MINERALOGICAL MAGAZINE, JUNE 1976, VOL. 40, PP. 640–2

A new study of turquoise from Iran

TURQUOISE from the classical localities of Nishapur and Damghan, in north-east Iran, has been mined for centuries, and is one of the best for colour (Sinkankas, 1966), but has never been studied in adequate detail. An analysis by Hermann (1844) is of very doubtful accuracy, and those by Church (1867) and Carnot (1894) suggest, by their high Al_2O_3 and low CuO, possible admixture with variscite or other aluminium phosphate. The turquoise from both localities (which are 500 Km apart) ranges from sky-blue, considered the finest, to apple-green, and we have examined material of both colours from both localities.

The X-ray powder data, obtained on a Phillips diffractometer, agree well with those published on the A.S.T.M. (P.D.F.) cards, and by Erd (1953), apart from some minor differences in intensities, probably due to orientation effects.

TABLE I. *Chemical analysis of Iranian turquoise*

	1	2	3	4	5	
CuO	6·36	7·60	8·06	8·08	9·78	1. Nishapur, sky-blue
Al_2O_3	37·40	36·04	36·00	33·90	37·60	2. Nishapur, apple-green
Fe_2O_3	0·38	1·60	0·55	2·72	—	3. Damghan, sky-blue
P_2O_5	36·65	36·26	33·56	33·18	34·90	4. Damghan, apple-green
H_2O	18·11	17·88	19·28	19·28	17·72	5. Calculated for $CuAl_6(PO_4)_4(OH)_8.4H_2O$
	98·50	99·38	97·45	97·16	100·00	

The chemical analyses (Table I) were made by atomic absorption for Cu, Al, and Fe, by the molybdenum-blue method for phosphate, and by loss on ignition at 800 °C for water; the state of oxidation of the iron was not determined, but its inverse correlation with Al suggests that it is ferric. The analyses agree reasonably well with the accepted formula, $Cu(Al,Fe)_6(PO_4)_4(OH)_8.4H_2O$, and it is clear that the finest sky-blue turquoise is lowest in iron. Trace amounts of Si, Mg, Ca, Na, Ti, Mn, Ag, B, Ba, Be, Co, Cr, Ni, Pb, Sr, Zn, and Zr were detected spectrographically.

An experiment that yielded interesting results was the effect of solutions of different pH on turquoise samples: after fifteen months, turquoise was completely dissolved by a solution of pH 1, but was less affected by solutions of higher pH, those of pH 7 to 10 having no effect; alkaline solutions, of pH 11 to 13, increasingly destroyed the colour and structure of the samples.

Differential thermal analysis curves were obtained with a Netzsch 404 equipment and a heating rate of 10 °C/min. Damghan turquoise gave a strong endothermic peak at 355 °C and a strong exothermic peak at 748 °C; for Nishapur turquoise these peaks were at 390 and 765 °C. Manly (1950) reported an endothermic reaction at 380 °C and an exothermic one at 840 °C for turquoise from New Mexico, and Anderson *et al.* (1962) peaks at 350 and 740 °C for turquoise from Bingham, Utah. A static dehydration curve showed that the endothermic peak is due to loss of water, while the exothermic peak is due to recrystallization; a sample heated to 800 °C gave the X-ray pattern of phosphocristobalite (cf. Manly, 1950).

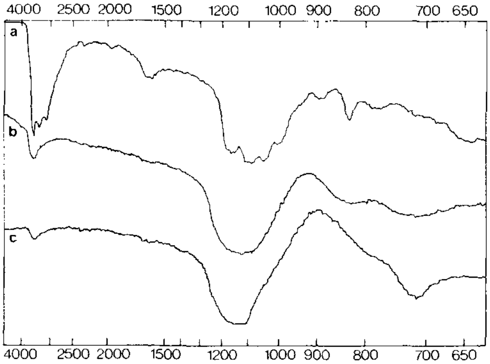

Fig. 1. Infra-red spectra of Iranian turquoise (*a*), and spectra after heating to 400 °C (*b*) and to 800 °C (*c*).

The infra-red spectra of turquoise from Nishapur and Damghan show the strong absorption bands characteristic of OH-stretching in the range 3560 to 3000 cm^{-1} and also strong bands characteristic of P–O stretching in the range 1180 to 1000 cm^{-1}. Infra-red spectra were also obtained from heated samples; after heating to 400 °C, when over 90 % of the water was lost, there was a substantial decrease in the OH-stretching band, while a sample heated to 800 °C, above the exothermic DTA peak, showed a new absorption band at 715 cm^{-1}, which might be due to the formation of some pyrophosphate (Heughebaert and Montel, 1970).

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Acknowledgement. The authors wish to thank Tehran University Research Council for a grant to cover part of the expenses of this work.

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[*Manuscript received 18 March 1975, revised 2 July 1975*]

MINERALOGICAL MAGAZINE, JUNE 1976, VOL. 40, PP. 642–4

Tamarugite from Anglesea, Victoria, Australia

THE water soluble double sulphate tamarugite, $NaAl(SO_4)_2.6H_2O$, has been described from only a few localities, most of which appear to have been from a dry or arid environment (e.g. see Keller, 1935; Bandy, 1938). Hutton (1970), however, reported this mineral as forming on altered volcanic rocks some 50 m above sea level on the island of Nevis in the West Indies, an area with a wet winter climate. Tamarugite has only been described once before from an Australian locality, an arid area in Western Australia (Simpson, 1923). Recently, however, it was found on rocks on the sea shore in southern Victoria, Australia, an area with a temperate climate and an annual rainfall of about 600 mm distributed throughout the year with a small maximum in winter.

The tamarugite occurred as yellow efflorescences and crusts about 1 cm thick coating black pyritic carbonaceous shales of Eocene age (Raggatt and Crespin, 1955). These shales form cliffs some 50 m high at the back of a sandy beach, and blocks of the shale up to a metre or more in size litter the beach at the base of the cliffs. The mineral formed the yellow (occasionally white) coating mainly on the fallen blocks. The coating was built up of small yellow rosettes, generally about 2 mm in diameter, of very fine apparently fibrous crystals of the mineral, often mixed with fine quartz, clay, and some alunogen. The scanning electron micrograph of fig. 1, however, shows that the crystal morphology is that of very thin platelets.

The X-ray diffraction pattern showed broadening of the diffractometer peaks, so that very close spacings were not resolved. Otherwise, the pattern agreed very closely with that of Robinson *et al.* (1966). The mineral was too finely crystalline for accurate measurement of optical properties; the refractive index, however, was near 1·48.

A chemical analysis (Na, K, Al, Fe by atomic absorption) gave the following result: 6·5 % Na_2O, 0·01 % K_2O, 11·7 % Al_2O_3, 0·5 % Fe_2O_3, 35·6 % SO_3, 9·1 % H_2O (at 100 °C), 32·9 % H_2O (100–250 °C), 1·4 % Cl. The excess alumina and sulphur trioxide over that required for tamarugite are present in the proportions required to form alunogen, which is present to a small extent in the sample. The small amount of iron may be