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Distinctive gem corundum suites from discrete basalt fields: a comparative study of Barrington, Australia, and West Pailin, Cambodia, gemfields

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ABSTRACT: Barrington, Australia, and West Pailin, Cambodia, basalt fields yield remarkably similar 'metamorphic' corundums (including ruby) and 'basaltic' type blue corundums. These represent different underlying sources tapped by basaltic eruptions. The 'metamorphic' suites have high chromium/low gallium chemistry, with Ga_2O_3 contents <0.01 wt% and Cr_2O_3/Ga_2O_3 ratios above 3. The 'basaltic' suites show higher Ga_2O_3 (up to 0.04 wt%) and Cr_2O_3/Ga_2O_3 ratios below 1. The absorption spectra of blue 'metamorphic' sapphires are dominated by Fe^{3+} bands in the ultraviolet (375, 387 nm) and visible region (450, 460, 469 nm). A broad $Fe^{2+} – Ti^{4+}$ charge transfer band lies between 550–750 nm, without significant $Fe^{2+} – Fe^{3+}$ charge transfer absorption toward the near infrared that is typical of blue 'basaltic' sapphires. Most absorption spectra of 'metamorphic' corundums represent a combination of Fe/Ti/Cr-bands, with variable relative intensities.

Keywords: corundum, sapphire, ruby, sapphirine, absorption spectra, trace elements, basalt, Barrington (Australia), Pailin (Cambodia)

Introduction

East Australia and South East Asia exploit rich corundum deposits from their basalt fields, in significant mining, processing and cutting industries (Mumme, 1988; Hughes, 1990, 1997). East Australia produces sapphire and rare ruby (Coldham, 1985; Olliver and Townsend, 1990; Sutherland, 1991), while SE Asia produces both sapphire and ruby in abundance (Vichit, 1992). In this paper we describe corundum suites from two widely separated basalt fields, Barrington in East Australia and West Pailin in Cambodia, and show that they contain mixed ruby and sapphire suites of remarkable similarity.

Two distinctive gem corundum suites appear in eluvial and alluvial deposits from the Barrington basalt province in New South Wales, one typical of East Australian sapphire fields and the other associated with rubies (Sutherland and Coenraads, 1996). Besides typical Australian

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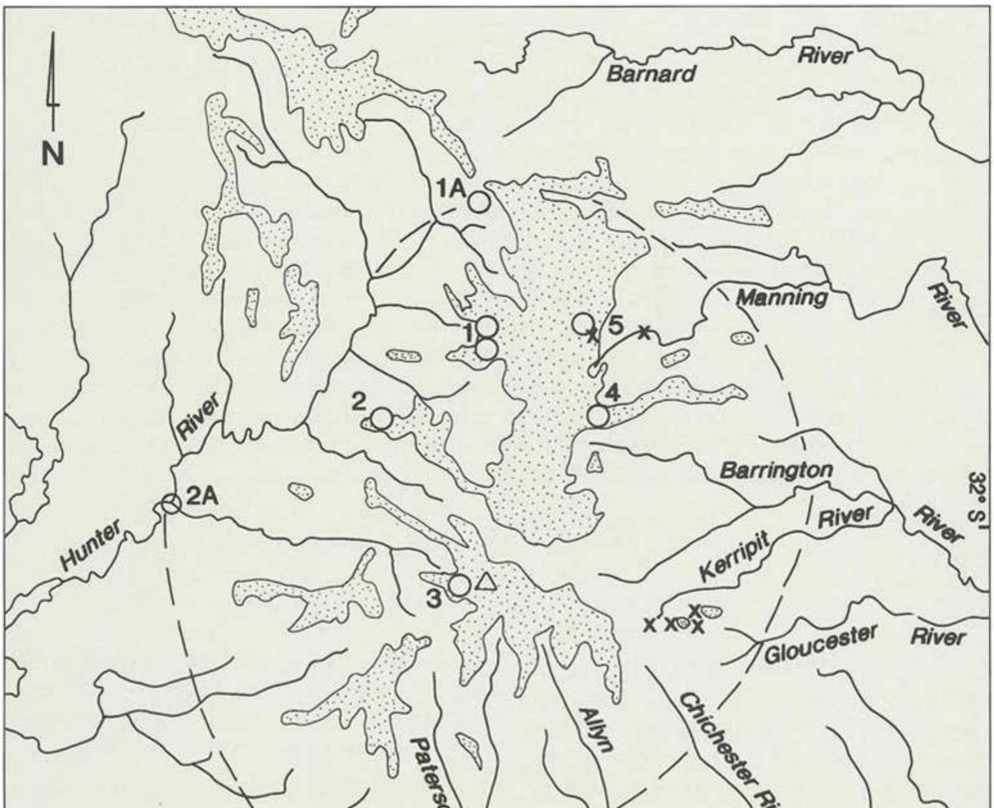
corroded blue-green-yellow zoned sapphires (Coenraads, 1992a, b; Sutherland, 1996; Guo *et al.*, 1996), the Barrington province also yields an abundant pastel-coloured sapphire-ruby suite (Sutherland *et al.*, 1993; Sutherland and Coenraads, 1996). Recognition of this last suite prompted a re-examination of ruby and sapphire collected from basalt fields around Pailin by E.A. Jobbins in 1974 (Berrangé and Jobbins, 1976; Jobbins and Berrangé, 1981).

Preliminary examination of West Pailin material showed its similarity to the Barrington suites, including sapphirine as an intergrowth in the ruby association (analysis by K. Williams). A more detailed investigation of samples collected by Jobbins was carried out by personnel from the Australian Museum and Gübelin Gemmological Laboratory, Switzerland. This work includes gemmological studies on

Figure 1: *Distribution of basaltic rocks (stippled areas) and main drainages, Barrington volcano province, 250 km north of Sydney, New South Wales. Corundum/zircon suites are marked by inclined crosses. The numbered sites are basalt age-dating sites, with the following ages, 1: 44–54 m.y., 1A: 54 m.y., 2: 37 m.y., 2A: 42 m.y., 3: 52–54 m.y., 4: 59 m.y., 5: 54 m.y. (based on Sutherland and Fanning, 1996). The main intrusive centre of Barrington volcano is marked by a triangle (1555 m above sea level) and the original extent of the volcano before dissection is marked by a dashed perimeter (600–800 m a.s.l.), after Pain, 1983.*



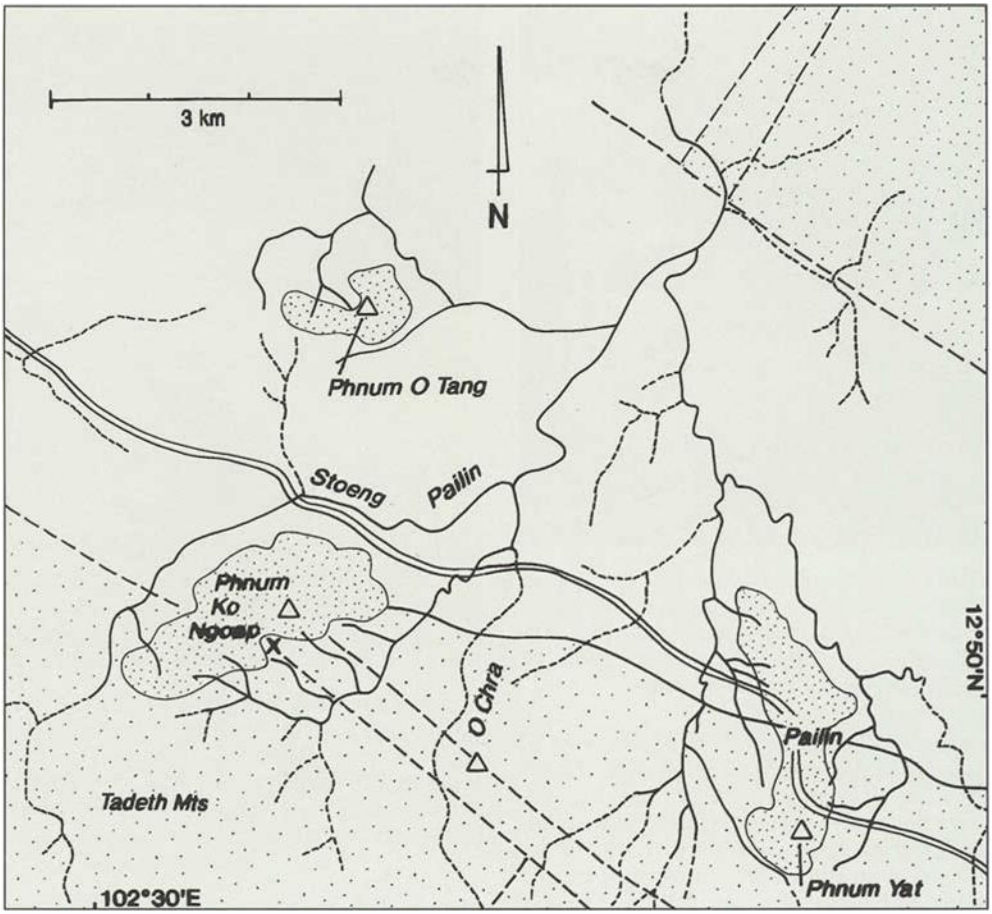


Figure 2: Distribution of basaltic rocks (denser stippled areas) and drainages, Pailin district, Cambodia. Gem-bearing drainage is shown as continuous lines, with gem-barren drainages shown as short dashed lines. Volcanic vents are indicated by triangles and the main basalt centres are Phnum Ko Ngoap, Phnum O Tang for dominant fancy coloured corundums, and Phnum Yat for dominant 'basaltic' blue corundums. The main drainages are the O Chra and Stoeng Pailin rivers and the road to Pailin is marked by a double line. The geological boundary between younger basement rocks (coarse stipple) and older crystalline basement (unmarked) is shown by a heavy line, and fault zones are marked by long dashes. Diagram modified from Berrangé and Jobbins, 1976, and Jobbins and Berrangé, 1981.

corundum from Barrington and West Pailin and comparative studies on sapphires from East Australia, from central Queensland (Anakie Fields) and New South Wales (New England Fields) and from East Pailin. Studies include photography and photomicrography (G. Webb, E.A. Jobbins), trace element and colour absorption spectral studies (EDXRF, UV-vis-NIR spectrometry; D. Schwarz), chemical analyses of inclusions and intergrowths in West Pailin corundums (CAMECA microprobe with WDS spectrometer; R.R. Coenraads, F.L. Sutherland) and comparisons of the corundum suites in discussion of their geological origins (F.L. Sutherland, D. Schwarz).

Geological settings

The Barrington corundums come from the eroded Barrington shield volcano in New South Wales within the Cainozoic

Figure 3: Working eluvial/alluvial gem gravels on the banks of a small stream about 0.4 km south-west of the Phnum Ko Ngoap vent. The analysed West Pailin specimens are from this locality. Photograph by E.A. Jobbins.

Figure 4: Washing gem gravel ('rai') at Phnum Ko Ngoap. Rubies, sapphires and garnets are recovered from impersistent lenses of sticky yellow-brown clays (green-grey when freshly exposed) which are difficult to break down. Photograph by E.A. Jobbins.

Figure 5: View looking south to the low hill (middle distance) forming the vent of the Phnum Ko Ngoap basalt body. Further south (in the background) are the jungle-clad Tadeth Mountains (largely greywacke sedimentary rocks). In the foreground are gem dealers on motorcycles, who collect and market the gem material from the miners. Photograph by E.A. Jobbins.

volcanic belt of eastern Australia (Pain, 1983; Johnson, 1989). This basaltic shield (*Figure 1*) was erupted through folded Palaeozoic basement and granite rocks, mostly between 50–60 million years (m.y.) ago, although episodic gem-bearing eruptions continued up to 5 m.y. ago (Sutherland *et al.*, 1993; Sutherland and Coenraads, 1996; Sutherland and Fanning, 1996). The shield is dominated by alkali basalts (O'Reilly and Zhang, 1995; Sutherland and Fanning, 1996). The oldest NE part sheds alluvial corundums that were studied from the Gummi area, which is drained by the upper Manning River. Associated zircons gave fission track ages of around 55 m.y. The youngest SE part provides near-source corundums that were studied from Gloucester Tops, in the headwaters of the Kerripit and Gloucester Rivers. Zircons with these corundums yield ages as young as 4–5 m.y.

The West Pailin material from the Pailin basalt field *(Figure 2)* came from the Phnum Ko Ngoap basalt body (E.A.J. collection station 29), from an eluvial/colluvial deposit on the basalt margin about 0.4 km south-west of the remnant vent *(Figures 3–5)*. The gem-bearing basalts around Pailin and adjacent eastern Thailand were erupted 1–4 Ma ago (Suttirat *et al.*, 1994; Davis and Barr, 1995). The West Pailin basalts yield corundum in which ruby is predominant over sapphire (about 70% ruby at Station 29), some pyrope-almandine garnet and little zircon. Phnum Ko Ngoap material is dominated by pale pink to red, light-blue, mauve and purple corundums. In contrast, at East Pailin sapphire predominates over ruby (about 95%) and zircon is a common accessory (Berrangé and Jobbins, 1976; Jobbins and Berrangé, 1981). Phnum Yat material is dominated by colourless to pale-blue to blue sapphires, many with colour zoning.

The western ruby-bearing basalts lie along a faulted older crystalline complex of metamorphosed granodiorite and diorite, amphibolitic gneisses and schists, whereas the eastern sapphire-bearing basalt intrudes younger rocks along a boundary between Devonian-Carboniferous metasedimentary and volcanic rocks and Triassic sedimentary beds *(Figure 2)*. These rocks lie within the Indo-China Terrane (microcontinental block), which extends west into Thailand (Bunopas and Vella, 1992). The West Pailin suites correlate with the Trat Thailand suites forming a 'ruby-rich' area. Further west basalts of south-eastern Thailand lie within the Shan-Thai block, which includes cratonic Precambrian gneiss (Bunopas and Vella, 1992), and show a significant sapphire component (see Hughes, 1990, *Figure 11.19*). They correlate more closely with the East Pailin sapphire fields.

Materials

Barrington suites

The Barrington corundums have been described in Sutherland *et al.*, 1993, Sutherland and Coenraads, 1996, and by Webb, 1997. The crystals and fragments show surface etchings *(Figure 6)* and a wide

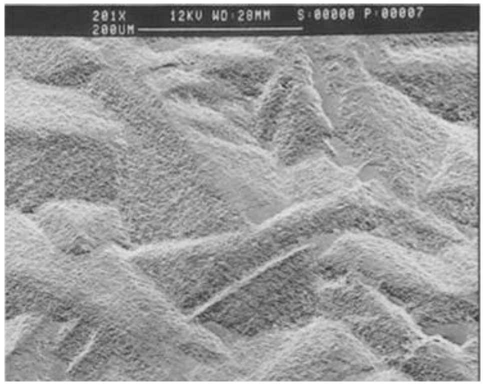


Figure 6: *Scanning Electron Microscope photomicrograph, showing corroded surface of a pink corundum grain from Gloucester Tops, Barrington volcano. Note the strong etching leaving a criss-cross ridge-like surface morphology. Photograph by G. Avern and B.J. Barron, X100.*

range of colours *(Figure 7)*. There are two distinct corundum suites, each with different trace-element patterns.

One suite contains ruby and sapphire ranging from colourless to pink, mauve, violet, blue, blue-green and purple with crystal forms which have been magmatically rounded with heavily etched

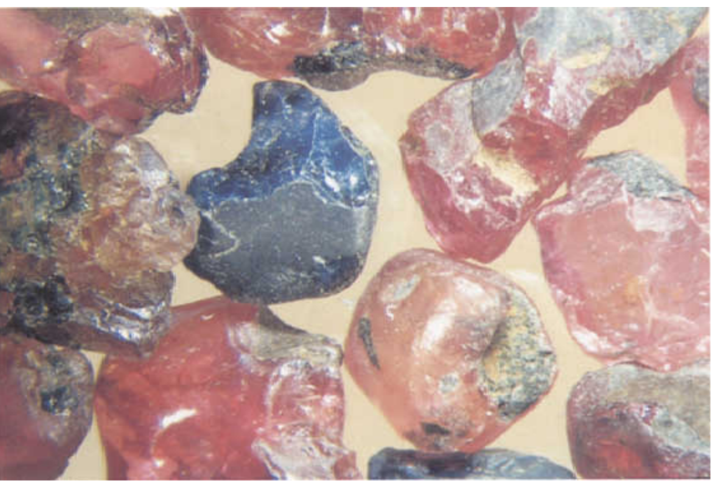
Figure 7: *Corundums from Gloucester Tops, Barrington volcano, showing surface corrosion features and range in colours. Photomicrograph by G. Webb, X15.*

Figure 8: Ruby series corundum crystal (mauve-pink) containing intergrowths of sapphirine (blue-green) and pleonaste spinel (dark opaque), from Gloucester Tops, Barrington volcano. Photomicrograph by G. Webb, X25.

Figure 10: Pale pink and ruby corundum crystals from Phnum Ko Ngoap suite, both showing prominent intergrowths of sapphirine (green). Photomicrograph by G. Webb, X20.

exteriors. Crystals range up to 6 mm across: chromian spinel, spinel and sapphirine occur as inclusions *(Figure 8)*, and crust-like spinel reaction rims are preserved on some grains. The other suite is typical of East Australian sapphires and is dominated by blue-green, euhedral, growth-zoned sapphire, often exhibiting corroded, broken-barrel habits. Crystals are generally larger than in the first suite and range up to 8 mm across.

Figure 9: Corundums from Phnum Ko Ngoap suite, West Pailin, showing surface corrosion features and range in colours. Note intergrowths of sapphire and spinel and fusion crusts on some corundums. Photomicrograph by G. Webb, X15.



West Pailin suites

These corundums *(Figures 9 and 10)* are very similar in characteristics to the Barrington suites and may also be considered in two groups of colours.

The first group of Phnum Ko Ngoap corundums range from 2 to 9.5 mm across and vary from pale pink to red, light blue, mauve and purple. Some show a colour change from red shades in incandescent light to blue shades in daylight. Pink and red corundums fluoresce red under long-wave ultraviolet, though less intensely than in equivalent Barrington stones. They are inert under short-wave ultraviolet. In habit, crystals are magmatically corroded and rounded. Mineral inclusions are present and negative crystals surrounded by decrepitation haloes are common, some with two-phase inclusions containing a gas bubble. Liquid-filled fractures often exhibit a thin-film effect and sometimes lie across twinning lamellae. Iron oxide/hydroxide staining is prevalent. Polysynthetic twinning is well developed and some twinning planes show tube-like, liquid-filled fractures, with associated mineralisations. Boehmite needles and crystallographically-controlled trellis patterns are present.

The second group of Phnum Ko Ngoap corundums contains a range from colourless to pale blue and many show colour zoning. Like Barrington blue crystals, they fall into two different types. The larger type measures up to 8 mm in broken-barrel shaped crystals or as cross-sections along parting planes. Faces are often strongly magmatically corroded or slightly rounded. Among the inclusions, silk is present as oriented needles, as particles along hexagonal growth zones or radiating in bunches, like crystal axes, from a central hexagonal core; polysynthetic twinning lamellae are evident. The second group of smaller corundums are around 2–3 mm across, lighter in colour and more transparent. Crystals are magmatically rounded and etched, with no obvious colour zoning or silk.

Methods of analysis

Twenty-one Barrington corundums (CORBAR 1–21) and fourteen West Pailin (Phnum Ko Ngoap) corundums (CORCAM 1–14) were polished and analysed for trace elements and colour-absorption spectra. Twenty-nine Pailin corundums (Jobbins 1–5), showing inclusions, intergrowths or fusion crusts were selected on the basis of microscope study and polished for electron microprobe analyses. Of these, 12 were analysed for major element oxides and 9 were analysed for minor element oxides. The pastel-coloured sapphire-ruby suites are termed *fancy colours or 'metamorphic' type suites* and the blue-zoned corundums are termed *'basaltic' type suites* in the following descriptions (these two categories with inferred different origins are based on geochemical comparisons made in the Discussion section).

Chemical data

Chemical analyses were obtained by a semi-quantitative EDXRF method, using a Spectrace 5000 EDXRF system (Stern, 1984).

A total of 162 samples were tested comprising:

21 Barrington, 14 Cambodian and 9 corundums from West Pailin (E.A. Jobbins); 61 blue 'basaltic' sapphires (varying hue and colour intensity) from 'Pailin' (probably East Pailin mining area); 18 'basaltic' sapphires (blue, green, yellow-brown, parti-coloured; including a green and a blue star sapphire) from the Anakie Fields in Central Queensland (Tomahawk Creek, Willows, Rubyvale); 9 'basaltic' sapphires (blue, dark green-blue, yellow-brown) from Inverell (New England Fields, NSW); and 30 'basaltic' sapphires (blue, green, green-blue, yellow, parti-coloured) from Eastern Australian mining fields in Queensland and New South Wales, but without exact localities.

The elements considered useful in characterising the corundums are iron, titanium, chromium, gallium, and vanadium, and a quantitative classification scheme for these elements (as wt% oxides) has been established empirically:

	Low	*Medium*	*High*	*Detection limit*
Fe_2O_3	<0.5	0.5–1.0	>1.0	0.005
TiO_2	<0.01	0.01–0.03	>0.03	0.005
Ga_2O_3	<0.01	0.01–0.03	>0.03	0.005
Cr_2O_3	<0.01	0.01–0.05	>0.5	0.005
V_2O_3	<0.01	0.01–0.03	>0.03	0.005

Electron microprobe analyses of corundums and associated mineral phases were made using an automated CAMECA SX50 CAMEBAX electron-microprobe with an EDS attachment, in the Materials Science Faculty, University of New South Wales, Sydney. Operating conditions included an accelerating voltage of 15 kV, a sample current of 20 nA, PAPS software for processing raw counts and an ASTIMEX standard block.

Spectroscopic data

Ultraviolet-visible-near infrared (UV-vis-NIR, 280 to 880 nm) spectra were run on a Perkin Elmer Lambda 9 spectrophotometer at the Gübelin Laboratory. Although ordinary ray (o) and extraordinary ray (e) spectra were recorded where possible, the size and shape of most Barrington and Cambodian samples precluded registration of polarised spectra.

Table I: *Trace-element ranges in corundums from Australia.*

	Barrington corundum range					*Typical Australian 'basaltic' sapphires*
		'metamorphic'		*'basaltic'*	*'basaltic' (Fe,Ti rich)*	
Colour	*blue*	*violet–blue*	*purple–red*	*blue*	*blue*	*blue, green, yellow, parti-coloured*
Wt%						
TiO_2	0.02–0.05[1]	0.04–0.09	0.0–0.06	0–0.04	~0.1	0.0–0.5 (0.14)[2]
V_2O_5	<0.01	0.01–0.04	<0.01	<0.01	<0.005	<0.005
Cr_2O_3	0.01–0.04	0.05–0.02	0.1–0.4	0.005	<0.005	<0.005
Fe_2O_3	0.6–1.0	0.5–1.2	0.4–0.6	0.7–1.6	~2	0.7–1.8
Ga_2O_3	<0.01	<0.01	<0.01	0.02–0.04	~0.02	0.015–0.04
Samples						
CORBAR[3]	1,2,5,6	3,4,10,15, 16,17,18,20	7,8,9,19	11,13,14,21	12	57 (see text for explanation)
Spectral type[4]	'Fe(+Cr)'	'metamorphic' 'Cr+Fe'	'Cr(+Fe)'	'basaltic'	'basaltic'	'basaltic'

Notes:
1. Results obtained by EDXRF
2. Blue star-sapphire from Anakie, NSW
3. CORBAR symbolises corundums from Barrington
4. See text for details

Table II: *Trace-element range for West Pailin corundums ('metamorphic' type, 'basaltic' type, and Fe/Ti-rich 'basaltic' type), compared to 'basaltic' type sapphires from East Pailin.*

	West Pailin					*East Pailin*
		'metamorphic'		*'basaltic'*	*Fe/Ti-rich 'basaltic' type*	*'basaltic'*
Wt%	*Blue*	*Violet-blue*	*Purple-red/red*			
TiO_2	~0.1	0.04–0.08	0.01–0.05	0.01–0.02	0.01–0.02	<0.01
V_2O_5	~0.01	~0.01	<0.01	<0.005	<0.005	<0.01
Cr_2O_3	~0.04	0.1-0.2	0.1-0.7	<0.005	<0.005	<0.005*
Fe_2O_3	~1	0.7-1.0	0.4-0.9	0.3-1.1	~2	0.3–0.8
Ga_2O_3	<0.01	<0.01	<0.01	0.02-.03	~0.04	0.02–0.04
Samples						
CORCAM	2,4–10, 12,13,15			1,11,14	3	61 blue sapphires of different hues and colour intensities
Jobbins	3–2, 3–4 to 3–9			Jobbins 5	3–1	
Spectral type[+]	'metamorphic'			'basaltic'	'basaltic'	'basaltic'

[+]see text for details

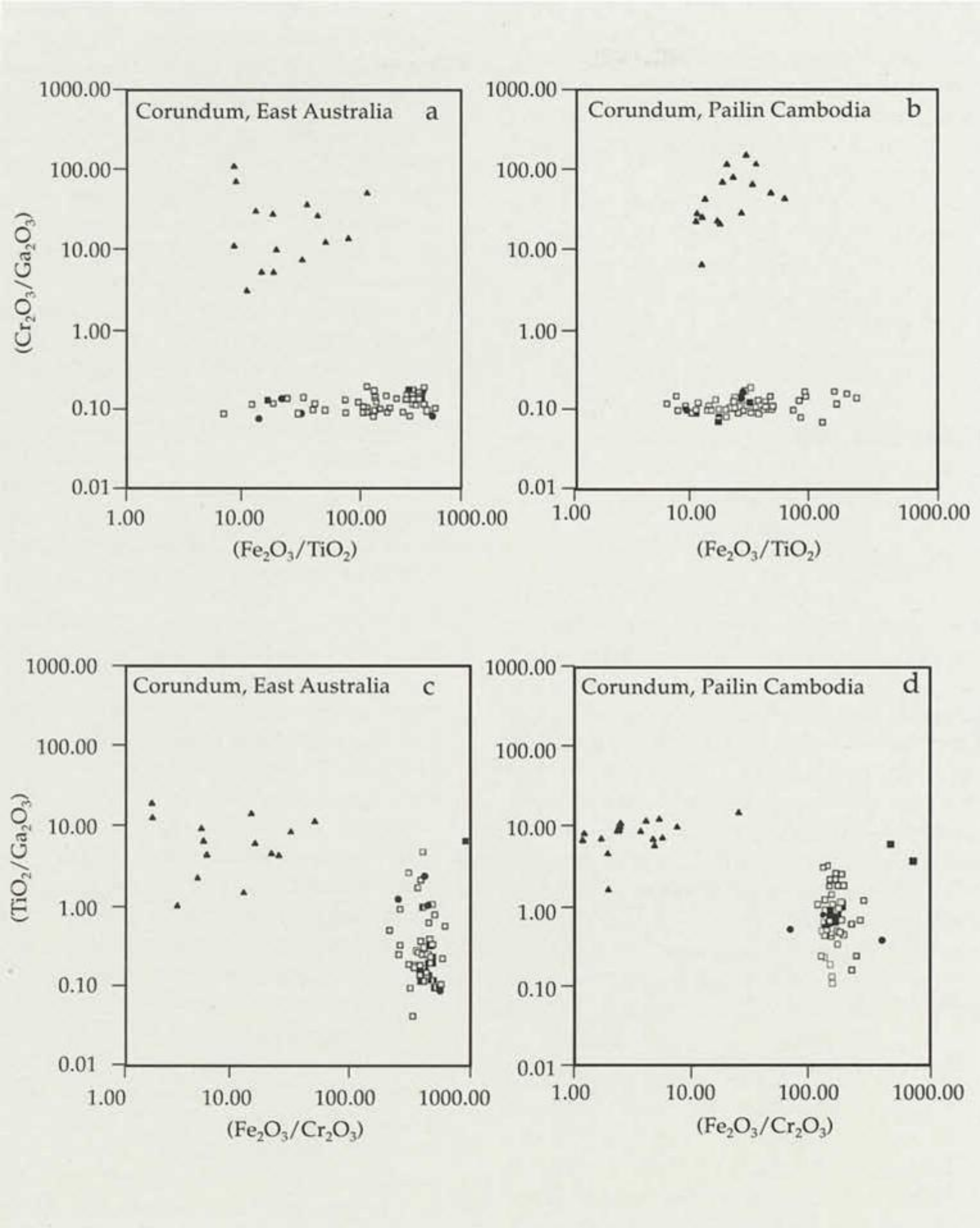


Figure 11: Chemical variation diagrams showing wt% plots of trace-element contents of corundums from East Australia (Barrington and other gemfields, a and c, and from Pailin, Cambodia, b and d.

(a) Cr_2O_3/Ga_2O_3 vs Fe_2O_3/TiO_2; Barrington 'metamorphic' type (▲); Barrington 'basaltic' type (●), East Australian 'basaltic' type (❑); Barrington high 'Fe, Ti type' (■).

(b) Cr_2O_3/Ga_2O_3 vs Fe_2O_3/TiO_2; West Pailin 'metamorphic' type (▲); West Pailin 'basaltic' type (●); West Pailin high 'Fe, Ti type' (■); East Pailin 'basaltic' type (❑).

(c) TiO_2/Ga_2O_3 vs Fe_2O_3/Cr_2O_3; Barrington and other East Australian corundums. Symbols as in Figure 11a.

(d) TiO_2/Ga_2O_3 vs Fe_2O_3/Cr_2O_3; West Pailin and East Pailin corundums. Symbols as in Figure 11b.

Results

Trace and minor element contents of corundums, that correlate with the absorption spectra, are summarised in *Table I* (Barrington 'metamorphic' type and 'basaltic' type compared to typical Australian 'basaltic' type sapphires from Queensland and New South Wales mining fields), *Table II* (West Pailin 'metamorphic' corundums compared to 'basaltic' type sapphires from East Pailin) and in *Figure 11a–d*. Major element values for corundums and co-existing minerals are summarised in *Tables IIIA and IIIB* and *Figure 12*. Selected UV-vis-NIR absorption spectra for East Australian and Pailin corundums are presented in *Figures 13–15*.

Corundum chemistry

Both Barrington and West Pailin corundums have comparable trace-element contents *(Figure 11)* and essentially fall into 2 distinct groups. The fancy coloured 'metamorphic' type suites are characterised by low Ga_2O_3 (<0.01 wt%) and by high Cr_2O_3/Ga_2O_3 ratios (mostly between 10 and 100). The 'basaltic' type sapphires show higher Ga_2O_3 (0.015–0.040 wt%) with Cr_2O_3/Ga_2O_3 always below 1. These two chemical groups correlate with two different patterns observed among the colour-absorption spectra, discussed below. Their chemistry in comparison to corundums from other areas provides the following results:

1. *Iron*

   The Fe- and Ti-concentrations of East Australian sapphires show some variation *(Table I)* with normally 0.4 and 1.8% Fe_2O_3, reaching up to about 2% Fe_2O_3 in a Fe/Ti-rich 'basaltic' type corundum from Barrington. Most 'metamorphic' Barrington corundums lie between 0.4 and 1.2% Fe_2O_3. The 'basaltic' corundums from the Anakie and New England fields range from 0.7 to 1.8% Fe_2O_3. The 'basaltic' corundums from the Pailin mining area show a smaller variation than in East Australian samples *(Table II)*. Over 90% of the 'basaltic' Pailin corundums occupy a narrow range between 0.3 and 0.7% Fe_2O_3. In 'metamorphic' Pailin corundums, however, values reach up to 1% Fe_2O_3. An Fe/Ti-rich 'basaltic' type sapphire from West Pailin contains about 2% Fe_2O_3.

   The Fe-content is a good 'separation criterion' for 'basaltic' corundums from East Australian and Pailin mining fields: most 'basaltic' Pailin corundums contain less than 0.5% Fe_2O_3. On the other hand, typical Fe-concentrations in 'basaltic' corundums from East Australia (Barrington, Inverell, Anakie) exceed 1% Fe_2O_3. Less than 10% of the 161 corundums examined here fall into the over-lapping 'corridor' between 0.6 and 1.0% Fe_2O_3. A separation of the 'metamorphic' corundums from East Australia and Pailin, using Fe, Ti concentrations, however, is not possible. As *Figure 11* shows, there is near complete overlap for these corundums.

2. *Titanium*

   Many East Australian 'basaltic' sapphires show only negligible Ti (<0.005% TiO_2). Some, however, may contain up to 0.05% TiO_2 (compare *Tables IA, B*), and the Fe, and Ti-rich 'basaltic' corundum from Barrington contains about 0.1% TiO_2. The highest Ti-content of 0.14% TiO_2 was found in a blue star sapphire from Anakie. The more usual 'basaltic' sapphires from Barrington fall into the concentration range of sapphires from Anakie and New England. Many 'metamorphic' Barrington corundums have Ti-contents over 0.04% TiO_2, with maximum values up to 0.09% TiO_2. The Ti-concentration in West Pailin 'metamorphic' corundums ranges from 0.01 to about 0.1% TiO_2, while four 'basaltic' sapphires from West Pailin contain only 0.01 to 0.02% TiO_2. The Fe- and Ti-rich type has 0.1-0.2% TiO_2. Many 'basaltic' sapphires from East Pailin are almost Ti-free, while maximum contents lie around 0.07% TiO_2 *(Table II)*.

3. *Gallium*

   Gallium in particular delineates two 'types' of corundum suites for East Australia and Pailin, with pronounced differences in their mineralogical/ chemical features.

'Basaltic' corundums have high Ga-contents (0.015 to 0.040% Ga_2O_3), whereas Ga concentrations for the 'metamorphic' corundums are low (<0.01% Ga_2O_3; compare *Tables I and II*).

4. *Chromium*

Chromium concentrations, like gallium, also differ in the basaltic and 'metamorphic' corundums.

The 'basaltic' corundums from East Australia analysed here are yellow, green, or blue, while those from Pailin are all blue with different hues and intensities. Gemmologically, they are considered as Fe- and Ti-coloured sapphires. The chromium contents of these sapphires are below the detection limit for the analytical method (about 0.005% Cr_2O_3). The 'metamorphic' East Australian and Pailin corundums show a quite distinctive range of colours: pink, red, mauve, violet, purple and blue, which can be considered in three groups as blue sapphires, fancy colour sapphires and rubies. Chromium is present in all 'metamorphic' Barrington and Pailin corundums, including blue or greenish-blue varieties, and contents range up 0.5% Cr_2O_3. Intensely coloured crystals may contain more; the highest analysed content of 0.75% Cr_2O_3 was found in a Pailin ruby. The highest Cr-content found in a Barrington ruby in this study was 0.4% Cr_2O_3, although 1.4 wt% Cr_2O_3 has been recorded previously (Sutherland *et al.*, 1993).

5. *Vanadium*

The vanadium contents in corundums from East Australia and Pailin generally lie below the detection limit of the EDXRF analytical method (about 0.005% V_2O_5), but rarely V_2O_5 may attain 0.01%. In the 'metamorphic' corundums, the range of content is wider and reaches 0.015% V_2O_5 for Pailin and 0.04% V_2O_5 for Barrington purple sapphires.

A more complete chemical characterisation of 'basaltic' and 'metamorphic' corundums from Pailin, Cambodia, and East Australia is based on the correlation diagrams shown in *Figure 11a, b*. These diagrams show the ratios (Cr_2O_3/Ga_2O_3) vs (Fe_2O_3/TiO_2) and are an excellent tool to distinguish two gem corundum suites in these basaltic fields. The metamorphic corundum field characterised by high Cr_2O_3/Ga_2O_3 ratios (mostly between 10 and 100) is clearly separate from the basaltic corundum field for which Cr_2O_3/Ga_2O_3 is always <1. The Fe/Ti-ratio is not diagnostic for separating these types, because of their practically identical width of variation.

The fields for the two 'metamorphic' suites from Pailin and Barrington are almost identical. For basaltic fields from East Australia and Pailin, the 'areas of highest density' are different: Pailin mostly has Fe_2O_3/TiO_2 ratios below 100 *(see Figure 11b)*, whereas East Australian ratios are mostly over 100 *(Figure 11a)*. This stems from 'typical' Fe-contents in Eastern Australian sapphires exceeding those for Pailin sapphires *(Table II)*.

The representative points for 'normal' basaltic corundums from Barrington and West Pailin all lie in the fields for sapphires from other East Australian (Anakie, New England) and East Pailin sapphire fields.

The TiO_2/Ga_2O_3 vs Fe_2O_3/Cr_2O_3 diagrams *(Figures 11c, d)* also clearly separate 'metamorphic' and 'basaltic' corundum suites. The Fe_2O_3/Cr_2O_3 ratio for metamorphic corundums from East Australian and Pailin mostly ranges between 1 and 10 (extending up to 50 for Barrington corundums). The ratios for 'basaltic' sapphires are much higher: mostly 100–200 for the blue sapphires from East Pailin, and 300–600 for the yellow, green, blue and parti-coloured sapphires from East Australia. Whereas typical TiO_2/Ga_2O_3 ratios for 'basaltic' sapphires from East Australia and Pailin are less than 1, for the vast majority of the members of the 'metamorphic' suite the ratio ranges from 1 to 10.

A few 'basaltic' sapphires from Barrington and West Pailin show unusually high Fe- and Ti-contents (2% Fe_2O_3 and 0.1–0.2% TiO_2), beyond the Fe_2O_3/Cr_2O_3 range of 'normal basaltic' corundums *(Figures 11c, d)*. It is uncertain whether these corundums represent another corundum-type, or are fragments of larger colour-zoned

Table IIIA: *Representative analyses of corundums and some primary inclusions from West Pailin.*

Mineral	*Corundum (pink)*	*Corundum (blue)*	*Pleonaste spinel*	*Sapphirine (11.13.5)*	*Fassaite pyroxene*	*Hercynite spinel*
Type	'metamorphic'	'basaltic'	'metamorphic'	'metamorphic'	'metamorphic'	'basaltic'
Wt%						
SiO_2	0.03	–	0.02	13.81	48.86	0.03
TiO_2	0.01	0.04	0.01	0.04	0.19	0.26
Al_2O_3	98.14	100.20	66.60	62.31	13.66	63.00
Cr_2O_3	0.20	–	0.73	0.47	0.11	0.29
NiO	0.00	0.03	0.09	0.41	0.12	0.07
FeO_{tot}	0.70	0.64	10.68	3.44	2.43	21.77
MnO	0.03	–	0.10	0.02	0.03	0.15
MgO	0.04	–	17.47	19.55	12.09	13.50
CaO	0.02	–	–	0.07	21.18	–
Na_2O	–	–	–	0.02	1.54	–
K_2O	–	0.02	0.01	–	–	–
Total	99.17	100.93	98.99	100.54	100.21	99.07
Samples	Job 1.1	Job 3.4	Job 4.3	Job 4.3	Job 3.3	Job 3.10

FeO_{tot} = total iron oxides expressed as FeO

Table IIIB: *Representative analyses of reaction, exsolution and alteration minerals in corundums from West Pailin.*

Oxide *Wt%*	*Reaction spinel 1*	*Reaction spinel 2*	*Reaction spinel 3*	*Exsolution spinel 4*	*Alteration Fe hydroxide*	*Alteration chlorite*
SiO_2	0.06	–	0.01	0.04	–	28.33
TiO_2	0.06	0.15	24.24	0.46	0.07	1.07
Al_2O_3	67.44	63.15	6.69	36.59	3.25	24.75
Cr_2O_3	0.18	–	0.05	0.30	0.04	0.44
NiO	0.23	–	0.13	0.08	0.05	0.02
FeO_{tot}	8.38	22.70	60.99	53.60	84.36	31.54
MnO	0.18	0.26	0.59	0.21	0.01	0.04
MgO	21.57	12.28	3.21	6.06	0.05	0.23
CaO	0.01	0.03	–	–	–	0.18
Na_2O	–	–	0.03	–	–	0.14
K_2O	–	–	–	–	0.02	0.14
Total	98.11	98.57	96.94	97.34	87.85	86.88
Samples	Job 2.5	Job 3.4	Job 3.4	Job 1.1	Job 1.1	Job 2.1

Spinel 1: Reaction rim on sapphirine. Spinel 2: Reaction rim on blue corundum.
Spinel 3: Reaction phase in spinel 2. Spinel 4: Exsolution lamellae in pleonaste.
– means below detection

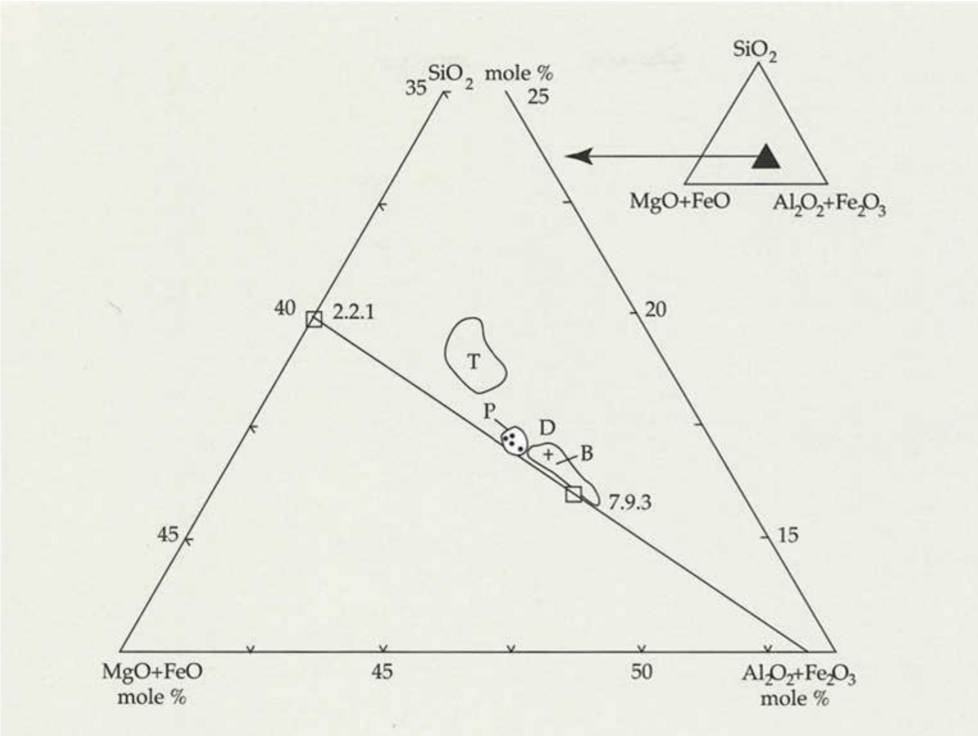


Figure 12: Mole % MgO+FeO, Al_2O_3+Fe_2O_3, SiO_2 chemical variation diagram, showing relationship of Barrington (B) and West Pailin (P) corundum-hosted sapphirine compositions, in relation to the sapphirine composition reference line (including 2.2.1 and 7.9.3 member compositions). Thailand (Rubywell Mine) alluvial sapphirines (T) and NSW granulite-hosted sapphirine from lower crustal xenolith, Delegate (D) are plotted for comparison, based on diagram after Sutherland and Coenraads, 1996, Figure 4.

crystals. Crystals with colour zoning and unusually high element concentrations related to certain zones have been found from other localities (Schwarz, in prep.).

Mineral inclusions and intergrowths

Despite their geographical separation, Barrington and West Pailin corundums include minerals of very similar compositions. Analyses of Pailin corundums and their primary inclusions *(Table IIIA)* are listed with those for alteration minerals *(Table IIIB)*. Primary sapphirine is near a 11(MgO + FeO) : 13(Al_2O_3 + Fe_2O_3) : 5SiO_2 mole % composition and approaches the 7 : 9 : 3 composition of sapphirine inclusions in Barrington fancy coloured corundums *(Figure 12)*. West Pailin spinels (Sp 78 Hc 22) are slightly more Al-rich and Fe-poor than spinels from the Barrington field (*cf* Sp 68–73 Hc 26–29 Cm 0–3 in Sutherland and Coenraads, 1996). In the 'basaltic' type corundums, spinels are more Fe-rich, but West Pailin compositions are less so than at Barrington. They are spinel-hercynite (Sp 53 Hc 45 Usp 1 Mt 1; analysis in *Table IIIA*), rather than hercynite-magnetite (Hc 51–73, Mt 18–35, Mf 6–8 Usp 2–5) reported in Sutherland and Coenraads, 1996.

Absorption spectroscopy

The most important minor elements in corundums from East Australia and Pailin are Fe, Ti, Cr, Ga, and V and of these, Fe, Ti, and Cr are significant in colour-causing processes (the V-concentration is generally

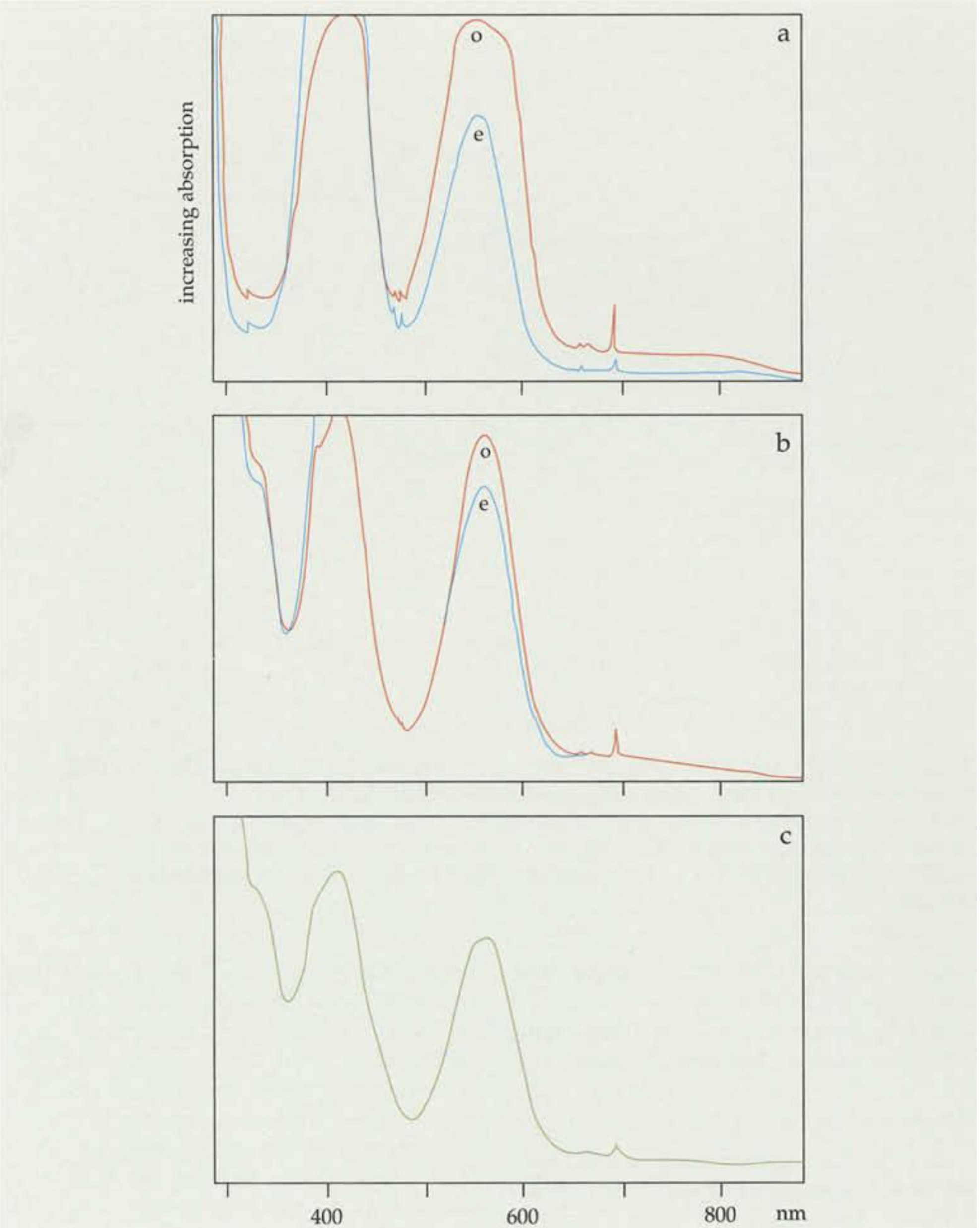


Figure 13: *Comparative colour absorption spectra related to Cr-bearing corundums.*

(a) Cr^{3+} absorption spectrum with intense bands around 400 and 550 nm in a metamorphic corundum (ruby) from Mogok, Burma. Such 'pure' Cr-spectra have not been observed in corundums from East Australian and Pailin basaltic gemfields.

(b) Representative absorption spectrum for ruby from basaltic fields, Thai-Cambodian border region. In addition to the two broad Cr^{3+} bands, a pronounced 'shoulder' in the UV region around 330 nm is present.

(c) The 'Thai ruby-type' absorption spectrum observed in 'metamorphic' type suites from Barrington and West Pailin basalts.

too low to act as colour agent). Chromium is the dominant chromophore in pink and red corundums (rubies). The 'pure' Cr-absorption spectrum shown in *Figure 13a* is characterised by two intense bands around 400 and 550 nm but such spectra are not observed in the red/pink corundums from Barrington and Pailin. Instead, they show a spectrum typical of rubies from the Thai/Cambodian border region *(Figure 13b)* with an absorption 'shoulder' around 330 nm that reflects relatively high Fe-contents (mostly about 0.3–0.7% Fe_2O_3; Schwarz, in prep.) and appears *(Figure 13c)* equally among Barrington and Pailin corundums.

Iron and titanium are the dominant colour-causing elements in blue sapphires. The absorption bands and characteristics in spectra of blue sapphires are related to the following mechanisms:

- sharp bands in the ultraviolet at 375 and 387 nm, due to dispersed Fe^{3+};
- sharp bands in the visible region at 450, 460 and 469 nm, due to dispersed Fe^{3+};
- broad bands with absorption maxima between 550 and 600 nm (ordinary ray spectrum) and between 680 and 750 nm (extraordinary ray spectrum), related to Fe^{2+}–Ti^{4+} intervalence charge-transfer processes (IVCT). Fe^{2+}–Ti^{4+} dominated spectra are typical for blue sapphires originating from Kashmir, Myanmar and Sri Lanka (cf. Schwarz *et al.*, 1996);
- an increasing absorption towards the near infrared (800–900 nm; *Figure 14a*), due to Fe^{2+}–Fe^{3+} charge transfer processes. Although this has been considered typical for sapphires from basaltic sources, the phenomenon is not entirely restricted to 'basaltic' sapphires as it also appears in sapphires from Andranondambo in Madagascar which originate from a skarn-type genetic environment (Schwarz *et al.*, 1996).

Absorption spectra dominated by Fe–Ti and Fe–Fe charge-transfer mechanisms typify blue sapphires from East Pailin *(Figure 14a)*. They also appear in the 'basaltic' *(Figure 14b)* suites in West Pailin and Barrington. Absorption spectra of green and yellow 'basaltic' sapphires from East Australia are compared in *Figures 14c and 14d*. The 'high Fe, Ti' 'basaltic' sapphires present absorption spectra marked by a relatively intense Fe^{2+}–Ti^{4+} absorption *(Figure 14e)*.

The absorption spectra of blue sapphires from the 'metamorphic' suites in West Pailin and Barrington are dominated by Fe^{3+} bands in the ultraviolet (375, 387 nm) and visible region (450, 460, 469 nm), and by a broad Fe^{2+}–Ti^{4+} charge-transfer between ca. 550 and 750 nm *(Figure 15a)*. There is no significant Fe^{2+}–Fe^{3+} charge-transfer absorption toward the near-infrared.

Practically all absorption spectra observed in the 'metamorphic' corundums from Barrington and West Pailin represent a combination of Fe, Ti and Cr bands with variations in the relative intensities of the absorption bands *(Figures 15b and 15c)*. Consequently, some 'blue' sapphires from the 'metamorphic' suites show considerable Cr components in their absorption spectra which can be seen in a hand-held spectroscope.

Discussion

Clearly, corundums from two distinct suites surfaced with basaltic eruptions at both Barrington and Pailin. Both exhibit surface features related to magmatic corrosion of former embedded crystal sites and the trigonal crystallographic structure (Coenraads, 1992b, and *Figure 6* of this study). Among these are 'needle-like' textures recently illustrated from sapphires at Cyangugu, Rwanda, Africa (Krzemnicki *et al.*, 1996). These authors attribute the needles to protection of the corundum by plagioclase crystals that crystallized from the coarse basalt host, but have since weathered away. Similar needle-like textures have been illustrated from corundums from other areas (Coenraads, 1992 b; Guo *et al.*, 1996) and have been interpreted as the results of differential corrosion of twinning planes. Thus, while large, flatter and squarer-ended ridges in Cyangugu sapphire may represent former random sheaths of plagioclase, the ridge-like textures of Barrington and Pailin material are considered to largely stem from crystallographically controlled corrosion. Fused crusts on some corundums and composites suggest little alluvial transport from their source.

More than one generation of corundum is seen within the fancy coloured suite. Small hexagonal crystals of white or pale yellow corundum without significant trace-element contents are intergrown with or included in larger blue corundums containing Fe as the main trace element. Some features typical of Thai ruby suites such as decrepitation haloes (Gübelin and Koivula, 1986) appear in both Barrington and West Pailin rubies, illustrating that such features are not exclusive to Thai rubies.

Origin of the metamorphic corundum suite

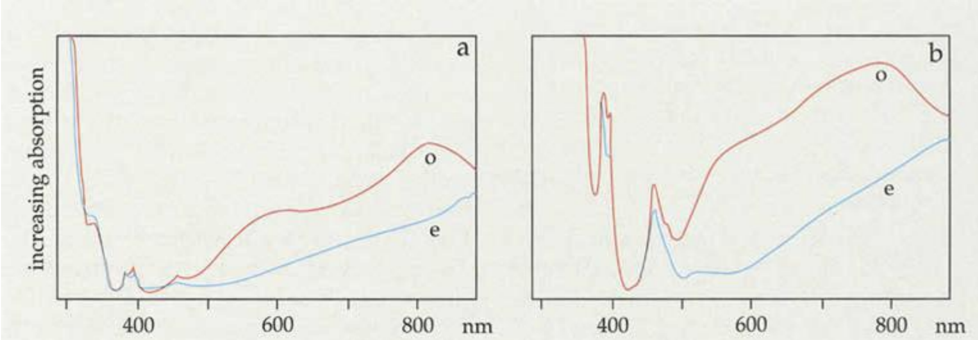
Possible origins for Barrington corundums that favour metamorphic or metasomatic sources have been outlined by Sutherland and Coenraads, 1996. Crystallisation temperatures for Barrington corundum-sapphirine-spinel assemblages were estimated at around 780–940°C, with subsequent reaction with magmatic hosts taking place around 1000°C. West Pailin mineral analyses (*Table IIIA, B*) were subjected to the Mg–Fe exchange sapphirine-spinel thermometer calculations of Owen and Greenough, 1991, which were used in the Barrington study. This thermometer uses an increase in temperature dependence with the partitioning co-efficient Kd for Mg and Fe in the sapphirine (sa)/spinel (sp) pair. The formulation is T (°C) = [800 + (228 ln Kd)] – 273, where Kd = $(Xsp_{Fe}/Xsp_{Mg})/Xsa_{Fe}/Xsa_{Mg})$, with X representing the molar fractions of Fe and Mg in the minerals. Calculations based on a sapphirine-spinel pair (Job 4.3, *Table IIIA*) gave 772°C (Fe^{2+} calculation) and 943°C (Fe^{2+} and Fe^{3+} recalculation). This suggests comparable crystallisation temperatures for both Pailin and Barrington suites.

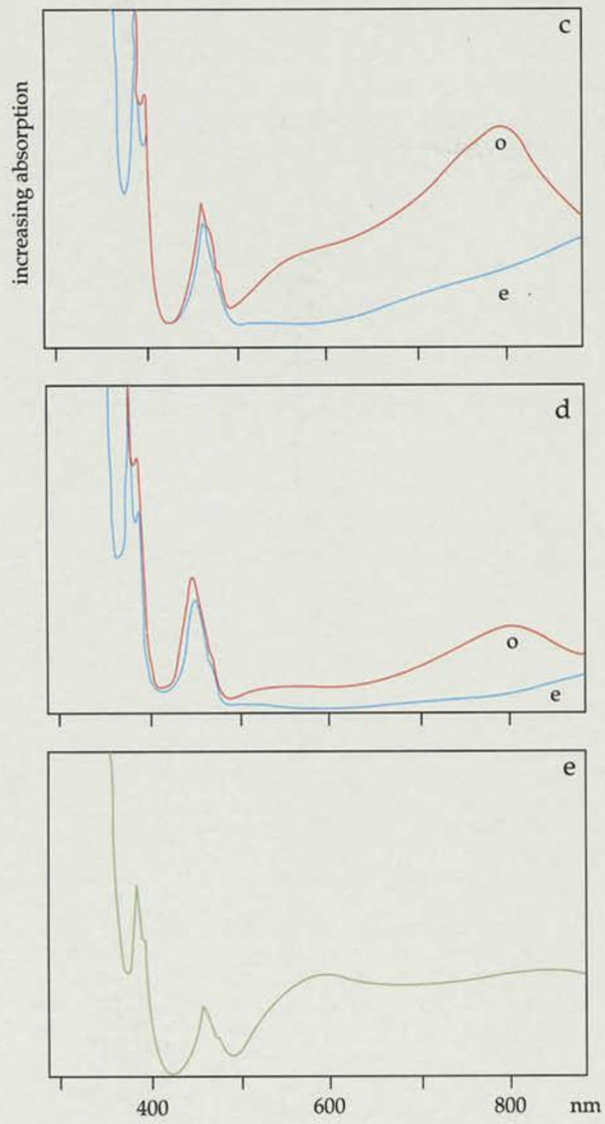
The trace-element and absorption characteristics of the fancy coloured corundums and co-existing minerals (*Figures 11, 12, 13 and 15*) are considered to characterise corundum assemblages produced by metamorphic recrystallization of aluminous material. Whether this metamorphism originated from contact metamorphism related to the basaltic magmas or from an earlier unrelated metamorphic event is not clear on present data.

Figure 14: Representative absorption spectra of blue-green-yellow 'basaltic' type sapphires from East Pailin and East Australia.

(a) Absorption spectrum of blue sapphire from East Pailin mining region, with absorption bands due to Fe^{2+}–Ti^{4+} and Fe^{2+}–Fe^{3+} charge transfer (o, ordinary ray; e, extraordinary ray).

(b) Typical absorption spectrum of blue 'basaltic' type sapphire from East Australia (New South Wales and Queensland mining areas). Blue absorption minimum (light transmission) only in the blue spectral region.





(c) Typical absorption spectrum of green 'basaltic' type sapphire from East Australia (New South Wales and Queensland mining areas). Two absorption minima in violet-blue region and blue-green region, resulting in (blue-) green body colours.
(d) Absorption spectrum of yellow 'basaltic' type sapphire from East Australia (New South Wales and Queensland mining areas). Yellow broad transmission over the whole green-yellow-orange spectral region.
(e) Absorption spectrum of blue 'basaltic' type sapphires with high Fe and Ti contents. The relatively strong absorption band in the 500 to 600 nm region is caused by Fe^{2+}–Ti^{4+} charge transfer.

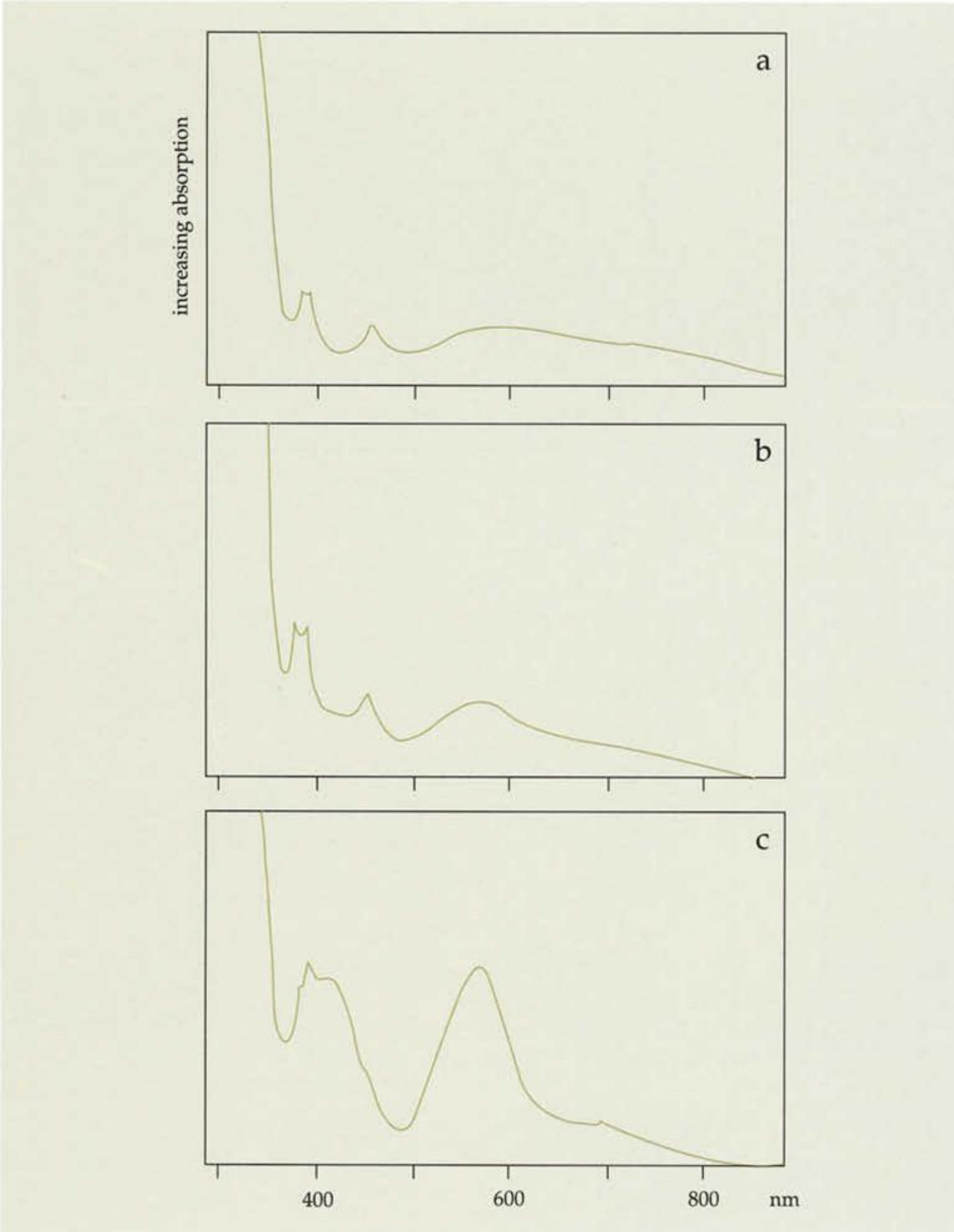


Figure 15: *Absorption spectra of 'metamorphic' type fancy colour corundums from Barrington and West Pailin corundum suites.*

(a) Blue sapphire, with dominating Fe^{3+} bands in the UV and visible region accompanied by the broad absorption band about 550 to 600 nm due to Fe^{2+}–Ti^{4+} charge transfer.

(b) Fancy colour corundum from 'metamorphic' type Barrington and West Pailin suites: typical spectrum showing strong Fe^{3+} and Fe^{2+}–Ti^{4+} charge transfer absorption bands with weak Cr^{3+} bands.

(c) Fancy colour corundum with dominant Cr^{3+} absorption spectrum combined with weak Fe^{3+} and Fe^{2+}–Ti^{4+} charge transfer bands.

Origin of the 'basaltic' corundums

Although subsidiary at Barrington and West Pailin, 'basaltic' corundums dominate suites elsewhere in East Australia and Pailin. The corundums range into higher Ga contents (up to 0.04 wt % Ga_2O_3) and lower Cr_2O_3/Ga_2O_3 (always <1) and their chemical ratios *(Tables I, II; Figure 11)* match values recorded for 'basaltic' corundums from South Vietnam (Smith *et al.*, 1995), China (Guo *et al.*, 1992), Madagascar (Schwarz *et al.*, 1996) and East Africa (Krzemnicki *et al.*, 1996). These 'basaltic' type corundums show Fe and Ti dominated absorption spectra *(Figure 14)* distinctly different from those of the fancy coloured corundums and contain a greater range of mineral inclusions, such as spinels, alkali and plagioclase feldspars, exotic Nb, Ta, U and Th oxides and Zr- or Th-rich silicates (Coenraads, 1992a; Guo *et al.*, 1996; Sutherland and Coenraads, 1996).

Work on the possible origin of these wide-spread 'basaltic' corundums has generated several models. Most involve plutonic crystallization from a melt, although wide-spread metamorphic recrystallization of Al-rich rock subducted below continental crust has also been advocated (Levinson and Cook, 1994). Several models use alkaline Si- and Al-rich melts, either evolved from basaltic magmas (Irving, 1986; Coenraads *et al.*, 1990; Coenraads, 1992a) or derived from melting of amphibolitised mantle (Sutherland, 1996). A more complex melt origin was proposed by Guo *et al.*, 1996, who claimed that mineral inclusions in the corundums reflect mixing of Si-rich and carbonatitic magmas under relatively low temperatures around 400°C at mid-crustal levels around 10–20 km in depth. Sutherland *et al.* (1998, in prep.), have questioned this model as a widespread means of generating 'basaltic' type gem corundum and favour melting of mantle source-rocks containing amphibole at depths of 35–40 km near the crust-mantle boundary; such melting could produce a final Si- and Al-rich rock with over 5 wt% corundum.

Regional distribution of corundum suites

Trace-element ranges for Barrington and West Pailin bimodal suites were compared with those from other East Australian and East Pailin gemfields *(Tables I and II)*. Similar bimodal suites also exist elsewhere, e.g. Tumbarumba in the Snowy River basalt field, East Australia (MacNevin and Holmes, 1980), between Chanthaburi and Trat, Thailand (Hughes, 1990) and possibly in Laos (Bosshart, 1995; D Schwarz, unpublished data). However, the situation appears more complicated than just basaltic tapping of two overlapping distinctive corundum suites.

Although many Thai sapphires carry mineral inclusions similar to Australian and Pailin suites (e.g. plagioclase, urano-pyrochlore; Gübelin and Koivula, 1986), Thai rubies carry mineral inclusions not seen in the Barrington and West Pailin fancy corundum suites (e.g. analcime, apatite, calcite, pyrope-almandine, plagioclase, olivine, diopside, biotite, rutile, pyrite and pyrrhotite, with only spinel being common to both groups). Similar species also appear in sapphires from Yogo Gulch (Montana, USA) and in corundums from metamorphic terrains (Burma, Sri Lanka and eastern Africa; Gübelin and Koivula, 1986). Thus, different metamorphic or pegmatitic sources and assemblages must exist under basaltic regions, and the corundum-sapphirine-spinel association is only one. The East Australian and Pailin corundum suites analysed here are clearly different to 'skarn' sapphires, such as those from Andranondambo, Madagascar, both in their trace-element ratios and inclusion content (Milisenda and Henn, 1996; Kiefert *et al.*, 1996; Schwarz *et al.*, 1996).

The West Pailin ruby source probably extends into Thailand, as sapphirine was recorded in Bo Rai ruby by Koivula and Fryer (1987) and inclusions are limited in mineral range (Keller, 1990). However, further east near Chanthaburi, Thai rubies show a greater range of mineral inclusions and may represent a different basement source within this complex tectonic region. Regional differences may also exist among 'basaltic' type corundums, as suggested by zircon inclusions. Zircons in Australian and Asian corundums (Guo *et al.*, 1996;

Sutherland *et al.*, 1998) are typically high in U and Th, but some are much less so. More detailed work on South East Asian corundum suites will help define corundum sources below these basaltic fields.

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References

Berrangé, J.P., and Jobbins, E.A., 1976. The geology, gemmology, mining methods and economic potential of the Pailin ruby and sapphire gem-field, Khmer Republic. *Institute of Geological Sciences Report*, **35**, 1–32, 3 maps

Bosshart, G., 1995. Sapphires and rubies from Laos. *Proceedings of the 25th International Gemmological Conference, Rayong, Thailand, 23-27 October, 1995*

Bunopas, S., and Vella, P., 1992. Geotectonics and geological evolution of Thailand. In: Piancharoen, C. (ed.). *Supplementary volume of proceedings of a National Conference on Geological Resources of Thailand.* Department of Mineral Resources, Bangkok, Thailand, 209–28

Coenraads, R.R., 1992a. Sapphires and rubies associated with volcanic provinces: Inclusions and surface features shed light on their origin, *Australian Gemmologist*, **18**(3), 70–80

Coenraads, R.R., 1992b. Surface features of natural rubies and sapphires associated with volcanic provinces. *Journal of Gemmology*, **23**(3), 151–60

Coenraads, R.R., Sutherland, F.L., and Kinny, P.D., 1990. The origin of sapphires: U–Pb dating of zircon inclusions sheds new light. *Mineralogical Magazine*, **54**, 113–22

Coldham, T., 1985. Sapphires from Australia. *Gems & Gemology*, **21**(3), 13–46

Davis, D.W., and Barr, S.M., 1995. U-Pb dating of 1-10 Ma mantle zircon megacrysts from South East Asia. *Geological Association of Canada/Mineralogical Association of Canada Annual Meeting, Victoria*, **20**, A23

Gübelin, E.J., and Koivula, J.I., 1986. *Photoatlas of inclusions in gemstones.* ABC Edition, Zurich

Guo, J., Wang, F., and Yakoumelos, G., 1992. Sapphires from Changle, in Shandong province, China. *Gems & Gemology*, **28**(4), 225–60

Guo, J.F., O'Reilly, S.Y., and Griffin, W.L., 1996. Corundum from basaltic terrains: an inclusion approach to the enigma. *Contributions to Mineralogy and Petrology*, **122**, 368–86

Hughes, R.W., 1990. *Corundum.* Butterworth-Heinemann, London

Hughes, R.W., 1997. *Ruby and sapphire.* R.W.H. Publishing, Boulder, Co., USA

Irving, A.J., 1986. Polybaric magma mixing in alkali basalts and kimberlites: Evidence from corundum, zircon and ilmenite megacrysts. In: Smith, C.B. (compl.) Fourth International Kimberlite Conference Extended Abstracts, Perth, Western Australia, August 11–15, 1986. *Geological Society of Australia Abstracts Series*, **16**, 262–64

Jobbins, E.A., and Berrangé, J.P., 1981. The Pailin ruby and sapphire gemfield, Cambodia. *Journal of Gemmology*, **17**(8), 555–67

Johnson, R.W., (comp. and ed.), 1989. *Intraplate volcanism in Eastern Australia and New Zealand.* Cambridge University Press, Cambridge

Keller, P.C., 1990. *Gemstones and their origins.* Van Nostrand Reinhold, New York

Kiefert, L., Schmetzer, K., Krzemnicki, M.S., Bernhardt, H.-J., and Hänni, H.A., 1996. Sapphires from the Andranondambo area, Madagascar. *Journal of Gemmology*, **25**(3), 185–209

Koivula, J.I., and Fryer, C.W., 1987. Sapphirine (not sapphire) in a ruby from Bo Rai, Thailand. *Journal of Gemmology*, **20**(6), 369–70

Krzemnicki, M.S., Hänni, H.A., Guggenheim, R., and Mathys, D., 1996. Investigations on sapphires from an alkali basalt, South West Rwanda. *Journal of Gemmology*, **25**(2), 90–106

Levinson, A.A., and Cook, F.A., 1994. Gem corundum in alkali basalt: Origin and occurrence. *Gems & Gemology*, **30**(4), 253–62

MacNevin, A.A., and Holmes, G.G., 1980. Gemstones. The Mineral Industry of New South Wales, *Geological Survey of New South Wales*, **18**, 2nd Edition, 119 pp

Milisenda, C.C., and Henn, U., 1996. Compositional characteristics of sapphires from a new find in Madagascar. *Journal of Gemmology*, **25**(3), 177–84

Mumme, I.A., 1988. *The world of sapphires.* Mumme Publications, Port Hacking, Australia

Olliver, J.G., and Townsend, I.J., 1990. *Gemstones in Australia.* Australian Government Publishing Service, Canberra

O'Reilly, S.Y., and Zhang, M., 1995. Geochemical characteristics of lava-field basalts from eastern Australia and inferred sources: connections with the sub-continental lithospheric mantle. *Contributions to Mineralogy and Petrology,* **121**, 148–70

Owen, J.V., and Greenough, J.D., 1991. An empircal sapphirine-spinel Mg-Fe exchange thermometer and its application to high-grade xenoliths in the Pope Harbour dyke, Nova Scotia, Canada. *Lithos,* **26**, 317–32

Pain, C.F., 1983. Geomorphology of the Barrington Tops area, New South Wales. *Journal of the Geological Society of Australia,* **30**, 187–94

Schwarz, D., in prep. The chemical properties of corundums (rubies and sapphires) from Eastern Asia (Thailand, Cambodia, Laos, Vietnam, Burma, etc.)

Schwarz, D., Petsch, E.J., and Kanis, J., 1996. Sapphires from the Andranondambo region, Madagascar. *Gems & Gemology,* **32**(2), 80–99

Smith, C.P., Kammerling, R.C., Keller, A.S., Peretti, A., Scarratt, K.V., Khoa, N.D., and Repetto, S., 1995. Sapphires from Southern Vietnam. *Gems & Gemology,* **31**(3), 168–86

Stern, B.W., 1984. Zur Simultananalyse von Silicaten (Hauptkomponenenten, Spuren) mittels energie-dispersiver Röntgenfluoreszenz-Spektrometrie (EDS-XFA). *Fresenius Z. Analaytical Chemistry,* **2560**, 1–9

Sutherland, L., 1991. *Gemstones of the southern continents.* Reed Books, Sydney

Sutherland, F.L., 1996. Alkaline rocks and gemstones, Australia: a review and synthesis. In: Sutherland, F.L., (ed.) The Nicholas Rock Symposium: Alkaline rocks and their associated mineralisation. *Australian Journal of Earth Sciences,* **43**, 323–43

Sutherland, F.L., and Coenraads, R.R., 1996. An unusual ruby-sapphire-sapphirine-spinel assemblage from the Tertiary Barrington volcanic province, New South Wales, Australia. *Mineralogical Magazine,* **60**, 623–38

Sutherland, F.L., and Fanning, C.M., 1996. Magmatism below Barrington volcano, NSW: Based on basalt and zircon megacryst dating. *Geological Society of Australia Abstract Series,* **41**, 426

Sutherland, F.L., Barron, B.J., and Webb, G., 1993. Barrington volcano – repeated gemstone eruptions (zircon, sapphire and ruby) at the edge of the Sydney Basin. In: Diesel, C.F.K. (conven.) *Twenty-Seventh Newcastle Symposium on Advances in the Study of the Sydney Basin.* University of Newcastle, Department of Geology, Publication **545**, 137–44

Sutherland, F.L., Hoskin, P.W.O., Fanning, C.M., and Coenraads, R.R., 1998. Models of corundum origin from alkali basalt terrains: a re-appraisal. In prep.

Suttirat, C., Charusiri, P., Farrar, E., and Clark, A.H., 1994. New $^{40}Ar/^{39}Ar$ geochronology and characteristics of some Cenozoic basalts in Thailand. *Proceedings of the International Symposium on: Stratigraphic Correlation of Southeast Asia,* 15–20 November 1994, Bangkok, Thailand, 306–21

Vichit, P., 1992. Gemstones in Thailand. In: Piancharoen, C. (ed.) *Supplementary Volume of Proceedings of a National Conference on Geological Resources of Thailand.* Department of Mineral Resources, Bangkok, Thailand, 124–50

Webb, G., 1997. Gemmological features of rubies and sapphires from the Barrington volcano, eastern Australia. *The Australian Gemmologist,* **19**(11), 471–75

Peridot from the Black Rock Summit lava flow, Nye County, Nevada, USA

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ABSTRACT: An extinct volcano's alkaline basalt lava flow has fissures and tumuli filled with large phenocrysts of peridot and occurs near Black Rock Summit in east central Nevada, USA. The peridot was studied to determine chemical, optical and physical properties and the variations in these properties from peridot from other world occurrences. This little-known source provides peridot in varying shades of green to brown, similar to material found in a caldera known as Kilbourne Hole (Volcano), Dona Ana County, New Mexico, USA – some 1126 km distant. Several identified 'new' inclusions, not previously cited in the literature, are described. Though not mined commercially, the peridot is of interest due to its variation in colour from peridots of other world sources.

Introduction

Approximately 277 km north-north-east of Las Vegas, Nevada, lies a desert area of flatlands *(Figure 1)* sparsely dotted with *playa* lakes and mountain ranges and known as a 'pancake' desert. The northerly highway from Las Vegas passes by top-security military bases and desolate areas which historically represent the underground test area of over 800 nuclear weapons. Still farther north in a remote area will be found an extinct volcano, Lunar Crater, and black volcanic lava flows of Cenozoic age listed on US Geological Survey maps as the Black Rock Summit lava flow.

Figure 1: *View of the cinder cone and very dark lava field looking easterly with the cinder cone rising approximately 300 m from the desert floor. The lava field consists of jagged protrusions rising between 0.5 m and 10 m above the sandy desert.*

In the Black Rock Summit lava flow can be found one of the most diverse examples of peridot found in the world. The colour ranges from yellowish-brown through greenish-yellow into very dark 'muddy' shades of brown. With a history of peridot going back to 1500 BC, the study of peridot associated with volcanoes of high-alkali olivine basalt will continue to be a 'new discovery' event inasmuch as North America

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Figure 2: The western portion of the United States of America showing volcanic areas in the continental USA younger than five million years old (modified from Smith and Leudke, 1984).

provides unlimited numbers of recorded volcanoes from the Aleutian Islands into Alaska, Canada, and the continental United States. The Western United States (*Figure 2*) provides a lifetime of study for the gemmologist with its readily accessible areas for prospecting for this 'old' but currently little-respected gem.

In an effort to compare peridot from different areas of the world with regard to optical and physical data, as well as characteristic inclusions, the author has attempted to collect specimens of peridot from 'little-known' sources. Numerous trips were made over a five-year period to Black Rock Summit lava flow to collect specimens. As each new source is investigated a 'new' inclusion has been reported that is characteristic of the peridot of the area.

A basalt flow (*Figure 1*) on the west slope of the Pancake Range, near Black Rock Summit, Nye County, Nevada, is the youngest unit in an upper Cenozoic volcanic

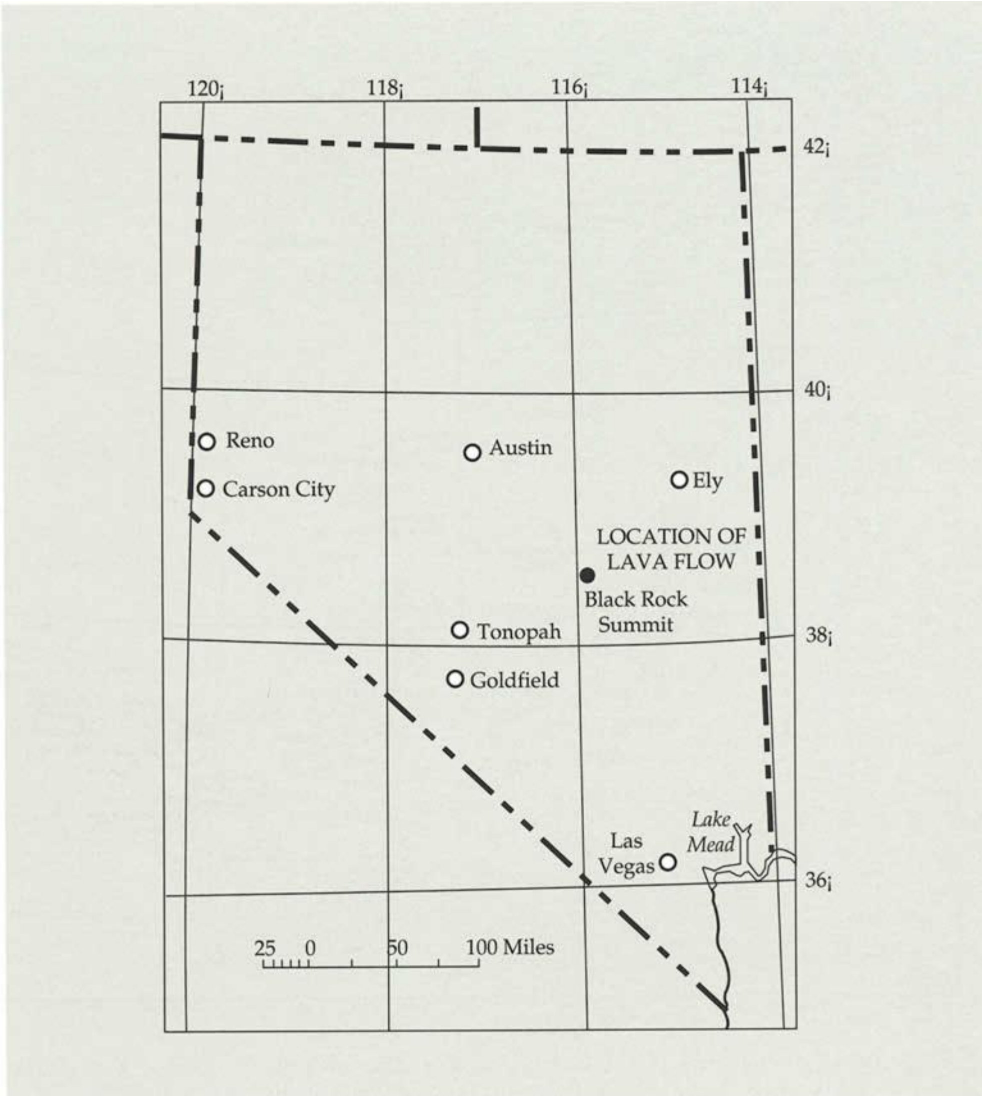


Figure 3: Index map of the State of Nevada, showing the location of Black Rock Summit lava flow (after Vitaliano and Harvey, 1965).

field composed mainly of cinder cones and ash deposits. The flow is black and vesicular to scoriaceous with the texture of the non-scoriaceous phase being porphyritic. Phenocrysts of olivine, pyroxene, and plagioclase are from 1 cm to 22 cm long.

Location and Access

The basalt flow is small covering an area approximately 8.0x4.8 km at 116°00′ west longitude and 38°29′ north latitude, and is accessible by Nevada State Highway Number 6 north-east from the city of Tonopah (*Figure 3*). US Geological Survey topographic maps which cover the area are Black Rock Summit (number 38115-E8), the Wall (number 38115-D8), Lunar Crater (number 38116-D1), and Moores Station SE (number 38116-E1) which are 7.5 minute quadrangles (Map scale: 1:25000;

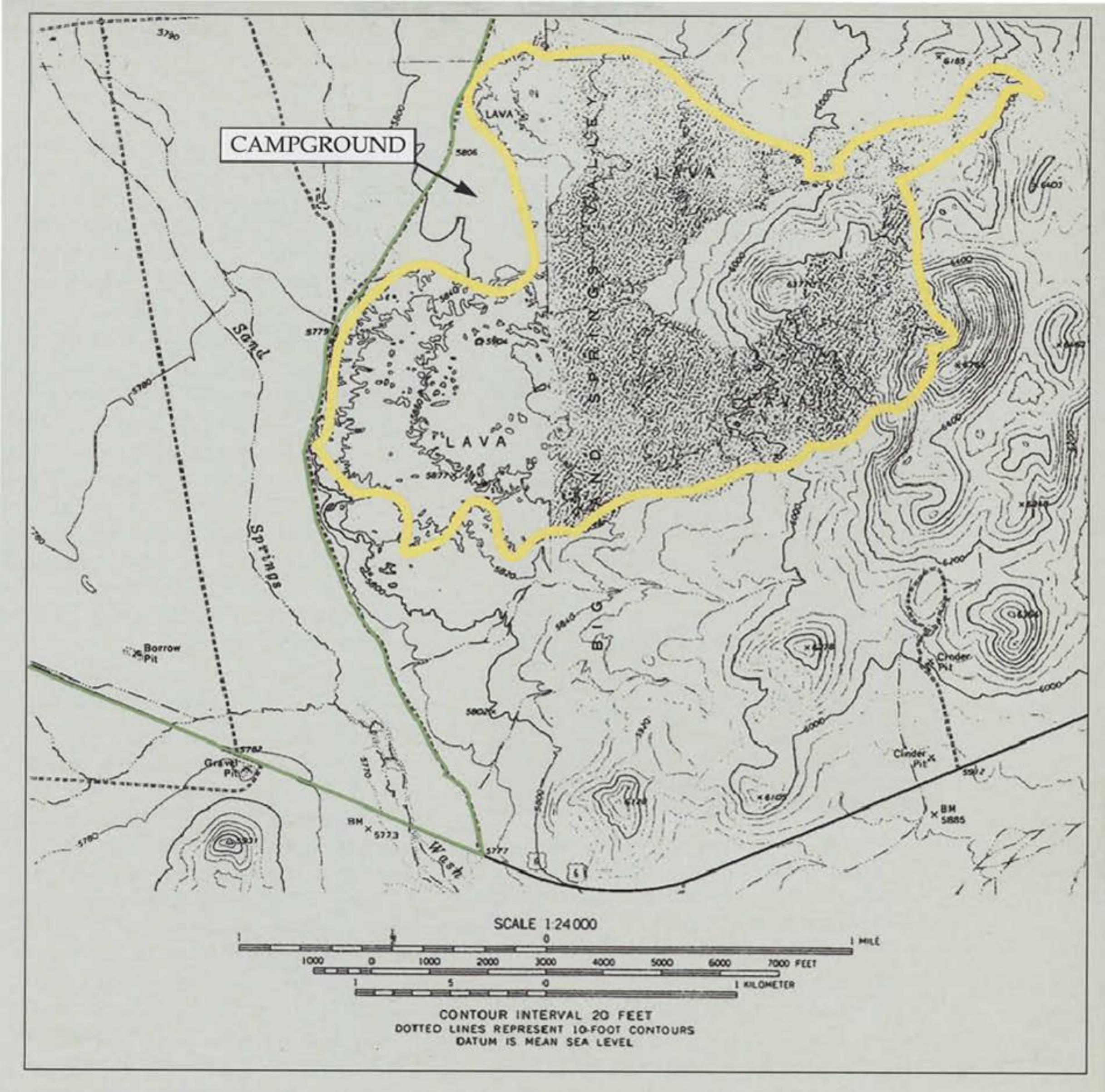


***Figure 4:** Outline showing access to the Black Rock Summit lava flow from Nevada State Highway Number 6 and the offroad to the encampment; based on US Geological Survey topographic maps. Due to the nature of the scattered lava pieces and the desert sand, it is highly recommended that only a four-wheel drive vehicle be used.*

1"=2083 feet). A composite of these four maps is shown in *Figure 4*.

The altitude varies from 1761 m on the desert floor to 2062 m at the summit. The area surrounding the flow is sandy desert with short dried grass and no brush. Typical daytime temperatures in the summer are in the range of 35°C to 46°C with slight cooling desert winds in the late evenings; humidity is less than 5 per cent. Access is from the main highway; however, adequate supplies of food and especially water are mandatory as the temperature on the lava flow in July was measured at midday in excess of 63°C!

Geology and occurrence

A study of the petrology and mineralogy of the lava flow was made by Vitaliano and Harvey (1965). The following is taken from the introduction to their paper:

Figure 5: Centre of the lava field showing the infrequently found tumuli which contain the larger crystals of peridot. This particular tumulus yielded a single peridot specimen which weighed 614.60 ct!

'The lava issued from a breach in the southwest wall of a small cinder cone, one of several located on a N.20°E. trending fissure. About 90% of the lava issued from this crater; the remainder flowed from an orifice located near the northeastern extremity of the fissure. The vent of the crater is about 91 m in diameter and is now filled with solidified lava up to the level of the breach in the wall.'

Within the crater the surface of the lava *(Figure 5)* is infrequently dotted with jagged protuberances called 'tumuli' *(Figure 6)*. The name 'tumulus' was proposed by Daly (1914) (from the Latin 'a swelling-up'), following its application to certain prehistoric burial mounds). Daly recognized that tumuli are common in Hawaii and explained them as having been raised by 'the local hydrostatic pressure of still-fluid lava beneath the already chilled crust', a view with which the author concurs.

The following description of the lava is quoted from the paper by Vitaliano and Harvey (1965):

'Outside the crater it is dominantly a pahoehoe type of lava. Residual monolithic blocks of pyroclastic material, now scattered throughout the flow, may represent fragments from the breach in the crater wall. In the steep north-western wall of longitudinal depression in the lava three layers are exposed, each separated from the other by thin scoriaceous horizons. The thickness of this location exceeds 15 m but the base of the lava was not observed anywhere

Figure 6: 'Tumili', 'lava rises' or 'lava pits' as defined by Hawaii's Institute of Geophysics are more prolific near the edges of the lava flow than in the centre, rising from about 1.5 m to about 10 m and may be the result of pressure ridges.

Figure 7: Variation in colour of the fragments collected from the tumuli debris; all pieces appear to be 'splintered' and 'spear-point-shaped' and these represent typical sizes of facetable quality: 7.03 ct (18.3 x 7.9 x 5.7 mm); 12.72 ct (26.7 x 11.1 x 10.1 mm); and 4.65 ct (19.6 x 6.7 x 6.9 mm). Photo by Maja DeMaggio.

within the confines of the perimeter and consequently the thickness could not be determined.

'The rock is black, vesicular and porphyritic except where marked oxidation attending vesiculation has colored it red. Its most striking characteristic is the large crystals of olivine (peridot), pyroxene and plagioclase.'

Vesicular walls of lava are occasionally lined with hydrous iron oxide or with a buff-coloured material. Specimens of peridot larger than 2 x 2 cm are generally fractured into elongated 'spear-point-shaped' pieces *(Figure 7)*; those in the central portion of the lava flow are darker in colour and the lighter more 'yellowish' and more transparent material is found within the tumuli at the periphery of the lava flow. The interiors of the tumuli are lined with lava which weathered to release the peridot and colourless plagioclase feldspar and augite crystals; the fine powdery grey ash which has decomposed from the inner walls of the

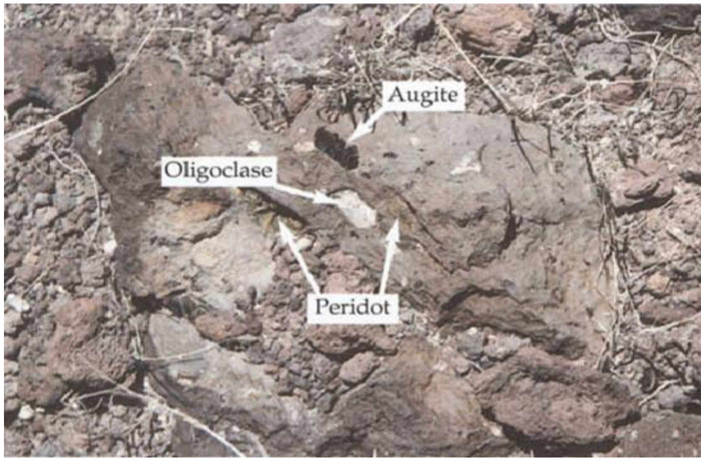


Figure 8: Typical specimen of the lava flow exhibiting single crystals of black augite, colourless (appears white) oligoclase feldspar and green peridot. Each crystal is approximately 5 x 2.5 x 2.5 cm.

tumuli and covers the floors is sifted to recover the gem material. Typical 'floor' lava flow material contains large individual crystals *(Figure 8)* of diopsidic augite, andesine and peridot (with 87% of the forsterite molecule) in proximity. Euhedral crystals of peridot are rare and their faces are highly etched or resorbed *(Figure 9)*.

Figure 9: A single crystal of peridot in lava. Single crystals are rare and this one has been partially rounded by chemical resorption. This faceting-quality peridot measures 22 x 11 x 9 mm.

Figure 10: The largest fissure observed in the lava flow measured 22.23 x 7.91 cm and was completely filled with peridot; the diameter of the coin is 17.9 mm.

The largest cavity observed in the lava flow *(Figure 10)* contained nothing but peridot and removal was only effected by use of a one-inch diamond core drill. Most of the peridot was highly fractured where the outer areas of the peridot met the lava.

Two of the larger tumuli contained large eroded and oxidized crystals of peridot *(Figures 11 and 12)* which exhibited iridescence on the weathered surface. These larger specimens could only be removed after many hours of pick and chisel drilling around each specimen.

Materials and methods

Over 5200 ct of rough samples were removed and segregated by colour and clarity, and representative faceted gems were cut *(Figure 13)* which ranged in weight from 0.55 ct to 15.90 ct. Colours ranged from a

Figure 11: This single crystal of peridot measured approximately 7 x 5 x 2 cm and the surface had been oxidized to iridescent colours resembling peacock feathers. Analogous coloration was experienced in the laboratory when heating unaltered material to 750°C for 10 hours.

Figure 12: Several hours of back-breaking work resulted in the removal of the largest peridot crystal found. Unfortunately it cleaved into three pieces but when reassembled it measured 70.0 x 43.0 x 26.0 mm and weighed 614.60 ct comprising three pieces weighing 140.00, 156.20 and 318.40 ct.

Figure 13: This group of cut stones (0.55 to 6.47 ct) is representative of the colour variation of peridot from the Black Rock Summit lava flow. Note the predominance of brown. Photo by Maja DiMaggio.

light greenish-yellow through olive-green into brownish-green and finally a dark brown. Gemmological properties were obtained from 30 samples representative of the colour range.

Refractive indices were determined with a Rayner Dialdex refractometer and GIA high-intensity sodium-vapour lamp. Refractive indices of grains taken at small intervals from edge to centre of large peridot crystals were determined by the immersion method. Pleochroism was determined with a GIA-GEM polariscope, Rayner and GIA calcite dichroscopes, and a modified Bausch & Lomb GIA Gemolite microscope. Specific gravities were measured hydrostatically using stabilized 1,2-dibromomethane (corrected for temperature) and an analytical balance with 0.1 mg sensitivity as well as the Berman balance. Ultraviolet testing was done with high-intensity (100 W), filtered, mercury-vapour lamps at typical short (253.7 nm) and long (366.0 nm) wavelengths.

Optical spectra were observed under darkroom conditions with two desk-top spectroscope units, one with a Beck prism spectroscope and the other with a GIA-GEM digital-readout, scanning, diffraction-grating spectroscope. Optical and infrared spectra were obtained from one of the larger (6.47 ct) faceted specimens using a Pye-Unicam 8800 UV-visible spectrophotometer and a Nicolet 60SX FTIR spectrometer.

Chemical analyses were obtained by electron microprobe and by proton-induced X-ray emission (PIXE) methods. PIXE is a non-destructive method which is similar in principle to energy-dispersive X-ray fluorescence (EDXRF). It employs an accelerator to drive a high-speed stream of protons toward the target sample, and each element in the sample responds by producing characteristic X-rays, which are detected and counted; within minutes of exposure, a computer produces both quantitative and qualitative data.

Description of the material

Peridot, a magnesium-iron silicate, is a member of the olivine group, an isomorphous series which ranges in composition from forsterite, Mg_2SiO_4 to fayalite, Fe_2SiO_4. The general formula is $(Mg, Fe)_2SiO_4$. Peridot lies close to the forsterite end of the series that has lower refractive indices and specific gravity than members of the fayalite end. Olivine is orthorhombic with two imperfect cleavages in the {010} and {100} crystal directions and a Mohs hardness of 6.5 to 7. Optically, it is biaxial with moderate to high birefringence.

Most of the material collected at Black Rock Summit lava flow, though large (30x14 mm), was weathered and eroded and quite difficult to remove from the matrix. Sectioned diamond-sawing of various specimens disclosed numerous fractures radiating from the surface of the peridot crystals resulting in limited flaw-free faceting material. Faceted specimens ranged in weight from 0.47 ct to 15.90 ct.

***Table I:** Gemmological properties and chemical compositions of three representative samples of Black Rock Summit lava flow peridot.*

Properties and elements	*BRP#1[a]*	*BRP#2[b]*	*BRP#3[c]*
RI α	1.6595	1.658	1.656
β	1.6725	1.676	1.676
γ	1.6930	1.694	1.696
SG	n.d.	3.351	3.388
Wt.%			
SiO_2	40.55	40.05	37.90
Al_2O_3	1.62	0.08	n.d.
FeO	10.27	11.79	13.81
MgO	47.43	47.34	47.62
MnO	0.16	0.16	0.20
NiO	n.d.	0.28	0.27
CaO	n.d.	0.22	0.15
Cr_2O_3	n.d.	n.d.	0.034
ZnO	n.d.	n.d.	0.008
Total	100.03	99.92	99.992

[a]Chemical analysis performed by M. Coller, Department of Geology, Indiana University. (From Vitaliano and Harvey, 1965.)
[b]Electron microprobe analysis by David E. Lang, Harvard University.
[c]Analysis performed on the PIXE system of a General Ionex Corp. Tandetron accelerator with an intense proton beam of up to 3MeV, a Tracor lithium-drifted silicon X-ray detector; and a multichannel analyzer system.
n.d. not determined

None of the Black Rock Summit peridot exhibits asterism or chatoyancy although these optical phenomena have been reported in peridot from other localities.

Gemmological properties

The colours of Black Rock Summit peridot range from light yellowish-green to olive-green, brownish-green and dark-brown. In the normal process of crystallization of a magma, the first olivine to form is high in magnesium and as crystallization proceeds and temperatures slowly decrease, the mineral becomes progressively richer in iron. Therefore, in the large phenocrysts, one could expect a zoning with a magnesium-rich core and an iron-rich margin. Such a change in chemistry should be reflected in colour and refractive index, i.e. darker colour and higher indices at the margin than at the core. It was thus surprising to find only a slight variation in refractive indices and little, if any, correlation between refractive indices and colour in Black Rock Summit peridot. Observed refractive index ranges were: $\alpha = 1.656–1.660$, $\beta = 1.674–1.678$, and $\gamma = 1.694–1.699$, with a birefringence range of 0.033-0.038. Measurements of α, β and γ on 19 peridots ranging from very light to very dark colours gave means of 1.659, 1.676 and 1.695 respectively. This would indicate that there is little variation in the chemistry of the crystals from core to rim and that the chemical analyses given in *Table I* are representative of the bulk composition of the crystals.

Pleochroism is distinct, with colour combinations for the various colour categories of: light-greenish-yellow being 'light-yellow and light greenish-yellow'; olive-green being 'medium yellowish-green and medium orangy-green'; brownish-green being 'medium to dark yellowish-green and medium orangy-brown' and finally the dark brown being 'dark yellowish-brown and dark greenish-brown'. Specific gravities of 3.351 to 3.388 were obtained. All specimens remained inert to both long- and short-wave ultraviolet radiation.

Spectroscopy and chemical composition

Absorption bands were observed in all specimens at 453, 474 and 635 nm, the last being very weak. A moderately strong band centred at about 495 nm was also observed with the prism spectroscope, but the diffraction-grating unit resolved it into two bands at about 497 and 489 nm. Spectrophotometry of the 6.47 ct sample revealed these and additional weak bands as follows: 399, 403, 412, 421, 431, 435, 445 and 530 nm *(Figure 14)*. As one might expect, all absorption bands were less apparent in the hand-held spectroscope in the paler stones. The spectral features have all been observed

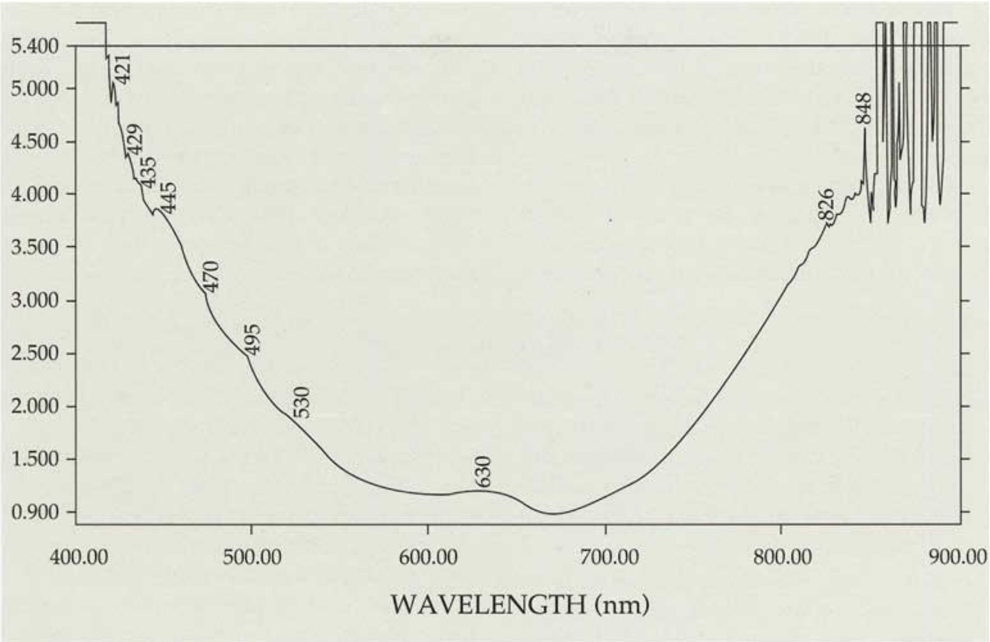


***Figure 14:** UV-visible spectrum of a representative sample of peridot from material found at Black Rock Summit lava flow – a 6.47 ct faceted stone (Figure 13, extreme left of picture) and recorded using a Pye-Unicam 8800 spectrophotometer.*

previously in peridot from other localities, particularly those from Arizona (Farrell and Newnham, 1965; Burns, 1974; Koivula, 1981). Similarly coloured peridot from the Kilbourne Hole (Führbach, 1992) showed absorption bands at 452, 473 and 640 nm, the last being relatively weak. A moderately strong band seen at about 492 nm with the prism spectroscope was resolved by the diffraction-grating unit into bands at 497 and 489 nm.

The data obtained by electron microprobe analysis and PIXE analyses of three samples revealed compositions typical for peridot (*Table I*). The Mg:Fe ratio for the Harvard analysis (omitting minor elements) is 87.9:12.1 from a formula: $(Mg_{88}Fe_{12})SiO_4$. The PIXE analysis gives a ratio of Mg:Fe of 86:14. The average of three analyses of comparable coloured material from Kilbourne Hole gives a ratio of Mg:Fe of 88.7:11.3.

The PIXE analysis gives the percentages of elements; it reports the metals but not oxygen. The analysis as reported has been recalculated to oxides and this in turn has been recalculated to 100 per cent. The new analyses from the microprobe and the PIXE agree well with the older analysis (Vitaliano and Harvey, 1965).

Yellowish-green peridot is a classic example of coloration by a transition metal ion, in this case Fe^{2+} (Farrell and Newnham, 1965), which produces a series of absorption bands visible in the spectroscope. Traces of chromium have been reported as contributing to the green colour (Arem, 1987), but no supporting data for this were found in Black Rock Summit peridot.

Spectrophotometry revealed essentially three components that, together, leave a transmission window centred around 550 nm, which corresponds to yellowish-green. The first of these is an absorption tail that absorbs much of the red and orange. This feature has been observed in peridots from other localities and is related to near-infrared absorptions that are attributed to Fe^{2+} (Burns, 1974).

The second component is the series of bands in the visible range, most of which have also been attributed to Fe^{2+} (Farrell and Newnham, 1965). The suggestion that some are related to Mn^{2+} (Gunawardene, 1985) was not substantiated.

The third spectral component is a general increase in absorption from about 550 nm toward the ultraviolet, which results in a brown colour. Studies on synthetic forsterite (Weeks *et al.*, 1974) and on other gem silicates and oxides (Fritsch and Rossman, 1987) indicate that this feature may arise from charge-transfer phenomena between oxygen and transition metal ions such as Fe^{3+} or Ti^{4+}. However, iron-rich olivine and the end member fayalite are often amber-coloured in thin section regardless of Ti content (Deer *et al.*, 1982, p 186), which suggests that Fe alone may be responsible.

Faceting procedure

Though peridot gives little or no trouble during preforming or cutting, it can be very unpredictable during polishing (Vargas and Vargas, 1989). Black Rock Summit peridot commonly has one direction in which polishing is quite difficult.

After trying numerous combinations of laps, polishing agents and lap speeds, the author recommends the following procedures for ease in faceting and polishing this and other peridot material: (1) preform on Crystalite® 100 Dot Disc, (2) facet on Crystalite® 260 Diamond Disc, (3) facet on RayTech® 1200 Nu-Bond Disc and (4) polish on Crystalite® Phenolic Lap with Crystalite® 14000 Mesh (1 micron) Diamond Spray @ 200 to 250 r.p.m. running the lap damp to nearly dry; moderate pressure. Care must be exercised on polishing with the phenolic lap as heat of friction develops rapidly and may cause the dopping cement to soften and the gem to shift!

When all else fails (as frequently happens with peridot) use a pure tin lap with half-micron (50 000 mesh) spray diamond.

Figure 15: Decrepitation haloes surrounding negative crystals; inclusion features descriptively known as 'lily pads' are rarely found in Black Rock Summit peridot. Photomicrograph by J. Koivula; 30x.

Microscopic features

Thorough examination of several thousand specimens taken from various areas, viz. tumuli from the central lava field, peripheral lava flow tumuli and material from the lava cone were examined with the microscope. From these some 10 types of inclusions were observed.

Lily Pads: although one expects to see inclusions of lily pads typical of peridot from other sources (Gübelin, 1974; Gübelin and Koivula, 1986), their near complete *absence* is characteristic of Black Rock Summit peridot. In fact, of more than 30 faceted specimens examined (0.55 ct to 15.90 ct) only one specimen contained an inclusion that could be described as lily pad *(Figure 15)*.

Geyser-Like: the most frequently noticed inclusion in the Black Rock Summit peridot consists of very fine geyser-like or fine hair-like patterns *(Figure 16)* which could not be resolved or defined at magnification up to 100x (Gübelin, pers. comm., 1991).

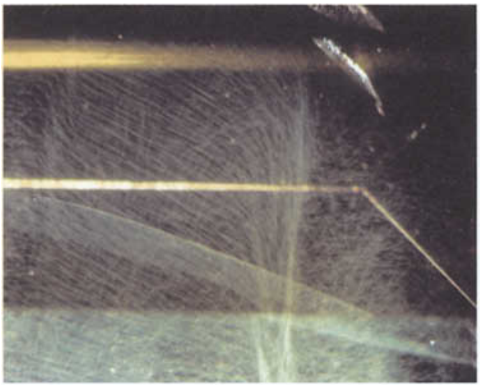


Figure 16: Since these inclusions in Black Rock Summit peridot have not been seen in other worldwide sources the author has elected to describe the newly found inclusions as 'geyser-like' or 'fine hair-like' inclusions. Photomicrographs by J. Koivula; 30x.

Milky: the second most encountered inclusion is an overall milky coloration which renders the apparently flawless material semi-transparent by transmitted light and hazy in appearance by reflected light.

Rosary-bead inclusions (Figure 17): straight and fine hair-like with tiny bright green chrome diopside crystals, partially resorbed.

PCB: one of the most intriguing new inclusions *(Figure 18)* was best described by Gübelin (pers. comm., 1990) as PCB (printed circuit board) in character. Its identity remains to be determined and of the thousands of specimens examined this inclusion was observed in but two specimens of very dark brown peridot. Dr Gübelin (pers. comm., 1991) described the inclusion(s) as '... tangle of regular thread-like inclusions ... difficult to interpret ...[possibly] the edges or borders of individual grains of a mosaic structure ...'

Smoke-like veils: the Black Rock Summit contains inclusions described as smoke-like

Figure 17: Tiny chrome diopside inclusions, partially resorbed, exhibit the low relief and bright green colour typical of this mineral. Photomicrograph by J. Koivula; 50x.

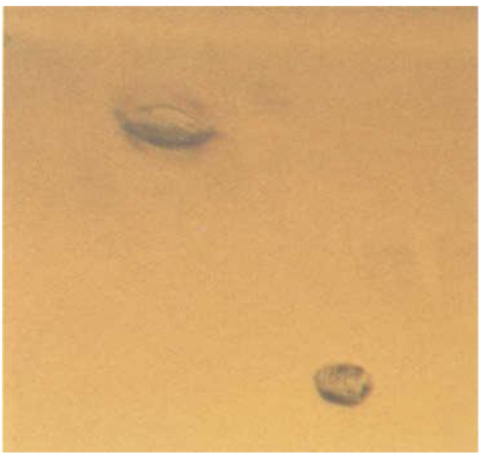
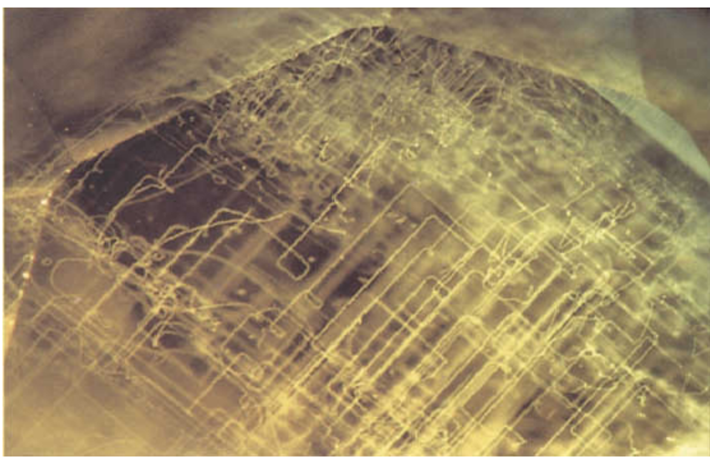


Figure 18: This unusual inclusion was found in only two specimens examined from the Black Rock Summit peridot and has been best described by Dr Edward Gübelin as PCB (printed circuit board) in character. Photomicrograph by E. Gübelin; 60x.



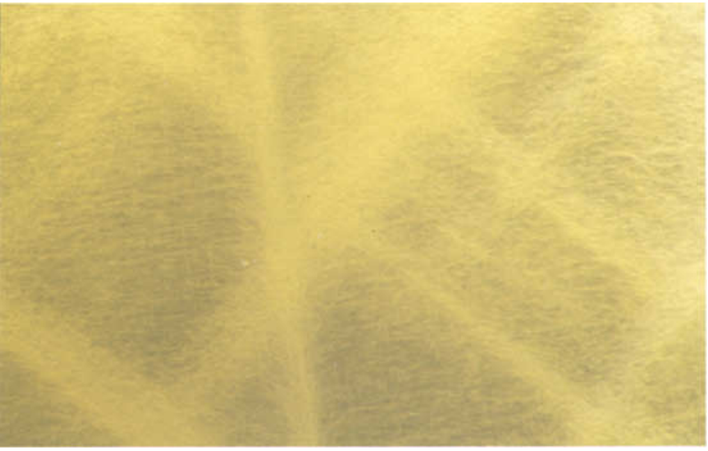


Figure 19: Patchy cross-hatched inclusions found in the Black Rock Summit peridot but not in peridot from other worldwide sources. This pattern could only be observed when the specimen was rotated 360° and examined by transmitted light, and is possibly the result of exsolution. Photomicrograph by J. Koivula; 35x.

Figure 20: Black metallic spheres in two peridots examined by dark-field illumination or transmitted light. When exposed by careful sectioning they reveal crystalline inclusions which were identified as pyrrhotite and pentlandite. Note the variation in colour between the two peridots. Photomicrograph by J. Koivula; 25x and 40x.

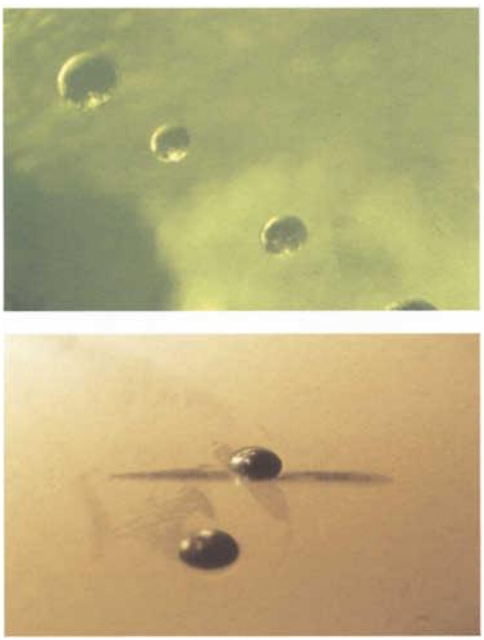


Figure 21: Countless dark orangy-brown near-parallel flow lines in transmitted light, possibly the result of exsolution. Photomicrograph by J. Koivula; 50x.

veils similar to those previously noted in peridots from Arizona and China (Koivula, 1981; Gübelin and Koivula, 1986; Koivula and Fryer, 1986; Führbach, 1992). They result from incomplete solid solution (Koivula, pers. comm., 1993) that develops as the peridot is brought to the Earth's surface and cools in the basalt; the process also causes dislocations which produce visible strain (Kohlstedt *et al.*, 1976). These veils appear as ghostly white streamers when viewed with darkfield illumination and appear hazy or milky in reflected light rendering the gem semi-transparent.

Patchy cross-hatched inclusions (Figure 19): observed by transmitted light at 10x magnification; these have not been observed in peridot from other sources.

Black metallic spheres: some black opaque spherical inclusions *(Figure 20)* are attracted to a magnet (Koivula, pers. comm., 1995) and

Figure 22: Dendritic crystals in fractures in darker brown specimens of Black Rock Summit peridot; this kind of inclusion is uncommon. Photomicrograph by J. Koivula; 15x.

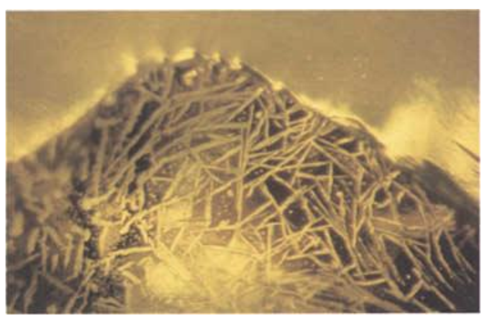


Table II: *Optical and physical properties of peridot from various world sources.*

Origin	*RI*			Δ	*OC*	*SG*	*Reference*
Antarctic	1.653	?	1.689	0.036	?	3.34–3.35	13
Arizona	1.653	1.669	1.690	0.037	B+/–	3.35	4
Arizona	1.652	1.671	1.689	0.037	B-	3.34	4
Arizona	1.652	1.668	1.689	0.037	B+	3.34	4
Arizona (light)	1.649	1.665	1.686	0.037	B+	3.28	10
Arizona (dark)	1.653	1.671	1.691	0.038	B+	3.38	10
Arizona	1.652	1.670	1.689	0.037	B+	3.33	9
Argentina*	1.650–1.656	1.670–1.675	1.688–1.691	0.035	B+/–	3.37–3.44	18
Australia	1.653	1.671	1.690	0.037	B+	3.39	7
Burma	1.654	1.671	1.689	0.036	B+	3.32	1
Burma	1.656	1.671	1.692	0.036	B+/–	3.35	6
China	1.653	1.670	1.689	0.036	B+	3.36	19
Ethiopia	No data available						20
Kentucky*	1.669	1.688	1.705	0.036	B–	3.47	18
Kenya (yellowish)	1.650	?	1.686	0.036	?	3.45	1
Kenya (brownish)	1.651	?	1.681	0.038	?	3.35	1
Kilbourne (yellowish)	1.659	1.674	1.693	0.034	B+/-	3.42	5
Kilbourne (greenish)	1.663	1.679	1.698	0.035	B+/-	3.43	5
Kilbourne (brownish)	1.669	1.684	1.705	0.035	B+/-	3.50	5
Nevada (Black Rock)							
(yellowish)	1.659	1.676	1.695	0.036	B+	3.37	14
(greenish)	1.659	1.676	1.695	0.037	B+	3.38	14
(brownish)	1.659	1.676	1.695	0.038	B+	3.39	14
New Mexico	1.652	1.671	1.688	0.036	B–	3.33	1
Mexico	1.652	1.671	1.688	0.036	B–	3.33	4
Mexico	1.652	1.668	1.685	0.033	B+	?	4
Norway (cabochon)	1.650		1.685	0.035	?	?	2
Pakistan	1.651	1.669	1.687	0.036	B+/–	3.35	15, 17
Sri Lanka	1.651	1.660	1.690	0.039	B+	3.36	7
Synthetic	1.65		1.68	0.03	B	3.30	16
Tanzania-Kenya (border)	1.650	1.658	1.684	0.034	B+	3.25	12
Unknown (cat's-eye)	No data available						11
Vietnam	1.650	1.666	1.688	0.038	B+	3.34	8
Zarbargad	1.652	1.668	1.690	0.035	B–	3.28	7

Notes:
OC Optical character.
B Biaxial positive or negative.
* Pallasitic meteorite peridot

1 Arem, 1987
2 Borg, 1980
3 Brown, Bracewell, 1983
4 Dunn, 1978
5 Führbach, 1992
6 Gübelin, 1975
7 Gunawardene, 1985
8 Koivula, 1993
9 Koivula, Fryer, 1987
10 Koivula, 1981
11 Kane, Koivula, 1987
12 Stockton, Manson, 1983
13 Wilson, Hendy, Taylor, 1974
14 Führbach, 1995
15 Larson, Thompson, 1994
16 Nassau, 1994
17 Thompson, 1994
18 Sinkankas, Koivula, Becker, 1992
19 Koivula, Fryer, 1986
20 Koivula, Kammerling and Fritsch, 1993

were found by X-ray diffraction to be pyrrhotite ($Fe_{1-x}S$) where x is between 0.0 and 0.2. Other similar-appearing spheres, but non-magnetic, were found to be pentlandite $(Fe, Ni)_9S_8$. Note the variation in colour between the two peridots photographed.

Paint-brush strokes: dark orangy-brown flow lines *(Figure 21)* seen in transmitted light appeared white in fibre-optic and dark-field illumination. Almost parallel arrangements, some consisting of only a few lines, others of several dozen, permeate the interior of many specimens, regardless of colour. They are possibly the result of exsolution.

Secondary inclusions in brown peridot are shown in *Figure* 22.

Conclusion

Black Rock Summit lava flow contains great fissures and cavities filled with peridot, and partially resorbed large peridot crystals within the alkali basalt – many exceeding 500 ct. Though of a darker hue than peridot from other world localities, the physical properties and chemical composition are consistent with those for peridot *(Table II)*. These peridots contain newly discovered inclusions which have not been reported in peridot from other world sources. Lily pad inclusions are rarely encountered in this material. While large specimens as well as cut gems are obtainable, the extent of the material available for commercial purposes has not yet been estimated.

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References

Anderson, B.W., 1971. *Gem testing* (8th ed). Van Nostrand Reinhold, New York, 134–63, 261, 293–4

Arem, J.E., 1987. *Color encyclopedia of gemstones.* Van Nostrand Reinhold Co., New York, 137–9

Bauer, M., 1896. *Precious stones.* Dover Publications, Inc., **II**, 407 pp.

Borg, S., 1980. An unusual star peridot, *Journal of Gemmology*, **17**(1), 1–4

Bosch Figueroa, J.M., de la Fuente Cullell, C., and Arbunies Andres, M., 1981. Mineralogical and gemmological study of olivine from Yaiza (Lanzarote). *Gemologia*, **14**(49–50), 5–18

Brenner, M.G., 1979. Sedimentary features in base surge tuffs, Kilbourne Hole, Potrillo Mountains, Dona Ana County, New Mexico (abs.). *Geological Society of America, Abstracts with Programs*, **11**(6), 267 pp.

Brown, G., and Bracewell, H., 1982. Chudleigh Park peridot. *Australian Gemmologist*, **14**(10), 253–6

Burns, R.G., 1974. The polarized spectra of iron in silicates: olivine. A discussion of neglected contributions from Fe^{2+} ions in M1 sites. *American Mineralogist*, **59**, 625–9

Cahill, T.A., 1980. Proton microprobes and particle-induced X-ray analytical systems. *Ann. Rev. Nucl. Part. Sci.*, 211–35

Cavenago-Bignami, S., 1972. Six-rayed star peridot. *Gemmologia*, 3rd ed., Editore Ulrico Hoepli, Milan, 828 pp.

Cipriani, C., and Borelli, A., 1986. *Guide to gems and precious stones.* Simon & Schuster, Inc., New York, 214–6

Daly, R.S., 1914. *Igneous rocks and their origin.* McGraw Hill, New York

Deer, W.A., Howie, R.A., and Zussman, J., 1982. *Rock-Forming Minerals*, **Vol 1A:** *Orthosilicates.* 2nd ed., Longman, London, 919 pp.

Desautels, P.E., 1971. *The Gem Kingdom.* Random House, New York, 109–10

Dunham, K.C., 1935. The geology of the Organ Mountains. *Bulletin No. 11, New Mexico School of Mines*, Socorro, New Mexico, USA, 182–3

Dunn, P.J., 1974. Chromian spinel inclusions in American peridots. *Zeitschrift der Deutschen Gemmologische Gesellschaft*, **23**(4), 304–7

Dunn, P.J., 1978. Gem peridot and enstatite with spinel inclusions from Chihuahua, Mexico. *Journal of Gemmology*, 16(4), 236–8

Eppler, W.F., 1973. *Praktische Gemmologie (Practical gemmology).* Ruhle-Diebener-Verlag KG, Stuttgart-Degerloch, West Germany, 272–6

Farrell, E.F., and Newnham, R.E., 1965. Crystal-field spectra of chrysoberyl, alexandrite, peridot and sinhalite. *American Mineralogist*, **50**(6), 1972–81

Fleischer, M., Wilcox, R.E., and Matzko, J.J., 1961. Microscopic determination of the nonopaque minerals. *US Geological Survey Bulletin 1627*, 371–2

Fritsch, E., and Rossman, G., 1987. An update on color in gems. Part I: Introduction and colors caused by dispersed metal ions. *Gems & Gemology*, **23**(3), 126–39

Fritsch, E., and Rossman, G., 1988. An update on color in gems. Part III: Colors caused by band gaps and physical phenomena. *Gems & Gemology*, **24**(2), 81–102

Führbach, J.R., 1992. Kilbourne Hole peridot. *Gems & Gemology*, **28**(1), 16–27

Gile, L., Hawley, J.W., and Grossman, R.B., 1981. Soils and geomorphology in the Basin and Range area of southern New Mexico – Guidebook to the Desert Project. New Mexico Bureau of Mines and Minerals Resources, Memoir 39, 222 pp.

Gonschorek, W., 1986. Electron density and polarized absorption spectra of fayalite. *Physics and Chemistry of Minerals*, **13**, 337–9

Gübelin, E., 1953. *Inclusions as a means of gemstone identification*. Gemological Institute of America, Santa Monica, California, 194–7

Gübelin, E., 1974. *Internal world of gemstones*. ABC Druckerei-Verlags AG, Zurich, 168–9

Gübelin, E., 1975. *The Colour treasury of gemstones*. Elsevier-Phaidon, Phaidon Press Ltd., London, 80–3

Gübelin, E., 1981. Zabargad: the ancient peridot island in the Red Sea. *Gems & Gemology*, **17**(1), 2–8

Gübelin, E., 1989. Personal communication

Gübelin, E.J., and Koivula, J.I., 1986. *Photoatlas of inclusions in gemstones*. ABC Edition, Zurich, 305–8

Gunawardene, M., 1985. Peridot from Ratnapura District, Sri Lanka. *Journal of Gemmology*, **19**(8), 692–702

Hodgman, C.D., 1950. *Handbook of chemistry and physics*. Chemical Rubber Publishing Co., Cleveland, Ohio, USA, 1818–24

Hoffer, J.M., 1976. Geology of Potrillo basalt field, south-central New Mexico, New Mexico Bureau of Mines and Mineral Resources, Circular 149, 30 pp.

Hurlbut, C.S., Jr., 1979. *Gemology*. John Wiley & Sons, New York, 161–3

Kammerling, R.C., 1993. Peridot from Ethiopia. *Gems & Gemology*, **29**(1), 59

Kane, R.E., Koivula, J.I., 1987. Peridot, cat's-eye. *Gems & Gemology*, **23**(2), 106

Keller, A.S., and Kammerling, R.C., 1993. Peridot from Vietnam. *Gems & Gemology*, **29**(3), 211–2

King, W.E., Hawley, J.W., Taylor, A.M., and Wilson, R.P., 1983. Hydrologic Report 1: Geology and ground-water resources of central and western Dona Ana County, New Mexico, State Bureau of Mines and Mineral Resources, New Mexico Institute of Mining and Technology, Socorro, *Abstract*, **23**, 59

Kohlstedt, D.L., Goetze, C., Durham, W.B., and Vander Sande, J., 1976. New technique for decorating dislocations in olivine. *Science*, **191**, 1045–6

Koivula, J.I., 1981. San Carlos peridot. *Gems & Gemology*, **17**(4), 205–14

Koivula, J.I., 1993. Peridot from Vietnam. *Gems & Gemology*, **29**(3), 211–12

Koivula, J.I., and Fryer, C.W., 1987. Chalcopyrite in peridot: a first observation. *Journal of Gemmology*, **20**(5), 272–3

Koivula, J.I., Stockton, C., and Fryer, C., 1980. Diopside as an inclusion in peridot. *Gems & Gemology*, **16**(9), 332–3

Koivula, J.I., and Fryer, C.W., 1986. The gemological characteristics of Chinese peridot. *Gems & Gemology*, **22**(1), 38–40

Koivula, J.I., Kammerling, R.C., and Fritsch, E., 1993. Peridot from Ethiopia. Gem News. *Gems & Gemology*, **29**, 59

Liddicoat, R.T., Jr., 1972. *Handbook of gem identification*. GIA, Santa Monica, 176–207, 238–9

Lindberg, J.D., 1974. The peridot deposits of Kilbourne Hole, New Mexico. *Lapidary Journal*, October, 768–71

Nassau, K., 1994. Synthetic forsterite and synthetic peridot. *Gems & Gemology*, **30**(2), 102–8

New Mexico index to topographic and other map coverage. 1985. Denver. 38, 42 pp.

New Mexico catalog of topographic and other published maps. 1987 United States Geological Survey, Denver, 15 pp.

Nolan, L., 1989. *PIXE* (Proton Induced X-Ray Emission)*. Element Analysis Corporation, Tallahassee, Florida

Northrop, S.A., 1959. *Minerals of New Mexico* (revised ed.). New Mexico University Press, Albuquerque, 380–4

Reiche, P., 1940. The origin of Kilbourne Hole, New Mexico. *American Journal of Science*, **238**, 212–5

Roedder, E., 1965. Liquid CO_2 inclusions in olivine-bearing nodules and phenocrysts from basalts. *American Mineralogist*, **50**, 1746–82

Roedder, E., and Weiblen, P.W., 1971. Petrology of silicate melt inclusions, Apollo 11 and Apollo 12 and terrestrial equivalents. Proceedings of the Second Lunar Science Conference, M.I.T. Press, **1**, 507–28

Roedder, E., 1976. Petrologic data from experimental studies on crystallized silicate melt and other inclusions in lunar and Hawaiian olivine. *American Mineralogist*, **61**, 684–90

Seager, W.R., 1987. *Caldera-like collapse at Kilbourne Hole maar, New Mexico*. New Mexico Geology, University of New Mexico, Albuquerque, 69–73

Seager, W.R., Shafiqullah, M., Hawley, J.W., and Marvin, R., 1984. New K-Ar dates from basalts and the evolution of the southern Rio Grande rift. *Geological Society of America Bulletin*, **95**, 87–99

Shaub, B.M., and Shaub, M.S., 1975. *Treasures from the Earth: the world of rocks and minerals*. Crown Publishing, Inc., New York, 192 pp.

Shoemaker, E.M., 1957. Primary structures of maar rims and their bearing on the origin of Kilbourne Hole and Zuni Salt Lake, New Mexico (abs). *Geological Society of America Bulletin*, **68**, 1864

Sinkankas, J., 1959. *Gemstones of North America*, Vol. 1. Van Nostrand Reinhold Company, New York, 206–7

Sinkankas, J., 1961. *Gemstones and minerals*. D. Van Nostrand Co., Inc., New York. 206 pp.

Sinkankas, J., 1976. *Gemstones of North America*. Vol. II. Van Nostrand Reinhold Company, New York, 114–5

Sinkankas, J., Koivula, J.I., and Becker, G., 1992. Peridot as an interplanetary gemstone. *Gems & Gemology*, **28**(1), 43–51

Smith, G.H., 1958. *Gemstones*. Pitman Publishing Corp., New York, 347–51

Smith, R.L., and Luedke, R.G., 1984. Potentially active volcanic lineaments and loci in western coterminous United States: in *Explosive Volcanism: Inception, Evolution, Hazards*. Natl. Acad. Press, Washington, DC, 47–66

Stockton, E.M., and Manson, D.V., 1983. Peridot from Tanzania. *Gems & Gemology*, **19**(2), 103–7

Stuart, C.J., 1981. Hunt's Hole maar volcano, Dona Ana County, south-central New Mexico and geology of the border, southern New Mexico-northern Chihuahua. *El Paso Geological Society Guidebook*, 64–72

Stuart, C.J., and Brenner, M.G., 1979. 'Log Regime' base surge dunes – an example from Kilbourne and Hunt's Holes, south-central New Mexico (abs.). *Geological Society of America, Abstracts with Programs*, **11**(7), 525

Thompson, L., 1994. More on peridot from Pakistan. *Gems & Gemology*, **30**(4), 275

Thompson, L., and Larson, B., 1994. Peridot from Pakistan. *Gems & Gemology*, **30**(3), 196

United States Geological Survey, 1968. Black Rock Summit, Nevada (Map), SW/4 Portuguese Mtn. 15' Quadrangle, N3830-W11552.5/7.5, US Geological Survey, Denver

United States Geological Survey, 1967. Lunar Crater, Nevada (Map), NE/4 Lunar Crater 15' Quadrangle, N3822.5--W11600/7.5, US Geological Survey, Denver

United States Geological Survey, 1967. Moores Station SE, Nevada (Map), SE/4 Moores Station 15' Quadrangle, N3830–W11600/7.5, US Geological Survey, Denver

United States Geological Survey, 1985. Nevada/Index to topographic and other map coverage. US Department of the Interior, Geological Survey, Reston

United States Geological Survey, 1968. The Wall, Nevada (Map), NW/4 The Wall 15' Quadrangle, N3822.5–W2552.5/7.5, US Geological Survey, Denver

Vargas, G., and Vargas, M., 1989. *Faceting for amateurs*. 3rd ed. Desert Printing Company, Indio, California, 271 pp.

Vitaliano, C.J., and Harvey, R.D., 1959. Black Rock Summit basalt flow, Nevada. *Geological Society of America Bulletin*, **70**(2), 1691–2

Vitaliano, C.J., and Harvey, R.D., 1965. Alkali basalt from Nye County, Nevada. *American Mineralogist*, **50**, 73–84

Walker, G.P.L., 1991. Structure and origin by injection of lava under surface crust of tumuli, 'lava rises', 'lava-rise pits' and 'lava-inflation clefts' in Hawaii. *Bull. Volcanology*, **53**, 546–58

Webster, R., 1975. *Gems, their sources, descriptions and identification*. 3rd ed. Butterworths, London, 133–41, 279–82, 314, 577–81

Weeks, R.A., Pigg, J.C., and Finch, C.B., 1974. Charge-transfer spectra of Fe^{3+} and Mn^{2+} in synthetic forsterite (Mg_2SiO_4). *American Mineralogist*, **59** (11 and 12), 1259–66

Wilson, A.T., Hendy, C.H., and Taylor, A.M., 1974. Peridot on Ross Island – Antarctica. *Australian Gemmologist*, **14**(4), 124

Wood, C.A., and Kienle, J., 1990. Lunar Crater (Nevada). *Volcanoes of North America/United States and Canada*. Cambridge University Press, New York, 258–9

Rubies and pink sapphires from the Pamir Mountain Range in Tajikistan, former USSR

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ABSTRACT: A small number of gem-quality rubies and pink sapphires are being recovered from marble-type deposits in the Pamir mountains of the Republic of Tajikistan, southern portion of the former USSR. Presented in detail are the standard gemmological properties and internal features of a few samples from this remote locality. Some distinctive inclusion patterns were noted and a variety of mineral inclusions were identified. In addition, the spectral characteristics and chemical composition of the samples are provided.

Keywords: corundum, ruby, sapphire, Pamir mountains, Tajikistan, USSR, gemmological properties

Introduction

The Pamir mountain range traverses Tajikistan, along the southern region of the former Soviet Union, bordering Afghanistan and China. This mountain sequence is well known to professional and hobbyist mountain climbers for its beautiful and challenging topography. The mountains are relatively unknown, however, to most gemmologists around the world as a source of gemstones. The most recognized gems are the red spinels from along the eastern portion near the border with China (Koivula and Kammerling, 1989); however, these mountains also produce limited quantities of gem-quality clinohumite, tourmaline, topaz, danburite, scapolite, jeremejevite and corundum (Henn and Bank, 1990).

Rubies from the Pamir mountains were first described by Henn and Bank (1990) and Henn *et al.* (1990). Therein, these researchers described a marble-type deposit which was first discovered by a Soviet geologist in the early 1980s. Since their discovery, a limited supply of these rubies has entered the gemstone trade.

Turakuloma is the name of the ruby-producing region (I. Pojarevski and A. Trushin, 1997, pers. comm.) and is located about 6 km from the Chinese border and about 40 km NE of the town of Murgab (Henn and Bank, 1990; Henn *et al.*, 1990). Within this region several mines have been worked, the richest and best known being Snejnaya at an elevation of about 3500 m. The mines are typically worked from June until August – the weather conditions are too harsh during the rest of the year. In general about 30 people work each mine using picks and shovels, but at some, such as at Snejnaya, dynamite and a bulldozer are also used to recover the gems (I. Pojarevski and A Trushin, 1997, pers. comm.).

Samples, methods and equipment

This brief description of the rubies and pink sapphires from the Pamir mountains is

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Figure 1: Gem-quality rubies and pink sapphires from the Pamir mountains in Tajikistan. The samples range from 0.30 to 0.80 ct, with such qualities typically being found in sizes up to one and a half carats. Photographed by Nicole Surdez.

the result of an investigation of eight gemstones (ranging in weight from 0.30 ct to 1.48 ct), which were obtained from Ivan Pojarevski, president of Bulgaria Gems, Sofia, Bulgaria, and from other dealers specializing in gems from the Pamir region. The samples were purchased from miners working directly within the corundum deposits of the Pamir mountain range.

A binocular microscope combined with fibre-optic lighting techniques was used to examine internal and external characteristics. A Duplex II refractometer was used to measure the refractive indices, as well as determine the birefringence and optic character. Specific gravity determinations were made with a Mettler electronic balance equipped with the appropriate attachments for hydrostatic weight measurements. Long-wave (365 nm) and short-wave (254 nm) lamps were used to test the ultraviolet fluorescent reactions and a calcite dichroscope was used to observe the pleochroism.

Table I: *The gemmological properties of the rubies and pink sapphires from the Pamir Mountain Range, Republic of Tajikistan.*

Visual appearance	Highly transparent with richly saturated hues ranging from purplish-pink to purplish-red
Refractive index	Ne = 1.761–1.762 No = 1.770
Birefringence	0.008–0.009
Optic character	Uniaxial negative
Specific gravity	3.99–4.02
Pleochroism	Moderate to strong dichroism; Pinkish/reddish-orange to red-orange parallel to the c-axis Purple-pink to purple-red perpendicular to the c-axis
UV luminescence	Long-wave (365 nm): strong to very strong, slightly orangy- red to red Short-wave (254 nm): very weak to medium red
Visible absorption spectrum	General absorption up to approximately 450 nm; 468, 475 and 476 nm lines; broad band between approximately 530–580 nm; 659, 692 and 694 nm lines
Internal features	Very fine clouds, short rutile needles and pinpoint particles, faint to moderately distinct growth structures, occasionally faint colour zoning, twin lamellae, mineral or negative crystals with oriented equatorial thin films – singly or aligned in rows, various healed fracture patterns, 2- and 3-phase negative crystals, as well as crystalline inclusions of calcite, titanite, zircon, rutile and plagioclase feldspar

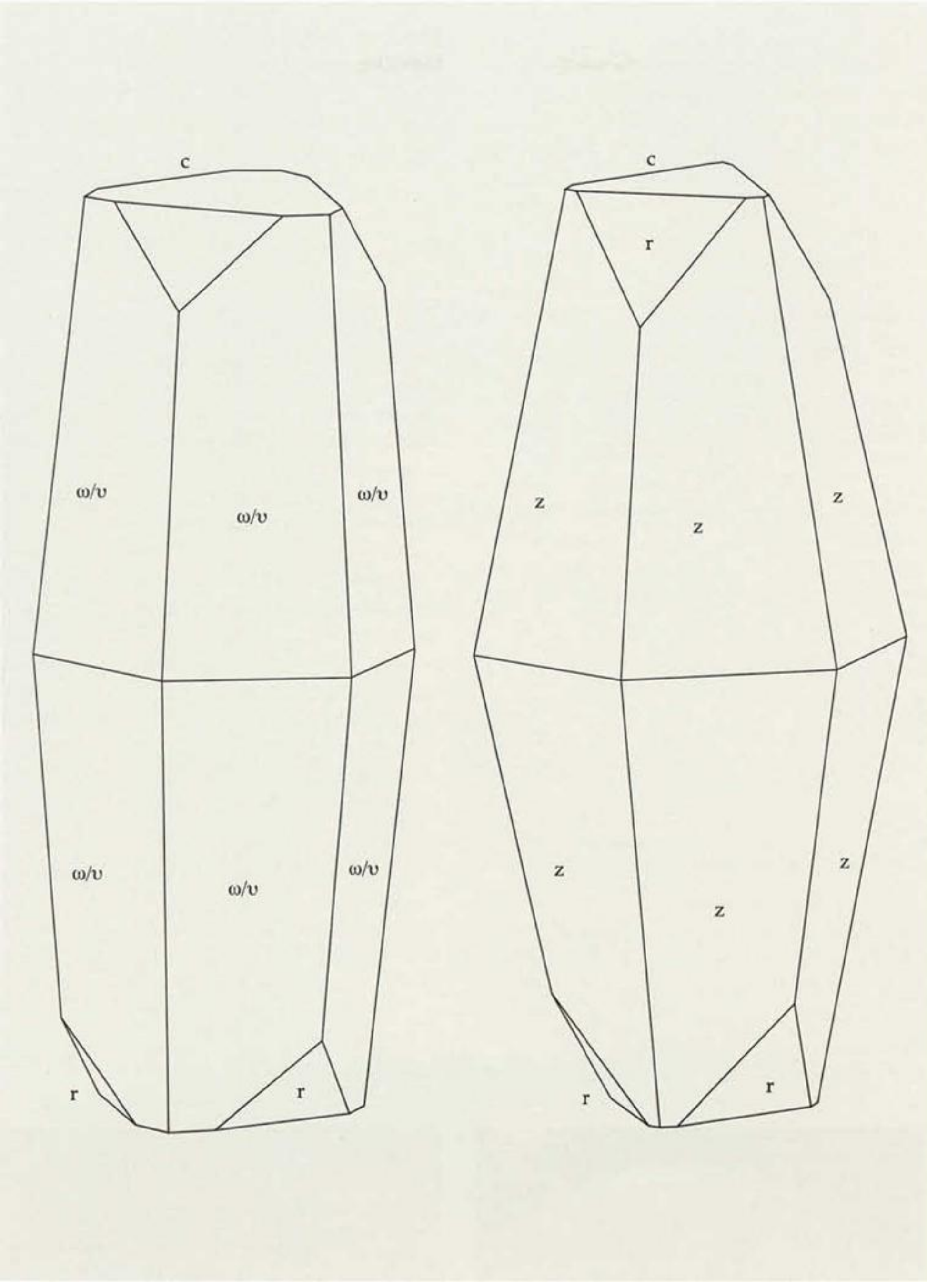


***Figure 2:** Two dipyramidal crystal habits were identified in rubies and pink sapphires originating from the Pamir Mountains: (a) habits composed of subordinate basal pinacoid c (0001) and positive rhombohedral r ($10\bar{1}1$) crystal faces and dominant ω (14 14 $\overline{28}$ 3) or ν ($44\bar{8}1$) crystal faces, and (b) Habits composed of subordinate basal pinacoid c (0001) and positive rhombohedral r ($10\bar{1}1$) crystal faces, with dominant dipyramidal z ($22\bar{4}1$) crystal faces.*

The internal growth characteristics were classified using a specially designed stone-holder and immersion microscope incorporating the techniques described by Schmetzer (1985, 1986), Kiefert and Schmetzer (1991) and Smith (1996). The various mineral inclusions were identified using a scanning electron microscope equipped with an energy-dispersive X-ray fluorescence unit (SEM-EDS). Absorption spectra were taken with a standard desk-model spectroscope and a UV-Vis-NIR Perkin Elmer Lamda 9 spectrometer with a beam condenser and polarising filters in the region between 200 and 800 nm. Infrared spectra in the region between 400 and 7000 wavenumbers (cm^{-1}) were taken with a Pye-Unicam FTIR 9624 spectrometer using a diffuse reflectance unit. A semi-quantitative chemical analysis was performed with a Spectrace TN 5000 system energy-dispersive X-ray fluorescence spectrometer.

Visual appearance

The samples in this study are transparent and display richly saturated colours ranging from purplish-pink to purplish-red *(Figure 1)*.

Properties

Gemmological properties

The refractive indices, birefringence, optic character, specific gravity, UV fluorescence reaction and pleochroism are summarized in *Table I* and are consistent with rubies and pink sapphires in general (Liddicoat, 1989; Hurlbut and Kammerling, 1991; Webster, 1994; Hughes, 1996).

Internal growth structures, colour zoning and twinning

Faint to moderate linear and angular growth structures were observed parallel to the dipyramidal ω (14 14 $\overline{28}$ 3) or v (44$\overline{8}$1) and positive rhombohedral r (10$\overline{1}$1) crystal faces. A dipyramidal crystal habit composed of subordinate c (0001) and r (10$\overline{1}$1), with dominant ω (14 14 $\overline{28}$ 3) or v (44$\overline{8}$1) crystal faces, may therefore be considered as typical for the rubies and pink sapphires from the Pamir mountains. The author was also shown a small pink sapphire crystal, reportedly from the same locality in the Pamir mountains, which possessed a subordinate basal pinacoid c (0001) and positive rhombohedral r (10$\overline{1}$1), with dominant dipyramidal z (22$\overline{4}$1) crystal faces *(Figure 2)*. Although in general the Pamir samples are homogeneously coloured, one sample also displays a pale pink columnar zone bordered by darker pink sapphire with slightly irregular growth structures. Lamellar twin planes parallel to a single positive rhombohedral r (10$\overline{1}$1) plane were also observed *(Figure 3)*.

Inclusion features

Although the sampling of the rubies and pink sapphires from the Pamir mountains was small, they provided an interesting array of inclusions. Most commonly, these consisted

Figure 3: *Twin planes parallel to the positive rhombohedron r (10$\overline{1}$1) in a Pamir ruby. Fibre-optic illumination, 35x.*

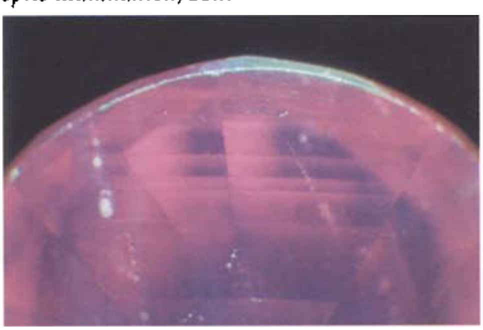


Figure 4: *Short rutile needles and pinpoint particles in a columnar pattern, distinctive of Pamir rubies. Fibre-optic illumination, 35x.*

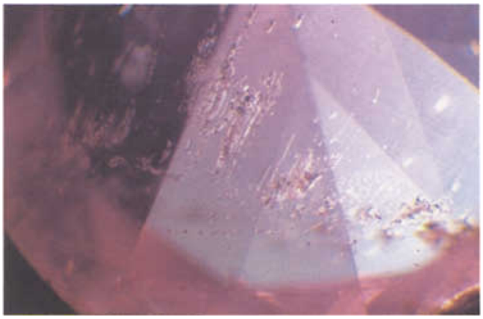


Figure 5: *Calcite crystals, highly resorbed, in parallel rows form a distinctive inclusion pattern in the rubies and pink sapphires from Pamir. Fibre-optic illumination, 40x.*

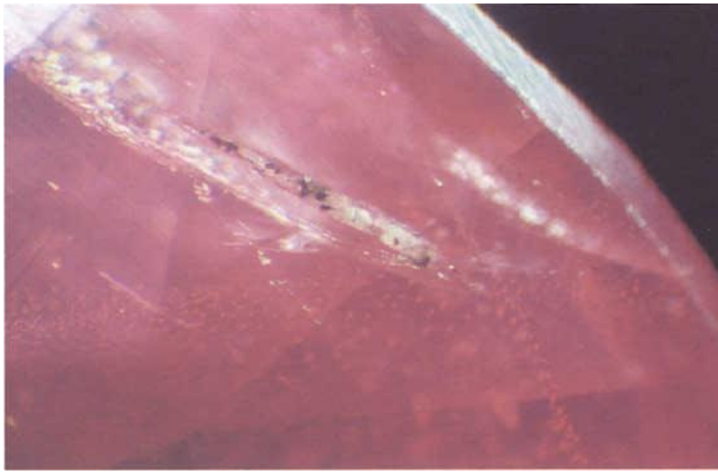


Figure 6: *Oblong transparent, colourless crystals of plagioclase feldspar in a 0.80 ct purplish-pink sapphire from Pamir. Fibre-optic illumination, 48x.*

of very fine whitish to bluish-white clouds, where the individual pinpoint particles were not identifiable. In sufficient concentration, such clouds occasionally instilled a slightly hazy appearance. In addition, short very fine rutile needles and particles populated the samples, and in some stones formed a distinctive columnar pattern *(Figure 4)*.

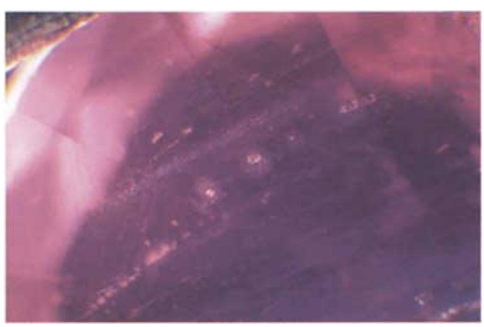
A variety of larger crystalline inclusions were also identified. The most plentiful were distinctly rounded, irregular masses of transparent calcite. These consisted of highly resorbed platy crystals which were predominantly equidimensional to oblong in form and which were occasionally accompanied by thin films. Commonly the calcite crystals were present in distinctive, roughly parallel formations *(Figure 5)*. Pale yellow crystals of titanite (sphene) typically occurred as tiny rounded crystals, although larger more irregular forms were also identified. Small prismatic zircon crystals with a length-to-width ratio of approximately 3:1 occurred singly and one was identified intergrown with a larger irregular sphene crystal. Columnar crystals of rutile were either a vibrant orange or black, and oblong crystals of plagioclase feldspar were also identified *(Figure 6)*.

Another unusual inclusion feature consisted of aligned rows of small minerals or negative crystals, where each crystal was accompanied by an oriented equatorial thin film *(Figure 7)*. These inclusions also occurred singly. Various healed fracture patterns were noted and distinctive idiomorphic negative crystals often contained immiscible liquid and gas phases *(Figure 8)*.

Absorption spectra

The spectra of the rubies and pink sapphires from the Pamir mountains are dominated by Cr^{3+} absorption, with broad bands centred at approximately 405 and 550 nm, and weak to moderate sharp bands at approximately 468, 475, 476, 659, 692 and 694 nm. Such absorption characteristics are typical of rubies and pink sapphires in general (see e.g. Liddicoat, 1989; Hughes, 1996).

Figure 7: *Aligned rows of small mineral or negative crystals, each being accompanied by an oriented thin film. Such inclusions also occurred singly. Fibre-optic illumination, 50x.*



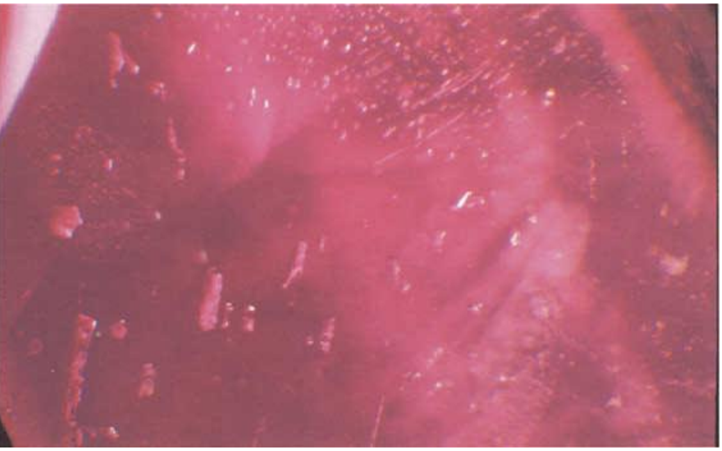


Figure 8: Idiomorphic negative crystals commonly contain immiscible liquid and gas phases. Fibre-optic illumination, 38x.

The infrared spectra are dominated by the AlO stretching frequencies typical for corundum, between approximately 300 and 1000 cm^{-1} (peak positions at approximately 760, 642, 602 and 405 cm^{-1}; Wefers and Bell, 1972). No absorption features were detected in the mid-infrared region (1900 to 4000 cm^{-1}), relating to foreign mineral phases or structural OH groups (see e.g. Volynets *et al.*, 1974; Moon and Phillips, 1994; Smith, 1995; Smith *et al.*, 1997).

Chemical analysis

Semi-quantitative chemical analyses of the five specimens shown in *Figure 1* revealed the presence of various minor to trace elements. Of these, Cr is the most significant minor element and is responsible for the pink to red hues of the gemstones. Ti is generally the next most abundant minor to trace element, followed by V, Fe and Ga. The contents of these oxides in five Pamir corundum samples are presented in *Table II*. In parts, Zr was also recorded in minute quantities and this is attributed to the presence of zircon inclusions.

***Table II:** Semi-quantitative chemical analyses of rubies and pink sapphires from the Pamir Mountain Range, Republic of Tajikistan.*

	Sample weight				
Wt% Oxide	*0.30 ct*	*0.38 ct*	*0.44 ct*	*0.56 ct*	*0.80 ct*
Al_2O_3	99.5	99.3	99.4	99.5	99.6
Cr_2O_3	0.224	0.516	0.498	0.286	0.185
TiO_2	0.156	0.047	0.017	0.091	0.068
Fe_2O_3	0.018	0.011	0.006	0.007	0.004
V_2O_5	0.024	0.015	0.025	0.025	0.016
Ga_2O_3	0.012	0.014	0.013	0.012	0.010

Discussion

The Pamir mountains which extend along the southern perimeter of Tajikistan, in the former Soviet Union, are probably most well known to gemmologists because of their spinel deposits. Since their initial discovery in the early 1980s, rubies and pink sapphires have been recovered in small quantities and sold in the international gemstone market.

As a consequence of civil war, financial limitations and harsh climate, only the richest mine, Snejnaya, is currently worked. Although no details were obtainable as to the past or current production of these deposits, it can be assumed that any production is small and sporadic. It follows that the potential reserves are also unknown.

To date, fine gem-quality faceted gemstones are typically a carat and a half or less, while cabochon-quality gemstones are cut in sizes up to two or three carats. Low-quality ruby crystals may reach sizes of 5–7 kg. The largest known gem-quality faceted ruby from Pamir weighs nearly 3.5 ct (I. Pojarevski, 1997, pers. comm.). There are reports that fine gem-quality Pamir rubies or pink sapphires have been seen in sizes up to five carats, but these are unconfirmed.

The Pamir rubies and pink sapphires are most similar to stones from the Quy Chau deposits in central Vietnam. However, the combination of the parallel arrangements of calcite inclusions, the columnar concentrations of short rutile needles and particles, and the negative crystal inclusions, appear to be distinctive of rubies and pink sapphires from the Pamirs. The small mineral or negative crystals accompanied by oriented thin films are also distinctive and are quite different in appearance to the doubly truncated negative crystals with equatorial thin films which characterize the rubies from magmatic sources, such as in Thailand and Cambodia.

In contrast, inclusion features frequently observed in rubies from other marble-type sources were not observed in the ruby and pink sapphire samples from the Pamirs. Such inclusion features include swirled growth structures, colour zoning and nest-like concentrations of rutile needles, typical of rubies from the Mogok stone-tract, or dense cross-hatch to flake-like inclusion patterns and distinctive growth structures indicative of Mong Hsu rubies, both from Myanmar (Burma), various stringer and cloud-like formations commonly seen in the rubies from northern Vietnam and Nepal, and the mineral inclusion assemblages typical of the rubies from east Africa.

Since gaining its independence from the former Soviet Union in September 1991, Tajikistan has suffered from regional conflicts, and this political factor, coupled with the difficulty of physical access to the region, has meant that the full gem potential of the Pamir region has yet to be fully exploited.

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References

Henn, U., and Bank, H., 1990. Gem-quality rubies from the Pamir range, USSR. *Bourse Bulletin*, 6, 1990, *Goldshmiede Zeitung*. 6, 107–8

Henn,U., Bank, H., and Bank-Scherner, M., 1990. Rubine aus dem Pamir-Gebirge, UdSSR. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **39**(4), 201–4

Hurlbut, C.S., and Kammerling, R.C., 1991. *Gemology*, 2nd ed. Wiley Interscience, New York

Hughes, R.W., 1996. *Ruby and Sapphire*. RWH Publishing, Boulder, Colorado

Kiefert, L., and Schmetzer, K., 1991. The microscopic determination of structural properties for the characterisation of optical uniaxial natural and synthetic gemstones. Part 1: General considerations and description of the methods. *Journal of Gemmology*, **22**(6), 344–54

Koivula, J.I., and Kammerling, R.C., 1989. Examination of a gem spinel crystal from the Pamir Mountains. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **38**(2), 85–8

Liddicoat, R.T., 1989. *Handbook of gem identification*, 12th ed. Gemological Institute of America, USA

Moon, A.R., and Phillips, M.R., 1994. Defect clustering and colour in Fe, Ti:αAl_2O_3. *J. Am. Ceram. Soc.*, **77**(2), 356–67

Schmetzer, K., 1985. Ein verbesserter Probenhalter und seine Anwendung auf Probleme der Unterscheidung natürlicher und synthetischer Rubine sowie natürlicher und synthetischer Amethyste. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **34**(1), 30–47

Schmetzer, K., 1986. An improved sample holder and its use in the distinction of natural and synthetic ruby as well as natural and synthetic amethyst. *Journal of Gemmology*, **20**(1), 20–33

Smith, C.P., 1995. A contribution to understanding the infrared spectra of rubies from Mong Hsu, Myanmar. *Journal of Gemmology*, **25**(5), 321–35

Smith, C.P., 1996. Introduction to analyzing internal growth structures: Identification of the negative d plane in natural ruby. *Gems & Gemology*, **32**(3), 170–84

Smith, C.P., Gübelin, E.J., Bassett, A.M., and Manandhar, M.N., 1997. Rubies and fancy-color sapphires from Nepal. *Gems and Gemology*, **33**(1), 24–41

Volynets, F.K., Sidrova, E.A., and Stsepuro, N.A., 1974. OH-groups in corundum crystals which were grown with the Verneuil technique. *Journal of Applied Spectroscopy*, **17**, 1626–28. Translated from *Zhurnal Prikladnoi Spektroskpii* 1972, **17**(6), 1088–91

Webster, R., 1994. Gems. 5th ed. Ed. Read. Oxford. Butterworth-Heinemann

Wefers, K., and Bell, G.M., 1972. *Oxides and Hydroxides of Aluminium*. Technical Paper No. 19, Alcoa Research Laboratories, USA

Gemstone deposits of the former Soviet Union

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ABSTRACT: The most important gemstone deposits of the former Soviet Union are described. The deposits range from diamond and ruby to amber and pearl. Some genetic features of gemstones are reported.

Keywords: agate, aquamarine, diamond, gemstone, genetic mineralogy, gypsum, ruby, Soviet Union, topaz, tourmaline

Introduction

The famous Russian poet of the XIX century, Feodor Ivanovich Tiutchev writes in one of his poems:

'Nicht, was Ihr meint, ist die Natur
Nicht blind und geistlos von Gesicht
Freiheit und Liebe sind in ihr,
Nicht seellos ist sie, fühllos nicht ....'

'Nature is neither blind nor spiritless as you implied but includes freedom and love: nor is it without soul or feeling.' [Transl. M.O'D]

The territory of the former Soviet Union occupies one-sixth of the land mass of the Earth, including the larger portion of the European and nearly one-half of the Asian continents. The geological structure is very diverse and for this reason numerous types of gemstone deposits have been identified: only the largest and most interesting examples are dealt with in this paper.

Generally speaking, gem minerals are late to crystallize from the fluid phase in free space. The creation of cavities, dissolution, leaching and sometimes recrystallization follow original formation. In the paper we shall discuss three types of association, each of which hosts gem minerals.

1. Igneous (or magmatogene) associations

Diamond-bearing kimberlite

The former Soviet Union hosts large *in situ* diamond deposits with kimberlite pipes and accompanying placers accounting for one-fifth of world diamond production. More than 100 kimberlite pipes have been identified from Archaean-Proterozoic Siberian and Russian platforms. The age of the Siberian pipes ranges from early Paleozoic to Mesozoic and that of the north Russian pipes from Early Paleozoic to middle Carboniferous. The structure of the kimberlite breccia (autobrecciated foam-lava) pipes does not differ from similar structures in other countries. The north and centre of the Siberian platform house the richest pipes, which include the Mir [1], Aikhal [2], Udachnaya [3] and Internatsionalnaya [4], all in current operation. Mines which may be developed later include Yubileynaya [5], Zarnitsa [6] and Batuobinskaya [7]. In the north of the Russian platform are the Lomonosovskaya [8], Karpinskaya [9] and Pervomayskaya [10] pipes (*Figure 1*).

Each of these deposits contains millions of carats of diamonds and no doubt many will be of high gemstone quality. There is a higher

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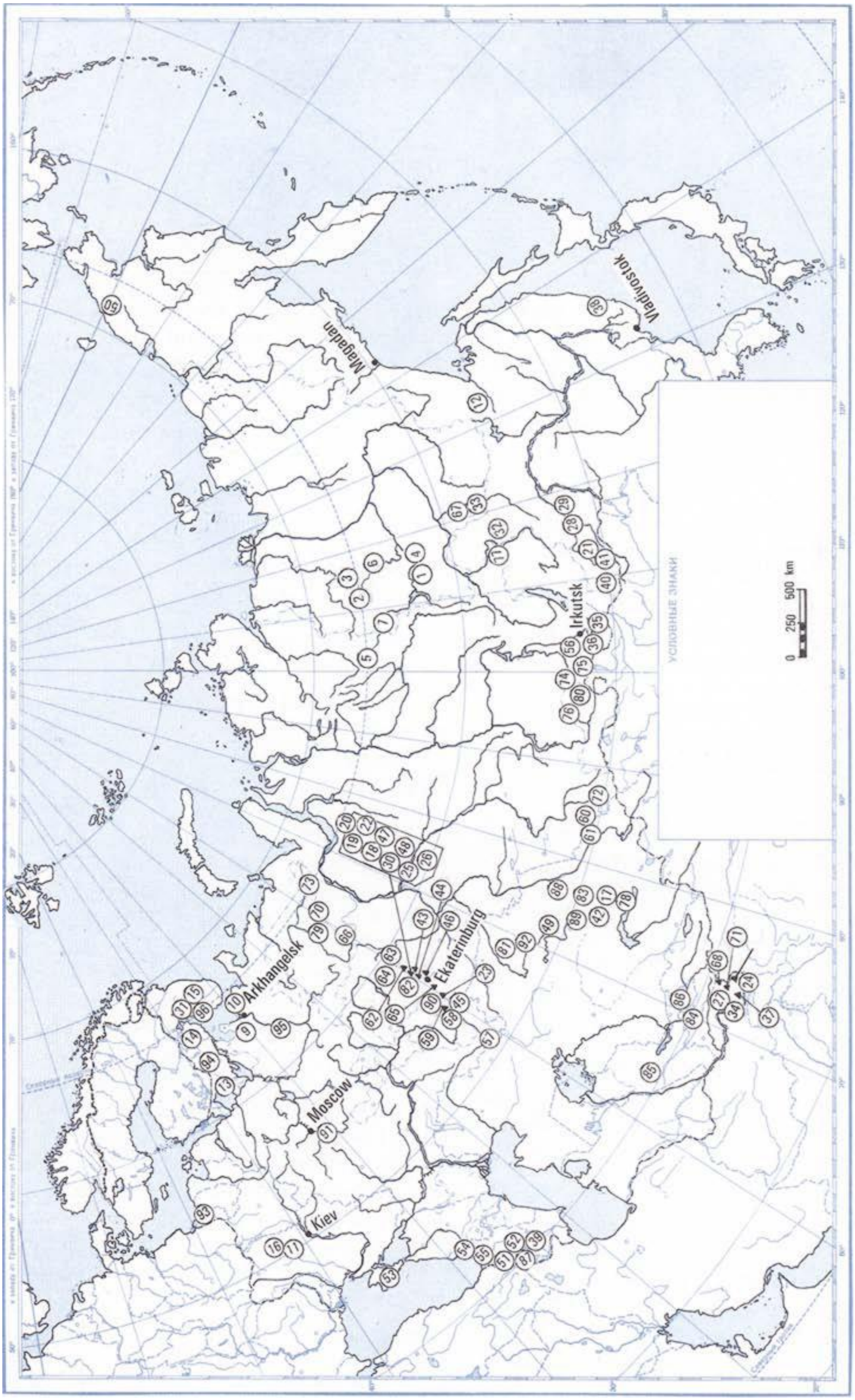

***Figure 1:** Map of the precious and jewel stone deposits of the Former Soviet Union. Number corresponds to that of a deposit referred to in the text.*

gem diamond percentage in the pipes of northern Russia than in those of Siberia, which contain coarse and mainly medium-to-small-sized crystals. The Russian kimberlites produce mainly small and coarse diamond crystals. Siberian kimberlites have produced many crystals in the 50–100 ct weight range. The largest Russian gem-quality diamond weighs 342.5 ct and is a pale citron colour.

Diamonds from kimberlites in Russia and elsewhere are equivalent in size to characteristic mantle megacrysts from alkaline magmatic rocks such as ilmenite, pyrope, enstatite and clino-pyroxene.

Diamond crystals from Siberia are 90 per cent irregular or fragmentary with only 10 per cent showing regular polyhedral forms. The deepest Siberian kimberlites are pyrope-poor and are enriched in diamond which occurs as plane-faced octahedral and dodecahedral crystals. The shallower Siberian kimberlites are richer in pyrope and poorer in diamond which frequently show curve-faced dodecahedra and other antiskeletal forms.

Russian diamonds occur in a wide range of colours, most commonly colourless and less commonly yellow, green, smoky, brown, grey and black. Crystals with dense colours are comparatively rare. Earlier-formed plane-faced octahedra are most often colourless while later-formed crystals of cuboid habit, with rounded edges, have a yellowish colour of different intensity.

The interior features of Siberian diamonds include many blob-like and faceted inclusions of monosulphide solid solutions, mainly composed of troilite or pentlandite, of native iron and wüstite and intergrowths of sulphides, wüstite and iron: formerly these were believed to be graphite. This shows that the diamonds crystallized from the participation of locally-occurring metal (iron)-oxide-sulphide melts.

Kimberlite intrusions have cut sedimentary sequences and sills of dolerites. When limestone is the host rock it may house diamond crystals and pyrope grains at distances of up to 0.5 to 1 m from the pipe contact. At the Mir pipe, for example, fluid pressure on the solid phases in the kimberlite fluid-saturated foam-lava was so strong that the most durable individual crystals have been forcibly emplaced in the relatively soft country rock. In the Udachnaya pipe a collection of diamond-bearing eclogitic xenoliths up to 10 cm across has been sampled. Some of the xenoliths contain a lot of diamonds (up to a third in volume). The largest crystals range from 6 to 15 mm in size (*Figure 2*). Examination of these samples certainly supports the theory that diamond-bearing eclogite from the mantle is one of the main sources of diamond in kimberlite breccia.

While northern Russian kimberlites are pyrope-poor, Siberian kimberlites are pyrope-rich. Some Siberian pyrope crystals found in association with chrome diopside show an alexandrite effect with bluish-green colour in daylight and violet-red in artificial light. Rich diamond placers near to kimberlite pipes are found on the White Sea shelf.

Labradorite

Iridescent labradorite is found at the very large Golovinskoe deposit [11] located in the Volyn district which forms part of the western Ukrainian shield, itself

Figure 2: *Xenolith of a diamondiferous eclogite from the Udachnaya kimberlite pipe. Size of the diamond crystal is 6 mm. Photo by M.A. Bogomolov.*

GLOSSARY OF SOME GEOLOGICAL TERMS USED IN THIS REVIEW

Anorthosite	Rock composed mainly of plagioclase feldspar
Boudin	Elongate rounded fragment of relatively strong and cohesive rock detached from a larger piece by flow of the more plastic rocks surrounding it; from the French 'boudin', a sausage
Breccia	Rock composed of angular fragments mixed with finer material
Facies	Group term for a range of rocks formed under a specified range of chemical, pressure, temperature or other physical conditions
Granitoid	Rock with granitic character but not necessarily a granite in the strict sense
Hydromica	Mineral with a structure like mica but altered to accommodate more OH groups or water molecules
Jadeitite	Petrologists' term for rock consisting largely of jadeite the mineral
Karst	Countryside formed on limestone which has suffered solution by groundwater to form caves and underground drainage
Leucogranite	Granite consisting mainly of light-coloured minerals
Meta	Abbreviation for metamorphosed
Metasomatism	Process of alteration by action on rocks of fluids from an external source
Metasomatite	Rock formed as a result of metasomatic processes
Miarolitic	Adjective used to describe granite with irregular cavities lined with well-terminated crystals of both the normal constituents of the rocks (quartz and feldspar) and some rarer accessory minerals
Protolith	Rock which is subsequently altered in some way – for example, by metamorphism or metasomatism
Septaria	Egg-shaped nodules up to 100 cm across characterized by radiating cracks that widen towards the centre and die out near the margin, crossed by cracks that are concentric with the margin
Supergene	Adjective describing processes involving water percolating downwards from the earth's surface; involves solution, reaction and deposition of minerals
Ultrabasite	Ultrabasic rock, one generally low in silica content, lower than basic rocks such as most basalts

forming part of a Proterozoic anorthosite and gabbro-norite pluton. Crystals may reach 20 x 12 x 3 cm and show black with dark blue, greenish- or yellowish-blue iridescence. Very thin ilmenite lamellae are responsible for the black body colour of the crystals. The Dzhugdzhurskoe deposit [12], also very large, is located within the Archean anorthosite in the east of the Aldan shield.

Granitic pegmatites

The deepest pegmatites are feldspar and muscovite-rich, occurring among high pressure metamorphic rocks (kyanite-bearing gneisses). The northern Karelian pegmatites may contain iridescent oligoclase and rose quartz while those from southern Karelia may contain gem-quality almandine. Translucent or semi-transparent peristerite-oligoclase with an attractive light blue or yellowish light blue iridescence [known in Russia as belomorite] is found in the Chupa pegmatite [14] as blocks of up to 20 x 20 x 5 cm and also in small segregations in the contact gneiss. Some examples of water-transparent oligoclase with a strong, gentle blue schiller are particularly attractive.

Gem-quality amazonite has been found in a shallower granitic pegmatite containing rare metals at the Zapadnokeivskoe deposit [15], the largest in the former USSR. It is situated on Mount Ploskaya in the centre of the Kola Peninsula and consists of a series of thick, steeply-dipping pegmatite veins with a zoned structure. Bright bluish-green amazonite occurs in the feldspar zone of the pegmatite: crystals may reach more than 1 cubic metre in volume and show blades of snow-white albite forming exsolution patterns. Such crystals are not rare.

The shallowest miarolitic granite pegmatites of the Urals, Ukraine, Transbaikalia and Pamir contain quartz, beryl, topaz, tourmaline and gem-quality crystals of other species. Smoky quartz (morion) crystals are widespread in the cavities of Ukrainian and Uralian pegmatites. The Volynskoe pegmatite [16] in the Ukraine is a large example, related to the apical part of the late-Proterozoic Korosten leucogranite pluton: it contains cavities up to 250 cubic metres in volume and on occasion a shaft has had to be sunk in order to reach a single crystal of morion. The author was present at the recovery of such a crystal measuring 8 x 1 x 1 m, which rested near-horizontally on the druse of large orthoclase-perthite covering the cavity walls. Smoky quartz from Volyn shows colours ranging from a dense pitch-brown through brown with a lilac hue to yellow.

A light and completely transparent violet-rose amethyst found in blocks measuring up to 1.5 cubic metres occurs within a pegmatite nucleus in the Kent leucogranite pluton [17] of central Kazakhstan. This area also contains pegmatites in which light-blue fluorite of optical and gem quality has been found. The crystals may reach 350 kg in weight.

Figure 3: Verdelite crystals from a granitic pegmatite in the Pamirs. Long dimension of the image is 9 cm. Photo by M.A. Bogomolov.

Beryl – heliodor, aquamarine, morganite. Miarolitic pegmatites of the central Urals and in particular the Murzinskoe [18], Alabaschkoe [19] and Aduiskoe deposits [20] are celebrated for their crystals of heliodor which may show various shades of green and yellow and reach 27 cm in length. Heliodor of gem quality is found in every tenth cavity of the Volyn pegmatite in Ukraine and forms crystals up to 5300 g. Aquamarine is fairly widespread in the pegmatites of the central and south Urals, Altay, Transbaikalia and Pamir. Morganite [vorobyevite] is known in the Transbaikalia pegmatite (near the Urchugan river, close to the Russian-Mongolian border) [21] and at Schaytanka [22] in the central Urals.

Topaz [tyazheloves (heavyweight)] is found in miarolitic pegmatites of the Ilmen Mountains, south Urals [23] and the Murzin-Aduy belt in the central Urals. It also occurs in Transbaikalia and in the eastern Pamirs where notable crystals of light- and sky-blue are found. Blue, golden and pale-yellow topaz are found in the pegmatites of the middle Urals. Very fine yellow topaz can be found in the pegmatites of the Kukurt deposit, eastern Pamirs [24]. Every third cavity of the Volyn deposit (Ukraine) contains gem-quality topaz, specimens

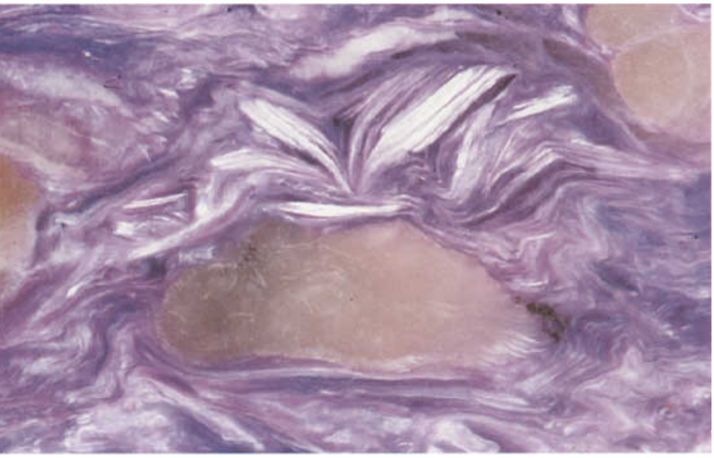

Figure 4: Charoitites – tectonites with rounded inclusions of greenish ferrous orthoclase. Long dimension of image is 6 cm. Photo of author's sample by M.A. Bogomolov.

weighing up to 117 kg. These crystals are commonly zoned with the centre blue and the outside the colour of tea, the sectors having different densities. Associated with the topaz is colourless phenakite with crystals up to 4 cm long. The Volyn deposit also contains 'landscape' topaz and water-clear crystals measuring up to 20 x 10 x 15 cm with an intense brown outer zone 3 to 5 cm wide and a blue core. Snow-white skeletal cuneate fluorite crystal inclusions up to 2 cm long appear to float in the blue, the effect suggesting swans in flight against a blue sky.

Tourmaline – rubellite, verdelite, indicolite. Fine gem-quality tourmaline occurs in the miarolitic granite pegmatites of the central Urals, Transbaikalia and the Pamirs. The best-known deposits are Schaytanskoe, Sarapulskoe [25] and Lipovskoe [26] in the central Urals. These contain dense crimson crystals of elbaite-rubellite up to 14 cm long, known in Russia as siberite or red schorl. Polychrome crystals (black with crimson ends, crimson crystals with blue ends) are also common in these deposits.

Miarolitic granites of the southern Pamirs [27] contain fine coloured tourmalines including verdelite of elbaite-liddicoatite composition. Fine rubellite, verdelite, indicolite and polychrome tourmalines are distributed in the miarolitic pegmatites in the centre of Transbaikalia in the Borschovochny [28] and Malkhansky [29] ridges. Most crystals are 2–4 cm long though some specimens are reported to have reached 12 cm. An unusual colour of verdelite (elbaite-tsilaisite) *(Figure 3)* is ascribed to a Bi-content of 0.3 per cent.

Andalusite may crystallize instead of topaz when the availability of fluorine is low. Transparent pink and crimson andalusite in crystals up to 10 x 0.5 x 0.5 cm is recovered from the Yuzhakovskoe pegmatite [30] in the central Urals. Andalusite is associated with spessartine-almandine, schorl, muscovite and aquamarine. Hambergite occurs in the pegmatites of the Pamirs, middle Urals and Transbaikalia. Danburite in gem-quality crystals up to 12 x 2 x 2 cm can be found in pegmatites of the eastern Pamirs and Transbaikalia.

Syenite pegmatites

Sunstone as a sodic feldspar occurs in the pegmatites of the Ilmen and Vischenevy mountains of the Urals as well as in many other regions. It contains tiny inclusions of hematite, biotite and other coloured minerals as oriented lamellae which produce a characteristic sheen reminiscent of the sun at its rising or setting.

Sapphire. Dark-blue sapphire has been found in some syenite pegmatites of the central and south Urals and is plentiful in some areas. Grains of gem-quality sapphire have occurred in placers adjacent to the syenite-pegmatite.

Nepheline-syenite pegmatites

Eudialyte, a sodium calcium REE iron manganese zirconium silicate is sometimes used ornamentally. It has a fine dense lilac-red colour and occurs as separate segregations of up to 8 cm across in alkaline and peralkaline pegmatite and coarse-grained nepheline-syenite in the Khibinian massif, Kola Peninsula [31].

Post-magmatic high-temperature metasomatites of alkaline magmatites - fenites

Charoite rocks are found in a unique mineralization of the Sirenevy Kamen deposit [32], occurring in a halo around the Murun leucite-kalsilite pluton in north-eastern Transbaikalia. In this contact zone, fluids replaced the limestone and quartz sandstone. Charoite is a layered silicate with composition $(K_{Na,Sr,Ba})(Ca_{Na,Mn})_2[Si_4O_{10}](OH,F) \times H_2O$ and *en masse* forms the spectacular purple rock charoitite with pale green ferrous orthoclase and yellow tinaksite *(Figure 4)*.

Chrome diopside with a fine emerald-green colour has been called Siberian emerald. It forms separate segregations up to 50 cm in size and occurs in patches in coarse-grained orthoclase-phlogopite and amphibole-orthoclase-phlogopite metasomatites. These metasomatites occur within contact zones of alkaline syenite and Cr-bearing ultrabasite of the Inaglinsky massif [33] in the western Aldan shield.

***Figure 5:** Lazurite-ferrous magnesium skarn at the contact between calciphyres and high alkali granitoids, Sludyanskoe deposit. Photo by author.*

Post-granitoid metasomatites-Mg skarn

Titanium-clinohumite is bright orange or reddish-orange. A variety enriched in Ti occurs in the zoned bodies of the deepest magnesium skarn in the Kukhi-lal deposit [34] within areas of calcic rocks recrystallized to assemblages of calcite, spinel, forsterite and other silicates (calciphyres). The size of the transparent pieces of clinohumite ranges up to 2 cm. Rose-coloured, red and lilac gem-quality spinel in the Kukhi-lal deposit is associated with titanium-clinohumite and chlorite within areas of recrystallized calciphyre. Octahedral and transparent but fractured spinel crystals may reach 7 cm in length, but those with faceting potential are in the range 5–9 mm.

Lazurite. This feldspathoid mineral is close to hauyne in composition and occurs in the deep magnesium-enriched alkaline skarn which is related to the horizons of dolomite marbles and associated high-pressure metamorphic rocks. These are the Sludyanskoye [35] and Malobystrinkskoe [36] deposits in the southern Baikal region. The Lyadzhvardarinskoe deposit [37] in the Pamirs is structurally similar to the celebrated Badakshanskoe deposit in north-east Afghanistan.

The Sludyanskoe deposit is composed of patches and lenses of diopside-lazurite, calcite-scapolite-lazurite, forsterite-lazurite, phlogopite-lazurite and azurite-scapolite rocks occurring along contacts of high-alkali granitoids and graphite-bearing marbles *(Figure 5)*. Lazurite crystals up to 5 cm in size are found in calciphyres. Lazurite-bearing rocks are considerably impregnated by pyrite and by grains of native sulphur. The composition of the Baikal lazurite is $Na_6Ca_2Al_6Si_6O_{24}[(SO_4)_{1.35}S_{0.45}(CO_3)_{0.15}Cl_{0.1}]$, and its colour is ascribed to S.

Post-granitoid metasomatites-calcic skarns

Hedenbergite-wollastonite skarn makes an excellent ornamental material, being composed of micro-, mezo- and macro-spherolites composed of regular bands of differing thickness. These are radial aggregates of bright-green manganous hedenbergite and light-grey or pale-brown ferrous and manganous wollastonite which is predominant. This rock forms a deposit approximately 100 m long and approximately 10 m thick at the Tetiukhe mine [38] (Dalnegorsk) near Vladivostock in the Russian Far East.

Hessonite-andradite. One of the large skarn-magnetite deposits is at Daschkesan in Azerbaidzhan [39]. Distributed within the ore of massive garnet-magnetite are geodes encrusted by acicular epidote over which have grown large crystals of amethyst, carbonates, chalcopyrite and transparent yellowish-red and brownish-red andradite up to 2 cm across.

Post-granitoid metasomatites – zwitter and greisen

The high-temperature acidic (HF) metasomatites are *zwitter* (zinnwaldite and Li-Cs phlogopite-bearing) and *greisen* (muscovite-bearing). They may sometimes be accompanied by quartz veins and lenses with fine crystals of aquamarine, topaz and morion, among others.

In Russia *aquamarines* do not originate from pegmatites but from zwitter. Densely-coloured long prismatic crystals up to 30 cm are found at the Sherlovaya Gora deposit [40] in Transbaikalia. The colour is due to divalent Fe impurities which are stable in an acidic environment. Fine greenish-blue aquamarines are found in the Adunchilonskoe deposit [41] in Transbaikalia and in the quartz-pyrite-wolframite veins of the Akchatau deposits [42] in central Kazakhastan. Short prismatic crystals of blue topaz and large smoky quartz crystals with deep colour are often associated with aquamarine.

Processes of hydrofluoric metasomatism often occur outside the parent leucogranite pluton. When ultrabasite material containing chrome-magnetite (e.g. serpentinite, talc-carbonate rock) was infiltrated, zwitter-glimmerite containing Li-Cs phlogopite, fluorite, fluorapatite, emerald, chrysoberyl, phenakite and Be margarite were formed. The metasomatite is accompanied by oligoclase veins and lenses containing beryl, Cr-beryl and emerald. While Cr-beryl is unevenly coloured, containing residual chrome spinel and chrome-magnetite, emerald is coloured in crystal zones and contains inclusions of chrome spinel. Late metasomatic segregations contain the deepest-coloured transparent emeralds. The largest emerald deposits in the world are at Mariinskoe [43] and Sretenskoe [44] in the central Urals where they appear in elongate zones extending for approximately 25 km.

Emerald. It is possible that the 'Scythian emeralds' mentioned by Pliny the Elder are specimens from the Urals. These have a fine dense, clear green colour with Cr^{3+} as the main chromophore. Gem-quality crystals vary a good deal in size: production in 1977 reached 12 600 ct (1979 7 000 ct, 1982 12 900 ct, 1990 10 450 ct). In total, the mines have produced more than 2.5 million carats of faceted stones and approximately 50 tons of Cr-bearing beryl. Reserves are estimated at approximately 10 million carats.

Phenakite occurs with the emerald in glimmerite, oligoclase veins and cavities among them, with crystals reaching 20 cm in size. Intergrowths of phenakite weigh up to 6.5 kg. Transparent crystals are colourless, more rarely pink or wine-yellow. A water-clear and dark smoky phenakite crystal measuring 13 x 12 x 7 cm was found in 1991 at the Mariinskoe deposit.

Alexandrite, the chrysoberyl variety showing an emerald-green colour in daylight and reddish-violet in artificial light, was discovered at the emerald mines in the Urals and named for the famous Tsar Alexander II on the day of attaining his majority. The change of colour is considered to have a mystic association with the Tsar in that the green reflects his humanity and concern for the Russian peasantry while the red calls to mind his assassination. Russian alexandrite has been considered the best in the world and commonly forms penetration trillings of rhombo-pyramidal and short prismatic forms or aggregates of trillings. The largest of these measures 25 x 14 x 11 cm. Alexandrite mineralization is closely related to that of emerald but the deposits are separate, the alexandrite being found in glimmerite and margarite-plagioclase veins in association with pink fluorite.

Quartz, pink topaz and euclase. Late minerals of the zwitter-greisen assemblages are generated by slightly acidic to neutral fluids, depleted in fluorine, in which Fe^{3+} is stable. The results are veins with quartz, pink topaz and euclase in the Kochkar district, southern Urals. Crystals of pink fluor-hydroxyl topaz may reach 5 cm in length and multi-coloured euclase 8 cm; most are found in placers.

Post-granodiorite metasomatites – beresite

Rock crystal and light-coloured smoky quartz are found in mid-temperature hydrothermal ankerite-quartz-sericite metasomatites (beresite) at the Beriozovskoe deposit [46] in the Urals.

Post-granitoid metasomatites – argillizites

Amethyst. Zones of low-temperature hydrothermal hydromicaceous and quartz-chlorite-kaolinite metasomatites (argillizites) hosted in granite, syenite and monzonite often contain quartz veins with amethyst druses. They occur in the central Urals, particularly at the Vatikha deposit [47] where a celebrated dark blood-red colour of amethyst is found together with lighter-coloured sceptre forms, at Aduy [48] and at Vischnevskoe [49] in Kazakhstan.

2. Metamorphic associations

Low-grade zeolite facies metamorphic rocks

Most of the agate deposits occur in volcanic rocks of a wide range of compositions. Most are basalts in which gas bubbles have been filled by agate (metamorphosed amygdaloidal basalts). No agate occurs, however, in the contemporaneous volcanic rocks. They occur only in the volcanic sequences affected by metamorphism during burial – in other words low-grade zeolite facies metamorphism (T = 130–220°C, P = 1–5 kb). Such metamorphosed rocks are widespread along the edges of folded areas and in the lower parts of plate margins. Mineral assemblages of the zeolite facies in metavolcanic rocks are heulandite, stilbite, chabazite, chlorite, albite, quartz, chalcedony, amethyst, celadonite, montmorillonite, goethite and pyrite.

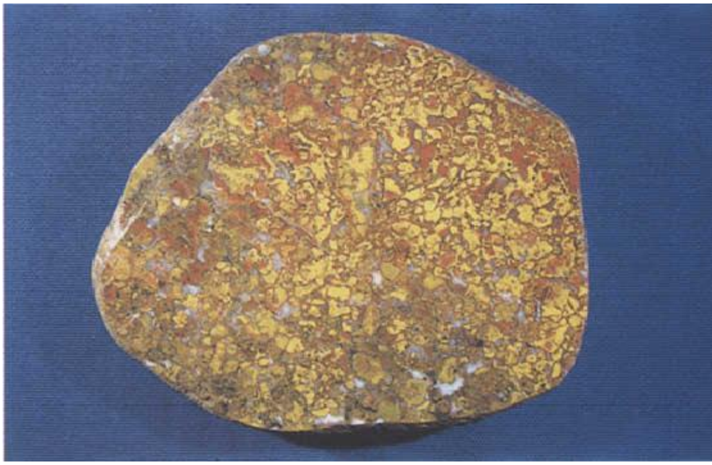

Figure 6: *Brocaded jasper-like moss agates with goethite and hematite, western Georgia. Long dimension of image is 13 cm. Photo by M.A. Bogomolov of author's sample.*

Agate is widespread among metavolcanic rocks in the north-east of European Russia, the mountains of the Crimea, Caucasus, southern Urals, central and eastern Kazakhstan, eastern Siberia, Chukotka and eastern Transbaikalia south of the Russian Far East. The best agates occur in Jurassic metavolcanic rocks in Georgia [50] and resemble brocaded jasper in their patterning *(Figure 6)*. Fine agates are found in mesozoic-paleogene metavolcanic rocks in Armenia at the Idzhevan [51] and Sarigiukh [52] deposits. The former deposit contains agate with amethyst and goethite coated with reddish heulandite *(Figure 7)*; the latter deposit contains mossy celadonite and goethite-bearing agate *(Figure 8)*. Agate mineralization in Siberia is often accompanied by fine zeolite druses with crystals of gem-quality prehnite and apophyllite. On passing to the laumontite-prehnite facies (220–300°C) agates are recrystallized and lose their soft lustre.

Figure 7: Agates with amethyst and goethite, with red rim of heulandite hosted in metavolcanic rocks, Idzhevan. Long dimension of image is 18 cm. Photo by M.A. Bogomolov of author's sample.

Figure 8: Carpet agates with goethite and celadonite, Sarygiukh. Long dimension of images is 19 cm. Photo by M.A. Bogomolov of author's sample.

Jet also occurs in lignite and soft coal deposits in low-grade zeolite metasedimentary bodies. Occurrences are at Beschuevskoe [53] in the Crimea, Tkvartchely [54], Tkibuli [55] and Akhaltsikhe [56] in western Georgia and Cheremkhovskoe near Baikal [57].

Prehnite-pumpellyite facies metamorphic rocks

If agate is characteristic for zeolite facies, the corresponding material for higher-temperature prehnite-pumpellyite facies (T = approximately 300°C, P = 2–6 kb) is jasper *(Figure 9)*. This is the fine-grained metarock with predominantly quartz composition. It is coloured by hematite, garnet, epidote, pumpellyite, actinolite, chlorite or manganese minerals. The many deposits of different kinds of jasper (cherty-metasedimentary, cherty debris, carbonaceous-cherty, volcanic-cherty rocks) and felsic volcanic rocks lie in the greenstone belts from the south Urals (Orsk [57], Kalkansk [58], Muldakaevskoe [59] and others) to the near-Polar region at the Altais (Kolyvan [60] and others). They are also found in central Asia and Kazakhstan.

Figure 9: Map of France composed of the different kinds of Ural jaspers. Product of the Ekaterinburg faceting factory. Late XIX century. Photo by author.

Prehnite-pumpellyite facies metamorphism is fluid-dominated, the main fluid being water vapour. Metarocks contain numerous fractures resulting from hydrofracturing. These fractures are filled by the constituent minerals of metarocks – quartz, prehnite, epidote, albite, chlorite and carbonates. Metamorphism affected not only sedimentary and volcanic sequences but also magmatic massifs. Prehnite-pumpellyite facies metagabbroids and meta-ultrabasic rocks contain a range of gem and ornamental minerals. They are related mainly to the rodingite association comprising grossular, andradite (including demantoid), vesuvianite, uvarovite, chrome titanite and jade as precious rodingite.

Grossular A recorded grossular deposit with greenish and yellowish-green crystals up to 8 cm in size lies in the Viluy river valley [61] of the eastern Siberian platform. Grossular and vesuvianite crystals are included in a fine-grained groundmass of hydrogrossular composition.

Demantoid is andradite or hydroandradite containing chromium and is associated with serpentine, asbestos, magnetite and residual chrome spinellids. It contains fine syngenetic actinolite fibres which give a golden tinge to the stones. Pavel Piotrovich Bazhov, a writer from the Urals, said that demantoid 'smells as sweet as Spring and sun'. Heavily serpentinized ultrabasites in the central Urals host a number of deposits, including Poldnevskoe [62] and Bobrovskoe [63]. The finest specimens are found in placers and one high-quality example weighing 76 ct appears to be unique.

Chrome garnets of the rodingite association, uvarovite and chrome-grossular from the Saranovskoe deposit [64] in the north-west of the central Urals have a fine colour. This deposit is a steeply dipping peridotite massif containing numerous chromitite beds and the massif itself is cross-cut by a series of gabbro-dolerite dykes. The massif was subsequently tectonized and affected by regional prehnite-pumpellyite facies metamorphism. Fractures caused by hydrofracturing in chrometite are filled by carbonates, uvarovite, chrome-chlorite, quartz and pumpellyite with chrome titanite, rutile, diaspore, anatase and millerite. The fracture surface in chromitite is often encrusted with druses of uvarovite crystals up to 6 mm in size. Uvarovite and chrome grossular are often associated with chrome-chlorite and acicular shuiskite *(Figure 10)*, a brown mineral of the pumpellyite group containing chromium.

Chrome titanite from the Saranovskoe deposit is a fine emerald-green to golden-green and occurs as transparent crystals up to 20 x 20 x 5 mm in size though most are less than 5 mm. Faceted chrome sphene is similar in colour to the finest demantoid.

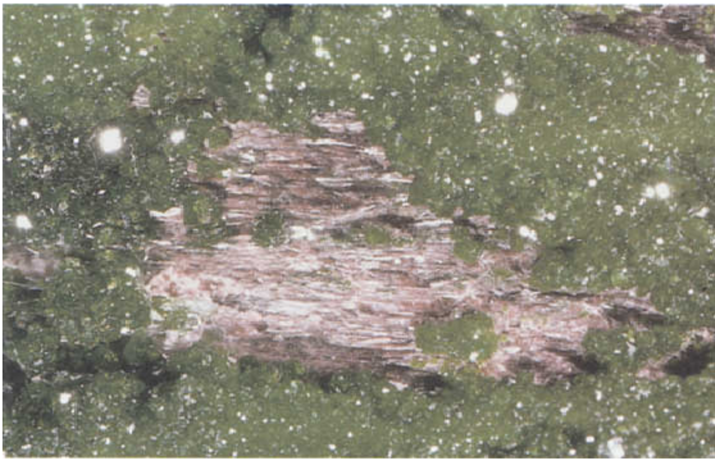

Figure 10: *Druse of emerald-green uvarovite crystals and acicular shuiskite (on metachromitite), Saranovskoe deposit. Long dimension of image is 3 cm. Photo by M.A. Bogomolov of author's sample.*

Metamorphic rocks of medium temperature and pressure

'Orlets', a rhodonite rock of very fine pink and crimson colour, is a celebrated Russian ornamental material. It is a manganous cherty-carbonaceous metamorphic rock in the greenschist facies. The finest material comes from the Malo-Sidelnikovskoe deposit [65]: other deposits are located not far from Ekaterinburg. 'Orlets' is composed of fine micrograined aggregates of rhodonite, rhodochrosite, tephroite (a Mn silicate of the olivine group), sonolite (a hydrated Mn silicate of the humite group), spessartine and quartz with supergene black Mn oxides located along fractures. Cobaltian rhodonite with an unusual lilac-violet colour has recently been discovered in the Polar Urals.

Rock crystal, amethyst and *citrine* as well as *axinite* and *titanite* as splendid crystals occur in the Alpine veins hosted in meta-morphic rocks of the Near-Polar Urals (the Khasavarka deposit – No. 66 and others).

Metamorphic rocks of high pressure

Ruby occurs only in the high-pressure metamorphic complexes within core parts of the Pamirs and Uralian folded areas, among

Figure 11: Table set with Urals malachite. Russian mosaic style typical of XIX century production. Ekaterinburg Museum of Applied Art. Photo by author.

Figure 12: The figure of the legendary 'Hostess of Copper (malachite) Mountain' produced from gypsum-selenite, 1975. Height of the figure is 130 cm. Ekaterinburg Museum of Applied Art. Photo by author.

meta-evaporites (most often a dolomite marble). A ruby-bearing belt in the eastern Pamirs is 200 km long and is the most interesting as a ruby producer. Deposits occur at Snezhnoe [67], Nadezhda [68] and Tura-Kuloma [69]. The semi-transparent prismatic ruby crystals reach 2300 g and 25 cm in length. Transparent deep-coloured areas are found in the apex and in the peripheral parts of the crystals and fine faceted stones up to 2 ct have been obtained. Ruby mineralization occurs within a sequence of coarse-grained dolomite, calcite and magnesite marbles containing intercalations of crystalline schist with scapolite. Ruby crystals occur in patches with carbonates, scapolite and fuchsite. At the Makar-Ruz deposit [70] in the Polar Urals rubies occur within small bodies of phlogopite plagioclasites hosted in meta-ultrabasites.

Experiments indicate that at a high CO_2 fugacity spinel breaks down according to the reaction $MgAl_2O_4 + CO_2 \rightarrow Al_2O_3 + MgCO_3$. The experiments show that at temperatures above 400°C aluminium oxide migrates within aqueous fluid – in other words, corundum formation is possible in the metamorphic process provided that the environment is fluid-saturated. Low activities of silica, potassium and sodium, and the presence of chromium, are necessary for ruby corundum formation. Such conditions are met in both meta-evaporites and meta-ultrabasites.

Scapolite. Gem-quality scapolite in yellow, light-lilac to lilac and deep-purple colours is widespread in cavities among scapolite and albite-scapolite veins hosted in meta-evaporite sequences of the eastern Pamirs near the town of Murgab. The largest deposit is the Kukurt [71] where scapolite-bearing stockworks are found. Gem-quality scapolite crystals weigh up to 150 g and some display asterism. Some places produced crystals of gem-quality weighing up to 20 kg. Compositionally it is marialite containing appreciable CO_3^{2-} and S^-.

Cordierite with deep-blue and blue-violet colours forms patches and metacrysts within metarocks of the Mountain Altaysm [72], East Pamirs and Transbaikalia. Transparent pieces may reach 4 x 3 x 3 cm in size.

Lazulite, a Mg–Al–Fe^{2+}–Fe^{3+} phosphate, is fairly widespread in metarocks of elevated pressure. The only Russian deposit of gem-quality lazulite is located near the Longotiegan river in the Polar Urals [73]. The lazulite patches in cavities in quartz veins measure up to 30 x 20 cm. Transparent fine blue and dark-blue crystals are found up to 2–4 mm, sometimes reaching 30 mm. Fine cabochons are fashioned from this hematite-included material.

Nephrite, green and white. White nephrite is a fine-grained tremolite with felted texture resulting from crystallization under high-pressure conditions, and with green nephrite, forms along the contacts between chromite-bearing serpentinized ultrabasites and gabbroids in most deposits. Variation of colour is due to differences in the amounts of Cr^{3+}, Fe^{2+} and Fe^{3+} in the tremolite. Deposits of green nephrite are at Ospinskoe [74], Bartogolskoe [75] and at other places in the eastern Sayans. Deposits also occur in the western Sayans at Kartashubinskoe [76], Polar Urals and Transbaikalia.

A rarer white to light citron-coloured nephrite comes from metasomatites at the contact zones between deep granitoids and dolomites. White nephrite may be translucent to depths of 2 cm. Deposits such as Buromskoe [77] and others occur in the Vitim river valley.

Metamorphic rocks of ultra-high pressures

Jadeite and chrome-jadeite. Lenticular bodies and boudins of jadeitite are found within Alpine basite-ultrabasite massifs in the zones of deep faults. Large deposits are at Itmurundy [78] in central Kazakhstan, Levokechpelskoe [79] in the Polar Urals and Kashkarskoe [80] in the western Sayans. Jadeitite is quite commonly present in the margins of enstatite or glaucophane rock where it is accompanied by albite- and quartz-bearing rocks. White and light-grey jadeitite is made up of almost pure jadeite. Gem-quality emerald-green chrome-bearing omphacite and ferri-omphacite (chloromelanite) are found as small areas in these rocks but occur more often as fine impregnations. The jadeitite is generally formed from

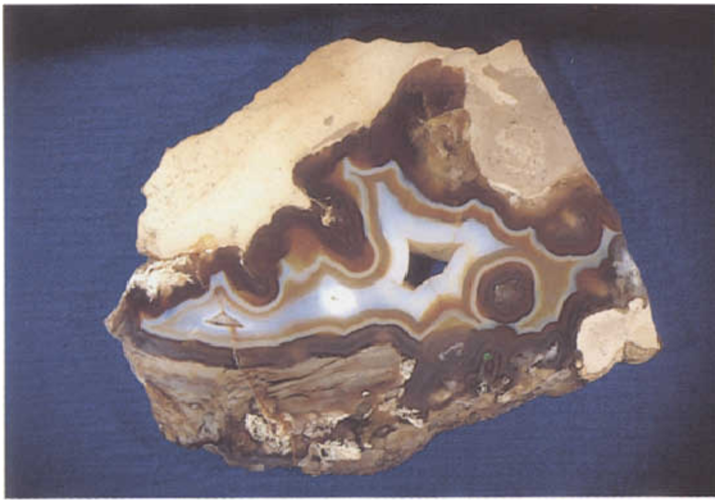

Figure 13: *Agates (carnelian and quartzite) hosted in silicified limestone, Golutvin. Long dimension of image is 9 cm. Photo of author's sample by M.A. Bogomolov.*

a plagiogranitoid or leucogabbro containing chromite: at low-grade metamorphism such rocks are altered to albitite or analcite-bearing rock but at ultra-high pressure they are altered to jadeitite.

Diamond in the very large metamorphic deposit near Kokchetav [81], north Kazakhstan, occurs as small grains averaging approximately 30 µm in size (microdiamonds). Some crystals are cube-shaped. The diamonds are of Cambrian age and the host rocks early Proterozoic. Small but good-quality diamonds are concentrated in Cretaceous-Tertiary placers.

3. Supergene associations

Malachite. The ornamental material malachite is both the archetypal Urals stone and the favourite of the Russian people! *(Figure 11).* High-grade, silky-velvet, patterned malachite occurs in the residuum of the skarn magnetite-chalcopyrite deposits in the contact zone between limestone marble and syenite at the Vysokaya mountain in the Nizhny Tagil region; Mednorudnyanskoe [82] is a main producer among others. Limestone is heavily karsted and the size of the karst caves is in the region of 140 x 100 x 30 m. The caves are completely or partially filled with ferruginated clays with malachite occurring as septaria, patches and impregnations, as massive nodules, stalactites and stalactitic aggregates. The size of some of the segregations in the Mednorudyanskoe deposit reaches an exceptional 450 t.

Dioptase, sometimes known as 'copper emerald', occurs in the residuum of copper ores at the Altyn Tiube deposit [83] in Kazakhstan. It is found as transparent crystals up to 2 cm long (though more often 3–7 mm) in limestone marble.

Turquoise. There are numerous deposits of turquoise in Tadzhkistan, including Biriuzakan [84], in Uzbekistan (Kyzylkumskoe [85] and Kalmakyrskoe [86]), Armenia (Tekhutskoe [87]) and in the Polar Urals. It is found in the residuum of phosphate-bearing sedimentary sequences, porphyry-copper and gold deposits. Recently a number of turquoise specimens were found at the Zhilandy deposit [88] near Ekibastuz, north-east Kazakhstan, where they occurred as nodules weighing exceptionally 1.5 kg though more commonly 3–20 g. The inner zone is light-blue zinc-rich turquoise with goyazite as an impurity while the outer zone is a deep-blue turquoise. It is penetrated by capillary veinlets of brown rancieite, a hydrated Ca Mn oxide.

Chrysoprase of fine quality forms patches and veinlets in birbirite, the name given to a weathering crust after carbonatized peridotite consisting of limonite, chalcedony and quartz at the Sarykoulboldy deposit [89] in Kazakhstan.

Gypsum. The selenite variety of gypsum forms as aggregates with long crystals of a warm pinkish-yellow. Selenite occurs as veins in the Permian gypsum and salt-bearing clay formations near the town of Kungur [90].

Flints. Concretions of flint measuring up to 150 x 150 x 30 cm (usually around 20 cm across) are widespread in the Carboniferous limestone of northern European Russia.

Agate. Fine coloured agates come from interbanded light-grey and milky chalcedonies, reddish-brown and gold-reddish-brown sard (carnelian) and bluish quartzites (*Figure 13*). They occur as separate patches and metasomatic segregations of irregular form within Carboniferous silicified limestones locally overlain by Jurassic pyrite-bearing clays. Good examples are found at the Golutvin deposit [91] not far from Moscow. This rare type of agate may have formed with the participation of glacial water. Ornamental-quality agates measure up to 30–50 cm.

Fire opal has been found in the so-called pelikanite: this name has been given to kaolinized granitoids with leached quartz, as found at the Voznesenskoe deposit [92] in north Kazakhstan. Red, orange-red, yellowish-red and other opals form veinlets and patches, the size of absolutely transparent blocks being in the region of 10 x 10 x 4 cm. Vein-like segregations of semi-transparent opal have been found in the clay of recent dumps – it might have been possible to watch its formation! Semi-transparent opal adheres to the tongue; when it collects water it becomes completely transparent and as water is lost it resumes its translucency. This material is very suitable for polishing.

Amber. The largest deposit of amber in the world is at Palmnikenskoe [93]. Located near Kaliningrad-Keniksberg, it produces a bluish amber-bearing sandy clay of Paleogene age overlain by Miocene rocks rich in organic material and Quaternary moraine. This mine is the world's largest amber producer.

Freshwater pearl used to be bound in nearly all rivers of north European Russia and a large production was necessary to satisfy the demand for the ornamentation of dress and for icons. Two large centres of production were on the river Kem in Karelia [94] (the coat-of-arms of the town of Kem features a pearl coronet) and on the river Dvina [95] where very large pearls have been recovered. Currently the largest formations of freshwater pearls in the world can be found in the interior of the Kola peninsula.

Acknowledgements

M. O'Donoghue very kindly assisted in the preparation of this paper for publication, and Elisabeth Strack is thanked for suggesting that the paper be published in the Journal. Dr I.A. Baksheev (MSU) is thanked for translation from Russian into English.

Further Reading

Bukanov, V.V., 1995. Rockcrystal-bearing veins of the Near-Polar Urals. *World of Stones*, 7, 7–11

Bulanova, G.P., Barashkov, G.P., Talnikov, Yu.P. *et al.*, 1993. Natural diamond: genetic aspects (in Russian). *Novosibirsk*, Publ. Nauka, pp 168

Fersman, A.E., 1925. *Precious and colored stones of the USSR* (in Russian) Moscow. Publ. Academy of Science, USSR, pp 592

Fersman, A.E., 1954, 1961. *Essays on the stone history* (in Russian). Moscow. Publ. Academy of Science, USSR. 1, pp 371, 2, pp 372

Lazarenko, E.K., Pavlishin, V.I., Latysh, V.G., *et al.*, 1973. *Mineralogy and genesis of the chamber pegmatites*, Volyn. Lvov. Publ. Lvov University, pp 360

Mineralogy of the Baikal region. Guide of the Baikal trip, 1978. *XI Meeting of International Mineral Association*, pp 222

Lomonosov, I.S. (ed). 1990. Geochemical prospecting of gems (in Russian). *Novosibirsk*, Publ. Nauka, pp 199

Rogova, V.P., Rogov, Uy.G., and Drits, V.A., 1978. Charoite – new mineral and new jewel stone (in Russian). *Zap. VMO*, **107** (1), 94–100

Samsonov, Ya.P., and Turinge, A.P., 1984. *Gems of the USSR*. Moscow. Publ. Nedra, pp 335

Skrigitil, A.M., 1996. Precious stones in the pegmatites, Eastern Pamirs. *World of Stones*, *11*, 11–18

Yushkin, N.P., Ivanov, O.K., and Popov, V.A., 1986. *Introduction to the topomineralogy of the Urals* (Russian). Moscow. Publ. Nauka, pp 294.

Zhernakov, V.I., 1993. The Urals Emerald mines (Russian). *Izvestiya VUZov – Gorny Zhurnal*, **11**, 46–52

Zagorsky, V.E., and Peretyazhko, I.S., 1992. Pegmatites with gems, Central Transbaikalia (Russian). *Novosibirsk*, Publ. Nauka, pp 187

Zolotukhin, F.F., 1996. *The Mariynskoe emerald deposit. Middle Urals* (Russian) St.-Petersburg. Publ. St.-Petersburg University, pp 70.

Abstracts

Diamonds | Synthetics and Simulants

Gems and Minerals | Techniques and Applications

Diamonds

Modern diamond cutting and polishing.

A. CASPI. *Gems & Gemology*, 33(2), 1997, 102–20, 24 illus. in colour.

Since 1980 there has been a revolution in the cutting of diamonds, with great advances in the use of modern technology, especially in Israel, Belgium, South Africa and Russia. The manufacturing component of the final retail value is equal to only 2 per cent. The new advances made include a decision support system for marking diamonds, e.g. deciding where to cut a rough diamond, by using a Sarin Dia-Expert System. The rough diamond is shown on a computer screen identifying the best position to mark a stone for cleaving and sawing. Laser kerfing allows a greater precision in following the markers lines, with a narrower and shallower kerf being made; also many diamonds may be processed together. Laser mechanical sawing has given rise to greater accuracy and higher production rates. A bruting laser has also been developed and is mostly used for fancy cut diamonds. J.J.

Gem Trade Lab notes.

C.W. FRYER. *Gems & Gemology*, 33(2), 1997, 134–41, 19 illus. in colour.

A yellow heart-shaped diamond was found to have a distinct orange patch of colour, which was caused by a limonitic stain to a fracture. It should be possible to remove the stain by boiling in acid. A green and pink rough diamond showed properties of a natural pink diamond. The green colour arose from green radiation stains from natural radiation, which did not penetrate the body. Yellow to yellowish-green treated diamonds were found to have been treated possibly by a new method using very high temperatures (>1400°C). These diamonds showed a frosted burnt appearance on the facet junctions and a peak at 985 nm (not visible with a spectroscope) caused by the H2 centre, otherwise they exhibited many properties normally associated with natural diamonds. J.J.

Gem news.

M.L. JOHNSON AND J.I. KOIVULA. *Gems & Gemology*, 33(2), 1997, 142–52, 23 illus. in colour.

A diamond set in a platinum filigree mount was found to be two diamonds placed one on top of another and held together by the claws. J.J.

Gems and Minerals

Zwei angeblich römische Gemmen aus Chalcedon bzw. Mis Sodalith aus dem ehemaligen Jugoslawien.

F. BRANDSTÄTTER, W. MELCHART AND G. NIEDERMAYR. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft*, 46(2), 1997, 93–5, 2 photographs, 4 microphotographs, 1 table, bibl.

Two cameos of questionable Roman origin were found in the former Yugoslavia (Serbia). One was a chalcedony cameo from Sirmium found to be artificially coloured blue. Although the Romans had dark-blue to grey-blue gems, we have no examples of their colouring agates and chalcedonies blue. The second cameo was reported to come from Viminacium and was identified as transparent sodalite, similar to material discovered in 1973 in Namibia. The cameos themselves and the way they were produced closely resemble genuine Roman gems – the materials used, however, showed them to be fakes. E.S.

Broken Hill.

Australian Journal of Mineralogy, 3(1), special issue, 1997, 87 pp, illus. in colour.

A number of gem-quality species are found at Broken Hill, New South Wales. This is a thematic rather than a special issue of the journal since it is not outside the part numbering, and contains papers on some notable cabinets (fine gem-quality crystals from the Milton Lavers collection are illustrated) and on species recently obtained from the Kintore and Block 14 open cuts at the mine:

Abstractors

R.A. Howie	R.A.H.	M. O'Donoghue	M.O'D.	E. Stern	E.S.
J. Johnson	J.J.	P.G. Read	P.G.R.	I. Sunagawa	I.S.

For further information on many of the topics referred to, consult *Mineralogical Abstracts*.

 ISSN: 1355–4565

collectors of micromounts will be especially interested in the range of species found. Papers have their own lists of references. M.O'D.

Puiva: Gwindel und Axinit aus dem Polar-Ural.

J.V. Burlakov. *Lapis*, 22(7/8), 1997, 59–70, illus. in colour, 2 maps.

Fine crystals of ferroaxinite and of quartz with the so-called 'gwindel' habit are described, with other minerals, from the Puiva area of the Polar Urals of Russia. M.O'D.

Pridorozhnoje: Morionfunde im Polar-Ural.

J.V. Burlakov. *Lapis*, 22(7/8), 1997, 71–4, illus. in colour.

Fine crystals of morion (smoky quartz) are described from Pridorozhnoje in the Russian Polar Urals. Occurring in Alpine cleft-type deposits, crystals may reach up to 15 cm in length. Other minerals from the area are listed. M.O'D.

Die Smaragdgruben des Urals: Tokowaja-Malyshevo.

J.V. Burlakov, J.A. Polenov, V.J. Gernakov and A.V. Samsonov. *Lapis*, 22(7/8), 1997, 44–55, illus. in colour, 2 maps.

Superb crystals of emerald and alexandrite with a very marked colour-change are described from the Tokowaja-Malyshevo area of the Russian Urals. Specimens from the Fersman Mineralogical Museum, Moscow, are illustrated: the geology and the mineralization of the area are described, most emerald and alexandrite being recovered from mica schists. Yellow-green chrysoberyl is also found. Other minerals of interest to the gemmologist include euclase, topaz, phenakite, beryl and apatite. M.O'D.

Mines and minerals of Peru.

J.A. Crowley, R.H. Currier and T. Szenics. *Mineralogical Record*, 28(4), 1997, 7–98, illus. in colour.

Among the minerals of Peru, fine crystals of fluorite and rhodochrosite are most likely to interest the gemmologist. The different mining districts of Peru are described with geological and mine maps: details of the geology and mineralization are given in all cases and there is a useful bibliography. M.O'D.

GIA Gem Trade Lab notes.

C.W. Fryer (ed.). *Gems & Gemology*, 33(1), 1997, 54–9.

A red and yellow semi-translucent portrait of a Buddha proved to be 'hornbill ivory' from the helmeted hornbill. The most diagnostic feature of this organic material is the bright red border of the yellow helmet.

Three large baroque beads which were reported to have belonged to the Mogul emperor Alban Shah (1542–1605) were identified as spinel, sapphire and a green aquamarine. The hand drilling, the inscribing of the Mogul names and the colour of the aquamarine lent credence to their provenance.

A piece of rough and a cabochon-cut, greenish-yellow opal showed a chatoyant effect caused by linear inclusions.

A quartz cat's-eye effect was caused by large rutile needles: it was concluded that these stones should be known as cat's-eye rutilated quartz. J.J.

Gem Trade Lab notes.

C.W. Fryer. *Gems & Gemology*, 33(2), 1997, 134-41, 19 illus. in colour.

An unusual doublet composed of a fully faceted beryl over which a green plastic layer had been added to give an emerald colour and extra depth had a convincing appearance. Another unusual stone was a dark brown, oval cabochon feldspar, which exhibited a four-rayed star and two parallel bands of chatoyancy. A variegated banded brown, white and light-green bead necklace was composed of naturally-coloured jadeite; it was probably cut from the outside layer of a naturally stained jadeite boulder.A heat-treated blue sapphire showed all the diagnostic features together with a raised area on the culet, which was part of the original heat-treated surface. A small dark green stone was identified as a very rare mineral known as serendibite, with biaxial RIs of 1.697 and 1.704, a weak absorption line at 470 nm and no fluorescence. Unusually a dark brown zircon cabochon exhibited a play of colour showing flashes of green and red, similar to an opal. The cause of the colour was not determined. J.J.

Minerali in vetrina: alcune tormaline della collezione Giazotto [second part].

A. Giazotto. *Rivista mineralogica italiana*, 16, 1993, 93–101, illus. in colour.

Tourmaline crystals from pegmatites of the Gilgit area of Pakistan, from Madagascar, Nepal, Mozambique, California and Brazil are described and illustrated. M.O'D.

La cueillette des minéraux gemmes du massif du Mont-Blanc.

E. Gonthier. *Revue de Gemmologie*, 131, 1997, 21–4.

The geology and mineralization of the Mont Blanc massif are described with particular reference to the occurrence of gem-quality crystals: fine crystals of fluorite are especially notable. M.O'D.

Rubies and fancy coloured sapphires from Nepal.

E.J. Gübelin, A.M. Bassett and M.N. Manandhar. *Gems & Gemology*, 33(1), 1997, 24–41, 26 coloured illustrations, 2 tables.

Although Nepal is not a major source of gem-quality corundum, it does produce some unusual rubies and fancy coloured sapphires, together with a broad range of gemstones. The corundum is found as a primary deposit in the Dhading District in Nepal in isolated dolomite pods, which have been subjected to low-grade metamorphism. The exploration and mining of the gemstones have been sporadic due to the terrain and the harsh climate. Most stones are cut as cabochons with a very small percentage of higher gem quality faceted.

Much of the corundum is similar to that found in other marble type deposits, but there are some notable differences with inclusions comprising dense concentrations of very fine short rutile needles, rod-shaped apatite crystals, colourless margarite, anorthite feldspar and uvite tourmaline; distinct colour zoning is common and there are bicolour stones with red and violetish-blue zones in thick or wedge-shaped bands; also there are almost colourless halos surrounded by mineral inclusions.

Also found in Nepal are trapiche corundums with rays formed of phologopite, apatite, calcite and graphite which differ from those of other localities. J.J.

Gemmologische Kurzinformationen. Short gemmological notes.

U. Henn and C.C. Milisenda. Smaragde aus China [Emeralds from China]. *Gemmologie. Z. Dt. Gemmol. Ges.*, **46**(2), 109–12.

The emeralds come from Malipo, 300 km south of Kunming, near the Vietnamese border. The samples occur in mica schists with quartz and fluorite; they show long prismatic crystals up to 3 cm, mostly heavily included, translucent with an attractive green colour; dark needle-shaped tourmaline inclusions are visible to the naked eye. A few smaller crystals were transparent and of gem quality. RI 1.573–1.575 to 1.580–1.583, DR 0.007–0.008, SG 2.68–2.71. Apart from the tourmaline inclusions, fine cracks as well as distinct growth zoning were visible under the microscope.

U. Henn and H. Bank. Beryll-Katzenaugen und Sternberylle. Cat's-eye beryls and star beryls. *Gemmologie. Z. Dt. Gemmol. Ges.*, **46**(2), 113–17.

The cat's-eye effect is described in aquamarines, golden beryls, morganites, emeralds; this is caused by parallel needle-like inclusions, especially hollow tubes. Asterism is due to mineral inclusions or fluids oriented in layers parallel to the crystal base and is described as occurring in aquamarines and very rarely in emeralds. E.S.

Gem news from Tucson 1997.

M.L. Johnson and J.I. Koivula (Eds.). *Gems & Gemology*, **33**(1), 1997, 60–70, 27 coloured illustrations.

Gem-quality andradites were for sale from a new locality in Arizona, not far from the Stanley Butte locality, which has produced non-gem andradite for some years. All the andradites showed typical properties but no 'horsetail' inclusions were observed.

An unusual trapiche emerald from Colombia exhibited two central columns each with black spokes that extended through the length of the stone. Jet is now being quarried at Matagan near Lake Baikal, north of Irkutsk, some of the jet was just massive lumps of rough and some had been carved. Many cabochons of bicolour-labradorite were being marketed in different shapes and sizes, as were 'Rainbow' obsidian hearts. Botryoidal white opal from Milford, Utah, has been on the market for at least twenty years and is sometimes known as satin flash opal. Similar opal from Utah banded in translucent to transparent white is also now on the market.

Drusy iridescent pyrite from Russia. This new material is formed as crystals lining concretions and found in the bed of the River Volga in Russia. Quartz with 'rainbow' hematite inclusions comes from the Aldan Mountains in Yakutia. The inclusions are hexagonal to irregular, with the thinner inclusions appearing red, while the thicker inclusions appear black and opaque. Aventurescence in some rock crystal may arise from pyrite inclusions. To obtain the desired effect specific orientation of the inclusion plane just off parallel to the table facet is needed.

A very vivid orange natural sapphire from Tunduru region of Tanzania was being exhibited, but it was not known whether it had been heat treated. Also from the region were peridot, unusually coloured grossular and spinels. One very large tanzanite had a fluid inclusion with a movable gas bubble.

Fine gem tourmaline from the Neu Schwaben region, Namibia, is expected to come onto the market. The colours are mainly greens, blue and blue-green with only facet grade material to be marketed.

A green and black nephrite with magnetite inclusions from Victorville, California, has been electroplated with the gold adhering to the magnetite. J.J.

Gem news

M.L. Johnson and J.I. Koivula. *Gems & Gemology*, **33**(2), 1997, 142–52, 23 illus. in colour.

A mine near Patna, Bihar State, India, produces moonstones with a 'royal' blue sheen. Much of the good quality material is 1 ct or less. Properties of the stones are consistent with labradorite or bytownite (high calcium plagioclase). A brownish-purple stone was identified as very rare musgravite, a close relative of taaffeite. A new emerald filler has been developed and is reputed to have better properties than Opticon. The new filler consists of a resin and hardening agent and does not turn yellow with time. J.J.

Brasilianische Opale aus Pedro II.

J. Knigge and C.C. Milisenda. *Gemmologie. Zeitschrift der Deutschen Gemmologie Gesellschaft*, **46**(2), 1997, 99–105, 8 photos, bibl.

The Piaui State is the only place in Brazil where gem-quality opals have been mined in commercial quantities; although these opals are of high quality, the importance of these occurrences has decreased dramatically during the past few years as only very small quantities are now produced. The mines are located within a radius of 50 km of Pedro II which is about 200 km away from the capital, Teresina. Except for the Boi Morto mine all opals are recovered from secondary deposits. At Boi Morto the stones are found at a sandstone quartz-dolerite contact. In contrast to the Boi Morto opals the alluvial stones show no signs of cracking due to the relatively low water content. Most opals are translucent to semi-transparent and white to whitish; body colours include white, reddish, orangy, yellow, greenish and bluish. Some material has a very distinctive layer structure in its body colour and play-of-colour resembling synthetic opals, but with no lizard-skin effect. E.S.

Gem rhodochrosite from the Sweet Home Mine, Colorado.

K. KNOX AND B.K. LEES. *Gems & Gemology*, 33(2), 1997, 122–33, 15 illus. in colour, 1 table.

Some of the finest transparent vivid red rhodochrosite has been found in the Sweet Home Mine, in the Mosquito Range in Colorado. The mine is situated 11,600 ft above sea level and is only accessible two to three months a year. The geology of the area is Precambrian granite and gneiss, which were intruded 30 million years ago by a magma that formed a porphyry-molybdenum system. The veins are polymetallic (silver, lead, zinc and copper) and follow a NE trend with the rhodochrosite forming as a gangue mineral in pockets.

Mining was originally for silver but when it became unproductive mining switched to rhodochrosite in 1966. This was irregular until better geological mapping was used, and Ground Penetrating Radar (GPR) to locate the pockets. Also special tools and collecting techniques had to be developed to prevent damage to the stones. To date 90 per cent of the pockets have been found to be of little commercial value, but approximately a hundred 0.50 ct+ stones a year are cut. Due to its cleavage and softness it is a difficult stone to facet and has to be set with great care. Cutting is slow and has to be done by hand. As mining is problematical the future of the Sweet Home Mine is dependent on advances in methods used for geological exploration. J.J.

Geographie, Bergbau, Geologie und Lagerstätten des Urals.

P. KOLESAR. *Lapis*, 22(7/8), 1997, 13–24, illus. in colour, 3 maps.

The Ural mountains extend over 2000 km in length and contain a number of major precious metal and gemstone deposits. The skarn deposits and pegmatites of Mursinka are described in some detail: this area produces aquamarine, heliodor, fine specimens of rock crystal and amethyst and is well known for museum quality examples of blue topaz. M.O'D.

New emerald deposits from Southern India.

J. PANJIKAR, K.T. RAMCHANDRAN AND K. BALU. *Australian Gemmologist*, 19(10), 1997, 427–32, 1 illus. in black-and-white, 1 graph, 3 tables.

Early in 1995 emeralds were discovered on the inner walls of a well in the village of Sankari Taluka in Southern India's state of Tamil Nadu. This initial discovery led to further exploration which uncovered deposits in the Salem district of Tamil Nadu state. Investigation into the properties of the emeralds and their characteristic inclusions have revealed similarities between them and the emeralds from several locations in Madagascar. This suggests that the Sankari emeralds may have been emplaced into the ancient supercontinent of Gondwanaland before India separated from it and the nascent island of Madagascar some 20 million years ago. P.G.R.

Rubis et saphirs du Viêt-Nam.

J.-P. POIROT. *Revue de Gemmologie*, 131, 1997, 3–5, 1 map.

An overview of ruby and blue sapphire production in Vietnam with details of the specimens found. Notes on characteristic inclusions are given. M.O'D.

Das Geologische Museum von Jekaterinburg im Ural.

J.A. POLENOV, J.V. BURLAKOV AND V.N. AVDONIN. *Lapis*, 22(7/8), 1997, 56–8, illus. in colour.

Some of the mineral specimens in the collections of the Geological Museum at Ekaterinburg (formerly Sverdlovsk) are described. One large rock crystal reaches 1.7 m in height and a number of type specimens, including uvarovite, are also held. M.O'D.

Colourless diopside and tremolite: two new 'end-member' gems from Canada.

G. ROBINSON AND W. WIGHT. *Canadian Gemmologist*, 18, 1997, 45–9.

Diopside and tremolite are reported and described from rocks of the Grenville geological province, a belt of igneous and metamorphic rocks extending from south-eastern Ontario to northern Quebec. That part of the province known as the Central Metasedimentary Belt hosts a number of gem-quality minerals. Diopside of gem quality occurs at Lot 22, Range II, Cawood Township, Pontiac County, Quebec. Constants are given for the rare colourless material: white opaque material occurs more commonly. Colourless tremolite of gem quality is found on the Dancey Farm near Irondale, Snowdon Township, Haliburton County, Ontario: constants are given. Both minerals are near to end-member composition. M.O'D.

Neuer spektakulärer Amethystfund aus Südnorwegen.

F. STEINAR NORDRUM, A.O. LARSEN, T. BERGSTRØM AND S. LARSEN. *Mineralien Welt*, 8(4), 1997, 45–50, 1 map.

Large well-formed crystals of amethyst are reported from Holmestrand, south Norway. Many of the crystals show sceptre form: details of the mineralization of the area and other minerals are described. M.O'D.

Update on emeralds from the Sandawana Mines, Zimbabwe.

J.C. ZWAAN, J. KANIS AND E.J. PETSCH. *Gems & Gemology*, 33(2), 1997, 80–100, 31 illus. in colour, 4 tables.

Since 1965 emeralds have been mined at Sandawana which is situated in the Mberengwa district in southern Zimbabwe. Emeralds are found along the southern limits of the archaean Zimbabwe craton, within the greenstone belt, which is composed of a series of intensely deformed metamorphic, mafic volcanic rocks and pegmatites. The emeralds occur near the pegmatites especially where they are in contact with the ultramafic rocks (komatiites).

Much of the emerald produced is small, less than 0.50 ct, and most is less than 0.25 ct. The emeralds are a vivid green and normally show an even colour distribution. Other typical characteristics are a high RI (n_ϵ 1.584–1.587, n_ω 1.590–1.594) and a high SG (2.74–2.77). Most stones contain fibrous amphibole, both actinolite and cummingtonite. Fluid inclusions are not common and are usually present as partially healed fractures. The absorption spectra show broad bands around 430 nm, 610 nm (ordinary ray) and a sharp peak at 683 nm. Chemical analyses show these emeralds have a high Cr content (0.6–1.3 wt%) together with high MgO and Na_2O contents. The above characteristics and the constant properties of Sandawana emeralds are distinctive. J.J.

Synthetics and Simulants

Gemologie Aktuell.

H. Bank, U. Henn and C.C. Milisenda. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft*, 46(2), 1997, 63–70.

Some tanzanite 'synthetics' on the market were found not be true synthetics but imitations; in particular, polysilicate which was rejected as real synthetic tanzanite. A transparent faceted red stone was found to be a natural corundum overgrown by synthetic ruby resulting in a small layer of dust-like mineral inclusions concentrated in a thin layer just underneath the rim. Recently an increasing number of hydrothermally produced synthetic alexandrites from Novosibirsk, Russia, have appeared on the market. Their most diagnostic features are distinct swirl-like growth inhomogeneities, sometimes visible under a 10x lens but obvious under a microscope. These synthetic alexandrites are produced in Novosibirsk. E.S.

The application and properties of Monocrystal.

P.R. de Heus. *Industrial Diamond Review*, 57(572), 1/97, 15–18, 4 diagrams, 2 photographs, bibl.

Unlike natural diamonds where slow crystal growth has concentrated the nitrogen atoms in flat layers (platelets), in a synthetic diamond the growth is rapid with the result that there are hardly any nitrogen crystals within the lattice; instead they are randomly distributed throughout the lattice, giving the Monocrystal its typical golden colour. These crystals display exceptional thermal conductivity and very low level of internal stress making them most suitable for industrial applications, which can vary from dressing of grinding wheels, machining of non-ferrous metals (such as aluminium disks for the computer industry), machining hard and soft contact lenses, to the milling of items of jewellery made of 22 ct gold. E.S.

Growth mechanism of flattened diamond crystals synthesized by chemical vapor deposition.

K. Hirabayashi and Y. Hirose. *Journal of Crystal Growth*, **142**, 1994, 140–6.

Flattened diamond crystals were synthesized under high oxygen gas concentration and low substrate *T*. Preferential growth along side faces due to the presence of twin re-entrant corners, and the fact that a {111} face is oriented II the substrate surface due to texture growth in the early stage of nucleation, are responsible for the flattened morphology. SEM observations and Raman spectroscopic measurements indicated that the diamond crystals were of good crystallinity and high quality. I.S.

Gem news from Tucson 1997.

M.L. Johnson and J.I. Koivula. *Gems & Gemology*, 33(1), 1997, 60–70.

A green beryl had a cabochon Australian opal set within the culet area, giving rise to a curious effect to the beryl. When viewed face up, the play-of-colour from the opal appeared throughout the stone. Other such stones were on exhibition including amethyst, aquamarine and golden beryls. Gilson synthetic opal chips have been set in glass to form briolettes, hearts and spheres. J.J.

Structural analysis on flux grown emerald crystals.

J.-S. Lee, P.-L. Lee and S.-C. Yu. *Journal of the Geological Society of China [Taiwan]*, 38(3), 1995, 273–85.

Crystals of synthetic emerald grown by a V_2O_5-PbO flux had the composition SiO_2 66.31, BeO 13.70, Al_2O_3 19.42, Cr_2O_3 0.70, V_2O_5 0.04 = 100.17 giving the formula $Al_{2.04}Cr_{0.05}Be_{2.95}Si_{5.95}O_{18}$; their structure was refined to R 1.5% (*a* 9.203, *c* 9.172 Å, space group *P6/mcc*, $D_{calc.}$ 2.668 g/cm³). The partial substitution of the excess octahedral cations (Al and Cr) for the tetrahedral Be and Si produced a highly distorted BeO_4 tetrahedron, confirmed by bond-angle variance and NMR spectrum. The substitution also involves the incorporation of minor V atoms as impurities in the channels of the beryl structure: difference Fourier analysis showed V to be located at (0,0,0.2901) and (0,0,0.2909). The centre of these two positions is (0,0,¼) which is the 2a site for alkali cations in hydrous alkali-rich beryl. The doublet configuration for V in the synthetic emerald is attributable to the high-*T* growth effect of these crystals. R.A.H.

Yttrium aluminium perovskite.

T. Linton. *Australian Gemmologist*, 19(10), 1997, 419–20, 3 illus. in colour.

Pink and orange faceted stones, marketed in the USA as yttrium aluminium perovskite or YAP, and manufactured in Russia by the crystal pulling process, were found to have properties of hardness, SG and RI, which did not match those of perovskite and are therefore a simulant of that mineral. The pink stones have a high refractive index of 1.85, and a dispersion near that of diamond. While these stones may superficially resemble pink Argyle diamond, their lower RI and striking rare earth absorption spectra should be sufficient to identify this new man-made product. P.G.R.

Diamants: la synthèse a une histoire.

D. SIRAKIAN. *Revue de Gemmologie*, **131**, 1997, 6–10.

Continuation of a history of diamond synthesis: the studies of Hannay, Moissan, Parsons and later workers are described. M.O'D.

A two-stage method for growing large single crystals of diamond with high quality.

WEI LI, H. KAGI AND M. WAKATSUKI. *Journal of Crystal Growth*, **160**, 1996, 78–86, 7 figs.

A novel method to grow high-quality large diamond crystals with a large net growth rate has been developed for diamond synthesis at high temperature and high pressure in metallic solution. The growing space is designed to have a recess at its lower temperature side, and the seed crystal is located at the bottom of the recess. When the recess is filled by the first-stage growth of diamond from the seed, its top surface serves as a large seed for the second-stage growth. If the size of the recess is selected appropriately, the perfection and quality of the second-stage are very high. The growth rate is small for the first-stage growth in the recess, but becomes larger for the second-stage growth. The diffusion field around a growth crystal is numerically simulated, satisfactorily explaining the growth nature.

I.S.

Two synthetic phenakites and their structure analysis.

S.-C. YU AND J.-S. LEE. *Journal of the Geological Society of China [Taiwan]*, **38**(4), 1995, 383–96.

Two flux-grown phenakites, one colourless and the other bluish-green, formed as minor accessories in an emerald growth experiment; both phenakites are close to the ideal composition of Be_2SiO_4 but the coloured one contains 0.3 wt% of V impurities. Both are trigonal, space group $R\bar{3}$; the colourless (bluish-green) crystals have *a* 12.466 (12.472), *c* 8.244 (8.253) Å; structural refinements gave final R factors of 1.81 (1.49)%. In the bluish-green phenakite two V atom positions are recognized; these are at interstitial positions rather than substituting for Be or Si. It is inferred that the green colour is due to the crystal field splitting of the d electron orbitals of the interstitial vanadium. R.A.H.

Techniques and Applications

Applications of geophysics in gemstone exploration.

F.A. COOK. *Gems & Gemology*, **33**(1), 1997, 4–23, 11 illus. in colour.

Geophysics has played a vital role in the exploration of minerals and hydrocarbons for many years, but this has not been the case for gemstones, where exploration techniques have remained relatively simple. The most common geophysical techniques include the use of gravity, magnetism, seismic reflection profiling, etc., but these are not always very useful for gemstone exploration as the resolution is not fine enough. More recently ground-penetrating radar (Georadar) has been used for the exploration of gemstones using radiowaves to measure the contrast in electroconductivity, producing images similar in appearance to seismic data. The main advantages are that Georadar can define subsurface features as small as 0.25 m, e.g. small pockets, and is particularly good for mapping shallow subsurface deposits; the data can also give three-dimensional images and is cheaper than most of the other methods.

The author explains the roll of plate tectonics with regard to rock types and therefore where various gemstones are most likely to be found. He also gives details of how and why all the geophysical methods are used; these are summarised in a table relating their usefulness for gemstones exploration and for the development of known ore bodies. J.J.

Réflexions sur des techniques lapidaires mogholes.

E. GONTHIER. *Revue de Gemmologie*, **131**, 1997, 25–7.

Lapidary work during the Mogul period is described and some details of settings are also given. M.O'D.

Short information about gemmological science and practice.

V.V. INDUTNY AND L.I. VISHNEVSKA. *Precious and Decorative Stones*, **1**(7), 1997, 7–14, illus. in colour, in Ukrainian.

Comments on the establishment and publication of the rights of jewellery manufacturers by the use of trade and other distinguishing marks on their products. Particular attention is paid to the amber recovered from the deposits of the state enterprise 'Ukrburshtin'. M.O'D.

A new view on the mechanism of diamond polishing.

F.M. VAN BOUWELEN, L.M. BROWN AND J.E. FIELD. *Industrial Diamond Review*, **57**(572), 1/97, 21–5, 4 illus. in black-and-white, 2 tables.

A concept is proposed for the development of a model to describe the highly anisotropic behaviour of diamond during frictional contact and polishing. The use of Scanning Probe Microscopy techniques have confirmed that after polishing in the hard octahedral {111} plane the diamond's surface shows that fracture and chipping mechanisms are involved in material removal. However, in the soft {100} cubic direction, a form of nano-grooving appears to take place which produces amorphous and graphitic debris (often referred to as 'black powder').

The removal of material while polishing in the soft direction may be caused by a mechanically induced degradation of diamond by bond bending. In the hard direction, the distortion of the crystal by bond bending is relatively small, and does not allow for a weakening of the structure. Further theoretical work is needed to study the realistic value of this concept. P.G.R.

Discover opals.

S. Aracic, 1996. The Author [P.O. Box 143, Lightning Ridge, NSW 2834, Australia]. pp 352, illus. in colour, hardcover. $A100.00. ISBN 0 959583 01 7.

Of course, an illustrated book on opal can hardly fail to be attractive and interesting. There have been many books on opal in the last few years, most of them published in Australia: as a general survey of Australian opal, its mining and geology, the present book (published as a limited edition of 1500 copies) is the best I have seen and should persist in availability (perhaps as a general rather than a limited print-run), finally establishing itself as an accepted classic along with the books of Wollaston and Murphy.

The text deals with the major fields of New South Wales, South Australia, Queensland and Western Australia and many of the individual mines in these states are described in some detail. But before the survey begins there is considerable coverage of surveying for likely deposits of opal, divining, pegging and working claims, processing of the recovered rough opal: there are also pen-portraits of celebrated miners and characters of the opal fields. The next 40 pages deal with opal as a mineral, its formation, the types of opal and the very large number of colour patterns recognized by miners and dealers. Some famous stones are illustrated and described and an attempt is made to equate opal types with their fields of origin. Matrix opal is described and a good account of treated opal matrix will be most interesting to readers in Europe and countries outside Australia, where this interesting, deceptive and beautiful material is less often encountered. Synthetic opal is also described along with the problem of cracking, opal pseudomorphous after fossils, the first discovery of opal, opal cutting and polishing, automatic cutting, selling value and investment. World markets and superstitions are covered in the last part of the general section before the area coverage begins.

Of the New South Wales opal fields, Lightning Ridge takes pride of place and about fifty pages are devoted to it. A map gives its location within the state and the coverage of the field would serve as an industrial and social history as well as a survey of the economics of opal mining and its effects. As it happens, colour photographs of most Lightning Ridge opal specimens are found chiefly in the preceding sections where exceptional opals are described. Nonetheless a very large coverage of the opals is here and a second and later maps give, in close detail and to scale, all the working deposits that can be said to be in the Lightning Ridge area. Useful diagrams show the strata in which opal can be found and there are many pictures of mines, of their dumps and of claim maps. Details of some famous cases concerning miners' rights are given so that as complete a Lightning Ridge history as possible is available to the reader who may find the smaller locally published histories hard to find.

Similar treatment, if less extensive, is given to White Cliffs, Tintenbar (once more the opal from this area is stated to be unstable though material with a jet-black body and play of colour is attractive), and to other smaller mines in New South Wales. Opal from other Australian states is described in a similar way so that there is little left unsaid. In South Australia, Coober Pedy and Andamooka take pride of place and there are extensive descriptions of Queensland boulder and nut opal. Perhaps less well known is the opal found in the gold-fields of Western Australia: quality is reported to be high and specimens have a black background but deposits were not being worked at the time of writing.

This is not only an authoritative study of Australian opal with an amazing amount of information but a book that can be read at any time with the greatest pleasure. I am not sure that the binding will stand up to very heavy usage and it would be churlish to expect a comprehensive list of references – this is not the aim of the author. In any case they appear in other studies and there is a book devoted to opal bibliography [De Boer, 1995]. Aracic's beautiful book deserves to stand with the greatest of opal studies if it is not that same study itself. M.O'D.

The F. John Barlow mineral collection.

F. John Barlow, 1996. Sanco Publishing [PO Box 177, Appleton WI 54912-0177], Appleton, Wisconsin. pp 408, illus. in colour, hardcover. US$208.68. ISBN 0 9653510 0 9.

The F. John Barlow mineral collection has been known for years, not only by mineralogists and collectors but also by many who have visited museums to which items have travelled from the collection to find their final home through the generosity of the collection's founder. It is one of the finest cabinets of minerals ever assembled and includes many gem minerals in their most beautiful crystal forms and colours: the aim has been to obtain the best specimens of their kind and no doubt frequent upgrading has taken place.

The first of the six main sections of the book opens with a short biography of John Barlow and then commences the mineral descriptions with the 'classics', this section being followed by fifty pages of gem crystal species: here, tourmaline has a section to itself, followed by a survey of beryl and the gem minerals to be found in pegmatites. Gemstones with other rare and important minerals complete this third section.

Part four describes a suite of native elements which include gold, platinum and gold and silver-bearing minerals. Part five covers minerals from especially notable locations, including Africa, Mexico, the major red beryl site in the Wah Wah mountains of Utah and others. The collector gives an outline of his own philosophy of mineral collecting in a concluding chapter.

Once the descriptive part of the book is opened the reader finds magnificent colour pictures on each opening, with some pages accommodating two or even three photographs. All are accompanied by full details of the mineral depicted, notes on the size, mode of occurrence, chemical composition, world ranking where applicable and full crystal morphology. The photographs of gem minerals occupy quite a lot of the book and intending readers should save up to buy it — yes, it is expensive but worth every cent. I have seen no comparable book in thirty years' familiarity with the world's mineralogical literature. M.O'D.

Encyclopaedia of mineral names.

W.H. Blackburn and W.H. Dennen, 1997. Mineralogical Association of Canada, Ottawa. [Mineralogical Association of Canada, special publication no. 1.] pp 360, artwork in black-and-white, hardback. US$40.00. ISBN 0 921294 45 X.

Now that the number of valid mineral species approaches 3800 the appearance of an encyclopaedia is timely. Unlike previous attempts, all more or less good for their time, this one is not overloaded with discredited, trade and fanciful names but is confined only to species accredited by publication in standard mineralogical journals, some of the latest citations being published in 1997. Annual lists of additions are scheduled to be carried in the *Canadian mineralogist*, the first of these to appear in the August 1998 issue (vol. 36 part 4). In this way the monograph can enjoy a continuing usefulness until the number of additions makes a fresh single volume necessary.

Introductory matter introduces the reader to the derivation of words from their roots, which may lie in a variety of languages, not all of them European. A short history and summary of how minerals are named explains the various classifications of minerals used in the past: the Linnean system of groupings was for a time attempted for minerals but never got far because techniques of chemical analysis were insufficiently refined until quite recently.

The species are listed in alphabetical order with each entry carrying name, chemical composition, crystal system and space group – some of these characteristics are queried in the text when ambiguities or options exist. The etymology of the name is given next with transliterations from Arabic, Chinese, Greek, Japanese, Persian or Cyrillic. Species entries for persons (about 45% of those cited) carry brief biographical information and referrals to biographical notes published elsewhere. The source of the original study material is given, when known and when not already included in the etymology. References to major journals are given for all original species descriptions.

The book, with attractive artwork, is very easy on the eye and a careful read-through failed to show up any glaring omissions or inconsistencies. There is a short though useful bibliography and a list of journal abbreviations which is handier than it may seem at first: you can never find the precise title of a journal from abbreviations in papers! The authors and artist (Peter I. Russell) are to be congratulated on a fine and very reasonably priced work which will have considerable relevance for gemmologists.

M.O'D.

A brilliant history: jewels at Sotheby's.

1997. Sotheby's, London. Unpaginated, illus. in colour, softcover.

Presentation of the work of Sotheby's jewellery departments with notes of illustrations from major sales. Short biographies are given and a section on world record prices is arranged by gemstone. This is a beautifully produced celebration booklet which will become a collector's item. M.O'D.

Gold im Herzen Europa: Gewinnung, Bearbeitung, Verwendung. Aufsätze und Katalog.

1996. Bergbau-und Industriemuseum Ostbayern, Kümmersbruck. pp 294, illus. in colour, softcover. DM44 including postage and packing. ISBN 3 925690 33 6. (The Museum is at Schloss Theuern, Portnerstrasse 1, 92245 Kümmersbruck, Germany.)

Although the book includes a catalogue of an exhibition of gold and gold-mining artefacts in place at the Bergbau- und Industriemuseum Ostbayern during 1996, the catalogue itself occupies only a relatively small portion of the complete text, being placed at the back of the book, the remainder of which gives an authoritative account, current and historical, of gold and gold mining in Bavaria and in a few neighbouring areas. Since many gemmologists are also interested in precious metals, their recovery and application, the book should arouse considerable interest. A number of authors contribute chapters on the history of Bavarian gold deposits, on similar deposits in Bohemia, on gold in history and art, on Celtic money found in the Oberpfalz and considerably more. The catalogue describes and illustrates gold objects, mining implements and pages from books, with a high quality of reproduction overall (dimensions are given where appropriate). The chapters have their own lists of references which in some cases are extensive: black-and-white photographs scattered among the non-catalogue portion of the text illustrate the diverse uses of gold and some of the working methods of former times. M.O'D.

Mineralien Fundstellen in der Tchechischen und Slowakischen Republik.

P. Pauliš and R. Haake, 1997. Bode Verlag, Haltern. [Oerter Pütt 28, D-45721 Haltern, Germany.] pp 96, illus. in colour, softcover. DM22.80 (including post and packing). ISBN 3 925094 51 2.

Mineral locations in the Czech and Slovakian Republics are described. On maps of the two countries locations are marked, carrying numbers which refer to an accompanying list which then provides the reader with a page number. An odd arrangement but bearing language difficulties in mind one which works fairly well in so small a book. A more serious desideratum is the absence of a species index, so that the searcher for 'edelopal' would have to know the local name for the deposit or (as I did) read right through the text in the hope of finding something.

Precious opal from the Dubnik deposit, now in Slovakia, is described on page 86: a brief sketch of the deposit is given with a brief description of its geology, mineralogy and history. This is the deposit sometimes shown as Cervenica on specimen labels and little work appears to be going on at present.

Many other important mineral sites are described and despite the small size and the lack of a species index, this is a welcome book and includes a good current bibliography.

M.O'D.

The bead jewellery book.

S. TOMALIN, 1997. David & Charles, Newton Abbot. pp 128, illus. in colour, hardcover. £16.99. ISBN 0 7153 0465 8.

With excellent photographs by Maggie Campbell Pedersen and at so reasonable a price this book would make a good present for almost anyone, let alone the many professional bead craft workers and the increasing number who make their own jewellery at home. The point made by the book is that you can in fact do this, and notes on materials and techniques accompany descriptions of classic jewellery forms. This reviewer, all of whose fingers are thumbs, might manage one or two of the very simplest designs but if greater skills were called for, this would be the first book to consult. It would be hard to beat. M.O'D.

The necklace from antiquity to the present.

A. TRIOSSI AND D. MASCETTI, 1997. Thames and Hudson, London. pp 224, illus. in colour, hardcover. £32.00. ISBN 0 599 01767 0.

The authors jointly have previously added lustre to the literature of jewellery history with *Earrings* (1990) and *Bulgari* (1996). Their account of the development, manufacture, style, use and significance of the necklace is a well-produced tribute to one of the oldest and most adaptable pieces of ornament. You can do anything you want with a necklace – make it yourself, give it any magical or medical properties that seem appropriate at any one time, put any stones you want into it, change them (with or without telling anyone) and upgrade them when more money is at hand. Necklaces are easily made to echo styles of dress and with no assistance from any other ornament, tell those who look at them when they were made and why a particular style was chosen.

To cover this great range of topics means that considerable selection has had to be exercised and the book succeeds in keeping a balance between ages, methods of manufacture, styles and gemstones. While the jewellery historian will welcome the conjunction of so many necklace examples, the gemmologist will also learn something about why particular stones are well-suited to this form of display: the general reader, coming across a book so reasonably priced, will dip into it and decide to buy it.

The material is arranged chronologically, thus placing the necklaces of antiquity first and present-day ones last. This survey is completed in five chapters, which are followed by a discussion of necklace types and clasps, a glossary and a bibliography. Working drawings accompany some of the photographs – they always add to the picture – and descriptions include provenance where appropriate as well as details of style, metal and gemstones. M.O'D.

Die Mineralien und Fundstellen von Schweden.

H.-J. WILKE, 1997. Christian Weise Verlag, München. pp 200, illus. in colour, hardcover. DM80.00 (including postage). ISBN 3 921656 41 9.

Though specimens of gem quality are absent from the mineralogy of Sweden, many gemmologists are mineral collectors too and for more than one reason this book deserves a note. Four chemical elements derive their names from Ytterby, near Stockholm, and the Långban area is one of the world's most productive of individual species. Furthermore, this is the only book I have seen in which the first pages of text link location with individual map sheets of the country's geological survey. This feature, together with a particularly extensive bibliography, provides an outstanding example of how such mineralogy should be arranged. The sites, arranged in four geographical sections, are fully described and each has its own sketch-map. Collectors of rare minerals will be particularly interested in this excellent survey in which many species are beautifully illustrated in colour.

M.O'D.

Zillertal.

Das Tal der Gründe und Kristalle, 1997. pp 100, illus. in colour, softcover. DM48.92 (including postage). ISBN 3 921656 40 0. [*extraLapis* no 12.]

The latest monographic supplement to the German journal *Lapis* (costed outside the journal subscription) deals with an area of considerable interest to gemmologists and mineral collectors. While the Zillertal in the Austrian Alps provides ornamental and sometimes gem-quality dark-red garnet which is often faceted, there are also fine sceptre crystals of rock crystal and amethyst, euhedral crystals of amethyst, citrine and smoky quartz, epidote, green grossular, orange hessonite, green diopside, green titanite (sphene), colourless moonstone and green tourmaline. Chapters deal with the major mines and collecting areas, their mineralogy and geology, with gold and with the finding of garnet and its ornamental use. There are attractive reproductions of early maps and panoramas and sections have their own lists of references, though these are short and there is no general bibliography. As always with this series, the printing, photography and general layout is beyond reproach. Readers are warned that at the time of writing five issues out of the first eleven are already out of print: reprinting may not always be an option and the second-hand market should be contacted before these magnificent surveys of species and areas become unavailable. So far emerald, rock crystal, fluorite, tourmaline, opal and garnet have been published, among others aimed at ore mineral collectors but not without significance to the gemmologist. M.O'D.

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

OBITUARY

Mr John B. Taylor, FGA (D. 1979), Brisbane, Queensland, Australia, died on 22 June 1997.

Mr Philip G. Wyer, FGA, DGA (FGA 1964, DGA 1965), Edgbaston, Birmingham, died on 3 November 1997.

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Argyle Diamonds, West Perth, WA, Australia, for the videos *The brilliant light of Australia* and *The diamond pipe line.*

Mr John R. Führbach, Amarillo, Texas, USA, for 8 cut peridots.

Miss Frances Garrett, Crawley, West Sussex, for a cellulose bracelet and a sphere of quartz.

Mrs Sonia Glaser, Galle, Sri Lanka, for 194 rough and cut stones.

Mr Robert Hsu, Taipei, Taiwan, for a financial donation.

Mr David Pratt, Bradford, West Yorkshire, for 7 pieces of ivory and 26 assorted cut stones.

L.M. Van Moppes & Son Ltd, London, for 50 boart diamonds.

NEWS OF FELLOWS

At the invitation of Dr Frank Placido of the Physics Department, Paisley University, **Alan Hodgkinson** set up the *Hodgkinson method of visual optics* to demonstrate a series of hands-on experiments at a two-week open campus for secondary school pupils interested in working for a degree in physics. Demonstrations included the measurement of refraction, birefringence, dispersion and the use of a thermal probe and Hanneman Diamond Eye for the distinction of diamonds. Alan Hodgkinson has also been invited to lecture on *Visual optics* at Rhode Island University, New York State. The University has incorporated the Hodgkinson Method in its Physics Department gemmology course as standard syllabus for the last three years.

In addition to his involvement on the courses mentioned above, **Alan Hodgkinson** has had a very busy lecture programme including presentations to the National Trust for Scotland and the East Kilbride Historical Society in autumn 1997, to the American Gem Society at Anaheim, California, and, together with **Richard Hughes, E. Alan Jobbins, Stephen Kennedy** and **Colin Winter,** at the American Gemological Assocation Symposium held at the Tucson Gem Show.

Michael O'Donoghue, Lecturer in Gemmology at London Guildhall University since 1967, has been appointed Lecturer in charge of all gemmological work at the University.

Peter Read gave a talk on the identification of synthetic gem-quality diamonds and the new diamond simulant, synthetic moissanite, to the Wessex branch of the National Association of Goldsmiths on 28 January 1998. He concluded his talk with an illustrated review of his development work on the Brewster-angle meter. A prototype meter was then used by NAG members to identify a selection of gemstones.

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MEMBERS' MEETINGS

Trips and Tours

A field trip to Whitby, Yorkshire, was held over the weekend 6 to 8 March. As well as hunting for jet on the beaches, visits to a workshop and a local museum were arranged. A report of the trip will be published in the June issue of *Gem and Jewellery News*.

London

On 14 January 1998 at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8SU, Clare Lawrence gave an illustrated talk entitled *Chinese snuff bottles: the use of stone in Chinese art*.

On 18 February at the Gem Tutorial Centre, Brian Jackson, Chairman of the Scottish Branch of the GAGTL, gave a talk on collecting gemstones in Scotland.

On 18 March at the Gem Tutorial Centre, Dr Jack Ogden, Chief Executive of the National Association of Goldsmiths and Secretary General of CIBJO, gave a talk entitled *Fired with enthusiasm: the early history of enamel*.

Midlands Branch

On 30 January 1998 at the Discovery Centre, 77 Vyse Street, Birmingham, a Bring and Buy Sale and Practical Gemmology Quiz were held.

On 27 February at the Discovery Centre, Michael Houghton of Phoenix Far East Pearls Ltd gave a talk on Chinese and Japanese pearls.

On 22 March, Professor R.A. Howie, President of the GAGTL, gave a lecture on gemstones, illustrated by slides and specimens.

On 27 March at the Discovery Centre a talk was given by Dr Jack Ogden.

North West Branch

On 18 March at Church House, Hanover Street, Liverpool 1, David J. Callaghan gave an illustrated talk entitled *The beauty of opal*.

Scottish Branch

On 25 January 1998, members joined the East of Scotland Jewellers Association at their Burns' Supper in the Witchery Restaurant, Secret Garden, Edinburgh.

On 22 February in the Geology Department of the National Museums of Scotland, Edinburgh, Clive Burch and John Harris ran a practical day entitled *Photographing gemstones and their inclusions*.

GEM DIAMOND EXAMINATIONS

In January 1998, 43 candidates sat the Gem Diamond Examination worldwide of whom 35 qualified, 5 with Distinction. The names of the successful candidates are listed below:

Qualified with Distinction

Ao Yan, Beijing, P.R. China
Hu Chin-Ching, Taipei, Taiwan, R.O. China
Li Jian, Beijing, P.R. China
Liu Ay Hwa, Taipei, Taiwan, R.O. China
Liu Jian, Beijing, P.R. China

Qualified

Balzan, Cortney G., San Francisco, Calif., USA
Chan Kwong Chi, Hong Kong
Chen Lili, Wuhan, Hubei, P.R. China
Gandhi, Amar A.A., Stanmore, Middlesex
Gao Bin, Wuhan, Hubei, P.R. China
Huang Yichun, Beijing, P.R. China
Huang Yizhi, Wuhan, Hubei, P.R. China
Iannicelli, Marco, Salerno, Italy
Kabangi, Nsapu, Leyton, London
Karim, Zapherali, Leicester
Kemp, Margaret A., Backwell, Somerset
Li Hongjun, Wuhan, Hubei, P.R. China
Li Li, Beijing, P.R. China
Li Li, Wuhan, Hubei, P.R. China
Lu Xin, Wuhan, Hubei, P.R. China
Lu Yung Ching, Taipei, Taiwan, R.O. China
Lüle, Çigdem, Ankara, Turkey
Marolla, Marianna, Athens, Greece
Mitchell, Susannah, Newton by Tattenhall, Cheshire
Panagopoulou, Anastasia, Athens, Greece
Qu Li, Beijing, P.R. China
Renard-Richard, Joelle M., Ruislip, Middlesex
Seligman, Dominic, Southfields, London
Slater, Richard M., Radstock, Bath, Avon
Sun Jingyu, Wuhan, Hubei, P.R. China
Tang Yun Hing, Frances, Hong Kong
Webster, Paul T., Greenford, Middlesex
Wong Ti Yin, Heather, Hong Kong
Yang Hong, Beijing, P.R. China
Zhu Ling, Wuhan, Hubei, P.R. China

FORTHCOMING EVENTS

22 April	**London.** Pearls – a Fashion Opportunity. Christianne Douglas.
24 April	**Midlands Branch.** AGM followed by A Mosaic of Gemmological Tessera.
26 April	**Midlands Branch.** Diploma pre-examination seminar.
3 May	**Midlands Branch.** Preliminary pre-examination seminar.
8–10 May	**Scottish Branch.** Annual Conference and AGM, Peebles. Speakers will include Gail Levine and Howard Rubin from America.
13 May	**London.** The Gemstone Collections of the GAGTL. Dr Roger Harding.
20 May	**North West Branch.** Time-bomb or fun? Brian Dunn.
29–31 May	**Gem trip to Scotland.** The weekend will include a field trip to the Campsie Fells, a visit to the National Museums of Scotland and a lecture on the gemstones of Scotland by Brian Jackson.
29 June	**London.** AGM (GAGTL members only) followed by the Reunion of Members and a Bring and Buy Sale.
8 July	**London.** The Evolution of Georgian and Victorian Jewellery. John Benjamin.
16 September	**North West Branch.** Gem collection with anecdotes. John Pyke, Snr.
3 October	**Trade Dinner.** To be held at the Café Royal, Regent Street, London. Guest speaker: Geoffrey C. Munn.
21 October	**North West Branch.** Silversmith of Williamsburg 1780. Martin Connard.
1 November	**Annual Conference.** Gems in Jewellery. To be held in the Barbican Centre, London.
18 November	**North West Branch.** Annual General Meeting.

For further information on the above events contact:

London and Trips:	Mary Burland on 0171 404 3334
Midlands Branch:	Gwyn Green on 0121 445 5359
North West Branch:	Deanna Brady on 0151 648 4266
Scottish Branch:	Joanna Thomson on 01721 722936

GAGTL WEB SITE

For up-to-the-minute information on GAGTL events and workshops visit our web site on www.gagtl.ac.uk/gagtl

EXAMINATIONS IN GEMMOLOGY

In the Examinations in Gemmology, held worldwide in January 1998, 127 candidates sat for the Preliminary Examination of whom 93 qualified. In the Diploma Examination 113 sat, of whom 53 qualfiied, three with Distinction. The names of the successful candidates are as follows:

Diploma

Qualified with Distinction

Liu Huai, Wuhan, Hubei, P.R. China
Park, Chan Won, Taegu, R.O. Korea
Zizi Zheng, Guilin, Guangxi, P.R. China

Qualified

Andaluz Sanchez, Maria, Peckham, London
Anderson, Elizabeth A., Peacehaven, East Sussex
Banks, Michelle, Leicester.
Boccard, Jean-Marie, Geneva, Switzerland
Britton, Andrea L., Woking, Surrey
Chan Sau King, New Territories, Hong Kong
Chen Xiatao, Wuhan, Hubei, P.R. China
Davidge, Elizabeth A., Pimlico, London
Draper, Zoe S., Upper Abbeywood, London
Han Lirong, Wuhan, Hubei, P.R. China
Ho Chuan-Hsiang, Taipei, Taiwan, R.O. China
Holt, Judith A., Darwen, Lancashire
Hsieh Pao Lien, Hong Kong
Htun Han, Yangon, Myanmar
Hu Chin-Ching, Taipei, Taiwan, R.O. China
Iannicelli, Marco, Salerno, Italy
Jacquat, Stephane, Geneva, Switzerland
Ji Tianxi, Shanghai, P.R. China
John, Victoria A., Agar Grove, London
Kiefert, Lore, Basel, Switzerland
Krzemnicki, Michael S., Basel, Switzerland
Liang Weizhang, Guangzhou, P.R. China
Lin, Chief R., Kaohsiung, Taiwan, R.O. China
Lin Yi Hwa, Yangon, Myanmar
Ling Li, Shanghai, P.R. China
Liu Yujun, Wuhan, Hubei, P.R. China
Lodge, Tim, Muswell Hill, London
Millard, Simon R., Corsham, Wiltshire
Mutton, Valerie, Langley, Buckinghamshire
Nazos, Konstantinos I., Athens, Greece
Oo, Thein Lwin, Yangon, Myanmar
Pancratz, Mark, Weybridge, Surrey
Park, Sung Ok, Taegu, R.O. Korea
Qiang Yin, Shanghai, P.R. China
Rommens, Catharina M.C., Eindhoven, The Netherlands
Rowntree, Josephine, Knaresborough, North Yorkshire
Sandar Win, Yangon, Myanmar
Song, Ruohan, Shanghai, P.R. China
Tinnyunt, Emma J., Kensal Green, London
Tong Tao, Guilin, Guangxi, P.R. China
Tupper, Michael I., South Holmwood, Surrey
Wang Chao, Guilin Guangxi, P.R. China
Wang Cun, Wuhan, Hubei, P.R. China
Wang Mingxun, Wuhan, Hubei, P.R. China
Wu Shizhou, Guilin, Guangxi, P.R. China
Xiang Xiaodan, Wuhan, Hubei, P.R. China
Xie Bing, Wuhan, Hubei, P.R. China
Zhang Caixia, Shanghai, P.R. China
Zhao Yanzeng, Guilin, Guangxi, P.R. China
Zheng Kaiwen, Wuhan, Hubei, P.R. China

Preliminary

Aster, Flora, London
Blatherwick, Clare, London
Brown, Vanessa, Sittingbourne, Kent
Browne, Dione, Battersea, London
Chan Kam Wai, Carolyn, Hong Kong
Chen Pai-Rong, Taipei, Taiwan, R.O. China
Cheong-Ly Karine, London
Cho, Chang-Bae, Taejon, R.O. Korea
Cropp, Alastair F.R., Lewes, East Sussex
Curran, Rose, Ealing, London
de Vries, Marius, South Kensington, London
Dun Yee Man, Stella, Chaiwan, Hong Kong
Eggerbratt, Pauline, Sundbyberg, Sweden
Fan Liying, Shanghai, P.R. China
Fris, Arnold, Goedereede, The Netherlands
Fujinara, Motoko, London
Fung Wai Man, Winnie, Shaukeiwan, Hong Kong
Garrett, Frances S.J., Crawley, West Sussex
Grech, Carrieann, Richmond, Surrey
Greenfield, Dawn M., Eynsford, Kent
Gudmundson, Inger M., Lannavaara, Sweden
Gwati, Martha, Harare, Zimbabwe
Han Xiao, Guilin, Guangxi, P.R. China
Harrison, Tarn J., Leamington Spa, Warwickshire
Henry-Stogdon, Sarah A., Sutton Common, Surrey
Hong, Angela Swee Leng, London
Hunter, Pauline A., Caversfield, Oxfordshire
Ikebe, Emi, London
Ip Kit Ling, New Territories, Hong Kong
Jain, Reena, Jaipur, India
Kang, Sung-Oong, Taegu, R.O. Korea
Kassas, Demetrios, Larissa, Greece
Kellerson, Laurent P., London
Kerkhof, Peter A.M., Eindhoven, The Netherlands
Koh, Hock Heng, Singapore
Konstandopoulou, Garoufallia, London
Lai Hoi Shan, Kowloon, Hong Kong
Lanz, Ernst, Veytaux, Switzerland

Lee Chun Man, Hong Kong
Lee Kwan Sui Ying, Yeline, Kowloon, Hong Kong
Lee Siu Ying Kwan, Fanny, Hong Kong
Li Yat Choi, Kowloon, Hong Kong
Liu Pei-Chin, Taipei, Taiwan, R.O. China
Loe Shue Mon, Taipei, Taiwan, R.O. China
Long Chu, Guilin, Guangxi, P.R. China
Lüle, Çigdem, Ankara, Turkey
McFarlin, Michael, Amarillo, Texas, USA
Mafara, Ezekiel M., Harare, Zimbabwe
Martin, Edward, St. Ouen, Jersey, Channel Islands
Maung Aung Min, Yangon, Myanmar
Myo Thaw Lin, Yangon, Myanmar
Nang Latt Latt Htun, Yangon, Myanmar
Notaro, Tina M., Kandy, Sri Lanka
O'Byrne, Rose-Marie, Bicester, Oxfordshire
Okamoto, Chizuko, London
Ono, Shiho, London
Pang Chi Keung, Shatin, Hong Kong
Panoutsopoulou, Dolomidou G., Athens, Greece
Paphitis, Constantinos, Bayswater, London
Park, Chan Won, Taegu, R.O. Korea
Parker, Sarah J., East Dulwich, London
Patel, Nita, Newbury, Berkshire
Pavlou, Tasos, Nicosia, Cyprus
Pedersen, Gunnar, Lannavaara, Sweden
Qiang Yin, Shanghai, P.R. China
Rambukkange, Timothy P., Kandy, Sri Lanka
Roberts, Justin J., Wembley, Middlesex
Said, Mohammad Ali, Lannavaara, Sweden
Savla, Rajvee B., Bangalore, India
Schmocker, Karin, Fribourg, Switzerland
Shin, Hyun-Sook, Daejon, R.O. Korea
Smith, Peggy E.J., Rochester, Kent
Smith, Wayne M., Harrogate, Yorkshire
Soe Moe Naing, Yangon, Myanmar
Srithai, Boontarika, London
Su Cho Win, Yangon, Myanmar
Suda, Junko, London
Sun Pinghong, Shanghai, P.R. China
Sung, Jae-Bum, Daejon, R.O. Korea
Suwichakornpong, Sirima, Kensington, London
Tang Suk Yee, New Territories, Hong Kong
Tang Tiande, Wuhan, Hubei, P.R. China
Tharn Htite, Yangon, Myanmar
Thompson, Ian, Wood Green, London
To Man Fang, Hong Kong
Tsakanika, Christina, Athens, Greece
Tulo, Karen, London
Van Spaendonck, Anouk D., The Hague, The Netherlands
Vasilevskaya, Polina, San Francisco, Calif., USA
Wang Ming-chi, Taipei, Taiwan, R.O. China
Yin Sheng Shen, Shanghai, P.R. China
Zagana, Aphrodite, Athens, Greece
Zhou Wen Hao, Guilin, Guangxi, P.R. China

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held at 27 Greville Street, London EC1N 8SU, on 28 January 1998 the business transacted included the election of the following:

Diamond Membership and Fellowship (FGA/DGA)

Patel, Pankaj, Sudbury Hill, Middx. 1991,1992
Taylor, Roger, Birmingham, Warwicks. 1986, 1994

Fellowship (FGA)

Campbell, Robert Desmond, Wallington, Sutton, Surrey. 1995
Kan Wing Lok, Singapore. 1995
Karandikar, Surendra Narayan, Maharashtra, India. 1997
Kei, Oo Oo Tracy, Hong Kong. 1996
Lau Joyce Pao Ching, Hong Kong. 1997
Lee Yow Hon, Hong Kong. 1997
Pani, Tõnu, Tartu, Estonia. 1996
Pethiyagoda, Upali, Manama, Bahrain. 1978
Winiski, Ken, Vancouver, BC, Canada. 1995

Ordinary Membership

Asanuma, Yukiko, Kyoto City, Kyoto, Japan
Atarashi, Yoshie, Osaka City, Osaka, Japan
Blatherwick, Clare, London
Castoro, Loretta, New York, N.Y., USA
Finlay, Louden B., London
Gupta, Ashwani Kumar, Windsor, Berkshire
Hasegawa, Takako, Toyonaka City, Osaka, Japan
Hashiguchi, Naoko, Sendai City, Kagoshima Pref., Japan
Higashi, Moritomi, Yao City, Osaka, Japan
Higo, Chizuyo, Uda-gun, Nara Pref., Japan
Hoshino, Tomiko, Amagasaki City, Hyogo Pref., Japan
Ikeda, Yumi, Osaka City, Osaka, Japan
Inoue, Kazuko, Tokyo, Japan
Ishibashi, Shigeru, Kishiwada City, Osaka, Japan
Jinsenji, Osamu, Toda City, Saitama Pref., Japan
Kawahara, Miki, Enuma-gun, Ishikawa Pref., Japan
Kishikawa, Toshio, Osaka City, Osaka, Japan
Koukou, Katerina, Athens, Greece
Kubota, Mie, Higashi-Chikuma-gun, Nagano Pref., Japan
Lallerstedt, Anna, Barnes, London
Momosaki, Nobuko, Hirakata City, Osaka, Japan
Morris, David John, Stoke, Plymouth, Devon
Muratsu, Hirotoshi, Neyagawa City, Osaka, Japan
Nemoto, Kyoko, Kyou-Tanabe City, Kyoto, Japan
Nichol, Douglas, Wrexham, North Wales
Nilsson, Paul Graham, Auckland, New Zealand
Nishimura, Yoko, Nabari City, Mie Pref., Japan
Nishioka, Kimie, Osaka City, Osaka, Japan
Okamoto, Mayumi, Higashi-Osaka City, Osaka, Japan
Onohara, Miwa, Kobe City, Hyogo, Japan
Oya, Kenichi, Niigata City, Niigata Pref., Japan
Plant, Monika, Altrincham, Cheshire
Sakai, Junko, Otsu City, Shiga Pref., Japan
Sanui, Atsuko, Kawanishi City, Hyogo Pref., Japan
Smith, Christopher, Lucerne, Switzerland
Takayama, Rie, Kyoto City, Kyoto, Japan
Tanimura, Hiromi, Osaka City, Osaka, Japan
Taylor, Duncan Lawrence, Stowting, Near Ashford, Kent
Thoresen, Lisbet, Santa Monica, Calif., USA
Tsutsumi, Masao, Higashi-Hiroshima City, Hiroshima Pref., Japan
Yamamoto, Hiroka, Osaka City, Osaka, Japan
Yanagisawa, Nobuko, Ibaraki City, Osaka, Japan
Yawata, Keiko, Ayase City, Kanagawa Pref., Japan

Laboratory Membership

Guy Steel Jewellers, London W1Y 0B2
Rennie & Co. Ltd, London EC1N 8SU

At a meeting of the Council of Management held at 27 Greville Street, London EC1N 8SU, on 25 February 1998 the business transacted included the election of the following:

Fellowship (FGA)

Kjendlie, Ole-Richard, Larvik, Norway. 1997
McCarthy, Kieran Martin, London. 1997
Van der Molen, Wouter Nicolaas, Zwolle, The Netherlands. 1996

Ordinary Membership

Bell-Burrow, Briony, London
de Vries, Marius Leonardus, South Kensington, London
Dube, Nokuthula, Cambridge, Cambs
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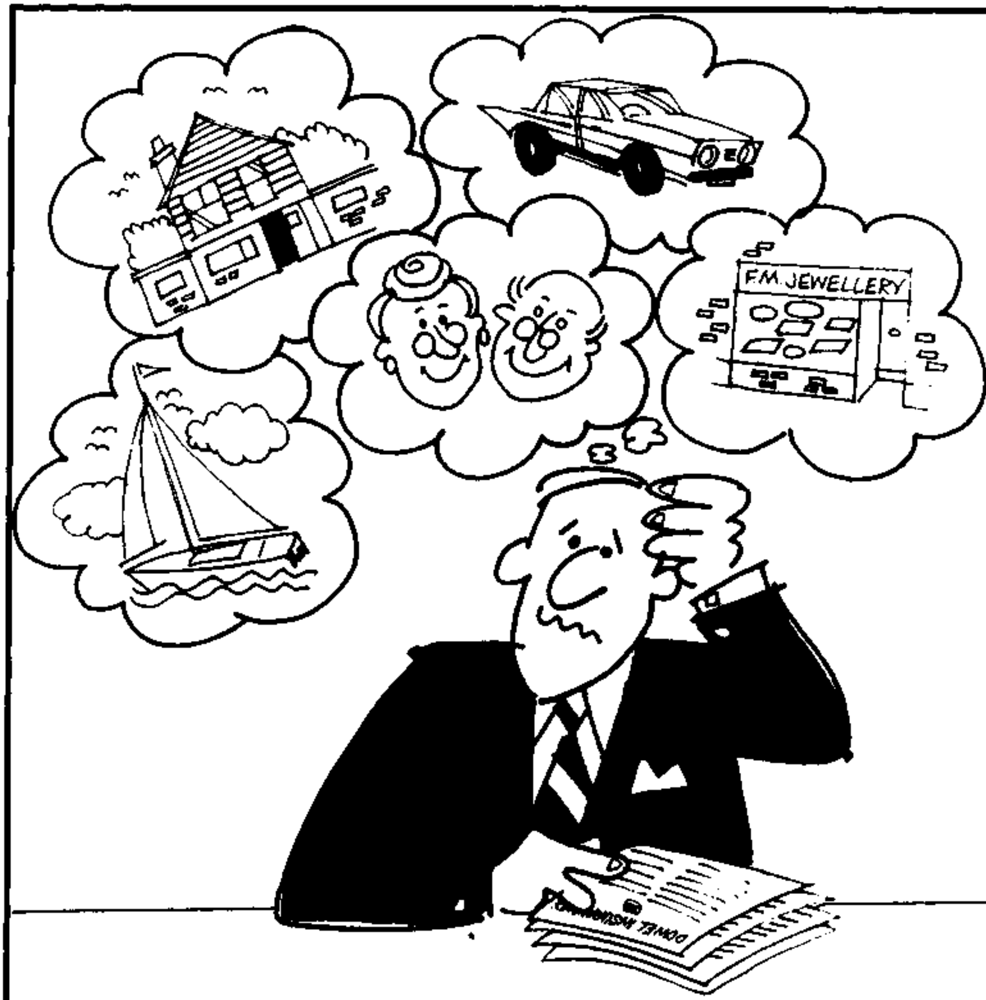
Transfers from Ordinary Membership to Fellowship (FGA)

Roper, Bebs, Rokeby, Tasmania, Australia, 1997

CORRIGENDA

On p.48 above, first column, second line, for 'Single-chain silicates' read 'Double-chain silicates'

On the back cover of Vol. 26 (1), under Contents, fifth item, for 'Colour in tapazes ...' read Colour in topazes ...'


F.M. JEWELLERY

Guide to the preparation of typescripts for publication in *The Journal of Gemmology*

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in *The Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Typescripts Two copies of all papers should be submitted on A4 paper (or USA equivalent) to the Editor. Typescripts should be double spaced with margins of at least 25 mm. They should be set out in the manner of recent issues of *The Journal* and in conformity with the information set out below. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

The abstract, references, notes, captions and tables should be typed double spaced on separate sheets.

On matters of style and rendering, please consult *The Oxford dictionary for writers and editors* (Oxford University Press, 1981).

Title page The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses.

Abstract A short abstract of 50-100 words is required.

Key Words Up to six key words indicating the subject matter of the article should be supplied.

Headings In all headings only the first letter and proper names are capitalized.

A **This is a first level heading**

First level headings are in bold and are flush left on a separate line. The first text line following is flush left.

B *This is a second level heading*

Second level headings are in italics and are flush left on a separate line. The first text line following is flush left.

Illustrations Either transparencies or photographs of good quality can be submitted for both coloured and black-and-white illustrations. It is recommended that authors retain copies of all illustrations because of the risk of loss or damage either during the printing process or in transit.

Diagrams must be of a professional quality and prepared in dense black ink on a good quality surface. Original illustrations will not be returned unless specifically requested.

All illustrations (maps, diagrams and pictures) are numbered consecutively with Arabic numerals and labelled Figure 1, Figure 2, etc. All illustrations are referred to as 'Figures'.

Tables Must be typed double spaced, using few horizontal rules and no vertical rules. They are numbered consecutively with Roman numerals (Table IV, etc.). Titles should be concise, but as independently informative as possible. The approximate position of the Table in the text should be marked in the margin of the typescript.

Notes and References Authors may choose one of two systems:

(1) The Harvard system in which authors' names (no initials) and dates (and specific pages, only in the case of quotations) are given in the main body of the text, e.g. (Gübelin and Koivula, 1986, 29). References are listed alphabetically at the end of the paper under the heading References.

(2) The system in which superscript numbers are inserted in the text (e.g. ... to which Gübelin refers.[3]) and referred to in numerical order at the end of the paper under the heading Notes. Informational notes must be restricted to the minimum; usually the material can be incorporated in the text. If absolutely necessary both systems may be used.

References in both systems should be set out as follows, with *double spacing* for all lines.

Papers Hurwit, K., 1991. Gem Trade Lab notes. *Gems & Gemology*, 27, 2, 110–11

Books Hughes, R.W., 1990. *Corundum*. Butterworth-Heinemann, London. p. 162

Abbreviations for titles of periodicals are those sanctioned by the *World List of scientific periodicals* 4th edn. The place of publication should always be given when books are referred to.

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The Journal of Gemmology

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Cover Picture

Ladies' bracelet

A magnificent 105.57 ct peridot from Myanmar set with 35.45 ct and 35.74 ct citrines from Brazil, on ten strands of black nephrite beads (5.0–5.2 mm diameter) from Wyoming, USA. Bracelet the property of Georgia and Quentin Isaacs, Texas, USA. Photo courtesy of J.R. Führbach (see Peridot from Black Rock Summit lava flow, Nye County, Nevada, USA. p. 86)

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