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The occurrence of pumpellyite in basic igneous rocks from the Coloured Series NE of Neyriz, Iran

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ABSTRACT. The occurrence of pumpellyite in Late Cretaceous volcanic rocks of the Coloured Series, NE of Neyriz, is reported for the first time. The form of the pumpellyite and its chemistry are described. The mineral assemblages of the prehnite–pumpellyite facies of metamorphism are present, indicating that burial metamorphism has occurred, a new factor to be considered in the tectonic evolution of the Zagros suture zone.

THE intermittent zone of the Coloured Series stretches along the foot of the main Zagros thrust and can be traced along strike for about 100 km.

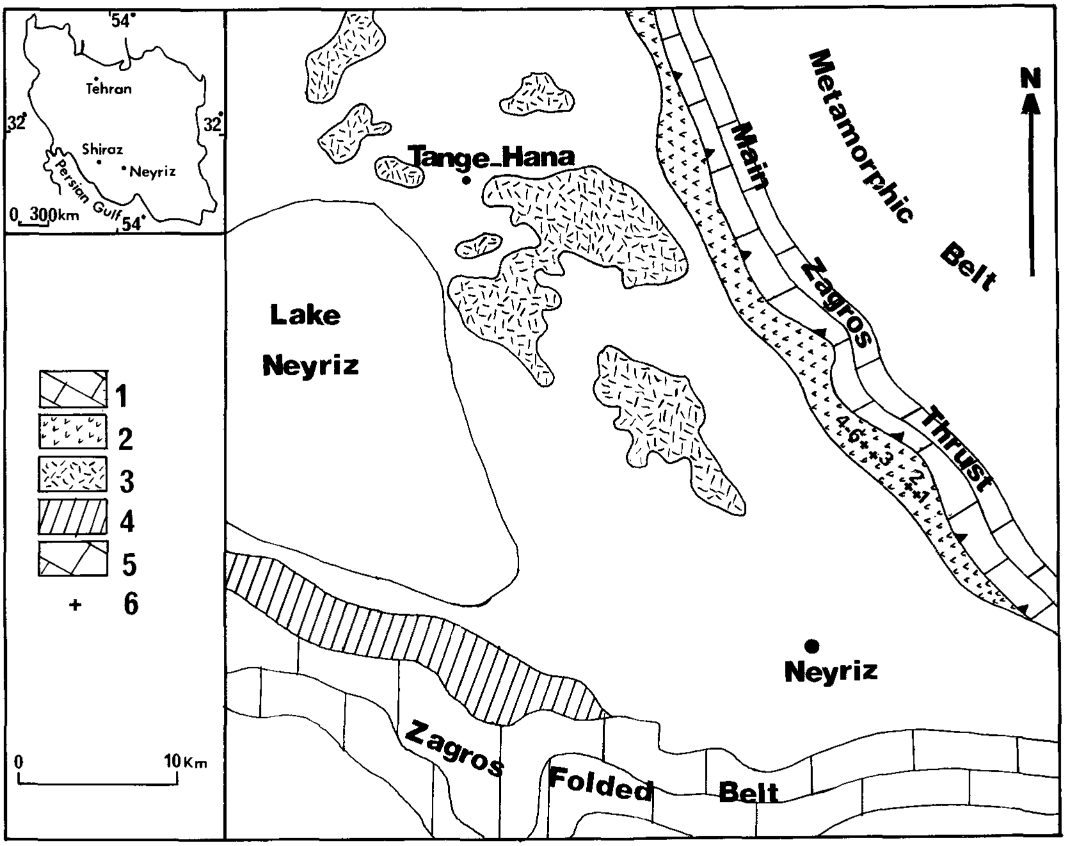

FIG. 1. Geological map of the Neyriz area. 1. Upper Cretaceous limestones; 2. Coloured Series; 3. Ultramafics; 4. Radiolarites; 5. Zagros folded belt; 6. Location of samples. (1 = Pl + Cpx + Pu + Chl + Ca + Op 2 = Pl + Cpx + Pu + Chl + Ca + Op 3 = Pl + Cpx + Pu + Pr + Ca + Op + Q + Glass 4-6 = Pl + Cpx + Pu + Pr + Chl + Ca + Op Ca = Calcite; Chl = Chlorite; Cpx = Clinopyroxene; Pl = Plagioclase; Pr = Prehnite; Pu = Pumpellyite; Q = Quartz; Op = Opaque.)

The Coloured Series (Melange of Gansser, 1974) is composed mainly of spilites (both as flows and pillow lavas), keratophyres, and ignimbrites and more rarely gabbros, porphyrites, cherts, sandstones, and Late Cretaceous limestones. Tertiary fossiliferous limestones and conglomerates also occur along steep faults. Individual lava flows can often be distinguished, and they may be separated by thinly bedded radiolarian cherts, and biomicritic reddish and creamy limestones. The proportion of lava to sediment varies locally but on average it is about one to one. The Coloured Series is overlain structurally by the Cenomanian Sarvak Limestone with which it has an imbricated contact, further complicated by steep faulting. Despite the imbrication many internal contacts are undistrubed and original relationships between lavas and sediments are preserved in the Coloured Series.

The volcanic rocks characteristically retain their primary igneous fabrics despite the alteration which transformed them into spilites and keratophyres, typical of rocks which have undergone low-grade metamorphism (Levi, 1969; Vallance, 1960, 1969). Porphyritic, glomeroporphyritic, and amygdaloidal textures are present. The first two textures are defined mainly by phenocrysts of plagioclase and pyroxene. The groundmass surrounding the phenocrysts is generally strongly altered, but variolitic, pilotaxitic, axiolitic, fluidic, and sub-ophitic textures are readily recognizable.

The volcanic rocks have been subjected to burial type metamorphism (Coombs, 1961) with new minerals replacing the original igneous assemblage. In terms of mineral facies, the assemblage of pumpellyite + prehnite + albite + calcite $\pm$ epidote $\pm$ quartz indicates clearly metamorphism in prehnite–pumpellyite facies. However it must be added that the occurrence of zeolite and actinolite in some spilites may indicate a possible extension from prehnite–pumpellyite facies into contiguous low-grade mineral facies. Plagioclase is commonly albitized and pyroxene pseudomorphed by chlorite, calcite, and occasionally actinolite, though some pyroxene remains unaltered.

TABLE I. *Representative mean analyses of pumpellyite from the spilites within the Coloured Series NE of Neyriz*

	1	2	2A	3	4	5	6
SiO_2	36.93	37.24	37.09	36.52	36.98	36.14	36.90
TiO_2	n.d.	0.44	0.49	n.d.	n.d.	0.07	0.15
Al_2O_3	20.92	21.60	21.80	16.49	21.19	19.95	20.66
FeO*	9.21	7.31	6.63	13.62	8.31	9.61	8.74
MnO	n.d.	0.33	0.32	n.d.	n.d.	n.d.	n.d.
MgO	2.97	2.52	2.49	2.94	2.85	3.29	2.88
CaO	22.79	21.97	22.01	21.83	23.67	22.92	22.69
Na_2O	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
K_2O	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Total	92.82	91.41	90.83	91.40	92.95	91.98	92.02
Atomic Proportions, Σ Cation = 16.00.							
Si	6.03	6.17	6.16	6.15	6.01	5.96	6.08
Al^Z	—	—	—	—	—	—	—
Al^Y	4.00	4.00	4.00	3.27	4.00	3.87	4.00
Al^X	0.02	0.21	0.27	—	0.06	—	0.01
Ti	—	0.05	0.06	—	—	—	—
Fe	1.25	1.01	0.93	1.90	1.11	1.31	1.19
Mg	0.71	0.62	0.62	0.72	0.67	0.79	0.69
ΣX	1.98	1.89	1.88	2.62	1.84	2.10	1.89
Mn	—	0.05	0.05	—	—	—	—
Ca	3.97	3.89	3.91	3.93	4.12	4.04	4.00
ΣW	3.97	3.94	3.96	3.93	4.12	4.04	4.00

Pumpellyite crystals were analysed on a Cambridge Scientific Instruments Microscan V microprobe fitted with a Link System 860 energy dispersive analyser; 20 Kv, $\sim 1.0 \times 10^{-8}$ probe current, $\sim 1\ \mu m$ diameter beam.
FeO* = Total Fe as FeO.
n.d. = Not detected.

Location of pumpellyite in the Coloured Series

Pumpellyite has been identified at a number of locations in the Late Cretaceous Coloured Series, where it occurs in the spilites. These locations are shown in fig. 1.

Description of pumpellyite

Optical properties. Pumpellyite displays a variety of forms. It occurs in veins, as prismatic crystals (up to 0.3 mm long), associated with prehnite and calcite (figs. 2*a*, *b*), as radiating clusters of acicular crystals frequently associated with palagonitized glass and quartz in amygdales (fig. 2*c*), and as interstitial fillings which are probably formed by complete replacement of microlitic plagioclase. These pumpellyite crystals show low birefringence, generally of first-order or of anomalous colour. All types show a marked pleochroism and are generally yellowish-green and yellow (β) to colourless (α and γ). The pumpellyite which replaces the devitrified glass has the highest iron content and strongest pleochroism, supporting Coombs (1953) who suggested a correlation between pumpellyite colour and iron content.

Pumpellyite also occurs as aggregates of crystals which pseudomorph pyroxene or olivine phenocrysts (fig. 2*d*). They are characterized optically by $2V \sim 55\text{--}60$ $\alpha = X$ colourless, $\beta = Y$ yellow, $\gamma = Z$ very pale yellow, and positive or negative biaxial interference figures. Pumpellyite positive (faintly pleochroic) and negative types show only slight differences in their 'chemistry, mostly in iron content which is higher in those of negative sign (Coombs, 1953)'.

Chemistry. The microprobe analyses are shown in Table I. Structural formulae for pumpellyite have been calculated on the basis of sixteen cations, using Coombs *et al.*'s (1976) formula for pumpellyite which assumes the cation sites of pumpellyite to be totally filled and without any excess. The relatively low Al_2O_3 and high total FeO in analyses 3 and 5 results in the absence of Al from the octahedral *X* sites and the presence of Fe^{3+}, 0.73 and 0.13 respectively, in octahedral *Y* sites. The Fe-rich pumpellyite (anal. 3) appears to have recrystallized from a devitrified glass (fig. 2*c*). This has also been suggested by Liou (1979) who described an enrichment of original glass (due to palagonitization in Fe_2O_3 as a possible source for high Fe-rich pumpellyite, prior to its recrystallization from such a devitrified glass. Analyses 2 and 2A have the highest Al_2O_3 and lowest FeO values. This is reflected in the absence of Fe in their octahedral *Y* sites and occurrence of 0.21 and 0.27 Al in the octahedral *X* sites. Passaglia and Gottardi (1973) put forward the range of values 0.71 to 1.55 (out of 2) for $(Mg+Fe^{2+}+Mn)$ in the *X* sites stating that any values within the quoted range exhibited a very high degree of reliability of the pumpellyite analysis. In other words $(Fe^{3+}+Al)$ in the *X* site should be in the range 1.29 to 0.45 per formula unit. Accepting this the Fe occupying the octahedral *X* position in the pumpellyite of the Neyriz Coloured Series may be substantially in the ferric state. This conclusion is supported by the inverse relationships between Al_2O_3 and FeO*

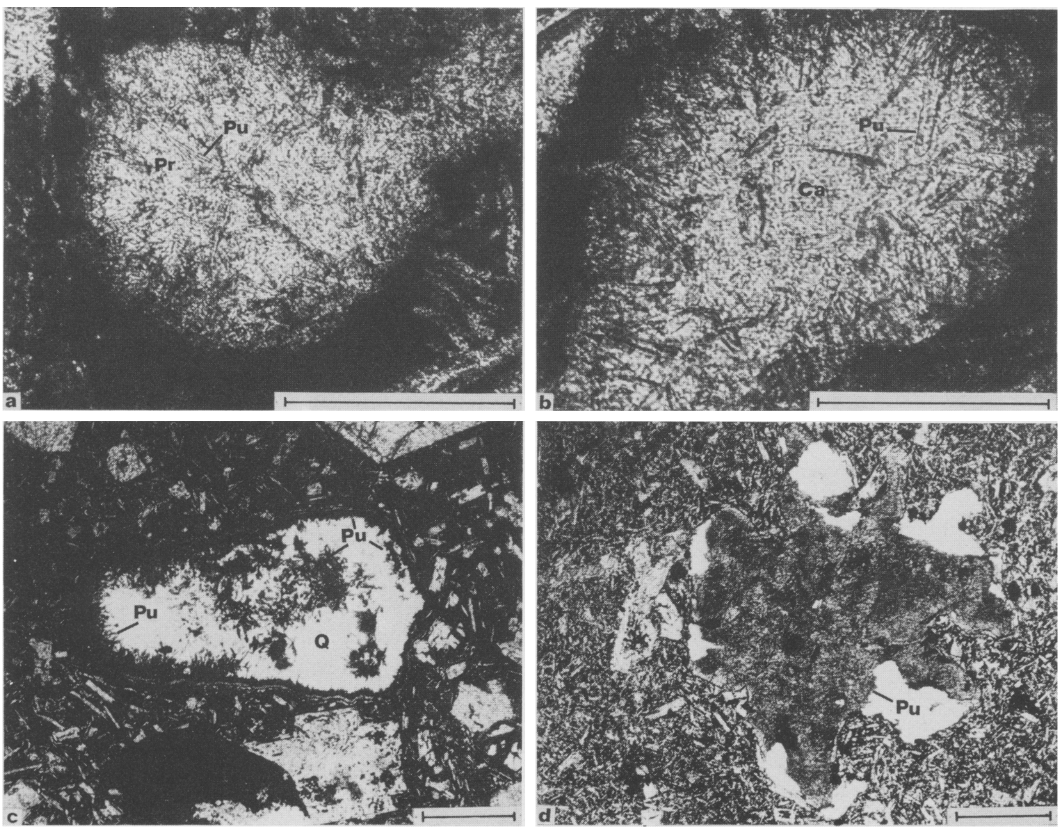

FIG. 2. Photomicrographs of spilites containing pumpellyite from the Neyriz Coloured Series. Bar scale represents 0.5 mm. (*a,b*) Well-formed pumpellyite (Pu) crystals in prehnite (Pr) and calcite (Ca) alteration veins. (*c*) Needle and radiating or cluster pumpellyite frequently associated with palagonitized glass and quartz (Q) in amygdales. (*d*) Pumpellyite replacing olivine or pyroxene crystals. The relic of crystal is clearly visible.

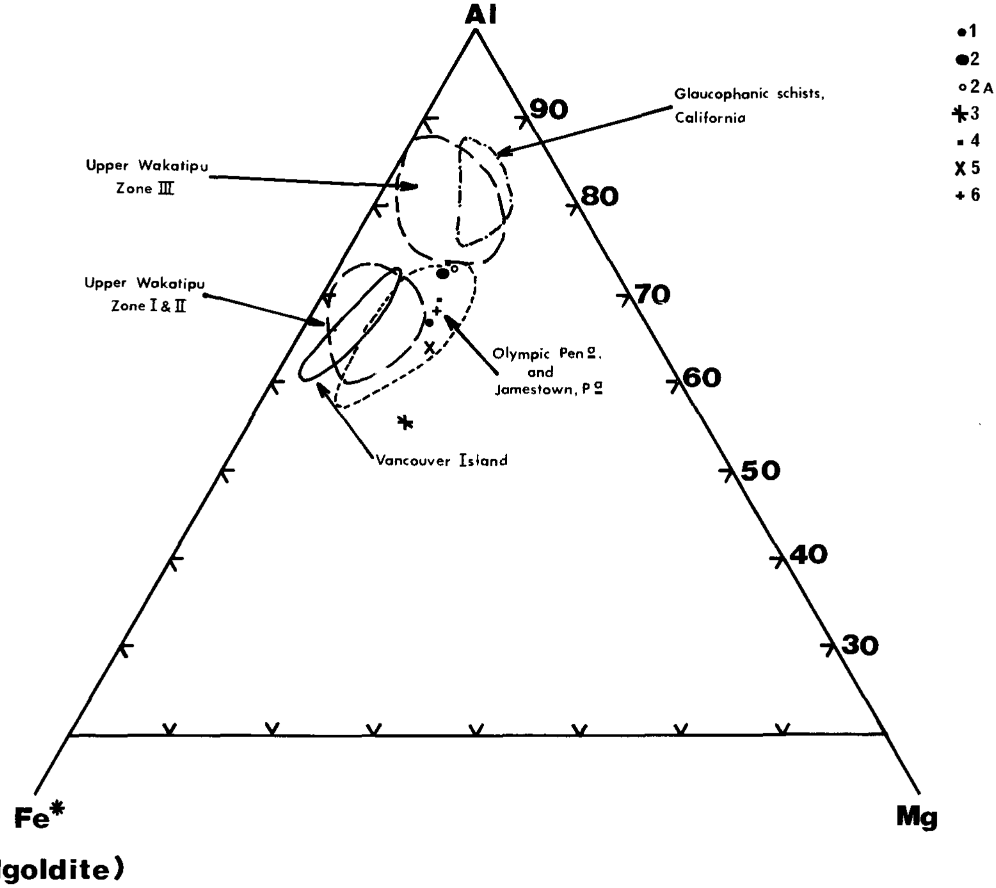

FIG. 3. Compositional variations of analysed pumpellyite from the Coloured Series NE of Neyriz, Iran, in Al–Fe–Mg diagram of Coombs *et al.* (1976). Compositional fields of pumpellyites are from Coombs *et al.* (1976). 1—Filling amygdales. 2,2A—Negative and positive, pseudomorph after olivine or pyroxene phenocrysts. 3,4,5—Associated with palagonitized glass, prehnite, and calcite veins. 6—Replacing plagioclase.

content of the Neyriz pumpellyite (fig. 3). The Neyriz Coloured Series pumpellyite are Fe-pumpellyite according to classification scheme of Coombs *et al.* (1976) or ferropumpellyite according to that of Moore (1971).

Compositions of the Coloured Series pumpellyites are plotted on the Al–Fe*–Mg diagram of Coombs *et al.* (1976) in order to make a comparison with the compositional fields of pumpellyite from other areas (fig. 3). It is apparent from such a comparison that the pumpellyite from the Coloured Series are similar to those of the very low-grade terrains of the Olympic Peninsula (Glassley, 1975), zone I and II in the Caples terrain of SW New Zealand (Kawachi, 1975). They are poorer in Al than pumpellyites from the higher grade Wakatipu zone III (Kawachi, 1975) and the California glaucophane schists (Ernst *et al.*, 1970).

Conclusion

The Neyriz Coloured Series volcanic rocks belong to the prehnite-pumpellyite facies and resemble those rocks of the same facies in New Zealand (Coombs, 1974) and in other reported areas (Seki, 1961; Kuniyoshi and Liou, 1976). The occurrence of zeolites, epidote, actinolite, and calcite (minerals whose stabilities are dependent on μ_{CO_2}; Brown, 1977 and Winkler, 1976) suggests considerable local variation in μ_{CO_2} in the Neyriz Coloured Series volcanic rocks throughout the period of their metamorphism.

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