, -log fO_2=29.1
15. Ernst (1966): 459°C, 1 kbar, 903 h, -log fO_2=31.4
16. Ernst (1966): 420°C, 0.5 kbar, 1125 h, -log fO_2=33.6
17. Ernst (1966): average of No. 8-16 this table
18. Hinrichsen and Schürmann (1977): 750°C, 4 kbar
19. Colville et al. (1966): 850°C, 2 kbar, 3 days
20. Colville et al. (1966): 600°C, 3 kbar, 31 days, IW buffer
21. Colville et al. (1966): synthesized by Boyd (1954, 1956, 1959)
22. Holloway (1973): 1002°C, 1.24 kbar, 103 h

23. Oba (1980): 950°C, 5 kbar
24. Westrich (1978), Westrich and Holloway (1981): 1205°C, 4kbar, 72 h
25. Braue and Seck (1977)
26. Droll and Seck (1976)
27. Hinrichsen and Schürmann (1977)
28. Charles (1980): 750°C, 5 kbar, 527 h, yield = 95
29. Charles (1980): 750°C, 2 kbar, 333 h, yield = 95
30. Charles (1980): 750°C, 2 kbar, 330 h, yield = 80
31. Charles (1980): 750°C, 2 kbar, 330 h, yield = 85
32. Charles (1980): 750°C, 2 kbar, 330 h, yield = 90
33. Charles (1980): 750°C, 2 kbar, 330 h, yield = 60
34. Charles (1980): 850°C, 1 kbar, 336 h, yield = 95
35. Charles (1980): 850°C, 1 kbar, 331 h, yield = 99
36. Charles (1980): average No. 28-35 this table
37. Charles (1980): 600[, 2 kbar, 368 h, FMQ buffer, yield=90%
38. Charles (1980): 700[. 2 kbar, 368 h, CCH_4 buffer, yield=90%
39. Gilbert (1966): average (4 runs), IW buffer
40. Gilbert (1966): average (4 runs), WM buffer
41. Gilbert (1966): average (4 runs), FMQ buffer
42. Gilbert (1966): single run, NNO buffer
43. Gilbert (1966): 847°C, 2014 bar, 81 h, IW buffer, cell dimensions refined in this study from X-ray powder data (Gilbert 1966, Table 2, No. AI1)
44. Gilbert (1966): 683°C, 1021 bar, 517 h, WM buffer, cell dimensions refined in this study from X-ray powder data (Gilbert 1966, Table 2, No. HI8)
45. Gilbert (1966): 640°C, 1989 bar, 408 h, FMQ buffer, cell dimensions refined in this study from X-ray powder data (Gilbert 1966, Table 2, No. AF4)
46. Colville et al. (1966): 600°C, 3 kbar, FMQ, 31 days
47. Charles (1978)
48. Thomas (1979): 600°C, 3 kbar, IQF buffer
49. Thomas (1979): 600°C, 3 kbar, IW buffer
50. Thomas (1979): 600°C, 3 kbar, WM buffer
51. Thomas (1979): 660°C, 3 kbar, FMQ buffer, ME340
52. Thomas (1979): 680°C, 3 kbar, IQF buffer, MI322
53. Thomas (1979): 680°C, 3 kbar, IW buffer, MH321
54. Thomas (1979): 680°C, 3 kbar, WM buffer, MF323
55. Thomas (1979): 680°C, 3 kbar, FMQ buffer, ME339
56. Thomas (1982a): 680°C, 3 kbar, WM buffer
57. Colville et al. (1966): 850°C, 2 kbar, MH buffer, 3 days
58. Semet (1973): 850°C, 2 kbar, IQF buffer, av. of 8
59. Semet (1973): 850°C, 2 kbar, WM buffer, av. of 5
60. Semet (1973): 850°C, 2 kbar, FMQ buffer, av. of 10
61. Semet (1973): 850°C, 2 kbar, NNO buffer, av. of 3
62. Semet (1973): 850°C, 2 kbar, MH buffer, av. of 6
63. Semet (1973): 850°C, 2 kbar, CT buffer, av. of 12
64. Oba (1978): 810°C, 15 kb
65. Oba (1978): 850°C, 10 kb
66. Oba (1978): 850°C, 12 kb
67. Oba (1978): 850°C, 15 kbar, +cpx+grt+qtz

68. Oba (1978): 850°C, 20 kb
69. Oba (1978): 850°C, 20 kbar, no buffer
70. Forbes (1971): 850-950°C, 100-750 bar
71. Braue and Seck (1977): 1030°C, 1 kb
72. Charles (1974b): 800-850°C, 1 kbar, av. of 4
73. Charles (1974b): 700°C, 1 kbar, 72 h
74. Charles (1974b): 800°C, 2 kbar, 48 h
75. Charles (1974b): 700°C, 5 kbar, 119 h
76. Charles (1974b): 600°C, 7 kbar, 456 h
77. Charles (1974b): 510°C, 10 kbar, 600 h
78. Westrich (1978): 950°C, 4 kbar, 72 h
79. Huebner and Papike (1970): 760-916°C, 1-2 kbar, 3.5 h - 56 days av. of 7
80. Phillips and Rowbotham (1966): 750-1000°C, 1-5 kbar, 18-192 h. Note that these cell dimensions are incorrect, see No. 81
81. Phillips and Rowbotham (1966): same as No. 81. Cell dimensions refined in this study from X-ray powder data in their Table 1.

81a. Grigor'eva et al. (1975). Synthesized by Makarova et al. (1971)

82. Charles (1974b): 500-530°C, 5-10 kbar, 535-721 h, av. of 3, IW buffer
83. Charles (1974b): 600-700°C, 5-7 kbar, 120-216 h, av. of 2, IW buffer
84. Huebner and Papike (1970): 732-916°C, 1-2 kbar, 3.5 h-56 days
85. Huebner and Papike (1970): 601°C, 1 kbar, CCH_4 buffer
86. Ernst (1959, 1961): 800°, 1 kbar, "glaucophane I"
87. Ernst (1959): 800°, 20 kbar, "glaucophane II"
88. Ernst (1961, 1963): cell dimensions refined in this study from X-ray powder data in Ernst (1961), Table 5, Ernst (1963), Table 1, same sample as No. 86, this table, "glaucophane I"
89. Ernst (1963): cell dimensions refined in this study from X-ray powder data in Ernst (1963), Table 5, same sample as No. 87, this table; "glaucophane II"
90. Ernst (1963): Run No. GM-1 obtained from W.G. Ernst, same as No. 95 this table, cell dimensions refined in this study, "glaucophane I"
91. Ernst (1961): Run No. G-119 obtained from W.G. Ernst, 857°C, 1.69 kbar, 10 h, cell dimensions refined in this study, "glaucophane II"
92. Ernst (1961, 1963): Run No. G-134 obtained from W.G. Ernst, 603°C, 4.6 kbar, 1092 h, same as No. 97, this table, cell dimensions refined in this study; "glaucophane I"
93. Ernst (1963): 815°C, 1 kbar, 1920 h, glass
94. Ernst (1963): 835°C, 1.19 kbar, 37 h, mix
95. Ernst (1963): 760°C, 2 kbar, 221 h, glass
96. Ernst (1963): 294°C, 4.6 kbar, 1460 h, mix
97. Ernst (1963): 603°C, 4.6 kbar, 1082 h, glass
98. Ernst (1963): 403°C, 4.75 kbar, 1414 h, mix
99. Ernst (1963): 680°C, 10 kbar, 52 h, mix
100. Ernst (1963): 796°C, 10 kbar, 8 h, glass
101. Ernst (1963): 631°C, 10.4 kbar, 15 h, glass
102. Ernst (1963): 521°C, 11.1 kbar, 4 h, glass
103. Ernst (1963): 600°C, 12.4 kbar, 72 h, mix
104. Ernst (1963): 797°C, 12.8 kbar, 6 h, glass

105. Ernst (1963): 697°C, 13.8 kbar, 6 h, glass
106. Ernst (1963): 750°C, 15 kbar, 47 h, mix
107. Ernst (1963): 750°C, 16.7 kbar, 20 h, mix
108. Ernst (1963): 800°C, 16.7 kbar, 18 h, mix
109. Ernst (1963): 690°C, 17 kbar, 13 h, mix
110. Ernst (1963): 700°C, 20 kbar, 3? h, mix, No. GC-1
111. Ernst (1963): 800°C, 20 kbar, 20 h, mix
112. Ernst (1963): 700°C, 25 kbar, 13 h, mix, No. GC-2
113. Ernst (1963): 599°C, 30 kbar, 6 h, glass
114. Ernst (1963): 296°C, 2.99 kbar, 1096 h, glaucophane I
115. Ernst (1963): 713°C, 20.3 kbar, 5 h, glaucophane I
116. Ernst (1963): 500°C, 0.5 kbar, 241 h, glaucophane II
117. Ernst (1963): 350°C, 2.99 kbar, 1097 h, glaucophane II
118. Maresch (1973): 700°C, 28 kbar, "amphibole 2"
119. Gilbert and Popp (1973): 750°C, 25 kb
119a Koons (1982): 700°C, 25 kbar, 152 h
120. Carman and Gilbert (1983): No.4100, 800°C, 35 kbar, 16 h
121. Carman and Gilbert (1983): No.G31, 750°C, 25 kbar, 0.5 h
122. Carman and Gilbert (1983): No.G35, 750°C, 25 kbar, 24 h
123. Carman and Gilbert (1983): No.4126, 815°C, 25 kbar, 24 h
124. Hoffmann (1972): I500°C, 5 kbar, 4 weeks, WM buffer
125. Ernst (1960): no conditions given
126. Ernst (1960): refined in this study from X-ray powder data in his Table 13 (data for No. 125 used by Ernst)
127. Ernst (1960): refined in this study from data collected on run R-129 provided by W.G. Ernst using BaF_2 as internal standard. 802°C, 1950 bar, 5 h
128. Ernst (1960): refined in this study from data collected on run R-129 provided by W.G. Ernst using Toxaway qtz as internal standard. Compare with No. 127, 126, 125
129. Ernst (1960): refined in this study from data collected on run R-101 provided by W.G. Ernst. 876°C, 730 bar, 119 h
130. Ernst (1960): refined in this study from data collected on run R-130 provided by W.G. Ernst. 808°C, 500 bar, 18 h
131. Ernst (1962): No. 12, his Table 10, 408°C, 2 kbar, 161 h
132. Ernst (1962): refined in this study from data collected on run HR-54-8 provided by W.G. Ernst. Same as No. 131
133-143. Ernst (1962), Table 10
144. Phillips and Rowbotham (1968): 770-1000°C, 1-5 kbar, 18-92 h. Note that these cell dimensions are incorrect, see No. 145
145. Phillips and Rowbotham (1968): refined in this study from X-ray X-ray powder data in their Table 1; same sample as No. 144.
146. Carman and Gilbert (1983): 980°C, 33.6 kbar, 20 h
147. Carman and Gilbert (1983): 900°C, 25.0 kbar, 30 h
148. Witte *et al.* (1969): 750-770°C, 1 kbar, 47-119 h
149. Grebenschikov *et al.* (1974): 450-550°C, >750 atm
150. Grebenschikov *et al.* (1974): 350-450°C, 250-750 atm
151. Gier *et al.* (1964): $Na_{2.5}H_{1.5}Mg_5Si_8O_{22}(OH)_2$, 700°C, 3000 atm, 6 h
152. Witte *et al.* (1969): $Na_3Mg_5Si_8O_{21}(OH)(OH)_2$, 500-600°C, 2 kbar, 44-117 h
153. Prewitt (1963): $Na_2H_2Co_5^{2+}Si_8O_{22}(OH)_2$
154. Prewitt (1963): $Na_2H_2Mg_5Si_8O_{22}F_2$

TABLE 6

Cell dimensions and optical properties of previously synthesized fluor-amphiboles: pure endmember compositions

A. Cell Dimensions

Ref.	a (Å)	b (Å)	c (Å)	β (°)	V (Å³)
		Fluor-tremolite			
		$\square Ca_2Mg_5Si_8O_{22}F_2$			
1.	9.787(3)	18.004(2)	5.263(2)	104.44(2)	898.1(5)
2.	9.781(5)	18.007(4)	5.267(6)	104.52(8)	898.0
3.	9.783(3)	18.016(4)	5.268(3)	104.52(3)	898.8(5)
4.	9.777(4)	18.013(6)	5.265(2)	104.50(3)	897.5(6)
5.	9.876(7)	18.007(11)	5.220(6)	106.10(5)	891.9(7)
		Fluor-pargasite			
		$NaCa_2Mg_4AlSi_6Al_2O_{22}F_2$			
6.	9.858(5)	17.922(9)	5.284(3)	105.73(8)	898.7(6)
7.	9.88				
		Fluor-edenite			
		$NaCa_2Mg_5Si_7AlO_{22}F_2$			
8.	9.847(5)	18.004(4)	5.282(6)	104.83(8)	905.2
9.	9.807(5)	17.957(4)	5.266(6)	104.45(8)	898.0
		Fluor-richterite			
		$NaCaNaMg_5Si_8O_{22}F_2$			
10.	9.823(5)	17.957(4)	5.268(6)	104.33(8)	900.3
11.	9.653(8)	18.019(8)	5.244(8)	103.37(7)	887.4(6)
12.	9.834(1)	17.963(2)	5.262(1)	104.21(1)	901.1(2)
13.	9.826(1)	17.963(2)	5.263(1)	104.23(1)	900.3(2)
14.	9.828(1)	17.963(3)	5.262(1)	104.24(1)	900.3(2)
15.	9.824(3)	17.968(3)	5.263(1)	104.22(1)	900.6(4)
		Potassium-fluor-richterite			
		$KCaNaMg_5Si_8O_{22}F_2$			
16.	9.948(2)	17.977(4)	5.267(1)	104.80(2)	910.6(3)
17.	9.953(1)	17.981(2)	5.264(1)	104.81(1)	910.8(2)
		Sodian fluor-magnesio-cummingtonite			
		$NaMgNaMg_5Si_8O_{22}F_2$			
18.	9.677(5)	17.914(9)	5.274(3)	102.95(5)	891.01
19.	9.65(1)	17.92(1)	5.26(1)	102.74(8)	887(2)
20.	9.68	17.92	5.27	102.92	891
21.	9.67(1)	17.92(1)	5.27(1)	103.00(8)	890(5)

Ref.	a (Å)	b (Å)	c (Å)	ß (°)	V (Å^3)
		Miscellaneous compositions			
22.	9.65(1)	17.91(1)	5.26(1)	102.70(8)	887(2)
23.	9.61(1)	17.92(1)	5.26(1)	102.81(8)	883(2)
24.	9.67(1)	17.96(1)	5.26(1)	102.84(8)	891(2)
25.	9.69(1)	17.98(1)	5.26(1)	102.88(8)	893(2)
26.	9.70(1)	17.94(1)	5.26(1)	102.87(8)	892(2)
27.	9.71(1)	17.97(1)	5.26(1)	103.57(8)	892(2)
28.	9.51(1)	17.86(1)	5.28(1)	104.08(8)	870(2)
29.	9.55(1)	17.87(1)	5.27(1)	104.00(8)	873(2)
30.	9.68(1)	17.93(1)	5.26(1)	102.53(8)	890(5)
31.	9.70(1)	17.92(1)	5.27(1)	102.75(8)	892(5)
32.	9.72(1)	17.94(1)	5.26(1)	102.67(8)	895(5)
33.	9.65(1)	17.89(1)	5.26(1)	102.63(8)	887(5)
34.	9.68(1)	17.90(1)	5.26(1)	103.00(8)	888(5)

B. Optical Properties

Ref.	α	ß	γ	Z^c
2.	1.581(1)	1.593(2)	1.602(2)	21
2a	1.58		1.61	16
8.	1.605(2)	1.617(2)	1.624(2)	18
9.	1.588(2)	1.598(2)	1.605(2)	12
10.	1.603(2)	1.614(2)	1.622(2)	22
18.	1.576(1)	1.589(1)	1.595(1)	11.4
19.	1.577(2)	1.589(2)	1.596(2)	12
20.	1.577(2)		1.596(2)	12
21.	1.577(2)		1.596(2)	12
22.	1.605(2)		1.618(2)	16
23.	1.597(2)		1.618(2)	25
24.	1.607(2)		1.616(2)	17
25.	1.604(2)		1.612(2)	20
26.	1.603(2)		1.610(2)	16
27.	1.612(2)		1.620(2)	23
28.	1.608(2)		1.618(2)	20
29.	1.623(2)		1.630(2)	
30.	1.582(2)		1.594(2)	12
31.	1.580(2)		1.596(2)	12
32.	1.603(2)		1.615(2)	12
33.	1.586(2)		1.599(2)	10
34.	1.590(2)		1.599(2)	12

REFERENCES

1. Cameron (1971), Cameron and Gibbs (1973): 1150°C, 1 atm, 168 h
2. Comeforo and Kohn (1954): 1450°C 2h, 5°Ch^{-1} to 1100°C, 1 atm
3. Troll and Gilbert (1972): 1142°C, 1 atm, 29 h
4. Troll and Gilbert (1972): 1132°C, 1 atm, 71 h
5. Westrich (1978): 900°C, 1 atm, 24 h
6. Westrich (1978): 1000°C, 1 atm, 24 h
7. Droll and Seck (1976)
8. Kohn and Comeforo (1955)
9. Kohn and Comeforo (1955)
10. Kohn and Comeforo (1955)
11. Westrich (1978): 1000°C, 4 kbar
12. Huebner and Papike (1970): 818°C, 2 kbar, 39 days
13. Huebner and Papike (1970): 1244-791°C, 1 atm, 9 days
14. Huebner and Papike (1970): 1132-843°C, 1 atm, 9 days
15. Cameron (1970), Cameron and Gibbs (1971): 1170-1000°C, 1 atm, 5°Ch^{-1}
16. Huebner and Papike (1970): 1244-791°C, 1 atm, 9 days
17. Huebner and Papike (1970): 1131-843°C, 1 atm, 9 days
18. Gibbs et al. (1962)
19. Fedoseev et al. (1970)
20. Grigor'eva et al. (1973a)
21. Grigor'eva et al. (1973b)
22-29. Fedoseev et al. (1970)
    22. $Na_2Mg_5NiSi_8O_{22}F_2$
    23. $Na_2Mg_{5.5}Cu_{0.5}Si_8O_{22}F_2$
    24. $Na_2Mg_5CoSi_8O_{22}F_2$
    25. $Na_2Mg_{4.6}Zn_{1.4}Si_8O_{22}F_2$
    26. $Na_2Mg_5MnSi_8O_{22}F_2$
    27. $Na_2CdMg_5Si_8O_{22}F_2$
    28. $Na_{2.5}Mg_5Cr^{3+}_{0.5}Si_8O_{22}F_2$
    29. $Na_3Mg_4Fe_5^{+}Si_8O_{22}F_2$
30-34. Grigor'eva et al. (1973b)
    30. $Li_{1.3}Na_{0.9}Mg_{5.5}Si_8O_{22}F_2$
    31. $Li_{0.5}Na_{1.5}Mg_5Si_8O_{22}F_2$
    32. $Li_{1.0}Mn_{1.7}Mg_{4.7}Si_8O_{21.9}F_{2.1}$
    33. $Li_{1.9}Ca_{0.19}Mg_{5\ 7}Si_8)_{21.8}F_{2.0}$
    34. $Li_{1.5}Ca_{0.5}Mg_6Si_8O_{22}F_2$

TABLE 7

Cell dimensions of previously synthesized amphiboles: non-endmember compositions

Ref.	a (Å)	b (Å)	c (Å)	β (°)	V (Å^3)
		Actinolite			
		$^{\square}Ca_2Mg_{2.5}Fe_{2.5}Si_8O_{22}(OH)2$			
1.	9.892(5)	18.191(12)	5.295(3)	104.65(5)	921.9(7)
2.	9.869(5)	18.184(16)	5.301(4)	104.39(7)	921.4(10)
3.	9.853(7)	18.185(13)	5.294(5)	104.44(8)	918.6(10)
4.	9.854(7)	18.193(20)	5.294(2)	104.44(4)	917.8(9)
5.	9.836(9)	18.193(20)	5.295(4)	104.45(7)	917.5(11)
6.	9.836(6)	18.189(23)	5.294(4)	104.25(8)	918.0(10)
7.	9.861(5)	18.206(9)	5.298(2)	104.52(3)	920.8(5)
8.	9.836(5)	18.195(9)	5.295(2)	104.38(4)	917.8(5)
9.	9.883(4)	18.209(10)	5.230(3)	104.56(5)	923.0(6)
10.	9.846(5)	18.192(9)	5.289(3)	104.33(5)	917.8(5)
11.	9.836(5)	18.175(16)	5.295(10)	104.38(11)	917.0(14)
		Pargasite-richterite join			
		$NaCa_2Mg_4AlSi_6Al_2O_{22}(OH)_2$-$NaCaNaMg_5Si_8O_{22}(OH)_2$			
12.	9.899(3)	17.955(5)	5.273(2)	105.43(4)	903.4(4)
13.	9.902(2)	17.973(5)	5.270(2)	105.35(3)	904.5(3)
14.	9.903(2)	17.985(4)	5.271(2)	105.31(3)	905.5(3)
15.	9.904(2)	17.991(5)	5.272(3)	105.12(3)	906.9(4)
16.	9.905(2)	18.006(5)	5.273(1)	105.05(4)	908.2(4)
17.	9.903(4)	18.002(5)	5.269(2)	104.89(4)	907.9(5)
18.	9.904(2)	18.000(4)	5.271(1)	104.73(2)	909.0(3)
19.	9.906(1)	17.994(2)	5.271(1)	104.56(1)	909.6(2)
20.	9.902(1)	17.984(3)	5.269(1)	104.42(1)	908.9(1)
		Pargasitic hornblende			
		$Na_{0.75}Ca_{2.0}Mg_{4.0}Al_{1.0}Si_{6.25}Al_{1.75}O_{22}(OH)_2$			
21.	9.879(2)	18.012(7)	5.264(7)	105.18(4)	904.1(13)
		Pargasite...ferro-pargasite join			
		$NaCa_2Mg_4AlSi_6Al_2O_{22}(OH)_2$-$NaCa_2Fe^{2+}_4AlSi_6Al_2O_{22}(OH)_2$			
22.	9.904(1)	17.989(5)	5.291(2)	105.45(2)	908.6(5)
23.	9.915(3)	18.031(7)	5.301(3)	105.40(1)	913.6(10)
24.	9.930(5)	18.104(6)	5.320(2)	105.27(1)	922.6(9)
		Potassium-pargasite			
		$K_{0.50}Na_{0.50}Ca_2Mg_4AlSi_6Al_2O_{22}(OH)_2$			
25.	9.901(4)	17.924(10)	5.288(3)	105.54(4)	904.1(8)

Ref.	a (Å)	b (Å)	c (Å)	β (°)	V (Å^3)
		Potassium-edenite			
		$K_{0.50}Na_{0.50}Ca_2Mg_5Si_7AlO_{22}(OH)_2$			
26.	9.933(6)	18.028(18)	5.327(3)	105.34(8)	919.9(1)
		Edenitic hornblende			
		$Na_{0.5}Ca_{2.0}Mg_{4.0}Al_{1.0}Si_{6.5}Al_{1.5}O_{22}(OH)_2$			
27.	9.851(4)	18.009(16)	5.294(6)	105.06(6)	906.9(15)
		Tschermakites...ferri-tschermakite join			
		$\square Ca_2Mg_3Al_2Si_6Al_2O_{22}(OH)_2$-$\square Ca_2Mg_3Fe^{3+}_2Si_6Al_2O_{22}(OH)_2$			
28.	9.874(3)	17.91(1)	5.291(1)	105.61(2)	901.0(3)
29.	9.887(3)	17.94(1)	5.294(4)	105.23(4)	905.5(3)
30.	9.761(6)	17.99(1)	5.319(5)	105.16(4)	901.6(5)
31.	9.763(4)	18.01(1)	5.312(5)	105.02(4)	902.4(3)
		Richterites...ferro-richterite join			
		$NaCaNaMg_5Si_8O_{22}(OH)_2$-$NaCaNaFe^{2+}_5Si_8O_{22}(OH)_2$			
32.	9.917(2)	18.020(5)	5.277(1)	104.13(5)	914.5(3)
33.	9.935(2)	18.063(3)	5.284(2)	104.08(5)	919.6(6)
34.	9.962(5)	18.122(6)	5.292(2)	104.07(3)	926.7(3)
35.	9.980(7)	18.180(7)	5.297(5)	103.97(3)	932.7(9)
		Crossite			
		$\square Na_2Mg_{1.5}Fe^{2+}_{1.5}Al_{0.67}Fe^{3+}_{1.33}Si_8O_{22}(OH)_2$			
36.	9.85	18.03	5.33	103.4	919(12)
		Riebeckite-arfvedsonite			
		$\square Na_2Fe^{2+}_3Fe^{3+}_2Si_8O_{22}(OH)_2$-$NaNa_2Fe^{2+}_4Fe^{3+}Si_8O_{22}(OH)_2$			
37.	9.76	18.09	5.32	103.3	914.3
38.	9.75	18.08	5.33	103.3	914.1
39.	9.76	18.07	5.33	103.3	914.4
40.	9.75	18.07	5.33	103.3	913.0
41.	9.75	18.06	5.33	103.3	913.0
42.	9.75	18.06	5.33	103.3	913.6
43.	9.74	18.07	5.34	103.4	913.1
44.	9.73	18.03	5.33	103.3	910.0
45.	9.74	18.07	5.33	103.4	913.3
46.	9.78	18.10	5.30	103.2	914.5
47.	9.77	18.07	5.33	103.4	915.5
48.	9.76	18.05	5.33	103.4	914.1
49.	9.76	18.07	5.33	103.4	914.6
50.	9.76	18.06	5.34	103.4	915.0
51.	9.75	18.06	5.33	103.5	913.3
52.	9.74	18.05	5.33	103.4	911.4
53.	9.75	18.08	5.33	103.4	914.2
54.	9.82	18.22	5.31	102.9	926.1
55.	9.83	18.10	5.33	103.3	922.1
56.	9.85	18.23	5.31	102.9	929.0

Ref.	a (Å)	b (Å)	c (Å)	β (°)	V (Å^3)
57.	9.84	18.13	5.32	103.3	923.5
58.	9.80	18.15	5.32	103.0	920.9
59.	9.91	18.14	5.31	103.2	929.8
60.	9.90	18.16	5.32	103.0	931.5
61.	9.88	18.21	5.31	103.1	931.4
62.	9.87	18.18	5.31	103.0	928.9
63.	9.88	18.23	5.30	103.1	930.5
64.	9.91	18.21	5.31	103.1	933.3
65.	9.89	18.16	5.31	103.1	929.8
66.	9.82	18.14	5.32	103.2	923.5
67.	9.82	18.13	5.32	103.2	920.8
68.	9.83	18.09	5.33	103.3	922.0
69.	9.87	18.16	5.32	103.2	928.4
70.	9.85	18.13	5.32	103.3	924.6
71.	9.87	18.22	5.31	103.1	930.6
		Richterite...potassium-richterite join			
		$NaCaNaMg_5Si_8O_{22}(OH)_2$-$KCaNaMg_5Si_8O_{22}(OH)_2$			
72.	10.030(1)	17.986(1)	5.272(1)	104.74(1)	919.8(3)
73.	10.009(3)	17.984(2)	5.270(1)	104.65(2)	917.8(3)
74.	9.983(2)	17.980(6)	5.269(1)	104.56(3)	915.5(2)
75.	9.948(2)	17.981(3)	5.268(1)	104.42(5)	912.7(3)
		Fluor-richterite			
		$Na(Na_{0.51}Ca_{0.45}Fe_{0.04})_2(Mg_{0.69}Fe_{0.32})_5Si_{7.79}O_{22}F_2$			
76.	9.846(2)	18.019(3)	5.274(3)	104.25(1)	906.9(6)

REFERENCES

1-11. Cameron (1975)
1. 558°C, 2 kbar, 73B-100, 48(4) (100FeO/FeO+MgO)
2. 505°C, 2 kbar, 16E-50, 46(6) (100FeO/FeO+MgO)
3. 550°C, 2 kbar, 17D-50, 46(4) (100FeO/FeO+MgO)
4. 582°C, 2 kbar, 18C-50, 39(6) (100FeO/FeO+MgO)
5. 603°C, 2 kbar, 15B-50, 49(7) (100FeO/FeO+MgO)
6. 665°C, 2 kbar, 43C-50, 48(8) (100FeO/FeO+MgO)
7. 556°C, 2 kbar, 38C-80, 53(3) (100FeO/FeO+MgO)
8. 651°C, 2 kbar, 53D-80, 50(3) (100FeO/FeO+MgO)
9. 505°C, 2 kbar, 92D-90, 54(3) (100FeO/FeO+MgO)
10. 650°C, 2 kbar, 52E-90, 49(3) (100FeO/FeO+MgO)
11. 650°C, 2 kbar, 61B-100, 43(6) (100FeO/FeO+MgO)

12-20. Braue and Seck (1977)
12. $pa_{90}ri_{10}$
13. $pa_{80}ri_{20}$
14. $pa_{70}ri_{30}$
15. $pa_{60}ri_{40}$
16. $pa_{50}ri_{50}$

17. $pa_{40}ri_{60}$
18. $pa_{30}ri_{70}$
19. $pa_{20}ri_{80}$
20. $pa_{10}ri_{90}$

21. Loida and Hinrichsen (1975): 800°C, 4 kb

22-24. Charles (1980)
22. Mg_3Fe, av. of 10
23. Mg_2Fe_2, av. of 6
24. $MgFe_3$, av. of 4

25. Hinrichsen and Schürmann (1977): 750°C, 4 kb
26. Hinrichsen and Schürmann (1977): 750°C, 4 kb
27. Loida and Hinrichsen (1975): 800°C, 4 kb

28-31. Oba (1978)
28. $ts_{90}fts_{10}$, 850°C, 12 kb
29. $ts_{70}fts_{30}$, 850°C, 12 kb
30. $ts_{60}fts_{40}$, 850°C, 12 kb
31. $ts_{50}fts_{50}$, 850°C, 12 kb

32-35. Charles (1974)
32. $FeMg_4$, av. of 7, IW buffer
33. Fe_2Mg_3, av. of 7, IW buffer
34. Fe_3Mg_2, av. of 5, IW buffer
35. Fe_4Mg, av. of 3, IW buffer

36. Koslowski and Hinrichsen (1979): 700°C, 4 kbar

37-71. Ernst (1962)

72-75. Heubner and Papike (1970)
72. $K_{0.875}$, av. of 2
73. $K_{0.75}$, av. of 3
74. $K_{0.50}$, av. of 3
75. $K_{0.25}$, av. of 3

76. Cameron (1970), Cameron and Gibbs (1971): 1050-880°C, $5°Ch^{-1}$, 1 atm

Chapter III

EXPERIMENTAL METHODS

CHARGE PREPARATION

Starting Materials

Dry mixtures of appropriate anhydrous amphibole stoichiometry and solid oxygen-buffer materials were prepared from commercial reagent-grade oxides and other compounds. Source chemicals and procedures for mix-component preparation are given in Table 8.

After weighing out components, the mixture was blended by hand for 5 minutes and then ground in a powered alumina mortar under alcohol for at least 1 hour. The thoroughly ground mix was again blended by hand for about 5 minutes and dried overnight at 400° to 1000°C, depending on the stability of the components. Prior to use, the mixes were stored tightly capped in a desiccator over $Mg(ClO_4)_2$.

Anhydrous gels, prepared gravimetrically according to the method of Hamilton and Henderson (1968), were used for certain pargasite, alumino-magnesio-hornblende, edenite, and alumino-winchite compositions. Components required in addition to those for dry mixes are also listed in Table 8.

TABLE 8

Sources and preparation of starting materials

Component	Source	Treatment
SiO_2	Corning Fused Silica Code 7940	Cleaned in aqua regia. Washed in distilled H_2O. Dried to constant weight at 1000°C.
γ-Al_2O_3	$Al(OH)_3$ Fisher Lot 765051	Heated at 900°C, 48 h.
MgO	Fisher Lot 754056	Dried at 1000°C to constant weight.
CaO	$CaCO_3$ Fisher Lot 740807	Decarbonated to constant weight before weighing, or added to mix as $CaCO_3$, mix decarbonated at 1000°C.
Na_2O	$Na_2Si_2O_5$	Prepared after Schairer and Bowen (1955). Dried at 200°C for 3 h.
Na_2O	Na_2CO_3 Fisher Lot 751625	Added as carbonate. Mix decarbonated at 700°C.
K_2O	$KHCO_3$ Fisher Lot 794339	Added as carbonate. Mix decarbonated at 700°C.
CaF_2	Fisher Lot 787317	Dried at 800°C, 24 h.
NaF	Fisher Lot 775169	Dried at 400°C, 24 h.
CdO	$CdCO_3$ Fisher Lot 734756	none, used as is
GeO_2	Matheson, Coleman & Bell, Lot 10M10	dried at 400°, 24 h.
NiO	Fisher Lot 730777	none, used as is
Sc_2O_3	Alfa Lot 081380	dried 400°, 24 h
Cr_2O_3	Fisher Lot 724579	none, used as is

Table 8 (continued)

Component	Source	Treatment
V_2O_2	Alfa Lot 032681	none, used as is
Ti_2O_3	Alfa Lot 081778	none, used as is
TiO_2	Fisher Lot 795530	none, used as is
Ga_2O_3	Aldrich Lot 1097	dried at 400°C, 24 h
In_2O_3	Johnson Matthey Lot 582934	dried at 400°C, 24 h
CuO	Cu_2O, Baker and Adamson Lot T318J	heated in air at 400°C for 48 h
MnO	$MnCO_3$ Fisher Lot 700983	none, used as is, added as carbonate
Li_2O	Li_2CO_3 Fisher Lot 754277	none, used as is, added as carbonate
Fe_2O_3	Fisher Lot 766122	none, used as is
Fe	Fe-metal powder Baker Lot 26698	none, used as is
	Additional components for gels	
Mg	Mg-metal powder Fisher Lot 794121	none, used as is
Al	Al-metal powder Fisher Lot 763574	none, used as is
SiO_2	$SiO_4(C_2H_5)_4$ Fisher Lot 780760	standardized as in Edgar (1973)

Fluor-amphibole Capsules

In most fluor-amphibole synthesis experiments, 4 mm o.d., 3.75 mm i.d. Pt tubes 22 to 23 mm long were used to contain the charge. The tubing was cleaned prior to use by boiling it in concentrated HCl and was annealed at red heat in a gas flame for a few seconds. After one end was crimped flat and welded shut with an electric arc welder, 20 to 40 mg of dried mix of appropriate fluor-amphibole stoichiometry were packed into the capsule, filling about one-fifth to one-quarter of it. The remainder of the tube was then flattened to expel air and sealed by welding. During the second weld, the lower portion of the capsule containing the charge was immersed in ice-water to prevent volatilization of low-melting point components.

Several fluor-amphibole runs were attempted in large-bore (5 mm) Au capsules. Au tubing apparently softens at temperatures about 100°C below its melting point, and capsule failure was frequent due to internal gas pressure. In successful runs, fluorine reaction with the Au capsule inner wall did not seem to be significant, and run products were not measurably different from those reacted in Pt capsules.

Satisfactory results were not obtained using large-volume (>1 g) charges in unsealed Pt crucibles similiar in configuration to runs by Westrich (1978). A Pt crucible containing the charge was covered with Pt foil, folded over the edge. This crucible was placed into a larger crucible half-filled with CaF_2 and also covered with foil. Because of uncontrollable amounts of fluorine leakage, high amphibole yields were rare and results could not be consistently reproduced. When successful, however, this method has the advantage of producing large amounts of product for characterization.

Hydroxy-amphibole Capsules

In hydroxy-amphibole experiments, about 30 to 90 mg of charge corresponding to the appropriate anydrous amphibole composition, plus 5 to 20 percent doubly distilled and de-ionized water were loaded into capsules prepared in the same way as for fluor-amphibole syntheses. When elements of variable oxidation state were not present, 4.5 or 5.0 mm o.d., 4.1 or 4.75 mm i.d. Au tubes 25 to 35 mm long were used to contain the charge. In order to fit the pressure vessel bore with less risk of jamming, the ends were crimped in a tricorn configuration with a drill chuck, rather than flat-crimped, before welding.

For runs requiring oxygen fugacity control, two methods were employed. First, if an approximate oxygen fugacity corresponding to the NNO buffer was suitable, the charge was simply loaded into 4 mm o.d., 3.75 mm i.d. Pt tubes 25 mm long and run with the pressure vessel wall (contains Ni and NiO) and H_2O pressure medium reaction as the buffering agent. Second, for precise oxygen fugacity control, the standard double-capsule solid-buffering techniques developed by Eugster (1957) and reviewed by Huebner (1971) were used. Inner capsules were 3 mm o.d. 2.5 mm i.d. Pt or $Ag_{70}Pd_{30}$ tubes 20 mm long; the outer capsules were 5 mm o.d., 4.75 mm i.d. Au tubes 35 mm long. Buffer reactions and abbreviations are listed in Table 9; source chemicals and preparation of buffer materials are given in Table 8.

TABLE 9

Solid Oxygen Buffers

$2Cu_2O$ cuprite	+	O_2	=	$4CuO$ tenorite	CT
$4Fe_3O_4$ magnetite	+	O_2	=	$6Fe_2O_3$ hematite	MH
$2Ni$ nickel	+	O_2	=	$2NiO$ bunsenite	NNO
$2Fe$ iron	+	O_2	=	$2FeO$ wüstite	IW

RUN PROCEDURE

Fluor-amphibole Syntheses

Fluor-amphibole synthesis experiments at one atmosphere pressure were conducted in vertical quenching furnaces similar to those described by Schairer (1959). Two types of furnace designs, both wound with $Pt_{60}Rh_{40}$ wire on mullite cores 30.5 cm long, were used: one with an inner tube diameter of 23 mm, the other with a 44 mm inner tube. Up to four charges in Pt or Au capsules were simultaneously reacted in the smaller furnaces by suspending them on a Pt wire at the hot spot. Quenching at the end of a run was accomplished by releasing the suspension wire and allowing the capsules to drop into a container of cold, distilled water located below the open lower end of the furnace tube. The larger furnace allowed the simultaneous reaction of up to 20 capsules packed into an alumina crucible. The crucible was positioned at the hot spot with a ceramic pedestal inserted from the bottom of the furnace tube. Runs were quenched either with a blast of cold, compressed air after lowering

the crucible-pedestal assembly, or by removing the crucible and dumping the capsules into cold, distilled water. Distilled water was used so that if capsules cracked during quenching, the run product was not contaminated and could be salvaged by drying.

Temperatures were measured with ceramic insulated, bare-wire Pt-$Pt_{87}Rh_{13}$ thermocouples (Type R). In single-capsule runs, the measuring junction was placed as close as possible to the middle of that part of the capsule containing the charge; in multiple-capsule runs, the junction was located at the centre of the capsule bundle. Thermoelectric potentials were measured with a Tinsley Type 3184-D potentiometer readable to 5 microvolts. A reference junction in the thermocouple circuit was maintained at 0°C by an ice-water bath. Thermocouples were not calibrated for each run, but similar calibrated circuits used in this laboratory are consistently within 3 degrees of the melting point of copper (1084.9°C).

Temperature during runs in the smaller furnaces was maintained within 5 degrees of the set value by home-made, proportional-type temperature controllers. The large-bore furnace was equiped with a Theall Engineering Company Model TP-2000 Thermocouple Temperature Programmer. In addition to precise isothermal proportional control within 1 degree or less of the set value, experiments could be performed at linear cooling rates of 0° to 10°C hr^{-1}.

Hydroxy-amphibole Syntheses

Hydroxy-amphiboles were synthesized between 600° and 800°C, 1 and 3 kbar water pressure with conventional hydrothermal equipment. Cold-seal pressure vessels with 6.4 mm bores, similar in design to that of Tuttle (1949), were machined from Rene 41 alloy and measured between 20 and 30.5 cm in length, and between 25 and 32 mm in diameter. Stainless steel or graphite filler rods were used to minimize fluid volume inside vessels and to prevent convection in the pressure medium. Water pressure was applied with a hand-operated pump.

Experiments up to 3 kbar at 1000°C were performed in LECO Temp-Pres TZM (Ti-Zr-Mo Alloy) pressure vessels 30.5 cm long and 25 mm in diameter with water-cooled head nuts. Argon pressure was applied with an air-driven stainless steel diaphragm pump to 2 kbar and then boosted to 3 kbar with a hand-operated pressure intensifier.

Pressure vessels were heated in nichrome-element, tubular, split-type furnaces. Temperature was maintained during runs by one of several types of temperature controllers: Theall Engineering Company Model TC-1000 with zero-switching, time proportioning control; Sirect M.K.2 Silicon-controlled Rectifier proportional type; and West Corporation Gardsman on-off type controller.

Temperatures during runs were monitored by stainless steel-sheathed, MgO-insulated, chromel-Alumel thermocouples (Type K) inserted into external wells drilled in the bottoms of the pressure vessels. The depth of the wells was appropriate to position the thermocouple tip about 5 mm away from, and approximately opposite to, the centre of a 25 mm sample capsule. The actual temperature inside the vessel was previously cali-

brated against the external thermocouple using an internal thermocouple and dummy capsule and filler rod, during simulated runs at 1 atm.

Thermoelectric potentials were measured with a Leeds and Northrup 8690-2 Millivolt Potentiometer readable to 0.01 mv. A reference junction in the thermocouple circuit was maintained at 0°C by an ice-water bath. Thermocouples were not calibrated for each run. Random checks using the thermal pause method and NaCl resulted in freezing-point values within 2 degrees of an acceptable value of 800.4°C. Temperature uncertainty in these experiments was approximately ±10°C.

Pressures were measured on 10 cm (1400 bar) and 18 cm (5500 bar) Ashcroft Maxisafe bourdon-tube gauges, calibrated at the factory. The given uncertainty was ±0.5 percent of the full-scale reading.

Pressure vessels were quenched under pressure by opening the furnace, removing the vessel to an adjacent metal support, and blasting it with a jet of cold, compressed air for about 1 minute. Immersion in cold water followed immediately; fresh cold water was continuously added to the bath while warm water was removed, to make the quench as quick as possible. The pressure vessel usually reached room temperature in less than 5 minutes.

CHARACTERIZATION

Optical Microscopy

Capsules were weighed before and immediately after runs to check for weight gains or losses that would indicate capsule leaks. The capsule was then examined under a binocular microscope for external signs of

leakage, especially if post-run and pre-run weights were not similar. After opening, the product was checked for contamination by leaks, signs of reaction with capsule material, texture and grain size. A small portion of the product was gently crushed and mounted on a glass slide with piccolyte (refractive index 1.52) under a cover glass for viewing at higher power with a polarizing microscope.

Scanning Electron Microscopy

A major block to the characterization of run products is their very fine grain size, which makes optical examination difficult and often useless in identifying phases other than amphibole. Furthermore, phases of poor crystallinity or very low abundance do not register, or are overlapped by major phases in X-ray diffraction patterns. Scanning electron microscopy offers much greater useful magnification and superior resolution to optical methods, allowing phases of different or complex morphologies to be readily distinguished in most cases. Magnifications of 2000 to 20000x are the most useful for examining typical run products in detail, but low magnifications in the optical microscopy range (100 to 500x) are also important in documenting the overall characteristics.

X-ray Powder Diffraction

X-ray powder diffractograms were routinely taken for all run products at fast scanning speed ($30°2\theta\ min^{-1}$). These allowed for quick evaluation of the amphibole yield and of the nature and approximate concentrations of non-amphibole phases. Subsequently, all runs with high yields of amphibole were scanned at slow speed ($0.6°2\theta\ min^{-1}$) for cell dimension determination and to obtain accurate d-spacings for identification of non-amphibole phases.

Powder diffractograms were obtained on a Philips Automated Powder Diffractometer System PW1710 using monochromatized Cu radiation (CuKα, wavelength=1.5418 Å). The finely-ground amphibole run product and a small amount of BaF_2 were blended thoroughly by grinding gently under alcohol. The mixture was spread on a glass slide with alcohol to form a thin (0.01 mm), uniform smear. The BaF_2 (a = 6.19860(5) Å) was calibrated against Si (NBS Standard Reference Material 640a, a=5.43083(4) Å). Amphibole peaks were indexed by comparison to published patterns of amphiboles with known structure and composition. Only those reflections that could be unambiguously indexed and did not overlap significantly with neighbouring peaks were used in cell dimension calculations. These requirements restricted usable amphibole reflections to 10 to 12, between 9° and 45°2θ Cell dimensions were refined using the CELREF program of Appleman and Evans (1973).

Infrared Spectroscopy

High-resolution infrared spectra of minerals containing hydroxyl groups, such as amphiboles, exhibit fine structure that is sensitive to the cation occupancies of the M(1) and M(3) sites (Hawthorne 1983a, b). In binary solid-solutions, there are eight possible ways of distributing two different cations over the three M-sites coordinating each hydroxyl. In amphiboles, however, the three M-sites coordinating the hydroxyl are in a pseudotrigonal arrangement that introduces an accidental degeneracy to some bands and reduces the number of resolvable bands to four. In endmembers, 2M(1)+M(3) configurations around each hydroxyl are identical, and a single, sharp hydroxyl-stretching band results (Figure 4A). Figure 4 displays typical natural amphibole spectra collected in this

study under the same experimental conditions as the synthetic amphibole spectra. Note the sharp, narrow peaks with band widths between 6 cm^{-1} and 9 cm^{-1}, values typical for other natural amphibole spectra (Strens 1974). Of particular interest is the peak shape of the single MgMgMg stretching band in the tremolite spectrum (Figure 4A). The shape corresponds to that of a markedly skewed gaussian distribution. Figure 4B shows a typical natural actinolite spectrum with Mg and Fe as the predominant octahedral cations. Table 10 shows the possible cation arrangements and hydroxyl-stretching band assignments in amphiboles with M(1,2,3) sites completely occupied by Mg and a another different cation,

TABLE 10

Possible cation-arrangements and hydroxyl-stretching band assignments in amphiboles with M(1,2,3) completely occupied by Mg and second cation, M

M(1)	M(1)	M(3)	M(1)≠M(3)[1]	M(1)=M(3)[2]
Mg	Mg	Mg	A	A
Mg	Mg	M	B'	B
Mg	M	Mg	B''	B
M	Mg	Mg	B''	B
M	M	Mg	C'	C
M	Mg	M	C''	C
Mg	M	M	C''	C
M	M	M	D	D

[1]ideal band assignment for crystallographically distinct configurations
[2]band assignments for configurations with accidental degeneracy due to pseudotrigonal arrangement
(from Hawthorne 1983b)

M. Interpretation of ternary and more complex solid solutions is diffi-

cult because the number of fine-structure bands becomes very large. For example, there would be ten hydroxyl-stretching bands in a three-component solid solution, and twenty in a four-component solid solution.

High-resolution (2.0 cm^{-1}) infrared spectra of hydroxy-amphiboles in the fundamental O-H stretching region (3600-3800 cm^{-1}) were recorded on a Nicolet Fourier transform interferometric infrared spectrophotometer, Model MX-1, equipped with a Nicolet 1280 computer for signal processing. The sample chamber was purged with dry nitrogen before and during spectrum collection. Frequency measurements were calibrated internally against a He/Ne laser and are accurate to 0.01 cm^{-1} according to the manufacturer.

Powdered samples were prepared by grinding 1 to 12 mg of amphibole by hand in an alumina mortar with ethanol until the grain size was generally less than 2 microns. This was achieved quickly because most of the synthetic amphiboles were less than 2 microns in grain size initially. After drying to evaporate the ethanol, the sample was mixed with KBr, either by hand grinding in an alumina mortar, or in a dentist's amalgamator (Wig-L-Bug). This mixture was dried under vacuum at 125°C and then was pressed in an evacuated, heated (about 90°C) die into a 13 mm pellet.

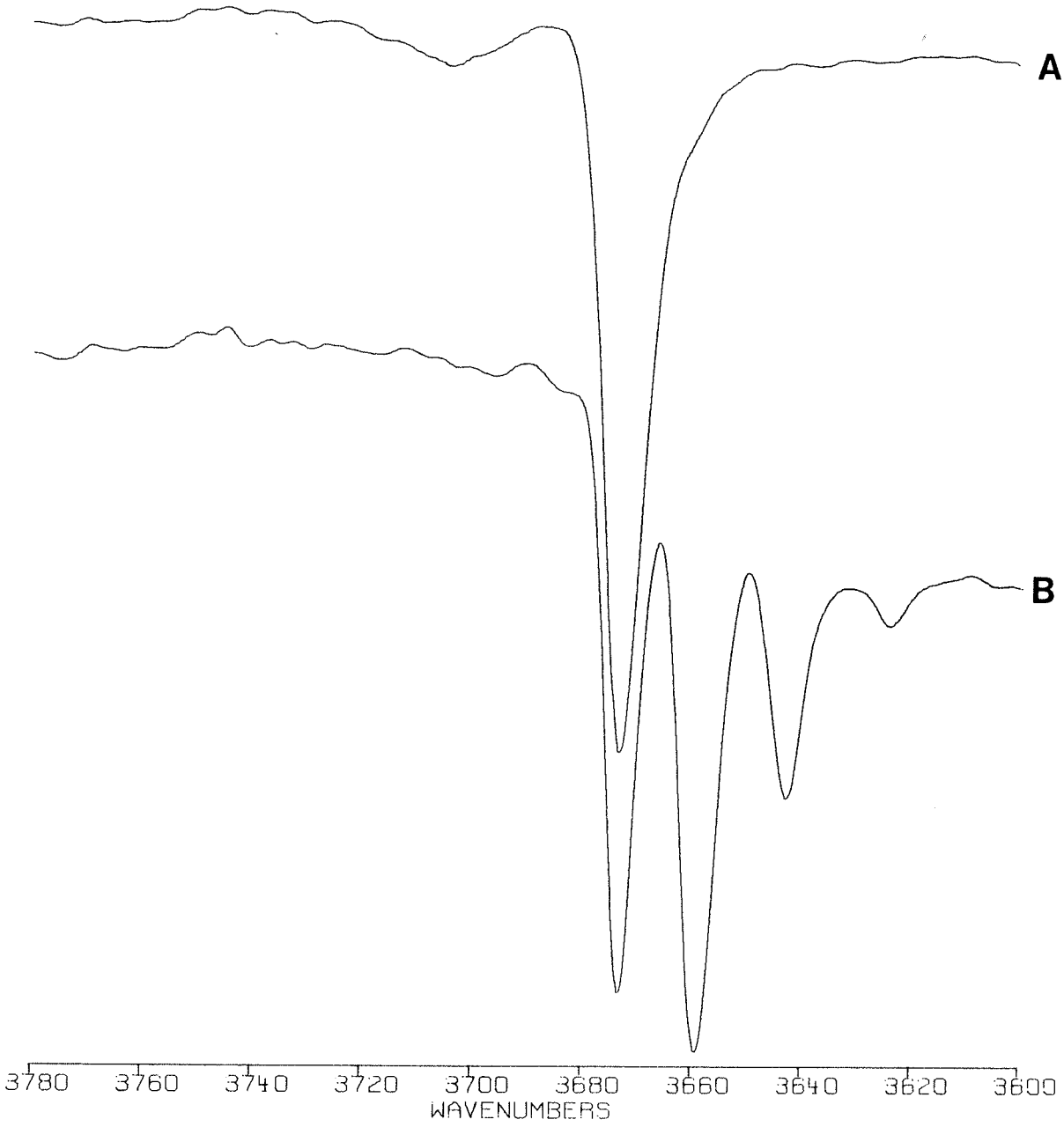

Figure 4: Typical infrared spectra of natural tremolite and actinolite. A: Tremolite, Gouverneur, New York. B: Actinolite, Setting Net Lake Area, Ontario.

Rietveld Method of Crystal Structure Refinement

The Rietveld method (Rietveld 1967, 1969) uses the whole powder diffraction pattern to characterize the structure of the material examined. The structure parameters of the mineral, atomic coordinates, site-occupancies and thermal parameters, together with various experimental parameters affecting the pattern, are refined by least-squares procedures to minimize the difference between the whole calculated and observed patterns.

X-ray intensity data were collected on a Philips Automated Diffraction System PW1710 equipped with graphite crystal monochromator for CuKα radiation. Beam divergence was controlled with an automatic divergence slit so that a constant area (approximately 1.9 cm^2) of the specimen was irradiated throughout the scanning range. Intensities were measured at 0.02°2θ steps with counting times of either 8 or 16 s per step; scanning ranges were between 8° and 73°2θ.

Specimens were ground with ethanol in an alumina mortar for at least 5 minutes and loaded into either an aluminum holder with a glass insert to support the powder, or into a HF-etched depression in a glass slide. The slurry was worked with a probe so that it was evenly distributed and dried with its surface precisely flush with the top of the holder. Grain size was generally less than 5 microns with some grains up to 20 microns long. All specimens analysed exhibit prismatic to acicular habits, but SEM photographs (Figure 5, 6) suggested that preferred orientation was apparently not severe in most samples and special precautions were not taken to eliminate it during sample preparation. Attempts by other workers (e.g. Young and Wiles 1981) to minimize

preferred orientation by mixing the specimen with an equal amount of ground glass did not significantly improve refinements.

Structures were refined using a slightly modified version of the program DBW 2.9 (Wiles and Young 1981). The features of this program are summarized in Appendix A. Refinements were done in three stages. First, the scale factor, cell parameters and zero-point were refined with atomic positions, site-occupancies and isotropic temperature factors for individual atoms fixed at estimated values approximately correct for amphiboles. In this stage, a background model based on inspection was used; other profile parameters were estimated either from the intensity data or from published work, and were not refined. In the second stage, the half-width parameters, peak asymmetry parameter and preferred orientation parameter were included in the refinement. In addition, the background was refined as a second order polynomial function in 2θ. Because most of the amphibole diffraction pattern above about 26°2θ consists entirely of severely overlapped peaks, background modelling is difficult. Attempts to model the background by extrapolation between areas of low intensity between peaks failed above 26°2θ. In the third stage, the remaining structural parameters were added to the refinement and the background model function was expanded to the third order. Background refinements at higher orders failed to converge. Parameter shifts in the final cycle of refinement were generally less than 0.1 to 0.2 sigma.

Best refinement results (lowest R-factors) were obtained with the Mod 2 Lorenzian profile function (Appendix A.) and by refining the overall isotropic temperature factor.

Complete refinement of a typical amphibole structure requires the simultaneous refinement of 45 to 50 parameters. In order to decrease computing time the refinements were performed at 0.04°2θ steps rather than at the collected interval of 0.02°. The results were essentially identical; standard errors were slightly larger at the larger step.

Chapter IV

AMPHIBOLE SYNTHESES: RESULTS

This chapter describes and evaluates the results of all endmember amphibole syntheses and isomorphic substitutions in these endmembers that were attempted during this study. Because the chief aim of the syntheses was to grow pure amphiboles for crystal-chemical characterization, run products were initially examined only for amphibole yield. Subsequently, products with high amphibole yields (>80 percent) were documented in detail. Experimental conditions and products for each run are organized according to nominal starting composition in Tables 11 and 12. In the run products that were examined in detail, only those phases that could be identified unambiguously from powder X-ray patterns, or rarely, optically, are listed under "Products." Thus, in complex, multi-phase run products, some low-abundance phases may have been masked in the X-ray powder patterns by the intense reflections of high-abundance phases. Runs with >80 percent amphibole are marked with an asterisk in the run number (e.g. PAA1*). Low-yield or amphibole-absent run products are described only by the approximate amphibole mode under "Products." In the text, results are summarized by principal amphibole group with headings showing all attempted substitutions collectively in the ideal endmember formula. Products were identified and characterized according to the method outlined in Chapter 3. Cell dimensions for amphiboles from high-yield runs are given in Table 13.

CALCIC AMPHIBOLES

Tremolite: $\square(Ca,Cd)_2(Mg,Ni,Mn)_5Si_8O_{22}(OH)_2$

$\square Ca_2Mg_5Si_8O_{22}(OH)_2$

Runs of up to 18 days duration on the endmember tremolite composition at 20° to 35°C below its 1 kbar stability limit (Boyd 1954, 1959) failed to grow perceptible amphibole. Both experiments were performed at similar temperatures, at 1 kbar, but gave different results. The short run (332 h) comprised abundant diopside and three metastably coexisting silica polymorphs: low-quartz, low-cristobalite and tridymite. Cristobalite was the most abundant; quartz was the least abundant. In the long run (445 h), the peaks in the X-ray powder pattern are better formed and sharper than in the short run. Low-quartz is the only silica phase; other phases are the same. Weak reflections corresponding to enstatite were observed. As tremolite is a common constituent of marbles, run TR-B1 was attempted on the bulk tremolite composition using a starting mix comprising $CaCO_3$, $MgCO_3$ and Corning 7940 silica glass. Modest amounts of amphibole (less than 20 percent) were formed. The presence of abundant CO_2 apparently encourages tremolite growth.

Substitution of Ni_5 for Mg_5

Replacement of Mg_5 by Ni_5 yielded about 10 to 20 percent very pale green, weakly pleochroic, acicular amphibole averaging about 4 um in length. No attempt was made to control oxygen fugacity. The presence of Ni in the product suggests that oxygen fugacities were close to that of the NNO buffer; NiO reflections, however, were not detected in the X-ray powder pattern. The most abundant phase was pale green, prismatic Ni-diopside with cell dimensions (a=9.7409(8), b=8.896(1),

$\underline{c}$=5.236(3), β=105.78(2), $\underline{V}$=436.6(2)) similar to those for $CaNiSi_2O_6$ given in Ribbe and Prunier (1977) ($\underline{a}$=9.737, $\underline{b}$=8.899, $\underline{c}$=5.231, β=105.9, $\underline{V}$=435.9), and three silica polymorphs, low-quartz, low-cristobalite and tridymite. Cristobalite was most abundant of the silica phases in the 1 kbar run, whereas quartz was most abundant in the 2 kbar run. Willemseite occurred in abundance in the 2 kbar run with a strong, sharp basal reflection in the X-ray powder pattern (d=9.42 Å) but was only detected optically in the 1 kbar run. Cell dimensions of the nickel amphibole were calculated (Tableh13).

Substitution of Mg_5 by Mg_3Ni_2

Replacement of Mg_5 by Mg_3Ni_2 resulted in higher amphibole yield (30 to 40 percent). Other phases were similar to the Ni_5 run composition. Cell dimensions of the Mg_3Ni_2 amphibole (Table 13) are consistent with the simple replacement of 2Mg by 2Ni in the octahedral strip. Because the ionic radius of Ni (0.69 Å) is smaller than that of Mg (0.72 Å), the cell volume of the Mg_3Ni_2 amphibole should be slightly smaller than that of endmember tremolite. Note, however, the large increase in the $\underline{a}$-parameter.

Substitution of Ca_2 by Cd_2

Tremolite synthesis with Ca in the M(4) site replaced by Cd was not successful. About 30 percent clinoamphibole was obtained whose cell dimensions are more like cummingtonite than tremolite. The presence of monteponite (CdO) suggests that the amphibole has little, if any, Cd.

Fluor-tremolite: $^{\square}Ca_2Mg_5Si_8O_{22}F_2$

Neither isothermal (Table 11) nor non-isothermal experiments (Table 12) yielded close to 100 percent amphibole. Best yields were about 70 to 80 percent. Isothermal experiments produced prismatic crystals up to 0.05 mm in length; in non-isothermal runs, spectacular crystals up to 1.0 mm were routinely obtained. In spite of this large contrast in growth habit, cell dimensions of these amphiboles were almost identical (Table 13) and are very similar to those determined by previous workers (Table 6) who claimed yields as high as 95 percent.

High yields of amphibole resulted only from starting mixes with SiO_2 added as Corning 7940 silica glass. Furthermore, yields were higher if $CaCO_3$ was decarbonated after mixing with the other components, rather than before. During decarbonation, the mix partially crystallized to diopside and $Mg_5F_2(SiO_4)_2$. Apparently such a mixture promotes amphibole nucleation and growth. Prior to this discovery, fluor-tremolite mixes were prepared with dehydrated $H_2SiO_3 \cdot nH_2O$ or cristobalite instead of silica glass. Runs with these mixes failed to produce significant amounts of amphibole; products were dominated by tridymite, quartz, diopside and fluorite.

Edenite: $NaCa_2(Mg,Ni)_5Si_7AlO_{22}(OH)_2$

$NaCa_2Mg_5Si_7AlO_{22}(OH)_2$

Edenite was not synthesized. All runs produced <5 percent amphibole with abundant clinopyroxene, forsterite, plagioclase and traces of quartz. A layer silicate ("ly" in Table 11) with basal spacing about 11.2 Å was present in all runs. Also present was an unidentified phase

with prominent X-ray peaks corresponding to d-spacings of 2.60 and 2.43 Å. Dry mixes and gels yielded identical results.

Substitution of Ni_5 for Mg_5

Replacement of Mg_5 by Ni_5 in the edenite formula resulted in increased amphibole yields (30 to 40 percent). Other phases were the same, or Ni-bearing equivalents of phases in endmember edenite runs.

Fluor-edenite: $NaCa_2Mg_5Si_7AlO_{22}F_2$

Fluor-edenite syntheses were generally successful. At least 90 percent yields were obtained from starting mixes prepared with silica glass; as for fluor-tremolite, mixes prepared with $H_2SiO_3 \cdot nH_2O$ did not grow significant amphibole. Largest crystals (up to 1 to 2 mm in length) were obtained in non-isothermal runs.

Pargasite: $(Na,K)(Ca,Cd)_2(Mg,Ni)_4(Al,Cr,Ga,Sc,In)\ Si_6(Al,Ga)_2O_{22}(OH)_2$

$NaCa_2Mg_4AlSi_6Al_2O_{22}(OH)_2$

Pargasite synthesized readily with yields of 80 to 95 percent. Best results were obtained at 800 to 900°C and 2 to 3 kb. Pargasite formed clear, colourless prisms up to 40 microns long and 8 microns wide. Run length had little effect on grain size and yield; runs of 25 h and 1126 h had similar yields, grain size and infrared spectra (see Chapter 5). Amphibole yields were similar in syntheses from dry mixes as opposed to gels, but crystals grown from gels were more acicular in habit. Gehlenite, however, was a prominent minor phase in runs with gels. Cell dimensions (Table 13) of these pargasites are consistent with one another and agree well with previous work (Table 5).

Substitution of Mg_4Al by Mg_4Cr

Substitution of Cr for octahedral Al reduced amphibole yields to about 80 percent. Chromium-pargasite formed pale green, slightly pleochroic prisms up to 24 microns long and 1 to 2 microns wide. Overall grain size is finer than pargasite, and crystals tend to be more acicular in habit. Abundant eskolaite (Cr_2O_3) in all runs suggests that the amphibole is not on composition; the amounts of Cr in clinopyroxene and spinel are uncertain. Cell dimensions (Table 13) of three typical runs were similar with cell volumes 4 to 6 $Å^3$ larger than pargasite. The increase in volume is due almost entirely to an increase in b, suggesting that substantial amounts of Cr have replaced Al in the octahedral strip.

Substitution of Mg_4Al by Mg_4Ga

Poor amphibole yields (20 to 30 percent) were obtained at 1 kbar and temperatures less than 800°C; the run product was mostly clinopyroxene with minor plagioclase, forsterite, nepheline and three different layer silicates with basal spacings of 14.8, 12.2 and 9.8 Å. Raising either the pressure to 2 kbar or the temperature above 800°C, increased amphibole yields to more than 90 percent. Amphibole formed clear, colourless crystals up to 15 microns long and 2 to 4 microns wide. Layer silicates were not present. The amphibole grown at 758°C, 1 kbar, has cell dimensions that are edenitic in character, rather than pargasitic (lower a, ß, higher b). Apparently little Ga, if any, was incorporated into the octahedral sites. At 817°C, 2.1 kbar, the cell dimensions of the amphibole are very similar to those of Cr-pargasites (Table 13). Because the ionic radii of Cr (0.615 Å) and Ga (0.620 Å) in octahedral coordination are almost identical, this similarity probably reflects the same degree

of Cr/Ga substitution for Al in these amphiboles. Ga not in amphibole probably replaces Al in plagioclase or, where present, in layer silicates.

Substitution of Mg_4Al by Mg_4Sc

Sc-pargasite synthesized readily but yields were never more than about 90 percent. Amphibole formed clear, colourless crystals up to 11 microns long and 1 to 2 microns wide (Figure 5). Sc_2O_3 was a minor phase in all run products, indicating that the amphibole was off-composition. Cell dimensions (Table 13) show that the amount of Sc in octahedral sites is high; the cell volume of Sc-pargasite is about 15 $Å^3$ larger than that of pargasite.

Substitution of Mg_4Al by Mg_4In

About 90 percent yields of amphibole were obtained in 2 kbar runs. Amphibole formed pale yellow, faintly pleochroic crystals up to 8 microns long and 1 micron wide. Although the cell volume of this amphibole (Table 13) is about 9 $Å^3$ larger than that of pargasite, it is 6 $Å^3$ smaller than that of Sc-pargasite, indicating only partial substitution of In for Al in the octahedral strip. Furthermore, all run products contained unreacted In_2O_3.

Substitution of Mg_4Al by Ni_4Al

Two runs were attempted with Ni_4 substituted for Mg_4, one with no oxygen fugacity control, the other on the CT buffer. Amphibole yields were about 10 percent in both runs.

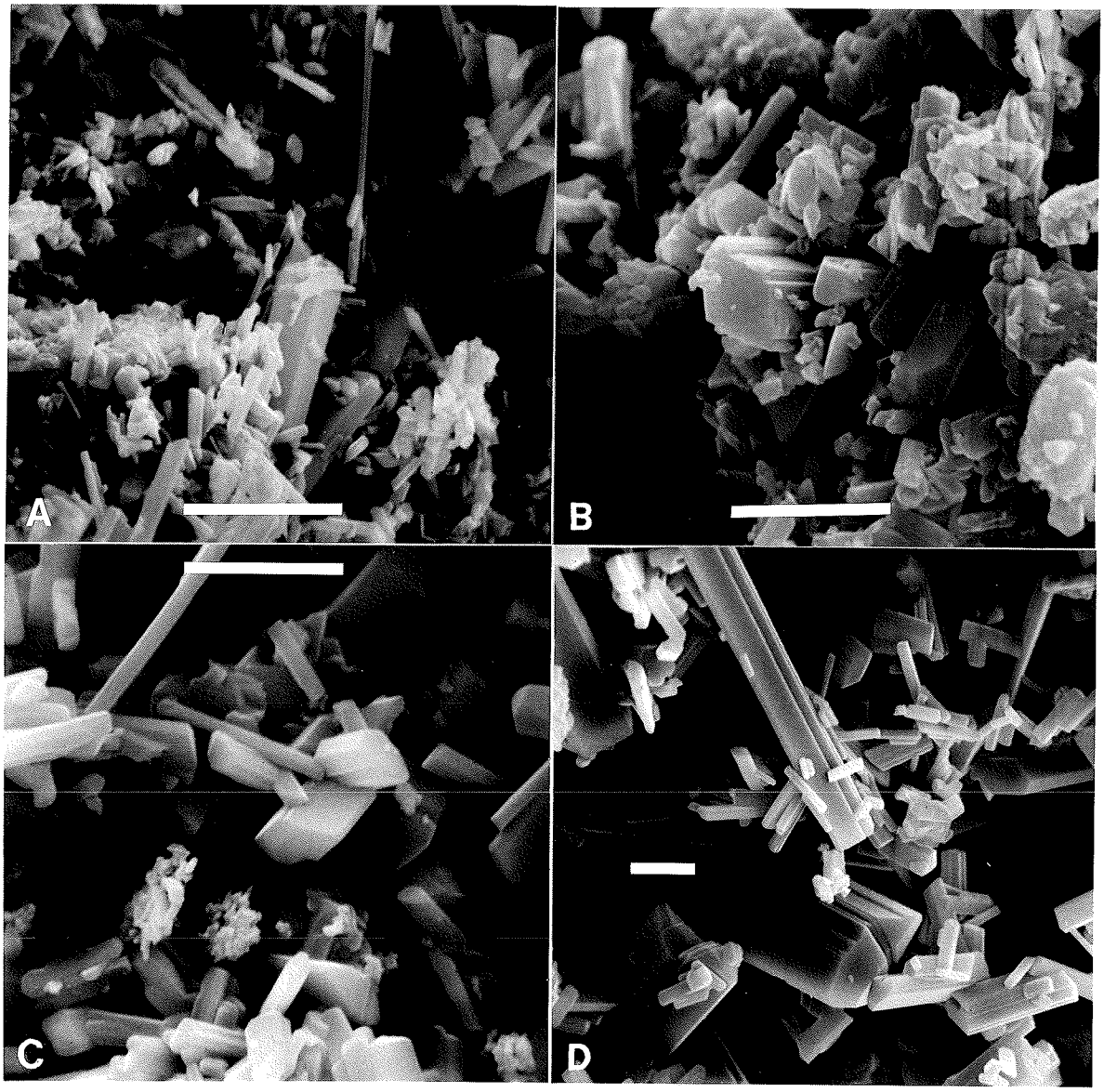

Figure 5: Scanning electron micrographs of synthetic pargasites and fluor-pargasites. A: scandium-pargasite (ScPA-A5,6). B: fluor-pargasite (FPA-BUL). C: chromium-fluor-pargasite (FCrPA-A3a). D: gallium-fluor-pargasite (FGaPA-A3a). Numbers in parentheses correspond to run numbers in Table 11. Scale bar represents 1 micron.

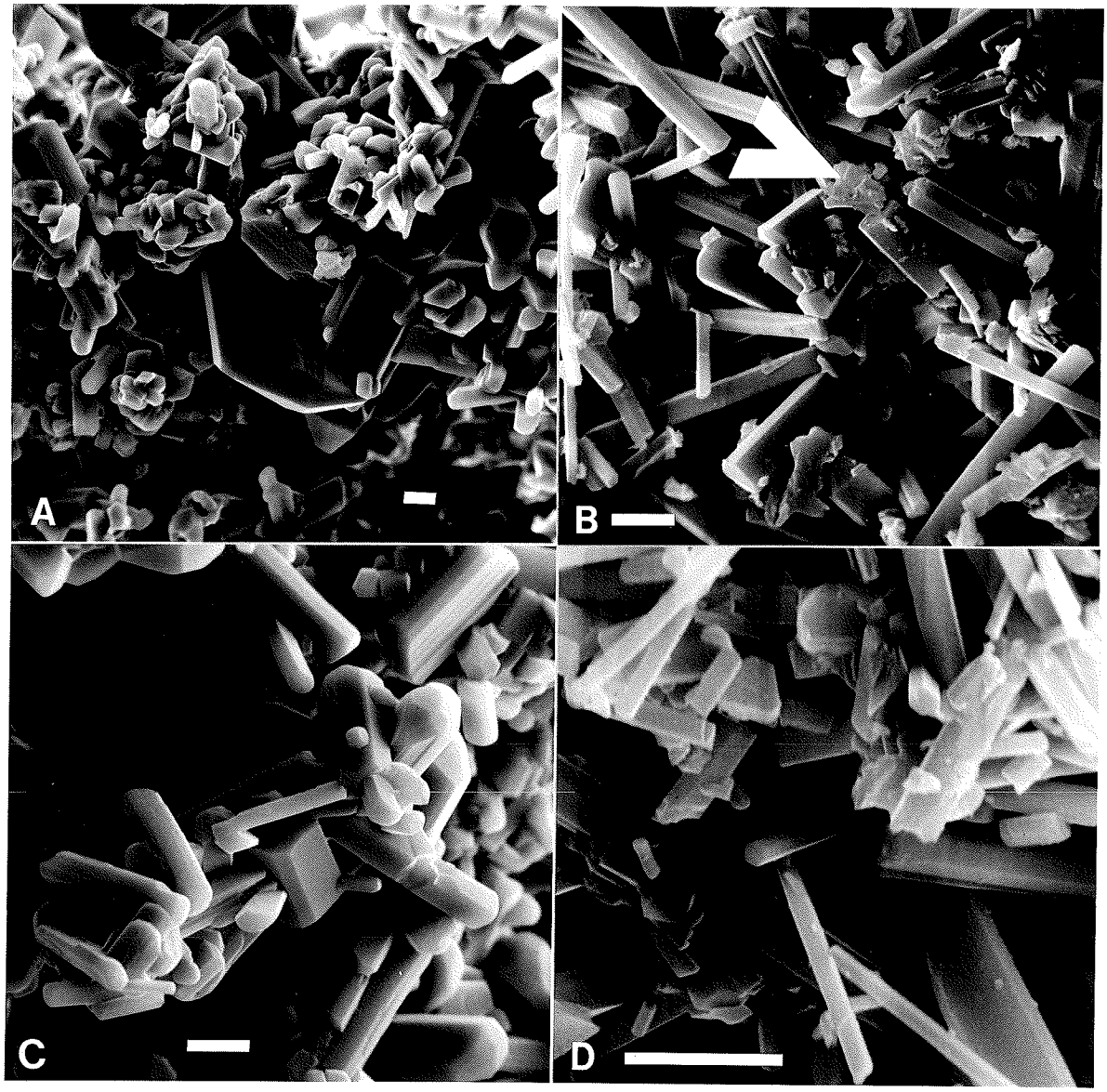

Figure 6: Scanning electron micrographs of synthetic fluor-pargasite, fluor-eckermannites and fluor-nyböite. A: scandium-fluor-pargasite (FScPA-A1). B: scandium-fluor-eckermannite (FScEC-A1). C: indium-fluor-eckermannite (FInEC-A1). D: scandium-fluor-nyböite (FScNY-A3). Numbers in parentheses correspond to run numbers in Table 11. Scale bar represents 1 micron. Arrow in B points to layer silicates.

Substitution of $Mg_4AlSi_6Al_2$ by $Mg_4GaSi_6Ga_2$

Replacement of both octahedral and tetrahedral Al by Ga was unsuccessful; amphibole yields were less than 10 percent. Ga apparently does not assume tetrahedral coordination in pargasite.

Substitution of Na by K

Replacement of Na in the A-site by K was not accomplished; both runs yielded less than 10 percent amphibole.

Substitution of Ca_2 by Cd_2

No significant amphibole was produced.

Fluor-pargasite: $\underline{NaCa_2Mg_4}(\underline{Al},\underline{Cr},\underline{Ga},\underline{Sc})\underline{Si_6Al_2O_{22}F_2}$

$NaCa_2Mg_4AlSi_6Al_2O_{22}F_2$

All runs on the fluor-pargasite mix prepared with Corning silica glass as SiO_2 source yielded >90 percent amphibole. Mixes prepared with $H_2SiO_3 \cdot nH_2O$ failed to grow amphibole. Fluor-pargasite formed clear, colourless crystals up to 16 microns long and 4 microns wide in isothermal runs (Figure 5). Non-isothermal runs produced large crystals between 0.02 and 1 mm in length. In both types of experiments, products were similar except for minor fluorite in non-isothermal experiments. Cell dimensions of amphiboles with either cooling history are similar (Table 13).

Substitution of Mg_4Al by Mg_4Cr

As in Cr-hydroxy-pargasite, Cr substitution reduced yields to about 80 percent in isothermal runs. Little amphibole was formed in the single

non-isothermal run. Cr-fluor-pargasite formed pale green, slightly pleochroic, blocky to prismatic crystals up to 18 microns long and 6 microns wide (Figure 5). Cell volume is 3 to 4 $Å^3$ larger than that of fluor-pargasite. This increase is due mainly to an increase in b, suggesting Cr occupancy in the octahedral strip.

Substitution of Mg_4Al by Mg_4Ga

Ga-fluor-pargasite formed about 85 to 90 percent blocky to prismatic, clear, colourless crystals up to 14 microns long and 5 microns wide in isothermal experiments (Figure 5). Larger crystals to 0.5 mm long were formed in non-isothermal runs. Cell dimensions were not affected by run history and are similar in both runs. The cell dimensions of an isothermal run analysed by the Rietveld method are systematically larger than the other two; it may have more Ga substituted for Al than the other two (see Chapter 5).

Substitution of Mg_4Al by Mg_4Sc

Sc-fluor-pargasite formed about 85 to 95 percent blocky to prismatic, grains up to 23 microns long and 5 to 16 microns wide. Figure 6 shows the wide variation in morphology. The single non-isothermal run grew crystals up to 0.5 mm in length but yielded only about 75 percent amphibole. The cell volume is about 20 $Å^3$ larger than that of fluor-pargasite which, suggests that most of the octahedral Al was replaced by Sc. Note that the volume of scandium-fluor-pargasite is larger by about 1 $Å^3$ than that of scandium-pargasite. As the volume of hydroxy-amphibole should be larger than that of its fluorine analogue, it is probable that the scandium-pargasite has a lower Sc-occupancy than the fluor-scandium-pargasite (see Chapter 5).

Tschermakite: $^{\square}Ca_2Mg_3(Cr,Sc)_2Si_6Al_2O_{22}(OH)_2$

Syntheses on the endmember tschermakite composition (Mg_3Al_2) were not attempted because previous work clearly shows that this amphibole does not grow at low pressures (see Chapter 2). Replacement of octahedral Al by either Cr or Sc also did not yield amphibole at 1 kbar; both run products were dominated by clinopyroxene and anorthite.

Fluor-tschermakite: $^{\square}Ca_2Mg_3Al_2Si_6Al_2O_{22}F_2$

Runs on the fluor-tschermakite composition also failed to grow amphibole. Products were dominated by anorthite, clinopyroxene and cristobalite.

Alumino-magnesio-hornblende: $^{\square}Ca_2Mg_4AlSi_7AlO_{22}(OH)_2$

Abundant amphibole on this composition was difficult to synthesize. At, or near 1 kbar pressure, amphibole yields varied between 10 and 30 percent; the remainder of the products was mainly clinopyroxene and anorthite. At 2 to 3 kbar, yields improved but did not exceed about 55 percent. Forsterite was present in all runs and at temperatures above 830°C coexisted metastably with quartz. Talc, and rarely chorite, appeared below 720°C. Talc was also present in a run (HB-A9, Table 11) which was aborted after 2 h at 840°C and 2.5 kbar because of a pressure leak. This experiment suggests that talc formed early in the run-up stage and reacted out at high temperature. Amphibole in these runs formed clear, colourless prisms less than 10 microns long and 0.5 microns wide. No significant differences in products were observed in runs with gel starting mixes as compared to dry mixes, except that the former tended to be not as well crystallized. Grinding run products and

rerunning increased neither the yield nor the grain size (HB-B1, Table 11). Cell dimensions (Table 13) of amphiboles grown on the alumino-magnesio-hornblende composition are intermediate to those of synthetic tremolite and tschermakite (Table 5). Because there is no cation in this composition that can occupy the A-site, and other cation substitutions are limited by charge balance to the stoichiometric formula, these amphiboles are probably close to the nominal composition, in spite of low yields. Any minor deviations from the nominal composition would be most likely the result of magnesio-cummingtonite solid solution.

Substitution of Mg_4 by Ni_4

Runs in Au capsules without any attempt to control oxygen fugacity failed to produced amphibole. Run products were mainly clinopyroxene, anorthite, quartz, Ni and minor olivine. On the MH buffer, however, about 10 to 20 percent amphibole was present along with abundant willemseite, clinopyroxene, anorthite, quartz and traces of olivine.

Substitution of Mg_4Al by $Mg_4(Cr,Sc,Ti,V)$

High amphibole yields were not achieved by substituting Cr, Ga ,Sc, Ti or V for octahedral Al. Amphibole yields varied from less than 5 to 60 percent. Highest yields were achieved in the 3 kbar runs.

Fluor-alumino-magnesio-hornblende: $\square Ca_2Mg_4AlSi_7AlO_{22}F_2$

Fluor-alumino-magnesio-hornblende was also difficult to synthesize. Mixes prepared with $H_2SiO_3 \cdot nH_2O$ failed to grow more than about 20 percent amphibole. Low-cristobalite and anorthite were the major phases in these runs. Runs with mixes prepared from Corning 7940 silica glass

yielded up to about 60 to 70 percent clear, colourless, prismatic amphibole crystals less than 5 to 10 microns long. Highest yields were obtained in cold-seal hydrothermal vessels pressurized to 3 kbar with Ar. Non-isothermal runs grew large crystals (up to 0.5 mm) of both clinopyroxene and amphibole. Amphibole yields in these runs did not exceed 50 to 60 percent.

Kaersutite: $NaCa_2Mg_4TiSi_6Al_2(O+OH)_{24}$

Runs on the kaersutite composition failed to grow amphibole.

SODIC-CALCIC AMPHIBOLES

Richterite: $(K,Na)(Ca,Cd,Na)(Mg,Ni,Mn,Cu)_5\ Si_8O_{22}(OH)_2$

$NaCaNaMg_5Si_8O_{22}(OH)_2$

Richterite was synthesized readily with greater than 95 percent yield. Minor diopside was the only other phase identified in the run product. Richterite formed clear, colourless prisms up to 36 microns long and 11 microns wide (Figure 7). Cell dimensions (Table 13) of synthetic richterite grown in this study are virtually identical to those of Heubner and Papike (1970) and Charles (1974) (Table 5).

Subsitution of Mg_5 by Ni_5

Replacing Mg_5 by Ni_5 also yielded about 95 percent amphibole. Runs were performed in Au capsules without attempting to control oxygen fugacity. Reducing conditions were implied by the presence of metallic Ni in the run products. Clinopyroxene was rare, but the presence of Ni suggests that the amphibole contains less than 5Ni. Nickel-richterite formed pale green, slightly plechroic, acicular crystals up to 35 microns long

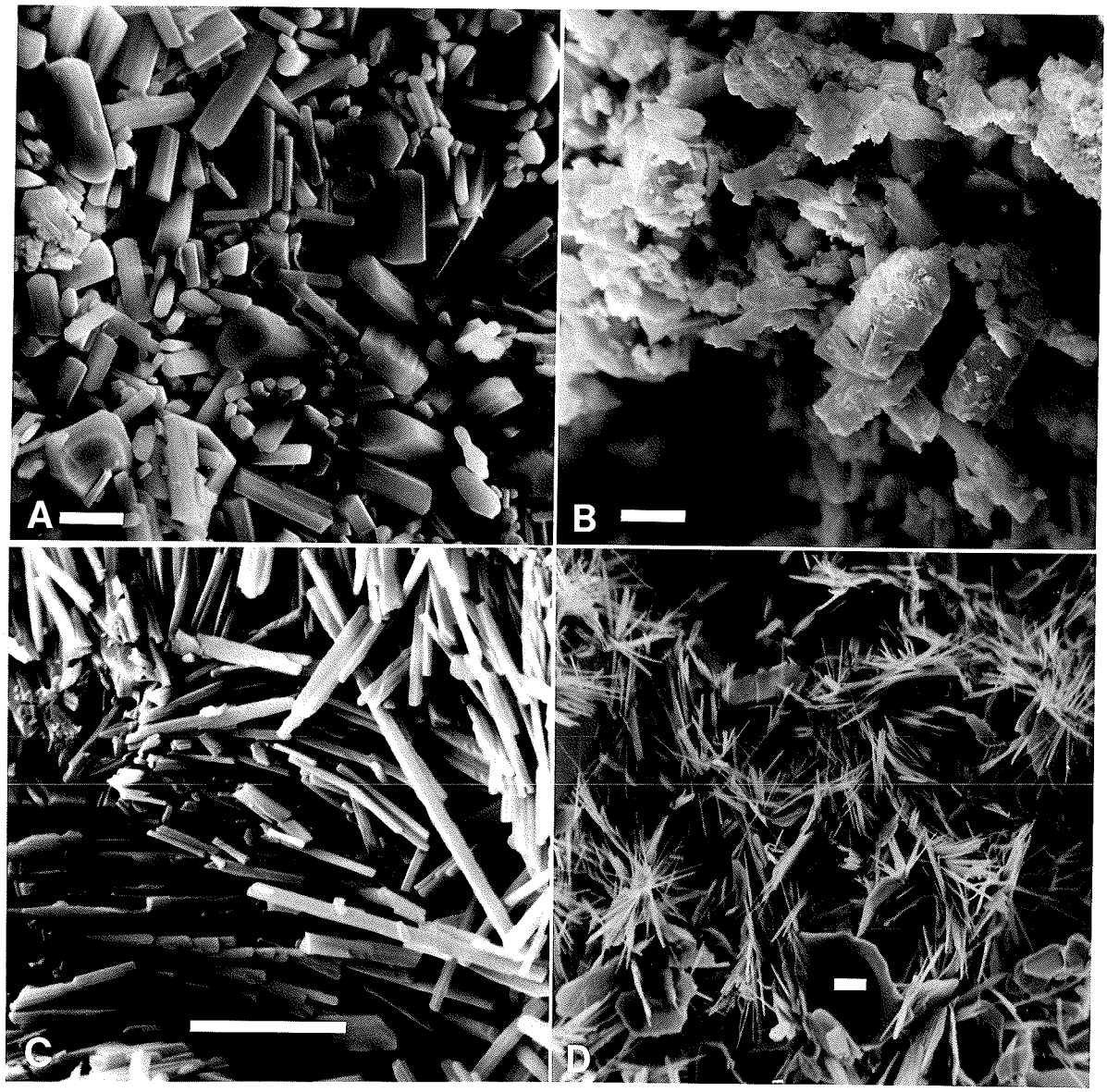

Figure 7: Scanning electron micrographs of synthetic richterites and sodian magnesio-cummingtonites. A: $KNaCaMg_5Si_8O_{22}(OH)_2$ (KRC-A1). B. $NaCaNaMg_4MnSi_8O_{22}(OH)_2$ (Mg4MnRC-A2). C: $NaMgNaMg_5Si_8O_{22}(OH)_2$ (MgRC-A1). D: $NaNiNaNi_5Si_8O_{22}(OH)_2$ (NiMgRC-A2). Numbers in parentheses correspond to run numbers in Table 11. Scale bar represents 1 micron.

and 3 microns wide. The cell volume (Table 13) is about 7 $Å^3$ less than that of richterite, which is consistent with substantial replacement of Mg by Ni.

Substitution of Mg_5 by Mg_3Ni_2

Richterite with this composition grew with yields slightly below that of richterite and Ni-richterite: about 90 percent. It formed pale green, slightly pleochroic, acicular crystals up to 25 microns long and 4 microns wide but not as acicular as the Ni-endmember. In addition to amphibole, clinopyroxene and metallic Ni were present; excess Ni indicates that there must be less than 3Ni in the octahedral strip. The cell volume (Table 13) is about 3 $Å^3$ less than that of richterite and about 3 $Å^3$ larger than that of endmember Ni-richterite.

Substitution of Mg_5 by Mn_5

Attempts to grow richterite with all Mg replaced by Mn failed both in unbuffered runs and in runs on the NNO buffer. Less than 5 percent amphibole was observed.

Substitution of Mg_5 by Mg_4Mn

Greater than 95 percent yields of amphibole resulted from both unbuffered runs and from runs on the NNO buffer. Mn-bearing richterite formed very pale yellow-pink, prismatic crystals up to 18 microns long and 7 microns wide. The crystals are not as well formed as richterite and exhibit a much larger variation in grain size (Figure 7). The cell volume (Table 13) is 8 $Å^3$ larger than that of richterite, evidence for Mn occupancy. Clinopyroxene was the only other phase detected in the run product.

Substitution of Mg_5 by Mg_3Mn_2

Runs on this compositition produced about 90 percent amphibole with physical properties essentially identical to those of the Mg_4Mn composition. Cell volume increased to 920.6 $Å^3$ in response to the higher Mn-content. This increase, however, is less than half the increase from richterite to Mg_4Mn composition, suggesting that there is less than 2Mn in this amphibole and that it is, therefore, not on composition.

Substitution of Mg_5 by Cu_5

No amphibole was grown on this composition. The run product comprised abundant cuprorivaite ($CaCuSi_4O_{10}$), tenorite (CuO) and minor chlorite.

Substitution of A-site Na by K

Virtually 100 percent amphibole was grown on this composition; no other phases were detected. K-richterite formed clear, colourless, short and stubby to prismatic crystals up to 20 microns long (Figure 7). The cell dimensions (Table 13) are essentially identical to those of Huebner and Papike (1970) (Table 5).

Substution of Ca by Cd

Substitution of Ca by Cd yielded about 95 percent clinoamphibole but with cell dimensions (Table 13) unlike those of all other richterites. Note especially the low $\underline{a}$, β, and $\underline{V}$ parameters that are similar to sodian magnesio-cummingtonites (Tables 13, 5). Furthermore, the infrared spectrum of this amphibole is identical to that of sodian magnesio-cummingtonite (see Chapter 5). Although it would seem unlikely that this amphibole contains Cd, no Cd-bearing phases were detected either optically or by powder X-ray diffractometry.

Fluor-richterites: $NaCaNa(Mg,Mn)_5Si_8O_{22}F_2$

$NaCaNaMg_5Si_8O_{22}F_2$

Fluor-richterite mixes prepared with $H_2SiO_3 \cdot nH_2O$ as the silica source did not yield significant amphibole. Mixes prepared with Corning 7940 silica glass grew up to 90 percent amphibole, the remainder being clinopyroxene and forsterite. Fluor-richterite crystals were very-fine grained (<10 microns) and blocky to prismatic in habit. The cell volume is about 10 $Å^3$ less than that of richterite; an amount consistent with most hydroxy-/fluor-amphibole cell differences except for pargasites (see Chapter 6). Non-isothermal runs produced similar results except for grain sizes up to 0.5 mm.

Substitution of Mg_5 by Mg_4Mn

Amphibole yield was about 95 percent, the remainder being clinopyroxene. Mn-bearing fluor-richterite formed pale-yellow, stubby prisms up to 30 microns long and 13 microns wide. The cell volume (Table 13) is about 11 $Å^3$ less than that of the hydroxy-analogue; this is comparable to the 10 $Å^3$ difference between fluor-richterite and richterite.

Alumino-winchite: $\square CaNaMg_4(Al,Cr,Sc)Si_8O_{22}(OH)_2$

Alumino-winchite could not be synthesized at pressures near 1 kbar, either from dry mixes or gels. No more than 20 to 30 percent clinoamphibole was grown under these conditions. Clinopyroxene, plagioclase and quartz and/or cristobalite dominated run products. Substitution of Cr for octahedral Al was also unsuccessful; Sc substitution yielded up to 40 to 50 percent amphibole, but not enough for adequate characterization.

Fluor-Alumino-winchite: $^{\square}CaNaMg_4AlSi_8O_{22}F_2$

Fluor-alumino-winchite synthesis attempts were no more successful than experiments on the hydroxy-equivalent compositions. Unlike previously discussed fluor-amphiboles, the nature of the starting mix was irrelevant to the results. Similarly poor yields obtained from mixes prepared with $H_2SiO_3 \cdot nH_2O$ or Corning 7940 silica glass. Some improvement in yield was obtained when $CaCO_3$ was decarbonated along with other mix components rather than before mixing; amphibole yields increased from nil to about 20 to 30 percent. Best yields (about 40 to 50 percent) were obtained in non-isothermal runs, but not sufficient for adequate characterization.

Magnesio-alumino-katophorite: $NaCaNaMg_4(Al,Cr,Sc)Si_7AlO_{22}(OH)_2$

Poor yields were obtained for all magnesio-alumino-katophorite compositions. Substitution of Cr and Sc for octahedral Al increased yields to about 40 percent.

Alumino-barroisite: $^{\square}CaNaMg_3(Cr,Sc)_2Si_7AlO_{22}(OH)_2$

Attempts to grow alumino-barroisite with octahedral Al replaced by Cr or Sc failed to produce more than about 5 to 10 percent amphibole. Runs on the endmember alumino-barroisite composition were not attempted because the aluminous endmembers of previous sodic-calcic amphibole syntheses had been more difficult to grow than Cr- or Sc-bearing ones.

Fluor-alumino-barroisite: $^{\square}CaNaMg_3Al_2Si_7AlO_{22}F_2$

Both isothermal and non-isothermal experiments on the fluor-alumino-barroisite composition failed to grow detectable amphibole.

Fluor-magnesio-alumino-katophorite:
$NaCaNaMg_4(Al,Cr,Ga,Sc,Ti,V)Si_7AlO_{22}F_2$

$NaCaNaMg_4AlSi_7AlO_{22}F_2$

Fluor-magnesio-alumino-katophorite syntheses produced amphibole yields between 20 and 80 percent; highest yields were in non-isothermal runs. The ubiquitous presence of abundant accessory phases, however, showed that the amphiboles grown are considerably off-composition and not suitable for characterization.

Substitution of Mg_4Al by $Mg_4(Cr,Ga,Sc,Ti,V)$

Although yields between 60 and 80 percent were obtained for amphiboles grown with these substitutions for octahedral Al, the presence of phases containing Cr, Ga, Sc, Ti and V indicate that the amphiboles are not of the nominal compositions.

Magnesio-alumino-taramite: $NaCaNaMg_3(Cr,Sc)_2Si_6Al_2O_{22}(OH)_2$

Runs with Cr and Sc replacing octahedral Al in the magnesio-alumino-taramite formula were unsuccessful; only 20 to 30 percent amphibole was grown.

Fluor-magnesio-alumino-taramite: $NaCaNaMg_3Al_2Si_6Al_2O_{22}F_2$

Runs on the fluor-magnesio-alumino-taramite composition failed to yield more than about 5 percent amphibole.

ALKALI AMPHIBOLES

Magnesio-riebeckite: $\square Na_2Mg_3(Cr,Ga,Sc)_2Si_8O_{22}(OH)_2$

Attempts to grow amphibole by replacing Fe^{3+}_2 with Cr, Ga or Sc failed. Amphibole yields were less than 30 or 40 percent. Sc-mix gave the highest yields.

Eckermannite: $NaNa_2Mg_4(Al,Cr,Ga,Sc,In)Si_8O_{22}(OH)_2$

$NaNa_2Mg_4AlSi_8O_{22}(OH)_2$

Runs on the endmember eckermannite composition grew virtually 100 percent clear, colourless amphibole crystals up to 35 microns long and 10 microns wide. No other phases were observed in the powder X-ray pattern. The cell dimensions (Table 13) of this amphibole are very close to those of sodian magnesio-cummingtonite, which suggests that it was synthesized, rather than eckermannite. Furthermore, the infrared spectrum of this amphibole is almost identical to that of sodian magnesio-cummingtonite (see Chapter 5). This means that the amphibole is Al-free, but no Al-bearing phases were detected.

Substitution of Al by Ga, Cr, Sc and In

Runs on the eckermannite composition with the above substitutions for the octahedral Al grew between 50 and 85 percent amphibole. None of these amphiboles, however, was suitable for detailed characterization because of the presence of other phases with Ga, Cr, Sc and In as constituents which implied that the amphiboles are off-composition.

Fluor-eckermannite: $NaNa_2Mg_4(Al,Ga,Cr,Sc,In)Si_8O_{22}F_2$

$NaNa_2Mg_4AlSi_8O_{22}F_2$

Isothermal runs on the fluor-eckermannite endmember composition grew greater than 90 percent amphibole with minor albite, forsterite and layer silicate with basal spacing of about 9.54 Å. This amphibole formed clear, colourless, prismatic to acicular crystals up to 15 microns long and 1 to 3 microns wide. Non-isothermal runs gave lower yields (about 80 percent) with nepheline and NaF in addition to albite, forsterite and layer silicate. The cell volume (Table 13) is 10.5 $Å^3$ less than the hydroxy equivalent, an amount typical of the difference between fluor- and hydroxy-amphiboles. However, these cell parameters are very similar to those of sodian magnesio-fluor-cummingtonite and it is unlikely that the amphibole is actually fluor-eckermannite.

Substitution of Al by Cr

Greater than 90 percent of pale green, prismatic amphibole with crystals up to 10 microns long and 3 microns wide were obtained. However, the presence of magnesio-chromite and eskolaite argue against complete substitution of Al by Cr. The cell dimensions (Table 13) are unlike those of sodian magnesio-fluor-cummingtonite; note especially larger a and β. Althought the volumes are similar, the amphibole is probably intermediate in composition between chromium-fluor-eckermannite and sodian magnesio-fluor-cummingtonite.

Substitution of Al by Ga

Runs on this composition yielded greater than 90 percent, clear, colourless amphibole with acicular crystals up to 30 microns long and 4 mi-

crons wide. The only other phase detected was a layer silicate with basal spacing of about 9.66 Å. The cell parameters (Table 13) are closer in magnitude to those of sodian magnesio-fluor-cummingtonite than the Cr-bearing variety, but the slightly larger a, ß and volume suggest that minor Ga was incorporated during growth.

Substitution of Al by Sc

Yields of more than 95 percent were obtained in isothermal runs with probable traces of $NaScSi_2O_6$; non-isothermal runs also grew clinoenstatite and forsterite. The amphibole was extremely fibrous with individual fibres greater than 100 microns long and only about 2 microns in diameter. Scanning electron micrographs (Figure 6) do not show the fibrous character because the fibers are very brittle and break easily into shorter lengths. The cell volume (Table 13) is 15 to 16 $Å^3$ larger than that of chromium-fluor-eckermannite which, along with the very high yield, suggests that Sc substitution was essentially complete (see Chapter 5 for occupancies). The remaining cell parameters, most importantly ß, are analogous to those of natural eckermannites (cf. Kempe 1969).

Substitution of Al by In

Essentially 100 percent amphibole was obtained in these runs; no other phases were detected. Indium-fluor-eckermannite formed clear, colourless, prismatic crystals up to 25 microns long and 4 microns wide (Figure 6). Cell dimensions are typically like those of natural eckermannites (cf. Kempe 1969). Detailed occupancies are given in Chapter 5.

Nyböite: $NaNa_2Mg_3(Al,Cr,Sc,In)_2Si_7AlO_{22}(OH)_2$

$NaNa_2Mg_3Al_2Si_7AlO_{22}(OH)_2$

Runs on the nyböite endmember composition failed to grow amphibole. This probably reflects the fact that nyböite is only stable at high pressures (Carman and Gilbert 1983).

Substitution of Mg_3Al_2 by $Mg_3(Cr,Ga,Sc,In)_2$

Runs with these compositions grew between 40 and 80 percent amphibole, but the low yields and presence of phases containing Cr, Ga, Sc and In demonstrate that these amphiboles are considerably off-composition. Attempts to grow nyböite with both octahedral and tetrahedral Al replaced by Ga failed completely.

Fluor-Nyböite: $NaNa_2Mg_3Sc_2Si_7AlO_{22}F_2$

These runs yielded greater than 90 percent amphibole with minor $NaScSi_2O_6$. Scandium-fluor-nyböite generally formed clear, colourless, extremely fibrous crystals up to 100 microns long and about 1 micron wide; more prismatic crystals measuring about 40 microns long and 10 microns wide are also present (Figure 6).

IRON-MAGNESIUM-MANGANESE AMPHIBOLES

Sodian magnesio-cummingtonite: $NaMgNa(Mg,Ni)_5Si_8O_{22}(OH)_2$

$NaMgNaMg_5Si_8O_{22}(OH)_2$

Sodian magnesio-cummingtonite grows readily with yields greater than 95 percent. The only other phase detected in the run product was forsterite. These amphiboles form clear, colourless, extremely acicular crystal up to 18 microns long, but generally less than 1 or 2 microns wide

(Figure 7). Cell dimensions (Table 13) compare well with those of sodian magnesio-cummingtonite grown by Witte et al. (1969) but are markedly different from those by Grebenschikov et al. (1975).

Substitution of $NaMgNaMg_5$ by $NaNiNaNi_5$

This substitution in the endmember sodian magnesio-cummingtonite formula yielded about 50 to 60 percent amphibole in runs on the CT buffer. The remainder of the run was willemseite. The amphibole formed pale amber, extremely fibrous needles less than 30 microns long and less than 1 microns wide (Figure 7). The cell volume (Table 13) is about 7 $Å^3$ less than that of endmember sodian magnesio-cummingtonite; this is the same as the difference in cell volumes of richterite and Ni-richterite. Unbuffered runs did not grow amphibole; the products consisted of abundant willemseite, Ni and quartz.

Sodian fluor-magnesio-cummingtonite: $NaMgNaMg_5Si_8O_{22}F_2$

Isothermal runs on this composition produced only about 30 to 40 percent amphibole; the run product was dominated by cristobalite and minor clinoenstatite and tridymite. Non-isothermal runs yielded up to about 70 percent amphibole with abundant clinoenstatite and minor cristobalite and tridymite. The cell dimensions (Table 13) are different from those of Gibbs et al. (1962); in particular the volume is smaller. It is probable that the amphibole grown is off-composition.

TABLE 11

Run Data: Isothermal Experiments

Run Number	T (deg)	P (bar)	t (h)	Products[1]
				Silicate Hydroxy-amphiboles
				Calcic Amphiboles
				□$Ca_2Mg_5Si_8O_{22}(OH)_2$
TR-A1	795	1000	332	di+qtz+crs+trd+en?
TR-A5	810	1000	445	di+qtz+en
				□$Ca_2Ni_5Si_8O_{22}(OH)_2$
NiTR-A1	793	1000	68	Nidi+crs+qtz+trd+cam+Ni+wil
NiTR-A2	801	2000	25	Nidi+crs+qtz+trd+cam+Ni+wil
				□$Ca_2Mg_3Ni_2Si_8O_{22}(OH)_2$
Mg3Ni2TR-A1	783	2000	51	MgNidi+qtz+cam+Ni+tlc
				□$Cd_2Mg_5Si_8O_{22}(OH)_2$
CdTR-A2	742	1000	91	qtz+cum+fo+en+mpt+tlc
				$NaCa_2Mg_5Si_7AlO_{22}(OH)_2$
ED-A1	770	1000	47	cpx+fo+pl+qtz+cam+ly+?
GED-A1	803	1000	92	cpx+fo+pl+qtz+cam+ly+?
GED-A2	811	2000	42	cpx+fo+pl+qtz+cam+ly+?
GED-A4	820	1000	67	cpx+fo+pl+qtz+cam+ly+?
				$NaCa_2Ni_5Si_7AlO_{22}(OH)_2$
NiED-A1	782	1000	26	cpx+cam+ly+ol+pl+?
				$NaCa_2Mg_4AlSi_6Al_2O_{22}(OH)_2$
PA-A1*	890	1000	155	cam+cpx+fo+pl+ne+spl?
PA-A2*	840	1-2kbar	384	cam+cpx+fo+pl+ne+spl?
PA-A2A*	500	1000	891	cam+cpx+fo+pl+ne+spl? (PA-A2 product rerun)
PA-A3*	923	1000	52	cam+cpx+fo+pl+ne+spl?
PA-A4*	865	1000	381	cam+cpx+fo+pl+ne+spl?
PA-A5*	865	1000	381	cam+cpx+fo+pl+ne+spl?
PA-A6*	923	1000	52	cam+cpx+fo+pl+ne+spl?
PA-A7*	890	1000	155	cam+cpx+fo+pl+ne+spl?
PA-A8*	840	1-2k	384	cam+cpx+fo+pl+ne+gh
PA-A8A*	590	1000	891	cam+cpx+fo+pl+ne+gh (PA-A8 product rerun)
PA-A8B*	400	1000	891	cam+cpx+fo+pl+ne+gh (PA-A8 product rerun)
PA-A9*	801	1000	1126	cam+cpx+fo+pl+ne+gh+spl?

Run Number	T (deg)	P (bar)	t (h)	Products
PA-A10*	801	1000	1126	cam+cpx+fo+pl+ne+spl?
PA-A11*	917	1100	47	cam+cpx+fo+pl+ne+gh+spl?
PA-A12*	842	2000	25	cam+cpx+fo+pl+gh+spl?
GPA-A1*	935	1000	27	cam+gh+cpx+fo+ne+spl?
GPA-A2*	838	1000	525	cam+gh+cpx+fo+ne+spl?
GPA-A2a*	930	1000	65	cam+gh+cpx+fo+ne+spl? (GPA-A2 product:mix=1:1)
GPA-A3*	895	1000	148	cam+gh+cpx+fo+ne+spl?
GPA-A4*	895	1000	148	cam+gh+cpx+fo+ne+spl?
				$NaCa_2Ni_4AlSi_6Al_2O_{22}(OH)_2$
NiPA-A1	868	2000	10	cpx+pl+Ni+cam+qtz+wil+ol +spl?+ly
NiPA-A2	796	1000	47	cpx+pl+qtz+cam+wil+ol +spl?+ly (CT buffer)
				$NaCa_2Mg_4ScSi_6Al_2O_{22}(OH)_2$
ScPA-A1*	820	1000	40	cam+cpx+Sc_2O_3+fo+ne+pl+?
ScPA-A1a*	840	2000	25	cam+cpx+Sc_2O_3+fo+ne+pl+? (ScPA-A1 product reground and rerun)
ScPA-A2*	840	2000	25	cam+cpx+Sc_2O_3+fo+ne+pl+?
ScPA-A4*	905	3000	45	cam+cpx+Sc_2O_3+fo+ne+pl+?
ScPA-A5*	834	2000	70	cam+cpx+Sc_2O_3+fo+ne+pl+?
ScPA-A6*	830	2000	70	cam+cpx+Sc_2O_3+fo+ne+pl+?
				$NaCa_2Mg_4CrSi_6Al_2O_{22}(OH)_2$
CrPA-A1*	820	1000	40	cam+cpx+esk+fo+ly+pl +ne+spl?
CrPA-A2*	845	2000	24	cam+esk+cpx+pl+fo+ne+Pl +spl?
CrPA-A3*	905	3000	45	cam+cpx+esk+spl+fo+pl+ne
CrPA-A4*	846	1000	70	cam+esk+cpx+pl+fo+spl+ne +ly
CrPA-A5*	831	2100	73	cam+esk+cpx+pl+fo+spl+ne +ly
				$NaCa_2Mg_4GaSi_6Al_2O_{22}(OH)_2$
GaPA-A1	758	1000	49	cpx+pl+cam+fo+ne+ly
GaPA-A2*	846	1000	70	cam+cpx+pl+fo+ne+ly?
GaPA-A3*	817	2100	73	cam+cpx+fo+pl?+ne?+ly?
				$NaCa_2Mg_4InSi_6Al_2O_{22}(OH)_2$
InPA-A1	810	1000	48	cpx+cam+gh+fo+In_2O_3
InPA-A2	755	1900	52	cam+cpx+gh+fo+In_2O_3
InPA-A4	838	2000	73	cam+cpx+gh+fo+In_2O_3

Run Number	T (deg)	P (bar)	t (h)	Products
				$NaCa_2Mg_4GaSi_6Ga_2O_{22}(OH)_2$
Ga3PA-A1	779	1000	49	<10% cam
				$KCa_2Mg_4AlSi_6Al_2O_{22}(OH)_2$
KPA-A1	835	1000	68	<10% cam
KPA-A2	830	2000	22	<10% cam
				$NaCd_2Mg_4AlSi_6Al_2O_{22}(OH)_2$
CdPA-A1	758	1000	49	<5% cam
				$\square Ca_2Mg_3Sc_2Si_6Al_2O_{22}(OH)_2$
ScTS-A1	768	1000	69	0% cam
				$\square Ca_2Mg_3Cr_2Si_6Al_2O_{22}(OH)_2$
CrTS-A1	792	1000	91	0% cam
				$\square Ca_2Mg_4AlSi_7AlO_{22}(OH)_2$
HB-A1	782	1000	158	cpx+an+cam+en+fo
HB-A2	748	1000	147	cpx+an+cam+en+fo
HB-A3	726	1000	238	cpx+an+cam+en+fo
HB-A4	696	1000	234	cpx+an+cam+en+fo
HB-A6	835	1000	136	cpx+an+cam+en+fo+qtz
HB-A7	766	1000	160	cpx+an+cam+en+fo
HB-A8	780	1000	47	cpx+an+cam+en+fo+qtz
HB-A9	840	2500	2	cpx+an+cam+en+fo+qtz+tlc?
HB-A10	804	3000	38	cpx+an+cam+en+fo
HB-A12	715	3000	71	cpx+an+cam+en+fo+tlc?
HB-A13	764	2000	141	cpx+an+cam+en+fo
HB-A14	743	2000	141	cpx+an+cam+en+fo
HB-A15	679	3500	74	cpx+an+cam+tlc+chl?
HB-B1	775	1000	165	cpx+an+cam+en+fo (HB-A1,A2 reground, rerun)
GHB-A1	798	1000	48	cpx+an+cam+en+fo
GHB-A2	930	1000	65	cpx+an+cam+en+fo+qtz
GHB-A3	803	1000	135	cpx+an+cam+en+fo
GHB-A4	803	1000	135	cpx+an+cam+en+fo
GHB-A5	705	1000	123	cpx+an+cam+en+fo
GHB-A6	705	1000	123	cpx+an+cam+en+fo
GHB-A7	600	1000	724	cpx+an+cam+en+fo
GHB-A8	811	2000	42	cpx+an+cam+en+fo
GHB-A9	780	1200	47	cpx+an+cam+en+fo
GHB-A10	812	3000	20	cpx+an+cam+en+fo
				$\square Ca_2Ni_4AlSi_7AlO_{22}(OH)_2$
NiHB-A1	793	1000	68	cpx+an+qtz+Ni+ol
NiHB-A2	801	1000	25	cpx+an+qtz+Ni+ol
NiHB-A3	790	1100	43	cpx+an+wil+qtz+cam+ol (MH buffer)

Run Number	T (deg)	P (bar)	t (h)	Products
				$^{\square}Ca_2Mg_4ScSi_7AlO_{22}(OH)_2$
ScHB-A1	768	1000	69	20-30% cam
ScHB-A2	850	3000	24	20-30% cam
				$^{\square}Ca_2Mg_4GaSi_7AlO_{22}(OH)_2$
GaHB-A1	804	3000	60	40-50% cam
				$^{\square}Ca_2Mg_4CrSi_7AlO_{22}(OH)_2$
CrHB-A1	792	1000	91	<10% cam
CrHB-A2	854	3000	46	30-40% cam
				$^{\square}Ca_2Mg_4TiSi_7AlO_{22}(OH)_2$
TiHB-A1	804	3000	48	20-30% cam
				$^{\square}Ca_2Mg_4VSi_7AlO_{22}(OH)_2$
VHB-A1	695	3kb	58	<5% cam
VHB-A2	810	3kb	68	50-60% cam
				$NaCa_2Mg_4TiSi_6Al_2(O+OH)_{24}$
KR-A1	783	1000	41	0% cam
KR-A2	792	2000	49	0% cam
				Sodic-calcic Amphiboles
				$NaCaNaMg_5Si_8O_{22}(OH)_2$
RC-A1*	903	1000	50	cam+cpx
RC-A2*	903	1000	50	cam+cpx
				$NaCaNaNi_5Si_8O_{22}(OH)_2$
NiRC-A1*	800	1000	30	cam+Ni+cpx
				$NaCaNaMg_3Ni_2Si_8O_{22}(OH)_2$
Mg3Ni2RC-A1*	852	1000	29	cam+Ni+cpx
				$NaCaNaMn_5Si_8O_{22}(OH)_2$
MnRC-A1	479	1000	165	<5% cam
MnRC-A2	608	1000	194	<5% cam
				$NaCaNaMg_4MnSi_8O_{22}(OH)_2$
Mg4MnRC-A1*	852	1000	29	cam+cpx
Mg4MnRC-A2	790	1000	103	cam+cpx
				$NaCaNaMg_3Mn_2Si_8O_{22}(OH)_2$
Mg3Mn2RC-A1*	854	1100	24	cam+cpx
Mg3Mn2RC-A2*	790	1000	103	cam+cpx (NNO buffer)

Run Number	T (deg)	P (bar)	t (h)	Products
				$NaCaNaCu_5Si_8O_{22}(OH)_2$
CuRC-A1	742	1000	26	$CaCuSi_4O_{10}$+CuO+chl? (CT buffer)
				$KCaNaMg_5Si_8O_{22}(OH)_2$
KRC-A1*	865	1000	93	cam
				$Na(NaCa_{0.5}Mg_{0.5})Mg_5Si_8O_{22}(OH)_2$
CaMgRC-A1	796	1000	64	cam+cpx?
				$NaCdNaMg_5Si_8O_{22}(OH)_2$
CdRC-A1	805	1000	70	cam+?
				¤$CaNaMg_4AlSi_8O_{22}(OH)_2$
WC-A1	800	1000	64	20-30% cam
WC-A2	707	1000	101	20-30% cam
WC-A3	866	1000	41	<5% cam
WC-A5	800	1075	67	20-30% cam
GWC-A1	800	1000	64	<10% cam
GWC-A3	866	1000	41	<5% cam
GWC-A4	706	1000	164	<5% cam
GWC-A5	762	750	26	<5% cam
GWC-A6	800	1075	67	<10% cam
				¤$CaNaMg_4AlSi_8O_{22}(OH)_2$
ScWC-A1	760	1000	91	40-50% cam
				¤$CaNaMg_4AlSi_8O_{22}(OH)_2$
CrWC-A1	690	1000	69	<10% cam
				$NaCaNaMg_4AlSi_7AlO_{22}(OH)_2$
KA-A1	889	1200	48	5-10% cam
KA-A2	755	1200	96	10-20% cam
				$NaCaNaMg_4ScSi_7AlO_{22}(OH)_2$
ScKA-A1	782	1000	69	30-40% cam
				$NaCaNaMg_4CrSi_7AlO_{22}(OH)_2$
CrKA-A1	782	1000	69	30-40% cam
				$NaCaNaMg_3Sc_2Si_6Al_2O_{22}(OH)_2$
ScTA-A1	798	1000	69	20-30% cam
				$NaCaNaMg_3Cr_2Si_6Al_2O_{22}(OH)_2$
CrTA-A1	797	1000	91	20-30% cam

Run Number	T (deg)	P (bar)	t (h)	Products
				¤$CaNaMg_3Sc_2Si_7AlO_{22}(OH)_2$
ScBA-A1	798	1000	69	5-10% cam
				¤$CaNaMg_3Cr_2Si_7AlO_{22}(OH)_2$
CrBA-A1	797	1000	91	5-10% cam
				Alkali Amphiboles
				¤$Na_2Mg_3Sc_2Si_8O_{22}(OH)_2$
ScRB-A1	690	1000	53	5-10% cam
ScRB-A2	765	1000	97	40-50% cam
				¤$Na_2Mg_3Cr_2Si_8O_{22}(OH)_2$
CrRB-A1	690	1000	53	<5% cam
CrRB-A2	777	1000	100	20-30% cam
				¤$Na_2Mg_3Ga_2Si_8O_{22}(OH)_2$
GaRB-A1	738	1000	79	<5% cam
				$NaNa_2Mg_4AlSi_8O_{22}(OH)_2$
EC-A1	775	1000	47	cam
EC-B1	817	2000	95	cam
EC-A2	790	1000	144	cam
				$NaNa_2Mg_4ScSi_8O_{22}(OH)_2$
ScEC-A1	718	1000	43	40-50% cam
ScEC-A2	860	1000	51	40-50% cam
				$NaNa_2Mg_4CrSi_8O_{22}(OH)_2$
CrEC-A1	718	1000	43	70-80% cam
CrEC-A2	850	1000	4	70-80% cam
				$NaNa_2Mg_4GaSi_8O_{22}(OH)_2$
GaEC-A2	769	1300	49	80-90% cam
GaEC-A3	790	1000	144	80-90% cam
				$NaNa_2Mg_4InSi_8O_{22}(OH)_2$
InEC-A1	800	1400	45	80-90% cam

Run Number	T (deg)	P (bar)	t (h)	Products
				$NaNa_2Mg_3Al_2Si_7AlO_{22}(OH)_2$
NY-A1	718	1000	43	0% cam
				$NaNa_2Mg_3Sc_2Si_7AlO_{22}(OH)_2$
ScNY-A1	700	1000	50	40-60% cam
ScNY-A3	790	1380	45	50-70% cam
				$NaNa_2Mg_3Cr_2Si_7AlO_{22}(OH)_2$
CrNY-A1	690	1000	91	70-80% cam
CrNY-A2	700	1000	50	70-80% cam
CrNY-A3	800	2000	51	70-80% cam
				$NaNa_2Mg_3In_2Si_7AlO_{22}(OH)_2$
InNY-A1	783	1000	16	60-80% cam
				$NaNa_2Mg_3Ga_2Si_7GaO_{22}(OH)_2$
Ga3NY-A1	738	1000	79	0% cam
		Iron-magnesium-manganese Amphiboles		
				$NaMgNaMg_5Si_8O_{22}(OH)_2$
MgRC-A1	806	1000	46	cam+fo
				$NaNiNaNi_5Si_8O_{22}(OH)_2$
NiMgRC-A1	806	1000	24	cam+wil (CT buffer)
NiMgRC-A2	787	1000	48	wil+qtz+Ni
		Silicate Fluor-amphiboles		
		Calcic Amphiboles		
				$^{\square}Ca_2Mg_5Si_8O_{22}F_2$
FTR-H1;2	1143	1	70	cam+di+fl+trd+en+crs
FTR-H3;4	1137	1	168	cam+di+fl+trd+en+crs
FTR-H5	1155	1	130	cpx+trd+en+fl+fo
				$NaCa_2Mg_5Si_7AlO_{22}F_2$
FED-A1	1202	1	1.3	gl+v.f.g.
FED-A2	1148	1	2.5	gl+v.f.g
FED-A3	1107	1	3.2	gl+crs+cpx+pl+fl+v.f.g.
FED-A4	1041	1	18	cpx+crs+pl+fl+cam?+gl
FED-A5	999	1	42	cpx+crs+pl+cam+fl+gl
FED-A7	1161	1	12	gl+v.f.g.
FED-A9	880	1	158	crs+cpx+pl+fl+cam
FED-B5*	938	1	120	cam+fo+pl+cpx

Run Number	T (deg)	P (bar)	t (h)	Products
				$NaCa_2Mg_4AlSi_6Al_2O_{22}F_2$
FPA-A1	1204	1	1	gl+pl+cpx
FPA-A2	1151	1	41	gl+pl+cpx
FPA-A3	1256	1	3.3	gl+v.f.g.
FPA-A6	880	1	158	pl+fl+cpx+ne+fo?+spl?
FPA-B1	1080	1	185	cam+cpx+pl+ne+fo+spl?
FPA-B2	1080	1	185	cam+cpx+pl+ne+fo+spl?
FPA-B5	938	1	120	cam+cpx+pl+spl+ne+fo
FPA-BUL	1000	1	48	cam+cpx+pl+spl+ne+fo
FPA-NMR	1000	1	63	cam+cpx+pl+spl+ne+fo
				$NaCa_2Mg_4ScSi_6Al_2O_{22}F_2$
FScPA-A1*	1006	1	71	cam+cpx+fo+ne?
FScPA-A3a*	1073	1	75	cam+cpx+fo+ne?
FScPA-A3b*	1073	1	75	cam+cpx+fo+ne?
FScPA-A3c*	1073	1	75	cam+cpx+fo+ne?
				$NaCa_2Mg_4GaSi_6Al_2O_{22}F_2$
FGaPA-A1*	1006	1	71	cam+pl+fo+cpx
FGaPA-A3a*	1000	1	90	cam+pl+fo+cpx
FGaPA-A3b*	1000	1	90	cam+pl+fo+cpx
FGaPA-A3c*	1000	1	90	cam+pl+fo+cpx
				$NaCa_2Mg_4CrSi_6Al_2O_{22}F_2$
FCrPA-A1*	1006	1	71	cam+mchr+pl+cpx+fo
FCrPA-A3a*	1000	1	90	cam+mchr+pl+cpx+fo
FCrPA-A3b*	1000	1	90	cam+mchr+pl+cpx+fo
FCrPA-A3c*	1000	1	90	cam+mchr+pl+cpx+fo
				$\square Ca_2Mg_3Al_2Si_6Al_2O_{22}F_2$
FTS-A1	1151	1	25	0% cam
FTS-A2	880	1	158	0% cam
				$\square Ca_2Mg_4AlSi_7AlO_{22}F_2$
FHB-A1	1148	1	2.5	50% gl+v.f.g.
FHB-A2	1107	1	3.2	20% gl+v.f.g.
FHB-A3	1041	1	18	<10% gl+v.f.g.
FHB-A4	1204	1	1	60% gl+v.f.g.
FHB-A5	999	1	42	crs+an+fl+cpx+cam+qtz
FHB-A6	880	1	158	crs+an+fl+cpx+cam+qtz
FHB-B1	845	3000	40	cam+qtz+an+cpx+fl
FHB-B4	938	1	120	cam+qtz+an+cpx+fl

Run Number	T (deg)	P (bar)	t (h)	Products
				Sodic-calcic Amphiboles
				$NaCaNaMg_5Si_8O_{22}F_2$
FRC-A1	1153	1	46	0% cam
FRC-A2	900	1	138	<5% cam
FRC-A3	1152	1	92	0% cam
FRC-B1*	1055	1	188	cam+cpx+fo
FRC-B5	938	1	120	cam+cpx+fo
				$NaCaNaMg_4MnSi_8O_{22}F_2$
FMg4MnRC-A2*	1035	1	44	cam+cpx
				$\square CaNaMg_4AlSi_8O_{22}F_2$
FWC-A2	1102	1	147	40-50% cam
FWC-A3	904	1	138	10-20% cam
FWC-C1	1151	1	108	0% cam
FWC-C2	1021	1	163	0% cam
FWC-E1	1107	1	24	5-10% cam
FWC-E2	1055	1	188	20-30% cam
FWC-E8	938	1	120	10-20% cam
				$NaCaNaMg_4AlSi_7AlO_{22}F_2$
FKA-A2	1102	1	147	cam+fl+gl
FKA-A3	904	1	138	crs+pl+cpx+fl+cam
FKA-A4	1020	1	163	cam+pl+fl+crs
FKA-A5	1072	1	215	cam+fl+gl
				$NaCaNaMg_4ScSi_7AlO_{22}F_2$
FScKA-A1	1006	1	71	60-80% cam
				$NaCaNaMg_4GaSi_7AlO_{22}F_2$
FGaKA-A1	1006	1	71	50-70% cam
				$NaCaNaMg_4CrSi_7AlO_{22}F_2$
FCrKA-A1	1006	1	71	50-70% cam
				$NaCaNaMg_4TiSi_7AlO_{22}F_2$
FTiKA-A1	1006	1	71	50-70% cam
				$NaCaNaMg_4VSi_7AlO_{22}F_2$
FVKA-A1	1006	1	71	50-70% cam
				$NaCaNaMg_3Al_2Si_6Al_2O_{22}F_2$
FTA-A1	1153	1	46	0% cam
FTA-A2	1109	1	12	0% cam
FTA-A4	900	1	136	<5% cam
FTA-A8	938	1	120	<5% cam

Run Number	T (deg)	P (bar)	t (h)	Products
				$^{\square}CaNaMg_3Al_2Si_7AlO_{22}F_2$
FBA-A1	1153	1	46	0% cam
FBA-A2	1109	1	66	0% cam
FBA-A3	904	1	138	<5% cam
				Alkali Amphiboles
				$NaNa_2Mg_4AlSi_8O_{22}F_2$
FEC-A1*	938	1	120	cam+ab+fo+ly(9.54 Å)
FEC-A2*	938	1	120	cam+ab+fo+ly(9.54 Å)
				$NaNa_2Mg_4ScSi_8O_{22}F_2$
FScEC-A1*	938	1	120	cam
FScEC-A3*	1000	1	90	cam
				$NaNa_2Mg_4GaSi_8O_{22}F_2$
FGaEC-A1*	938	1	120	cam+ly(9.66 Å)
FGaEC-A3*	1000	1	90	cam+ly(9.66 Å)
				$NaNa_2Mg_4CrSi_8O_{22}F_2$
FCrEC-A1*	938	1	120	cam+qtz+mchr+esk
				$NaNa_2Mg_4InSi_8O_{22}F_2$
FInEC-A1*	985	1	45	cam
FInEC-A3*	1000	1	90	cam
				$NaNa_2Mg_3Sc_2Si_7AlO_{22}F_2$
FScNY-A2*	938	1	120	cam+$NaScSi_2O_6$
FScNY-A3*	1000	1	90	cam+$NaScSi_2O_6$
				Iron-magnesium-manganese Amphiboles
				$NaMgNaMg_5Si_8O_{22}F_2$
MgFRC-A4	909	1	46	crs+cam+cen+trd

Notes

[1]Entries in this column include either phases identified in run products, or approximate amphibole mode.

TABLE 12

Run Data: Non-isothermal Experiments

Run Number	T (deg)	P (bar)	t (h)	Rate (deg/h)	Products
					Fluor-amphiboles
					Calcic-amphiboles
					¤$Ca_2Mg_5Si_8O_{22}F_2$
FTR-H6	1239- 816	1	332	1.30	cam+di+trd+en
FTR-H7	1193- 799	1	308	1.30	cam+di+trd+en
					$NaCa_2Mg_5Si_7AlO_{22}F_2$
FED-A8	1196-1058	1	147	0.94	crs+cpx+pl+fl+cam
FED-B1*	1239- 816	1	332	1.30	cam+fo+pl+cpx+crs
					$NaCa_2Mg_4AlSi_6O_{22}F_2$
FPA-A4	1164-1109	1	12	4.58	gl+pl+cpx
FPA-A5	1196-1058	1	147	0.94	gl+pl+cpx+spl?
FPA-B3	1239- 816	1	332	1.28	cam+pl+fl+cpx+spl +fo+ne
FPA-B4	1193- 799	1	308	1.30	cam+pl+fl+cpx+spl +fo+ne
FPA-B7	1273- 844	1	382	1.12	cam+pl+fl+cpx+spl +fo+ne
					$NaCa_2Mg_4ScSi_6Al_2O_{22}F_2$
FScPA-A2	1273- 844	1	382	1.12	cam+cpx+ne+fo+fl+gl
					$NaCa_2Mg_4GaSi_6Al_2O_{22}F_2$
FGaPA-A2	1273- 844	1	382	1.12	cam+fo+pl+cpx+fl+gl
					$NaCa_2Mg_4CrSi_6Al_2O_{22}F_2$
FCrPA-A2	1273- 844	1	382	1.12	cpx+mchr+fo+pl+cam +ne
					¤$Ca_2Mg_3Al_2Si_6Al_2O_{22}F_2$
FTS-A4	1193- 799	1	308	1.30	0% cam
					Sodic-calcic Amphiboles
					$NaCaNaMg_5Si_8O_{22}F_2$
FRC-B3	1239- 816	1	332	1.28	cam+cpx+fo
					¤$CaNaMg_4AlSi_8O_{22}F_2$
FWC-E6	1239- 816	1	332	1.30	40-50% cam
FWC-E7	1193- 799	1	308	1.28	40-50% cam

Run Number	T (deg)	P (bar)	t (h)	Rate (deg/h)	Products
					$NaCaNaMg_4AlSi_7AlO_{22}F_2$
FKA-A13	1239- 816	1	332	1.28	60-80% cam
FKA-A16	1193- 799	1	308	1.30	60-80% cam
					$NaCaNaMg_4ScSi_7AlO_{22}F_2$
FScKA-A2	1273- 844	1	382	1.12	50-70% cam
					$NaCaNaMg_4GaSi_7AlO_{22}F_2$
FGaKA-A2	1273- 844	1	382	1.12	50-70% cam
					$NaCaNaMg_4TiSi_7AlO_{22}F_2$
FTiKA-A2	1273- 844	1	382	1.12	50-70% cam
					$\square CaNaMg_3Al_2Si_7AlO_{22}F_2$
FBA-A4	1239- 816	1	332	1.28	0% cam
FBA-A5	1193- 799	1	308	1.30	0% cam
					Alkali-amphiboles
					$NaNa_2Mg_4AlSi_8O_{22}F_2$
FEC-A3	1273- 844	1	382	1.12	cam+fo+ab+ne+NaF +ly(9.59 Å)
					$NaNa_2Mg_4ScSi_8O_{22}F_2$
FScEC-A2*	1273- 844	1	382	1.12	cam+fo+cen+$NaScSi_2O_6$
					Iron-magnesium-manganese Amphiboles
					$NaMgNaMg_5Si_8O_{22}F_2$
MgFRC-A1	1240- 962	1	47	6.40	cam+cen+crs+trd
MgFRC-A5	1239- 816	1	332	1.30	cam+cen+crs+trd
MgFRC-A6	1193- 799	1	308	1.30	cam+cen+crs+trd

TABLE 13

Cell Dimensions of Synthetic Amphiboles

Run No.	a (Å)	b (Å)	c (Å)	β (°)	V (Å^3)
			Calcic Amphiboles		
			Tremolite		
			$\square Ca_2Ni_5Si_8O_{22}(OH)_2$		
NiTRA1	9.820(4)	18.012(10)	5.253(3)	104.82(6)	898.3(5)
			$\square Ca_2Mg_3Ni_2Si_8O_{22}(OH)_2$		
Mg3Ni2TR-A1	9.882(2)	18.032(4)	5.271(2)	104.68(3)	903.1(2)
			$\square Cd_2Mg_5Si_8O_{22}(OH)_2$		
CdTR-A2	9.666(13)	18.071(24)	5.290(8)	102.91(12)	900.7(15)
			Fluor-tremolite		
			$\square Ca_2Mg_5Si_8O_{22}F_2$		
FTR-H1,2	9.777(4)	18.006(7)	5.268(3)	104.48(5)	897.9(5)
FTR-H6	9.778(1)	18.013(2)	5.2665(7)	104.47(1)	898.2(1)
			Fluor-edenite		
			$NaCa_2Mg_5Si_7AlO_{22}F_2$		
FED-B1	9.827(2)	17.943(3)	5.285(2)	105.11(3)	899.7(3)
			Pargasite		
			$NaCa_2Mg_4AlSi_6Al_2O_{22}(OH)_2$		
GPA-A2A	9.904(3)	17.941(5)	5.281(2)	105.54(3)	904.0(3)
PA-A8A	9.907(3)	17.929(6)	5.282(2)	105.51(2)	904.0(3)
PA-A2A	9.894(2)	17.948(5)	5.280(1)	105.50(2)	903.5(3)
PA-A10	9.897(2)	17.946(4)	5.284(1)	105.51(2)	904.4(2)
			$NaCa_2Mg_4CrSi_6Al_2O_{22}(OH)_2$		
CrPA-A3	9.914(2)	17.993(4)	5.285(1)	105.44(2)	908.7(2)
CrPA-A4	9.917(3)	17.998(6)	5.287(2)	105.41(2)	909.8(3)
CrPA-A5	9.909(2)	17.989(5)	5.285(2)	105.42(2)	908.2(3)
			$NaCa_2Mg_4GaSi_6Al_2O_{22}(OH)_2$		
GaPA-A1	9.849(2)	17.953(4)	5.297(1)	105.17(2)	903.9(2)
GaPA-A2	9.923(3)	17.973(5)	5.292(1)	105.49(2)	909.7(3)
GaPA-A3	9.910(4)	17.976(7)	5.289(2)	105.54(3)	907.9(2)
			$NaCa_2Mg_4ScSi_6Al_2O_{22}(OH)_2$		
ScPA-A5	9.942(3)	18.101(5)	5.297(1)	105.37(2)	919.2(3)
ScPA-A6	9.944(2)	18.096(5)	5.298(1)	105.39(2)	919.2(3)
ScPa-A5,6R	9.9404(8)	18.094(2)	5.2983(4)	105.367(5)	918.89

Run No.	a (Å)	b (Å)	c (Å)	β (°)	V (Å^3)
			$NaCa_2Mg_4InSi_6Al_2O_{22}(OH)_2$		
InPA-A4	9.937(3)	18.030(4)	5.289(2)	105.54(2)	912.9(3)
			Fluor-pargasite		
			$NaCa_2Mg_4AlSi_6Al_2O_{22}F_2$		
FPANMR	9.830(4)	17.919(6)	5.294(2)	105.16(3)	900.0(3)
FPA-BUL	9.827(3)	17.927(7)	5.293(2)	105.19(3)	899.8(4)
FPA-BULR	9.8281(8)	17.932(2)	5.2942(4)	105.172(5)	900.52
FPA-B4	9.818(3)	17.929(7)	5.295(2)	105.27(4)	899.2(4)
FPA-B5	9.820(3)	17.931(5)	5.293(2)	105.20(3)	899.4(3)
			$NaCa_2Mg_4CrSi_6Al_2O_{22}F_2$		
FCrPA-A1	9.834(3)	17.971(5)	5.286(1)	105.07(2)	902.1(3)
FCrPA-A3	9.845(8)	18.005(13)	5.284(4)	105.06(6)	904.4(7)
FCrPA-A3R	9.8397(6)	17.977(1)	5.2916(3)	105.105(4)	903.68
			$NaCa_2Mg_4GaSi_6Al_2O_{22}F_2$		
FGaPA-A1	9.846(2)	17.951(4)	5.296(1)	105.16(2)	903.5(2)
FGaPA-A2	9.852(3)	17.945(4)	5.299(1)	105.25(2)	903.9(2)
FGaPA-A3R	9.8597(6)	17.968(1)	5.3028(3)	105.198(3)	906.58
			$NaCa_2Mg_4ScSi_6Al_2O_{22}F_2$		
FScPA-A1	9.881(2)	18.145(4)	5.317(1)	105.17(2)	920.1(2)
FScPA-3AR	9.8845(4)	18.1565(9)	5.3185(2)	105.215(3)	921.04
			$\square Ca_2Mg_4AlSi_7AlO_{22}(OH)_2$		
HB-A3	9.770(4)	18.039(4)	5.278(2)	104.62(5)	900.0(4)
			Sodic-calcic amphiboles		
			Richterite		
			$NaCaNaMg_5Si_8O_{22}(OH)_2$		
RC-A1	9.902(1)	17.980(3)	5.2683(8)	104.21(1)	909.3(2)
			$KCaNaMg_5Si_8O_{22}(OH)_2$		
KRC-A1	10.048(2)	17.990(3)	5.2733(9)	104.84(1)	921.5(2)
			$Na(NaCa_{0.5}Mg_{0.5})Mg_5Si_8O_{22}(OH)_2$		
CaMgRC-A1	9.843(4)	17.959(6)	5.275(2)	103.68(4)	906.0(4)
			$NaCaNaNi_5Si_8O_{22}(OH)_2$		
NiRC-A1	9.882(1)	17.944(2)	5.2579(7)	104.76(1)	902.8(1)
			$NaCaNaMg_3Ni_2Si_8O_{22}(OH)_2$		
Mg3Ni2RCA1	9.894(3)	17.962(6)	5.264(2)	104.29(3)	906.4(3)
			$NaCaNaMg_4MnSi_8O_{22}(OH)_2$		
Mg4MnRC-A2	9.920(3)	18.058(5)	5.278(1)	104.00(3)	917.3(3)

Run No.	a (Å)	b (Å)	c (Å)	ß (°)	V (Å^3)
			$NaCaNaMg_3Mn_2Si_8O_{22}(OH)_2$		
Mg3Mn2RCA2	9.927(3)	18.088(5)	5.282(1)	103.91(3)	920.5(3)
			$NaCdNaMg_5Si_8O_{22}(OH)_2$		
CdRC-A1	9.749(4)	17.946(4)	5.271(1)	102.70(2)	899.7(3)
			Fluor-richterite		
			$NaCaNaMg_5Si_8O_{22}F_2$		
FRC-A1	9.820(2)	17.964(4)	5.258(1)	104.11(2)	899.6(2)
			$NaCaNaMg_4MnSi_8O_{22}F_2$		
FMg4MnRCA2	9.835(3)	18.040(5)	5.265(1)	104.10(3)	906.0(3)
			Alkali Amphiboles		
			Eckermannite		
			$NaNa_2Mg_4AlSi_8O_{22}(OH)_2$		
EC-B1	9.710(2)	17.927(3)	5.270(1)	102.67(1)	897.7(2)
			$NaNa_2Mg_4AlSi_8O_{22}F_2$		
FEC-A1	9.654(4)	17.902(6)	5.262(1)	102.72(2)	887.2(3)
			$NaNa_2Mg_4GaSi_8O_{22}F_2$		
FGaEC-A1	9.683(2)	17.895(4)	5.2637(8)	102.95(1)	888.9(2)
			$NaNa_2Mg_4CrSi_8O_{22}F_2$		
FCrEC-A1	9.716(2)	17.817(3)	5.2740(7)	103.58(1)	887.5(2)
			$NaNa_2Mg_4ScSi_8O_{22}F_2$		
FSCEC-A1	9.829(2)	18.045(5)	5.287(1)	103.64(2)	911.3(3)
FSCEC-A2	9.826(2)	18.047(4)	5.291(1)	103.63(2)	911.8(3)
FSCEC-A3R	9.8383(4)	18.0629(2)	5.2926(2)	103.652(2)	913.97
			$NaNa_2Mg_4InSi_8O_{22}F_2$		
FInEC-A1	9.845(3)	18.081(8)	5.293(2)	103.49(3)	916.2(4)
FInEC-A3R	9.8526(2)	18.0967(7)	5.2927(2)	103.521(2)	917.53
			$NaNa_2Mg_3Sc_2Si_7AlO_{22}F_2$		
FScNY-A2	9.839(3)	18.160(7)	5.330(3)	103.95(4)	924.2(5)
FScNY-A3R	9.8467(5)	18.164(1)	5.3403(3)	103.986(3)	926.83
			Iron-magnesium-manganese Amphiboles		
			Sodian magnesio-cummingtonite		
			$NaMgNaMg_5Si_8O_{22}(OH)_2$		
MgRC-A1	9.740(2)	17.934(3)	5.2700(8)	102.60(1)	898.4(2)
			$NaNiNaNi_5Si_8O_{22}(OH)_2$		
NiMgRC-A1	9.737(3)	17.891(6)	5.254(2)	103.21(4)	891.0(4)

Run No.	a (Å)	b (Å)	c (Å)	ß (°)	V (Å^3)
		Sodian fluor-magnesio-cummingtonite $NaMgNaMg_5Si_8O_{22}F_2$			
MgFRC-A5	9.648(3)	17.914(5)	5.264(3)	102.68(5)	887.6(5)

Chapter V

DETAILED CHARACTERIZATION OF SYNTHETIC AMPHIBOLES

INFRARED SPECTROSCOPY

Pargasites: $NaCa_2Mg_4M^{3+}Si_6Al_2O_{22}(OH)_2$

Infrared spectra of synthetic pargasites with M^{3+}=Al, Cr, Ga and Sc are presented in Figure 8. For the ordered case, in which the M(2) site occupancy is $0.5Mg+0.5M^{3+}$ and the M(1,3) sites are occupied solely by Mg, the spectrum should consist of a single band corresponding to the MgMgMg configuration. The spectrum of pargasite (M^{3+}=Al), however, consists of two major bands at 3709 cm^{-1} and 3676 cm^{-1}, and a poorly resolved shoulder at about 3645 cm^{-1}. Because the sample is from a high-yield run and is therefore close to of the nominal composition, the two major bands were assigned to the MgMgMg (A) and MgMgAl (B) configurations respectively, and the minor band to the MgAlAl (C) configuration. The D-band, corresponding to the AlAlAl configuration, is absent. Band width is about 25 to 33 cm^{-1}, which is considerably larger than typical values of about 6 cm^{-1} for natural amphibole spectra (Strens 1974).

Frequency shifts (relative to the MgMgMg band) of bands involving Al are -33 and -65 cm^{-1} for the MgMgAl and MgAlAl configurations, respectively. Strens (1974) showed that the frequency shifts of individual bands are a function of the electronegativities of the bonded cations according to the approximate relationship:

$$\Delta v = 35n(Xmg - Xs)\ cm^{-1}$$

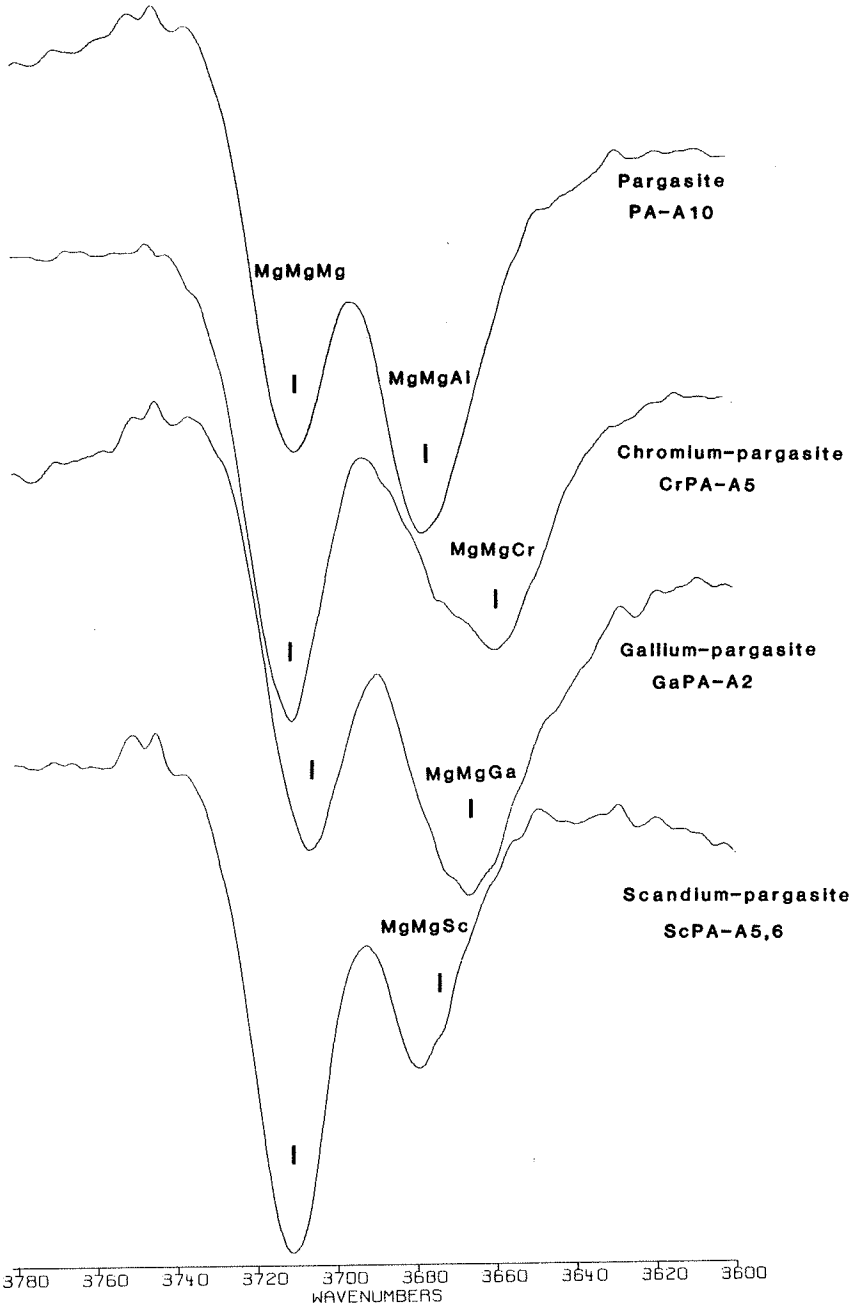

Figure 8: Infrared spectra of pargasites

where $0<n<3$ is the number of Mg ions replaced in any one $Mg_3(OH)_2$ cluster, and Xmg and Xs are the Allred-Rochow electronegativities of Mg and the substituent cation respectively. This gives a frequency shift of -9 cm^{-1} for the MgMgAl band relative to MgMgMg, which is significantly different from the observed shift of -33 cm^{-1}. Clearly, the magnitude of the frequency shift is not a simple function of electronegativity. Furthermore, because the frequency shifts given by Strens (1974) were determined mainly from configurations involving Mg and divalent cations, the shifts calculated for trivalent cations are underestimated. Semet (1973) also records the frequency shift of the MgMgAl band in the synthetic pargasite spectrum as -33 cm^{-1}, identical to this study.

Infrared spectra of chromium-pargasite, gallium-pargasite, and scandium-pargasite from this study, and magnesio-hastingsite (Semet 1972, 1973) all have shoulders near 3676 cm^{-1} corresponding to the MgMgAl configuration (Figures 3, 8). These spectra suggest that synthetic pargasites (M^{3+}=Cr, Ga or Sc) and magnesio-hastingsite (M^{3+}=Fe) are not of the nominal compositions but contain minor octahedral Al. The magic angle spinning nuclear magnetic resonance (MAS NMR) spectrum of scandium-fluor-pargasite supports this conclusion; the octahedral to tetrahedral Al ratio is 95:5 (Hawthorne et al 1984).

This discrepancy between the nominal composition and the composition of the synthetic amphiboles is reflected in the spectrum of chromium-pargasite (M^{3+}=Cr), which consists of major bands at 3710 cm^{-1} and 3659 cm^{-1}, a shoulder at 3674 cm^{-1}, and at least 8 minor bands or shoulders (Figure 8), suggesting that configurations other than those due simply to Mg, Cr and Al in amphibole are present. The two major bands were

assigned to MgMgMg and MgMgCr configurations; the shoulder at 3674 cm^{-1} is probably due to the MgMgAl configuration. Minor bands at lower frequencies, although of low probability, could result from one or more of configurations MgAlAl, AlAlAl, MgAlCr, MgCrCr, AlAlCr, AlCrCr or CrCrCr. Bands with frequencies between 3710 cm^{-1} and 3674 cm^{-1} are puzzling because they cannot be due to any configurations involving Mg, Cr or Al in amphibole. The presence of minor layer silicates in the run product, however, may account for some of these bands. In addition, a shoulder at about 3715 cm^{-1} on the high-frequency side of the MgMgMg band points to the splitting of this band and cannot be explained in terms of the C2/m amphibole structure.

Gallium-pargasite (M^{3+}=Ga) spectra exhibit similar anomalies. Bands at 3706 cm^{-1}, 3676 cm^{-1} and 3665 cm^{-1} were assigned to the MgMgMg, MgMgAl and MgMgGa configurations, respectively. Minor bands and shoulders at lower frequencies are the result of the other normal Mg, Ga and Al configurations. The MgMgMg band has a shoulder at about 3711 cm^{-1}; this is at a frequency shift of +5 cm^{-1}, identical to a similar shoulder in the chromium-pargasite spectrum. No fine structure was resolved between the MgMgMg and MgMgAl peaks as in the chromium-pargasite spectrum.

In contrast to chromium- and gallium-pargasites, the scandium-pargasite (M^{3+}=Sc) spectrum is straightforward. The three major bands at 3711 cm^{-1}, 3679 cm^{-1} and 3673 cm^{-1} were assigned to the MgMgMg, MgMgAl and MgMgSc configurations, respectively.

Richterites: $(K,Na)CaNaM_5^{2+}Si_8O_{22}(OH)_2$

Richterite: $NaCaNaMg_5Si_8O_{22}(OH)_2$

The infrared spectrum of synthetic richterite (Figure 9) is typical of endmember amphibole having Mg as the sole octahedral cation. It consists of a single, sharp band at 3729 cm^{-1} corresponding to the MgMgMg configuration. A barely resolved tremolite-like peak occurs at about 3673 cm^{-1}, suggesting that this richterite is slightly off-composition. This spectrum is almost identical to that of Rowbotham and Farmer (1973) except that their tremolite peak is more intense. Band width is 21 cm^{-1}, about 3 times wider than in typical natural amphiboles (Strens 1974).

Potassium-richterite: $KNaCaMg_5Si_8O_{22}(OH)_2$

The spectrum of potassium-richterite is almost identical to that of richterite except that the MgMgMg peak is shifted +3 cm^{-1} to 3732 cm^{-1} and the tremolite-like peak at about 3670 cm^{-1} is more intense. Band width is about 18 cm^{-1}. The magnitude of the MgMgMg band frequency shift is consistent with that of typical values of +3 cm^{-1} due to K substitution for Na in the A site (Hawthorne 1983b). As for richterite, the band at 3670 cm^{-1} suggests limited solid solution towards tremolite and consequent deviation from the nominal composition.

Manganese-richterite: $NaCaNaMg_4MnSi_8O_{22}(OH)_2$

The spectrum of richterite with $M_5^{2+}=Mg_4Mn$ consists of a single band at 3729 cm^{-1}. A slight swelling at the base of the peak on the low-frequency side may represent the contribution from another band. It is not likely, however, that this represents the MgMgMn band, because the fre-

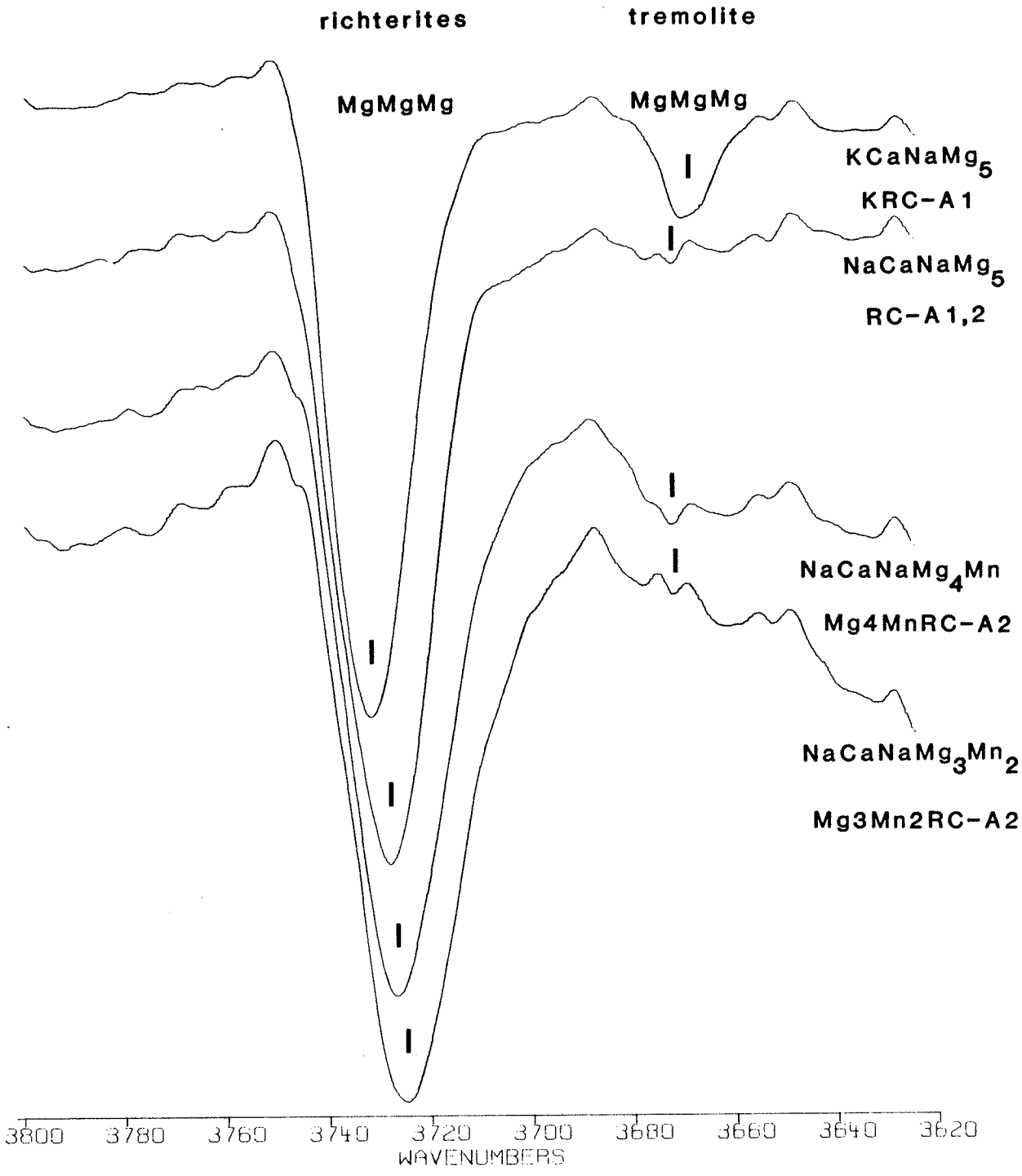

Figure 9: Infrared spectra of richterites.

quency shift is only about -22 cm^{-1}. Most probably, it is an artefact of the skewed gaussian peak shape (see Figure 4A.). Apparently, Mn must be virtually all ordered into the M(2) site. Band width is slightly wider than richterite (23 cm^{-1} versus 21 cm^{-1}).

The spectrum of richterite with $M_5^{2+}=Mg_3Mn_2$ is similar, consisting of a single band at 3725 cm^{-1}. Band width is 23 cm^{-1} and there is a slight swelling at the base of the peak at about 3707 cm^{-1} (see arrow, Figure 9). The spectrum suggests that most, if not all, of the Mn is ordered into the M(2) site. Note that the MgMgMg band shifts to lower frequencies by 4 cm^{-1} from endmember richterite to richterite with 2Mn. The reason for this shift is unknown. Both spectra of the manganese-richterites also show minor tremolite-like peaks at about 3673 cm^{-1}.

Sodian magnesio-cummingtonites: $NaMgNaMg_5Si_8O_{22}(OH)_2$

Ideally, the sodian magnesio-cummingtonite spectrum should consist of a single, sharp, hydroxyl-stretching band corresponding to the MgMgMg configuration. The observed spectrum (Figure 10), however, consists of two major absorbances: a single, well-resolved band at 376 cm^{-1}, and a broader band that could possibly result from three closely overlapping components. Between these two groups, there is also a weak shoulder at about 3729 cm^{-1}. This spectrum, with the exception of additional fine structure, is virtually identical to that of Maresch and Langer (1976) who observed two bands at 3739 cm^{-1} and 3716 cm^{-1} (Figure 26A). The higher frequency band is about twice as wide as the other band, and it is possible that the fine-structure seen in this study is not resolved in their spectrum.

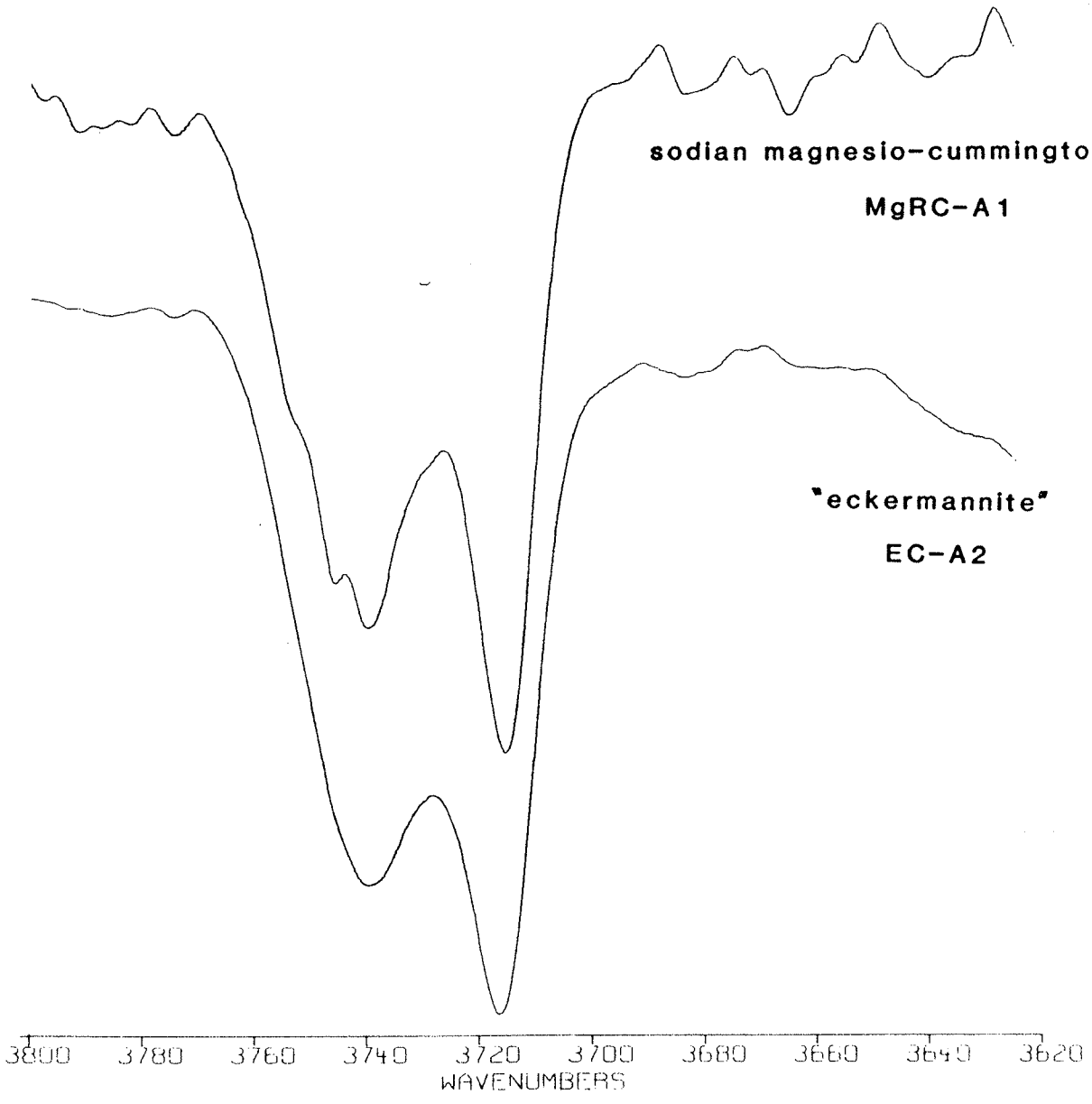

Figure 10: Infrared spectra of sodian magnesio-cummingtonite and eckermannite.

Because the octahedral sites in sodian magnesio-cummingtonite must be occupied solely by Mg, all bands in the spectrum must be from MgMgMg configurations. The presence of more than one band implies the existence of more than one hydroxyl environment, not possible in space group C2/m. Maresch and Langer (1976) assign a band at 3727 cm^{-1} to OH-valence vibrations in SiOH groups in the amphibole (Figure 26):

$$NaNa_2Mg_5Si_8O_{21}(OH)(OH)_2$$

They do not account for the other bands (see Chapter 6). The origin of the other bands is still unknown. Precession photographs (Hawthorne 1984, pers. comm.) show reflections with h+k=2n+1 suggesting that sodian magnesio-cummingtonite is primitive rather than C-centered. Until the crystal structure is known, the spectrum cannot be interpreted with certainty.

Eckermannite: $\underline{NaNa_2Mg_4AlSi_8O_{22}(OH)_2}$

The spectrum of the synthetic amphibole grown on the eckermannite composition is of interest because it is virtually identical to that of sodian magnesio-cummingtonite (Figure 10). It consists of a single, well-resolved band at 3716 cm^{-1} and a group of bands between 3739 cm^{-1} and 3754 cm^{-1}. Thus, this amphibole cannot be eckermannite, a conclusion reached earlier from cell dimensions (Table 13).

RIETVELD CRYSTAL STRUCTURE REFINEMENT

The Rietveld method (Rietveld 1967, 1969) uses the whole powder diffraction pattern to characterize the structure of the material examined. The structure parameters of the mineral, atomic coordinates, site-occupancies and thermal parameters, together with various experimental parameters affecting the pattern, are refined by least-squares procedures to minimize the difference between the whole calculated and observed

TABLE 14

Synthetic amphibole structures refined in this study

Name	Nominal Composition	†Run Number(s)
(1) Scandium pargasite	$NaCa_2Mg_4ScSi_6Al_2O_{22}(OH)_2$	ScPA-A5,6
(2) Fluor-pargasite	$NaCa_2Mg_4AlSi_6Al_2O_{22}F_2$	FPA-BUL
(3) Chromium-fluor-pargasite	$NaCa_2Mg_4CrSi_6Al_2O_{22}F_2$	FCrPA-A3a,b,c
(4) Gallium-fluor-pargasite	$NaCa_2Mg_4GaSi_6Al_2O_{22}F_2$	FGaPA-A3a,b,c
(5) Scandium-fluor-pargasite	$NaCa_2Mg_4ScSi_6Al_2O_{22}F_2$	FScPA-A3a,b,c
(6) Scandium-fluor-eckermannite	$NaNa_2Mg_4ScSi_8O_{22}F_2$	FScEC-A3a,b,c
(7) Indium-fluor-eckermannite	$NaNa_2Mg_4InSi_8O_{22}F_2$	FInEC-A3a,b,c
(8) Scandium-fluor-nyböite	$NaNa_2Mg_3Sc_2Si_7AlO_{22}F_2$	FScNY-A3a,b,c

†Table 11, Chapter 4

patterns.

The structures of eight amphiboles synthesized in this study were refined with the Rietveld method (Table 14). Raw intensity data is listed in Appendix B. Results of all structure refinements are summarized in Tables 15, 16, 18, 19 and 20. Calculated and observed powder diffraction patterns are given in Figures 11 to 18.

Refinement Results

Cell dimensions derived from the refinements are given in Table 16. In general, they are up to an order of magnitude more precise than those derived from normal least-squares refinement of powder diffraction data (Table 13). With the exception of gallium-fluor-pargasite, cell dimensions are identical within 2- or 3-sigma for both methods of determination when obtained for identical samples.

TABLE 15

Refinement Results

No.†	Scale	B	P	Asym	Zero	Rexp	Rp	Rwp	Rb
(1)	0.00264(4)	1.8(1)	0.15(1)	0.78(8)	0.027(2)	4.46	14.5	16.3	10.7
(2)	0.00642(9)	2.2(1)	0.14(1)	1.4(1)	0.076(2)	2.90	13.9	15.3	7.60
(3)	0.00427(6)	2.0(1)	0.07(1)	1.1(1)	0.072(2)	3.39	13.9	14.7	5.23
(4)	0.00610(7)	1.72(9)	0.04(1)	1.39(9)	0.127(2)	2.79	12.2	13.3	5.23
(5)	0.00533(5)	1.46(7)	0.15(1)	1.20(8)	0.061(1)	2.95	11.1	12.1	6.59
(6)	0.00763(8)	1.71(7)	0.09(1)	1.37(7)	0.115(1)	2.57	9.9	11.3	2.92
(7)	0.00459(5)	1.72(7)	0.05(1)	2.09(7)	0.097(1)	2.78	10.2	10.8	2.28
(8)	0.00717(8)	1.73(8)	0.28(1)	0.98(6)	0.107(1)	2.68	11.2	12.8	5.03

†No. corresponds to numbers in Table 14, B is the overall temperature factor, P is the preferred orientation parameter, Asym is the asymmetry parameter, Zero is the zeropoint correction, Rexp is the statistically expected value for Rwp, Rp is R-pattern, Rwp is the R-weighted pattern Rb is R-Bragg (see Appendix A for details).

Atomic positions are given in Table 18. Cation-anion and cation-cation distances (Table 20) were calculated using the RFINE program (Finger 1969). Typical ranges of natural and synthetic amphibole tetrahedral bond lengths are given in Table 21. Mean tetrahedral bond lengths

TABLE 17

Selected Correlations from the Rietveld Refinement of Indium-fluor-eckermannite

	x	y	z
O(4)-O(7)	-0.02	0	-0.45
O(1)-O(2)	-0.36	0.02	-0.28
O(5)-O(6)	-0.33	-0.16	-0.24
T(1)-T(2)	-0.47	0.14	-0.35

are a good test of the refinement results because they are well known from single-crystal structure studies and are not as variable as other cation-anion distances. Inspection of Table 20 shows that individual tetrahedral bond lengths exhibit extreme ranges of variation that are inconsistent with single-crystal structure data for both pargasites and alkali amphiboles. Mean tetrahedral bond lengths are better behaved and are reasonable, except for gallium-fluor-pargasite (4) in which <T(2)-O> is much larger than <T(1)-O>; this is not likely. Variation in individual <M-O> with mean ionic radii of constituent octahedral cations is not consistent with trends for single-crystal structures (Hawthorne 1983b).

Hawthorne (1984, pers. comm.) suggests that the existence of a pseudo-glide parallel to c in amphiboles is responsible for the incorrect atomic distances because the T(1) and T(2) tetrahedra are pseudo-symmetrically related and atomic positions are highly correlated during refinement (Table 17). This supposition is supported by Rietveld structure refinements of synthetic $P2_1/c$ clinopyroxenes by Raudsepp et al. (1984). Tetrahedral bond lengths were variable beyond reasonable ex-

TABLE 16

Cell Dimensions Determined by Rietveld Structure Analyses

No.†	a (Å)	b (Å)	c (Å)	β (°)	V (Å^3)
(1)	9.9398(7)	18.093(2)	5.2982(4)	105.363(5)	918.78
(2)	9.8284(7)	17.931(1)	5.2936(4)	105.169(4)	900.40
(3)	9.8401(5)	17.978(1)	5.2914(3)	105.100(3)	903.76
(4)	9.8598(5)	17.9682(9)	5.3026(3)	105.197(2)	906.57
(5)	9.8851(4)	18.1567(8)	5.3185(2)	105.214(2)	921.11
(6)	9.8385(3)	18.0636(6)	5.2927(2)	103.651(2)	914.04
(7)	9.8528(3)	18.0970(6)	5.2929(2)	103.521(2)	917.60
(8)	9.8465(4)	18.1643(8)	5.3401(3)	103.985(3)	926.79

†Numbers correspond to numbers in Table 14

tremes, but site-occupancies determined for the same material by Mössbauer spectroscopy were statistically identical to those determined from the Rietveld refinement. As with the amphiboles, the tetrahedra are highly correlated due to the occurence of pseudo C-centring in the $P2_1/c$ structure. To test the validity of this conjecture, the structure of a natural olivine was refined by the Rietveld method with the same experimental technique that was used for the synthetic amphibole refinements (L. Groat and F.C. Hawthorne, unpublished data). In addition, a single-crystal structure of the olivine was refined as a check on the Rietveld method. R-factors for the Rietveld refinement were Rp=12.41, Rwp=13.21 and Rexp=4.75, comparable with values from the amphibole refinements. Bond lengths and site-occupancies were statistically identical for both methods. This suggests that site-occupancies in the amphiboles are fairly accurate. Synthetic amphibole site-occupancies are given in Table 19. All negative values differ from zero by less than 3-sigma, and

may be regarded as zero; corresponding occupancies greater than 1.000 may be interpreted to be 1.000.

Some Comments on Rietveld Refinement

In general, powder structure refinements of these synthetic amphiboles are comparable with most refinements in the literature (Young 1980). Rietveld refinement is still a technique undergoing rapid development, and several aspects are currently not satisfactory:

1. The peak profile function currently used in all Rietveld routines does not adequately model the observed peak shape. Difference plots in Figures 11 to 18 show consistent sinusoidal fluctuations that reflect poor fits at the peak base. These are best observed for the (020) and (110) peaks between 9.5 and 10.6°2θ.
2. The single refinable asymmetry parameter does not adequately model peak asymmetry over the entire 2θ range. Best results (lowest Rwp's) were obtained by refining the asymmetry parameter only below about 32°2θ; refining this parameter for the whole pattern gave higher R-values.
3. All of the samples, except indium-fluor-eckermannite (8) contain up to 10 percent extraneous phases that contribute to the overall pattern. Peaks due to phases other than amphibole are marked by arrows in Figures 11 to 18. These correspond to phases other than amphibole listed in Table 11. The refinement program allows regions of extraneous intensity to be excluded, but extra intensity under amphibole peaks cannot be excluded in this way; this raises the R-factors significantly.

Significance of the Residual Pattern

The residual pattern that remains when the observed diffraction pattern is subtracted from the calculated pattern (Figures 11 to 18) is valuable because it comprises the diffraction patterns of phases other than amphibole in the run product. In the whole pattern, the scattering contribution of these phases are partly or completely masked by the intense amphibole pattern; this may lead to the false assumption that the amphibole yield is near 100 percent.

With the current profile function, the interpretation of the residual pattern is not straightforward because the diffraction patterns of extraneous phases are mixed with residual intensity derived from inadequate peak-shape models. The residual pattern of indium-fluor-eckermannite (Figure 17) contains only contributions from inadequate peak-shape modelling, and the run product may be confidently interpreted to be essentially 100 percent amphibole. All of the other residual patterns contain obvious contributions from non-amphibole phases, not all of which are obvious from the whole patterns.

Indexing of Synthetic Amphibole Powder Patterns

Use of the Rietveld method ensures that the amphibole pattern is correctly indexed, and that non-amphibole peaks are not indexed as amphibole peaks. This is of more importance than one would initially think, as several published patterns have incorrect indexing and wrong cell dimensions as a result of this.

Caption: Figures 11 to 18. Powder X-ray Diffraction Patterns.

Figures 11 to 18 show the results of Rietveld structure refinements with graphite-crystal monochromatized CuKα_1 and CuKα_2 X-ray data collected in 0.04°2θ steps in the range 8 to 72°2θ. Open squares are the observed data, the solid line is the calculated pattern, the vertical bars below the pattern represent all possible Bragg reflections and the arrows point to non-amphibole reflections. The residual pattern obtained by subtracting the observed and calculated patterns is shown at the bottom.

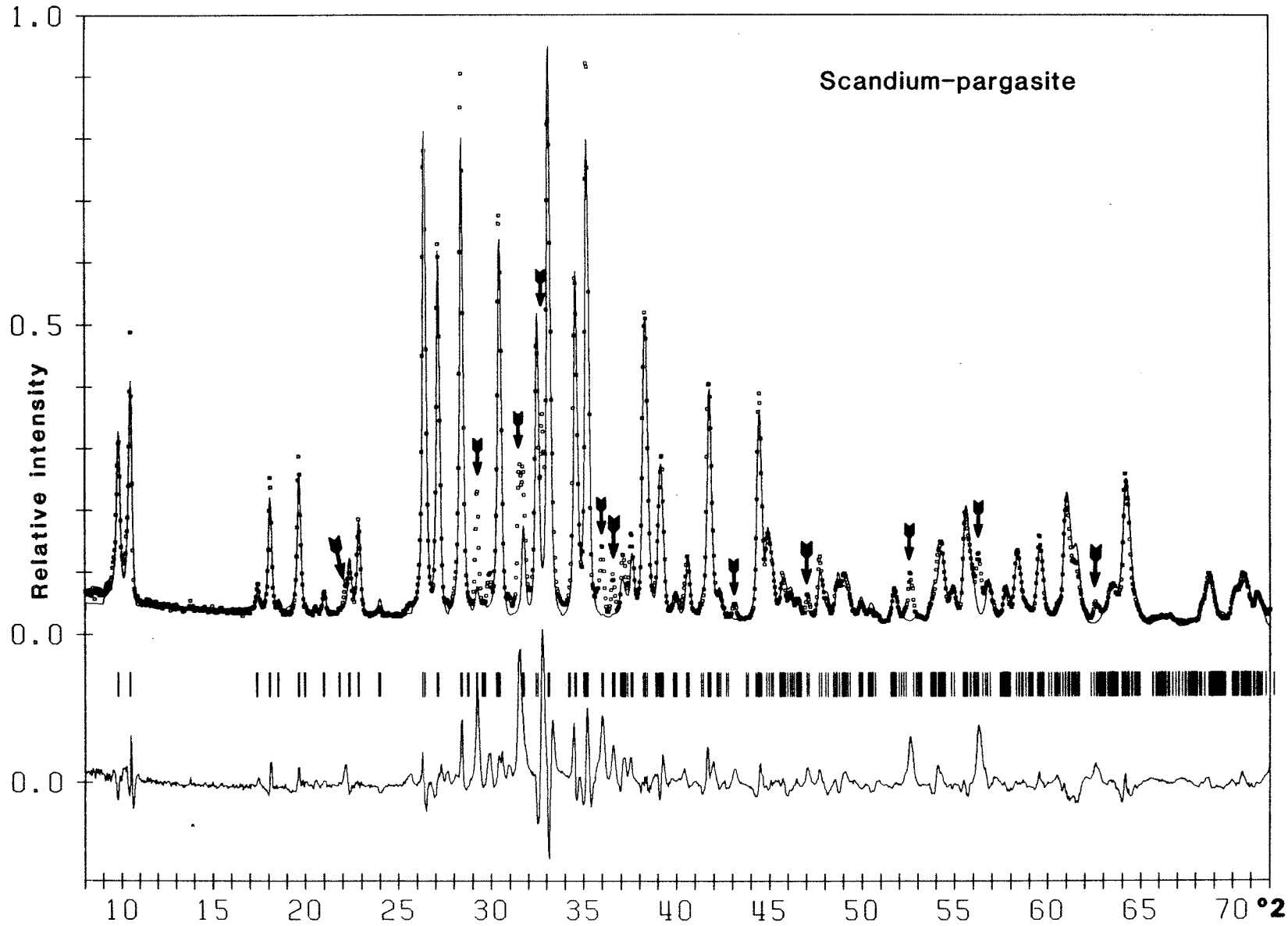

Figure 11: Powder X-ray diffraction pattern of scandium-pargasite.

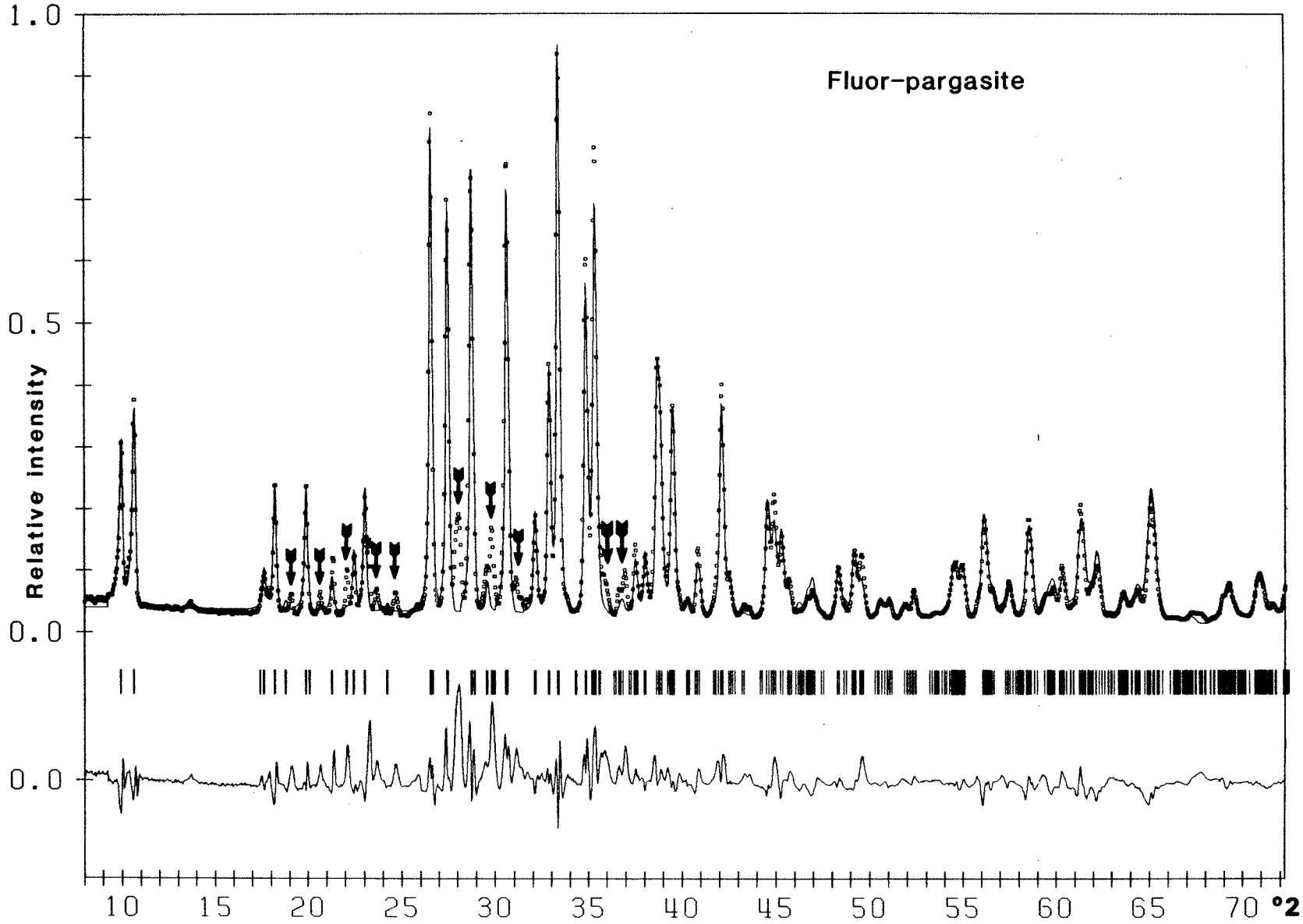

Figure 12: Powder X-ray diffraction pattern of fluor-pargasite.

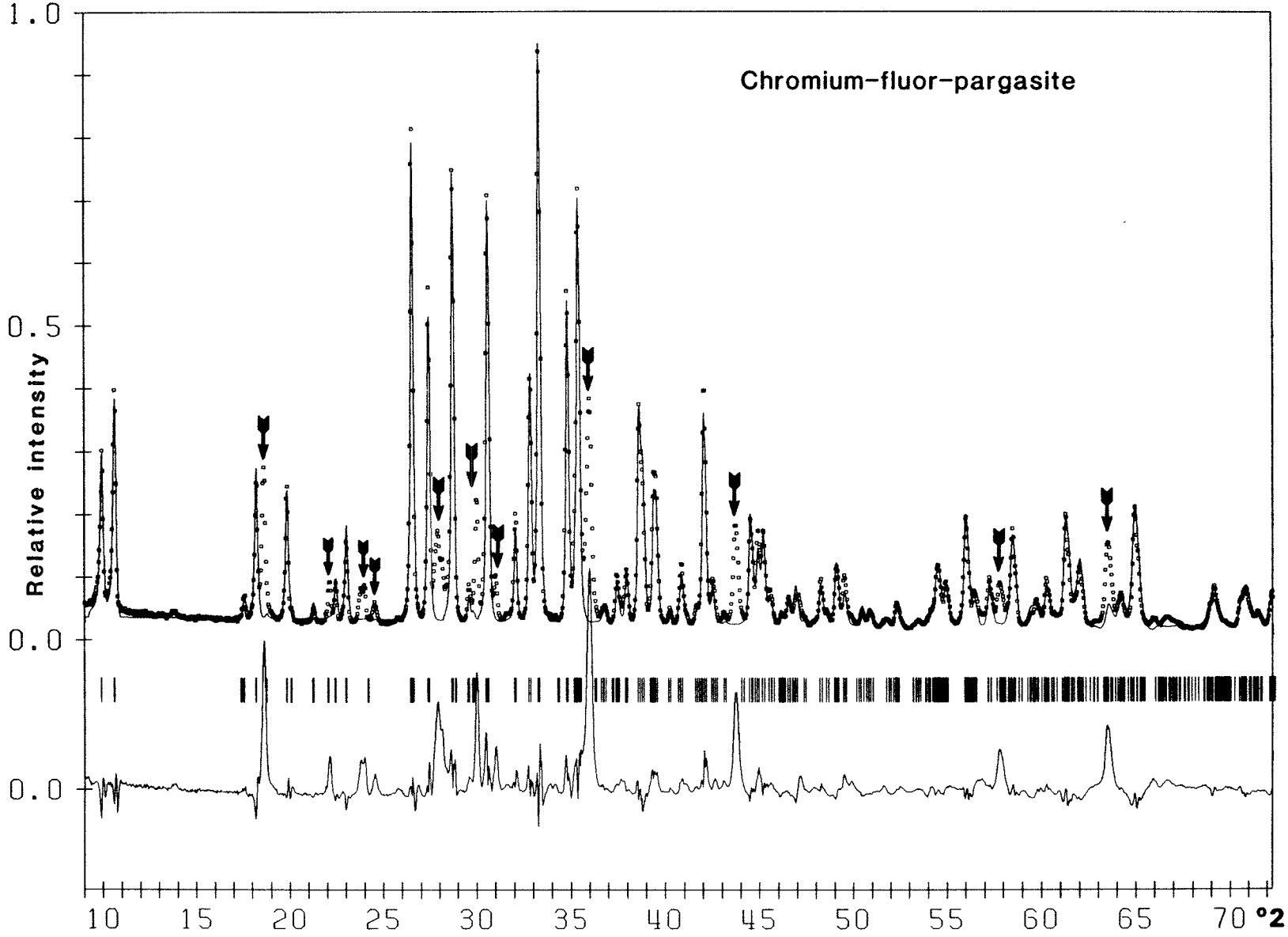

Figure 13: Powder X-ray diffraction pattern of chromium-fluor-pargasite.

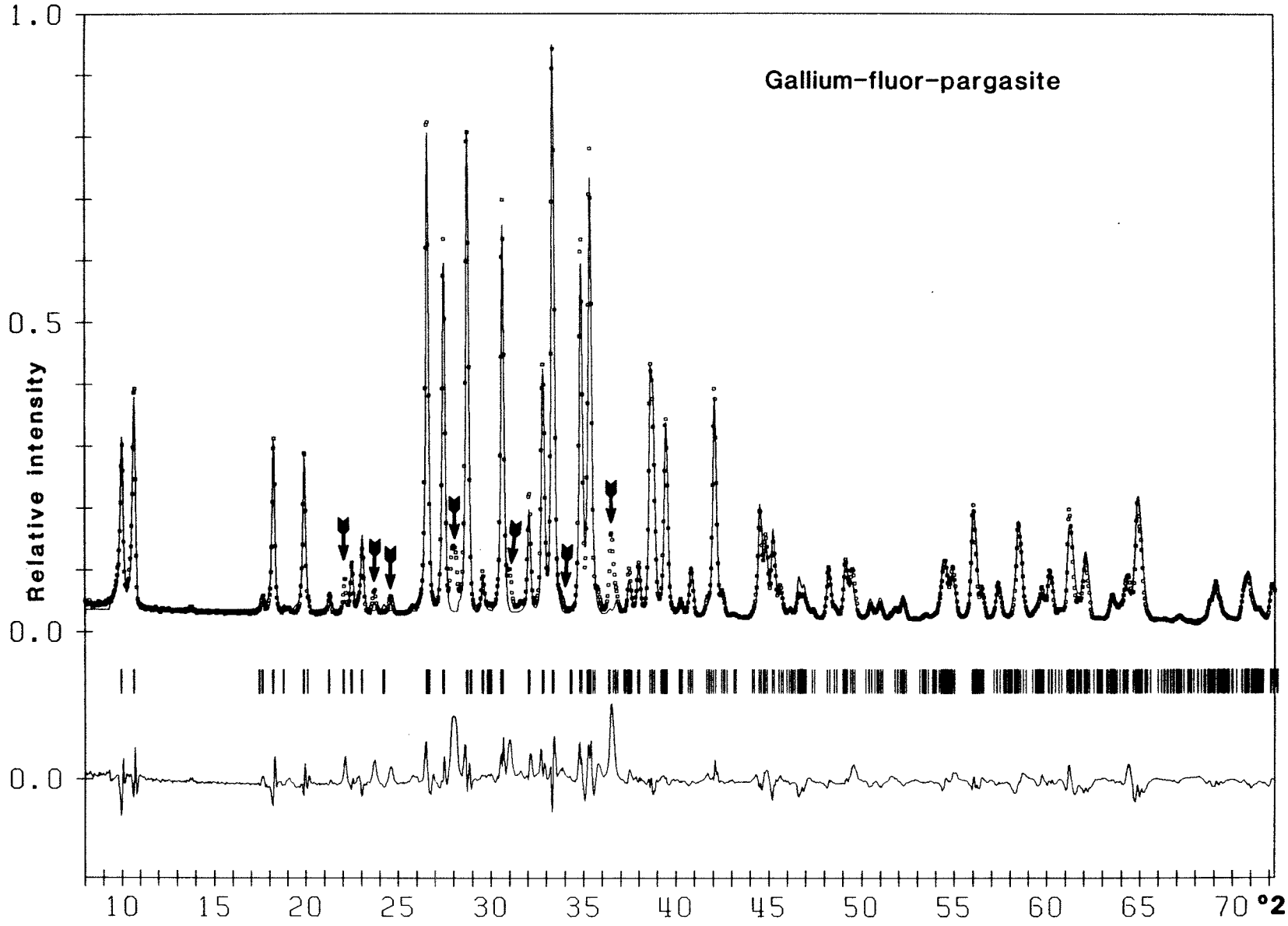

Figure 14: Powder X-ray diffraction pattern of gallium-fluor-pargasite.

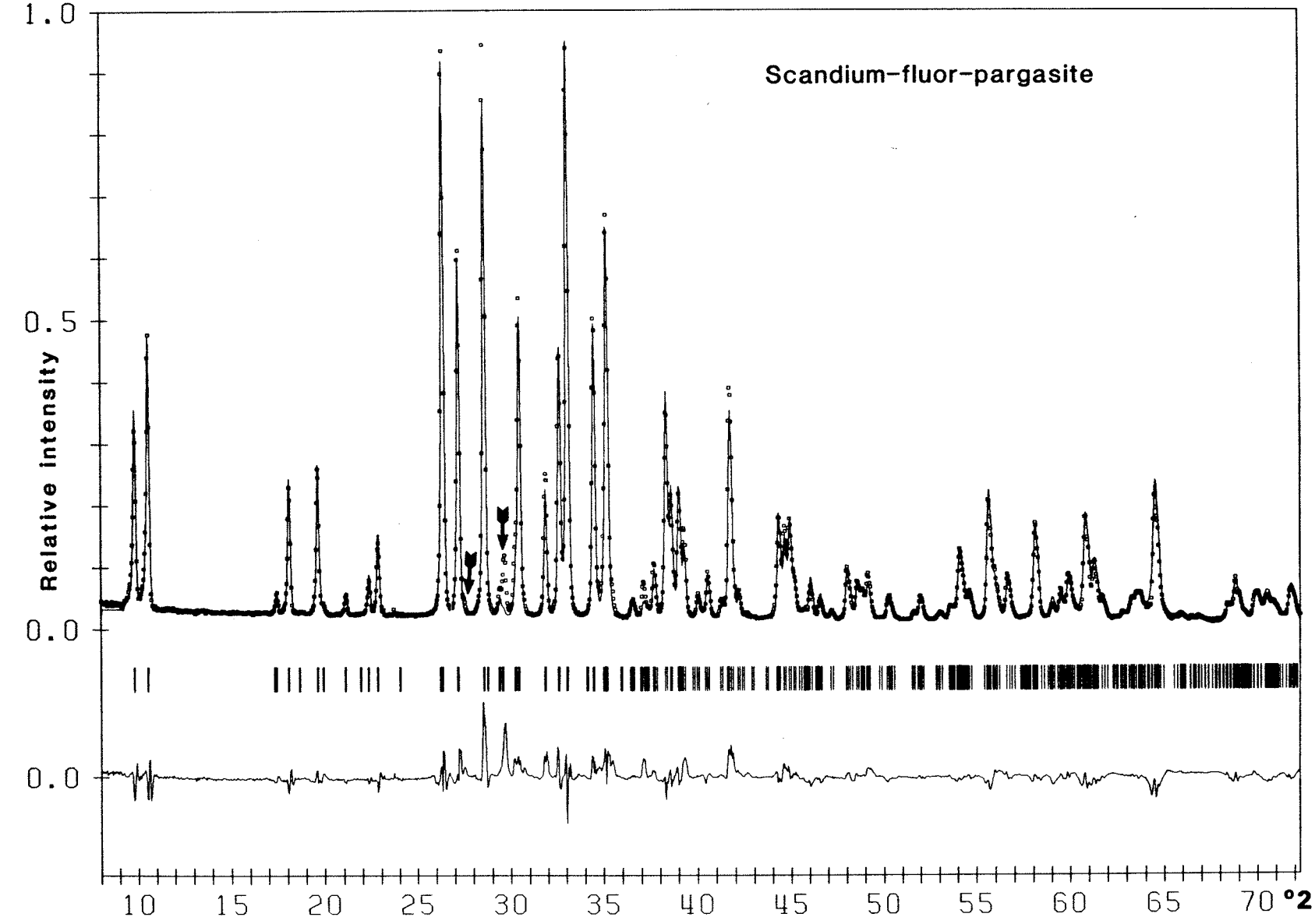

Figure 15: Powder X-ray diffraction pattern of scandium-fluor-pargasite.

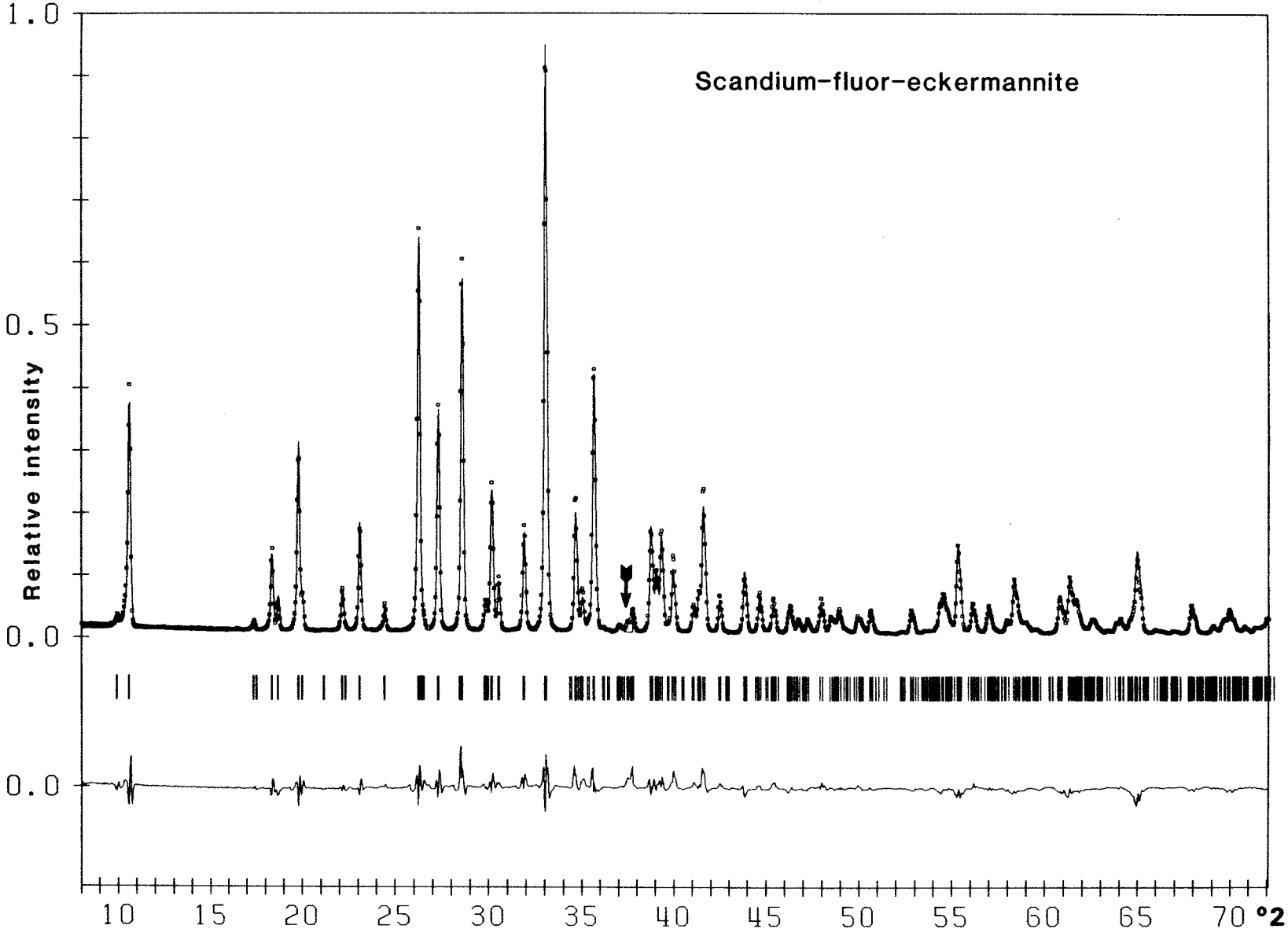

Figure 16: Powder X-ray diffraction pattern of scandium-fluor-eckermannite.

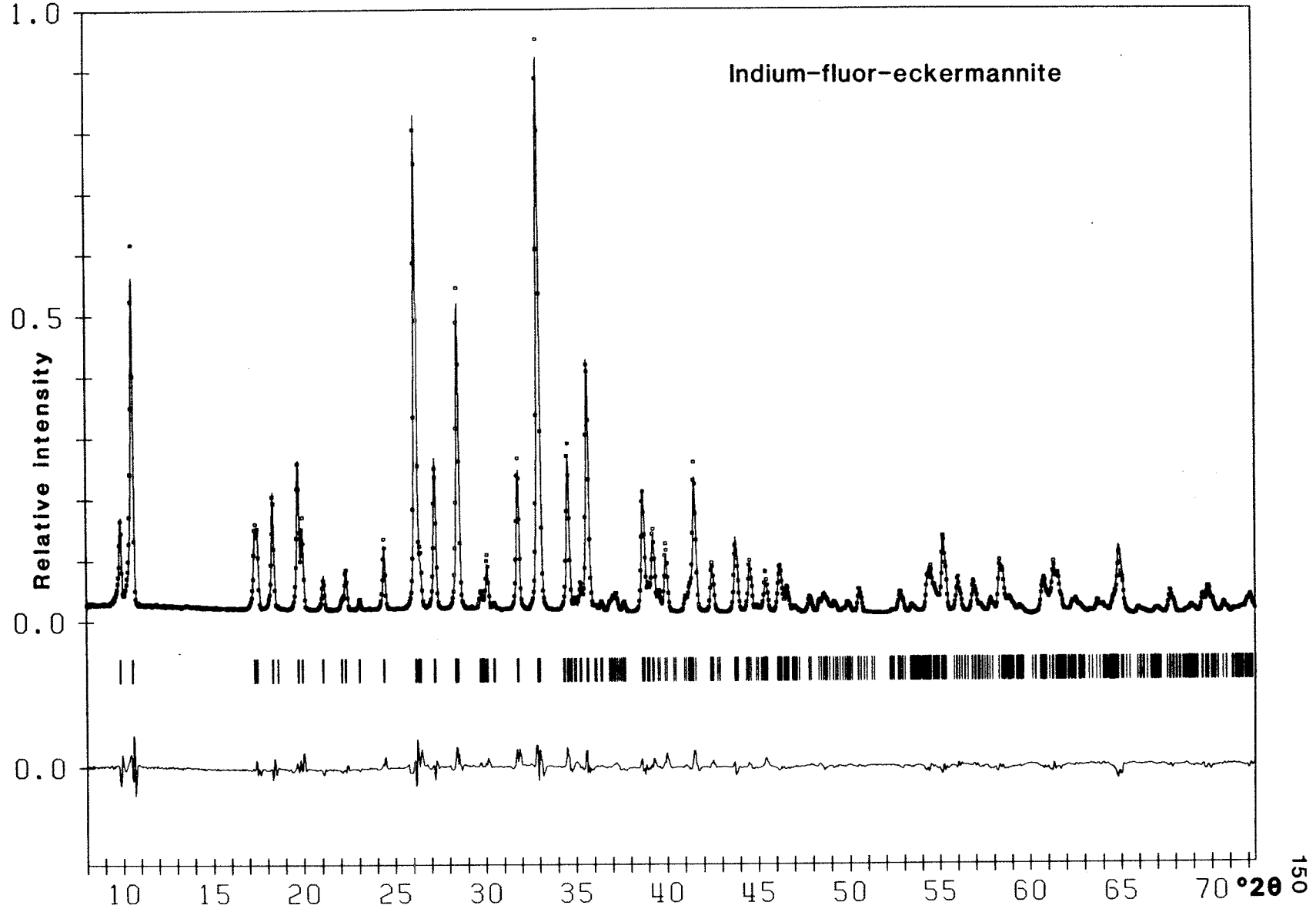

Figure 17: Powder X-ray diffraction pattern of indium-fluor-eckermannite.

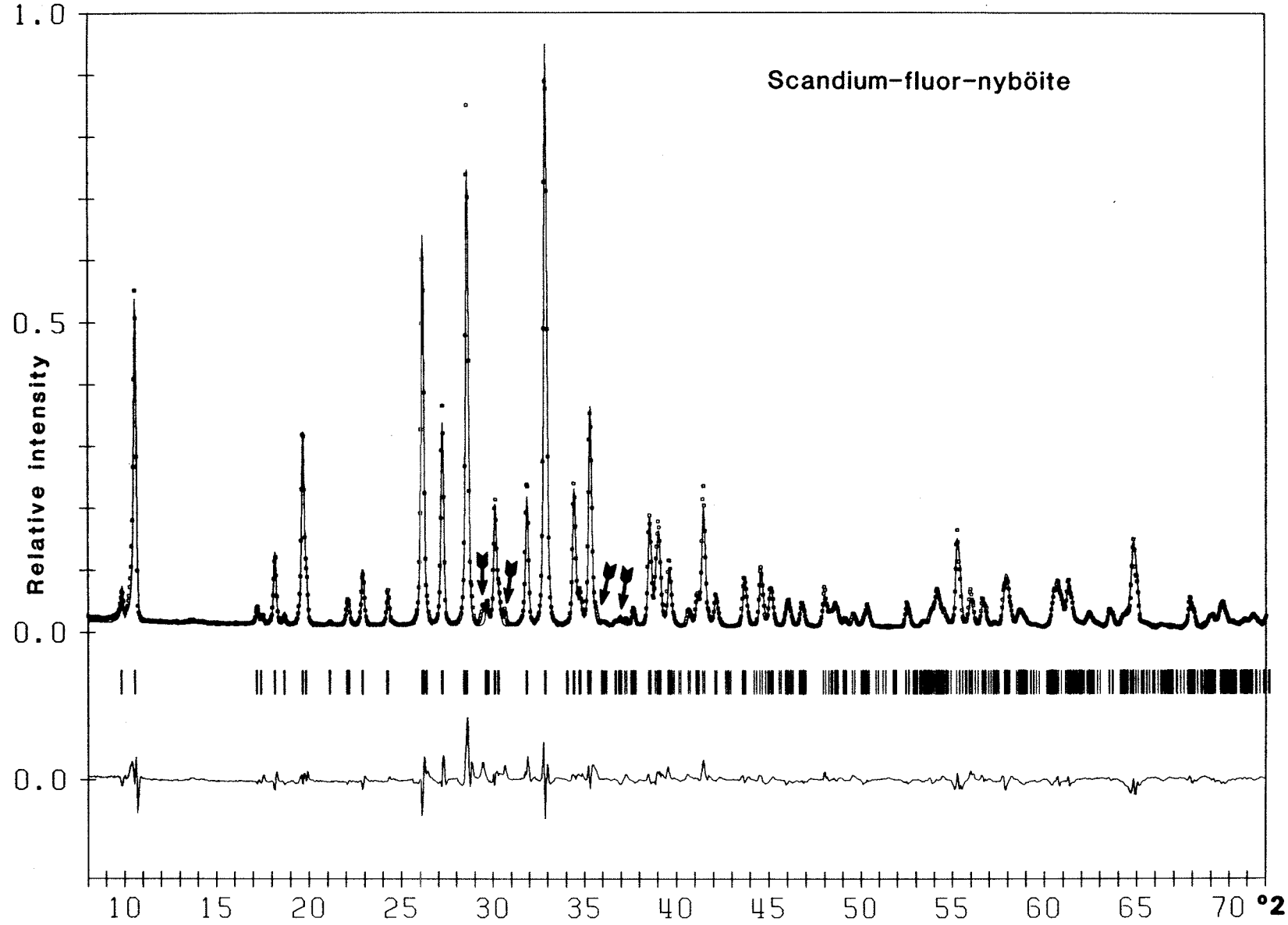

Figure 18: Powder X-ray diffraction pattern scandium-fluor-nyböite.

TABLE 18

Atomic Positions

A. Pargasites

		(1)	(2)	(3)	(4)	(5)
O(1)	x	0.127(1)	0.103(1)	0.103(1)	0.117(1)	0.107(1)
	y	0.0970(4)	0.0884(6)	0.0919(7)	0.0901(6)	0.0862(5)
	z	0.223(3)	0.207(2)	0.197(2)	0.214(2)	0.219(2)
	B	0.80				
O(2)	x	0.101(2)	0.127(1)	0.123(1)	0.104(1)	0.119(1)
	y	0.1758(7)	0.1702(6)	0.1705(6)	0.1683(6)	0.1698(5)
	z	0.722(3)	0.742(3)	0.742(2)	0.731(2)	0.724(2)
	B	0.80				
O(3)	x	0.101(2)	0.107(1)	0.103(2)	0.095(1)	0.099(1)
	y	0	0	0	0	0
	z	0.698(4)	0.716(4)	0.718(3)	0.704(3)	0.710(2)
	B	0.80				
O(4)	x	0.345(1)	0.365(1)	0.357(1)	0.353(1)	0.358(1)
	y	0.2489(6)	0.2482(6)	0.2467(6)	0.2450(5)	0.2447(4)
	z	0.767(4)	0.791(4)	0.794(3)	0.782(3)	0.787(2)
	B	0.80				
O(5)	x	0.352(1)	0.352(2)	0.359(2)	0.350(1)	0.351(1)
	y	0.1399(6)	0.1386(5)	0.1367(5)	0.1388(5)	0.1389(4)
	z	0.099(3)	0.122(3)	0.122(3)	0.105(2)	0.117(2)
	B	1.10				
O(6)	x	0.343(2)	0.339(2)	0.334(2)	0.340(1)	0.340(1)
	y	0.1134(6)	0.1096(6)	0.1137(6)	0.1097(5)	0.1160(4)
	z	0.640(3)	0.611(3)	0.595(3)	0.591(2)	0.607(2)
	B	1.10				
O(7)	x	0.339(2)	0.339(2)	0.334(2)	0.340(1)	0.347(1)
	y	0	0	0	0	0
	z	0.293(5)	0.276(5)	0.274(4)	0.276(3)	0.293(3)
	B	1.20				
T(1)	x	0.283(1)	0.274(1)	0.275(1)	0.286(1)	0.282(1)
	y	0.0827(4)	0.0836(3)	0.0834(3)	0.0859(3)	0.0841(2)
	z	0.302(2)	0.296(1)	0.293(1)	0.298(1)	0.298(1)
	B	0.40				

		(1)	(2)	(3)	(4)	(5)
T(2)	x	0.285(1)	0.298(1)	0.296(1)	0.285(1)	0.292(1)
	y	0.1681(3)	0.1719(3)	0.1725(3)	0.1703(3)	0.1692(2)
	z	0.807(2)	0.813(1)	0.814(1)	0.806(1)	0.809(1)
	B	0.40				
M(1)	x	0	0	0	0	0
	y	0.0868(6)	0.0913(6)	0.0893(5)	0.0884(5)	0.0883(4)
	z	1/2	1/2	1/2	1/2	1/2
	B	0.60				
M(2)	x	0	0	0	0	0
	y	0.1740(5)	0.1804(6)	0.1751(5)	0.1767(4)	0.1762(3)
	z	0	0	0	0	0
	B	0.60				
M(3)	x	0	0	0	0	0
	y	0	0	0	0	0
	z	0	0	0	0	0
	B	0.60				
M(4)	x	0	0	0	0	0
	y	0.2808(4)	0.2776(5)	0.2770(3)	0.2781(3)	0.2794(3)
	z	1/2	1/2	1/2	1/2	1/2
	B	0.90				
A	x	0	0.027(3)	0.033(3)	0.028(2)	0.035(2)
	y	1/2	1/2	1/2	1/2	1/2
	z	0	0.011(10)	0.036(2)	0.041(7)	0.048(5)
	B	2.30				

Nominal Compositions

(1) Scandium pargasite: $NaCa_2Mg_4ScSi_6Al_2O_{22}(OH)_2$

(2) Fluor-pargasite: $NaCa_2Mg_4AlSi_6Al_2O_{22}F_2$

(3) Chromium-fluor-pargasite: $NaCa_2Mg_4CrSi_6Al_2O_{22}F_2$

(4) Gallium-fluor-pargasite: $NaCa_2Mg_4GaSi_6Al_2O_{22}F_2$

(5) Scandium-fluor-pargasite: $NaCa_2Mg_4ScSi_6Al_2O_{22}F_2$

B. Alkali Amphiboles

		(6)	(7)	(8)
O(1)	x	0.112(1)	0.122(1)	0.105(1)
	y	0.0887(4)	0.0858(5)	0.0912(5)
	z	0.212(2)	0.219(2)	0.213(2)
	B	0.80		
O(2)	x	0.124(1)	0.122(1)	0.126(1)
	y	0.1647(4)	0.1639(5)	0.1677(5)
	z	0.731(2)	0.732(2)	0.724(2)
	B	0.80		
O(3)	x	0.101(1)	0.098(1)	0.098(2)
	y	0	0	0
	z	0.705(2)	0.704(2)	0.713(3)
	B	0.80		
O(4)	x	0.359(1)	0.354(1)	0.357(1)
	y	0.2449(3)	0.2438(4)	0.2461(4)
	z	0.794(2)	0.789(2)	0.787(2)
	B	0.80		
O(5)	x	0.346(1)	0.348(1)	0.340(1)
	y	0.1264(4)	0.1271(4)	0.1313(5)
	z	0.081(2)	0.073(2)	0.083(2)
	B	1.10		
O(6)	x	0.344(1)	0.338(1)	0.345(1)
	y	0.1183(4)	0.1171(4)	0.1162(4)
	z	0.577(2)	0.568(2)	0.595(2)
	B	1.10		
O(7)	x	0.340(1)	0.338(1)	0.340(1)
	y	0	0	0
	z	0.309(2)	0.299(3)	0.311(3)
	B	1.20		
T(1)	x	0.2804(4)	0.2831(4)	0.2831(4)
	y	0.0837(2)	0.0838(2)	0.0844(2)
	z	0.285(1)	0.285(1)	0.284(1)
	B	0.40		

		(6)	(7)	(8)
T(2)	x	0.2910(5)	0.2889(5)	0.2889(5)
	y	0.1682(2)	0.1677(2)	0.1664(2)
	z	0.795(1)	0.793(1)	0.805(1)
	B	0.40		
M(1)	x	0	0	0
	y	0.0890(3)	0.0870(4)	0.0870(4)
	z	1/2	1/2	1/2
	B	0.60		
M(2)	x	0	0	0
	y	0.1823(3)	0.1821(2)	0.1802(3)
	z	0	0	0
	B	0.60		
M(3)	x	0	0	0
	y	0	0	0
	z	0	0	0
	B	0.60		
M(4)	x	0	0	0
	y	0.2751(4)	0.2751(5)	0.2792(5)
	z	1/2	1/2	1/2
	B	0.90		
A	x	0.036(2)	0.040(2)	0.045(2)
	y	1/2	1/2	1/2
	z	0.066(4)	0.061(4)	0.070(4)
	B	2.3		

Nominal Compositions

(6) Scandium-fluor-eckermannite: $NaNa_2Mg_4ScSi_8O_{22}F_2$

(7) Indium-fluor-eckermannite: $NaNa_2Mg_4InSi_8O_{22}F_2$

(8) Scandium-fluor-nyböite: $NaNa_2Mg_3Sc_2Si_7AlO_{22}F_2$

TABLE 19

M(1)-, M(2)-, M(3)-site Occupancies

(1)	Scandium pargasite				
	M(1)	Mg	1.023(25)	Sc	-0.023(24)
	M(2)	Mg	0.771(23)	Sc	0.229(23)
	M(3)	Mg	0.812(29)	Sc	0.188(29)
(2)	Fluor-pargasite				
	M(1)	Mg	1-x	Al	x
	M(2)	Mg	1-y	Al	y
	M(3)	Mg	1-z	Al	z
(3)	Chromium-fluor-pargasite				
	M(1)	Mg	1.014(12)	Cr	-0.014(12)
	M(2)	Mg	0.890(14)	Cr	0.110(14)
	M(3)	Mg	1.016(20)	Cr	0.020(20)
(4)	Gallium-fluor-pargasite				
	M(1)	Mg	1.026(8)	Ga	-0.026(8)
	M(2)	Mg	0.888(8)	Ga	0.112(8)
	M(3)	Mg	0.964(12)	Ga	0.036(12)
(5)	Scandium-fluor-pargasite				
	M(1)	Mg	0.983(14)	Sc	0.017(14)
	M(2)	Mg	0.554(16)	Sc	0.446(16)
	M(3)	Mg	0.986(20)	Sc	0.014(20)
(6)	Scandium-fluor-eckermannite				
	M(1)	Mg	0.968(12)	Sc	0.034(12)
	M(2)	Mg	0.524(12)	Sc	0.476(12)
	M(3)	Mg	1.032(16)	Sc	-0.032(16)
(7)	Indium-fluor-eckermannite				
	M(1)	Mg	1.004(2)	In	-0.004(2)
	M(2)	Mg	0.498(2)	In	0.502(4)
	M(3)	Mg	1.012(4)	In	-0.008(4)
(8)	Scandium-fluor-nyböite				
	M(1)	Mg	0.932(14)	Sc	0.068(14)
	M(2)	Mg	0.104(16)	Sc	0.896(16)
	M(3)	Mg	1.052(20)	Sc	-0.052(20)

TABLE 20

Cation-anion and Cation-cation Distances

A. Pargasites

	(1)	(2)	(3)	(4)	(5)
T(1)-O(1)	1.514	1.624	1.649	1.608	1.662
T(1)-O(5)	1.756	1.664	1.676	1.643	1.656
T(1)-O(6)	1.817	1.687	1.647	1.567	1.693
T(1)-O(7)	1.602	1.657	1.662	1.648	1.660
<T(1)-O>	1.672	1.658	1.659	1.617	1.668
T(2)-O(2)	1.773	1.628	1.639	1.724	1.645
T(2)-O(4)	1.611	1.553	1.494	1.521	1.537
T(2)-O(5)	1.599	1.686	1.706	1.646	1.682
T(2)-O(6)	1.534	1.654	1.666	1.759	1.605
<T(2)-O>	1.629	1.630	1.626	1.663	1.617
M(1)-O(1) x2	2.142	2.064	2.108	2.132	2.049
M(1)-O(2) x2	2.088	2.086	2.105	1.988	2.064
M(1)-O(3) x2	2.004	2.111	2.082	2.010	2.048
<M(1)-O>	2.078	2.087	2.098	2.043	2.054
M(2)-O(1) x2	2.059	2.091	1.948	2.043	2.054
M(2)-O(2) x2	1.995	2.085	2.053	1.967	2.111
M(2)-O(4) x2	2.199	1.963	2.086	2.129	2.118
<M(2)-O>	2.084	2.046	2.029	2.060	2.117
M(3)-O(1) x4	2.320	2.040	2.070	2.132	2.069
M(3)-O(3) x2	2.103	2.047	2.012	2.025	2.031
<M(3)-O>	2.248	2.042	2.051	2.096	2.056
M(4)-O(2) x2	2.320	2.462	2.442	2.404	2.456
M(4)-O(4) x2	2.410	2.324	2.393	2.378	2.369
M(4)-O(5) x2	2.659	2.619	2.624	2.681	2.634
M(4)-O(6) x2	2.693	2.726	2.688	2.684	2.631
<M(4)-O>	2.521	2.533	2.537	2.537	2.523

	(1)	(2)	(3)	(4)	(5)
M(1)-M(1)	3.141	3.274	3.211	3.177	3.206
M(1)-M(2)	3.083	3.092	3.063	3.090	3.101
M(1)-M(3)	3.080	3.112	3.095	3.091	3.105
M(1)-M(4)	3.512	3.341	3.374	3.409	3.470
M(2)-M(3)	3.148	3.235	3.148	3.175	3.199
M(2)-M(4)	3.280	3.169	3.218	3.217	3.253
T(1)-T(2)	3.082	3.108	3.140	3.094	3.103
T(1)-T(2)	3.051	3.060	3.039	3.015	3.051
T(1)-T(1)	2.993	2.998	2.999	3.087	3.054

Nominal Compositions

(1) Scandium pargasite: $NaCa_2Mg_4ScSi_6Al_2O_{22}(OH)_2$

(2) Fluor-pargasite: $NaCa_2Mg_4AlSi_6Al_2O_{22}F_2$

(3) Chromium-fluor-pargasite: $NaCa_2Mg_4CrSi_6Al_2O_{22}F_2$

(4) Gallium-fluor-pargasite: $NaCa_2Mg_4GaSi_6Al_2O_{22}F_2$

(5) Scandium-fluor-pargasite: $NaCa_2Mg_4ScSi_6Al_2O_{22}F_2$

B. Alkali Amphiboles

	(6)	(7)	(8)
T(1)-O(1)	1.613	1.549	1.712
T(1)-O(5)	1.582	1.617	1.574
T(1)-O(6)	1.651	1.588	1.724
T(1)-O(7)	1.615	1.607	1.626
<T(1)-O>	1.615	1.590	1.659
T(2)-O(2)	1.595	1.599	1.646
T(2)-O(4)	1.539	1.522	1.571
T(2)-O(5)	1.662	1.634	1.581
T(2)-O(6)	1.643	1.666	1.595
<T(2)-O>	1.610	1.605	1.598
M(1)-O(1) x2	2.079	2.117	2.042
M(1)-O(2) x2	2.039	2.049	2.095
M(1)-O(3) x2	2.057	2.024	2.047
<M(1)-O>	2.058	2.063	2.061
M(2)-O(1) x2	2.180	2.272	1.099
M(2)-O(2) x2	2.108	2.091	2.155
M(2)-O(4) x2	2.033	1.088	2.073
<M(2)-O>	2.107	2.150	2.109
M(3)-O(1) x4	2.112	2.130	2.130
M(3)-O(3) x2	2.038	2.023	2.001
<M(3)-O>	2.087	2.084	2.087
M(4)-O(2) x2	2.503	2.512	2.518
M(4)-O(4) x2	2.344	2.357	2.366
M(4)-O(5) x2	2.965	2.982	2.896
M(4)-O(6) x2	2.555	2.595	2.565
<M(4)-O>	2.592	2.612	2.586

	(6)	(7)	(8)
M(1)-M(1)	3.215	3.149	3.161
M(1)-M(2)	3.137	3.157	3.162
M(1)-M(3)	3.096	3.079	3.103
M(1)-M(4)	3.362	3.404	3.491
M(2)-M(3)	3.293	3.295	3.273
M(2)-M(4)	3.133	3.136	3.219
T(1)-T(2)	3.085	3.079	3.124
T(1)-T(2)	3.028	3.024	2.998
T(1)-T(1)	3.024	3.033	3.066

Nominal Compositions
(6) Scandium-fluor-eckermannite: $NaNa_2Mg_4ScSi_8O_{22}F_2$
(7) Indium-fluor-eckermannite: $NaNa_2Mg_4InSi_8O_{22}F_2$
(8) Scandium-fluor-nyböite: $NaNa_2Mg_3Sc_2Si_7AlO_{22}F_2$

TABLE 21

Typical Amphibole Tetrahedral Bond Lengths†

	Min	Max	Mean
T(1)-O(1)	1.580	1.690	1.638
T(1)-O(5)	1.613	1.730	1.661
T(1)-O(6)	1.550	1.710	1.652
T(1)-O(7)	1.590	1.670	1.637
<T(1)-O>	1.610	1.681	1.647
T(2)-O(2)	1.608	1.720	1.633
T(2)-O(4)	1.572	1.650	1.601
T(2)-O(5)	1.580	1.676	1.643
T(2)-O(6)	1.600	1.704	1.659
<T(2)-O>	1.620	1.670	1.634

†Calculated from data in Appendix B, Hawthorne (1983b).

Chapter VI

DISCUSSION AND CONCLUSIONS

The discussion embraces three major themes:

1. What was learned from a critical evaluation of previous amphibole syntheses and how detailed characterization of these amphiboles, when accomplished, clearly demonstrates the need for such analyses as a routine part of all synthesis experiments.
2. What was learned from amphibole syntheses during this study, particularly the importance of sophisticated characterization of run products.
3. General conclusions about synthetic amphiboles, especially cation ordering, and how synthetic amphiboles differ significantly from natural amphiboles. The need for caution in applying the results of amphibole synthesis experiments to natural amphibole is emphasized.

PREVIOUS AMPHIBOLE SYNTHESES

Calcic Amphiboles

Tremolite

All tremolite syntheses have been difficult, requiring runs from several hundred to over a thousand hours. In spite of these lengthy runs, many with intermediate regrinding of charges, yields are generally poor, between 50 and 85-95 percent. Six synthetic tremolites have been charac-

terized by cell dimensions (Table 5, No. 1,2,3,4,5 and 6). Of these, No. 5, grown by Westrich (1978), is suspect, having a and c parameters much higher and lower respectively, than the others. Although yields are variable, the cell dimensions are remarkably similar and bracket those of natural tremolite characterized by Papike et al. (1969) (Table 22). The natural amphibole was characterized by single-crystal struc-

TABLE 22

Comparison of synthetic and natural tremolite cell dimensions

	1	2
a	9.818(5)	9.801-9.833
b	18.047(8)	18.054-18.07
c	5.275(3)	5.268-5.284
ß	104.66(5)	104.35-104.70
V	904.2(6)	904.6-905.8

1. Natural tremolite, Papike et al. (1969)
2. Synthetic tremolite, range from Table 5

ture refinement and is close to ideal tremolite in composition.

Troll and Gilbert (1972) argued that their tremolite was "on composition" for three reasons:

1. With the tremolite bulk composition, the only possible solid solution component is magnesio-anthophyllite/magnesio-cummingtonite, $\square Mg_7Si_8O_{22}(OH)_2$, with cell volume 1756 $Å^3$ for the synthetic endmember (Greenwood 1963). Solutions containing magnesio-anthophyllite should trend towards lower volumes because one-half the

cell volume of magnesio-anthophyllite is only 878 $Å^3$ compared to the average of 905.6 $Å^3$ for tremolites grown in these experiments. Because this cell volume is comparable to those of other tremolite syntheses, Troll and Gilbert conclude that their synthetic tremolite is "nearly" stoichiometric.

2. The proportions of the breakdown phases remain nearly constant whether an amphibole is present or not.
3. Published analyses of natural tremolites at the time of the study (Table 5, Troll and Gilbert (1972)), show no evidence of solution towards magnesio-anthophyllite/magnesio-cummingtonite.

Troll and Gilbert (1972) point out that the analysis of this natural tremolite shows no evidence of solid solution towards magnesio-anthophyllite/magnesio-cummingtonite. However, it has an excess of 0.08 octahedral cations and a deficiency of Ca (1.86) (Papike et al. 1969). At least minor solid solution towards magnesio-anthophyllite/magnesio-cummingtonite is suggested. This reinforces the argument of Jenkins (1981) that synthetic tremolite may be non-stoichiometric, having a Ca/(Ca+Mg) ratio of about 0.88. Furthermore, N. Chatterjee (pers. comm. 1971 to Wones and Dodge) concluded that tremolite synthesized at 750°C contains 5 to 10 mole percent $\square Mg_7Si_8O_{22}(OH)_2$. Goldman and Rossman (1977) and Goldman (1979) present evidence from electronic absorption and Mössbauer spectroscopy for Fe^{2+} in the M(4) site of calcic amphiboles; by analogy, Mg could also occupy the M(4) site in tremolite.

It is likely that stoichiometric tremolite has never been synthesized, and the possibility of magnesio-anthophyllite/magnesio-cummingtonite component in synthetic tremolite is an experimental difficulty that

has not been adequately resolved. Although synthetic tremolite run products are very fine-grained and cannot be readily characterized by electron microprobe or single-crystal structure analysis, it is essential that this synthesis problem is overcome in future tremolite studies; these techniques are the only ones presently available to determine M(4) site-occupancies in tremolite.

Ferro-actinolite

Ferro-actinolite provides an ideal example of the value of proper crystal chemical characterization. Ernst (1966) considers synthetic ferro-actinolite to be on composition because:

1. Phases of anhydrous condensed assemblages for the ferro-actinolite bulk composition are present in the same relative proportions, regardless of amphibole yields.
2. Optical and X-ray properties do not depend on the amphibole yield.
3. Mean indices of refraction and β cell angles indicate that the synthetic ferro-actinolite does not represent solid solution with grunerite.

These arguments for nominal composition are similar to those advanced by Troll and Gilbert (1972) in their tremolite study, and indeed, by most other synthesis studies. That these arguments are inadequate was shown by Burns and Greaves (1971) who examined the Mössbauer spectrum of one of these ferro-actinolites (Figure 19). If the amphibole were of the nominal composition, the spectrum should consist of three Fe^{2+} doublets with intensity ratios 2:2:1, corresponding to Fe^{2+} at M(1), M(2) and

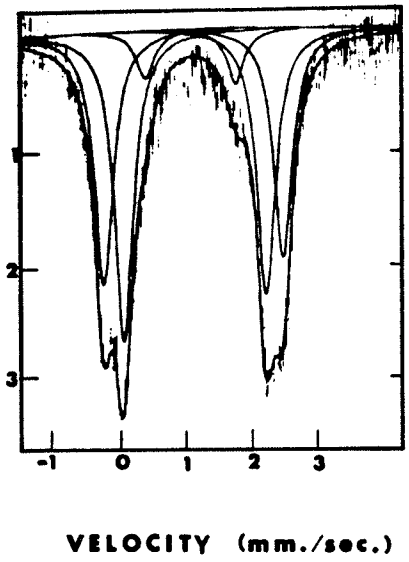

Figure 19: Mössbauer spectrum of synthetic ferro-actinolite grown by Ernst (1966). Spectrum from Burns and Greaves (1971).

M(3) respectively. This is not the case. Burns and Greaves (1971) propose that the doublet with the smallest quadrupole splitting is due to Fe^{2+} at M(4); this assignment is supported by electron absorption spectra examined by Goldman and Rossman (1977). The remaining doublets are assigned to Fe^{2+} at M(1) and at M(2)+M(3). These results show that ferro-actinolite grown by Ernst (1966) is off composition and contains some grunerite component in solid solution.

Actinolite

Cameron (1975) apparently synthesized actinolite midway on the tremolite...ferro-actinolite join. The run product contained minor magnesio-cummingtonite, clinopyroxene and quartz, but the cell volume (No. 1, Table 7) of 921.9(7) $Å^3$ is essentially identical to that calculated from average synthetic tremolite and ferro-actinolite (921.8 $Å^3$) in Table 5. The amount of magnesio-cummingtonite solid solution, if any, could not be determined from the relatively imprecise electron microprobe analyses given. In view of the probability of magnesio-anthophyllite/magnesio-cummingtonite solid solution in synthetic tremolite, demonstrated grunerite solid solution in ferro-actinolite and the cell volume exactly half-way between the endmembers with solid solution, this actinolite probably contains cummingtonite in solid solution as well. Mössbauer, infrared and electronic absorption spectra would have been invaluable here to investigate the occupancies of the M(1-3) sites, and especially the M(4) site.

Fluor-tremolite

Fluor-tremolite apparently grows readily, compared to tremolite, and most studies report yields of 95 to 100 percent in isothermal runs. Grain size is generally large enough for single-crystal structure analysis, particularly in non-isothermal experiments, where crystals up to 4 mm in length have been grown (Comeforo and Kohn 1954). Cameron (1971) and Cameron and Gibbs (1973) refined the crystal structure of fluor-tremolite from a run with greater than 95 percent amphibole. The cell dimensions of this fluor-tremolite are essentially identical to those of other studies (Table 6) except for Westrich (1978). It was pointed out in Chapter 2 that fluor-amphiboles grown in his study with HF in the mix give anomalous results and should be disregarded. The average cell volume of fluor-tremolite (898.1 $Å^3$), calculated from the data in Table 6 is 7.2 $Å^3$ less than that of tremolite (905.3 $Å^3$).

Unlike hydroxy-tremolite, fluor-tremolite grows readily with high yields, either in the solid state or from melts. Furthermore, the large crystals would be ideal for highly-precise single crystal structure refinement with the bulk-composition restrained by electron microprobe analysis of the crystal used to collect the X-ray data. Unfortunately, the existing structure refinement (Cameron 1971, Cameron and Gibbs 1973) used assumed cation site-populations, and thus the possibility of magnesio-anthophyllite/magnesio-cummingtonite solid solution was not resolved.

Edenites

Although edenite synthesis was claimed by Boyd (1954), neither his edenite nor any subsequent synthetic amphibole of this composition has been adequately documented. Edenite synthesized by Colville et al. (1966) has a c cell dimension that is not reasonable for any amphibole. Furthermore, the cell volume is lower than that expected for edenite. Colville et al. (1966) also synthesized ferro-edenite and give cell dimensions; the cell volume is 33 $Å^3$ larger than the volume of their edenite. One of these sets of data must be wrong. In the absence of other data, it is not possible to evaluate the validity of these results. Hinrichsen and Schürmann (1977) claim "unequivocally" edenites synthesized in the range Na_{100} to $Na_{50}K_{50}$. The cell dimensions of their endmember edenite meet expectations based on the parameters of tremolite and pargasite, but definitive characterization is lacking. Greenwood's (1979) exhaustive attempts to synthesize edenite from a variety of starting materials met with failure, as did experiments in this study. In view of these results, any amphiboles synthesized on the edenite composition in the future must be characterized in detail.

Fluor-edenite

Kohn and Comeforo (1955) give the only cell dimensions of fluor-edenite, determined on a run product that was beneficiated with respect to amphibole. The chemical analysis of this amphibole (plus 1-2 percent contaminants) shows it to contain Na in the M(4) site and octahedral Al; thus, it is off composition. The cell volume is 6.2 $Å^3$ less than that of edenite grown by Hinrichsen and Schürmann (1977). It is unlikely that pure fluor-edenite has been synthesized.

Pargasite

Although about a dozen, comprehensive studies of the physical properties and phase relations of pargasite and ferro-pargasite have been completed in the past 30 years, surprisingly, none have characterized these amphiboles except by optics and cell parameter refinement. Semet (1972, 1973), however, examined the infrared spectrum of pargasite in his study of magnesio-hastingsite and showed that Mg and Al were completely disordered among the M(1), M(2) and M(3) sites. No cell dimensions were given. All pargasite studies generally give consistent results. The fifteen sets of cell dimensions (Table 5) vary only between about 0.2 and 0.6 percent. Oba (1980) gave electron-microprobe analyses of coexisting amphiboles on the join tremolite-pargasite but neglected the endmembers. Hinrichsen and Schürmann (1977) claim to have synthesized pargasite with half of the A-site Na replaced by K. The cell volume of this amphibole (Table 7) is about 5 $Å^3$ greater than that of pargasite. Differences in cell volume between amphiboles with A-sites completely filled with either Na or K are in the range 8 to 12 $Å^3$, which supports Hinrichsen and Schürmann's (1977) claim. There is no direct evidence to support any claim of pure pargasite synthesis. It seems that most pargasite syntheses have yielded amphibole close to pargasite in composition, but the presence of both octahedral and tetrahedral Al requires careful documentation of their distribution.

Fluor-pargasite

In contrast to abundant pargasite syntheses, there are only three studies of endmember fluor-pargasite. Of these, one (Westrich 1978, Westrich and Navrotsky 1981) reports cell dimensions. Note that the differ-

ence in cell volume between fluor-pargasite and pargasite is only about 4 $Å^3$, in marked contrast to all other hydroxy-/fluor-amphibole pairs, which differ by about 7 to 11 $Å^3$. This fact is puzzling and requires careful documentation of the actual composition of synthetic amphiboles claimed to be fluor-pargasite, to determine whether this is a fundamental crystal chemical property of pargasite...fluor-pargasite or simply a reflection of deviation from nominal composition during synthesis.

Ferro-pargasite

Charles (1974a, 1980) synthesized pargasites across the join pargasite - ferro-pargasite at oxygen fugacities defined by the IW, CCH_4, FMQ and MH buffers. There are some problems with the results of this study, which are probably related to changes in the oxidation state of iron. Charles (1980) states that for a given bulk composition, cell parameters do not change within 2-sigma with changes in oxygen fugacity. Data to support this claim are given for amphiboles grown on the CCH_4 and FMQ buffers. Inspection of cell dimensions in his Table 3, however, shows ranges in cell volume of 4.7, 5.8 and 4.1 $Å^3$ for the Mg_3Fe, Mg_2Fe_2 and $MgFe_3$ compositions respectively. These are outside the 2-sigma range, even for the few volumes with high standard errors. There is no definite trend in volume with oxygen fugacity, but surprisingly, volumes are generally higher at higher oxygen fugacities. This is contrary to the expected trend to lower volumes as ferrous iron is oxidized to smaller ferric iron. Charles (1980) states that the cell dimensions do not vary with amphibole yield down to about 60 percent; however, amphiboles from 50 percent runs differ from high-yield runs up to about 5 $Å^3$. Cell dimensions of ferro-pargasites synthesized on FMQ and CCH_4 buffers are essen-

tially identical and are also very similar to those of Gilbert (1966) grown on the IW buffer. Charles (1980) concludes that Mg and Fe^{2+} are disordered among the M(1), M(2) and M(3) sites because cell dimensions vary linearly with composition.

Gilbert (1966) noted that the cell volume of ferro-pargasite decreased with increasing oxygen fugacity and suggested that this trend reflected the oxidation of octahedral Fe^{2+} to Fe^{3+}. He proposes that this reaction could be accounted for either by solid solution towards hastingsite or by the formation of oxyamphibole. Of the four sets of cell dimensions given in his study (Table 5), No. 39 is probably the best; the other samples contain Fe^{3+}. No.'s 43, 44, and 45 are refinements of X-ray powder data (Gilbert 1966, Table 2) done during this study of ferro-pargasites grown on the IW, WM and FMQ buffers respectively. Cell volumes from these refinements are about 2 $Å^3$ less than those of comparable samples refined by Gilbert (1966). The reason for this discrepancy is not known, but since the differences are consistently towards smaller cell dimensions for refinements in the present study, differences between internal standards are the probable cause.

These two studies on the pargasite...ferro-pargasite join serve to underline the problems created by not characterizing synthetic amphiboles of complex compositon, particularly if cations of variable oxidation state are present. Although the conclusions of these studies, especially with respect to the broader aspects of stability relations, are probably valid, the crystal chemical implications are obscure in the absence of further characterization. Spectroscopic methods, combined with either Rietveld or single-crystal structure refinement, would provide

direct evidence and obviate the need for circuitous crystal chemical reasoning about the nature of the octahedral and M(4) site-occupancies.

Pargasite-richterite

Braue and Seck (1977) studied the pargasite-richterite join with the interesting result that cell dimension variation between the two endmembers show positive deviations from linearity. The deviations cannot be explained on the basis of cation sizes and site occupancies, especially as synthetic pargasite infrared spectra (Semet 1972, 1973; this study) show that Mg and Al are randomly distributed among the octahedral sites. Rietveld structure analyses of the intermediate compositions could reveal any structural reasons for these trends.

Hastingsite

Hastingsites synthesed by Thomas (1977, 1979, 1982a, 1982b) were characterized by Mössbauer spectroscopy and are ideal examples of the value of detailed run-product characterization. Thomas (1972, 1982b) collected ^{57}Fe Mössbauer spectra for six of the products. He assumes that because the hastingsites are close to nominal composition, the M(1), M(2) and M(3) sites are entirely filled with iron and the M(4) site has little or no iron. Four doublets are assigned to the spectra, three for octahedral ferrous iron and one for octahedral ferric iron (Figure 20). Thomas (1982b) shows that observed fractional areas of the three ferrous doublets are inconsistent with predicted completely ordered (all Fe^{3+} in M(2)), completely disordered (Fe^{3+} over M(1,2,3)), or indeed, with intermediate configurations (Table 23). In spite of the anomalous area fractions in these spectra, the total ferrous intensity is well account-

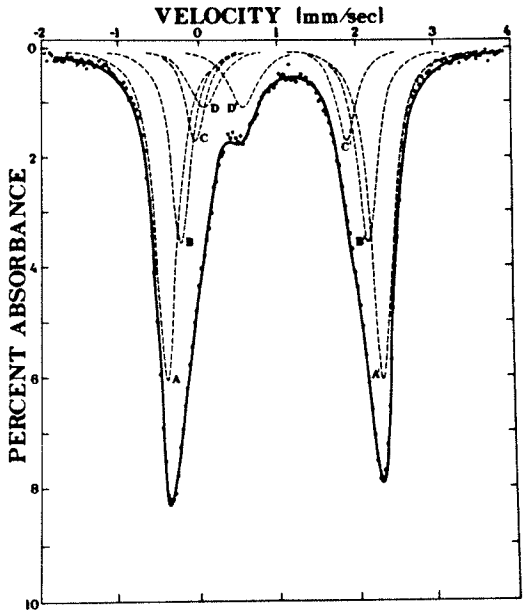

Figure 20: Mössbauer spectrum of synthetic hastingsite grown on the WM buffer. Note that the AA', BB', CC' and DD' peak intensities depart from the ideal ratios 2:1:1:1. From Thomas (1982).

ed for by the three ferrous doublets, and $Fe^{3+}/(Fe^{2+}+Fe^{3+})$ ratios were calculated from the ratios of the ferrous doublet areas to those of the ferric doublets (Table 23). Hastingsites crystallized on the IQF, IW and WM buffers carry considerably less than the 20 percent Fe^{3+} of the ideal formula; the two samples (ME339, ME340) crystallized on the IW buffer and then annealed on the FMQ buffer are close to 20 percent. Table 23 shows that the Fe^{3+}/Fe^{2+} ratio is a function of oxygen fugacity. This is also clearly reflected in the cell dimensions of these samples; cell volumes of hastingsites synthesized on the IW and IQF buffers are 2 to 5 $Å^3$ larger than those grown or annealed on more oxidizing buffers. Note that this range is comparable to the range in volumes of amphiboles grown on the pargasite...ferro-pargasite join by Charles (1974a, 1980) who claimed that similar volume differences did not reflect changes with oxygen fugacity. An alternate peak assignment of two ferrous doublets and one ferric doublet was statistically not as good as the four doublet fit. However, the inner ferrous doublet has a constant area fraction of about 0.20, a value consistent with all Fe&b38e. ordered into the M(2) site. The results of this study show the value of detailed characterization, particularly when cations of variable oxidation state are involved. It is unfortunate that infrared spectra were not collected; these could have substantiated the assertion that Fe^{3+} is ordered into M(2).

Magnesio-hastingsite

Semet (1970, 1972, 1973) and Semet and Ernst (1981) characterized synthetic magnesio-hastingsite with both Mössbauer and infrared spectroscopy. Four-doublet fits to Mössbauer spectra (Figure 21) of magnesio-has-

TABLE 23

Ideal and observed area fractions for synthetic hastingsites

Sample	Ideal area fractions								Observed area fractions			
	Ordered[1]				Disordered[2]							
	1	2	3	4	1	2	3	4	1	2	3	4
MI322(IQF)[3]	0.40	0.20	0.28	0.12	0.35	0.18	0.35	0.12	0.54	0.23	0.11	0.12
MH321(IW)	0.40	0.20	0.28	0.12	0.35	0.18	0.35	0.12	0.50	0.26	0.13	0.12
MF323(WM)	0.40	0.20	0.28	0.12	0.35	0.18	0.35	0.12	0.48	0.27	0.13	0.12
ME339([4])	0.40	0.20	0.21	0.19	0.32	0.16	0.32	0.19	0.49	0.22	0.10	0.19
ME340(IW)[4]	0.40	0.20	0.18	0.22	0.31	0.16	0.31	0.22	0.42	0.26	0.11	0.22
F193(WM)	0.40	0.20	0.28	0.12	0.35	0.18	0.35	0.12	0.47	0.28	0.13	0.12

(from Thomas 1982b)

[1]The four columns refer to Fe^{2+} in M(1), M(3) and M(2), and Fe^{3+} in M(2).
[2]The four columns refer to Fe^{2+} in M(1), M(3) and M(2), and the sum of Fe^{3+} in all sites.
[3]Buffer used during run.
[4]Synthesized on IW; annealed on IQF.

tingsites synthesized on the most-oxidizing buffers show that the major contribution of Fe^{3+} to the total absorption is by the M(2) site; only minor unresolved absorption of Fe^{3+} is attributed to Fe^{3+} in the M(1) and M(3) sites. Two remaining doublets are assigned to Fe^{2+}: an unresolved absorption from Fe^{2+} in the M(1) and M(3) sites and another from Fe^{2+} in the M(2) site. Area ratios of these peaks differ markedly from those calculated for random distribution of either Fe^{2+} or Fe^{3+} in the octahedral sites. Fe^{3+} strongly prefers the M(2) site, whereas Fe^{2+} prefers M(1) and M(3). Octahedral site occupancies of these synthetic magnesio-hastingsites as determined from the Mössbauer data are summarized in Table 24. Note that on the most oxidizing buffer (CT), only Fe^{3+} is present, but on the CCO buffer, significant Fe^{2+} is present.

The percentage of Fe^{3+} varies from about 13 percent on the IQF buffer to 100 percent on the CT buffer. Thus, the Fe^{3+}/Fe^{2+} ratio is a function of oxygen fugacity, and the synthetic magnesio-hastingsites are significantly off-composition at lower oxygen fugacities.

Infrared spectra of synthetic magnesio-hastingsite show two major peaks and several minor ones (Figure 3). The spectrum of amphibole grown on the CT buffer has two major peaks, one at 3705 cm^{-1} (MgMgMg-OH) and the other at 3660 cm^{-1} ($MgMgFe^{3+}$-OH); on the IQF buffer, the lower energy peak is shifted to 3675 cm^{-1} ($MgMgFe^{2+}$-OH). Minor peaks in both spectra between 3621 and 3645 cm^{-1} probably represent ($MgFe^{2+}Fe^{2+}$-OH), ($MgFe^{2+}Fe^{3+}$-OH) and ($MgFe^{3+}Fe^{3+}$-OH) groups. Evidence from infrared spectra of pargasites synthesized in the present study (see Chapter 5) with transition metals substituted for octahedral Al, suggests that some octahedral Al is generally present. The rough bulge at about 3670 cm^{-1} in the spectrum of magnesio-hastingsite synthesized on the CT buffer (Figure 3) may also reflect the presence of minor amounts of Al in the M(1) and M(3) sites. Ratios of peak areas representing occupancies of Mg, Fe^{2+} and Fe^{3+} in the M(1) and M(3) sites compare favourably with the ratios calculated from the Mössbauer spectra.

These results clearly show the necessity of detailed characterization of complex synthetic amphiboles. Mössbauer spectra show that only magnesio-hastingsite grown on the CT buffer contains no Fe^{2+}, and thus, is probably close to the nominal composition. In addition, the strong preference of Fe^{3+} for the M(2) site is clear. Infrared spectra support the Mössbauer data and point to the possibility of Al in M(1) and M(3) sites.

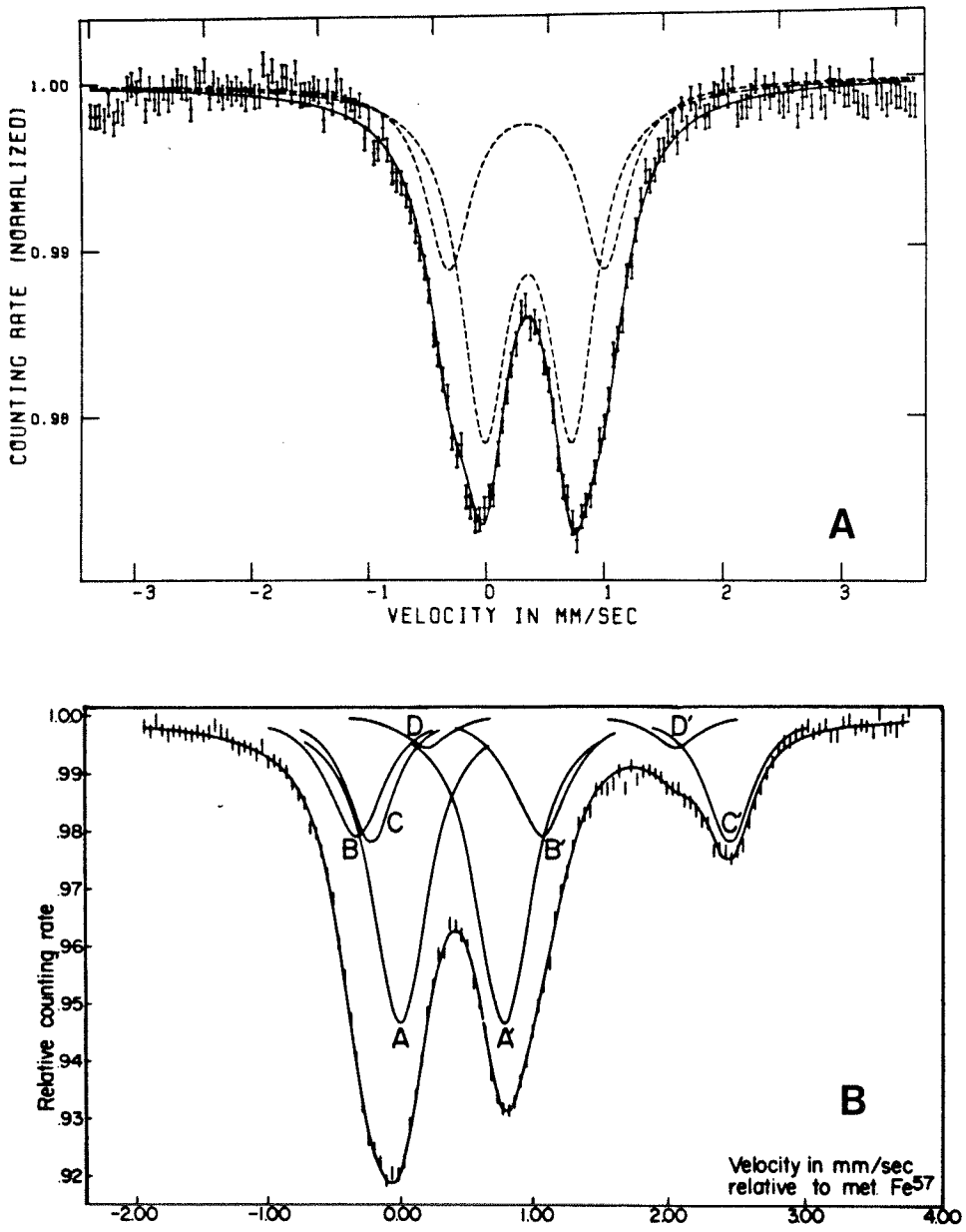

Figure 21: Mössbauer spectra of synthetic magnesio-hastingsites grown on the CT and CCO buffers. A: CT buffer, no Fe^{2+} present. B: CCO buffer, considerable Fe^{2+} present. From Semet (1973).

TABLE 24

Octahedral site occupancies in synthetic magnesio-hastingsites from Mössbauer data

Buffer	M(1),M(3) Mg	Fe^{2+}	Fe^{3+}	M(2) Mg	Fe^{2+}	Fe^{3+}
IQF(av.)	0.79	0.21	-	0.81	0.12	0.07
CCO	0.87	0.06	0.07	0.70	0.03	0.27
CT	0.85	-	0.15	0.73	-	0.27
IQF to CT	0.78	-	0.22	0.83	-	0.17
CT to IQF	0.84	0.16	-	0.73	0.09	0.17

Miscellaneous calcic amphiboles

Other calcic amphibole synthesis studies are few in number and generally lack detailed characterization (see Chapter 2). Oba (1978) attempted to characterize amphiboles on the alumino-tschermakite - ferri-tschermakite join by electron micropobe analysis. Unfortunately, only certain amphiboles in equilibrium with garnet were analysed; these are not on composition. Cell dimensions (Table 5) are given for endmember tschermakite and ferri-tschermakite, as well as for certain intermediate compositions. Yields of 100 percent are claimed for many of these, but no supporting evidence is given.

The paucity of other calcic amphibole studies probably reflects the experimental intractibility of these amphiboles with vacant A-sites. It was noted above that tremolite grows only with difficulty, requiring long run times and intermediate regrinding and rerunning of products. Other calcic amphiboles with vacant A-sites either are stable at only very high pressures or apparently grow extremely slowly.

Sodic-calcic amphiboles

Richterite, ferro-richterite, fluor-richterite

Both richterite and fluor-richterite synthesize very readily and all studies report close to 100 percent yields. Cell dimensions of all richterites and fluor-richterites are closely consistent between different studies with two exceptions. Richterite (No. 78, Table 5) and fluor-richterite (No. , Table 6) synthesized by Westrich (1978) are markedly different. Certain other amphiboles grown in this study have been shown also to have anomalous properties; apparently there are experimental problems with these syntheses and the results should be used with caution. In addition, the cell dimensions of richterite (No. 80, Table 5) given by Phillips and Rowbotham (1968) are apparently in error. Refinement of their powder X-ray data during the present study gave results (No. 81, Table 5) consistent with others. Cell parameters vary in an acceptably linear way for compositions on the join richterite and ferro-richterite (Huebner and Papike 1970), suggesting that the amphiboles are very close to the nominal compositions. Potassium-ferro-richterite grown on the CCH_4 buffer in the same study, however, probably contains Fe^{3+} and is, therefore, not on composition.

Although it seems that richterites synthesize readily on the nominal composition, infrared spectra of these amphiboles show otherwise. Rowbotham and Farmer (1973) examined the infrared spectrum of richterite grown by Phillips and Rowbotham (1968), and observed that instead of a single band corresponding to the MgMgMg configuration, an additional peak was present (Figure 22). This peak corresponds to the tremolite MgMgMg configuration, which is well developed in the spectrum of the

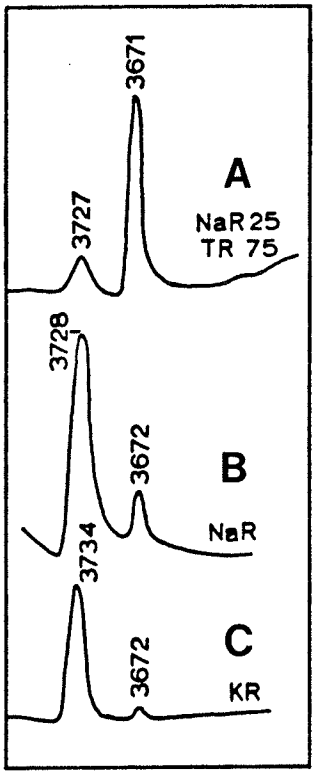

Figure 22: Infrared spectra of richterite, potassium richterite and solid solution of richterite in tremolite. A: solid solution of richterite in tremolite. B: richterite. C: potassium-richterite. Note the weak tremolite peaks at 3672 cm^{-1} in the richterite and potassium-richterite spectra. From Rowbotham and Farmer (1973).

richterite$_{25}$ - tremolite$_{75}$ solid solution (Figure 22). Rowbotham and Farmer (1973) conclude that the richterite is deficient in A-site cations. They also examined the infrared spectrum of potassium-richterite (Figure 22) provided by (and apparently synthesized by) B. Velde. The spectrum consists of a major band at 3734 cm^{-1} which was assigned to the MgMgMg configuration. In addition to this normal band, however, an additional weak band at 3672 cm^{-1}, corresponding to tremolite solid solution, indicates that the amphibole deviates from the nominal composition.

Mössbauer spectra (Virgo 1972) demonstrate that Fe^{3+} (Figure 23) is present in all of the Fe-bearing richterites grown by Charles (1972a, b). The ferro-richterite with the large cell but low yield (Type I) that is closest to the extrapolated trends of all the cell parameters contains about 5 percent Fe^{3+}; the other (Type II) with smaller cell but higher yield contains about 10 percent Fe^{3+}. This is surprising in light of the fact that these amphiboles were grown on the IW buffer.

Single-crystal structure analysis of Fe-bearing fluor-richterite with Mg/(Mg+Fe)=0.68 (electron microprobe analysis) shows that Fe^{2+} prefers M(2) relative to M(1) and M(3), and that the Fe/Mg ratios in M(1) and M(3) are similar (Cameron 1970, Cameron and Gibbs 1971). Charge balance considerations are given as evidence for little or no Fe^{3+} (Cameron 1970). Cell contents calculated from the analysis indicate a deficiency of Ca relative to the ideal formula and an excess of octahedral cations; excess Fe is assigned to the M(4) site. Because the amphibole yield was less than 100 percent, it would have been instructive to know the nominal composition (not given) and to compare it to the actual composition as determined by electron microprobe.

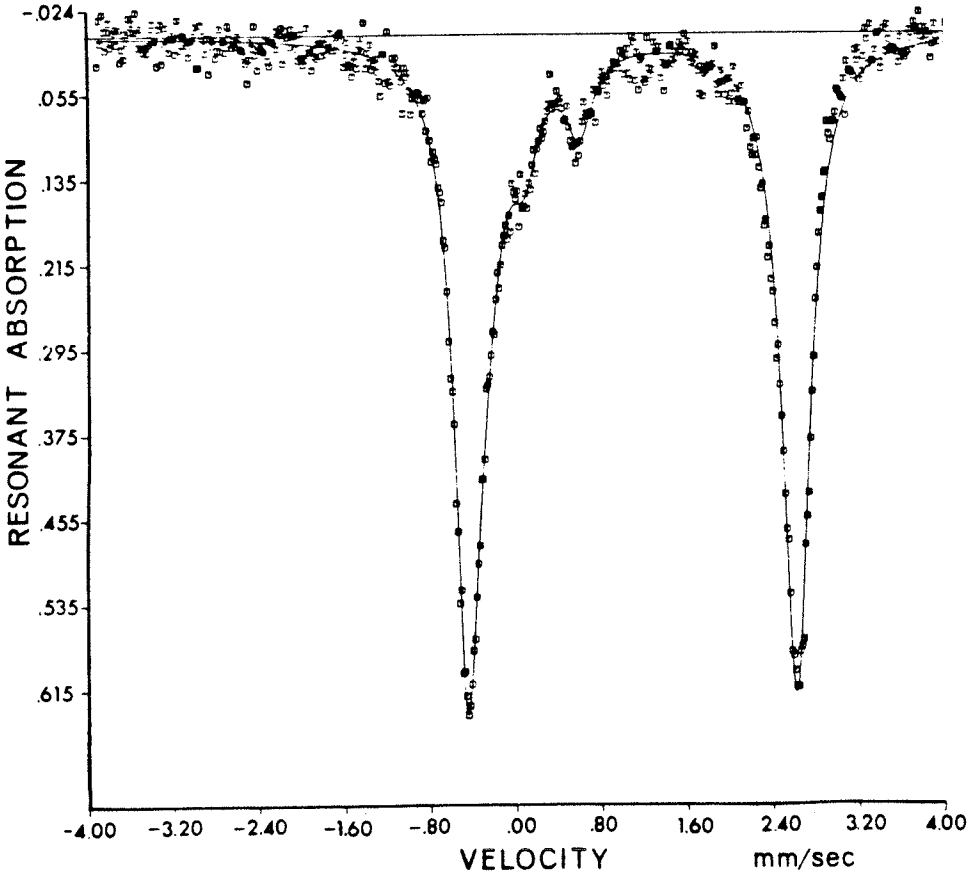

Figure 23: Mössbauer spectrum of synthetic ferro-richterite grown on the IW buffer. Note the presence of Fe^{3+}. From Virgo (1972).

Alkali amphiboles

Glaucophane

The results of glaucophane synthesis by Ernst (1957, 1958, 1959, 1961, 1963) and the subsequent attempts to explain them provide an outstanding case study of the need for detailed characterization of synthetic amphiboles. Ernst (1961) assumes that the amphibole grown is glaucophane because:

1. Long runs yield more amphibole than short runs.
2. Relative proportions, deduced by comparison with X-ray standards and by micrometric analyses, of metastable phases in the amphibole stability field are unaffected by the amount of amphibole present and are in the same proportion at temperatures in excess of the amphibole stability field.
3. Refractive indices and d-spacings of the amphibole show no measurable variation with the amount obtained and are independent of the starting material.

Ernst (1963) proposed that glaucophane occurs as two polymorphs: one with large volume - glaucophane I, the other with small volume - glaucophane II. Ernst reached this conclusion because amphibole grown from glaucophane bulk composition at low pressure has a unit cell volume more than two percent greater than that of natural glaucophane, while that grown at high pressure has volume comparable to natural glaucophane. He was puzzled by the lack of difference in optical properties of the assumed polymorphs: glaucophane I has α=1.595, β= 1.620, extinction angle 10°; glaucophane II has α=1.596, β =1.620, extinction angle 10°. According to the Gladstone-Dale relationship, the denser polymorph should

have a mean index of refraction about 0.013 greater than that of glaucophane I, if the compositions are identical.

Infrared spectra of three synthetic amphiboles of nominally glaucophane composition were collected on material generously supplied by W.G. Ernst (Figure 24). Cell dimensions and synthesis conditions of these samples are given in Table 6). The spectrum of "glaucophane I" (Figure 24C, sample GM-1, Ernst 1963) is similar to that of sodian magnesio-cummingtonite (Figure 10C), as are its cell dimensions (No. 90 and 95, Table 5). Comparison of the spectrum of GM-1 to the natural ferro-glaucophane spectrum (Figure 24D), shows clearly that this amphibole cannot be glaucophane. This confirms the proposal of Maresch (1973, 1977) that "glaucophane I" is "magnesiorichterite" (sodian magnesio-cummingtonite) and not a low-pressure, high-temperature polymorph of glaucophane. Furthermore, it supports the contention of Carman (1969) who argued that "glaucophane I" is a persodic amphibole remote from the glaucophane composition. It also argues against the suggestion that "glaucophane I" is an amphibole near nyböite ("miyashiroite") and eckermannite (Thompson 1981, Carman and Gilbert 1983). Thompson (1981) does point out, however, that a sodian magnesio-cummingtonite component cannot be ruled out entirely.

The spectra of samples GC-2 and GC-1 (Figures 24A and B, Nos. 112 and 110 in Table 5) are of poor quality, but it is obvious that these amphiboles also cannot be endmember glaucophane (cf. natural ferro-glaucophane, Figure 24D). Both spectra comprise two distinct groups of bands; one is centered at about 3664 cm^{-1}, the other is near 3723 cm^{-1}. The band at 3664 cm^{-1} corresponds exactly to the MgMgMg configuration in the

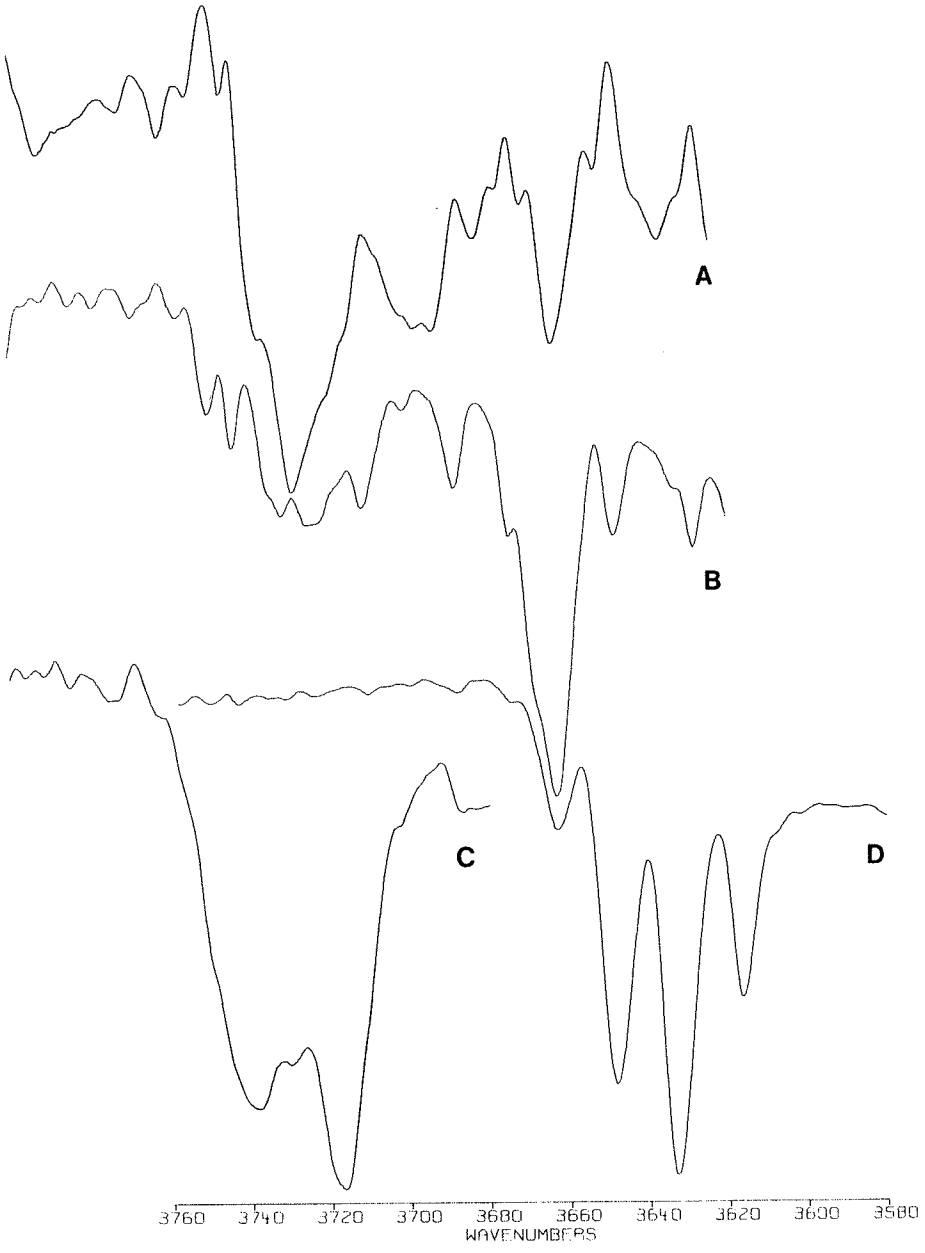

Figure 24: Comparison of infrared spectra of synthetic and natural glaucophanes. A: synthetic glaucophane II (GC-2, Ernst 1963). B: synthetic glaucophane II (GC-1, Ernst 1963). C: synthetic glaucophane I (GM-1, Ernst 1963). D: natural ferro-glaucophane (Piedmont, Italy).

natural glaucophane and it is likely that it is the same in the synthetic amphiboles. The other band group is very poorly resolved, but it represents a frequency shift of about +59 cm^{-1}, placing it in the frequency range of amphiboles with full Na-occupancy in the A-site. These spectra suggest that the samples, both designated as "glaucophane II" by Ernst (1963), are probably amphiboles intermediate in composition between glaucophane and eckermannite, or perhaps nyböite. Indeed, their cell dimensions are very similar to those of nyböites grown by Carman and Gilbert (1983). The interpretation of these three infrared spectra establishes without doubt that neither "glaucophane I" nor "glaucophane II" can be endmember glaucophane and contributes substantially to the case for routine characterization of all synthetic amphiboles with spectroscopic methods.

Riebeckites

In contrast to the glaucophane studies, riebeckite syntheses (Ernst 1962) seem to have been reasonably successful. The infrared spectrum (Figure 25) of riebeckite (sample HR-54-8, Ernst 1962, No. 131 in Table 5) consists of a single, sharp band at 3618 cm^{-1} and a very weak band at about 3673 cm^{-1}. The origin of the weak band at 3673 cm^{-1} may be due to minor Na-occupancy in the A-site, indicating minor solid solution towards eckermannite. It would have been instructive to see if this peak increases in intensity in the riebeckite-arfvedsonitic amphiboles. Band width of the 3618 cm^{-1} peak is between 6 to 7 cm^{-1} which is remarkably narrow for synthetic amphibole. It is not clear whether or not the main band is solely due to an $Fe^{2+}Fe^{2+}Fe^{2+}$ component, or whether or not there are additional components due to configurations involving Fe^{3+}, as there is no definitive evidence on the relative effects of Fe^{2+} and Fe^{3+}.

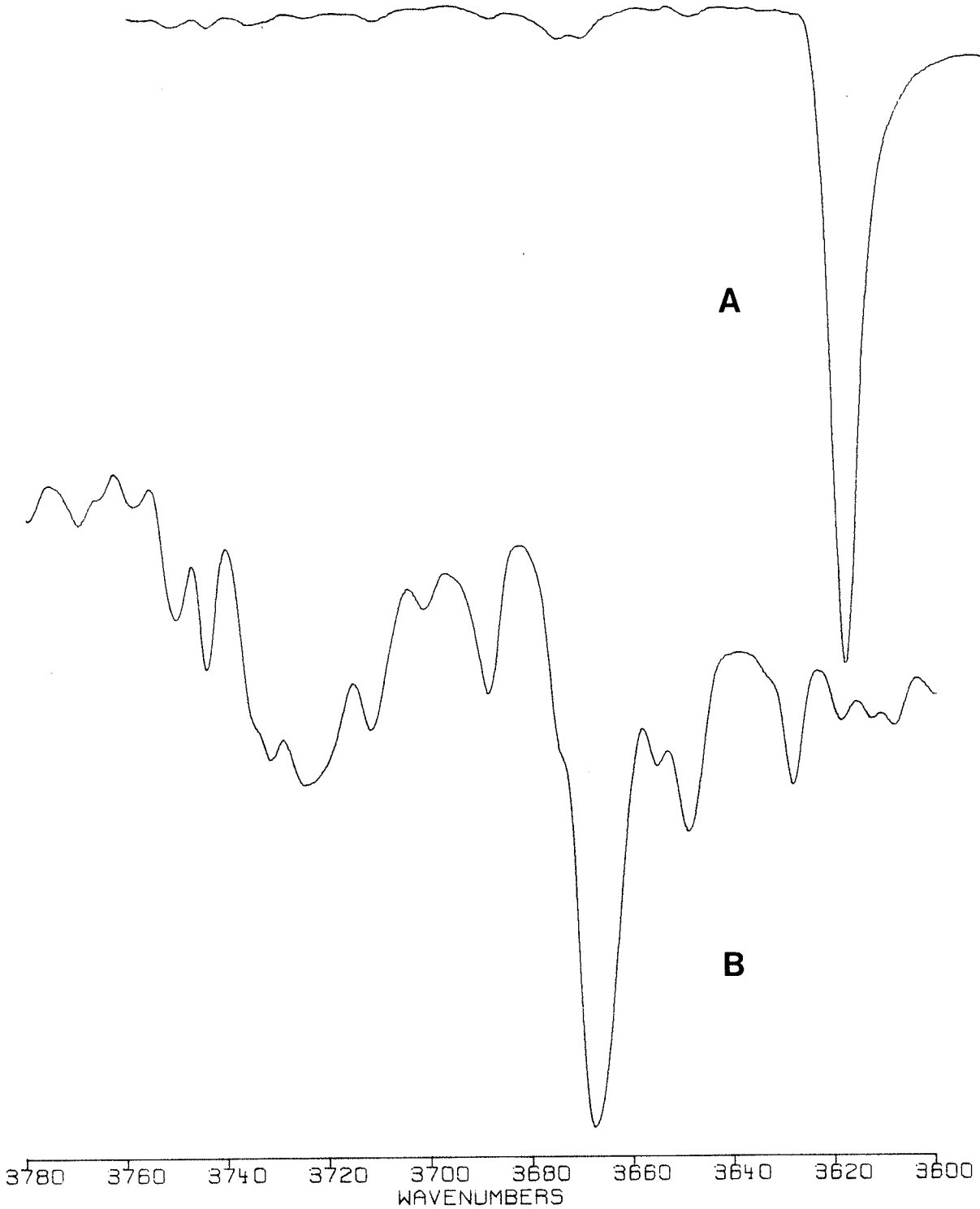

Figure 25: Infrared spectra of synthetic riebeckite and magnesio-riebeckite. A: riebeckite (HR-54-8, Ernst 1962). B: magnesio-riebeckite (R-101, Ernst 1960).

Magnesio-riebeckites

Magnesio-riebeckite syntheses (Ernst 1960) apparently failed to grow amphiboles on this composition. The infrared spectrum (Figure 25) of magnesio-riebeckite (sample R-101, Ernst 1960, No. 129 in Table 5) is of poor quality, but it is obvious that this amphibole cannot be of the nominal composition. Bands at 3667 cm^{-1}, 3649 cm^{-1} and 3629 cm^{-1} were assigned to the MgMgMg, $MgMgFe^{3+}$ and $MgFe^{3+}Fe^{3+}$ configurations respectively, after Bancroft and Burns (1969). The band at 3655 cm^{-1} may be due to the configuration $MgMgFe^{2+}$. The poorly resolved, complex group of bands around 3724 cm^{-1} is probably the result of frequency shifts caused by Na-occupancy of the A-site, indicating substantial solid solution towards magnesio-arfvedsonite. Thus, the amphibole is off-composition.

Eckermannite

It is unlikely that eckermannite has been synthesized. Cell dimensions (Table 5) of the amphibole grown by Phillips and Rowbotham (1968), regardless of which set is correct (see Chapter 2), are more like those of sodian magnesio-cummingtonite. Attempts in the present study to grow eckermannite under similar conditions to Phillips and Rowbotham (1968) grew amphiboles with infrared spectra similar to sodian magnesio-cummingtonite (Figure 10).

Nyböite

The results of Carman and Gilbert (1983), who claim nyböite synthesis, are difficult to evaluate. The high-pressure, vapour deficient stability and the cell dimensions are consistent with amphibole of this compo-

sition, but further characterization is necessary. Furthermore, one of the two amphiboles with published cell dimensions was grown from starting material of glaucophane composition.

Iron-magnesium-manganese amphiboles

Sodian magnesio-cummingtonites

Amphibole syntheses based on the sodian magnesio-cummingtonite commposition and equivalent fluor-amphiboles have been popular, but relatively little characterization of the nature of these amphiboles has been done (see Chapter 2). This is surprising because existing information strongly suggests that the structure is not C2/m. Witte et al. (1969) examined the infrared spectrum of sodian hydro-magnesio-cummingtonite; it shows a band at 842 cm^{-1} that is absent from the spectrum of sodian magnesio-cummingtonite. They propose that this band corresponds to the Si-O-H bending frequency in SiOH groups. A portion of this spectrum between 3600 and 3800 cm^{-1} is shown in Maresch and Langer (1976) along with the spectrum of sodian magnesio-cummingtonite (Figure 26). They suggest that the additional OH can only substitute for oxygen at the O(1), O(2) or O(4) sites, thus forming SiOH groups. Because O(4) is highly underbonded relative to O(1) and O(2), they conclude that O(4) is the likely site for the additional OH. The infrared spectrum (Figure 26) displays an extra O-H stretching band at 3727 cm^{-1} which they attribute to OH-valence vibrations in SiOH groups.

The spectrum of sodian magnesio-cummingtonite has two well resolved bands. The presence of two MgMgMg-OH stretching bands suggests that sodian magnesio-cummingtonite crystallizes in a space group other than

C2/m. It is not likely that the splitting of the MgMgMg-OH stretching band is due to chain-width disorder because the relative areas of the bands are always similar in both the specimens synthesized in this study and in those synthesized by others. If one of the bands were due to a chain-width modification phase, variation in chain-width disorder with different synthesis conditions should cause changes in the relative band areas. Furthermore, precession photographs of sodian magnesio-cummingtonite (Hawthorne 1984, pers. comm.) show reflections with h+k=2n+1 suggesting that it is primitive, rather than C-centered.

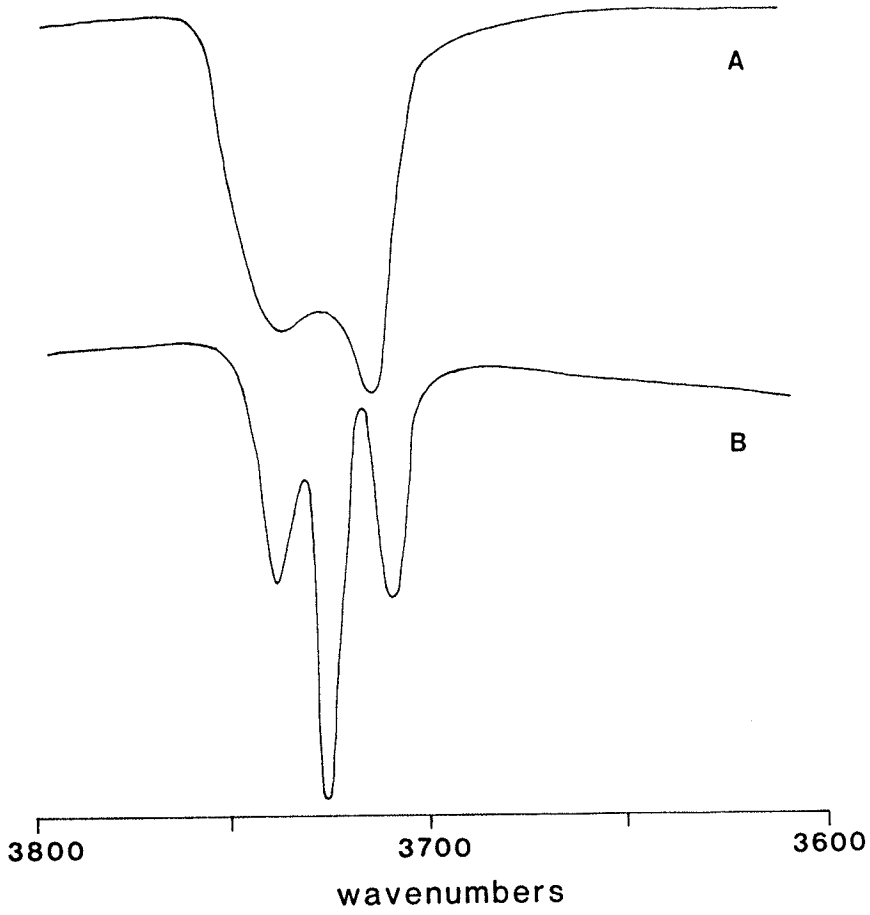

Figure 26: Infrared spectra of sodian magnesio-cummingtonite and sodian hydro-magnesio-cummingtonite . A: sodian magnesio-cummingtonite. B: sodian hydro-magnesio-cummingtonite. From Maresch and Langer (1976).

AMPHIBOLE SYNTHESIS: THIS STUDY

Calcic Amphiboles

Tremolites

Attempts in this study to grow tremolite confirm the difficulties experienced by previous workers. Substitution of Ni for Mg yielded more encouraging results, but lack of appreciable amphibole yields reflect the general reluctance of A-site empty calcic amphiboles to crystallize. Cd substitution for Ca failed also, as it did for pargasite and richterite. It seems both from previous work and this study that synthesis of pure tremolite-based endmembers, suitable for detailed characterization, is not possible with current techniques.

In contrast, fluor-tremolite grows fairly readily, but the optimistic claims of previous workers of easy growth were not seen in this study. More than 80 percent yields were never obtained, either isothermally or in non-isothermal experiments. The large crystals grown in non-isothermal experiments, however, have the advantage of being suitable for detailed characterization by any method and show promise for future studies. Cell dimensions (Table 13) of fluor-tremolites grown in this study are identical to high-quality cell dimensions (Table 6) from other studies. This is remarkable, considering that yields are at least 20 percent lower than those of some of the previous studies. Thus, it seems that because of the simple composition of fluor-tremolite lack of 100 percent yields is not critical to achieving synthetic amphibole of apparently nominal composition. There still may be minor solid solution towards magnesio-cummingtonite, as noted in the previous section, that is not detected by cell variation.

Edenites

Attempts to synthesize edenite suffered the same difficulties as in earlier studies. In view of these problems, careful consideration of synthetic products grown on this composition is advised. Fluor-edenite grew with yields of 90 percent or more, and yielded amphibole with plausible fluor-edenite cell dimensions. Fluor-edenite differs from fluor-pargasite by lacking octahedral Al and having only one tetrahedral Al; the M(4) and A site contents are the same. Thus, $\underline{a}$, β, and $\underline{V}$ should be about the same in both amphiboles, $\underline{b}$ should be larger and $\underline{c}$ smaller. These predictions are supported by the cell dimensions of fluor-edenite and fluor-pargasite synthesized in this study (Table 13). The cell volume based on comparison of results on edentite grown by Hinrichsen and Schürmann (1966) is too small, but with the possibility of solid solution between tremolite and edenite, further characterization is required. Fluor-edenite cell dimensions given by Kohn and Comeforo (1955) (Table 6) seem to be those of a more sodic amphibole with composition between fluor-edenite and fluor-richterite; note especially the lower β and higher $\underline{V}$.

Pargasites

Much effort was expended on pargasite synthesis, not only because of the apparent success of previous work, but also because this composition is intrinsically interesting with respect to Al ordering in the tetrahedral sites and M^{3+} ordering in the octahedral sites. Endmember pargasite synthesizes readily, but yields are never quite 100 percent. Cell dimensions (Table 13) are consistent with previous studies (Table 5). Substitution of Cr, Ga, Sc and In for octahedral Al reduced yields to

about 80 to 90 percent. Variation in cell volume with the radius of the octahedral cation (Figure 27) did not give an acceptably linear trend, indicating that complete substitution of Cr, Ga and Sc for Al in the octahedral strip did not occur (Raudsepp et al. 1982). This deviation from the nominal composition is well documented in the infrared spectra of this series (Chapter 5), which all showed MgMgAl bands in addition to Mg-M^{3+} configurations. Site-occupancies (Table 19) from the Rietveld structure refinement of the scandium-pargasite showed that the composition of the octahedral cations, in terms of Mg and Sc scattering, is $Mg_{4.35}Sc_{0.65}$. The octahedral Al content therefore is about 0.35 cations p.f.u. Furthermore, Sc has the ordering pattern M(2)>M(3) and avoids M(1). Endmember pargasite shows completely random distribution of Mg and Al over the octahedral sites from infrared spectrum analysis. Ordering in the Ga and Cr pargasites has not been confirmed by structure analysis but the infrared spectra suggest at least partial ordering.

Results of fluor-pargasite syntheses largely parallel those of hydroxy-pargasites except for higher yields of the scandium-fluor-pargasite compared to scandium-pargasite. Variation of cell volume with trivalent octahedral cation radius is also not acceptably linear but is improved over hydroxy-pargasites (Figure 28). The complete series of Ga, Cr and Sc substitutions for octahedral Al was characterized by Rietveld structure refinement to determine cation ordering among the octahedral sites. Rietveld structure analysis is particularly useful for fluor-amphiboles because of the inapplicability of infrared spectroscopy in the hydroxl-stretching region. Site-occupancies (Table 19) show that chromium-fluor-pargasite and gallium-fluor-pargasite are deficient in Cr

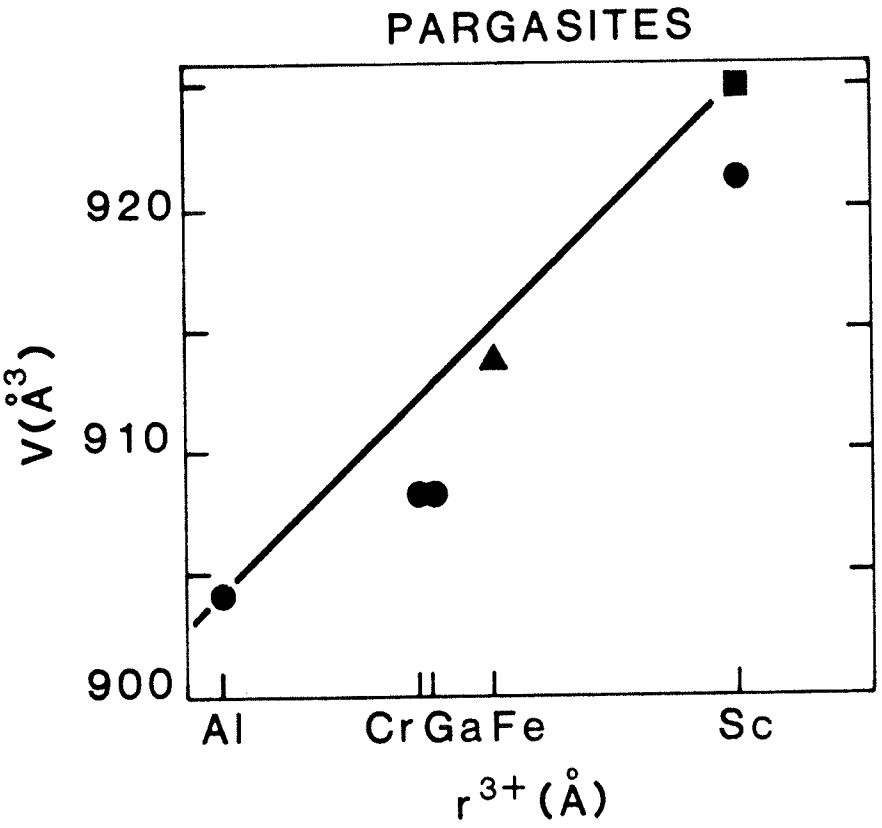

Figure 27: Cell volume versus radius of trivalent octahedral cations in synthetic pargasites. Solid circles are synthetic pargasites grown in this study; solid triangle is magnesio-hastingsite from Semet 1972, 1973.

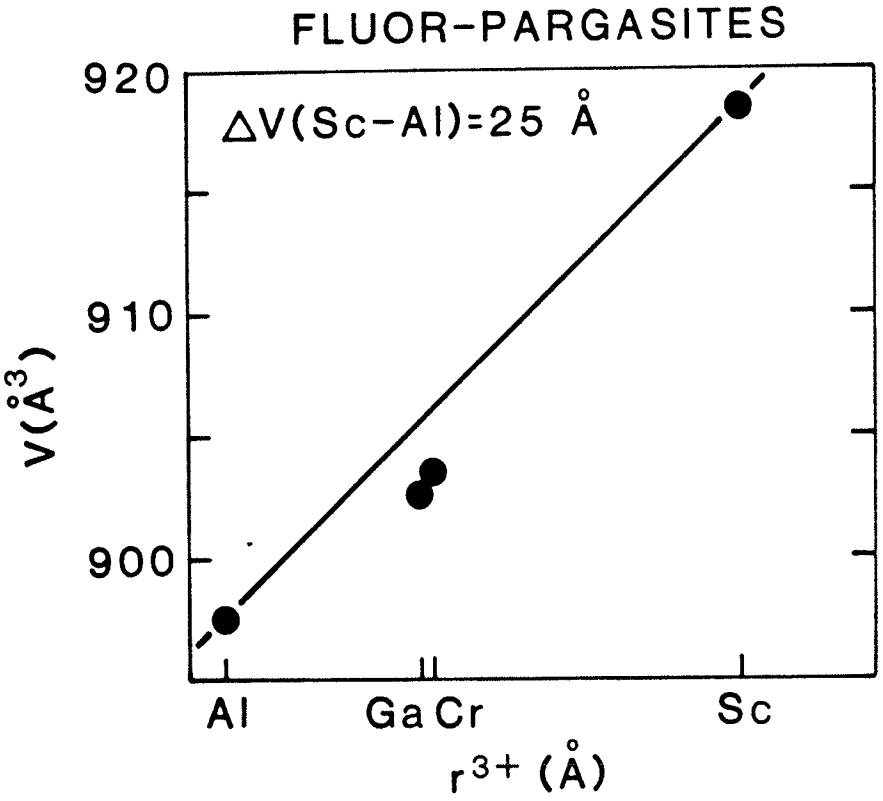

Figure 28: Cell volume versus radius of trivalent octahedral cations in synthetic fluor-pargasites.

and Ga respectivly, compared to the nominal composition, but that scandium-fluor-pargasite has nearly the ideal Sc-content. Furthermore, the M^{3+} cations are almost completely ordered into M(2).

Sodic-calcic Amphiboles

Richterites

Syntheses of amphiboles based on the richterite composition confirmed all aspects of previous studies. Richterites and fluor-richterites grow readily and with yields usually greater than 95 percent. Infrared spectra of endmember richterites and Mn-bearing richterites (Figure 9) showed limited, but definite, solid solution with tremolite for both the Na and K endmembers, confirming the conclusions of Rowbotham and Farmer (1973). In view of the confused state of Mn ordering information in amphiboles (Hawthorne 1983b), the infrared spectra of the Mn-bearing richterites (Figure 9) revealed the important result that Mn is apparently completely ordered into the M(2) site. Hawthorne (1976) and Hawthorne and Grundy (1978) attempted to derive Mn-site preferences in sodic-calcic amphiboles on the basis of mean bond lengths at the M(1), M(2) and M(3) sites. They observed the preference M(3)>M(1)=M(2), but their results were highly speculative. These spectra also showed tremolite-like peaks, indicating some solid solution towards tremolite.

Miscellaneous Sodic-calcic Amphiboles

Syntheses on other sodic-calcic amphibole compositions were generally unsuccessful for the purpose of detailed characterization. These results parallel, at least in part, the tendency of A-site empty calcic amphiboles to be extremely difficult to synthesize at low pressures.

Alkali Amphiboles

Previous studies show most alkali amphiboles to have high-pressure stability fields and it is not surprising that attempts to grow nyböite failed. Eckermannite syntheses were also disappointing. Infrared spectra (Figure 10) of hydroxy-eckermannite and cell dimensions of fluor-eckermannite (Table 6) clearly show that amphiboles similar to sodian magnesio-cummingtonite were grown. It is unlikely that eckermannite ever has been synthesized.

Iron-magnesium-manganese Amphiboles

Sodian magnesio-cummingtonites

Synthesis results with this interesting composition parallel those of previous studies and emphasize the need for very detailed and careful documentation of these amphiboles. Infrared spectra (Figure 10) show clearly that there are at least two different hydroxyl-stretching environments. This confirms the previous speculations of Witte et al. (1969) and Maresch and Langer (1976). Furthermore, preliminary single-crystal structure studies in progress (Hawthorne, unpublished data) confirm that the space group is not C2/m, but is primitive.

EVALUATION OF CHARACTERIZATION METHODS USED IN THIS STUDY

Optical Microscopy

Optical examination of synthesis products has been a routine part of previous amphibole syntheses. In this study, all synthesis products were routinely examined with both a low-power binocular microscope, and at high power with a polarizing microscope. Low-power examination of unopened capsules is critical in documenting leaks. In hydroxy-amphi-

bole experiments, the vapour phase was generally between 5 to 20 weight percent of charges weighing 30 to 90 mg; leaks were readily detected by weight loss during pre-experiment heating tests or during the experiment. In fluor-amphibole syntheses, however, the vapour phase is only about 4 percent of charges weighing between 20 to 40 mg; partial losses through hairline cracks and defective welds are not easily detected even with precise weighing. This problem is generally compounded by Pt loss from the capsule during high-temperature runs. Examination of the opened capsule interior reveals any evidence of reaction with the charge, a rare occurence with Pt and Au capsules and runs of the composition used. Low-power examination of the charge shows whether differentiation occurred during the run and is important in documenting the general physical properties of the products (colour, morphology, grain-size).

After low-power examination, a representative portion of the product is generally crushed and mounted on a glass slide with a suitable medium for observation at high-power with a standard polarizing petrographic microscope. This has been a standard characterization technique in stability studies, particularly in liquidus experiments, where it is necessary to identify small amounts of glass or minor phases. Refractive indices can be measured and modal analysis of the run products is, in principle, a possibilty.

Unfortunately these methods are inadequate as a practical characterization technique in the synthesis of pure minerals for crystal-chemical characterization. Synthesis products are generally too fine-grained to be identified optically and measurement of refractive indices is diffi-

cult, if not impossible in some cases. Minor phases can be unambiguously identified only if their optical properties are significantly different from the primary product; accurate modal analyses also are difficult for this reason. Furthermore, standard optical techniques are not fast enough for rapid characterization of large numbers of products, as in this study.

The difficulty in using optical methods in this type of study is well illustrated by the problems in glaucophane synthesis by Ernst (1961, 1963). Although Ernst measured refractive indices and the products were modally analysed, the amphiboles synthesized in these studies were later shown to be off-composition (Maresch 1977; this study). According to the Gladstone-Dale rule the denser polymorph should have had a mean refractive index approximately 0.013 greater than glaucophane I (Ernst 1963). Thus Ernst's interpretation of two glaucophane polymorphs of the same composition but of different densities could not have been correct. Optical methods in the present study were found to be of limited use in product characterization. They are most valuable for deciding whether a particular synthesis product is of sufficiently high yield and quality for more detailed characterization.

Scanning Electron Microscopy

Scanning electron microscopy has much potential in the initial characterization of run products. Extremely fine-grained products are readily imaged with this technique and the presence of extraneous phases that may be present in amounts too small or of inadequate crystallinity to be detected in X-ray powder diffraction patterns, are observable. Note the

abundant layer silicates mixed with fibrous amphibole in Figure 7D. More importantly, Figure 6B (arrow) shows a few flakes of layer silicate which were observed neither optically nor in the X-ray powder diffraction pattern. Inspection of other synthesis products in Figures 5, 6 and 7 also reveals traces of layer silicates, some of which were observed in X-ray diffraction patterns but not optically.

Other silicates (pyroxenes, olivines, feldspars), although obviously present in X-ray powder patterns, could not be positively identified in scanning electron micrographs. Semi-quantitative energy dispersive spectroscopic capability would have been invaluable in the identification of these important phases.

X-ray Powder Diffraction

Conventional X-ray powder diffractometry continues to be important for the identification of phases greater than a few percent, and in the rough estimation of their abundances. In addition, precise cell dimensions are readily calculated by least-squares refinement and the lattice spacings of extraneous phases can be determined. The usefulness of this method is decreased if synthesis phases are poorly crystalline (degraded peak intensity and shape), if their abundances are less than 4 or 5 percent, or if severe overlap of several phases occurs.

Infrared Spectroscopy

Infrared spectroscopy is a rapid and versatile technique in the characterization of order-disorder in sythetic minerals. Synthetic systems do not contain large numbers of minor components and spectra are generally

simpler to interpret than natural ones. In amphibole studies, infrared spectra in the hydroxyl-stretching region are the most important; ordering of M(1) and M(3) cations may be characterized with high sensitivity. Furthermore, the O-H stretching spectrum can reveal the presence of extraneous phases containing the hydroxyl group such as layer silicates, which are common in many run products. Deviations from nominal composition can also be revealed with sensitivity. For example, the common presence of small peaks near 3673 cm^{-1} in the infrared spectra of synthetic richterites (Figure 9) indicates a frequency shift in the MgMgMg-OH stretching band to lower frequencies due to the presence of vacant A-sites. Although infrared spectra in the O-H stretching region should be sensitive to chain-width and other local structural disorder, this possibility was not pursued in this study.

Synthetic pargasite spectra illustrate the application of this method to both problems of cation ordering and stoichiometry. It was shown in Chapter 5 that endmember pargasite has an essentially random distribution of Mg and Al over the M(1,2,3) sites. The spectra of pargasites with M^{3+}=Ga, Cr and Sc all have shoulders corresponding to the MgMgAl-OH configuration showing that they are off-composition, containing minor amounts of octahedral Al. Layer silicates in the chromium-pargasite run product that were reflected in the X-ray diffraction pattern (Table 11) are also evident in the infrared spectrum as fine-structure between 3674 cm^{-1} and 3710 cm^{-1}. The presence of substantial $MgMgM^{3+}$-OH configurations in the spectra of Cr-, Ga- and Sc-substituted compositions suggests that these pargasites are at least partially disordered.

Especially important is the very small amount (less than 5 mg) of material required. The sensitivity of infrared spectra to small variations in nominal compositions and the ability to detect order-disorder phenomena in these amphiboles is clear evidence that this method should be used routinely to characterize synthetic amphiboles.

Rietveld Crystal Structure Refinement

The Rietveld structure analysis method represents a significant advance in the detailed characterization of amphibole synthesis products. Although it has potential to refine the entire structure, problems in this study during refinement with certain highly-correlated positional parameters in the tetrahedral chains (see Chapter 5) limited the method to deriving accurate site-occupancies. The infrared spectrum of scandium-pargasite showed that Sc was present in either the M(1) or M(3) sites, or both; Rietveld analysis results showed that Sc-occupancy in the M(1) site was negligible, it having the ordering pattern M(2)>M(3)>>M(1)-0. Furthermore, the Rietveld results allowed the calculation of the deficiency in Sc-occupancy (0.354) and therefore the amount of Al-occupancy in octahedral coodination (0.21) as suggested by the infrared spectrum. The Rietveld method is particularly useful in characterizing fluor-amphiboles for which the infrared method in the O-H stretching region is not applicable. Six of the seven fluor-amphibole structures refined (No.'s 3-8, Table 14) in this study showed that these amphiboles have partial to complete ordering of Mg and the M^{3+}-cation in the octahedral strip. No ordering information was derived for fluor-pargasite (No. 2, Table 14) because there is insufficient contrast in the scattering powers of Mg and Al.

In addition to the above, the Rietveld method has other advantages over conventional X-ray powder diffractometry. Cell dimensions calculated during the refinement are up to an order of magnitude more precise than those by least-squares methods based on measurement of peak centroids in normal diffractometer scans. This improvement stems from the fact that in the Rietveld refinement, the peak positions are calculated from the whole peak profile, which takes into account any machine aberrations affecting its shape. In addition, the residual pattern from the subtraction of the observed diffraction pattern from the calculated pattern, contains the diffraction patterns of phases other than amphiboles. In the whole pattern, scattering from these phases is often partly to completely masked by the dominant amphibole pattern. Preliminary results with this method during the present study show that this technique has considerable potential for detailed characterization of synthesis products.

CONCLUSIONS

The present study has underlined the importance of detailed characterization of amphibole syntheses. Not only is it important to the crystal-chemical study of pure endmembers, but is also critical for modelling of petrologic systems, especially if thermodynamic properties are measured. Furthermore, with the increasing availability of high-resolution transmission electron microscopy, it is obvious already from preliminary work that this technique must also be added in order to study chain disorder and other defects.

In summary, the most salient conclusions resulting from this study are

1. It is unlikely that a pure amphibole endmember has ever been synthesized either previously, or in this study.
2. Because virtually all synthetic amphiboles are off-composition, they must be completely characterized before crystal-chemical or petrologic interpretations are made.
3. The usefulness of infrared spectroscopy and the relatively recent Rietveld powder structure method for detailed characterization have been demonstrated in this study. Although problems in the refinement of chain silicates were not entirely overcome, the site-occupancies were invaluable in documenting ordering in fluor-amphiboles. The development of a better profile function should lead to better results.
4. Because of the significant differences in cation ordering between natural and synthetic amphiboles, and the possibility of chain-width disorder, high densities of stacking faults or other structural disorder, this study has emphasized the importance of detailed characterization in documenting these differences. This is critical in applying the results of synthesis and stability studies to natural amphiboles; the interpretation is usually not simply one of analogy, but of contrast.

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Appendix A

RIETVELD STRUCTURE ANALYSIS PROGRAM DESCRIPTION

The basic DBW 2.9 program of Wiles and Young (1981) was slightly modified to convert intensities collected with an automatic divergence slit to corresponding fixed-slit intensities using the relationship (Philips Operating Manual: Automatic Divergence Slit PW1386/50):

$$If=[d(0.20268)Ia\ /[\sin(11.16°+0.8778\theta°)-0.19355]$$

where If=intensity for fixed slit, Ia=intensity measured with automatic slit and d=divergence of fixed slit (in degrees).

This program performs Rietveld (1967, 1969) analysis on x-ray powder diffraction data collected on a θ-2θ diffractometer operated in step scanning mode. It features single-pass operation and built-in direct applicability with all space groups and with all atoms for which the required scattering factors are listed in the International Tables for X-ray Crystallography (1974) as coefficients of an exponential series generating the X-ray scattering factors, plus anomalous scattering corrections as appropriate.

The Newton-Raphson method is used to minimize the quantity

$$\underline{R} = \sum_i w_i \left| y_i(o) - y_i(c) \right|^2$$

where $y_i(o)$ is the intensity observed at the ith step in the powder diffraction pattern, $y_i(c)$ is that calculated, and the weight w_i is given by

$$w_i = 1/(y_i + y_{ib})$$

where y_{ib} is the background intensity at the ith step.

The calculated counts $y_i(c)$ are determined by summing the contributions from neighbouring Bragg reflections plus the background as

$$y_i(c) = S\Sigma_K p_K L_K |F_K|^2 G(\Delta\theta_{iK}) P_K + y_{ib}(c)$$

where S is a scale factor, L_K=Lorenz and polarization factors for the Kth Bragg reflection, F_K=structure factor, p_K=multiplicity factor, P_K=preferred orientation function (currently only for platy habit as $\exp(P\alpha^2)$ where P_K is the refinable parameter and α is the acute angle between the scattering vector and the normal to the crystallite), θ_{iK} is the the Bragg angle for the Kth reflection, K=h,k,l, the indices identifying the Bragg reflection for which each of the above is evaluated, and $G(\Delta\theta_{iK})=G(2\theta_i-2\theta_K)$ is the reflection profile function $g(\Delta\theta_{iK})$ multiplied by an asymmetry function $a(\Delta\theta_{iK})$ given by

$$a(\Delta\theta_{iK})=1-[A(\text{sign}\Delta\theta_{iK})(2\Delta\theta_{iK})^2/\tan\theta_K$$

The background model may be obtained from the function

$$y_{ib}(c)=B_0+B_1(2\theta)+B_2(2\theta)^2+B_3(2\theta)^3+B_4(2\theta)^4+B_5(2\theta)^5$$

or from an operater-supplied table of background intensities, or from linear interpolation between operator-selected points in the pattern.

Currently available profile functions include

$\frac{C_0^{1/2}4}{\sqrt{\pi}H_K} e^{-4\ln 2\frac{(2\theta-2\theta_K)^2}{H_K^2}}$ Gaussian

$\frac{C_1^{1/2}}{\pi H_K} 1/1+C_1\frac{(2\theta_i-2\theta_K)^2}{H_K^2}$ Lorentzian

$\frac{2C_2^{1/2}}{\pi H_K} 1/[1+C_2\frac{(2\theta_i-2\theta_K)^2}{H_K^2}]^2$ Mod 1 Lorentzian

$\frac{C_3^{1/2}}{2 H_K} 1/[1+C_3\frac{(2\theta_i-2\theta_K)^2}{H_K^2}]^{1.5}$ Mod 2 Lorentzian

where H is the full-width at half-maximum, $C_0=4\ln 2$, $C_1=4$, $C_2=4(2^{1/2}-1)$ and $C_3=4(2^{2/3}-1)$.

H is approximated by

$$H^2=U\tan^2\theta + V\tan\theta + W$$

where U,V and W are constants for a particular X-ray pattern.

Three quantitative criteria of calculated to observed pattern fit are given ("R-factors"):

$$R_B = \frac{\Sigma \mid I(\text{"obs"}) - I(\text{calc}) \mid}{\Sigma I(\text{'obs'})}$$

$$R_p = \frac{\Sigma \mid Y_i(\text{obs}) - (1/c)\, Y_i(\text{calc}) \mid}{\Sigma Y_i(\text{obs})}$$

$$R_{wp} = \left\{ \frac{\Sigma w_i \left[Y_i(\text{obs}) - (1/c)\, Y_i(\text{calc}) \right]^2}{\Sigma w_i \left[Y_i(\text{obs}) \right]^2} \right\}^{1/2}$$

$$R_{exp} = \left\{ \frac{(n-p)}{\Sigma w_i \left[Y_i(\text{obs}) \right]^2} \right\}^{1/2}$$

Of these, the R_{wp} is the most important for following the progress of a refinement because its numerator is the quantity being minimized. In the R-Bragg expression, the symbol "I(obs)" is placed in quotation marks because it is not actually observed. It is calculated by allocating the actually observed intensities $y_i(o)$ to Bragg intensities, "I(obs)", on the basis of the calculated intensities I (c) after Rietveld (1969). In

the expression for Rexp, n is the number of observations and p is the number of variable parameters during refinement.

The following parameters can be refined simultaneously in the least-squares refinement:

1. lattice
2. atom postions (x,y,z)
3. isotropic or anisotropic temperature factors
4. atomic site occupancy
5. profile U,V,W and asymmetry
6. preferred orientation
7. background function
8. 2θ-zero correction
9. overal scale (one for each phase)
10. overall istropic temperature factor

Required input information includes

1. initial values of all variable parameters
2. step-scan data in equal increments in 2θ
3. 2θ limits and excluded regions in the data
4. wavelengths
5. background specification
6. space group symbol
7. chemical symbol and valence of each atom
8. number of phases
9. profile function choice

10. profile cut-off (in units of H)
11. preferred orientation vector for each phase
12. termination control: either number of cycles or 'Eps' value in which case the run terminates when the shifts <Eps. for all parameters.
13. relaxation factors for the shifts (separately specified for four different groups of parameters)

output controls

1. The output includes identifiers of the refinement conditions and subject so that a given run can be reconstructed unambiguously
2. adjustable-parameter final values, last shift, and standard deviations
3. R-weighted pattern, R-pattern, R-Bragg and 'expected' R-weighted pattern

The following user selected printouts are available

1. reflection list for each phase
2. corrected data list, with w values
3. observed and calculated intensities
4. correlation matrix
5. line-printer plot
6. off-line plot (e.g. CalComp or Versatec)

Appendix B

RIETVELD STRUCTURE ANALYSIS INPUT DATA

OBSERVED INTENSITIES

This appendix contains the observed intensities used as input for Rietveld structure analysis. The figures in brackets after the amphibole name are the starting 2θ value, step size in °2 0, and final 2θ value. Entries in the table read across, in the input format 8(F7.0,1X).

Scandium-pargasite (8.00, 0.01, 72.00)

226	222	217	192	213	239	253	236
225	246	234	234	236	207	236	199
232	239	222	228	227	234	217	221
215	203	204	253	242	224	238	225
210	260	222	230	220	212	241	220
257	217	226	235	234	229	231	198
239	197	222	223	198	207	240	220
258	213	238	222	249	235	200	244
232	224	255	237	260	233	255	226
249	232	231	243	225	221	244	233
259	246	229	240	253	238	257	257
229	242	235	231	240	265	270	256
235	244	224	231	258	259	269	285
246	260	248	258	244	267	258	260
285	279	283	262	303	254	279	260
261	273	317	286	300	288	276	282
318	327	318	317	301	316	333	310
286	350	370	351	339	334	368	363
355	355	347	427	416	398	396	444
455	467	468	480	488	511	546	507
536	546	607	605	588	645	677	701
764	735	776	833	904	901	957	939
1096	1158	1178	1243	1242	1220	1295	1292
1260	1207	1113	1093	1034	933	862	809
750	669	623	594	576	578	518	537
520	488	471	507	500	469	484	453
473	470	474	472	478	482	516	503
523	527	580	540	547	565	583	561
665	646	650	691	703	710	773	835
799	874	922	963	1018	1109	1178	1161
1298	1443	1535	1584	1685	1858	1892	2067
2101	1984	1945	1857	1664	1484	1424	1184
1054	889	741	668	589	513	496	441

382	373	388	334	318	321	290	318
298	252	277	284	272	300	260	273
261	233	306	247	270	264	259	268
276	236	265	244	237	222	261	258
243	277	253	233	247	245	244	240
219	232	243	233	236	244	239	212
238	228	211	240	214	246	235	277
235	250	267	270	217	255	230	203
230	226	234	241	217	258	246	247
259	252	250	225	262	242	245	255
224	226	236	240	234	222	254	255
257	223	258	239	251	255	229	237
214	226	242	232	246	245	221	220
233	206	250	214	242	250	215	225
227	214	241	197	244	232	255	224
215	207	228	227	254	209	212	217
221	236	219	252	237	237	224	252
216	205	219	245	230	234	236	241
239	227	256	240	239	208	228	238
220	245	222	254	229	245	234	222
207	205	224	220	245	221	220	219
249	228	185	216	238	215	234	209
224	218	215	229	230	243	222	237
245	230	221	252	241	251	256	224
250	209	227	218	234	230	231	211
225	221	236	228	199	243	263	251
225	242	215	216	240	238	261	228
222	219	240	250	229	231	263	231
247	259	214	221	232	239	241	227
210	234	232	205	253	246	260	244
235	251	239	247	232	275	242	233
221	226	219	245	221	240	241	217
224	244	243	209	227	211	265	241
231	271	209	236	220	237	233	238
201	215	235	240	228	246	207	213
208	238	235	260	224	233	239	219
229	219	209	217	228	247	224	235
229	262	245	231	231	236	233	212
236	206	213	233	252	239	256	217
302	245	239	248	230	217	240	241
232	239	251	254	236	226	240	204
258	216	198	227	247	216	208	210
215	233	222	216	242	222	208	213
230	227	210	239	228	244	202	234
244	247	228	246	239	237	244	245
242	248	233	248	222	224	253	250
232	221	245	230	239	220	222	247
236	231	273	243	224	253	238	204
253	236	222	248	253	247	236	209
263	235	217	249	240	250	217	231
239	213	204	220	229	222	227	253
213	264	216	233	246	232	235	242
233	213	231	235	221	223	247	227
245	250	214	238	234	221	246	245
278	253	232	244	235	240	226	235

237	254	248	257	221	222	256	233
241	242	250	230	228	241	270	243
211	250	242	245	230	246	228	243
225	224	244	250	237	225	241	225
238	224	240	232	266	236	243	217
246	242	242	243	270	224	216	276
234	232	227	225	233	211	229	231
249	221	227	222	247	225	229	260
242	230	227	242	247	227	228	240
220	207	260	235	218	244	243	252
237	238	280	224	230	232	269	234
240	231	253	208	237	245	234	233
234	244	240	231	264	229	266	245
260	237	245	258	218	235	249	218
227	232	243	227	246	222	250	231
264	243	225	238	224	231	234	259
233	221	226	256	230	246	264	271
244	230	251	235	273	235	261	255
237	254	220	237	267	254	224	232
268	228	244	262	203	265	264	230
236	223	243	240	251	239	238	234
234	213	279	264	278	226	200	248
262	260	249	255	234	260	266	240
242	236	220	240	258	268	232	254
285	238	255	240	230	262	256	261
285	273	254	257	290	245	251	255
299	274	265	298	291	305	272	246
307	313	311	326	310	328	334	382
369	414	401	378	426	444	477	497
515	541	573	589	579	596	551	590
574	585	550	533	492	475	448	444
402	370	441	382	373	364	370	351
349	321	329	305	315	304	294	319
333	298	315	322	322	319	341	341
329	338	376	370	372	357	395	397
392	406	448	455	471	482	503	535
557	555	665	661	747	768	910	1021
1002	1111	1178	1345	1464	1594	1636	1664
1859	1843	1818	1780	1748	1647	1527	1346
1328	1115	1019	880	806	738	664	621
558	505	472	472	459	440	397	392
382	381	367	353	326	373	329	360
369	336	355	374	321	357	359	375
362	386	390	365	389	341	378	387
384	369	352	362	358	340	314	329
336	313	317	301	289	313	281	288
292	286	254	273	256	257	252	257
242	301	289	280	248	299	264	273
293	289	276	272	244	284	279	282
272	287	273	279	261	279	251	282
275	291	260	263	265	291	267	260
255	265	296	256	249	288	279	277
285	315	302	280	272	309	314	325
333	329	316	307	335	341	360	332
370	387	369	407	429	464	452	486

506	537	584	326	694	707	825	897
1001	1178	1240	1263	1375	1536	1689	1805
1986	2106	2201	2246	2294	2365	2306	2170
2064	1987	1833	1718	1540	1417	1293	1188
1159	977	943	827	786	670	680	645
644	505	508	472	454	478	435	380
360	405	369	349	393	383	399	348
359	365	367	340	357	342	317	315
321	318	293	298	290	299	293	307
282	275	287	301	289	274	285	287
271	245	254	298	299	287	245	286
283	277	276	273	273	265	268	318
249	293	292	291	301	285	317	318
349	328	336	366	348	380	354	350
377	377	403	375	335	341	311	322
323	349	333	288	317	295	282	287
293	342	316	309	278	313	307	334
331	332	324	314	363	364	360	370
393	387	426	418	485	457	521	514
552	524	579	536	584	625	569	570
559	574	527	575	501	470	439	462
364	412	391	353	357	361	327	349
322	298	330	269	297	303	305	275
317	310	329	291	274	287	297	263
276	285	306	303	307	284	263	282
311	290	305	306	301	267	302	313
305	290	291	283	292	295	312	281
290	286	316	288	290	289	312	337
304	293	335	294	307	309	346	298
365	336	339	352	364	357	345	344
372	410	358	374	346	371	394	387
379	369	412	346	399	420	443	446
450	470	433	465	531	559	541	573
607	597	617	673	702	684	770	755
763	795	730	741	690	771	710	717
735	718	778	800	814	865	872	876
892	972	878	1014	999	995	913	907
900	925	890	818	814	765	709	627
632	609	601	565	511	539	489	543
512	508	504	510	473	553	509	563
609	633	659	653	680	719	783	860
883	964	1001	1055	1179	1207	1324	1353
1455	1538	1529	1595	1713	1618	1612	1630
1535	1525	1520	1404	1286	1239	1143	1081
976	885	857	738	670	628	615	559
518	478	456	436	451	399	360	336
362	365	391	354	344	330	317	317
312	318	321	293	308	310	284	303
302	277	328	347	300	306	318	279
325	313	319	324	303	289	267	303
275	309	283	297	325	281	283	288
291	286	303	304	287	263	269	335
312	284	326	298	302	299	308	290
321	320	317	334	333	308	300	311
313	303	298	332	342	349	332	348

368	341	320	364	362	385	391	363
371	426	405	390	417	413	384	385
398	402	383	353	353	348	364	315
348	320	311	301	288	308	316	307
308	283	339	318	298	289	281	275
299	270	301	302	321	292	258	308
298	302	319	300	292	282	272	318
321	327	290	333	337	306	285	345
308	312	301	268	302	322	267	303
317	302	296	303	304	299	292	268
304	288	313	301	322	304	314	297
288	305	324	310	312	293	304	312
318	307	276	311	336	323	297	300
333	288	333	320	287	302	320	332
303	282	307	309	311	302	330	345
329	303	351	306	328	314	345	327
296	323	313	325	316	339	332	341
314	302	325	342	378	351	355	358
379	347	335	388	337	379	348	367
395	366	390	420	426	420	422	414
413	459	439	486	471	478	465	497
466	525	504	527	490	466	488	494
515	522	469	499	514	530	475	483
509	526	498	496	504	475	507	535
487	465	484	502	521	485	556	498
530	525	554	542	553	556	576	561
594	629	621	643	608	672	657	666
713	694	795	749	841	892	882	901
956	943	1063	1080	1177	1208	1353	1388
1600	1731	1711	1988	2054	2339	2498	2879
3115	3387	3831	4236	4770	4988	5677	6098
6467	7001	7499	7917	8012	8302	8207	8364
8306	8305	7715	7363	6956	6436	5833	5496
4911	4797	4217	3786	3468	3098	2881	2509
2235	2157	1915	1685	1618	1437	1375	1297
1167	1138	1034	1039	994	946	857	867
875	723	786	775	763	713	779	776
742	772	754	801	804	846	809	872
856	913	942	1012	1116	1260	1352	1422
1633	1894	1947	2224	2487	2843	3158	3550
3997	4450	4987	5357	5743	6104	6393	6541
6875	6885	6957	6783	6665	6377	5972	5676
5272	5024	4631	4248	3784	3572	3179	2784
2641	2268	2076	1856	1695	1537	1411	1306
1224	1080	922	845	833	848	753	705
649	649	652	553	579	593	561	577
604	579	572	559	612	613	630	564
575	571	543	550	610	553	584	554
559	570	539	543	530	533	490	524
498	508	499	535	522	519	514	528
545	584	577	577	598	592	624	561
674	686	715	692	735	731	839	752
827	871	913	941	1014	995	1109	1077
1127	1176	1244	1223	1319	1376	1506	1584
1638	1770	1869	2101	2206	2404	2611	2915

3048	3443	3866	4153	4787	5299	5858	6407
7024	8134	8453	9121	9694	10044	10292	10269
0336	10056	9416	9173	8563	7900	7169	6705
5944	5341	4857	4403	3822	3401	2990	2778
2409	2138	1853	1743	1547	1476	1294	1170
1088	1028	1033	927	915	838	839	824
780	787	723	727	696	662	676	642
611	686	617	648	653	572	622	611
559	614	621	601	562	558	563	542
597	593	638	578	631	673	648	715
789	785	834	1026	986	1109	1183	1324
1398	1609	1699	1848	1992	2230	2350	2501
2650	2594	2725	2718	2699	2738	2473	2415
2224	2129	1997	1782	1640	1498	1420	1227
1145	1069	935	877	864	762	746	711
689	692	630	671	636	650	683	668
594	653	612	623	588	646	667	619
631	603	648	640	592	636	631	600
624	676	641	721	737	804	744	812
911	853	956	910	992	1013	1049	1087
1141	1206	1182	1139	1150	1218	1273	1212
1186	1175	1176	1094	1003	1012	944	982
905	891	886	896	896	863	876	862
817	817	852	921	936	933	994	1096
1230	1272	1408	1430	1631	1722	1929	2052
2314	2453	2832	2842	3228	3583	3926	4285
4692	5076	5634	6017	6540	7038	7285	7730
8072	8037	8567	8440	8250	7963	7732	7430
7137	6870	6438	6022	5606	5271	4730	4250
4033	3608	3257	2896	2570	2338	2191	2010
1795	1561	1453	1396	1252	1106	1003	1005
920	821	772	767	733	794	779	690
727	767	715	770	702	741	780	794
804	768	703	718	786	768	725	705
748	687	706	704	717	669	697	644
670	667	651	588	592	608	631	607
560	577	590	599	606	605	621	656
679	659	677	704	719	780	783	832
807	917	920	1028	1142	1098	1331	1341
1432	1574	1666	1879	2190	2300	2437	2775
2979	3052	3254	3318	3305	3371	3527	3443
3467	3370	3276	3332	3235	3236	3077	3067
3051	3091	3105	3199	3117	3307	3261	3335
3433	3315	3293	3314	3327	3204	3108	3036
2851	2784	2701	2507	2427	2413	2160	2052
1927	1796	1698	1624	1524	1427	1305	1276
1188	1247	1146	1069	1032	1034	919	970
940	972	914	916	911	889	849	915
912	929	858	897	899	899	935	985
959	994	981	1088	1185	1214	1238	1222
1328	1473	1556	1687	1766	1897	2060	2235
2532	2695	3102	3323	3667	3927	4385	4740
5094	5609	5717	5850	6042	6203	6046	5987
5893	5839	5364	5186	5105	4836	4595	4224
3920	3801	3645	3602	3280	3123	3130	3240

3314	3374	3638	3542	3804	4014	4214	4325
4398	4635	4499	4616	4666	4539	4447	4414
4292	4218	4042	3861	3874	3716	3616	3486
3552	3561	3533	3574	3836	3870	4230	4412
4975	5273	5700	6348	6913	7601	8234	8703
9247	9762	10252	10607	10870	10927	11014	11071
0961	10902	10867	10459	10463	9828	9134	9022
8374	8030	7452	7096	6495	6081	5621	5411
5032	4703	4458	4093	3889	3685	3399	3060
2836	2590	2498	2383	2198	1968	1856	1722
1646	1598	1488	1423	1367	1341	1235	1219
1128	1013	1026	1002	988	911	945	926
924	874	868	812	835	863	824	844
818	766	810	738	770	791	702	741
715	696	682	738	708	707	704	678
676	687	668	653	652	713	661	706
666	660	667	655	643	634	644	659
652	710	865	671	681	713	705	689
690	702	713	714	755	722	777	776
749	788	754	850	848	898	865	932
1023	1008	1075	1084	1186	1206	1305	1450
1551	1645	1784	1966	2174	2393	2700	2900
3354	3805	4149	4561	5014	5679	5873	6468
6642	7082	7416	7821	7912	7759	7861	7985
7808	7706	7538	7274	7141	6763	6491	6261
5788	5459	4999	4814	4441	4205	3867	3645
3360	3204	2878	2758	2451	2457	2259	2096
2019	1850	1808	1725	1622	1573	1595	1512
1535	1488	1409	1485	1508	1552	1630	1669
1858	1976	2278	2350	2756	2941	3331	3821
4221	4813	5482	6202	6826	7878	8762	9475
0281	10898	11818	12339	12913	12993	13154	13050
2847	12471	12002	11499	10573	10050	9370	8584
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2860	2689	2270	1884	1816	1622	1525	1388
1348	1241	1187	1155	1131	1080	1089	1009
1050	1030	948	998	878	925	871	891
857	943	941	939	990	887	905	949
966	972	999	1002	1032	1035	1054	985
1045	1001	1079	1106	1055	1107	1091	1101
1236	1221	1292	1308	1465	1524	1560	1672
1720	1886	1917	2021	2035	2073	2133	2136
2012	1965	1890	1855	1728	1749	1605	1576
1460	1294	1237	1201	1064	944	925	857
827	751	713	678	644	589	576	542
539	516	552	523	526	547	524	482
516	562	538	567	597	564	599	648
659	692	723	770	813	887	949	981
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1413	1380	1312	1276	1276	1245	1171	1133
1107	1086	972	914	901	873	799	785
765	713	682	638	573	574	579	574
580	586	565	601	632	594	588	610
647	665	682	761	742	805	821	935
938	1090	1115	1196	1337	1356	1445	1577

1691	1759	1768	1843	1893	1831	1962	1904
1879	1906	1798	1917	1771	1782	1754	1633
1626	1537	1477	1382	1369	1309	1230	1198
1191	1104	1122	1143	1095	1145	1106	1075
1227	1187	1247	1292	1354	1453	1518	1595
1734	1825	1948	2091	2106	2112	2229	2322
2420	2469	2344	2412	2374	2359	2239	2216
2113	2128	1992	1910	1856	1744	1670	1642
1586	1429	1323	1288	1298	1167	1213	1055
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883	917	854	875	882	894	909	925
991	962	943	1016	1102	1132	1170	1199
1262	1370	1505	1642	1625	1847	2025	2244
2650	2764	3020	3441	3807	4166	4595	4807
5282	5742	5954	6294	6546	6682	6945	7197
7543	7577	7543	7776	7892	8024	7839	8014
7757	7830	7428	7330	7273	6941	6494	6369
5743	5491	5154	4800	4577	4113	3815	3566
3277	3057	2784	2569	2486	2219	2063	1907
1711	1683	1509	1485	1417	1312	1240	1160
1190	1174	1096	1095	1084	1062	1012	973
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1413	1536	1580	1626	1787	1871	1989	2114
2313	2446	2499	2645	2709	2900	3034	3110
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4055	4143	4185	4302	4440	4385	4423	4426
4466	4408	4212	4046	4134	3854	3606	3585
3331	3132	2976	2738	2569	2347	2263	2113
1884	1734	1586	1433	1328	1225	1123	986
958	922	810	815	805	770	695	705
607	649	644	590	664	598	565	610
591	596	560	571	611	633	329	625
687	661	614	669	701	712	733	739
735	741	759	742	748	744	840	842
840	920	878	894	948	1002	967	995
1001	1000	1029	1015	1050	994	1042	948
971	1025	958	935	930	830	905	875
863	816	857	784	797	754	730	768
680	687	639	680	687	616	689	697
680	723	719	709	744	743	818	856
876	861	971	1018	982	1049	1061	1097
1191	1188	1176	1204	1299	1333	1381	1452
1492	1525	1621	1707	1784	1839	1915	1884
2007	1980	1917	1926	2024	1917	1918	1911
1801	1810	1776	1742	1616	1474	1458	1424
1299	1240	1153	1117	1003	944	917	846
817	773	793	720	683	675	653	625
654	597	566	607	612	638	577	596
601	587	611	595	602	558	553	615
605	589	619	585	551	621	553	590
582	558	552	592	542	586	605	629
630	636	644	695	690	668	706	710
798	728	794	785	770	836	831	891
788	905	878	917	875	949	932	919

1019	1049	1100	1118	1173	1168	1316	1389
1544	1567	1848	1915	2038	2378	2636	2811
3239	3529	3879	4126	4701	4921	5239	5600
5985	6187	6423	6546	6627	6681	6886	6806
6656	6587	6522	6357	6320	5926	5708	5631
5486	5239	5023	4922	4487	4123	4084	3835
3489	3281	3119	2982	2772	2511	2498	2202
2092	1918	1842	1809	1611	1529	1471	1405
1372	1230	1248	1173	1144	1155	1122	1000
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1045	1174	1124	1175	1125	1130	1073	1176
1121	1109	1114	1057	1081	1028	1008	999
963	942	961	822	898	837	864	772
755	659	705	725	690	562	638	598
700	592	581	532	554	504	530	517
465	511	536	536	518	500	443	506
499	497	489	487	498	480	508	492
473	477	486	484	505	467	486	525
491	540	563	517	544	564	580	589
567	598	609	646	700	700	751	756
780	779	812	803	829	856	812	837
836	826	773	801	810	747	742	731
724	722	696	655	599	618	614	586
550	538	489	480	490	488	473	488
458	449	430	424	416	462	438	370
461	410	384	422	416	405	388	425
421	412	424	407	413	413	439	427
418	437	424	405	430	439	381	416
451	422	464	450	441	432	435	442
463	450	409	460	457	435	490	446
471	454	453	449	485	449	465	461
455	498	480	450	545	503	538	487
522	567	547	594	620	629	621	648
673	685	681	753	733	861	915	886
972	1008	1106	1198	1258	1409	1571	1713
1810	1989	2245	2466	2697	2965	3279	3525
3782	4074	4372	4646	5123	5534	5665	6019
6265	6542	6687	6765	6780	6911	6689	6478
6511	6239	5865	5882	5525	5292	4983	4852
4540	4235	4101	3790	3601	3290	3070	2807
2640	2416	2282	2234	2125	2025	1913	1967
1969	1992	1941	2034	2120	2249	2298	2301
2414	2466	2612	2612	2727	2734	2799	2805
2859	2894	2818	2793	2852	2855	2767	2847
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2101	2114	2054	1998	2009	1969	1881	1919
1727	1669	1694	1576	1520	1452	1459	1333
1345	1323	1266	1179	1147	1080	1106	1004
968	971	1022	964	885	910	877	911
939	896	927	845	919	900	887	932
971	956	1025	993	1042	1142	1158	1246
1317	1283	1361	1481	1459	1543	1606	1605
1759	1666	1663	1737	1693	1749	1689	1599
1582	1566	1504	1501	1482	1377	1353	1290

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1181	1214	1180	1171	1211	1163	1188	1226
1150	1167	1156	1135	1140	1145	1105	1059
1015	1006	1000	980	1004	965	935	874
896	857	859	852	837	822	800	885
887	894	909	937	1039	919	957	969
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889	814	840	771	793	730	699	735
703	678	661	618	618	624	621	612
639	631	618	655	625	677	671	677
635	705	737	885	781	888	880	930
944	944	1060	1053	1157	1154	1119	1066
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799	761	758	703	643	661	587	573
607	626	592	567	593	566	578	542
554	512	531	564	566	609	602	606
627	692	642	622	706	683	752	778
889	888	1019	1008	1095	1151	1242	1391
1392	1601	1711	1818	1942	2107	2147	2137
2233	2274	2256	2271	2334	2270	2156	2216
2135	2092	2048	2018	1894	1812	1790	1716
1615	1607	1515	1534	1472	1384	1330	1291
1256	1185	1189	1158	1088	1107	1140	1081
1082	1047	1016	1046	1081	1006	1023	1076
975	981	950	941	887	917	893	890
862	877	844	765	827	763	827	707
740	736	688	635	628	624	635	660
671	625	659	643	639	682	693	749
715	761	795	780	857	886	899	940
917	1020	1068	1100	1150	1169	1212	1307
1343	1371	1390	1489	1437	1530	1574	1561
1541	1642	1545	1568	1620	1615	1592	1517
1590	1533	1525	1590	1520	1477	1400	1481
1467	1448	1511	1444	1489	1444	1458	1575
1610	1581	1627	1575	1622	1614	1763	1654
1798	1794	1868	1816	1845	1874	1935	1871
1859	1927	1849	1881	1840	1784	1779	1709
1779	1792	1714	1713	1678	1645	1612	1585
1581	1572	1514	1526	1489	1411	1392	1393
1393	1338	1299	1231	1222	1191	1225	1151
1127	1096	1042	1093	1024	917	879	910
901	844	815	826	715	792	749	725
765	680	729	724	715	667	620	612
680	621	666	634	612	611	645	609
627	630	653	621	654	628	656	665
658	683	668	765	776	817	791	843
837	961	905	939	968	983	987	1057
989	1082	1027	1071	1008	986	914	918
923	960	928	921	878	899	901	816
830	813	771	731	722	742	717	727
728	705	675	652	643	641	642	641

627	662	680	635	684	639	683	647
689	697	718	717	762	720	796	774
694	725	726	736	710	652	733	722
731	729	734	724	747	696	691	659
670	654	587	673	611	660	605	651
572	638	599	611	624	647	658	646
628	613	591	643	663	616	588	578
611	621	617	574	579	537	545	601
587	504	515	554	560	503	494	503
461	468	488	409	443	445	447	422
409	390	431	413	398	397	367	423
389	410	415	391	389	440	410	379
409	390	377	379	423	389	424	408
440	442	384	442	432	450	403	435
421	454	446	463	438	469	527	522
548	515	521	581	621	619	649	729
700	744	764	775	819	904	919	941
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1408	1504	1441	1476	1477	1477	1441	1459
1400	1418	1375	1366	1370	1301	1239	1231
1174	1169	1174	1075	1034	1051	1021	886
858	867	857	817	802	769	702	698
686	692	630	609	589	575	585	623
573	576	602	571	579	583	612	620
573	636	633	585	627	673	676	761
732	734	770	780	796	843	796	828
853	832	831	822	857	910	867	888
973	971	1050	1098	1097	1207	1253	1364
1459	1538	1552	1722	1706	1902	1955	2068
1998	2102	2086	2103	1966	1987	1895	1833
1766	1703	1718	1637	1570	1558	1489	1476
1487	1344	1272	1254	1117	1143	996	989
921	910	833	810	732	754	735	700
716	666	682	651	614	605	609	586
635	623	607	634	562	560	661	613
576	637	558	577	613	578	595	566
561	558	562	598	570	601	546	540
579	546	549	550	535	501	542	502
523	519	519	494	517	455	536	462
493	532	484	476	480	470	512	523
511	530	521	504	556	508	544	627
598	591	619	672	718	713	738	775
862	859	839	896	870	969	952	949
1003	1042	1071	1020	986	1099	1155	1116
1167	1181	1200	1232	1232	1292	1213	1290
1327	1313	1299	1324	1333	1355	1358	1360
1489	1603	1615	1744	1761	1864	1946	2035
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2877	3108	3091	3070	2971	3040	3187	3162
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2432	2285	2235	2208	2082	2041	1910	1970
1851	1714	1658	1583	1531	1514	1437	1396
1266	1259	1225	1202	1140	1112	1126	1136

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1216	1254	1274	1330	1387	1346	1401	1423
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1219	1189	1177	1138	1072	1059	1040	1085
1008	1045	976	888	953	963	911	960
881	870	915	884	883	882	921	936
898	1012	997	1045	1021	1165	1188	1273
1391	1529	1633	1788	1865	2084	2280	2465
2593	2797	3040	3184	3278	3453	3630	3796
3812	3894	4135	4092	4186	4130	4142	4138
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3271	3158	3148	3036	3093	2957	2935	2842
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2397	2384	2356	2289	2246	2152	2132	2102
2082	2061	1970	1966	1984	1972	1831	1931
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1618	1733	1703	1690	1727	1705	1772	1723
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1750	1776	1779	1679	1718	1697	1726	1615
1694	1636	1470	1535	1520	1508	1442	1331
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995	924	860	902	852	839	870	819
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765	715	739	678	680	733	660	668
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723	741	743	719	776	772	789	851
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1281	1403	1419	1527	1548	1637	1601	1641
1632	1656	1722	1678	1655	1638	1570	1660
1556	1512	1533	1524	1411	1487	1438	1378
1392	1324	1385	1300	1235	1215	1182	1157
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984	969	972	930	955	1009	1051	1046
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1624	1712	1816	1953	2039	2133	2360	2415
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2971	3012	2985	2957	3015	3016	2980	2926
2933	2904	2806	2758	2726	2567	2526	2504
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1857	1845	1771	1734	1577	1599	1582	1458
1519	1467	1321	1351	1296	1326	1268	1265
1218	1255	1238	1215	1202	1164	1141	1101
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874	879	830	808	856	853	842	908
837	821	846	813	850	846	805	864
918	889	969	963	918	940	1037	1092
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1847	1894	1985	1988	2197	2320	2414	2526
2730	2844	2923	3155	3166	3410	3521	3591
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3264	3138	3080	3010	3047	2912	2872	2730
2655	2597	2552	2494	2352	2394	2119	1994
1952	1839	1705	1514	1480	1457	1373	1258
1285	1123	1169	1097	1079	1047	978	936
970	950	949	853	906	858	852	790
906	846	787	803	788	767	770	786
803	735	773	769	742	801	794	744
715	713	735	660	711	753	758	770
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786	778	825	799	782	804	835	917
899	865	952	984	930	994	989	977
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1380	1417	1554	1619	1640	1848	1981	2145
2200	2426	2617	2784	2922	3208	3432	3591
3726	3777	3989	4244	4228	4411	4271	4489
4617	4661	4561	4697	5000	4843	4842	4752
4710	4810	4744	4521	4630	4539	4511	4526
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3582	3527	3396	3237	3242	3066	2974	2954
2936	2824	2804	2836	2741	2812	2749	2655
2721	2786	2767	2628	2785	2711	2732	2763
2742	2621	2824	2729	2672	2725	2712	2774
2691	2610	2687	2657	2648	2522	2500	2424
2346	2396	2335	2325	2164	2209	2146	2012
2127	2016	1900	1864	1747	1659	1702	1658
1633	1608	1500	1418	1493	1370	1273	1258
1273	1179	1196	1134	1131	1083	1086	1043
1023	994	1039	918	930	916	905	932
908	904	900	852	848	838	766	748
804	769	769	742	712	663	709	661
664	648	676	641	640	633	646	618
584	595	617	650	590	624	581	617
594	640	609	644	667	611	640	675
708	709	751	818	797	854	939	862
924	1016	1040	1132	1116	1117	1168	1247
1215	1212	1141	1209	1135	1211	1126	1027
1046	1018	1068	1011	1041	1031	999	1052
1063	1038	1001	1007	1001	1048	1009	932
1003	937	992	891	877	956	952	873
882	848	823	860	834	799	822	870
848	907	861	870	889	862	897	867
913	924	880	913	944	925	979	991
1009	1044	1108	1152	1090	1199	1172	1226
1194	1245	1304	1386	1389	1526	1529	1523
1578	1607	1578	1640	1677	1781	1819	1762
1729	1819	1784	1826	1872	1808	1803	1847

1792	1878	1873	1898	1881	1977	1940	1810
1940	1815	1960	1869	1868	1719	1790	1709
1836	1646	1695	1658	1588	1694	1596	1594
1589	1538	1502	1534	1498	1543	1563	1407
1555	1554	1445	1459	1563	1463	1465	1487
1500	1540	1571	1625	1689	1626	1774	1803
1804	1934	1926	1975	2099	2262	2257	2463
2677	2891	2975	3179	3566	3824	4042	4162
4592	4852	5007	5390	5608	5765	5961	5878
6256	6205	6188	6179	5967	6030	5813	5806
5744	5724	5455	5523	5302	5276	5066	4974
5058	4902	4693	4543	4337	4234	3939	3834
3684	3538	3264	3134	3102	2867	2805	2710
2541	2358	2373	2227	2168	2217	1977	1884
1929	1863	1863	1678	1724	1670	1689	1602
1638	1561	1482	1540	1541	1399	1479	1402
1322	1381	1306	1312	1177	1203	1168	1139
1100	1172	1115	1022	1086	1049	1025	965
962	950	913	891	905	825	830	742
790	807	764	701	720	684	680	646
664	670	606	639	641	629	602	566
622	594	536	609	548	567	523	536
541	519	582	523	497	540	533	476
505	504	492	505	529	481	506	530
491	514	525	530	496	545	541	528
533	547	540	557	581	545	571	563
590	606	571	620	585	620	614	608
626	721	633	697	648	679	649	664
633	663	659	709	620	665	668	617
669	667	662	629	647	685	619	674
625	623	638	660	678	685	695	626
679	646	631	592	600	663	650	595
667	629	652	665	655	643	611	660
630	669	633	666	738	713	651	659
665	653	660	679	658	644	675	637
677	687	679	675	706	695	680	672
660	671	664	649	659	679	639	732
618	699	675	690	717	698	763	732
676	738	751	721	690	733	708	705
709	701	739	758	753	692	685	682
687	686	717	655	636	694	607	627
648	698	627	615	604	617	585	593
554	575	575	555	542	545	588	495
531	522	511	529	543	524	509	474
536	510	523	480	510	503	493	482
505	529	485	499	469	508	497	524
499	527	559	494	520	534	465	497
507	480	482	489	515	501	469	534
459	509	501	516	504	481	459	481
496	452	459	488	440	509	531	507
482	426	451	461	465	460	479	442
403	449	472	451	458	454	469	488
474	515	483	455	537	460	504	486
475	535	527	496	527	510	546	514
546	525	512	522	520	497	504	515

551	525	539	522	506	485	545	559
513	533	552	533	522	541	550	529
519	516	531	542	548	541	541	560
589	594	569	586	583	641	668	676
686	758	733	744	868	879	961	910
994	1082	1001	1103	1157	1242	1148	1230
1244	1202	1256	1283	1270	1281	1292	1279
1371	1316	1355	1419	1449	1482	1504	1505
1586	1632	1627	1717	1780	1751	1798	1902
1924	1957	2006	2129	2092	2165	2219	2337
2290	2349	2351	2362	2486	2449	2434	2586
2479	2550	2494	2491	2499	2375	2453	2513
2354	2375	2269	2167	2171	2187	2117	1992
2066	1908	2018	1887	1891	1893	1827	1700
1715	1625	1558	1548	1502	1524	1445	1428
1329	1343	1239	1164	1187	1143	1140	1132
1094	960	978	974	933	917	939	882
805	904	800	809	828	777	784	744
765	741	718	703	715	717	626	667
693	720	677	656	698	640	650	673
628	645	608	596	608	570	647	643
633	623	642	629	651	689	641	613
614	618	623	619	666	618	568	647
666	597	634	635	633	683	677	646
675	743	719	744	803	830	782	813
832	873	936	937	1030	1083	1051	1143
1257	1274	1281	1311	1405	1405	1367	1408
1528	1570	1662	1631	1681	1735	1750	1790
1781	1819	1836	1836	1871	1899	1845	1834
1807	1885	1917	1898	1938	1897	1916	1964
1928	1895	1872	1850	1918	1917	1886	1926
1829	1903	1910	1901	2035	2074	2090	2156
2120	2178	2149	2209	2273	2336	2432	2446
2457	2496	2563	2509	2560	2512	2608	2551
2437	2543	2553	2575	2522	2483	2504	2552
2449	2499	2540	2496	2472	2490	2504	2377
2296	2271	2415	2298	2166	2204	2054	2115
1984	1975	1970	1898	1967	1835	1839	1701
1628	1671	1609	1637	1518	1524	1483	1392
1435	1339	1393	1329	1420	1283	1182	1268
1243	1222	1189	1178	1151	1192	1261	1242
1179	1184	1199	1224	1236	1315	1376	1353
1393	1416	1533	1561	1604	1682	1718	1736
1723	1727	1690	1792	1747	1662	1680	1647
1697	1649	1639	1633	1651	1532	1546	1545
1563	1567	1581	1561	1467	1550	1433	1409
1362	1414	1387	1360	1338	1261	1262	1260
1234	1187	1210	1125	1123	1086	1115	1045
1042	1042	976	989	1009	976	971	940
896	884	886	863	840	877	850	851
826	841	875	866	838	864	900	881
849	916	866	909	1004	952	929	1013
1012							

Fluor-pargasite (8.00, 0.02, 72.54)

381	433	456	469	455	417	428	459
429	406	424	440	444	458	438	416
467	418	424	433	420	440	419	448
410	387	455	453	393	389	439	464
434	454	450	418	488	459	437	429
445	446	463	431	448	456	494	467
460	473	462	491	442	468	452	508
464	475	494	505	513	567	506	535
553	603	544	551	561	563	552	546
567	569	564	621	634	643	698	695
726	673	812	783	923	920	980	1029
1161	1253	1269	1461	1474	1718	1961	2279
2481	2853	3020	3189	2868	2516	2039	1558
1112	1009	871	879	794	829	844	814
928	949	980	1009	1066	1151	1223	1229
1213	1286	1335	1460	1642	1858	2058	2390
2708	3171	3536	3922	3963	3885	3364	2808
2092	1433	1034	856	665	620	584	560
554	526	498	516	475	545	473	501
433	496	481	457	478	457	499	485
458	461	468	461	499	474	492	411
436	466	440	481	463	464	455	444
481	508	472	469	442	453	458	453
476	443	457	474	441	465	472	483
468	468	469	485	441	454	491	493
463	506	463	484	468	487	489	486
443	481	483	453	458	478	476	456
500	483	511	462	502	456	473	460
466	499	502	460	466	453	461	482
434	420	459	470	442	473	481	480
526	472	465	507	464	477	476	445
517	452	476	489	472	515	478	489
463	501	484	494	431	465	472	472
507	503	519	492	520	513	535	512
528	499	558	545	566	551	568	558
626	604	643	621	674	654	598	636
580	535	541	582	558	560	563	586
527	479	535	510	511	553	489	509
496	494	462	510	487	497	517	508
499	500	476	543	478	541	497	470
461	476	510	535	500	474	477	504
466	526	447	459	472	515	484	467
515	488	468	480	526	460	485	490
515	493	474	508	507	465	486	536
480	452	478	465	474	519	461	478
431	480	466	482	466	507	514	518
511	518	512	492	473	481	453	467
465	474	485	502	519	467	492	541
476	500	496	475	481	509	480	490
477	513	535	507	441	484	478	467
513	509	491	480	525	506	469	466
498	497	473	470	510	519	518	550
499	522	568	473	512	537	479	538
547	529	508	518	576	536	484	505
543	545	510	501	523	512	505	522

510	536	525	537	469	489	501	500
514	522	505	548	553	488	527	547
558	527	569	532	520	533	552	589
594	624	637	681	719	771	874	885
1014	1061	1182	1130	1240	1353	1400	1513
1549	1651	1646	1683	1478	1370	1187	1095
1064	1027	1037	1052	1110	1242	1244	1175
1174	1037	973	967	1054	1107	1245	1389
1595	1874	2270	2749	3269	3778	4246	4455
4264	3763	3174	2404	1920	1502	1199	1006
910	808	744	659	643	664	621	586
617	576	620	639	660	617	630	659
653	691	682	616	627	611	667	655
668	689	757	784	835	911	1003	1045
1115	1144	1159	1063	1143	953	956	835
720	651	560	632	590	577	592	600
576	575	533	575	620	667	634	709
708	683	751	766	795	800	931	1068
1185	1377	1607	1895	2143	2518	2952	3389
3747	4295	4597	4735	4624	4054	3415	2677
2056	1526	1205	977	879	859	755	746
688	624	626	605	605	585	605	585
554	592	621	590	562	642	650	690
713	729	819	901	942	1146	1185	1206
1312	1256	1100	1000	954	830	791	782
802	753	734	691	719	708	637	635
629	603	632	612	710	677	676	737
728	847	903	1035	1114	1276	1470	1742
1996	2254	2486	2479	2385	2004	1610	1251
1008	805	699	623	645	589	626	571
560	578	573	605	581	563	665	613
587	607	613	639	665	700	752	806
876	989	1079	1272	1485	1667	1898	2068
2182	2155	2130	1915	1729	1346	1233	1157
1038	1013	999	1099	1241	1361	1547	1808
2032	2302	2592	2717	2668	2417	2089	1766
1412	1212	996	957	968	960	954	1057
1121	1168	1247	1298	1331	1417	1517	1582
1782	2043	2359	2765	3313	3998	4288	4734
4919	4823	4494	4076	3472	3082	2914	2915
3123	3271	3383	3430	3235	2805	2410	1827
1406	1182	953	916	837	883	943	1029
1073	1112	1222	1326	1484	1480	1610	1578
1563	1534	1368	1345	1214	1260	1088	1124
937	943	883	858	888	883	884	920
905	765	817	803	777	775	707	718
814	891	957	1003	932	982	864	812
814	777	708	777	731	730	817	861
908	987	1099	1147	1205	1458	1489	1570
1525	1648	1492	1369	1305	1226	1157	1060
977	897	849	767	757	727	648	628
635	654	636	642	657	603	671	667
670	644	662	693	668	665	629	653
686	653	640	732	680	649	746	838
795	758	835	866	822	853	876	888

878	853	870	968	918	982	991	938
1041	1074	1140	1115	1136	1115	1092	1038
1048	1061	969	1004	976	981	1002	1030
1119	1112	1185	1290	1345	1474	1527	1650
1786	2037	2289	2651	3092	3724	4499	5459
6963	8715	10813	13460	16078	18462	20394	21494
1606	20553	18126	15423	12164	9433	6816	5021
3691	2802	2397	1999	1758	1668	1545	1363
1341	1226	1147	1178	1184	1162	1128	1150
1222	1296	1261	1409	1450	1629	1824	2185
2584	3035	3762	4616	5918	7251	8859	10618
2701	14387	15953	17698	18579	18383	17284	15216
3063	10505	8254	6331	4604	3593	2788	2429
2083	2079	2063	2204	2378	2594	2837	3231
3489	3818	4033	4335	4405	4605	4778	4857
4983	5131	5207	4939	5014	4707	4593	4197
3857	3425	2996	2561	2208	1973	1664	1560
1531	1434	1525	1658	1803	1879	2155	2677
3284	3778	4636	5507	6580	8018	9495	10835
2861	14309	16474	18220	19813	20307	20425	19679
8103	15890	13253	10744	8068	6216	4459	3353
2617	2264	1921	1717	1424	1392	1272	1160
1182	1106	1130	1071	1178	1177	1249	1345
1389	1424	1574	1653	1765	1841	2082	2166
2319	2541	2678	2782	2869	3037	3062	3055
3025	2998	2982	2908	2836	3214	3514	3925
4344	4727	4889	4965	4740	4413	3976	3517
3103	2883	2589	2332	2070	1968	1762	1703
1547	1452	1370	1360	1332	1367	1364	1529
1667	1979	2117	2363	2799	3208	3762	4273
4939	5869	6991	8470	10058	11903	13782	15759
8410	20094	22230	22706	22364	21317	18647	16212
3071	10235	7735	5831	4646	3573	2879	2409
2234	2091	2047	2059	2099	2141	2172	2323
2395	2415	2638	2550	2539	2502	2293	2185
1954	1792	1725	1612	1668	1624	1647	1687
1694	1725	1639	1563	1402	1326	1318	1278
1195	1226	1306	1395	1443	1527	1611	1618
1618	1628	1591	1573	1529	1501	1474	1401
1582	1653	1809	2015	2195	2542	2821	3249
3609	4012	4461	5027	5482	5746	5853	5662
5093	4684	4069	3563	2984	2615	2114	1920
1813	1689	1790	1782	1794	1887	1836	1784
1639	1668	1641	1724	1827	1893	2040	2308
2706	3305	3858	4900	6111	7513	9014	10602
1719	13007	13706	13848	13204	12131	10865	9180
7669	6304	5378	4505	3953	3809	3897	4250
4875	5747	6853	8266	10200	12569	14732	17228
0550	23488	26544	28679	29985	30265	28766	25754
1810	17553	13666	10869	8117	6132	4793	3803
3290	2725	2501	2312	2242	2102	2003	1935
1988	2023	1828	1917	1884	1773	1684	1675
1506	1533	1392	1368	1255	1206	1153	1119
1094	1120	1186	1070	1080	1144	1098	1144
1180	1168	1116	1157	1118	1161	1139	1203

1254	1234	1351	1381	1470	1542	1577	1734
1954	2177	2663	3043	3822	4848	6057	7161
8995	10991	12958	14782	16833	18709	19811	20367
0150	18878	17043	14357	12019	10125	8406	6846
5662	5253	5254	5703	6428	7608	8794	10339
2445	14562	17065	19795	22485	24947	26522	26488
5783	23347	20882	18063	15104	12590	10349	8557
7433	6560	5818	5326	4702	4533	4245	3826
3611	3528	3221	3273	3211	3172	3192	3033
3153	3009	2840	2748	2659	2520	2673	2350
2303	2111	2088	1933	1792	1637	1569	1518
1359	1192	1265	1157	1125	1043	1050	1041
1006	1033	1046	979	983	1131	1131	1200
1341	1457	1752	1841	2064	2282	2441	2490
2358	2352	2354	2413	2361	2343	2343	2412
2455	2611	2785	2826	3114	3261	3518	3502
3314	3299	3078	2816	2616	2289	2012	1773
1641	1512	1405	1337	1403	1300	1352	1443
1521	1626	1786	2155	2465	2846	3389	3888
4432	4887	5067	4954	4741	4438	3973	3677
3421	2937	2666	2304	2129	1964	2012	1873
1977	1985	2115	2202	2332	2395	2726	2934
3266	3524	3793	4124	4390	4464	4536	4310
4097	3747	3425	3090	2777	2615	2377	2202
2090	2092	2040	2171	2400	2578	2797	3209
3551	4127	4757	5536	6162	7133	8013	9052
0404	11764	13429	14537	15738	15905	16295	15960
5813	15430	15145	14838	14753	13807	13174	12346
1201	9902	8915	7886	6862	5815	4992	4266
3812	3504	3340	3285	3353	3575	3513	3681
3821	3921	4042	4356	4732	5259	5956	6849
8000	9392	10990	12506	13454	13940	13780	13148
2213	10853	9659	8545	7238	6128	4986	4303
3739	3383	3028	3007	2744	2736	2537	2319
2259	2200	1988	1772	1724	1586	1466	1442
1388	1428	1494	1471	1491	1582	1633	1722
1843	1832	1843	1923	1847	1971	2054	2000
1981	1925	1796	1596	1628	1528	1494	1383
1338	1300	1250	1254	1299	1375	1424	1628
1712	1999	2334	2654	3184	3541	4171	4494
5050	5170	5257	5269	4865	4546	4159	3712
3270	2923	2552	2206	1942	1781	1571	1486
1405	1235	1264	1226	1153	1113	1167	1151
1043	1058	1017	1081	1111	1113	1149	1163
1231	1274	1295	1426	1468	1528	1590	1550
1702	1799	1934	2140	2224	2316	2576	2712
3012	3165	3513	3748	4265	4647	5090	5746
6243	6977	7846	8890	10126	11655	13050	14155
5225	15920	16001	15402	14487	13368	12123	10661
9244	7993	6844	5595	4745	4136	3787	3442
3411	3470	3636	3791	3770	3890	3865	3651
3361	3019	2895	2769	2567	2335	2147	1973
1768	1698	1542	1478	1380	1245	1260	1277
1191	1159	1079	1112	1116	1132	1125	1113
1139	1237	1288	1268	1290	1384	1465	1492

1541	1707	1659	1694	1815	1837	1814	1835
1716	1709	1598	1612	1483	1579	1524	1548
1579	1628	1684	1665	1595	1508	1477	1426
1278	1224	1191	1191	1058	1005	1009	972
962	1018	997	983	965	1010	994	1037
1072	1078	1039	1126	1097	1113	1140	1173
1257	1353	1460	1495	1547	1725	1978	2141
2418	2695	3054	3564	4268	5006	5691	6700
7180	7893	8400	8673	8714	8254	7844	7473
7055	6439	6119	5875	5769	5927	6227	6934
7422	8213	8826	9087	9456	9410	8952	8669
8185	7819	7187	6534	6078	5534	5202	4845
4640	4759	4868	4996	5339	5741	6174	6349
6617	6651	6631	6250	5864	5411	4960	4601
4074	3801	3512	3204	3228	3072	3130	3229
3405	3613	3634	3694	3708	3684	3488	3422
3150	2907	2745	2608	2350	2223	2038	1844
1609	1563	1454	1486	1371	1404	1401	1367
1441	1443	1492	1490	1551	1501	1458	1505
1574	1584	1574	1597	1500	1600	1649	1710
1684	1683	1672	1842	1808	1857	1951	2055
2099	2268	2332	2303	2471	2481	2517	2508
2451	2391	2369	2445	2467	2570	2611	2723
2933	3020	2997	2962	2991	2964	2926	2712
2595	2512	2492	2444	2293	2232	2183	2135
1984	1856	1716	1707	1658	1564	1551	1607
1519	1476	1461	1416	1372	1387	1353	1395
1342	1263	1225	1091	1127	1073	1089	1027
1066	944	1017	986	1025	1035	1003	1025
1014	1023	1094	1043	1105	1198	1308	1356
1396	1511	1674	1702	1925	2045	2201	2272
2599	2768	3125	3371	3678	4151	4376	4637
4757	4696	4687	4380	4147	3875	3545	3434
3128	2894	2537	2419	2283	2251	2115	2133
2008	1906	1909	1818	1807	1819	1625	1612
1584	1594	1634	1609	1605	1777	1901	2045
2189	2325	2798	3159	3415	3819	4292	4810
5190	5416	5712	6145	6106	6045	5715	5417
5016	4697	4462	4309	4175	4154	4118	4276
4685	4875	5187	5506	5666	5719	5786	5568
5612	5259	4869	4525	4039	3768	3389	3066
2743	2399	2233	1893	1776	1716	1612	1468
1347	1321	1255	1242	1175	1178	1077	1138
1121	1130	1109	1134	1200	1181	1228	1221
1298	1316	1374	1362	1399	1501	1517	1685
1791	1853	1965	2018	2178	2281	2313	2393
2372	2324	2369	2262	2254	2156	2167	2114
2057	2111	2038	1970	2037	1987	1990	1934
2127	2065	2136	2296	2205	2271	2413	2416
2362	2242	2221	2155	2091	1949	1856	1722
1578	1471	1361	1276	1227	1222	1149	1115
1101	1160	1099	1113	1046	1102	1129	1190
1222	1207	1282	1417	1394	1465	1604	1639
1705	1763	1789	1866	1952	2018	2014	2031
2203	2185	2095	2148	2173	1985	2022	1890

1882	1873	1860	1807	1772	1738	1800	1899
1873	2078	2281	2485	2753	2982	3110	3249
3296	3318	3149	2906	2775	2686	2483	2277
2168	2062	1780	1715	1571	1547	1410	1457
1379	1367	1340	1237	1245	1189	1200	1222
1324	1219	1200	1248	1250	1267	1301	1312
1277	1173	1241	1301	1238	1175	1215	1190
1198	1185	1270	1242	1245	1255	1281	1276
1445	1365	1374	1428	1389	1506	1502	1522
1527	1634	1527	1572	1564	1567	1551	1598
1569	1503	1525	1539	1497	1469	1469	1481
1491	1441	1496	1541	1512	1562	1586	1577
1634	1805	1707	1781	1823	1806	1910	1959
1985	1957	2081	2099	2327	2303	2453	2726
2987	2999	3427	3529	3840	4171	4397	4727
5031	4967	5340	5211	5324	5531	5584	5467
5687	5639	5708	5603	5116	4877	4761	4629
4479	4464	4414	4528	4605	4772	5054	5223
5394	5456	5525	5535	5549	5323	5131	4754
4481	4049	3783	3503	3204	2850	2617	2299
2055	1822	1756	1633	1434	1453	1316	1265
1306	1261	1224	1245	1261	1276	1290	1281
1310	1378	1426	1415	1601	1657	1807	1973
2131	2309	2520	2546	2569	2846	2886	3060
3258	3409	3582	3881	3974	4489	5018	5273
5913	6609	7091	7639	8307	8967	9293	9409
9369	9066	8644	7904	7480	7163	6672	6152
5789	5181	4631	4226	3862	3733	3498	3401
3373	3425	3490	3637	3672	3678	3600	3470
3296	3202	2989	2888	2744	2508	2393	2222
2155	2018	1997	1966	1926	1976	1916	2022
1907	2000	2020	2132	2214	2194	2189	2233
2277	2285	2368	2400	2320	2534	2658	2790
2865	3013	3177	3311	3573	3931	4147	4316
4340	4405	4201	4113	3892	3573	3577	3280
3094	2859	2644	2401	2414	2232	2148	1878
1781	1651	1674	1556	1583	1535	1507	1457
1435	1459	1464	1519	1492	1530	1540	1598
1586	1635	1788	1800	1857	1997	2069	2235
2405	2574	2714	3133	3567	4110	5093	5885
6974	7972	8571	9294	9772	9936	9759	9316
8977	8415	7955	7360	7268	6530	6152	5398
4809	4071	3682	3307	2796	2610	2352	2156
2106	1910	1767	1811	1786	1658	1685	1687
1640	1658	1787	1876	1957	1938	2099	2234
2344	2441	2574	2713	2736	2864	2894	3073
3121	3157	3333	3251	3346	3350	3360	3440
3389	3302	3382	3340	3324	3372	3350	3309
3390	3320	3515	3624	3740	3885	3944	3937
3944	3716	3707	3573	3395	3476	3155	2981
2865	2961	2855	2796	2828	2911	3179	3434
3750	4288	4751	5187	5592	5803	5916	5709
5659	5285	5225	5040	4822	4518	4303	3916
3665	3279	3048	2812	2561	2486	2277	2212
2255	2122	2141	2128	2183	2220	2288	2297

2342	2403	2469	2459	2459	2482	2552	2493
2682	2628	2616	2860	3046	3389	3683	4217
4932	5681	6830	8067	9113	10247	11011	11423
1530	11190	10711	10143	9857	9619	9410	8907
8243	7693	6961	6207	5701	4960	4711	4208
3870	3816	3716	3552	3468	3490	3459	3665
3786	3879	4016	4083	4162	4323	4258	4185
4212	4304	4465	4386	4527	4825	4964	4952
5116	5214	5463	5471	5796	5759	6057	6045
6081	5868	5612	5140	4806	4424	4203	3971
3716	3239	3203	2806	2572	2246	2137	1805
1810	1712	1644	1563	1644	1526	1480	1599
1518	1526	1698	1713	1763	1785	1806	1791
1765	1678	1690	1790	1621	1758	1704	1703
1660	1600	1621	1616	1539	1542	1561	1582
1734	1669	1735	1829	1840	1940	2051	2226
2247	2361	2470	2690	2886	3023	3122	3348
3517	3490	3572	3753	3744	3496	3575	3358
3339	3291	3138	3031	3004	2794	2648	2609
2517	2388	2436	2426	2455	2468	2483	2462
2536	2726	2826	2926	2884	3127	3015	3144
3258	3311	3351	3445	3575	3743	3914	3948
3898	3961	3962	4029	3737	3636	3716	3429
3318	3273	3051	2979	3022	2932	2895	2890
2871	2988	2999	3144	3392	3719	3938	4369
4811	5375	5840	6524	7130	7800	8568	9505
0262	11095	11824	12384	12710	12780	12530	12183
1479	11192	10756	10580	10124	9863	9309	8921
8425	7937	7061	6225	5747	5321	4962	4376
4062	3789	3530	3320	3071	2866	2748	2429
2323	2177	2068	1957	1827	1689	1672	1643
1556	1513	1412	1474	1440	1396	1345	1424
1297	1310	1317	1398	1290	1329	1367	1374
1408	1391	1362	1325	1307	1349	1411	1339
1316	1404	1299	1382	1379	1387	1369	1397
1399	1379	1389	1346	1341	1380	1252	1277
1289	1275	1242	1182	1207	1244	1180	1187
1238	1176	1190	1167	1163	1174	1223	1258
1260	1298	1248	1305	1272	1416	1304	1375
1499	1530	1553	1683	1650	1681	1832	1874
1863	1836	1961	1826	1907	1814	1893	1930
1842	1917	1803	1859	1820	1898	1840	1822
1804	1740	1744	1700	1798	1696	1826	1816
1807	1748	1828	1770	1783	1717	1713	1615
1555	1504	1478	1394	1413	1295	1317	1314
1221	1259	1190	1195	1105	1200	1185	1119
1195	1107	1146	1206	1197	1179	1317	1365
1290	1343	1420	1382	1416	1437	1401	1489
1494	1537	1505	1441	1578	1547	1621	1692
1744	1909	1915	1987	1884	2196	2314	2558
2747	2870	3186	3368	3521	3458	3607	3610
3611	3512	3641	3692	3683	3812	4018	4112
4121	4359	4405	4605	4638	4642	4825	4853
4848	4653	4507	4400	4083	3825	3556	3460
3426	3200	3122	3083	2924	2724	2716	2530

2507	2326	2300	2210	2140	2069	1996	1915
1926	1944	1955	1927	1830	1883	1773	1852
1758	1721	1736	1608	1666	1670	1642	1618
1644	1612	1629	1659	1655	1557	1661	1592
1654	1608	1567	1598	1601	1677	1702	1827
1940	1945	2030	2233	2267	2487	2530	2821
3024	3317	3587	3834	4029	4440	4679	4879
5093	5197	5293	5431	5562	5625	5864	5749
5952	5868	5825	5774	5631	5512	5279	5049
4907	4630	4563	4290	4033	3844	3543	3441
3167	3022	2788	2770	2577	2508	2443	2407
2441	2394	2398	2445	2426	2538	2644	2658
2675	2779	2761	2810	2854	2723	2753	2638
2609	2488	2475	2461	2310	2318	2198	2303
2275	2104	2094	2209	2159	2189	2165	2122
2192	2301	2472	2634	2910	3059	3367	3584
3709	4034	4346	4486	4672	4781	4897	5111
5080	4952	4822	4727	4636	4381	4146	4003
3899	3681	3393	3225	0			

Chromium-fluor-pargasite (9.00, 0.02, 72.82)

470	450	439	441	461	446	450	446
475	460	462	487	468	497	515	463
460	505	503	497	502	520	530	554
536	534	592	587	630	641	679	706
720	754	798	846	871	986	1082	1154
1255	1438	1587	1852	2085	2324	2671	2536
2398	2194	1721	1268	970	761	678	632
632	586	642	655	639	674	708	681
708	702	825	885	909	989	1017	1151
1328	1451	1652	1859	2212	2554	2943	3461
3765	3813	3458	2947	2375	1511	1058	757
661	585	568	513	533	505	525	491
500	492	455	469	449	465	468	468
449	450	447	426	494	376	463	427
438	467	435	418	445	455	449	450
472	451	424	413	433	424	466	436
468	473	434	467	429	471	409	428
471	456	437	432	430	457	435	442
473	442	438	426	482	395	438	483
417	444	427	425	437	441	486	433
420	408	441	416	502	453	458	413
473	437	414	440	457	444	454	447
476	459	437	427	450	440	469	426
445	459	416	460	440	440	406	459
436	460	460	443	438	438	482	424
444	437	434	417	443	450	433	440
494	481	464	459	458	498	469	475
438	460	453	491	403	435	473	458
474	443	452	422	455	463	476	512
504	486	556	510	514	597	553	559
565	593	559	552	560	529	501	476
492	555	484	476	454	458	485	429
451	465	439	471	461	528	435	458
452	461	484	438	447	437	426	430

433	405	456	469	414	422	415	450
438	460	471	476	422	492	478	434
442	448	441	494	435	472	483	454
407	449	418	460	492	489	448	491
489	459	510	520	454	443	449	467
474	472	474	427	464	483	495	470
449	469	476	454	498	455	458	439
493	464	474	475	501	466	491	459
468	479	496	489	495	467	461	470
494	467	454	463	476	504	477	515
426	466	503	443	466	481	463	484
458	465	454	481	511	483	477	471
474	478	477	468	467	493	468	494
458	488	476	482	503	462	440	498
452	474	504	514	482	499	470	450
480	440	465	512	448	482	483	493
518	454	482	456	470	473	514	498
540	510	440	500	507	484	513	529
551	590	571	622	606	639	753	780
779	848	1003	1098	1059	1117	1100	962
805	765	689	656	607	592	546	549
627	589	588	586	639	648	693	736
823	880	883	1015	1148	1283	1520	1763
2183	2570	3195	3883	4034	4078	3983	3532
2844	2208	1774	1523	1362	1410	1446	1561
1813	2147	2446	2860	3258	3716	4113	4357
4536	4306	4191	3577	3085	2625	2074	1805
1508	1337	1221	1040	935	881	867	814
772	767	767	727	732	787	708	688
674	637	647	615	615	604	587	561
608	526	544	538	553	610	546	540
593	545	625	608	632	670	671	699
774	776	794	942	1011	1205	1362	1617
1876	2393	2843	3315	3940	4223	4290	4196
3589	2836	2177	1638	1152	1023	902	863
901	881	862	854	771	725	663	648
565	562	546	584	544	504	522	524
504	506	541	525	504	508	504	541
505	563	493	527	454	545	509	526
497	496	548	501	565	537	510	526
548	538	501	531	524	514	527	576
571	592	555	571	588	619	645	702
754	834	907	962	951	961	887	828
790	702	635	592	595	567	525	499
544	516	546	534	554	523	546	498
560	542	505	515	555	543	573	575
603	563	599	624	801	695	729	803
874	946	1109	1289	1518	1708	1781	1808
1802	1670	1521	1273	1046	946	841	858
851	911	971	1133	1244	1384	1583	1799
1795	1645	1530	1374	1096	897	760	697
644	683	654	661	691	676	726	783
816	871	962	987	1060	1247	1416	1588
1861	2145	2515	2769	3161	3120	2958	2555
2217	1736	1364	1120	907	762	709	626

601	602	627	589	573	579	591	607
575	610	592	587	639	600	657	653
719	747	851	937	1074	1171	1298	1433
1501	1694	1706	1681	1729	1642	1613	1560
1603	1523	1621	1774	1835	1823	1722	1596
1450	1215	994	883	776	769	770	749
689	745	729	700	679	741	796	771
721	844	938	941	1053	1168	1134	1277
1298	1211	1143	1118	1110	1079	962	889
841	801	727	687	691	628	661	608
573	608	560	536	543	589	600	571
547	541	550	539	544	571	604	564
570	589	529	577	563	603	598	613
570	551	582	588	611	589	616	596
634	617	624	670	621	646	666	671
688	740	757	841	807	840	811	804
757	753	788	780	710	711	747	736
705	722	780	858	845	931	887	980
964	1016	1057	1002	1197	1240	1450	1599
1857	2225	2731	3366	4291	5425	7140	9440
2115	15329	17597	19363	18917	17395	14719	11936
9245	6370	4587	3350	2452	2078	1881	1695
1592	1389	1342	1348	1206	1078	1031	995
932	908	901	897	858	922	907	934
970	1080	1126	1231	1419	1651	1960	2401
2983	3932	5037	6576	8317	10287	12023	13131
3445	12577	10685	8423	6355	4797	3436	2653
2191	2132	2034	2126	2279	2462	2656	2796
2915	3108	3445	3663	3690	3915	4106	4156
4251	4154	4029	3752	3657	3456	3201	3221
3131	3197	3171	3107	3175	3062	2787	2797
2431	2245	2082	2105	1995	2005	2106	2117
2167	2249	2188	2276	2487	2665	3092	3590
4299	5097	6477	8276	10110	12718	15223	17295
8736	19124	18026	16153	13537	10806	8848	6711
4864	3589	2511	2015	1686	1473	1310	1186
1123	1013	1016	873	921	843	870	835
813	786	775	785	851	828	766	835
813	837	869	990	961	1164	1249	1468
1668	1802	2023	2133	2270	2192	2035	1811
1783	1632	1599	1502	1527	1581	1621	1795
1927	2078	2437	2812	3242	3962	4639	5073
5827	5827	5722	5470	4929	4193	3363	2787
2245	1925	1564	1583	1505	1485	1535	1715
1912	2125	2545	3004	3625	4240	5127	6526
8350	10014	12107	14295	16348	17950	18848	19001
7905	15828	13432	10840	8525	6515	4829	3628
2702	2276	2101	1902	1893	1865	1986	2158
2238	2394	2699	2700	2783	2619	2424	2218
1991	1785	1478	1418	1149	1091	1045	924
894	891	854	870	880	930	902	911
922	941	957	1002	1023	1084	1124	1181
1161	1189	1132	1141	1160	1099	1156	1144
1116	1149	1132	1229	1282	1304	1357	1605
1737	2064	2543	2904	3587	4264	4906	5389

5609	5606	5207	4568	3983	3232	2622	2100
1632	1342	1189	1080	1045	1026	1032	1018
990	928	955	1006	970	1025	1076	1121
1217	1227	1398	1567	1858	2184	2702	3300
4248	5409	7013	9491	10052	11279	11820	11722
1345	10343	8939	7726	6265	4984	3947	3251
2758	2589	2667	3043	3423	4059	4994	6478
8481	10854	14058	17859	21400	25167	27051	27848
6168	23194	19731	16618	12938	9417	6276	4415
3285	2418	2219	1912	1766	1506	1479	1345
1288	1322	1239	1217	1229	1225	1189	1212
1200	1133	1171	1177	1183	1099	1059	1095
957	969	965	1025	1058	1058	1136	1166
1164	1131	1155	1091	1073	1035	972	924
936	923	906	983	1006	990	1020	950
1062	1151	1240	1314	1486	1697	2051	2503
3215	4040	5241	6836	9100	11434	14076	16075
6696	16736	15658	14406	12690	10633	9033	6991
5204	3887	3075	2581	2564	2629	2781	3007
3434	4005	4665	5412	6226	7058	7959	9033
0551	12214	14510	16986	19826	21660	21991	22112
0167	18076	15503	13339	11074	9022	7304	6219
5173	4803	4370	4021	3958	4040	4035	4360
4713	5225	5902	6461	7219	7849	8533	9274
9955	10568	11276	11682	11922	11644	11244	10482
9568	8541	7677	6724	5550	4851	4138	3535
2986	2725	2306	2084	1920	1684	1620	1466
1419	1351	1284	1215	1148	1196	1143	1212
1190	1207	1346	1358	1370	1426	1586	1555
1593	1679	1611	1664	1677	1695	1741	1580
1622	1469	1412	1342	1268	1109	1060	1053
959	987	953	973	851	905	886	890
987	933	1013	1135	1180	1336	1470	1726
1949	2299	2597	2913	3332	3456	3257	3129
2950	2655	2634	2420	2189	2137	2040	1898
1903	1817	1727	1747	1705	1802	1875	1995
2215	2395	2697	2984	3274	3614	3658	3644
3377	3350	2917	2529	2299	1992	1707	1472
1331	1153	1135	1029	1054	1108	1024	1109
1164	1252	1295	1359	1550	1822	2076	2522
3399	4296	5255	6821	8396	9751	11145	12298
2430	11828	11315	10351	9959	9715	9416	8980
9026	8644	8305	7719	7181	6266	5696	4846
4296	3517	2826	2374	1876	1685	1669	1588
1569	1680	1848	1907	2181	2527	2860	3350
4104	5008	5935	6898	7700	8617	9039	9390
8940	8794	9024	9061	8817	8427	7665	6691
6002	5236	4541	3869	3180	2637	2255	1961
1565	1460	1280	1223	1157	1101	1112	1040
1004	954	930	946	938	945	947	958
984	994	1078	1140	1278	1460	1482	1598
1746	1722	1598	1483	1464	1370	1247	1217
1110	946	939	920	879	905	883	939
963	1026	1102	1226	1284	1527	1728	1913
2172	2461	2878	3306	3555	3976	4203	4234

4198	4001	3703	3339	2989	2699	2418	2208
1925	1765	1660	1566	1493	1450	1368	1319
1242	1193	1042	1004	958	917	927	907
888	900	896	918	943	973	1038	1083
1166	1321	1449	1516	1663	1750	1899	1765
1941	1855	1807	1803	1856	1866	2079	2309
2493	2992	3456	4244	5452	6593	8327	10097
1826	13453	14202	14699	14254	13225	12095	11106
0198	8664	7302	5982	4974	4058	3395	2873
2595	2337	2299	2289	2308	2491	2578	2900
3277	3403	3523	3421	3395	3295	3073	3048
2819	2458	2223	1980	1815	1709	1452	1327
1286	1185	1091	1153	1121	1094	1113	1156
1155	1232	1238	1312	1305	1443	1584	1529
1604	1589	1550	1494	1453	1408	1353	1313
1240	1161	1223	1201	1188	1145	1290	1352
1437	1439	1661	1868	2094	2452	2661	3190
3686	4243	4830	5419	5959	6420	6771	6732
6775	6542	6347	5860	5450	5070	4581	4159
3701	3340	2921	2535	2298	2096	1893	1807
1646	1570	1545	1430	1411	1305	1298	1328
1274	1279	1302	1448	1490	1688	1906	2291
2733	3286	4171	5213	5939	6840	7302	7326
7206	6855	6376	6072	5542	5016	4704	4184
3663	3249	3163	3283	3541	4163	4668	5305
5873	6442	6652	6563	6602	6178	5805	5735
5460	5332	5132	5026	5112	5359	5710	6288
6667	6738	6596	6208	5766	5354	4765	4281
3916	3442	3100	2680	2471	2476	2579	2710
2956	3149	3089	3017	3022	2835	2673	2511
2460	2201	2156	1850	1618	1532	1412	1284
1258	1102	1067	1047	1038	975	1003	1020
1031	1065	1092	1173	1240	1348	1472	1519
1562	1548	1636	1544	1555	1519	1463	1452
1380	1332	1420	1408	1455	1611	1823	2052
2234	2428	2553	2608	2679	2532	2358	2264
2190	2099	2087	1907	1830	1806	1740	1758
1945	1967	2137	2311	2457	2557	2663	2733
2712	2741	2750	2752	2780	2911	2829	2702
2583	2586	2355	2196	2168	1949	1836	1761
1678	1558	1524	1509	1461	1477	1415	1526
1405	1325	1246	1142	1171	1038	1021	1006
918	967	909	857	880	935	943	948
995	1036	1097	1035	1133	1186	1203	1236
1178	1208	1199	1253	1268	1296	1341	1385
1452	1630	1835	2079	2342	2710	3073	3580
3748	3755	3913	3712	3381	3093	2990	2708
2565	2271	1995	1840	1796	1696	1709	1777
1805	1826	1850	1796	1674	1642	1550	1503
1431	1316	1248	1208	1206	1183	1223	1255
1295	1457	1653	1808	2112	2564	2982	3490
3957	4508	4683	4774	4838	4742	4545	4296
4095	3811	3426	3074	2663	2492	2270	2137
2121	2195	2280	2522	3028	3315	3910	4152
4290	4370	4066	3858	3585	3288	3145	2953

2653	2511	2177	1929	1768	1598	1610	1613
1594	1667	1672	1619	1595	1568	1494	1533
1362	1352	1251	1251	1227	1173	1113	1094
1121	1045	1008	1063	1062	1030	1072	1136
1199	1226	1348	1504	1667	1791	1828	1924
1948	1900	1794	1767	1620	1587	1551	1486
1408	1389	1301	1265	1284	1307	1380	1530
1616	1765	1850	1898	1986	2013	1909	1928
1817	1739	1752	1683	1615	1461	1456	1329
1185	1159	1126	1039	1000	944	969	906
909	879	871	850	837	816	857	862
886	959	947	1038	1030	1046	1117	1214
1290	1303	1323	1317	1312	1283	1354	1363
1419	1401	1416	1433	1376	1410	1351	1357
1297	1138	1158	1169	1107	1082	1052	995
1024	1073	1032	1070	1243	1313	1449	1656
1893	2157	2309	2450	2581	2550	2477	2421
2283	2341	2157	2198	2051	1991	1847	1652
1513	1407	1341	1327	1219	1185	1092	1090
1012	968	932	892	881	866	792	793
793	837	813	832	744	812	782	844
791	780	808	802	800	853	921	906
963	915	997	947	1038	1039	1091	1119
1197	1212	1247	1317	1291	1299	1286	1325
1388	1379	1271	1246	1280	1142	1144	1176
1202	1099	1051	1042	1052	1057	1075	1098
1131	1172	1239	1271	1346	1338	1311	1396
1447	1454	1653	1713	1739	1894	2057	2116
2167	2199	2171	2181	2157	2317	2352	2464
2615	2673	2874	3181	3578	4016	4538	4842
5125	5421	5413	5392	5339	5281	5009	4690
4278	3979	3772	3425	3234	3085	2914	2820
2727	2936	3143	3356	3701	3915	4132	4175
4239	4212	3857	3829	3623	3325	3141	3073
2817	2464	2379	2093	1896	1649	1588	1552
1450	1418	1344	1329	1321	1215	1287	1238
1183	1226	1174	1183	1142	1145	1196	1251
1236	1264	1361	1418	1517	1594	1631	1800
1962	2212	2494	2983	3464	4014	4593	5271
5929	6739	7584	8378	8963	9353	9143	8887
8271	7275	6789	6307	5780	5466	4959	4341
3835	3355	2818	2652	2494	2527	2755	3047
3333	3485	3647	3636	3557	3504	3398	3311
3266	3135	3027	2837	2792	2536	2358	2257
2149	2051	2061	2010	1897	1930	1950	1904
1962	1955	1826	1790	1818	1724	1842	1811
1887	1944	1961	2195	2393	2663	3036	3278
3693	4114	4344	4674	4694	4609	4386	4082
3801	3672	3401	3305	3110	2846	2662	2480
2323	2113	2099	2193	2124	2310	2436	2689
2998	3162	3362	3626	4098	4203	4288	4266
4347	4214	4187	3990	3923	3815	3613	3600
3289	3204	2985	2741	2598	2494	2237	2267
2270	2127	2216	2258	2442	2446	2778	2960
3263	3658	3899	4456	4944	5603	6305	6965

7738	8268	8578	8315	7917	7128	6381	6057
5681	5342	5114	4558	4086	3380	2948	2417
2055	1785	1580	1429	1343	1251	1282	1206
1191	1128	1127	1081	1125	1020	1100	1057
1088	1023	1100	1137	1180	1177	1249	1313
1391	1502	1501	1626	1609	1741	1786	1964
1951	2029	2040	2004	2015	1960	2002	2041
2089	2180	2317	2589	2739	2922	3032	3144
3112	3131	3039	3006	2694	2573	2406	2373
2395	2269	2257	2050	2014	1943	1829	1794
1835	1954	2075	2289	2542	3074	3481	2852
4296	4578	4831	4927	4576	4370	3960	3857
3825	3627	3461	3180	3015	2672	2456	2304
2119	2041	2006	1993	1986	2021	1962	2060
1990	1976	1912	1965	1832	1906	1836	1874
1940	1919	1907	1913	1943	1901	2002	2006
2044	2159	2417	2622	3074	3578	4429	5269
6388	7788	8921	9754	10082	10460	9865	9167
8014	7638	7206	7175	6853	6515	5966	5437
4781	4144	3615	3262	3078	2944	3043	2947
3065	3153	3155	3276	3285	3420	3445	3539
3574	3820	3792	4276	4573	4966	5432	5801
5866	5825	5771	5439	5436	5025	4871	4751
4409	4064	3859	3595	3316	3082	2599	2330
2121	1912	1733	1555	1427	1441	1361	1244
1269	1217	1235	1210	1224	1263	1275	1226
1228	1201	1201	1287	1307	1344	1349	1461
1494	1485	1505	1491	1459	1458	1437	1453
1463	1372	1406	1439	1467	1503	1514	1531
1553	1630	1680	1688	1868	1894	2160	2324
2685	2922	3237	3821	4501	5079	5747	6386
7035	7310	7848	7917	8062	8178	8021	7775
7653	7308	6758	6585	6110	5863	5373	5016
4507	4142	3857	3477	3291	2948	2752	2595
2463	2372	2383	2391	2486	2647	2757	2954
3000	3095	3216	3431	3599	3699	3883	3731
3847	3800	3640	3567	3354	3001	2839	2754
2599	2390	2314	2165	2091	2021	1980	1917
1885	1926	1994	2017	2090	2140	2362	2453
2628	2927	3475	3913	4619	5343	6363	7366
8430	9538	10538	11031	11191	10751	10215	9573
8838	8075	7909	7764	7501	7142	6849	6208
5527	4826	4169	3796	3285	3059	2793	2514
2251	2224	2089	1853	1743	1704	1623	1471
1541	1436	1416	1274	1275	1221	1263	1186
1241	1292	1230	1308	1322	1357	1453	1440
1471	1584	1612	1693	1795	1735	1781	1776
1697	1689	1716	1679	1757	1579	1620	1562
1433	1455	1384	1365	1297	1296	1281	1265
1293	1301	1366	1391	1447	1499	1584	1596
1616	1644	1697	1725	1799	1824	1873	1921
1906	1928	1869	2036	1891	2008	1850	1874
1830	1831	1728	1813	1699	1574	1568	1552
1563	1559	1623	1565	1544	1530	1492	1456
1485	1396	1449	1502	1464	1522	1429	1379

1389	1457	1330	1341	1324	1312	1305	1291
1203	1159	1061	1151	1132	1066	1071	1074
1072	1056	982	1032	1061	1018	997	966
984	944	1014	976	984	946	984	976
873	913	913	850	903	861	903	861
927	978	941	933	966	922	986	1021
1053	1077	1073	1034	1078	999	1057	1053
1068	1084	1066	1099	1030	1135	1160	1172
1137	1203	1237	1251	1260	1347	1445	1385
1495	1506	1658	1743	1855	1972	2222	2524
2570	2816	3036	3028	3124	3204	3264	3257
3482	3808	3894	4416	4536	4657	4751	4584
4423	4210	3864	3485	3397	3008	3132	2919
2840	2616	2569	2349	2265	1996	2017	1900
1887	1708	1717	1663	1633	1583	1591	1479
1599	1666	1594	1656	1586	1504	1471	1477
1422	1351	1255	1356	1333	1221	1323	1294
1294	1194	1134	1151	1256	1213	1176	1150
1123	1132	1146	1113	1097	1157	1208	1250
1318	1431	1499	1716	1743	2036	2310	2466
2736	3132	3311	3475	3532	3719	3726	3834
3637	3658	3853	4056	4220	4384	4441	4426
4226	4349	4265	4345	4483	4529	4416	4250
3978	3743	3545	3404	3166	2864	2874	2703
2721	2640	2453	2509	2312	2180	2096	2027
2026	1928	1982	1945	2007	2132	2101	2230
2254	2331	2521	2535	2502	2527	2365	2199
2227	2019	2020	1999	1913	1864	1793	1755
1650	1558	1419	1537	1416	1360	1266	1349
1293	1363	1371	1440	1457	1627	1705	1843
2083	2336	2594	2952	3244	3712	3858	4157
4233	4402	4358	3983	3812	3669	3579	3600
3521	3319	3276	3096	2879	2798	2415	2239
2062	1776	1678	1582	1408	1365	1233	1219
1143	1142	1073	980	997	1042	943	991

Gallium-fluor-pargasite (8.00, 0.02, 72.38)

500	466	485	487	445	467	478	474
465	448	467	449	527	455	494	465
470	475	465	477	426	489	485	455
498	491	473	472	468	478	461	521
473	469	461	458	546	483	476	489
530	475	506	475	488	508	522	542
536	496	497	525	498	554	510	525
574	511	540	541	564	526	551	556
623	583	560	602	611	579	586	644
659	684	664	740	722	799	772	816
814	857	913	964	1010	1049	1124	1081
1275	1385	1352	1537	1635	1762	2041	2206
2624	2976	3376	3673	3821	3788	3317	2512
1861	1503	1241	1064	972	956	967	905
938	967	965	1048	1071	1127	1118	1255
1316	1467	1564	1602	1826	2006	2278	2559
2983	3456	4001	4724	5210	5558	5307	4465
3345	2379	1677	1188	985	862	730	700

659	597	619	613	623	600	589	591
595	539	584	533	567	522	579	539
576	556	530	567	516	537	525	494
530	549	574	538	534	550	535	506
570	530	566	543	559	544	503	539
563	552	534	533	526	566	555	581
602	535	553	526	552	540	539	550
535	517	508	568	492	580	555	540
583	545	558	528	573	564	526	550
564	538	538	546	559	542	545	528
583	569	595	530	567	582	542	582
544	548	560	536	507	552	568	524
572	555	549	560	574	568	554	569
545	554	578	551	587	570	560	554
588	548	554	541	547	607	570	569
587	553	550	593	573	571	612	541
545	582	620	584	593	619	615	616
577	610	629	599	696	684	635	691
638	727	701	616	590	618	610	567
630	562	583	588	603	610	535	595
586	593	578	565	558	618	588	615
563	546	624	647	608	592	582	588
560	568	571	635	611	646	569	542
600	570	591	625	635	574	563	596
624	650	620	608	587	656	603	636
624	571	630	622	617	591	623	563
612	612	610	599	584	627	659	586
602	602	605	605	600	605	626	603
633	622	612	642	616	571	614	595
605	619	559	662	626	626	657	588
604	569	636	626	630	638	603	614
616	597	632	663	625	657	624	589
605	635	611	590	613	643	646	603
628	641	644	603	629	654	613	604
674	630	631	638	603	607	625	684
659	674	636	647	625	645	639	627
631	635	630	621	666	619	647	622
673	650	639	657	639	663	590	676
654	672	665	616	661	625	660	668
669	689	635	692	693	721	652	693
698	720	708	731	785	787	744	770
775	853	856	932	956	992	1124	1162
1230	1265	1304	1232	1135	953	974	850
809	883	912	856	841	904	875	943
1023	1024	1149	1165	1347	1518	1575	1883
2182	2628	3121	3793	4789	5725	6779	7114
7158	6504	5469	4286	3183	2184	1649	1426
1257	1153	1032	1003	913	902	852	807
794	835	804	797	762	798	709	842
806	842	881	788	829	844	829	851
871	852	877	896	877	886	926	982
934	886	927	834	833	913	787	732
752	757	766	732	755	751	759	775
731	742	770	748	747	767	809	831
853	872	943	966	992	1023	1094	1247

1442	1560	1814	2061	2537	2864	3485	4118
5136	6271	7198	7503	7148	6225	4892	3785
2661	2116	1646	1392	1395	1477	1435	1294
1235	1121	1027	894	808	794	806	820
765	815	798	721	840	783	796	759
757	779	789	762	706	789	766	803
771	782	804	775	721	789	808	740
748	760	789	801	825	797	792	811
820	822	804	845	874	877	947	959
953	1011	1056	1161	1321	1459	1563	1702
1620	1566	1484	1375	1158	1090	953	906
859	872	865	860	862	775	815	789
802	756	750	846	775	765	803	877
835	824	842	936	841	895	974	1058
1089	1130	1312	1461	1632	1787	2034	2339
2355	2401	2350	2086	1721	1557	1326	1215
1201	1161	1212	1155	1367	1485	1689	1911
2200	2608	2953	3163	3148	2850	2618	2224
1748	1493	1362	1174	1205	1155	1159	1207
1254	1344	1382	1484	1464	1615	1652	1681
1797	1849	2149	2325	2604	3022	3492	3672
3845	3835	3438	2876	2494	2015	1628	1314
1285	1122	997	1048	1047	962	986	898
967	964	914	930	895	1006	1027	1017
1162	1157	1324	1442	1576	1738	1898	1961
1910	2002	2006	1825	1682	1484	1358	1239
1188	1099	1129	946	1025	1002	931	938
922	910	900	895	919	914	949	959
950	980	1003	1004	1014	984	939	929
1029	966	1012	989	1097	1176	1220	1333
1422	1488	1623	1672	1768	1764	1716	1701
1586	1552	1391	1329	1208	1148	1081	1090
990	1002	991	1002	905	954	934	874
887	938	918	939	901	926	964	932
945	951	923	963	933	942	977	929
895	978	958	1007	943	1012	967	1017
960	970	1046	1043	1032	1025	1007	1075
1054	1108	1171	1208	1217	1293	1299	1387
1380	1367	1357	1360	1285	1366	1285	1317
1257	1274	1265	1341	1304	1352	1466	1530
1517	1585	1651	1694	1803	1874	2004	2168
2237	2514	2704	3113	3541	4197	5233	6279
7929	10134	12947	16925	20463	24116	27011	28472
7212	24570	20705	16784	12641	9459	6859	4900
3682	3019	2532	2366	2124	1960	1917	1837
1743	1624	1561	1534	1478	1521	1470	1532
1504	1551	1628	1606	1648	1738	1864	2196
2303	2710	3148	3992	5065	6233	8042	10467
3361	16680	19602	21812	21657	20234	17288	13969
0957	8380	6029	4442	3496	2907	2577	2390
2277	2263	2427	2696	2852	3247	3505	3989
4164	4370	4657	4701	4751	4875	4816	4898
4740	4700	4765	4713	4469	4345	4183	3668
3368	3003	2694	2573	2444	2446	2330	2284
2301	2351	2456	2651	2684	3037	3424	3955

4533	5233	6197	7636	9468	11212	14272	17759
1290	25478	28198	29224	28757	26257	22429	18705
5270	11766	8789	6286	4336	3499	2809	2418
2196	2026	1858	1767	1590	1516	1465	1383
1413	1429	1344	1373	1248	1349	1336	1355
1357	1405	1484	1529	1578	1678	1947	2222
2443	2801	3141	3373	3560	3537	3284	3193
2817	2570	2271	1986	1797	1702	1663	1667
1678	1622	1619	1610	1691	1614	1578	1608
1596	1610	1708	1675	1574	1600	1629	1574
1552	1572	1623	1564	1620	1667	1721	1834
1962	2176	2304	2539	2789	3007	3203	3721
4377	5306	6680	8445	10736	13487	16791	20123
2932	25937	26445	26208	24069	20844	17017	13816
0565	7896	5924	4697	4103	3640	3497	3454
3456	3725	3811	3824	3886	3963	3888	3706
3482	3268	3081	2698	2417	2227	2077	1901
1853	1732	1671	1660	1533	1576	1561	1532
1559	1485	1585	1581	1628	1633	1635	1741
1769	1816	1939	2008	1953	1865	1900	1795
1755	1675	1764	1729	1764	1807	1807	2014
2061	2294	2540	2929	3315	3856	4625	5467
6522	7501	8636	8965	8820	8349	7531	6541
5648	4673	3838	3109	2658	2316	2175	2009
1821	1900	1877	1873	1863	1874	1974	1945
2150	2236	2360	2558	2699	3113	3547	4329
5109	6312	7989	9795	11840	14166	15906	17234
7451	17348	16158	14773	12992	10774	8794	7206
5852	4946	4180	3862	3789	3978	4086	4527
5090	6221	7296	9147	11569	14644	18423	23189
8521	33229	37395	39047	38751	36637	32030	27074
1479	16915	12905	9674	7495	6014	4893	4287
3830	3518	3146	2955	2865	2783	2690	2624
2587	2547	2322	2299	2302	2242	2099	1978
1968	1823	1734	1699	1646	1674	1586	1524
1552	1514	1518	1596	1488	1525	1528	1497
1597	1506	1540	1477	1503	1501	1523	1543
1538	1641	1718	1788	1795	1826	1959	2057
2505	2620	3125	3687	4740	5909	7517	10041
2828	16761	20435	23746	26304	27346	27162	25643
2916	19491	16470	13164	10361	7670	6149	5002
4465	4551	5115	6128	7216	8814	10763	13404
5961	19264	22893	26966	30643	33049	33872	32765
0477	27443	23059	18843	14680	11120	8593	6686
5226	4354	3926	3434	3277	3200	3118	3098
3069	3061	3196	3165	3009	2894	2801	2668
2462	2346	2251	2158	1988	1771	1820	1750
1685	1636	1574	1571	1637	1674	1712	1693
1801	1823	1900	1970	2195	2423	2581	3026
3391	3853	4369	4996	5820	6380	6981	7012
7150	6858	6662	6163	5820	5365	4906	4521
4124	3831	3538	3285	3242	3136	2971	2695
2561	2464	2224	2104	1958	1787	1791	1666
1557	1526	1536	1467	1485	1429	1563	1458
1540	1523	1538	1524	1530	1605	1677	1745

1969	1994	2287	2715	3111	3539	4234	4569
4705	4728	4358	4117	3750	3476	3041	2673
2463	2168	1977	1951	1896	1957	1937	2006
2118	2323	2545	2791	3049	3464	3867	4317
4870	5144	5174	5117	4814	4433	3863	3630
3190	2782	2519	2255	2054	1999	2006	1920
1918	1979	2014	2044	2162	2292	2519	2770
3308	3912	4901	6236	7770	9871	12222	15131
7359	19070	20416	20441	19871	19510	19178	18463
7770	17064	15666	13982	12766	11126	10007	8945
7699	6507	5544	4636	3847	3315	2956	2769
2724	2570	2499	2479	2555	2680	2922	3042
3360	3732	4328	4971	5922	7113	8568	10504
2479	14491	16013	16628	16528	15713	14282	12910
1411	9843	8097	6559	5271	4304	3512	2978
2720	2386	2277	2189	2083	1939	1827	1770
1815	1710	1695	1578	1525	1571	1588	1577
1599	1586	1629	1642	1754	1792	1880	1996
2143	2250	2434	2450	2593	2393	2295	2255
2207	2040	1930	1845	1742	1576	1590	1490
1540	1541	1536	1616	1631	1811	1942	2036
2326	2512	2957	3236	3728	4238	4684	5026
5041	4804	4695	4432	4027	3751	3271	2902
2510	2160	1888	1671	1544	1424	1465	1427
1384	1334	1303	1346	1320	1311	1365	1285
1282	1308	1385	1336	1352	1444	1412	1455
1495	1506	1598	1603	1792	1844	1975	2147
2317	2544	2558	2778	2879	2841	2844	2967
2942	3094	3160	3498	3804	4286	5231	6199
7734	9807	12080	14383	16925	18647	20023	19851
9196	17910	16019	14267	12322	10621	8860	7170
5672	4769	3851	3404	3092	3003	3016	2946
3183	3418	3463	3377	3425	3269	3108	2813
2724	2529	2386	2149	1943	1796	1710	1619
1548	1390	1374	1362	1337	1381	1411	1310
1350	1325	1437	1416	1369	1422	1492	1466
1466	1465	1462	1486	1436	1433	1464	1423
1427	1360	1365	1364	1322	1341	1324	1332
1290	1254	1181	1192	1192	1204	1239	1197
1177	1193	1186	1229	1218	1127	1159	1227
1274	1213	1171	1195	1214	1178	1186	1232
1165	1288	1242	1248	1288	1296	1300	1322
1399	1482	1492	1518	1681	1653	1753	1882
2016	2056	2201	2384	2578	2891	3167	3388
3807	4229	4830	5791	6572	8090	9011	9945
0475	10720	10390	9725	8840	8175	7525	7447
6653	6316	6216	6529	7021	7417	7848	8239
8528	8231	8207	7806	7425	7074	6482	5870
5095	4627	4210	4059	3832	4040	4226	4573
5391	5945	6716	7473	7942	8110	7898	7496
6897	6605	5803	5333	4916	4386	3722	3409
3213	3199	3438	3459	3851	4221	4133	4231
4145	4105	3855	3683	3430	3256	2967	2825
2413	2430	2102	1910	1938	1818	1748	1846
1656	1757	1737	1812	1803	1836	1861	1893

1919	1931	1904	1974	1934	1881	1912	1852
1825	1737	1691	1734	1703	1743	1740	1739
1883	2067	2200	2433	2568	2822	3007	3209
3386	3519	3464	3527	3368	3254	3278	3242
3172	3300	3326	3341	3314	3477	3310	3390
3418	3277	3266	3118	3019	2787	2803	2655
2603	2429	2295	2172	2111	2031	1996	1960
1949	1827	1904	1897	1822	1924	1995	1970
2020	1996	2043	1968	1868	1762	1680	1691
1525	1528	1435	1322	1315	1355	1277	1198
1289	1233	1312	1237	1279	1230	1230	1273
1281	1256	1374	1384	1485	1482	1554	1699
1804	2047	2326	2662	3100	3672	4225	4892
5544	5844	6038	5936	5751	5388	4980	4592
4396	3840	3456	3056	2757	2564	2346	2227
2348	2294	2378	2395	2309	2258	2190	2092
2067	1947	1924	1806	1773	1690	1658	1708
1675	1717	1710	1845	1956	2080	2304	2654
3006	3455	3994	4465	5188	5694	6372	6909
6874	6907	6535	6205	5815	5515	5066	5095
4774	4591	4586	4586	4784	5054	5243	5483
5773	5722	5966	6066	5829	5716	5405	4951
4595	4211	3888	3606	3184	2949	2709	2310
2065	1933	1785	1729	1645	1598	1508	1542
1482	1426	1415	1365	1349	1394	1286	1349
1354	1394	1411	1391	1473	1558	1489	1450
1598	1598	1679	1870	1952	2043	2287	2496
2561	2624	2661	2545	2453	2380	2285	2150
2263	2040	2034	1909	1857	1884	1837	1821
1882	1944	1964	2085	2094	2265	2320	2398
2539	2701	2706	2680	2802	2666	2522	2532
2385	2314	2214	2143	2009	1903	1758	1743
1583	1539	1435	1437	1393	1448	1284	1329
1334	1407	1357	1469	1489	1543	1648	1708
1761	1784	1843	1808	1873	1808	1893	1973
2007	2052	2152	2192	2189	2283	2351	2320
2362	2289	2227	2182	2015	1996	1999	2001
2036	2027	2143	2231	2465	2577	2752	2921
3174	3172	3191	3166	3045	3134	2850	2818
2666	2483	2399	2075	1995	1863	1686	1565
1480	1436	1372	1361	1315	1297	1272	1270
1286	1264	1328	1284	1265	1284	1252	1306
1215	1310	1351	1292	1373	1275	1286	1317
1219	1353	1329	1318	1302	1318	1243	1388
1295	1341	1332	1356	1376	1418	1493	1521
1424	1577	1629	1570	1596	1683	1718	1828
1769	1751	1803	1756	1746	1758	1597	1667
1613	1640	1556	1531	1509	1447	1527	1450
1571	1585	1581	1609	1674	1667	1695	1690
1806	1938	1913	1854	1927	1970	2022	2133
2320	2499	2703	2838	2985	3303	3497	3657
3926	4254	4636	4947	5250	5774	6270	6363
6680	6838	7027	7185	7392	7478	7384	7234
6713	6359	5871	5360	5122	4998	4997	4885
4661	4855	5019	5179	5580	6011	6337	6767

6807	6969	6642	6642	5990	5876	5440	5169
4788	4468	4026	3572	3172	2814	2483	2331
2069	1949	1834	1730	1749	1677	1622	1587
1516	1530	1521	1528	1547	1549	1591	1631
1617	1640	1646	1667	1818	1885	1990	2059
2167	2348	2515	2660	2956	3359	3967	4489
5404	6297	7345	8265	9629	11069	12429	13298
3530	13513	12869	12246	10900	10257	9557	8896
8342	7517	6615	5676	4859	4344	4047	3817
3699	3817	4153	4517	4806	4861	4868	4814
4575	4296	3952	3841	3649	3356	3081	2917
2585	2347	2090	1967	1738	1715	1595	1510
1539	1633	1494	1494	1531	1561	1552	1552
1605	1671	1689	1715	1771	1884	1985	2068
2296	2461	2555	2861	3266	3508	4021	4344
4937	5251	5246	5336	5294	4899	4692	4416
4273	4116	3732	3535	3184	3102	2716	2430
2206	2110	2035	1922	1858	1809	1784	1647
1787	1676	1706	1577	1670	1629	1604	1751
1752	1705	1733	1781	1807	1833	1904	1930
2053	2232	2456	2697	2957	3189	3516	3977
4508	5119	5726	6185	7245	7974	9259	10085
1335	11658	11981	11783	11780	11250	10600	10210
9796	9417	8862	8507	7624	6887	6171	5299
4891	4348	3969	3719	3329	3037	2748	2532
2375	2362	2225	2093	2011	1890	1859	1861
1847	1776	1771	1794	1786	1879	1920	1985
1962	2070	2154	2186	2281	2293	2360	2479
2529	2585	2682	2726	2756	2851	2820	2886
3057	3148	3321	3493	3712	4000	4233	4604
4893	5007	5064	4804	4638	4334	4123	3952
3727	3754	3605	3504	3557	3430	3562	3755
4041	4522	5169	5659	6321	6776	6941	6777
6836	6584	6199	6097	6167	5805	5567	5053
4593	4116	3588	3297	2967	2698	2464	2404
2233	2100	2094	2133	2240	2249	2395	2434
2536	2511	2503	2584	2566	2506	2449	2502
2446	2382	2446	2461	2459	2581	2565	2620
2865	3084	3432	3976	4781	5809	6850	8314
0082	11829	12997	13734	14126	14050	13455	12673
2267	11597	11456	10681	9805	9382	8117	7246
6384	5684	5068	4545	4199	3757	3595	3406
3425	3548	3664	3751	3859	3898	3894	3794
3809	3607	3622	3792	3924	4285	4487	4816
5201	5376	5881	6441	7186	7612	8209	8583
8548	8344	7784	7363	6885	6410	5969	5811
5335	4922	4534	3958	3414	2907	2576	2271
2076	1933	1768	1648	1646	1667	1585	1624
1631	1599	1649	1612	1524	1495	1536	1612
1651	1539	1635	1578	1651	1573	1554	1642
1590	1585	1629	1575	1610	1516	1542	1565
1598	1546	1625	1613	1576	1649	1693	1639
1745	1774	1915	2028	2107	2228	2561	2818
3040	3221	3570	3792	3870	4094	4318	4321
4388	4403	4312	4165	3872	3655	3447	3500

3317	3293	3171	3154	2955	2927	2881	2992
2838	3013	3130	3212	3200	3240	3327	3231
3283	3483	3536	3733	3747	4069	4405	4679
5009	5321	5818	6021	6236	6414	6571	6504
6691	6848	6814	6855	6571	6284	5900	5582
5236	5013	4790	4897	4729	4531	4733	4592
4817	5052	5856	6516	7517	8918	10411	12021
3526	14964	15654	15644	15573	14783	14043	13361
2826	12173	12265	11862	11198	10560	9942	8896
7776	7101	6181	5394	4752	4398	4001	3640
3327	3056	2851	2743	2543	2578	2315	2240
2130	2138	1989	1870	1815	1664	1638	1615
1564	1553	1557	1532	1486	1517	1444	1470
1394	1382	1373	1385	1524	1414	1497	1428
1523	1552	1460	1553	1505	1582	1500	1464
1501	1487	1411	1490	1466	1457	1402	1543
1458	1414	1476	1514	1620	1493	1535	1445
1468	1386	1404	1430	1415	1443	1356	1441
1370	1307	1357	1412	1320	1330	1289	1330
1238	1304	1243	1344	1461	1400	1529	1422
1446	1431	1585	1569	1568	1615	1746	1705
1795	1811	1804	1894	2026	1926	1869	1758
1885	1824	1784	1754	1708	1664	1540	1521
1542	1459	1424	1369	1367	1361	1365	1350
1300	1347	1355	1337	1333	1298	1290	1359
1280	1344	1379	1313	1250	1232	1240	1239
1223	1214	1268	1154	1194	1198	1237	1156
1168	1174	1240	1202	1246	1300	1302	1355
1332	1352	1395	1331	1298	1351	1387	1318
1417	1435	1426	1454	1496	1572	1589	1558
1624	1675	1797	1743	1860	1956	2099	2227
2448	2668	2969	3297	3481	3674	3827	3842
3965	3934	3976	3955	4043	4375	4454	4694
4893	5029	5498	5658	5805	6222	6397	6408
6274	6083	5758	5306	5041	4817	4508	4446
4316	4118	4111	3835	3693	3525	3258	3029
2802	2673	2559	2374	2332	2233	2158	2197
2123	2092	2033	2016	1933	1848	1873	1807
1704	1723	1726	1801	1702	1748	1734	1665
1674	1608	1618	1647	1598	1615	1590	1577
1563	1592	1606	1561	1488	1507	1487	1599
1574	1646	1709	1788	1845	2050	2110	2272
2626	2906	3124	3411	3849	4164	4647	4978
5369	5673	5872	6020	6206	6347	6607	6841
7014	7064	7214	7263	7212	7149	7302	6912
6968	6524	6236	5726	5332	4987	4764	4620
4428	4115	4048	3790	3720	3379	3346	3195
3084	2895	2869	2939	2781	2989	2860	2833
3009	3033	3057	3020	3016	2981	2895	2793
2707	2604	2465	2373	2396	2257	2110	2070
2112	1959	1941	1866	1883	1789	1730	1818
1873	1966	2082	2313	2424	2771	3144	3556
3991	4421	5027	5348	5896	6141	6252	6312
6133	6060	5938	5821	5780	5517	5449	5164
4960	4649	4366	4015				

Scandium-fluor-pargasite (8.00, 0.02, 72.30)

437	417	403	461	422	388	404	404
421	412	401	431	430	427	450	429
381	435	405	402	398	430	430	412
422	440	423	430	464	465	395	437
439	467	445	428	417	439	457	427
464	415	425	483	450	461	414	416
464	450	462	439	422	454	402	476
419	470	424	474	451	471	484	476
517	518	519	513	540	520	585	598
595	612	694	688	763	834	847	896
1027	1092	1257	1439	1585	1923	2133	2587
3042	3364	3782	3669	3580	3130	2466	1763
1322	938	793	651	611	613	612	583
641	631	608	726	709	687	809	835
858	939	1005	1119	1212	1400	1534	1774
1966	2245	2756	3277	4036	4769	5549	6148
6041	5295	4171	2849	1753	1170	742	662
619	535	492	494	504	487	479	455
439	481	495	503	443	444	461	427
411	469	420	427	444	431	436	430
447	409	420	474	421	471	416	417
453	480	457	430	421	464	471	419
445	460	437	477	427	460	483	417
456	495	454	453	466	452	470	449
431	476	494	446	465	449	464	446
438	461	434	438	469	454	452	417
412	445	440	439	457	426	462	478
418	463	431	419	448	446	420	493
450	424	460	445	461	432	485	430
449	497	429	443	461	444	445	468
459	447	454	449	430	466	437	455
445	458	461	443	457	448	393	423
478	471	413	442	488	440	433	471
473	513	485	445	476	460	456	471
485	440	519	475	499	468	472	491
472	500	423	481	497	479	461	462
487	478	474	450	464	479	470	442
476	475	449	488	429	482	474	509
457	430	427	500	471	507	447	457
479	510	464	455	460	523	455	478
468	458	439	494	464	478	501	464
496	468	502	460	482	463	475	492
460	508	484	471	477	506	452	495
458	457	496	462	446	494	472	508
460	498	512	483	487	499	472	453
459	492	484	482	511	491	525	518
473	506	493	503	481	447	489	486
510	476	492	514	508	498	468	479
483	475	496	510	471	466	520	524
513	518	495	521	525	467	524	462
508	479	498	517	477	492	526	483
454	522	472	524	516	542	508	491
546	497	486	545	512	512	492	511
551	541	484	534	512	500	509	512

537	490	532	508	509	531	549	545
558	541	568	518	533	500	538	508
505	541	558	535	555	515	496	530
547	602	523	544	587	583	589	667
621	701	768	869	957	1080	1171	1252
1226	1120	960	811	812	661	610	631
578	576	577	548	628	603	595	621
684	682	678	743	806	815	900	1026
1242	1389	1584	2013	2460	3134	3832	4469
4933	4931	4489	3805	3000	2084	1471	1084
843	751	684	642	610	597	658	584
572	584	560	574	555	567	612	571
597	589	555	614	612	683	596	610
639	611	586	598	596	631	590	597
620	619	568	569	555	588	564	544
576	587	568	571	579	587	558	602
592	601	617	596	687	675	700	724
786	819	880	1084	1229	1427	1818	2303
2992	3787	4763	5427	6015	6040	5714	4964
3934	3036	2217	1605	1284	1090	998	991
985	1027	985	1027	969	965	890	875
774	773	680	641	668	562	590	592
603	607	567	572	543	586	598	567
567	540	518	586	555	533	526	555
569	555	576	566	588	565	604	573
543	607	623	613	563	589	612	584
558	624	607	608	606	587	690	686
724	790	781	913	1037	1057	1286	1318
1388	1297	1160	1080	834	788	662	642
617	625	606	613	573	570	572	603
596	609	607	578	598	567	596	588
552	575	609	610	632	609	598	599
572	585	597	598	646	636	627	573
661	661	674	660	634	660	672	649
664	721	730	799	798	884	1049	1140
1354	1453	1745	1939	2079	2072	1993	1707
1576	1215	1012	830	838	759	759	738
779	798	782	866	971	1052	1180	1433
1674	2200	2706	3017	3477	3475	3767	3483
3162	2664	2245	1715	1433	1207	966	937
788	769	772	698	825	721	642	612
618	609	645	625	631	645	572	653
637	617	600	620	630	608	661	617
647	591	652	630	617	633	664	638
890	652	665	687	672	697	700	702
729	655	600	616	665	637	687	631
653	669	652	597	603	632	709	648
654	635	596	637	623	614	669	640
628	658	606	685	624	653	610	669
682	661	623	680	658	645	632	677
638	641	671	660	627	624	635	686
674	634	689	649	596	670	634	644
683	644	658	636	654	673	652	640
680	634	676	639	659	661	719	688
656	666	691	633	681	666	708	698

680	686	687	737	708	696	761	671
723	740	736	777	763	810	844	796
784	831	814	850	857	856	944	905
968	1033	1020	1080	1215	1267	1441	1546
1653	1976	2409	2861	3650	4604	6143	8315
0891	15100	19741	24233	27803	29605	29012	26312
1654	16643	11883	7999	5493	3798	2797	2164
1885	1617	1477	1322	1227	1227	1193	1128
1107	1072	1086	1109	1080	1071	1048	1170
1110	1203	1304	1458	1715	2049	2556	3135
4110	5422	7596	10176	13316	16502	19037	20205
9538	17595	14712	11851	9092	6554	4667	3342
2612	2154	1794	1735	1668	1670	1565	1514
1382	1239	1167	1081	994	952	888	865
856	843	791	794	814	757	808	844
818	847	786	803	841	801	813	827
854	951	908	981	925	1052	1043	1100
1154	1216	1255	1386	1472	1530	1774	1851
2113	2486	3014	3759	5008	6746	9483	13781
8883	24206	28594	31340	31641	29925	25990	21545
6974	12439	8651	6079	4123	3072	2507	2121
1861	1736	1560	1442	1317	1223	1139	1047
1048	1025	981	951	912	918	890	958
959	932	913	979	990	1024	1116	1216
1404	1583	1798	2054	2207	2296	2283	2251
2178	2207	2198	2310	2645	2827	3035	3530
3869	3891	4113	3959	3728	3188	2728	2489
2015	1717	1438	1307	1211	1128	1125	1060
1041	1108	1114	1194	1211	1304	1410	1709
1912	2270	2759	3174	3714	4353	4661	5035
5402	5764	6095	6844	7980	9787	12002	14540
7451	18818	19027	17720	15467	13074	10560	8070
6091	4384	3461	2880	2452	2246	2057	1901
1687	1489	1327	1276	1120	1066	982	973
944	875	898	901	874	905	906	937
905	864	903	861	840	875	835	828
759	784	823	797	799	775	829	852
821	842	875	843	858	902	844	948
938	992	1026	1097	1209	1270	1429	1643
1918	2491	3089	4069	5430	6645	7931	8683
9312	9028	8955	7816	6811	5624	4598	3484
2616	2033	1687	1369	1283	1182	1152	1130
1060	1071	1035	1077	1148	1198	1258	1251
1499	1535	1671	2012	2395	3160	4191	5716
7743	10161	12449	14765	16619	17348	16764	15662
3875	12059	10184	8035	6548	5186	4706	4263
4309	4545	5094	6123	8012	10413	14095	18908
3762	29326	33501	36208	36171	33673	30805	25681
1085	16854	12681	9472	6768	5126	3929	3137
2572	2249	1942	1727	1501	1361	1280	1184
1256	1112	1061	1029	997	1000	931	1010
1036	924	1006	933	922	917	902	925
877	843	918	870	901	918	958	893
904	932	978	979	990	978	942	1022
1060	1126	1083	1170	1228	1345	1525	1581

1877	2256	2929	3847	5289	6975	9411	12233
5642	18283	20095	20415	19358	17290	15329	12724
0555	8371	6526	5020	4000	3590	3097	2878
2730	2601	2460	2423	2436	2464	2456	2521
2984	3486	4049	5033	6076	7637	9223	11054
3481	16624	20000	23792	26120	27602	27309	25862
3156	19904	17132	13698	10806	8248	6034	5003
4131	3646	3265	3182	2946	2725	2479	2183
1995	1736	1535	1343	1249	1167	970	943
1046	915	903	923	884	950	921	877
848	799	807	805	794	752	835	752
802	785	714	725	787	794	725	753
736	763	719	777	867	790	871	888
937	1117	1190	1283	1357	1528	1634	1718
1827	1949	1908	2030	2022	1826	1729	1627
1479	1364	1290	1235	1095	1036	1006	992
919	928	924	920	962	1041	1107	1307
1438	1870	2202	2638	2895	3120	3254	3220
3121	2874	2769	2462	2224	2157	1854	1631
1573	1536	1555	1621	1496	1426	1475	1395
1389	1359	1554	1712	1928	2281	2815	3471
3954	4387	4613	4697	4471	4210	3764	3377
3018	2566	2220	1870	1662	1475	1330	1302
1165	1190	1182	1202	1223	1319	1461	1479
1747	2081	2586	3351	4396	5836	7716	10054
2207	14175	15458	15469	15310	14391	13034	12059
0417	9045	8099	7594	7954	8368	9176	9576
9624	9323	8874	8022	7440	6619	5708	4822
4108	3571	3194	3084	3114	3428	3870	4458
5503	6605	7762	8929	9800	10168	9836	9315
8564	8020	7249	6547	5924	5547	5526	5869
6287	6711	7348	7330	7213	6608	6113	5607
5041	4228	3467	2778	2233	1864	1571	1426
1212	1173	1165	1042	981	979	939	930
949	924	893	973	1020	992	1020	1106
1138	1253	1374	1575	1956	2074	2389	2493
2627	2613	2389	2370	2142	2054	1861	1774
1558	1484	1395	1386	1325	1299	1325	1296
1362	1354	1448	1562	1807	2222	2681	3117
3615	4038	4266	4148	3921	3700	3444	3109
2725	2367	2046	1655	1461	1284	1186	1104
1044	973	985	962	917	887	907	916
905	917	972	952	934	968	1078	1159
1282	1404	1638	1773	2095	2223	2255	2315
2216	2154	2116	2026	1918	1878	1800	1783
1829	2016	2351	2873	3701	4700	6394	8441
0737	13632	16077	17979	18660	18948	18096	17337
6042	14732	13271	11340	9978	8339	6730	5530
4567	3802	3254	2834	2598	2415	2436	2590
2678	2856	2953	3100	2997	2764	2615	2417
2374	2092	1932	1650	1540	1423	1268	1206
1122	1082	1073	1063	1181	1091	1155	1181
1150	1180	1266	1201	1165	1112	1132	1044
1042	944	978	905	898	930	878	902
932	921	926	894	870	849	863	838

901	812	825	809	783	793	803	846
781	813	777	799	756	818	815	758
814	812	833	767	809	800	838	810
845	835	858	885	888	910	910	907
902	891	882	899	892	924	956	898
908	892	893	960	1046	1063	1094	1200
1314	1414	1546	1779	1891	2172	2580	2881
3479	4305	5077	6037	6993	8242	9096	9171
9052	8722	7827	7271	6737	6190	5555	5455
5313	5572	6126	7183	7781	8205	8411	8358
7993	7440	7237	6978	6583	6379	6094	6344
6959	7499	8305	8823	9112	9246	8572	8212
7656	7120	6611	6092	5677	5395	4932	4900
4661	4437	4284	4047	3906	3552	3256	2982
2653	2356	2108	1843	1750	1602	1488	1554
1560	1468	1497	1461	1403	1468	1476	1463
1459	1479	1544	1504	1571	1630	1577	1565
1553	1546	1534	1635	1501	1648	1754	1963
2360	2652	3001	3324	3554	3643	3529	3322
3193	2980	2850	2536	2443	2136	1783	1633
1513	1366	1292	1261	1336	1197	1141	1248
1310	1577	1809	1969	2230	2406	2485	2556
2472	2457	2264	2238	2009	1880	1833	1702
1495	1396	1242	1240	1168	1102	1053	1033
1059	962	960	920	985	1020	1019	997
1074	1193	1236	1376	1425	1464	1555	1531
1517	1445	1251	1269	1264	1173	1078	1079
904	942	869	846	790	815	832	778
789	796	758	857	842	842	903	835
916	899	923	998	1057	1087	1228	1466
1630	1964	2402	3113	3803	4402	5040	5414
5399	5304	4997	4668	4695	4352	4057	3937
3483	3212	2791	2480	2227	2115	1945	1911
1778	1800	1703	1748	2017	2379	2719	3203
3551	3861	4181	4114	4118	3988	3869	3664
3726	3580	3484	3428	3347	3313	3402	3416
3520	3496	3490	3419	3340	3141	2909	2935
2906	3052	3180	3737	3965	4398	4750	4904
4973	4721	4574	4254	4008	3934	3709	3316
3056	2666	2379	2129	1868	1641	1538	1358
1377	1246	1103	1071	953	984	966	918
898	871	915	902	901	896	907	944
931	968	910	989	961	926	933	999
953	915	959	1024	1000	1063	1125	1303
1453	1646	2062	2315	2477	2595	2697	2949
2986	2852	2971	2846	2655	2464	2287	2167
2153	1912	1817	1661	1597	1487	1338	1294
1161	1160	1015	1042	976	897	919	905
871	857	943	828	833	826	788	794
742	757	787	769	792	733	779	777
803	824	768	758	772	796	801	802
801	798	759	835	777	775	802	821
831	810	861	926	876	988	1109	1250
1284	1428	1445	1527	1542	1446	1415	1372
1414	1317	1287	1383	1360	1427	1536	1703

1882	2161	2453	2636	2981	2982	3030	2810
2795	2693	2730	2516	2446	2146	1945	1778
1554	1450	1261	1182	1132	1036	1049	988
894	882	905	842	823	853	801	787
783	811	806	822	845	782	808	847
840	865	796	833	828	880	942	941
929	978	1043	1038	1158	1182	1209	1368
1398	1475	1546	1600	1477	1541	1414	1428
1425	1371	1305	1233	1132	1169	1102	1066
1019	996	975	970	934	1117	1126	1167
1325	1511	1644	1934	1980	2157	2178	2161
2145	2097	2137	2170	2060	1995	2063	2058
1968	2072	2106	2031	2091	2203	2307	2409
2811	3295	3908	4751	5533	6205	6911	7460
7742	7675	7430	7167	6890	6521	6275	6051
5694	5335	5117	4654	4351	3941	3615	3304
3019	2914	2946	2929	2952	3014	3245	3410
3510	3639	3710	3680	3423	3290	3152	2949
2783	2506	2424	2159	2063	1762	1608	1520
1443	1287	1203	1104	1054	1013	1044	1011
1026	959	1006	953	924	999	976	1009
1031	1107	1106	1137	1228	1233	1351	1459
1571	1761	1971	2364	2762	3487	4290	5478
6986	8685	10399	11898	12874	13249	12755	11919
1185	10391	9983	9879	9312	8668	7906	7169
6742	6296	6106	6103	6171	6040	5858	5494
4960	4664	4376	4372	4055	3877	3648	3170
3002	2746	2593	2357	2174	2155	1992	1818
1805	1731	1689	1806	1790	1995	2147	2408
2768	3383	4003	4453	4946	5237	5479	5408
5190	4957	4719	4427	4414	4154	3776	3491
3159	2800	2492	2285	2128	1874	1793	1628
1548	1451	1370	1267	1228	1171	1135	1158
1054	1053	1054	1042	1038	987	1020	974
961	945	971	1022	1073	1107	1104	1066
1148	1060	1069	1092	1095	1121	1192	1158
1184	1205	1214	1247	1206	1222	1247	1296
1360	1412	1494	1619	1709	1911	2183	2618
3123	3841	4923	6028	7540	8712	9857	10849
1001	11107	10697	9816	9338	8680	8225	7680
7308	6555	5795	4864	3999	3337	2651	2287
1998	1797	1640	1526	1397	1353	1279	1200
1114	1206	1114	1125	1192	1166	1173	1193
1170	1199	1198	1256	1241	1342	1510	1668
1736	1858	2025	2211	2351	2384	2447	2496
2296	2196	2165	2131	2122	1951	2040	1905
1861	1816	1712	1735	1852	1866	2103	2308
2694	3173	3440	3790	4138	4205	4074	3740
3727	3399	3159	3214	3069	2880	2807	2734
2650	2513	2703	2912	3376	4140	4800	5415
5650	5810	5801	5707	5591	5386	5323	5290
5143	4902	4717	4309	4005	3685	3362	3053
2925	2810	2650	2436	2397	2331	2147	2071
2061	2041	2063	2056	2103	2057	2047	1958
1902	1909	2029	2185	2341	2562	2953	3525

4425	5427	6887	8410	9776	11373	12093	12484
2109	11459	10965	10406	9842	9654	9544	9131
8689	8025	7017	6305	5471	4974	4608	4396
4442	4694	5177	5812	6350	6876	7130	7340
7347	6870	6375	5979	5784	5611	5496	5214
4918	4407	3958	3460	3188	2931	2842	2935
2923	3093	3351	3468	3539	3506	3388	3220
2937	2716	2730	2598	2561	2470	2312	2081
1979	1764	1656	1537	1460	1330	1251	1203
1132	1129	1112	1102	1124	1087	1043	1089
1085	1121	1079	1080	1176	1157	1154	1136
1145	1083	1160	1053	1072	1118	1051	1119
1077	1145	1174	1197	1220	1378	1416	1533
1655	1627	1756	1666	1646	1595	1582	1574
1648	1575	1663	1606	1575	1591	1575	1695
1681	1865	2022	2080	2316	2502	2616	2965
3125	3367	3406	3341	3283	3128	3205	3082
3198	3385	3460	3604	3734	3940	3925	4028
3991	3873	3811	3873	3877	3836	3953	3929
4014	4069	3936	3825	3707	3498	3282	3014
2914	2872	2705	2682	2626	2579	2512	2362
2146	2176	2151	2063	2187	2241	2218	2320
2387	2341	2433	2469	2553	2788	3245	3887
5105	6458	8285	10323	12368	14210	15188	15639
5317	14257	13707	13187	12771	12467	12268	11995
1371	10581	9344	8398	7453	6640	5867	5183
4525	4173	3597	3231	3032	2732	2563	2450
2249	2097	1994	1945	1915	1827	1677	1652
1697	1598	1521	1535	1436	1411	1320	1334
1300	1222	1174	1217	1210	1092	1110	1131
1191	1192	1214	1179	1253	1209	1273	1205
1249	1273	1233	1296	1330	1363	1374	1361
1443	1439	1465	1531	1593	1555	1612	1581
1532	1566	1517	1446	1385	1341	1328	1307
1237	1154	1158	1104	1073	1036	1065	934
1021	971	930	997	1085	1140	1131	1224
1229	1188	1205	1217	1217	1152	1151	1136
1110	1206	1146	1090	1071	1115	1132	1074
1137	1171	1232	1239	1358	1286	1251	1236
1264	1223	1160	1093	1104	1123	1133	1055
1058	1033	988	1037	961	978	963	868
930	930	906	935	876	935	823	871
873	880	862	898	866	853	840	855
821	809	815	786	766	799	834	828
810	867	813	858	838	808	830	868
889	820	844	851	796	866	857	860
828	914	882	923	931	1041	1018	1056
1102	1226	1246	1411	1433	1526	1798	2098
2532	2587	2792	2816	2794	2613	2523	2434
2480	2478	2581	2581	2611	2561	2607	2596
2766	3000	3266	3720	4184	4730	5457	5773
6027	5913	5460	5118	4489	4197	4029	3986
4178	4104	4105	4035	3747	3616	3316	3058
2860	2725	2555	2475	2192	2173	2061	2008
1962	1893	1861	1806	1772	1730	1647	1572

1454	1468	1394	1363	1287	1338	1355	1736
1424	1497	1522	1752	1847	2086	2479	2864
3211	3500	3746	3930	4030	4051	4202	4055
4201	4217	4323	4335	4363	4261	4091	3944
3725	3441	3327	3252	3136	2899	2922	2868
2708	2624	2750	2785	2901	3176	3321	3592
3707	3840	3759	3757	3734	3724	3740	3695
3913	3813	3602	3492	3300	3236	3112	2977
2973	3153	3169	3117	3276	3262	3254	3090
3111	3166	2903	2940	2760	2771	2617	2612
2540	2402	2287	2161	2080	1981	1912	1731
1630	1602	1587	1537	1480	1564	1547	1434
1443	1293	1424	1379	1424	1369	1520	1531
1634	1746	1972	2272	2683	3149	3702	4112
4433	4763	4763	4741	4798	4827	4924	4816
4809	4713	4481	4342	4179	4051	3899	3730
3536	3293	3021	2644	2543	2196	2182	1974
1851	1796	1728	1667	1587	1517	1505	1565

Scandium-fluor-eckermannite (8.00, 0.02, 72.10)

415	405	425	382	374	427	371	433
414	404	382	386	398	420	420	414
418	384	398	434	422	421	425	422
431	366	453	433	418	422	403	425
410	414	405	406	457	423	411	456
436	440	393	391	447	399	417	421
448	442	414	430	422	410	405	425
398	404	454	453	469	399	416	452
429	440	470	433	445	391	448	395
425	478	435	454	464	466	468	490
524	548	516	534	487	535	519	539
551	629	558	636	659	700	760	811
914	903	896	820	748	671	657	639
640	705	665	761	734	827	841	968
977	1093	1232	1245	1477	1572	1730	1947
2133	2444	2876	3338	3955	4801	6112	7387
9002	10160	10746	9958	8050	5368	3419	1829
1099	823	732	641	587	559	500	491
461	504	499	472	437	486	466	470
470	457	477	446	471	458	452	430
471	461	456	460	427	439	462	482
469	434	444	426	425	404	472	448
460	445	444	465	428	388	439	447
461	486	434	415	453	432	468	475
458	488	455	445	428	440	458	420
450	409	445	444	470	430	458	455
442	430	451	427	464	415	441	447
443	490	477	471	460	443	506	444
484	474	456	445	448	468	435	454
435	451	473	416	469	479	470	451
442	456	450	446	448	417	457	460
461	431	426	434	484	444	464	426
471	479	439	457	430	426	479	478
466	443	460	407	478	430	449	454
437	460	448	462	455	458	459	460

467	481	442	449	443	442	442	485
476	473	465	472	477	453	470	471
434	521	507	472	470	481	467	462
488	471	467	508	485	467	443	471
455	456	446	482	460	472	515	447
456	471	459	473	454	456	479	487
485	518	506	496	492	455	461	459
458	419	479	446	484	471	499	440
440	451	476	446	508	489	432	461
490	483	439	476	508	444	457	476
470	486	447	441	484	468	464	463
444	449	491	478	488	464	469	462
438	468	505	530	498	478	456	518
461	479	499	485	503	470	497	491
468	485	434	446	529	489	508	481
483	514	476	508	483	479	511	498
465	433	480	491	466	510	497	462
492	503	480	525	473	476	563	451
499	503	501	498	548	480	489	539
519	503	468	502	493	494	489	457
448	539	470	532	498	513	505	489
520	534	496	577	479	523	534	520
567	549	590	571	614	606	676	742
757	879	975	1160	1186	1147	1071	980
836	702	572	576	558	537	525	527
508	526	508	478	522	515	542	524
535	532	505	553	571	555	585	572
607	573	589	632	661	696	741	716
763	801	910	1084	1147	1319	1624	1833
2353	2925	3646	4568	5578	6181	6527	5711
4804	3568	2441	1668	1256	1074	1023	1129
1261	1325	1600	1882	2150	2328	2560	2357
2068	1726	1390	1094	853	724	687	638
619	619	597	558	553	636	571	547
532	540	565	627	570	595	537	561
580	565	585	624	593	654	651	667
667	704	722	754	869	915	1044	1150
1349	1507	1804	2090	2699	3199	3919	5000
6642	8424	10768	12758	13947	14752	14067	12462
9981	7415	5366	3870	3320	3259	3500	3663
3539	3262	2795	2100	1635	1226	967	840
760	679	668	631	627	653	648	663
616	542	595	608	551	596	562	579
605	593	562	528	625	537	601	547
526	549	561	549	582	611	555	614
572	591	572	607	532	622	571	557
574	588	551	622	625	622	587	662
642	651	648	644	652	585	592	570
589	571	607	583	614	603	589	584
553	604	556	602	617	593	576	600
591	605	656	583	574	602	595	677
659	672	662	654	682	709	704	769
805	883	976	1119	1325	1584	1882	2258
2802	3491	3952	4308	4334	3916	3298	2671
2049	1712	1346	1152	1110	1044	949	899

800	763	726	675	727	661	695	717
680	653	695	679	691	689	704	714
761	772	821	845	887	948	1056	1138
1262	1531	1711	2122	2707	3420	4485	5927
7443	8911	9929	10450	9682	8415	6630	4831
3373	2384	1627	1235	1098	1022	939	824
850	845	771	798	758	695	730	711
711	740	736	750	722	773	739	717
721	742	717	750	750	701	647	679
680	678	655	740	646	702	702	701
694	706	757	746	786	792	807	820
849	906	995	953	1060	1060	1178	1307
1450	1748	2069	2504	3008	3152	3271	3041
2698	2094	1667	1308	1064	962	861	795
755	731	765	749	749	659	678	718
688	707	675	703	683	632	717	676
674	690	672	689	739	719	685	723
705	698	684	738	685	696	727	684
694	711	716	707	693	682	708	776
818	767	728	688	726	771	777	779
771	844	877	864	916	944	1015	999
1009	1121	1134	1142	1172	1206	1286	1409
1462	1722	1945	2231	2759	3269	4019	5272
7024	9265	12588	17134	22564	29359	35758	40669
2251	39948	34817	28267	21068	15558	10045	6986
4926	3701	3354	3079	2783	2670	2341	2033
1762	1486	1351	1252	1169	1062	998	1041
1055	1014	1094	1013	969	1076	1045	1092
1095	1091	1125	1217	1263	1348	1451	1655
1887	2148	2566	3299	4264	5602	7421	9821
3023	16759	20755	23787	25019	24182	21779	17978
4043	10290	6993	4502	2917	2239	1662	1518
1386	1334	1223	1132	1112	1019	999	1018
981	966	967	937	932	903	895	922
857	882	931	988	949	953	967	945
1057	997	923	1054	1112	1053	1132	1145
1218	1333	1320	1425	1540	1864	2054	2355
2733	3480	4380	5747	7810	10581	15308	20911
7571	34275	39555	42610	42465	39013	32949	26195
9898	14301	9596	6162	4265	3180	2499	2195
2002	1859	1600	1507	1392	1318	1121	1165
1048	1074	997	1041	999	1003	917	961
893	943	955	963	977	911	856	915
888	857	846	892	873	899	923	945
908	956	936	998	1024	949	1039	1068
1213	1281	1414	1603	1917	2175	2601	3092
3698	4070	4357	4359	4413	4184	3798	3396
3111	3097	3168	3476	4063	4984	6346	8423
0629	13638	15987	18194	18366	17528	15966	13185
0535	8015	5854	4156	3239	2707	2510	2452
2881	3589	4395	5558	6290	7150	7295	7136
6395	5515	4575	3638	2836	2071	1683	1450
1231	1129	1064	983	939	974	948	980
970	859	921	935	842	895	871	872
831	902	895	889	942	883	890	947

970	949	988	958	972	984	1015	1032
1011	974	1092	1017	1040	1004	1060	1095
1017	1068	1085	1139	1233	1425	1518	1735
2029	2582	3161	3901	5193	6528	8077	9803
1631	12959	14079	13746	12745	11091	9137	7300
5682	4313	3107	2384	1873	1710	1485	1392
1320	1235	1182	1142	1178	1069	1065	1121
1122	1064	1126	1136	1134	1084	1189	1167
1246	1229	1281	1418	1440	1553	1606	1631
1903	1947	2005	2392	2649	3035	3703	4283
5430	6903	8920	11703	16055	22383	30435	41121
3199	65091	73423	76220	73082	66483	56522	46775
6858	27290	19039	12679	8169	5612	4436	3567
2996	2675	2329	2168	1838	1795	1580	1592
1493	1347	1319	1229	1291	1209	1228	1137
1162	1164	1083	1105	1060	1123	1031	1023
1041	1013	1002	987	1035	1018	1013	939
975	1036	997	1022	942	986	955	954
966	1031	1002	1060	1050	1040	1027	1059
1097	1139	1151	1179	1220	1380	1433	1555
1747	2182	2624	3392	4493	5923	8005	10547
3709	16658	18570	19630	18812	17334	14745	12641
0449	8092	6092	4658	3720	3060	2964	2982
3219	3859	4671	5377	6336	6695	6698	6727
6118	5435	4953	4217	3545	3061	2502	2138
2026	1943	1941	2030	2169	2292	2550	2657
2739	2887	3177	3711	4494	5658	7654	10298
4260	19548	25571	31162	35940	37658	37200	33815
0214	26351	21943	17240	12739	9305	6712	5015
3855	2925	2351	1999	1829	1665	1520	1454
1401	1296	1326	1268	1351	1467	1394	1428
1520	1438	1450	1438	1274	1279	1172	1116
1108	1055	1122	1047	1124	1100	1151	1113
1080	1027	1049	983	938	934	951	912
839	857	881	914	858	926	870	985
999	849	1031	1084	1199	1368	1515	1598
1699	1819	1892	1875	1889	1795	1742	1564
1544	1366	1348	1276	1512	1124	1221	1203
1221	1198	1305	1443	1481	1736	1862	2094
2263	2492	2470	2454	2271	2311	2212	2094
2233	2330	2683	2973	3427	3954	4043	4154
4173	3737	3460	3122	2819	2455	2127	1744
1446	1266	1111	1025	989	991	987	936
962	953	943	889	978	974	930	954
970	999	1032	998	1083	1070	1081	1107
1130	1292	1407	1469	1673	1811	2137	2691
3248	4003	5175	6843	8626	10898	12973	15005
5935	16357	15489	14401	12972	12195	10884	9869
8752	7871	7479	7801	8556	9058	9989	10336
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8814	10138	12199	13854	15829	16595	16336	15090
3468	11694	10225	8129	6268	4778	3476	2682
2225	2120	2004	1995	2063	2176	2172	2199
2227	2174	2465	2689	3083	3567	4470	5276
6682	8231	10058	11683	12715	12857	12143	11378

0216	9185	8012	6575	5175	4146	3179	2573
2162	1812	1594	1437	1312	1257	1163	1099
1103	1116	1089	1047	1048	1015	979	1011
1035	1086	1020	995	1028	1055	1007	976
1019	1019	1003	1010	1066	1028	1138	1148
1242	1260	1327	1533	1755	1998	2366	2986
3625	4199	4889	5154	5226	4885	4772	4528
4124	3968	3680	3582	3590	4026	4454	5129
6191	7010	7491	7659	7485	7233	7117	7493
8371	9852	11592	14362	17647	20974	23428	24499
3974	22194	19643	17296	15113	12959	10346	8097
5739	4149	3042	2553	2097	1833	1635	1601
1391	1325	1265	1228	1187	1185	1131	1091
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1255	1357	1484	1748	2081	2531	3141	4126
5032	6191	6912	7058	6750	6361	5788	5269
4630	3952	3568	2749	2321	1900	1615	1445
1276	1184	1175	1029	1096	1017	1070	1072
1043	1032	1014	1006	893	962	909	991
958	907	931	895	993	884	923	905
931	914	923	913	824	909	931	960
894	961	896	985	971	998	998	1093
1095	1210	1261	1366	1574	1689	2078	2538
3097	4102	5129	6420	7697	8926	9800	10002
9881	9562	8689	8118	7327	6428	5697	4724
3687	3047	2454	2064	1763	1542	1358	1305
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1076	1130	1149	1183	1257	1497	1675	1924
2249	2699	3344	4190	4989	6189	7078	7647
7785	7386	6724	6004	5294	4823	4484	3831
3061	2601	2080	1767	1578	1372	1296	1210
1306	1308	1325	1352	1331	1237	1334	1296
1323	1363	1492	1606	1932	2173	2466	2939
3776	4311	5381	5964	6640	6975	6872	6515
5918	5242	4718	4360	3901	3272	2715	2147
1806	1574	1384	1278	1165	1134	1099	1086
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1074	1076	1033	1166	1251	1234	1370	1560
1832	2248	2622	3171	3498	4041	4316	4651
4849	5274	5708	5725	5597	5346	4842	4365
3734	3382	2922	2599	2305	2005	1815	1696
1665	1855	1984	2267	2539	2956	3241	3314
3423	3333	3097	2881	2679	2528	2442	2240
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1459	1573	1702	2024	2260	2533	2904	3225
3381	3356	3206	3092	2923	2640	2580	2435
2297	1947	1849	1688	1532	1431	1393	1379
1382	1388	1217	1312	1226	1241	1270	1295
1407	1486	1629	1716	2110	2409	2908	3491
4079	4807	5529	6425	7195	7477	7222	6866
6209	5529	4966	4722	4262	3779	3139	2467
2045	1807	1484	1443	1459	1415	1398	1531
1700	1964	2314	2703	3213	3641	3911	3910
3883	3639	3619	3455	3510	3383	3348	3283
3109	3087	3142	3020	2884	2941	3069	3256

3452	3807	4276	4597	4992	5305	5483	5245
4930	4394	3992	3838	3561	3335	2948	2665
2321	2002	1920	1813	1818	1804	1768	1810
1737	1676	1549	1494	1497	1532	1474	1340
1302	1284	1248	1203	1187	1145	1172	1171
1098	1106	1194	1159	1199	1198	1250	1397
1495	1833	2130	2437	2845	3274	3616	3874
4146	4014	3812	3817	3592	3579	3689	3575
3502	3341	3307	3040	2754	2704	2505	2282
2104	1954	1864	1792	1649	1536	1442	1371
1318	1463	1598	1794	2083	2535	3087	3783
4336	4947	5177	5462	5311	5062	4490	4209
3934	3494	3342	3051	2531	2121	1860	1606
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963	931	885	918	935	940	978	927
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909	963	987	924	937	848	925	889
906	858	890	929	841	859	827	855
857	871	888	891	859	850	866	887
796	809	898	890	898	926	947	950
1047	1024	1146	1146	1181	1189	1226	1296
1233	1242	1222	1155	1167	1112	1142	1090
1171	1091	1081	1151	1162	1277	1335	1538
1655	2017	2373	2733	3480	3992	4687	5208
5583	5518	5309	5058	4634	4455	4092	3907
3549	3165	2906	2509	2143	1758	1498	1350
1301	1192	1162	1082	1103	1066	1054	1038
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1272	1384	1419	1409	1431	1366	1375	1312
1378	1457	1404	1410	1480	1381	1417	1387
1366	1379	1372	1385	1460	1473	1495	1489
1481	1397	1487	1456	1501	1512	1608	1726
1924	1959	2148	2261	2321	2524	2660	3088
3441	4296	5043	5860	6333	6797	6985	6835
6578	6821	7133	7522	8023	8695	9154	9206
9012	8655	8255	7643	7180	6688	6447	6094
5855	5932	5782	5500	5145	4738	4540	4166
3801	3603	3527	3359	3195	2995	3090	2894
2746	2767	2863	2879	3280	3807	4499	5825
7190	8816	10847	13601	15976	17917	19242	19406
7669	15636	13783	12600	12115	11428	10403	9182
7534	5886	4538	3577	2889	2472	2214	1999
1813	1736	1756	1752	1671	1641	1687	1632
1600	1797	1768	1890	2110	2357	2489	2913
3569	4145	4985	5616	6381	7064	7282	7248
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3603	3130	2557	2162	1954	1759	1621	1510
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2200	2564	3116	3537	4132	4705	5238	5927
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4584	4360	4111	3689	3118	2806	2430	2239
2129	1934	1950	1897	1877	1873	1792	1627
1590	1577	1551	1415	1428	1397	1363	1230

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3270	3520	3849	3879	3706	3490	3260	3139
3039	3034	3030	3157	3165	3365	3699	4189
5117	6180	7829	9548	11200	12362	12794	12267
1530	10587	10055	9973	9479	9352	8766	7883
6987	6321	5717	5347	4985	4957	4493	4289
3854	3569	3467	3373	3336	3370	3346	3355
3446	3390	3336	3318	3352	3404	3512	3446
3280	3186	3032	2817	2544	2435	2471	2341
2361	2167	2012	1939	1719	1697	1550	1564
1739	1646	1721	1873	1851	1883	1934	1939
1911	2005	1923	1770	1844	1737	1681	1672
1661	1528	1483	1446	1356	1295	1191	1195
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1007	983	1131	1074	1075	1111	1124	1063
1091	1113	1176	1196	1240	1228	1259	1295
1394	1413	1484	1637	1756	1865	2301	2614
3206	3729	4540	5395	6656	7323	8365	8952
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6146	5945	5616	5046	4392	3873	3441	3328
3376	3552	4119	4822	5819	7036	8427	10412
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7220	6634	6074	5864	5404	5361	5068	4935
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2419	2357	2265	2120	2089	2120	2131	2048
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3166	3248	3368	3793	3960	4101	4274	4365
4309	4286	4312	4289	4103	3969	3907	3436
3396	3183	3128	2887	2721	2597	2496	2479
2259	2248	2184	2111	2083	1796	1842	1720
1654	1612	1516	1487	1485	1424	1368	1435
1235	1337	1360	1412	1529	1592	1683	1824
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1772	1907	2129	2418	2724	3009	3212	3498
3600	3673	3585	3449	3279	3367	3397	3675
3963	4183	4532	4567	4597	4337	4011	3648
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7278	7897	8661	9819	11418	12972	14400	15973
7345	18479	18718	18066	16981	15246	13373	12416
1738	11462	10994	10243	9642	8485	7088	5772
4640	3819	3090	2678	2264	2077	1883	1789
1659	1554	1530	1482	1338	1375	1323	1302
1237	1215	1206	1182	1203	1145	1186	1235
1235	1165	1346	1367	1508	1610	1755	1859
1910	1961	2027	2001	1923	1863	1757	1674
1688	1747	1703	1699	1723	1661	1586	1658
1580	1656	1683	1637	1560	1616	1470	1509

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1622	1594	1635	1600	1492	1503	1574	1564
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1205	1140	1175	1305	1371	1434	1584	1680
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5946	5430	5375	5306	5205	4908	4733	4359
3721	3105	2706	2258	1990	1768	1658	1575
1495	1450	1418	1358	1259	1267	1279	1271
1241	1253	1221	1315	1212	1220	1300	1236
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1333	1345	1389	1445	1590	1747	1773	2030
2285	2412	2608	2929	2955	3131	3019	2939
2771	2593	2334	2402	2323	2251	2216	2284
2144	2056	1875	1825	1814	1823	2000	2149
2330	2640	2854	3201	3562	3892	3950	4102
4327	4196	4517	4673	4615	4808	4806	4666
4556	4477	4501	4709	4936	5376	6032	6500
6797	7091	7169	6884	6574	6013	5668	5215
4789	4687	4719	4768	4629	4596	4637	4213
3840	3594	3241	2870	2622	2404	2257	2234
2143	2166	2066	1858	1909	1780	1833	1685
1738	1723	1828	1874	1966	1992	2236	2476
2673	2832	2845	2872	2972	2824	2661	2568
2419	2236	2229	2027	2131	2064	2039	1877
1909	1782	1688	1566	1462	1528	1525	1605
1727	1864	2044	2168	2419	2624	2645	2780
2673	2615	2586	2629	2555	2504	2584	2658
2621	2673	2560	2439	2532	2518	2639	2671
2642	2824	3061	3010	3088	3079	3081	3124
3090	3267	3651	3837	4317	4665	4978	5184
5041	5190	5137	4827	4863	4833	0	

Indium-fluor-eckermannite (8.00, 0.02, 72.38)

492	529	519	509	533	534	555	564
473	554	520	483	503	522	544	541
575	504	519	536	556	566	549	559
550	540	545	537	506	564	541	561
556	555	566	529	562	555	545	571
573	534	588	554	548	592	549	564
608	608	574	560	609	571	603	622
588	553	564	581	600	627	574	629
626	629	655	717	688	657	659	712
712	716	804	784	777	871	889	859
934	1011	1036	1127	1152	1347	1366	1526
1614	1843	2013	2387	2822	3333	3680	3836
3258	2573	1820	1289	1072	914	966	964
997	1035	1061	1166	1221	1322	1413	1529
1645	1768	1928	2148	2312	2734	3001	3484
4031	4682	5694	6512	8296	10308	12448	14284
4727	12703	9622	5948	3183	1815	1230	1010

903	820	764	768	778	740	762	737
777	701	714	714	710	697	720	705
672	720	726	691	709	693	691	661
716	704	716	679	652	654	673	673
731	721	688	685	696	662	687	666
740	685	723	693	726	750	653	726
737	730	732	673	718	742	708	686
704	768	794	722	710	707	702	687
711	691	731	751	741	693	752	708
697	687	686	657	722	716	723	686
769	688	683	743	679	774	712	716
740	761	702	703	764	705	755	743
702	777	774	730	774	719	775	731
700	749	744	683	769	745	759	702
717	759	785	780	707	711	729	759
734	765	758	715	722	764	740	763
672	709	779	730	741	711	732	728
767	766	765	791	833	831	791	835
809	760	800	781	782	735	757	739
735	760	793	771	738	776	756	734
758	763	802	727	775	796	773	754
784	779	718	745	815	744	768	769
755	738	795	793	724	800	789	755
724	777	708	795	792	774	705	767
706	762	725	719	767	769	801	762
767	774	757	774	745	765	782	801
740	746	727	753	729	747	783	753
755	732	765	764	719	761	722	763
822	742	718	779	711	788	774	796
713	777	745	788	741	816	776	768
758	778	751	731	765	815	775	800
779	809	752	763	794	741	760	724
723	758	803	778	764	760	766	793
806	806	813	720	825	688	730	769
777	780	808	759	782	787	761	807
782	796	809	761	769	812	754	799
801	816	758	816	848	903	765	811
792	809	850	820	748	775	827	847
841	793	793	800	815	810	856	867
895	963	928	964	1029	977	1104	1100
1249	1366	1514	1666	1972	2275	2698	3229
4253	4954	5842	6139	6194	5926	5545	5515
5639	6135	5957	5101	4154	2977	2097	1570
1132	1029	952	890	967	920	836	901
905	891	857	922	874	893	884	877
924	905	981	893	1050	981	1074	1136
1191	1361	1473	1594	1768	2109	2526	2823
3794	4681	5913	7199	8368	8650	7934	6632
4918	3329	2127	1481	1149	1081	1064	1044
1078	1056	1089	1062	955	1004	996	928
904	938	895	890	934	856	890	928
875	856	936	919	841	859	900	826
880	874	852	844	821	912	826	866
858	940	907	885	908	923	953	965
968	993	1062	1131	1186	1311	1432	1684

1827	2125	2542	3098	3889	4783	6011	7909
9575	10864	11376	11027	9553	7826	6482	5132
4367	4248	4857	5740	6705	7653	7588	6949
5722	4410	3104	2136	1582	1354	1079	1058
1063	1018	1004	975	959	907	935	909
923	896	946	882	865	866	886	861
904	862	908	871	862	873	922	917
847	907	895	947	919	982	902	949
983	990	1015	1056	1121	1132	1151	1280
1366	1606	1801	2125	2549	2833	3112	3109
2816	2377	2036	1601	1317	1124	1040	973
984	947	910	992	963	913	986	942
852	920	890	966	960	1006	842	866
945	915	932	962	894	927	960	973
916	961	908	938	911	1011	1008	997
1028	1036	1090	1184	1311	1429	1524	1687
1740	1808	1849	1826	1821	1993	2127	2379
2952	3408	3869	4220	4193	3681	3184	2517
1919	1501	1238	1161	1107	1018	975	1013
984	1065	983	1043	1002	950	1013	963
1011	1002	1045	994	963	1042	1047	1006
978	1083	1121	1210	1204	1365	1420	1685
1796	1878	1842	1672	1608	1447	1291	1159
1099	1080	1033	1002	1064	1022	1007	1014
1023	1003	1001	1056	1039	967	998	947
1058	1069	1047	1048	1142	1098	1103	1119
1040	1027	1077	1023	1076	993	1069	1001
1070	1095	1052	1029	1103	1069	1043	1066
1038	1120	1098	1127	1096	1179	1206	1239
1296	1418	1475	1561	1813	2144	2433	2900
3661	4618	5551	6533	7278	7337	6525	5309
4136	2973	2295	1824	1555	1429	1272	1221
1168	1212	1191	1084	1113	1175	1139	1075
1149	1101	1098	1153	1120	1046	1121	1150
1139	1095	1097	1155	1174	1125	1130	1162
1147	1163	1230	1114	1126	1132	1120	1129
1140	1079	1134	1210	1171	1192	1132	1152
1161	1173	1211	1189	1196	1168	1218	1271
1273	1282	1361	1376	1416	1405	1496	1498
1529	1640	1649	1697	1857	1944	2190	2443
2697	3179	3804	4858	5928	7810	10568	13815
9272	25748	33975	41824	46628	47455	43473	36754
8647	21403	14824	10320	7625	6616	6497	6874
7164	7315	6607	5712	4698	3808	2983	2403
1929	1768	1569	1531	1497	1547	1454	1550
1530	1413	1407	1426	1429	1446	1476	1442
1465	1527	1535	1725	1793	1933	2132	2457
2962	3452	4406	5549	7237	9099	11567	13609
5043	15331	14206	11993	9661	7302	5345	3915
2797	2166	1879	1673	1591	1485	1489	1492
1369	1360	1349	1282	1298	1305	1221	1264
1328	1288	1246	1268	1263	1379	1352	1310
1276	1284	1300	1339	1376	1313	1338	1401
1461	1434	1465	1577	1582	1581	1733	1808
1909	2057	2393	2514	3005	3636	4720	6071

7473	9557	12188	15496	19804	25218	30708	34002
4298	31090	26511	21469	16517	11989	8102	5534
4026	3051	2720	2318	2092	2018	1869	1744
1584	1599	1595	1531	1372	1511	1479	1354
1400	1363	1358	1366	1458	1378	1330	1424
1362	1430	1323	1408	1408	1456	1546	1422
1444	1501	1407	1382	1341	1328	1366	1278
1365	1354	1408	1381	1417	1520	1525	1756
1858	2108	2402	2787	3054	3186	3217	3094
2969	2899	2690	2488	2453	2252	2281	2280
2401	2731	3289	3771	4600	5561	6550	6944
7222	6620	5907	4938	4162	3422	2693	2120
1895	1657	1506	1436	1545	1448	1541	1575
1683	1793	1949	1965	1975	1898	1796	1703
1598	1575	1446	1441	1377	1381	1385	1395
1402	1320	1381	1348	1337	1347	1291	1312
1237	1293	1302	1382	1285	1330	1282	1321
1319	1299	1348	1320	1348	1319	1359	1330
1335	1372	1342	1341	1415	1373	1334	1400
1458	1431	1418	1479	1499	1519	1558	1724
1810	1966	2164	2400	2838	3534	4280	5554
7047	8889	11432	14171	16603	18375	18593	17765
6332	13850	11661	9248	7122	5153	3747	2838
2452	2145	1985	1878	1751	1736	1672	1630
1621	1619	1490	1440	1497	1496	1565	1544
1471	1483	1504	1450	1508	1639	1622	1706
1737	1715	1879	2033	2076	2085	2340	2417
2622	2910	3403	3960	4743	6345	8144	10617
3860	18425	24290	32998	43936	55068	64190	68883
8907	64515	58162	49129	38842	30605	22532	16034
1093	7897	5639	4300	3599	3226	2739	2525
2201	2253	2056	1905	1857	1725	1663	1720
1542	1551	1495	1528	1447	1508	1478	1431
1463	1498	1464	1428	1410	1389	1337	1383
1363	1367	1385	1396	1372	1331	1364	1370
1321	1307	1391	1329	1420	1345	1462	1368
1390	1466	1394	1460	1478	1600	1524	1703
1796	1882	2015	2119	2297	2658	3022	3369
4198	5287	7386	10057	13524	17413	20337	22308
1942	20330	18034	15241	12713	9806	7538	5535
3853	2973	2495	2246	2160	2130	2073	2268
2419	2632	2861	2836	2876	2844	2805	2675
2556	2434	2308	2299	2393	2631	2980	3424
3928	4371	4823	4921	4658	4411	4019	3749
3345	3376	3322	3443	4079	5153	6693	9287
3150	17787	23645	28743	32617	33296	31721	28895
5615	21824	18052	14108	10405	7471	5449	4570
3570	2881	2425	2179	1963	1904	1896	1841
1962	1893	2013	2045	1962	1930	1929	1795
1649	1652	1604	1581	1556	1530	1758	1899
2121	2244	2490	2521	2449	2395	2143	2101
1907	1702	1640	1473	1419	1347	1357	1294
1300	1402	1342	1378	1546	1694	1852	1987
2182	2409	2497	2556	2487	2397	2641	2708
2834	3071	3190	3260	3299	3200	3173	3155

3209	3327	3587	3494	3586	3373	2987	2935
2667	2418	2250	1902	1787	1582	1507	1413
1409	1426	1480	1565	1632	1827	1942	2081
2304	2451	2477	2329	2188	2060	1809	1850
1536	1481	1353	1325	1240	1220	1275	1205
1164	1192	1191	1222	1179	1196	1172	1190
1164	1208	1197	1195	1236	1251	1180	1186
1273	1245	1292	1317	1366	1422	1468	1485
1639	1698	1841	2282	2616	3181	4040	5178
6849	9057	11488	14171	16363	17737	17716	16688
4907	13180	11805	10323	8666	7274	6019	5174
4461	4280	4682	4878	5194	5114	5104	4918
4576	4642	4954	5288	5928	7244	8441	10398
2053	12870	12742	12049	10881	9755	8596	7558
6090	4987	3898	3431	3270	3415	3678	4116
4200	4326	4219	3966	3555	3306	3078	2894
2589	2366	2276	2526	2723	3298	4021	5053
6200	7774	9244	10550	10955	10479	9964	8840
8102	7262	6117	5142	3862	3110	2526	2177
1845	1670	1474	1485	1312	1384	1322	1292
1277	1338	1336	1262	1223	1297	1258	1172
1242	1242	1231	1287	1190	1249	1222	1218
1203	1249	1226	1266	1278	1285	1285	1296
1411	1395	1408	1594	1686	2039	2341	2611
2948	3306	3522	3451	3362	3174	3264	3216
3321	3617	3941	4413	4817	5169	5442	5545
5371	5726	6057	6908	8142	10284	12776	16579
0630	22931	23246	22073	20095	17725	15706	13917
1865	9321	6971	4960	3682	2808	2325	2017
1816	1716	1704	1631	1535	1531	1465	1435
1383	1359	1326	1350	1324	1382	1349	1261
1288	1382	1379	1365	1376	1437	1522	1618
1645	1754	1948	2255	2839	3584	4805	5809
7430	8492	8649	8439	8013	7297	6635	6168
5314	4514	3677	2988	2254	2096	1814	1651
1522	1505	1463	1305	1272	1275	1298	1253
1270	1277	1160	1147	1268	1166	1178	1231
1223	1149	1232	1203	1218	1213	1225	1211
1208	1174	1165	1229	1215	1241	1258	1280
1326	1341	1373	1396	1418	1505	1681	1734
1933	2170	2647	3259	4158	5379	6826	8585
0177	11119	11535	11617	10741	10588	9648	9004
8283	7186	6077	5026	4108	3387	2814	2423
1958	1906	1665	1539	1549	1476	1450	1463
1489	1474	1566	1532	1538	1715	1791	1973
2187	2439	2802	3324	4007	5009	6339	7471
8592	9320	9358	8888	7908	7031	6461	5984
5238	4548	3647	2973	2309	2004	1913	1840
1865	1887	2005	2062	2265	2302	2308	2271
2191	2050	2092	2085	1916	1952	1826	1824
1826	1876	1997	2205	2302	2502	2853	3236
3962	4839	5836	6862	7773	7815	7652	6898
6431	5932	5582	4944	4304	3624	3110	2477
2144	1921	1775	1542	1545	1442	1423	1475
1382	1474	1416	1444	1404	1413	1534	1533

1691	1758	1979	2311	2803	3328	4176	5049
5915	6774	7382	8072	8591	8875	8870	8656
7961	7155	6243	5827	5044	4497	4104	3584
3299	3142	3234	3613	3761	4190	4696	5079
5434	5459	5273	4730	4397	3989	3642	3416
3114	2632	2360	2044	1768	1761	1706	1756
1819	1974	2104	2240	2276	2362	2228	2270
2235	2123	2000	2056	1897	1935	1840	1686
1675	1577	1538	1424	1449	1426	1390	1317
1340	1295	1205	1241	1191	1301	1224	1264
1251	1266	1389	1378	1452	1563	1700	1741
2025	2177	2540	2907	3341	3798	3926	3961
3748	3624	3492	3115	3047	2763	2577	2375
2126	1878	1715	1554	1507	1499	1404	1430
1432	1492	1504	1686	1820	2191	2460	2795
3162	3234	3384	3203	3132	3043	3018	3189
3384	3493	3589	3903	4243	4391	4281	4365
4161	3936	3687	3678	3776	3673	3414	3344
3236	3213	2885	2735	2564	2451	2341	2265
2189	2076	2160	2057	2104	2148	2368	2564
2916	3092	3132	3163	2961	2738	2614	2452
2341	2308	2120	2012	1755	1629	1562	1411
1488	1364	1435	1389	1453	1480	1587	1665
1783	1836	1815	1972	1877	1777	1799	1905
2057	2236	2435	2627	2950	3044	3102	3165
2935	2851	2808	2565	2626	2409	2244	2057
1905	1647	1596	1584	1457	1405	1415	1376
1371	1388	1403	1480	1584	1750	1949	2363
2770	3483	4069	4812	5377	5568	5353	5199
4622	4284	4026	3787	3625	3225	2788	2332
1977	1763	1450	1500	1398	1316	1275	1356
1271	1281	1317	1269	1276	1154	1180	1219
1227	1239	1223	1230	1202	1194	1161	1146
1143	1187	1215	1197	1153	1139	1134	1167
1160	1164	1172	1187	1150	1137	1091	1164
1190	1195	1101	1126	1136	1056	1187	1160
1098	1118	1144	1124	1084	1179	1105	1145
1101	1136	1111	1135	1066	1139	1120	1039
1147	1160	1135	1174	1166	1168	1182	1157
1205	1167	1210	1229	1349	1369	1526	1515
1625	1617	1610	1505	1577	1511	1540	1502
1517	1484	1578	1511	1692	1825	2030	2290
2677	3026	3329	3792	4239	4622	4984	5155
5053	4599	4271	4135	3889	3873	3682	3372
3205	2758	2480	2119	1941	1836	1783	1670
1499	1449	1466	1392	1346	1477	1504	1468
1575	1709	1800	2063	2299	2397	2608	2573
2758	2535	2390	2324	2270	2204	2207	2156
2057	1973	1888	1751	1782	1687	1674	1680
1523	1576	1550	1578	1499	1470	1499	1476
1490	1512	1519	1617	1604	1593	1645	1703
1857	2001	2198	2510	2967	3582	4279	5352
6300	7467	8154	8450	8368	7940	7695	7623
8302	8719	9423	9899	10117	9576	9276	8371
7617	6990	6584	6622	6605	6533	6466	6032

5924	5707	5375	5054	4826	4616	4721	4558
4454	4300	4322	4173	4315	4264	4509	5070
5953	6978	8601	10338	12619	14533	16022	16064
5277	13819	12410	11591	10729	10231	9883	8787
7286	5656	4583	3584	2898	2485	2244	2028
1869	1795	1680	1636	1625	1754	1772	1689
1729	1810	1845	1867	2035	2232	2476	2827
3289	3843	4361	5207	5930	6942	7775	8260
8158	7772	6973	6276	5763	5552	5300	5142
4721	4183	3621	3036	2593	2286	2176	1973
1865	1648	1689	1625	1545	1553	1555	1545
1502	1552	1466	1500	1552	1695	1627	1773
1902	2097	2382	2720	3255	3894	4595	5517
6428	7151	7519	7333	7104	6535	6147	5863
5611	5510	5279	5023	4615	4080	3493	3089
2833	2691	2740	2823	2939	3004	2954	2989
2785	2692	2535	2213	2222	2137	2193	2100
1905	1793	1731	1644	1550	1570	1593	1542
1678	1696	1807	1979	2117	2529	2704	2939
3381	3743	4018	4133	3883	3493	3349	3183
3066	3036	3070	2999	2821	2731	2551	2426
2191	2319	2331	2569	2979	3691	4680	6176
7823	9567	10939	12035	11842	10957	10573	10119
9764	10208	10216	9942	9624	8797	7689	6934
5988	5321	4793	4476	4332	4007	3924	3900
3807	3972	4119	4117	4407	4480	4437	4427
4246	4098	4005	3667	3660	3543	3409	3250
3162	3037	3010	2876	2722	2547	2303	2264
2080	2042	1969	1975	2042	2091	2061	2153
2258	2397	2677	2727	2685	2650	2436	2430
2406	2358	2180	2086	2067	1911	1856	1716
1650	1558	1439	1355	1356	1254	1242	1241
1189	1165	1145	1187	1224	1282	1159	1197
1149	1184	1209	1196	1191	1140	1209	1222
1208	1191	1247	1223	1191	1219	1287	1283
1296	1425	1380	1446	1539	1600	1606	1829
2040	2382	2672	3099	3686	4468	5322	5942
6623	7071	7528	7880	8036	8543	8668	8342
7902	7317	6537	6082	5945	5644	5513	5587
5177	4846	4671	4636	4599	5029	5266	5473
5441	5800	6075	6527	7379	8723	10049	11386
2140	12048	11197	9871	9217	8817	8881	9140
9574	9756	9748	9825	9701	9075	8618	8019
7083	6228	5452	5308	5103	4943	4725	4287
3766	3277	2784	2510	2283	2087	1987	1920
1957	1990	2043	1972	1985	1940	1861	1781
1918	1747	1916	1881	1988	2062	2175	2353
2685	3029	3364	3643	3828	3709	3722	3650
3582	3730	3886	4231	4306	4367	4370	4137
3718	3458	3191	3079	2991	3066	3112	3113
2989	2980	2980	2823	2622	2524	2416	2317
2126	2100	2042	1925	1922	1849	1791	1754
1663	1589	1532	1435	1382	1424	1554	1583
1678	1785	1816	1958	1972	1897	1838	1833
1717	1807	1731	1757	1831	1804	1822	1750

1891	2082	2237	2453	2821	3160	3541	3933
4016	3907	3816	3511	3182	3011	2982	2954
2904	3046	2990	2972	2975	3013	3033	3052
3169	3058	2801	2612	2331	2394	2356	2281
2333	2296	2327	2224	2134	2006	1893	1804
1893	1937	2022	2198	2431	2687	3136	3353
3653	4080	4525	4701	4799	4880	5027	5267
5650	5655	5993	6454	7033	7938	9055	10533
1891	13483	14592	14872	14524	13567	12182	11034
0184	9444	9353	9255	9051	8429	8074	6932
5887	4907	4025	3522	2998	2600	2289	2174
2013	1805	1785	1617	1521	1511	1420	1359
1281	1300	1308	1231	1235	1251	1210	1160
1235	1213	1167	1199	1154	1155	1204	1273
1285	1355	1398	1586	1740	1924	2170	2448
2416	2466	2407	2413	2166	2034	2024	1979
1977	2039	1987	2053	1843	1796	1695	1782
1756	1846	1765	1758	1614	1553	1485	1409
1415	1413	1451	1479	1384	1408	1307	1278
1310	1216	1245	1272	1313	1255	1349	1306
1379	1429	1432	1537	1736	1866	1988	2161
2199	2231	2178	2209	2253	2305	2369	2329
2266	2307	2253	2075	1967	1906	1732	1737
1674	1581	1590	1429	1448	1381	1361	1353
1283	1326	1336	1457	1444	1551	1601	1716
1953	2267	2619	3042	3668	4469	5017	5776
6478	6728	6370	6040	5317	4821	4529	4497
4375	4267	4374	4093	3812	3508	3050	2652
2252	2106	1833	1598	1470	1480	1382	1403
1360	1353	1294	1333	1331	1372	1271	1257
1299	1251	1317	1332	1328	1381	1413	1389
1513	1630	1713	1882	1909	1895	1914	1855
1914	1891	1922	2094	2173	2173	2357	2490
2689	2834	2975	3072	3079	2958	2815	2727
2622	2530	2489	2414	2445	2422	2329	2248
2082	1990	1894	1788	1654	1595	1612	1701
1651	1827	1934	2071	2347	2693	3233	3916
4457	5059	5420	5753	5695	5316	4995	4673
4503	4486	4640	4863	5323	5801	6308	6845
7342	7349	7526	7378	6899	6257	5552	5052
4769	4608	4561	4686	4705	4687	4332	4034
3440	3210	2930	2720	2413	2265	2101	1998
1904	1783	1661	1614	1571	1675	1648	1629
1694	1688	1762	1753	1899	1963	2282	2557
2863	3328	3594	3831	3839	3766	3585	3164
2836	2658	2673	2711	2645	2669	2638	2534
2210	2113	1836	1713	1681	1526	1455	1468
1478	1512	1571	1774	1824	2008	2164	2260
2252	2243	2168	2075	2079	2030	2106	2136
2144	2186	2204	2125	2168	2220	2208	2405
2488	2467	2517	2546	2580	2665	2734	2764
2732	2698	2795	2517	2568	2578	2714	2943
3253	3510	3767	4121	4444	4475	4571	4570
4685	4772	4979	5239	5350	5545	5688	5208
4910	4428	4027	3836	3569	3448	3441	3313

3056 2773 2349 2199

Scandium-fluor-nyböite (8.00, 0.02, 72.10)

419	389	392	395	402	425	380	367
394	414	396	380	397	379	416	395
427	397	374	395	387	383	411	394
435	403	415	403	430	395	405	392
401	422	423	387	397	403	406	390
403	403	408	400	415	397	415	400
428	403	386	413	429	408	455	376
423	425	431	416	466	400	467	463
439	456	440	480	454	443	524	507
468	519	512	533	517	498	560	575
597	601	590	639	681	745	754	879
915	969	1116	1166	1322	1422	1290	1231
1016	853	767	688	667	646	646	682
763	733	793	855	889	1022	1068	1071
1244	1360	1546	1710	1840	2068	2254	2712
2976	3581	3892	4753	5774	7130	8886	10580
2045	11946	11105	9070	6215	3828	2191	1289
923	776	712	654	651	552	558	550
526	505	458	475	435	435	468	423
440	398	443	429	428	404	429	436
434	415	416	458	456	443	429	421
415	423	402	416	420	428	399	437
449	436	406	428	435	400	426	428
437	433	425	428	407	408	411	437
416	407	399	395	393	432	450	452
398	421	425	437	396	426	429	435
412	497	420	424	424	424	440	449
386	437	423	407	396	402	410	404
418	445	390	453	408	449	424	422
430	395	436	439	453	422	428	452
455	429	473	447	399	456	410	499
416	451	421	465	419	392	445	442
428	449	442	419	441	443	426	402
485	424	458	475	442	445	469	460
463	517	458	484	504	509	557	573
536	526	566	585	553	625	568	590
518	490	500	464	510	511	490	498
486	470	509	478	480	446	474	450
501	511	512	484	530	511	480	508
491	491	529	472	465	475	473	446
484	441	471	437	464	471	454	444
420	496	427	453	447	467	449	440
433	444	479	472	443	443	439	426
484	470	442	446	431	432	435	437
418	451	474	469	462	458	417	398
456	505	446	481	444	486	464	457
452	441	447	464	444	482	451	481
446	441	451	450	424	466	418	441
477	442	466	461	446	444	454	448
461	468	458	443	446	472	464	479
436	466	500	480	451	451	423	474
437	484	485	461	491	508	464	460

503	473	489	440	468	505	489	510
460	511	470	494	474	453	445	477
499	453	468	499	511	486	483	457
482	472	520	513	500	498	546	525
517	546	567	555	602	581	692	749
850	737	1145	1288	1376	1468	1456	1410
1255	1141	997	869	759	804	771	768
893	922	962	995	1006	930	951	775
693	614	603	533	511	537	549	539
551	571	545	584	593	633	671	673
722	817	879	975	1041	1343	1456	1752
2188	2587	3180	3794	4253	4568	4510	4128
3426	2689	2169	1615	1261	989	867	768
697	669	605	560	574	622	669	626
719	713	840	890	954	962	1028	973
974	894	716	666	615	600	552	521
496	499	505	526	485	509	562	510
512	540	512	492	572	504	579	600
577	591	633	622	655	719	818	879
881	1008	1205	1245	1662	1960	2460	3013
3599	4679	5907	7486	9257	11190	12824	13229
2726	11263	9257	7505	6186	5232	4801	4470
4195	3871	3633	2967	2437	1835	1454	1112
942	853	776	661	664	614	613	618
620	528	572	577	477	551	501	531
550	532	577	521	536	471	490	544
538	519	496	498	540	531	526	522
503	508	550	532	522	550	498	507
487	505	528	529	525	532	534	558
516	563	576	637	627	636	697	729
762	765	679	644	681	620	532	497
567	551	552	513	551	574	575	609
583	558	526	549	503	534	495	504
565	522	514	497	564	513	554	598
556	559	630	601	634	656	730	814
882	977	1185	1371	1648	1856	2124	2391
2387	2353	2289	2182	1961	1688	1455	1296
999	900	817	723	702	591	632	619
639	633	563	574	546	605	633	606
606	606	606	683	754	823	859	975
1062	1286	1476	1824	2047	2429	3031	3606
4096	4349	4331	4162	3726	3055	2568	2066
1639	1433	1155	950	882	812	774	723
635	638	593	617	550	583	617	558
573	534	562	563	564	583	576	635
621	580	613	595	576	596	556	557
558	549	582	591	559	579	562	540
580	558	636	619	599	591	633	648
650	649	720	790	862	946	1065	1290
1557	1852	2331	2741	3173	3335	3335	3172
2733	2346	1909	1436	1209	1051	932	921
869	863	839	803	826	808	712	758
720	658	700	667	678	628	622	591
599	583	605	625	575	601	593	599
625	602	627	643	573	602	652	653

594	614	631	595	617	671	613	631
672	625	663	633	687	654	678	668
675	670	705	758	721	769	753	804
828	876	762	911	1011	1054	1140	1269
1320	1429	1508	1597	1832	2025	2484	2966
3765	4580	5964	7723	10121	13530	17264	21573
6372	29805	31883	31895	29269	25170	20525	15836
1913	8532	6295	4986	4023	3508	3116	2755
2529	2234	1769	1509	1381	1199	1074	1025
990	941	960	909	897	977	867	903
881	948	922	926	941	973	988	1038
1110	1140	1269	1381	1552	1894	2245	2783
3518	4573	5878	7671	10103	12974	16140	18600
0141	19779	17715	14911	12017	8874	6224	4188
2873	2082	1689	1487	1349	1289	1163	1156
1066	948	927	862	855	849	823	784
815	828	750	824	836	792	814	799
868	829	818	860	857	817	854	884
912	891	918	965	981	1122	1185	1229
1273	1384	1454	1632	1725	1968	2226	2654
3213	3836	4793	6088	8253	10949	15370	20757
7628	35479	42578	47170	49105	46668	40566	33560
5388	18842	13217	9138	6561	5296	4688	4661
4414	3929	3377	2798	2341	2034	1562	1308
1233	1137	1052	997	1061	938	972	926
890	937	959	988	990	965	1075	1136
1280	1380	1624	1829	2006	2347	2557	2550
2628	2473	2299	2194	2108	2179	2287	2444
2673	2750	2998	3031	3015	2850	2617	2438
1996	1860	1740	1625	1507	1574	1634	1844
2169	2635	3241	4068	6063	6795	8608	10503
2111	12829	12996	12299	10995	9426	8201	7021
6097	5638	5245	5129	4818	4469	3880	3567
2986	2543	2206	1907	1755	1630	1525	1545
1538	1821	2053	2285	2292	2180	1915	1759
1504	1277	1128	927	933	871	834	751
836	841	813	822	765	821	759	773
758	801	819	837	805	786	777	815
791	830	844	833	825	865	846	897
922	933	1029	1071	1110	1170	1149	1287
1369	1487	1543	1612	1689	1999	2207	2561
3063	3903	4931	6393	8224	10260	12316	13888
5226	15896	15070	13538	11278	9416	7449	5518
4056	2742	2111	1703	1521	1408	1318	1241
1250	1220	1205	1201	1154	1176	1176	1206
1143	1222	1268	1372	1354	1465	1530	1654
1792	2050	2081	2413	2803	3169	3878	4714
5937	7689	10151	13705	18115	24353	32323	40169
7891	53698	58700	60134	57972	53045	47102	40013
2430	24981	18753	13722	10111	7527	5850	4491
3733	3141	2702	2345	2068	1839	1712	1556
1503	1394	1324	1266	1224	1228	1186	1134
1079	1072	1022	1014	1034	967	986	1016
959	931	918	973	907	903	945	910
905	936	895	952	903	970	956	947

967	949	1083	1048	1053	1079	1149	1111
1188	1170	1394	1390	1553	1724	2068	2560
3170	4050	5529	7177	9189	11683	14199	15829
6526	16156	15004	13152	11775	10113	8199	6810
5717	4865	4412	4361	4428	4409	4756	4800
4963	4868	4460	4250	3746	3573	3379	2949
2586	2337	2177	2082	2042	1946	2022	2221
2511	2921	3517	4380	5640	7328	9718	12719
5858	19288	21911	23922	24931	24443	23430	21737
9631	17236	14183	11618	9213	7690	6275	5406
4529	3819	3434	3091	2874	2613	2416	2215
1982	1790	1611	1395	1356	1252	1103	1128
1096	1081	1156	1171	1203	1312	1278	1309
1231	1236	1240	1172	1246	1183	1152	1188
1163	1122	1051	1028	1042	953	914	883
882	818	837	774	780	795	786	810
816	849	878	869	962	982	1176	1215
1270	1300	1350	1379	1264	1318	1327	1392
1291	1275	1328	1402	1471	1577	1703	1640
1624	1580	1540	1461	1301	1306	1231	1180
1237	1224	1318	1390	1576	1660	1659	1666
1619	1494	1434	1351	1251	1223	1084	1029
1038	1051	1179	1304	1362	1643	1829	2167
2474	2714	2951	3013	2774	2557	2334	2114
1977	1659	1478	1317	1103	1110	967	960
986	935	962	960	930	864	947	927
927	970	944	991	1028	1072	1065	1177
1248	1337	1515	1702	1999	2422	2929	3524
4777	6239	8103	10134	12330	13610	14407	14499
3398	12583	11159	9804	8730	7327	6098	4994
4513	4220	4266	4750	5446	6291	6891	8242
9210	10078	10683	11536	12310	13125	13860	13932
3154	12120	11425	10212	8737	8017	6801	5729
4674	3884	3448	2982	2632	2357	2218	2072
2136	2088	2314	2681	3387	4218	5161	6558
7598	8464	9094	9138	9049	8715	8045	7597
6431	5689	4757	4042	3443	3001	2518	2292
2095	1922	1638	1532	1356	1332	1230	1185
1092	1020	1049	995	941	943	917	952
871	931	826	891	899	905	848	840
879	891	872	937	930	1066	1071	1287
1373	1579	1739	1871	2261	2654	2763	2896
2986	2971	2815	2768	2628	2461	2336	2136
2011	1826	1813	1729	1651	1698	1701	1973
2165	2471	2949	3340	3926	4507	4827	5018
5111	4932	4587	4518	4473	4377	4319	4629
5220	6085	7847	9724	12069	14939	17568	19163
9364	18611	16812	15203	13447	11781	9902	8043
6434	5038	3932	3354	3134	2874	2773	2420
2151	2044	1974	1851	1741	1699	1669	1582
1638	1718	1999	2300	2725	3356	3879	4535
5065	5108	4946	4789	4517	4278	4030	3670
3206	2901	2531	2248	1889	1736	1672	1520
1366	1267	1296	1128	1072	1084	1014	968
967	904	921	924	894	860	851	865

839	865	797	809	811	736	784	819
784	839	762	810	783	772	839	803
855	892	845	904	837	891	859	939
923	887	904	965	986	941	947	1031
1087	1146	1163	1329	1586	1906	2171	2793
3196	3941	4615	5533	6401	6927	7521	7478
7515	7325	6881	6476	5976	5504	4900	4317
3674	3156	2735	2321	2140	1867	1604	1392
1338	1193	1192	1158	1118	1130	1135	1138
1158	1097	1099	1158	1205	1183	1203	1288
1445	1609	1868	2186	2850	3618	4578	5496
6621	7889	8650	9236	9231	8940	8170	7369
6573	5876	5283	4458	3720	3003	2504	2193
2007	1955	1895	1952	2071	2239	2391	2924
3414	4164	4745	5532	6085	6291	6331	6353
6162	6112	5791	5229	4757	4253	3565	3039
2537	2387	1990	1820	1514	1311	1260	1138
1134	1110	1073	1052	1025	1018	1021	1044
958	1021	1031	1062	1013	1178	1194	1352
1446	1610	1851	2047	2437	2593	2846	3216
3451	3757	4048	4323	4489	4726	4733	4509
4197	3873	3555	3416	3020	2767	2367	2049
1886	1666	1509	1363	1288	1277	1168	1135
1156	1073	1081	1075	1170	1210	1246	1401
1403	1696	1940	2385	2645	3148	3582	4030
4269	4215	4270	4082	3859	3679	3474	3261
3074	2761	2383	2032	1825	1506	1476	1375
1238	1172	1166	1068	1101	1048	1036	1020
1055	1053	1084	972	975	984	887	899
936	889	933	914	879	888	859	866
865	835	920	924	972	954	1002	1031
1115	1175	1360	1352	1596	1937	2221	2610
3116	3548	4190	4911	5773	6399	6825	6610
6364	5663	5046	4580	4309	4216	3997	3540
3190	2921	3065	3182	3253	3308	3261	3237
3308	3179	3139	3194	3344	3365	3388	3573
3856	3921	4139	4374	4467	4376	4337	4061
3868	3737	3622	3389	3173	2822	2583	2383
2187	2050	1820	1642	1622	1595	1570	1541
1530	1589	1712	1815	1920	2048	2138	2219
2101	2207	2063	1848	1742	1632	1587	1480
1406	1273	1188	1163	1169	1245	1445	1610
1854	2147	2362	2538	2875	2890	2869	2776
2696	2557	2447	2265	2159	1854	1818	1607
1425	1303	1320	1227	1208	1210	1193	1214
1180	1295	1311	1319	1463	1570	1711	1824
1889	2127	2312	2530	2714	2901	2921	3210
3477	3740	4289	4301	4362	4225	3835	3629
3417	3322	3004	2727	2434	2212	1912	1672
1540	1378	1319	1186	1052	1093	1014	1039
1001	979	961	935	960	965	940	1003
949	938	973	985	909	904	810	977
902	830	840	847	838	884	821	925
925	886	930	908	858	885	896	915
964	922	1038	964	1000	1063	983	1029

999	934	947	948	893	947	902	914
945	894	921	917	912	966	955	911
909	882	907	878	834	831	827	863
848	893	924	868	833	832	877	835
903	975	880	997	937	1064	1129	1246
1345	1598	2006	2379	2869	3435	3842	4495
4887	4550	4526	4167	3998	3753	3677	3476
3138	2972	2556	2196	1868	1720	1588	1433
1328	1222	1157	1110	1060	1017	981	939
962	991	914	884	930	875	978	948
977	994	1040	1062	1179	1203	1369	1395
1509	1681	1761	1779	1876	1778	1728	1784
1803	1740	1869	1837	1810	1799	1732	1714
1645	1893	1920	2194	2379	2622	2886	3228
3321	3483	3683	3789	3855	3847	4019	4072
3963	4286	4534	4671	4963	5327	5878	6403
6905	7171	7268	7269	7150	6970	6651	6577
6167	5783	5470	5170	4761	4432	4220	3938
3925	3839	3924	3948	3946	3875	3804	3524
3340	2993	2777	2877	2691	2375	2312	2084
2039	1829	1807	1705	1647	1679	1678	1711
1666	1692	1697	1698	1885	1946	2195	2336
2875	3399	4105	5372	6899	8663	10807	13188
5154	16740	17530	16975	15474	13600	12148	11306
0761	10079	9128	7637	6134	4789	3748	3129
2555	2345	2159	2038	1870	1814	1755	1800
1834	1942	1936	2124	2302	2681	2987	3606
4174	4892	5677	6313	6907	7404	7427	6944
6479	5806	5578	5265	5259	4888	4633	4125
3433	2889	2388	2167	1900	1815	1625	1692
1551	1413	1455	1596	1589	1753	1999	2208
2685	3266	3684	4526	5049	5461	5862	5919
5842	5339	5043	4996	4764	4746	4519	4188
3659	3224	2872	2465	2275	2025	1980	1788
1639	1628	1458	1419	1289	1341	1338	1376
1352	1403	1478	1602	1582	1779	1774	1825
1745	1776	1647	1573	1567	1565	1526	1512
1480	1481	1371	1437	1433	1497	1537	1754
2093	2493	2888	3527	4325	5088	5765	6565
7447	7825	8119	8215	8604	8652	8773	9488
9338	9370	9492	9163	8941	8795	7765	7076
6286	5702	5371	5005	4679	4265	3835	3387
2973	2698	2395	2185	1935	1886	1897	1852
1943	2026	2052	2168	2456	2654	2943	3195
3497	3707	3896	4044	4014	4062	3992	3968
3868	3823	3780	3567	3410	3255	3166	3057
2940	2844	2745	2630	2574	2461	2376	2206
1981	1928	1703	1692	1659	1567	1555	1472
1432	1392	1383	1331	1394	1413	1308	1298
1338	1228	1284	1375	1416	1373	1382	1276
1304	1291	1280	1318	1287	1215	1163	1168
1070	1090	1066	1092	1052	1050	1027	959
961	971	969	977	1001	989	959	1038
1063	1127	1096	1126	1274	1204	1307	1344
1423	1523	1597	1723	1929	2063	2346	2730

3094	3718	4128	4748	5335	5905	6535	7138
7688	7837	8023	7768	7751	7677	7902	8631
8901	9232	9579	9478	9334	8851	8392	7940
7615	7385	7270	7058	6791	6310	6093	5552
5278	4927	4606	4554	4222	4221	4396	4512
4781	5273	5853	6752	7603	8553	9558	9684
9836	9497	8481	7804	7407	7171	7201	6858
6487	6069	5462	4887	4394	3942	3626	3304
2922	2866	2603	2478	2397	2308	2283	2146
2044	2005	1983	1944	1894	1920	1829	1832
1814	1720	1748	1715	1725	1683	1740	1713
1685	1634	1772	1797	1911	2017	2246	2368
2421	2531	2813	2961	3167	3340	3538	3627
3786	3698	3653	3507	3367	3102	2982	2809
2679	2682	2512	2378	2265	2135	2027	1893
1822	1845	1784	1821	1855	1826	1781	1695
1659	1608	1610	1522	1511	1521	1434	1428
1402	1324	1356	1308	1192	1262	1158	1194
1251	1178	1228	1318	1372	1490	1631	1926
2199	2559	2831	3345	3726	4136	4345	4464
4416	4184	4134	3923	3837	3828	3704	3550
3396	3135	3037	2636	2322	2156	1947	1790
1731	1649	1531	1532	1484	1406	1420	1435
1488	1537	1645	1727	1789	2075	2223	2399
2731	2844	3006	3205	3287	3340	3296	3232
3390	3474	3439	3557	3455	3531	3584	3741
3738	3799	3951	4112	4237	4537	5054	5856
6632	7838	9210	11059	12978	14818	16723	17873
8407	17812	16288	14508	12860	11634	11300	11046
1107	10724	10058	9274	7790	6259	5075	4076
3411	2906	2527	2244	2107	2023	2034	2015
1977	2046	2024	2059	1939	1949	1811	1800
1715	1741	1848	1763	1761	1761	1767	1705
1619	1579	1525	1444	1473	1489	1392	1421
1341	1308	1356	1236	1244	1148	1138	1218
1212	1237	1229	1122	1192	1180	1074	1072
1038	1070	1211	1153	1250	1208	1358	1311
1327	1385	1509	1486	1455	1394	1374	1417
1366	1368	1330	1313	1309	1309	1274	1282
1236	1290	1261	1232	1227	1283	1305	1305
1254	1250	1313	1315	1282	1156	1161	1192
1189	1229	1222	1164	1203	1151	1112	1124
1039	1059	1009	1053	1030	1002	1044	1013
985	1018	1006	1047	1046	977	1016	1020
973	1035	1023	1135	1084	1065	1090	1208
1158	1241	1327	1377	1495	1573	1759	1926
2274	2728	3143	3779	4583	5186	6118	6602
7079	7210	6848	6289	5830	5347	5053	4808
4708	4597	4551	4350	4072	3639	3027	2651
2219	1911	1659	1492	1388	1283	1198	1153
1111	1068	1152	1113	1106	1098	1227	1211
1223	1292	1382	1299	1458	1413	1558	1636
1722	1650	1760	1855	1886	1941	1953	2080
2212	2254	2466	2741	3016	3207	3256	3438
3340	3288	3294	3477	3542	3559	3618	3572

3530	3295	3048	2770	2504	2498	2469	2513
2529	2583	2699	2677	2907	3163	3582	4013
4421	4819	5112	5465	5738	5614	5974	6068
6215	6171	6267	6042	5825	5527	5131	4727
4533	4320	4039	3866	3558	3431	3048	2898
2721	2500	2357	2293	2151	2096	2033	2061
2059	2197	2274	2281	2347	2345	2242	2125
2060	1903	1864	1967	1885	1815	1783	1808
1804	1728	1660	1604	1586	1729	1757	1817
1885	1935	1990	2067	2106	2084	2096	2157
2198	2292	2442	2717	2694	2698	2816	2678
2574	2421	2334	2293	2348	2220	2354	2351
2488	2476	2627	2737	2732	2776	3007	3124
3368	3581	3608	3724	3675	3717	3719	3439
3361	3346	3197	3112	3006	3015	2904	2826
2661	2519	2297	2282	2141	2134	2081	2081
1984	2095	1942	1962	1822	1931	1892	1900
1936	2054	2143	2252	2424	2635	2830	3181
3384	3683	4065	4237	4402	4505		

Appendix C

AMPHIBOLE END-MEMBER NAMES AND FORMULAE, LEAKE (1978)

THE SODIC-CALCIC AMPHIBOLES: END MEMBER NAMES AND END MEMBER FORMULAE

End member	Formula
Richterite	$NaCaNaMg_5Si_8O_{22}(OH)_2$
Ferro-richterite	$NaCaNaFe^2_5Si_8O_{22}(OH)_2$
Alumino-winchite	$CaNaMg_4AlSi_8O_{22}(OH)_2$
Alumino-barroisite	$CaNaMg_3Al_2Si_7AlO_{22}(OH)_2$
Magnesio-alumino-katophorite	$NaCaNaMg_4AlSi_7AlO_{22}(OH)_2$
Magnesio-alumino-taramite	$NaCaNaMg_3Al_2Si_6Al_2O_{22}(OH)_2$

THE ALKALI AMPHIBOLES: END MEMBER NAMES AND END MEMBER FORMULAE

End member	Formula
Glaucophane	$Na_2Mg_3Al_2Si_8O_{22}(OH)_2$
Ferro-glaucophane	$Na_2Fe^2_3Al_2Si_8O_{22}(OH)_2$
Magnesio-riebeckite	$Na_2Mg_3Fe^3_2Si_8O_{22}(OH)_2$
Riebeckite	$Na_2Fe^2_3Fe^3_2Si_8O_{22}(OH)_2$
Eckermannite	$NaNa_2Mg_4AlSi_8O_{22}(OH)_2$
Ferro-eckermannite	$NaNa_2Fe^2_4AlSi_8O_{22}(OH)_2$
Magnesio-arfvedsonite	$NaNa_2Mg_4Fe^3Si_8O_{22}(OH)_2$
Arfvedsonite	$NaNa_2Fe^2_4Fe^3Si_8O_{22}(OH)_2$
Nyböite	$NaNa_2Mg_3Al_2Si_7AlO_{22}(OH)_2$

THE CALCIC AMPHIBOLES: END MEMBER NAMES AND END MEMBER FORMULAE

End member	Formula
Tremolite	$Ca_2Mg_5Si_8O_{22}(OH)_2$
Ferro-actinolite	$Ca_2Fe^2_5Si_8O_{22}(OH)_2$
Edenite	$NaCa_2Mg_5Si_7AlO_{22}(OH)_2$
Ferro-edenite	$NaCa_2Fe^2_5Si_7AlO_{22}(OH)_2$
Pargasite	$NaCa_2Mg_4AlSi_6Al_2O_{22}(OH)_2$
Ferro-pargasite	$NaCa_2Fe^2_4AlSi_6Al_2O_{22}(OH)_2$
Hastingsite	$NaCa_2Fe^2_4Fe^3Si_6Al_2O_{22}(OH)_2$
Magnesio-hastingsite	$NaCa_2Mg_4Fe^3Si_6Al_2O_{22}(OH)_2$
Alumino-tschermakite	$Ca_2Mg_3Al_2Si_6Al_2O_{22}(OH)_2$
Ferro-alumino-tschermakite	$Ca_2Fe^2_3Al_2Si_6Al_2O_{22}(OH)_2$
Alumino-magnesio-hornblende	$Ca_2Mg_4AlSi_7AlO_{22}(OH)_2$
Kaersutite	$NaCa_2Mg_4TiSi_6Al_2(O+OH)_{24}$

THE IRON-MAGNESIUM-MANGANESE AMPHIBOLES: GENERAL FORMULAE, END MEMBER NAMES AND END MEMBER FORMULAE

Monoclinic forms

Cummingtonite series $(Mg,Fe^2,Mn)_7Si_8O_{22}(OH)_2$

End member	Formula
Magnesio-cummingtonite	$Mg_7Si_8O_{22}(OH)_2$
Grunerite	$Fe^2_7Si_8O_{22}(OH)_2$
Tirodite	$Mn_2Mg_5Si_8O_{22}(OH)_2$
Dannemorite	$Mn_2Fe^2_5Si_8O_{22}(OH)_2$