

Julgoldite from Tafjord, Sunnmøre. Contribution to the Mineralogy of Norway, No. 67

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Julgoldite occurs in open fissures in a Precambrian granitic gneiss situated between Tafjord and Fjóra. Mineral growth in the fissures started under medium or low grade conditions and was completed, after a break, under very low grade conditions. The julgoldite-bearing association consists of calcite + quartz ± chlorite ± laumontite ± babingtonite ± julgoldite ± hematite ± titanite. Julgoldite crystals are very scarce and are found as small inclusions in calcite crystals or in equilibrium with calcite + laumontite ± titanite. The composition of this julgoldite (s.s.) is intermediate, ranging from 62% to 86% of the julgoldite component, and with an average composition corresponding to the formula $(\text{Ca}_{7.88}\text{Na}_{0.17})(\text{Fe}^{2+}, \text{Fe}^{3+})_{3.62}\text{Mn}_{0.05}\text{Mg}_{0.27}(\text{Fe}^{3+}_{5.75}\text{Al}_{2.25})(\text{Si}_{11.76}\text{Al}_{0.24}\text{O}_{43.21-39.59})(\text{OH})_{12.80-16.41}$. The large cell size of this mineral from Tafjord is indicative of extensive substitution of Fe^{2+} for Fe^{3+} and hence a low oxidation state.

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During the construction of a new road tunnel between Tafjord and Fjóra in the Sunnmøre district of western Norway, some mineralized open fissures were discovered. Most of these were destroyed by the construction work, but small pieces of the material were found by mineral collectors who sent some of it to the Mineralogical-Geological Museum in Oslo for identification. This material contained a number of uncommon minerals, e.g. babingtonite, bavenite, datolite, stilpnomelane and julgoldite, in addition to a number of common low-temperature minerals. Julgoldite, which is the Fe-dominant equivalent of pumpellyite, is very rare and previously only described from the Långban area of Sweden (Moore 1971), and from two localities in Scotland (Livingstone 1976). This study concerns the mode of occurrence and chemistry of this mineral in Tafjord.

Geological setting and petrography

The wallrock for these mineral occurrences is a light red, granitic Precambrian gneiss with low or medium grade mineral assemblages. The normal mineral assemblage is K-feldspar + plagioclase + quartz + hornblende ± biotite ± Fe/Ti-oxides. The gneiss encloses also a number of metaeclogites with relics of assemblages formed during high pressure metamorphism (Brueckner 1977).

The general sequence of crystal growth is simi-

lar for all the fissures, although there are some differences in mineral assemblages from one fissure to the next. The crystallization sequence consists of at least four associations of minerals, whose age relationships can be established because of overgrowth. These associations are:

- I. Orthoclase + calcite I + hastingsitic amphibole ± apatite ± biotite ± ilmenite ± magnetite ± zircon.
- II. Calcite II + quartz ± chlorite ± laumontite ± babingtonite ± julgoldite ± haematite ± titanite.
- III. Chlorite ± stilpnomelane ± magnetite ± apophyllite ± laumontite ± epidote ± tremolite/actinolite ± pyrite ± galena ± sphalerite.
- IV. Stilpnomelane ± chlorite ± datolite ± thau-masite ± bavenite.

Two other minerals, axinite and prehnite, have also been identified but it is not clear to which of these associations they are related.

The julgoldite-bearing association (II) consists mainly of calcite, quartz and chlorite. Laumontite, babingtonite, titanite, haematite and julgoldite are minor constituents. Julgoldite and haematite are commonly found as inclusions in, respectively, calcite and quartz, but in one sample julgoldite is also found outside calcite together with calcite, laumontite and minor titanite. Calcite from this association is transparent, colourless, and has well-developed crystals, 0.1 mm –

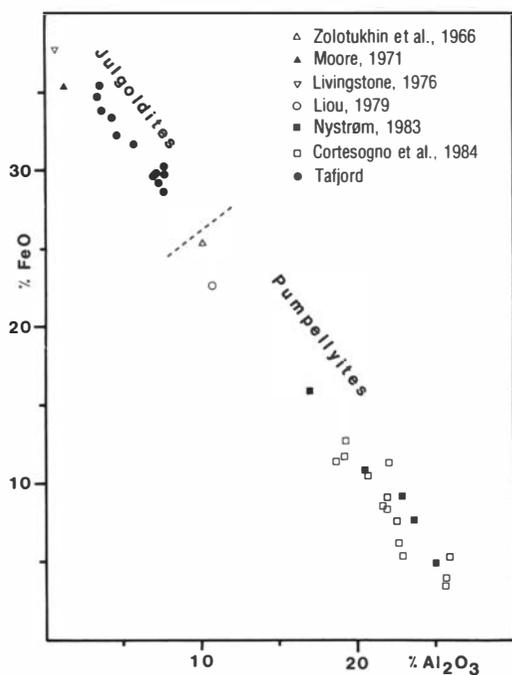


Fig. 1. Al/Fe-plot of julgoldites and some Fe-rich pumpellyites. FeO = Fe^{tot}.

> 10 cm in diameter. Chlorite is dark green and occurs as very fine grained masses. Aggregates of well developed bladed chlorite crystals, 1–2 mm in diameter, are also common. The quartz crystals exhibit large size variations, ranging from 1–2 mm to ca. 50 cm. Large crystals are usually subhedral while smaller ones are euhedral. Babingtonite occurs as euhedral black crystals, 0.2–2 mm in diameter. Laumontite and titanite crystals are euhedral and colourless, with diameters between 0.1–1 mm. Julgoldite grains are long prismatic, either single crystals or fanshaped intergrowths of single crystals with a maximum length of 1–1.5 mm. The crystals are subhedral with a black, submetallic lustre. Haematite inclusions are thin reddish blades with maximum length < 1 mm.

The first association of minerals is clearly formed under somewhat special conditions, as is seen from chloritization of amphibole and biotite and the strong corrosion of calcite and magnetite, while minerals belonging to association II, III and IV seem to have formed in uninterrupted sequence under similar conditions. Association I probably formed under nearly the same conditions as the medium grade assemblages in the

surrounding gneisses, while associations II, III and IV formed under much lower grade conditions. Pumpellyites are characteristically formed under very low grade conditions (Winkler 1979) and Fe-rich pumpellyites are generally considered to have formed under lower P, T-conditions than Al-rich ones (Seki 1961, Coombs et al. 1976, Liou 1979). The Tafjord julgoldite is compositionally not very different from some Fe-rich pumpellyites (Fig. 1) and has probably approximately the same conditions of formation. Lack of diagnostic mineral equilibria and ignorance of the chemical system forming the Tafjord julgoldite make it impossible to define the conditions of formation closer than to those of the low P, low T part of the very low grade of Winkler (1979).

Terminology

The general formula for pumpellyite group minerals can be written as: $W_8X_4Y_8Z_{12}O_{56-n}(OH)_n$, where W is Ca; X is Mn, Mg, Fe²⁺, Fe³⁺, Al; Y is Fe³⁺, Al; Z is Si and n is 12–16 (Allmann & Donnay 1971, 1973, Passaglia & Gottardi 1973). Substitution of Al for Si and Na and K for Ca increase n still further, while substitution of Ti in Y position could reduce n to less than 12. The data of Passaglia & Gottardi (1973) show, however, that these substitutions are seldom significant. The Fe²⁺, Fe³⁺ dominant member of this group, julgoldite, was first described by Moore (1971). Moore proposed that 'julgoldites are defined when Fe^(2+,3+) in X and Fe³⁺ in Y each occupy greater than fifty mole % of their positions'. Passaglia & Gottardi (1973) have proposed a different nomenclature where minerals with the pumpellyite structure are named pumpellyite if Al is predominant in the Y-position and julgoldite if Fe³⁺ is predominant. The julgoldites are further denoted Fe²⁺- or Fe³⁺-julgoldite depending on which ion dominates the X-position. The Tafjord julgoldite (Ca_{7.88}Na_{0.17}) ((Fe²⁺, Fe³⁺)_{3.62}Mn_{0.05}Mg_{0.27}) (Fe³⁺_{5.75}Al_{2.25}) (Si_{11.76}Al_{0.24}O_{43.21–39.59}) (OH)_{12.80–16.41} has distinct Fe dominances in both X and Y positions and would therefore be classified as julgoldite by either of the above definitions.

Analytical data

X-ray powder diffraction data and chemical analyses were made on a mineral separation obtained

Table 1. X-ray diffraction data for julgoldite from Tafjord, and for two julgoldites from the literature (I: Moore 1971; II: Livingstone 1971). The lists of $d_{I,II}$ are not complete for $d < 2$. hkl-values refer to the Tafjord julgoldite.

d_{obs}	d_I	d_{II}	hkl	d_{obs}	d_I	d_{II}	hkl
9.59	9.57	9.71	200	2.558	2.568	2.574	420
8.88	8.82	8.85	001	2.489	2.491	2.501	$\bar{7}11$
7.01	—	7.07	$\bar{2}01$	—	—	2.473	—
6.11	6.14	6.16	201	—	2.433	—	—
4.809	4.80	4.817	400	2.370	2.385	—	222
4.739	—	—	111	—	—	2.323	—
—	—	4.479	—	—	—	2.294	—
4.439	4.43	—	002	2.242	2.240	2.247	$\bar{8}02$
—	—	4.232	—	2.218	2.209	2.213	004
4.087	—	4.068	$\bar{3}11$	2.194	—	—	620
3.845	3.84	3.859	202	2.149	2.158	2.159	422
—	—	3.588	—	—	2.121	2.125	—
3.507	—	3.494	$\bar{4}02$	—	—	2.102	—
—	—	3.305	—	—	2.034	2.039	—
—	—	3.158	—	1.949	1.948	1.952	$\bar{6}04$
3.064	3.059	3.068	402	1.903	1.902	1.911	622
2.941	2.950	2.958	003	1.881	1.885	1.888	$\bar{8}21$
2.885	—	2.881	220	1.626	—	1.627	730
2.857	—	—	021	1.621	1.622	—	$\bar{7}11$
2.773	2.778	2.780	$\bar{5}12$	1.606	1.605	1.607	1200
2.710	2.717	2.724	221	1.512	1.517	1.519	040
2.674	2.680	2.675	$\bar{1}13$	—	—	—	—

by dissolution in cold diluted HCl of calcite containing julgoldite inclusions. For accurate diffraction data, a Guinier camera with FeK_{α} radiation ($\lambda = 1.93728 \text{ \AA}$) was used, with $Pb(NO_3)_2$ as internal standard. The observed d-values (Table 1) and calculated unit-cell dimensions (Table 2), are very close to the literature values of julgoldite from Långban (Moore 1971), and distinctly different from the cell dimensions of pumpellyite (Table 2).

Chemical analyses were performed on an ARL-EMX microprobe analyser equipped with a LINK energy-dispersive system. Altogether 12 analyses were made on a few mineral grains. If we define julgoldite (s.s.) as a mineral with 100% Fe^{3+} in the Y positions, then the average of all analyses from Tafjord contains 72% julgoldite (s.s.) while the Långban julgoldite has for comparison 94%. Zoning has been established in two grains and shows generally increasing Al and decreasing Fe from core to rim. This variation in Fe/Al-ratio corresponds to a range in composition from 86% julgoldite (s.s.) in the core to 62% julgoldite (s.s.) at the rim. Lack of material has made it impossible to determine the Fe^{2+}/Fe^{3+} ratio of the Tafjord julgoldite by analysis. The theoretical upper limit for this ratio will be when there is only enough Fe^{3+} to fill the Y position, and the lower limit when all Fe is Fe^{3+} . The structural formulae calculated from the aver-

age analysis (Table 3) give, according to these limitations, a possible range for n from 12.8 to 16.4. The compositional range shown by the analyses fills up most of the gap previously existing between the most iron-rich pumpellyite reported (Zolotukhin et al. 1966) and the Långban julgoldite (Moore 1971) (Fig. 1). The existence of a nearly continuous range of compositions from the julgoldite end to the pumpellyite end of this isomorphous series suggests that it is continuous, as was proposed by Moore (1971).

Discussion

The calculated unit-cell volume (1041.92 \AA^3) is surprisingly large compared to what might be

Table 2. Structure cell parameters for julgoldite from Tafjord. Published data for julgoldite and pumpellyite are shown for comparison.

	Julgoldite		Pumpellyite
	Tafjord	(Passaglia & Gottardi 1973)	(Surdam 1969)
a(Å)	19.426	19.432	19.12
b(Å)	6.047	6.081	5.89
c(Å)	8.949	8.922	8.81
β	97°38'	97°36'	97°24'
V(Å ³)	1041.92	1045.02	983.89

Table 3. Analysis of juldite from Tafjord (1A, B-2) and Långban (3) (Moore 1971), and pumpellyite from Noril'sk (4) (Zolotukhin et al. 1966).

	1A	1B	2	3	4
SiO ₂	33.09	33.09	32.92	34.0	34.83
TiO ₂	0.02	0.02	—	0.1	0.10
Al ₂ O ₃	5.93	5.93	3.58	1.3	10.10
Fe ₂ O ₃	35.02	21.50	25.82	29.6	18.05
FeO	—	12.16	12.06	8.7	9.09
MnO	0.18	0.18	0.18	0.2	0.02
MgO	0.51	0.51	0.40	0.2	0.94
CaO	20.70	20.70	20.84	22.0	20.50
Na ₂ O	0.25	0.25	0.39	—	0.18
K ₂ O	0.05	0.01	0.02	—	—
H ₂ O	n.d.	n.d.	n.d.	4.69	5.62
Total	95.71	94.35	96.21	100.79	99.43
Structural formulae.					
Si	11.761	11.761	11.639	12.00	12.34
Al	0.239	0.239	0.361	—	—
Al	2.245	2.245	1.131	0.48	4.22
Fe ³⁺	5.750	5.750	6.869	7.52	3.81
Ti	0.005	0.005	—	—	0.02
Fe ³⁺	3.616	—	—	2.08	1.01
Fe ²⁺	—	3.616	3.565	1.92	2.68
Mn	0.054	0.054	0.054	—	0.01
Mg	0.270	0.270	0.211	—	0.49
Ca	7.883	7.883	7.894	8.0	7.78
Na	0.172	0.172	0.267	—	0.13
K	0.005	0.005	0.009	—	—
O	43.205	39.590	39.363	42.08	42.70
OH	12.795	16.410	16.637	13.92	13.30

1A, B is the average of 12 single analyses; 1A with minimum Fe²⁺/Fe³⁺ ratio, 1B with maximum ratio. 2 is the most ironrich analysis, and with maximum Fe²⁺/Fe³⁺ ratio. Structural formulae for; 1A, 1B and 2 are calculated on the base of 32 cations, 3 and 4 are taken from Passaglia and Gottardi (1973).

expected from the Fe versus cell volume diagrams of Passaglia & Gottardi (1973). This could be explained by postulating an erroneously high Al/Fe ratio in the average composition given in Table 3. However, there is no reason to suspect such an error; this Al/Fe ratio is most probably if anything too low since most of the analyses were performed on the Fe-rich parts of the grains. Another explanation might be that there is not a simple linear relation between Fe and cell size as proposed by Passaglia & Gottardi (1973). There are several substitutions involved here and Passaglia & Gottardi based their line on relatively few data. The most important effects of substitutions in a juldite are: Al instead of Fe³⁺ in Y position and Fe³⁺ instead of Fe²⁺ in X position – both of which will reduce cell size. Al instead of Si in Z position will increase cell size. This last substitution is not very extensive and cannot be sufficient to account for the observed large cell size. The only actual substitution which can in-

crease the cell size markedly is thus Fe²⁺ instead of Fe³⁺ in X position. The large cell size might thus be indicative of a low oxidation state for this juldite which would also mean a high value for n (close to 16). This deviation from the "expected" value merely shows that the spread in cell size is just as great at the juldite end as it is at the pumpellyite end of this isomorphous series.

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