

Indialite in xenolithic rocks from Somma-Vesuvius volcano (Southern Italy): Crystal chemistry and petrogenetic features

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ABSTRACT

The rare mineral indialite, a hexagonal high-temperature form of cordierite, has been discovered for the first time in Italy at Somma-Vesuvius volcano in unusual pyrometamorphic ejecta. The indialite-bearing xenoliths are composed of several pale yellow fragments consisting of very fine-grained indialite with traces of cristobalite. On the surface of the fragments, colorless indialite and pale-blue, prismatic osumilite crystals form whitish crusts, with subordinate phlogopite and trace amounts of corundum. Gypsum and Fe-oxides are ubiquitous. Chemical composition of the Italian indialite is characterized by high X_{Mg} (~0.95) and significant K_2O (~1.4 wt%). Single-crystal X-ray diffraction measurements give cell dimensions very similar to those of the indialite from the Bokaro coalfield. The diffraction pattern shows no significant deviation from the symmetry conditions of the space group $P6/mcc$, which is the space group generally accepted for high-cordierite. The presence of guest K (and lesser Ca) in the sixfold channel does not produce appreciable distortions in the framework of T2 tetrahedra, probably because of the weak interactions between guest and the ring O2 atoms. Indialite-bearing rocks originated through a pyrometamorphic process at shallow depth and at maximum temperature close to ~1200 °C. Rapid crystallization and subsequent quenching favored a higher symmetry, thus “freezing” the space group $P6/mcc$.

INTRODUCTION

Indialite, the rare high-temperature hexagonal form of cordierite (Gibbs 1966; Meagher and Gibbs 1977; Cohen et al. 1977; Hochella et al. 1979; Wallace and Wenk 1980; Armbruster and Bloss 1982; Armbruster 1986; Geiger et al. 2000; Malcherek et al. 2001), was originally discovered in fused sediments formed by the burning of underlying coal seams at Bokaro, India, but described as cordierite (Venkatesh 1952). Later, it was proved that this mineral was actually a high-temperature polymorph of cordierite and was named indialite (Miyashiro and Iiyama 1954; Miyashiro et al. 1955). Indialite was subsequently reported from few other natural occurrences (Table 1) typically in metamorphic rocks of the sanidinite facies, that is buchites and paralavas, or in xenoliths within young volcanics (Kitamura and Yamada 1987; Schreyer et al. 1990; Wood 1994). Synthetic hexagonal cordierite is often found in glass ceramics and has a wide range of technical applications (Evans et al. 1980; Haas et al. 1987; Peplinski et al. 1998, 2000). Other hexagonal forms of cordierite containing boron or beryllium have been synthesized by Sei et al. (1997) and Smolin et al. (1999), respectively, to investigate structural changes and variations of physical properties. Moreover, the nature of the Al/Si ordering and the structural transition from high- (hexagonal) to intermediate- (modulated hexagonal) to low- (orthorhombic) cordierites have been the subject of numerous studies (Putnis et al. 1987; Güttler et al. 1989; Redfern et al. 1989; Daniels and Gies 1992; Capitani et al. 2002).

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Indialite from Mt. Somma-Vesuvius volcano, near Naples, Southern Italy, is the only known occurrence in Italy. It was found together with osumilite (Balassone et al. 2001) in microgranular metapelitic ejecta within lavas erupted in 1872. Here we present a detailed crystal-chemical study of Somma-Vesuvius indialite, and analyze the petrologic conditions required for its genesis.

GEOLOGICAL SETTING AND SAMPLE DESCRIPTION

Somma-Vesuvius volcano (Fig. 1), a Quaternary silica-undersaturated alkaline potassic to ultrapotassic eruption center (Beccaluva et al. 1991), is one of the most studied volcanoes in the world because of its accessibility, repeated recent eruptions, and controversial origin (Santacroce 1987; Spera et al. 1998). It belongs to the Roman Comagmatic Province (RCP), and is located on a several kilometers thick Meso- to Cenozoic carbonate platform, locally covered by Tertiary pelitic sediments. The petrologic affinity of Somma-Vesuvius products ranges from high K (HKS) to K series (KS). The HKS ranges from leucite-bearing basanites and plagioclase-bearing leucites to leucite phonolites. The KS ranges from slightly silica undersaturated to silica saturated, with leucite common in the groundmass. The volcanological history of Somma-Vesuvius is very complex (Santacroce 1987; De Vivo and Rolandi 2001 and references therein). Its last eruptive events are commonly reported as recent activity (1631–1944 AD), and comprise exposed lavas including those from the very plentiful 1872 eruption. The variety of minerals at Somma-Vesuvius is well known (Gilg et al. 2001) and many new minerals have been discovered in the ejected xenoliths, which

TABLE 1. World indialite localities

Locality	Host rock	Associated minerals
1. Bokaro coalfield, India	Fused sediments derived from the burning of underlying coal seams	Pl, En, Mag, Crn, Sil, glass
2. Unazuki schists, Hida terrane, Japan	Cordierite vein of polymetamorphosed pelites	Crd, Sil, And, Bt, Qtz
3. Southwestern Shannon County, South Dakota	Fused sediments	
4. Pyramid Lake, Nevada		
5. Bellerberg and Herchenberg volcanoes, Eifel district, Germany	Metapelitic xenoliths	Crd, Os, Trd, Sa, Psb, glass
6. Powder River Basin, Wyoming	Natural burned coal beds	Ol, Trd, Crs, Fe-Crd, An, Mag-Hc-Usp _{ss} , Hem-Mag _{ss} , Mel _{ss} , Ti-Adr, Wo, Mul, En, Ap, Ne, Al-cpx, K- and Ba-Fld, Dor, Psb, Shm
7. Somma-Vesuvius, Italy	Xenoliths in 1872 A.D. lavas	Os, Hem, Phl, Gp, Mag, Crn, Crs, glass

Notes: Source of information on indialite localities: 1 = Venkatesh (1954), Miyashiro and Iiyama (1954); 2 = Kitamura and Hiroi (1982); 3 = Roberts et al. (1990); 4 = Anthony et al. (1995); 5 = Schreyer et al. (1990); 6 = Cosca et al. (1989); 7 = Balassone et al. (2001), this paper. Symbols (partly from Kretz, 1983): Pl = plagioclase, En = enstatite, Mag = magnetite, Crn = corundum, Sil = sillimanite, Crd = cordierite, And = andalusite, Bt = biotite, Qtz = quartz; Trd = trydimite; Sa = sanidine; Os = osumilite; Ol = olivine; Psb = pseudobrookite; Crs = cristobalite; Fe-Crd = iron-rich cordierite; An = anorthite; Mag-Hc-Usp_{ss} = magnetite-hercynite-ulvöspinel solid solutions; Hem-Mag_{ss} = hematite-magnetite solid solutions; Mel_{ss} = melilite solid solutions; Ti-Adr = titanian andradite; Wo = wollastonite; Mul = mullite; Ap = apatite; Ne = nepheline; Al-Cpx = aluminium-rich clinopyroxene; K- and Ba-Fld = potassian and barian feldspar; Dor = dorrte; Shm = sahamalite; Phl = phlogopite; Gp = gypsum.

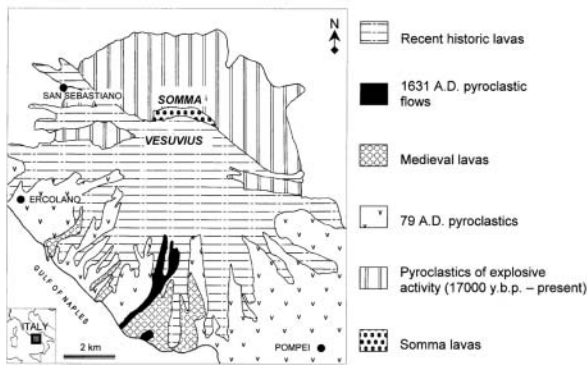


FIGURE 1. Map of Somma-Vesuvius volcanic complex. The locality of outcrop of indialite-bearing samples is just south of the town of San Sebastiano.

are often associated with pyroclasts in the Plinian eruptions. The genesis and mineralogy of peculiar xenoliths found in the 1872 lava were widely described by Scacchi (1886 and references therein), who was able to characterize many crystal phases.

Indialite-bearing xenoliths were collected by one of us (E.F.) from an 1872 lava outcrop close to Belvedere (1 km south of S. Sebastiano; Fig. 1). These xenoliths, rough size 100 × 80 × 40 mm, are friable and show a microgranular texture. They are composed of several pale-yellow rounded fragments (~20 mm diameter) and consist of very fine-grained indialite, trace amounts of cristobalite, and glass. On the surface of the fragments, colorless indialite and pale-blue prismatic osumilite crystals form whitish crusts (~0.3 mm thickness). Phlogopite is subordinated in these crusts, and traces of corundum are also present. Euhedral Fe-oxides (hematite and traces of magnetite) occur both in the fragments and in the crusts. Concentrations of gypsum as grains line cavities. The whole mineral assemblage of the 1872 Somma-Vesuvius ejecta was identified by a combination of XRD and qualitative-quantitative SEM-EDS techniques. SEM images of indialite crystals, also together with osumilite, clearly show hexagonal prismatic morphologies (Fig. 2). The maximum dimension of the indialite individuals is around 0.5 mm.

EXPERIMENTAL METHODS

Great care was taken to pick inclusion-free indialite crystals with the help of a stereomicroscope. When viewed under cross-polarized light the crystals showed homogenous behavior in different crystallographic directions. Density measurements were made with heavy liquids. The preliminary identification of indialite was performed by means of powder X-ray diffraction (XRD) patterns, using a Seifert MZVI automated diffractometer (CuK α radiation 1.5418 Å, 40 kV, and 30 mA; 2 θ range between 5 and 75°; 2 θ /min speed equal to 0.5°). The program XDATA (part of the software package XDAL 3000 from Rich. Seifert & Co.) was used for evaluating the profiles. Major-element analyses were performed by energy-dispersive spectroscopy (EDS) on a Jeol JSM-5310 instrument (Link Analytical 10000 system with ZAF4/FLS quantitative software) at CISAG, Naples. Silicates, oxides, and pure elements were used as standards; operating conditions were 15 kV accelerating voltage and 12 μ m spot size. For the euhedral indialite forming the crusts, four to ten individual points on several grain mounts, equally spread across each sample, were analyzed. Microanalyses also were carried out on the single crystal used for the structure refinement. EMP analyses of the fine-grained indialite of the fragments were conducted on thin sections. The occurrence of a fluid phase such as H₂O and CO₂ in the channel cavities of indialite was tested on several crystals by polarized single-crystal FTIR measurements at room temperature (Perkin Elmer GX-Custom/Optica instrument, with a microscope attachment) at ENEA, Naples.

Single-crystal diffraction experiments were carried out by means of Enraf-Nonius CAD-4 diffractometer on line with a MicroVAX 3100 computer (CAD-4 software) and graphite monochromatized CuK α radiation ($\lambda = 1.5418$ Å) at room temperature (293 K) at IBB-CNR, Naples. A small single crystal (0.13 × 0.09 × 0.08 mm) was used for the cell parameters measurements and data collection. Accurate cell dimensions were obtained by least-squares refinement of the setting angles of 25 reflections at medium θ ($31 < \theta < 38^\circ$). Cell constants are: $a = b = 9.775(2)$, $c = 9.354(2)$ Å, $\alpha = \beta = 90^\circ$, $\gamma = 120^\circ$, $V = 774.1(5)$ Å³ and compare very well with those of the indialite from Bokaro (Meagher and Gibbs 1977). A total of 2615 reflections in the range $-12 \leq h \leq 11$, $-2 \leq k \leq 12$, $-2 \leq l \leq 11$, $\theta_{\max} = 75^\circ$, were measured using ω - θ scan mode as suggested by peak-shape analysis. During the data collection, the crystal and equipment stabilities were checked by the intensities of three standard reflections monitored every 3h. No significant decay was observed (2% variation). The diffraction pattern well agrees with the symmetry conditions required by the space group $P6/mcc$, and a careful check on the systematically absent reflections did not show extra reflections with significant intensity [$I > 3\sigma(I)$]. The trends of $\log(I/\sigma_I)$ vs. $\sin \theta/\lambda$ for the possible and the systematically absent reflections are shown in Figure 3. The equivalent intensities were averaged ($R_{\text{int}} < 0.026$) yielding a set of 298 unique reflections. The intensities were corrected for the usual Lorentz and polarization factors.

RESULTS

Under the petrographic microscope, indialite crystals appear uniaxial, untwinned, and have rare Fe-oxide inclusions. Its cal-

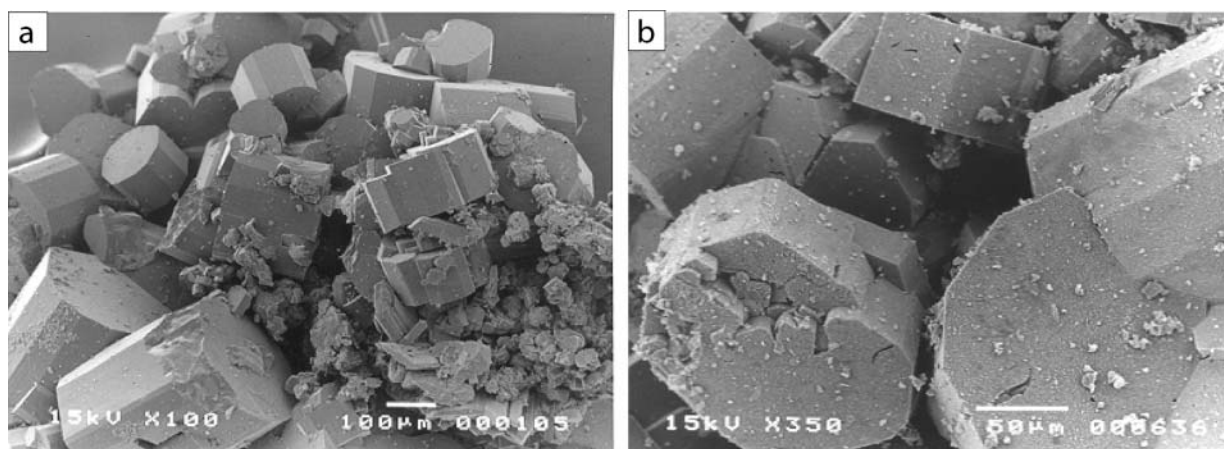


FIGURE 2. SEM images of indialite clusters – alone (a) and with flattened prisms of osumilite (lower half) (b).

culated and measured densities are 2.54 and 2.52, respectively. Accurate XRD measurements show no splitting of peaks in the diffraction patterns, so that the distortion index Δ (as defined by Miyashiro 1957) is zero, in agreement with the hexagonal metrics.

Table 2 shows representative chemical compositions of both fine-grained indialite and euhedral crystals from Somma-Vesuvius xenoliths (mean of six to ten analyses; column 1 and 2, respectively). The average chemical analysis (six points) of the crystal used for structure refinement is shown in column 3, and, the compositional ranges observed in all the euhedral crystals analyzed are shown in column 4. For comparison, the chemical analyses of the Unazuki, Bokaro coalfield, and Eifel indialites are also reported. The Italian indialite differs from the other specimens in having a higher MgO content and a lower FeO content. [Note that for the Italian indialites, higher FeO contents characterize the fine-grained yellow fragments (FeO = 2.51 wt%, see column 1)]. The molar fraction $X_{Mg} = Mg/(Mg + Fe^{2+})$ is in the range 0.90–0.98, whereas values of X_{Mg} for indialites from the other localities lie between 0.45 and 0.86.

The indialite studied here always contains significant amounts of K₂O (1.21–1.44 wt%), and K also is as found in indialites from Bokaro coalfield and from Eifel (Schreyer et al. 1990). Low amounts of CaO (up to 0.58 wt% for the euhedral crystals) are rather common, whereas traces of Na₂O (up to 0.28 wt%) were found in ~10% of the analyzed crystals. MnO (up to 0.10 wt%) was also sporadically detected in the spot analyses.

As regards elemental zonation, each Italian sample proved to be homogeneous. The structural formulae always show a slight deficiency in Si (<5 apfu, atoms per formula unit) and an excess in Al (>4 apfu), as compared with the ideal formula of cordierite, but anyway, the sum Si + Al is close to the ideal value of 9.0 apfu for the tetrahedral sites. A slight excess in the sum of cations is also typical, with an average value of 11.16 apfu for the euhedral crystals. Micro-FTIR investigations in the range 5000–200 cm⁻¹, which relate to the presence of H₂O and CO₂, have shown no absorption in the concerned regions, thus excluding the presence of volatiles in the channels.

To better investigate the peculiarities of Italian indialite, a

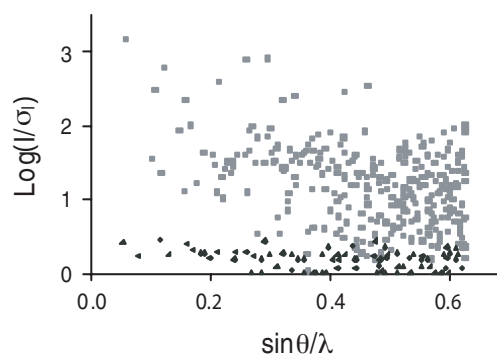


FIGURE 3. Trends of $\log(I/\sigma)$ vs. $\sin \theta/\lambda$ of the possible (gray squares) and systematically absent (black triangles) reflections in the Somma-Vesuvius indialite.

single-crystal diffraction study was undertaken. Three-dimensional anisotropic refinement (on F) was carried out in the $P6/mcc$ space group by full-matrix, least-squares method (SDP programs), using as initial values the atomic parameters of the indialite of Meagher and Gibbs (1977). The Al/Si occupancy-ratio in T2 sites was chosen equal 1/3 according to the best ratio found in high-cordierite (Daniels 1992). At convergence, the discrepancy index R reached the value of 0.045 on 298 independent reflections and 28 variables, without significant differences from the Meagher indialite model. However, the difference Fourier map showed, along the sixfold axis, a region of residual electron densities, within $2e/\text{\AA}^3$, in the shape of an hourglass and confined in the channels delimited by two six-member rings formed by T2 tetrahedra. This residual electron density is confined to the sixfold axis but not in a special position, so it hardly can be ascribed to error accumulation. It can be caused by the presence of a guest with a low occupancy factor (see Daniels 1992). According to the chemical composition determined on the same crystal used for the single-crystal study (Table 2, Column 3), K and Ca were identified as guests and the following chemical composition was used in the structure refinement:



TABLE 2. Representative electron-microprobe analyses of indialite from Somma-Vesuvius (SV), compared with Unazuki (U), Bokaro coalfield (BC) and Eifel (E) samples

	SV				U	BC	E
	1	2	3	4			
SiO ₂	48.28	48.91	48.74	48.48–49.68	47.33	46.60	47.46
TiO ₂						0.49	
Al ₂ O ₃	34.22	35.41	35.83	34.18–35.91	32.96	33.96	35.42
FeO	2.51	0.52	0.72	0.70–1.27	12.30	3.33	5.98
MgO	12.58	12.68	12.86	12.21–12.92	5.64	11.62	9.87
MnO	0.08			0.00–0.10	0.35	0.01	0.21
K ₂ O	1.34	1.41	1.37	1.21–1.44		1.23	1.16
Na ₂ O	0.03			0.00–0.28	0.36	0.04	0.06
CaO	0.57	0.41	0.42	0.00–0.58		0.15	
Sum	99.61	99.34	99.94		98.94	97.43	100.16
Formula proportions based on 18 O atoms							
Si	4.842	4.861	4.820		4.945	4.791	4.793
Ti						0.038	
Al	4.045	4.148	4.177		4.059	4.115	4.216
Fe ²⁺	0.211	0.043	0.060		1.074	0.286	0.505
Mg	1.881	1.879	1.895		0.879	1.781	1.486
Mn	0.007				0.031	0.001	0.018
K	0.171	0.179	0.173			0.161	0.149
Na	0.006				0.073	0.008	0.012
Ca	0.061	0.043	0.045			0.016	
S _{cations}	11.224	11.154	11.170		11.061	11.197	11.179
X _{Mg}	0.90	0.98	0.97		0.45	0.86	0.75

Notes: 1 = fine-grained indialite (mean of 10 analyses); 2 = euhedral crystals (mean of 6 to 10 points on 25 selected grains); 3 = crystal used for structure refinement (mean of 6 analyses); 4 = compositional variation related to the euhedral indialite grains analyzed. Chemical composition of U indialite is from Kitamura and Hiroi (1982), chemical data of BC and E indialites are from Schreyer et al. (1990).

TABLE 3. Positional and thermal parameters of Somma-Vesuvius indialite*: in square brackets, the corresponding parameters of BC indialite (Meagher and Gibbs 1977) are reported

Site	x	y	z	B _{eq}	Element Occupancy	β ₁₁	β ₂₂	β ₃₃	β ₁₂	β ₁₃	β ₂₃
T1	0.5 [0.5]	0.5 [0.5]	0.25 [0.25]	1.10(2) [0.9(1)]	Al 0.917 Si 0.083	0.0041(1)	β ₁₁	0.0032(2)	0.0048(2)	0.0	0.0
T2	0.3734(1) [0.3727(4)]	0.2665(1) [0.2668(4)]	0.0 [0.0]	1.33(2) [1.16(9)]	Si 0.750 Al 0.250	0.0056(1)	0.0041(1)	0.0040(1)	0.0059(2)	0.0	0.0
M	0.3333 [0.3333]	0.6667 [0.6667]	0.25 [0.25]	1.40(3) [1.8(2)]	Mg 0.970 Fe 0.030	0.0047(2)	β ₁₁	0.0043(2)	β ₁₁ /2	0.0	0.0
O1	0.4852(2) [0.4851(6)]	0.3494(2) [0.3494(5)]	0.1444(2) [0.1445(6)]	1.60(4) [1.4(1)]		0.0063(2)	0.0052(2)	0.0048(2)	0.0065(3)	-0.0005(5)	0.0002(4)
O2	0.2306(4) [0.2305(11)]	0.3081(4) [0.3093(11)]	0.0 [0.0]	2.47(7) [2.2(3)]		0.0108(4)	0.0095(4)	0.0070(4)	0.0147(5)	0.0	0.0
K	0.0	0.0	0.162(6)	9(1)	K 0.168 Ca 0.042	0.020(3)	β ₁₁	0.05(1)	β ₁₁ /2	0.0	0.0

Note: Anisotropic displacement parameter are in the form: $\exp[-(\beta_{11}h^2 + \beta_{22}k^2 + \beta_{33}l^2 + \beta_{12}hk + \beta_{13}hl + \beta_{23}kl)]$.

* Space group P6/mcc with $a = b = 9.775(2)$ Å, $c = 9.354(2)$ Å, $\alpha = \beta = 90^\circ$ and $\gamma = 120^\circ$.

where the stoichiometry has been calculated from the formula $K_xCa_yMg_zFe_{2-z}Al_{4+x+2y}Si_{5-x-2y}O_{18}$ through weighted least-squares using a weighting factor of $1/\sigma^2$, where σ^2 was chosen proportional to individual molar content. Taking into account the low Ca amount (Ca/K molecular ratio about 1/4), the guest, K and Ca, is hereafter simplistically indicated as K. A new anisotropic refinement was carried out on the 298 independent reflections and 31 variables including the extinction coefficient = $5.9(2) \times 10^{-6}$ (Stout and Jensen 1968). At convergence, the conventional R factor was 0.040, $R_w = 0.043$ with $w = 1/[\sigma^2(F_o) + (0.010F_o)^2 + 2]$ (Killeen and Lawrence 1969), maximum shift/error = 0.001, and residual electron densities in the range -0.57 and $0.46e/\text{\AA}^3$. The final atomic parameters are given in Table 3 together with, for comparison, the positional values of the Meagher and Gibbs indialite. The guest cation is positioned in the hexagonal channel delimited by T2 tetrahedra, on the sixfold axis and at $z = 0.162$. For the symmetries of $P6/mcc$ space group, this position

gives rise to a distance of $1.64(8)$ Å with the equivalent one at $1/2 - z$. This distance is too short for the cation dimension and, consequently, K cannot occupy the two positions at the same time, but only alternatively. An arbitrary choice of the two alternative positions, leaving out the translation symmetry along a , is shown in Figure 4. The guest cation is coordinated with two sets of six O2 atoms at the distances $3.11(3)$ and $4.16(4)$ Å, respectively, whereas the distances from the O1 oxygen atoms are rather longer: $4.24(1)$ and $4.61(2)$ Å. The most significant interatomic distances and bond angles are given in Table 4. The averaged T1-O and T2-O bond lengths are 1.718 and 1.651 Å, respectively. These distances agree fairly well with the estimated values (1.745 and 1.646 Å, respectively) on the basis of Si, Al contents in T1 and T2 tetrahedra (Cohen et al. 1977), even if the T1-O value (1.718 Å) indicates less Al enrichment in the T1 site than that used in the refinement (70% against 90%). The wide T2-O2-T2 angle (172.6°) and the narrow T1-O1-T2

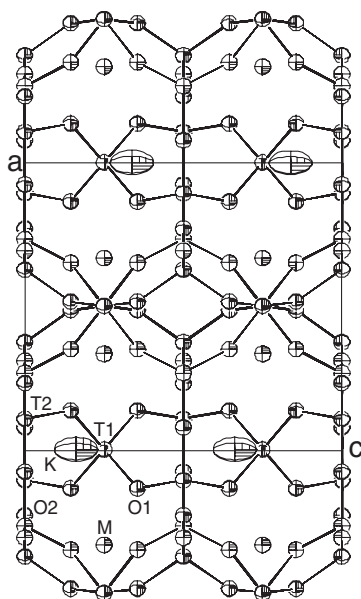


FIGURE 4. Structure arrangement of Somma-Vesuvius indialite onto *ac* plane. Displacement ellipsoids are drawn at the 50% probability level. For clarity, only one alternative K position is shown (see text).

TABLE 4. Selected interatomic distances (Å) and angles (°) of the studied K-bearing indialite

	(Å)		(Å)		(°)
T1-O1	1.718(2)	O1-O1 ^a	2.553(3)	O1-T1-O1 ^a	96.0(1)
		O1-O1 ^b	2.810(4)	O1-T1-O1 ^b	109.8(1)
		O1-O1 ^c	3.031(4)	O1-T1-O1 ^c	123.8(1)
T2-O1	1.670(2)	O1-O1 ^d	2.701(3)	O1-T2-O1 ^d	107.9(1)
T2-O2	1.637(5)	O1-O2	2.679(4)	O1-T2-O2	108.1(1)
T2-O2 ^e	1.626(5)	O1-O2 ^e	2.699(4)	O1-T2-O2 ^e	110.0(1)
		O2-O2 ^e	2.714(6)	O2-T2-O2 ^e	112.6(1)
M-O1 ^b	2.104(3)	O1 ^b -O1 ^c	2.553(3)	O1 ^b -M-O1 ^c	74.7(1)
		O1 ^b -O1 ^f	2.875(3)	O1 ^b -M-O1 ^f	86.2(1)
		O1 ^b -O1 ^g	3.218(4)	O1 ^b -M-O1 ^g	99.7(1)
				T1-O1-T2	129.4(2)
				T2-O2-T2 ^h	172.6(2)
K-O2	3.11(3)				

Note: The errors in parenthesis apply to the last digit. Symmetry code: a = 1-y, 1-x, 1/2-z; b = 1-x, 1-y, z; c = y, x, 1/2-z; d = x, y, -z; e = y, y-x, z; f = 1-x, 1+y-x, 1/2-z; g = y, 1+y-x, z; h = x-y, x, z.

angle (129.4°) are consistent with the higher content of Si in T2 and of Al in T1 (Brown and Gibbs 1970). These angles agree well with the values (171.9 and 129.8°, respectively) found by Daniels (1992) in Cs-bearing high cordierite, which yielded Al and Si occupancy factors in the T1 and T2 sites very close to the Italian indialite.

The overall framework of the Somma-Vesuvius indialite is very similar to that from Bokaro (Meagher and Gibbs 1977) and the presence of a guest cation does not produce appreciable distortions in either the channel or tetrahedra structures. By comparison with the K-bearing high cordierite synthesized by Daniels (1992), the shortest set of K-O2 distances in the structure of the Italian specimen is significantly longer than in the synthetic compound

(3.11 against 3.02 Å). Assuming an ionic radius of 1.40 Å for oxygen, the distance of 3.11 Å gives a K ionic radius of 1.71 Å, which is much larger than the average value (1.52 Å) of the observed distances for a six-coordinated K (Shannon 1976). Therefore, in this structure, there are only weak interactions between K and O2 that do not require deformation in the holding cavities.¹ The shorter K-O2 interactions present in the synthetic K high-cordierite of Daniels lead instead to deform the O2 rings (dislocation of the O with consequent loss of the mirror plane) and to destruction of the exact *P6/mcc* symmetry.

CONCLUDING REMARKS

Indialite found in the 1872 xenolithic ejecta of Somma-Vesuvius is typically potassic and highly magnesian. The mineralogical association of these ejecta (indialite-osumilite-phlogopite-hematite, with minor magnetite, corundum, and cristobalite) and the geological evidence indicate that these rocks were formed by pyrometamorphic processes affecting mainly pelitic hosts at shallow depth (<1 kbar; De Vivo and Rolandi 2001) and at maximum temperature close to ~1200 °C. This crystallization temperature corresponds to the temperature of Vesuvius magma of the recent activity, as was determined by the melt inclusion studies (Marianelli et al. 1995). This *T*-value limit is also corroborated by experimental studies on cordierites (Putnis et al. 1987; Daniels et al. 1992), which reported the presence of stable hexagonal high-cordierite at 1185 and 1290 °C.

Schreyer et al. (1990), by examination of three natural potassic cordierites, have demonstrated that the high-temperature polymorph (i.e., potassic indialite) can be considered a characteristic and stable phase for high-temperature metamorphic environments—sanidinite facies—at very low-pressure. These authors found that the hexagonal nature of K-bearing cordierite found at Eifel, in xenoliths very similar to the Somma-Vesuvius rocks, must be due to very rapid crystallization from fluid (melt or gas) in the high-temperature/low-pressure environment of the Quaternary volcanoes, during or shortly after magma eruption. This feature is particularly important, to ensure a rapid cooling history of the xenoliths. The petrologic constraints of Schreyer et al. (1990) are perfectly in line with the genetic evolution inferred for the potassic indialite-bearing ejecta studied here. A rapid crystallization and subsequent quenching agree well with the Somma-Vesuvius indialite occurrence and also with the structural feature of this mineral. This structure refinement has established that the presence of a guest cation in the cavities around the sixfold axis does not cause deviation from the *P6/mcc* symmetry. Lowering of symmetry was instead found by Daniels (1990, 1992) for a synthetic potassic high-cordierite. The differences in symmetry between the synthetic and natural phases can be correlated to their different thermal histories. In particular, a rapid quenching from high temperatures, also indicated by the presence of glass in the Somma-Vesuvius indialite-bearing rocks, would favor the higher symmetry in the natural form, so “freezing” its space group *P6/mcc*.

¹ The presence of only weak interactions suggests that also a guest with smaller van der Waals radius (for instance Na, which was detected in few samples) would lie out of the O₂ ring plane.

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