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

F.L. Sutherland1, D. Schwarz1, E.A. Jobbins1, R.R. Coenraads1 and G. Webb1

1. Geodiversity Research Group, Australian Museum, Sydney, Australia
2. Gübelin Gemmological Laboratory, Lucerne, Switzerland
3. Caterham, Surrey, U.K.

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 Ga2O3 contents <0.01 wt% and Cr2O3/Ga2O3 ratios above 3. The ‘basaltic’ suites show higher Ga2O3 (up to 0.04 wt%) and Cr2O3/Ga2O3 ratios below 1. The absorption spectra of blue ‘metamorphic’ sapphires are dominated by Fe3+ bands in the ultraviolet (375, 387 nm) and visible region (450, 460, 469 nm). A broad Fe3+ – Ti4+ charge transfer band lies between 550–750 nm, without significant Fe2+ – Fe3+ 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
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 Gubelin 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.
Distinctive gem corundum suites from discrete basalt fields

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 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 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.](image)

![Figure 7: Corundums from Gloucester Tops, Barrington volcano, showing surface corrosion features and range in colours. Photomicrograph by G. Webb, X15.](image)
features and range in colours. Note intergrowths of sapphire and spinel and fusion crusts on some corundums. 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.

Like Barrington blue crystals, they fall into two groups of colours.

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

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.

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.
Distinctive gem corundum suites from discrete basalt fields

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:

<table>
<thead>
<tr>
<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>Detection limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe₂O₃</td>
<td>&lt;0.5</td>
<td>0.5-1.0</td>
<td>&gt;1.0</td>
</tr>
<tr>
<td>TiO₂</td>
<td>&lt;0.01</td>
<td>0.01-0.03</td>
<td>&gt;0.03</td>
</tr>
<tr>
<td>Cr₂O₃</td>
<td>&lt;0.01</td>
<td>0.01-0.03</td>
<td>&gt;0.03</td>
</tr>
<tr>
<td>V₂O₅</td>
<td>&lt;0.01</td>
<td>0.01-0.03</td>
<td>&gt;0.03</td>
</tr>
</tbody>
</table>

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-visible-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.

<table>
<thead>
<tr>
<th>Wt%</th>
<th>Barrington corundum range</th>
<th>Typical Australian 'basaltic' sapphires</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour</td>
<td>'metamorphic'</td>
<td>'basaltic' (Fe,Ti rich)</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.02-0.05¹</td>
<td>0.0-0.5 (0.14)²</td>
</tr>
<tr>
<td>V₂O₅</td>
<td>&lt;0.01</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Cr₂O₃</td>
<td>0.01-0.04</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.6-1.0</td>
<td>0.7-1.8</td>
</tr>
<tr>
<td>Ga₂O₃</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Samples</td>
<td>CORBAR 3,1,2,5,6</td>
<td>3,4,10,15,16,17,18,20</td>
</tr>
<tr>
<td>Spectral</td>
<td>'Fe(+Cr)'</td>
<td>'Cr(+Fe)'</td>
</tr>
<tr>
<td>type⁴</td>
<td>'metamorphic'</td>
<td>'basaltic'</td>
</tr>
<tr>
<td></td>
<td>'Cr+Fe'</td>
<td>'basaltic'</td>
</tr>
<tr>
<td></td>
<td>blue, green, yellow, parti-coloured</td>
<td></td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Wt%</th>
<th>West Pailin</th>
<th>East Pailin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>'metamorphic'</td>
<td>'basaltic'</td>
</tr>
<tr>
<td></td>
<td>Blue</td>
<td>'basaltic'</td>
</tr>
<tr>
<td>TiO₂</td>
<td>~0.1</td>
<td>0.01-0.02</td>
</tr>
<tr>
<td>V₂O₅</td>
<td>~0.01</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Cr₂O₃</td>
<td>~0.04</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>~1</td>
<td>0.3-0.8</td>
</tr>
<tr>
<td>Ga₂O₃</td>
<td>&lt;0.01</td>
<td>0.02-0.04</td>
</tr>
<tr>
<td>Samples</td>
<td>CORCAM 2,4-10,12,13,15</td>
<td>1,11,14 3</td>
</tr>
<tr>
<td></td>
<td>Jobbins 3-2,3-4,3-9</td>
<td>Jobbins 5 3-1</td>
</tr>
<tr>
<td>Spectral type</td>
<td>'metamorphic'</td>
<td>'basaltic'</td>
</tr>
<tr>
<td></td>
<td>'basaltic'</td>
<td>'basaltic'</td>
</tr>
</tbody>
</table>

*see text for details

J. Gemm., 1998, 26, 2, 65-85
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$_2$O$_3$/Ga$_2$O$_3$ vs Fe$_2$O$_3$/TiO$_2$; Barrington ‘metamorphic’ type (▲); Barrington ‘basaltic’ type (●), East Australian ‘basaltic’ type (□); Barrington high ‘Fe, Ti type’ (■). (b) Cr$_2$O$_3$/Ga$_2$O$_3$ vs Fe$_2$O$_3$/TiO$_2$; West Pailin ‘metamorphic’ type (▲); West Pailin ‘basaltic’ type (●); West Pailin high ‘Fe, Ti type’ (■); East Pailin ‘basaltic’ type (□). (c) TiO$_2$/Ga$_2$O$_3$ vs Fe$_2$O$_3$/Cr$_2$O$_3$; Barrington and other East Australian corundums. Symbols as in Figure 11a. (d) TiO$_2$/Ga$_2$O$_3$ vs Fe$_2$O$_3$/Cr$_2$O$_3$; 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 IIIIB 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$_2$O$_3$ (<0.01 wt%) and by high Cr$_2$O$_3$/Ga$_2$O$_3$ ratios (mostly between 10 and 100). The ‘basaltic’ type sapphires show higher Ga$_2$O$_3$ (0.015–0.040 wt%) with Cr$_2$O$_3$/Ga$_2$O$_3$ 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$_2$O$_3$, reaching up to about 2% Fe$_2$O$_3$ in a Fe/Ti-rich ‘basaltic’ type corundum from Barrington. Most ‘metamorphic’ Barrington corundums lie between 0.4 and 1.2% Fe$_2$O$_3$. The ‘basaltic’ corundums from the Anakie and New England fields range from 0.7 to 1.8% Fe$_2$O$_3$. 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$_2$O$_3$.

In ‘metamorphic’ Pailin corundums, however, values reach up to 1% Fe$_2$O$_3$. An Fe/Ti-rich ‘basaltic’ type sapphire from West Pailin contains about 2% Fe$_2$O$_3$.

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$_2$O$_3$. On the other hand, typical Fe-concentrations in ‘basaltic’ corundums from East Australia (Barrington, Inverell, Anakie) exceed 1% Fe$_2$O$_3$. Less than 10% of the 161 corundums examined here fall into the overlap ‘corridor’ between 0.6 and 1.0% Fe$_2$O$_3$. 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 0.1 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 III).

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% Ga₂O₃), whereas Ga concentrations for the 'metamorphic' corundums are low (<0.01% Ga₂O₃; 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% Cr₂O₃). 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% Cr₂O₃. Intensely coloured crystals may contain more; the highest analysed content of 0.75% Cr₂O₃ was found in a Pailin ruby. The highest Cr-content found in a Barrington ruby in this study was 0.4% Cr₂O₃, although 1.4 wt% Cr₂O₃ 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% V₂O₅), but rarely about 0.1-0.2% V₂O₅ is attained. In the 'metamorphic' corundums, the range of content is wider and reaches 0.01% V₂O₅ for Pailin and 0.04% V₂O₅ 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 (Cr₂O₃/Ga₂O₃) vs (Fe₂O₃/TiO₂) and are an excellent tool to distinguish two gem corundum suites in these basaltic fields. The metamorphic corundum field characterised by high Cr₂O₃/Ga₂O₃ ratios (mostly between 10 and 100) is clearly separate from the basaltic corundum field for which Cr₂O₃/Ga₂O₃ 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 Fe₂O₃/TiO₂ 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 TiO₂/Ga₂O₃ vs Fe₂O₃/Cr₂O₃ diagrams (Figures 11c, d) also clearly separate 'metamorphic' and 'basaltic' corundum suites. The Fe₂O₃/Cr₂O₃ 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 TiO₂/Ga₂O₃ 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% Fe₂O₃ and 0.1-0.2% TiO₂), beyond the Fe₂O₃/Cr₂O₃ 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 II A: Representative analyses of corundums and some primary inclusions from West Pailin.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Corundum (pink)</th>
<th>Corundum (blue)</th>
<th>Pleonaste spinel</th>
<th>Sapphirine (11.13.5)</th>
<th>Fassiate pyroxene</th>
<th>Hercynite spinel</th>
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<tbody>
<tr>
<td>Type</td>
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<td>'basaltic'</td>
<td>'metamorphic'</td>
<td>'metamorphic'</td>
<td>'metamorphic'</td>
<td>'basaltic'</td>
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<td>-</td>
<td>0.02</td>
<td>13.81</td>
<td>48.86</td>
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<tr>
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<td>0.01</td>
<td>0.04</td>
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<td>Al₂O₃</td>
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<tr>
<td>FeO₉₀</td>
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<td>10.68</td>
<td>3.44</td>
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<tr>
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<tr>
<td>Na₂O</td>
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<td>-</td>
<td>0.02</td>
<td>1.54</td>
<td>-</td>
</tr>
<tr>
<td>K₂O</td>
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<td>0.02</td>
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<td>98.99</td>
<td>100.54</td>
<td>100.21</td>
<td>99.07</td>
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<td>Samples</td>
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<td>Job 3.4</td>
<td>Job 4.3</td>
<td>Job 4.3</td>
<td>Job 3.3</td>
<td>Job 3.10</td>
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</table>

FeO₉₀ = total iron oxides expressed as FeO

### Table II B: Representative analyses of reaction, exsolution and alteration minerals in corundums from West Pailin.

<table>
<thead>
<tr>
<th>Oxide</th>
<th>Reaction spinel 1</th>
<th>Reaction spinel 2</th>
<th>Reaction spinel 3</th>
<th>Exsolution spinel 4</th>
<th>Alteration Fe hydroxide</th>
<th>Alteration chlorite</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Wt%</td>
<td>Wt%</td>
<td>Wt%</td>
<td>Wt%</td>
<td>Wt%</td>
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</tr>
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<td>SiO₂</td>
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<tr>
<td>TiO₂</td>
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<td>FeO₉₀</td>
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<tr>
<td>MnO</td>
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<td>K₂O</td>
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<td>Job 3.4</td>
<td>Job 1.1</td>
<td>Job 1.1</td>
<td>Job 2.1</td>
</tr>
</tbody>
</table>

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(Al₂O₃ + Fe₂O₃) : 5SiO₂ mole % composition and approaches the 7 : 9 : 3 composition of sapphire 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, 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 12:** Mole % MgO+FeO, Al₂O₃+Fe₂O₃, SiO₂ 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 sapphires (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.
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% Fe₂O₃; 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 Fe³⁺;
- sharp bands in the visible region at 450, 460 and 469 nm, due to dispersed Fe³⁺;
- broad bands with absorption maxima between 550 and 600 nm (ordinary ray spectrum) and between 680 and 750 nm (extraordinary ray spectrum), related to Fe²⁺-Ti⁴⁺ intervalence charge-transfer processes (IVCT). Fe²⁺-Ti⁴⁺ 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 Fe²⁺-Fe³⁺ 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 Fe²⁺-Ti⁴⁺ absorption (Figure 14e).

The absorption spectra of blue sapphires from the ‘metamorphic’ suites in West Pailin and Barrington are dominated by Fe²⁺-Ti⁴⁺ bands in the ultraviolet (375, 387 nm) and visible region (450, 460, 469 nm), and by a broad Fe²⁺-Ti⁴⁺ charge-transfer between ca. 550 and 750 nm (Figure 15a). There is no significant Fe²⁺-Fe³⁺ 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, 1992b; 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 coefficient Kd for Mg and Fe in the sapphirine (sa)/spinel (sp) pair. The formulation is

\[ T (\degree C) = [800 + (228 \ln K_d)] - 273 \]

where

\[ K_d = \frac{X_{sp Fe}}{X_{sp Mg}} = \frac{X_{sp M}}{X_{sp F}}, \]

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 (Fe²⁺-Fe³⁺-Fe²⁺) and 943°C (Fe²⁺-Fe³⁺-Fe³⁺) 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 Fe²⁺-Ti⁴⁺ and Fe²⁺-Fe³⁺ 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 corundum ranges into higher Ga contents (up to 0.04 wt % Ga₂O₃) and lower Cr₂O₃/Ga₂O₃ (always <1) and their chemical and favourable melting of mantle source-rocks (Guo et al., 1996). These ‘basaltic’ type corundums show lower Fe and Ti dominated absorption spectra (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 widespread ‘basaltic’ corundums has generated several models. Most involve plutonic crystallization from a melt, although widespread 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 amphibolitized 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. (1996, 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 (Boissard, 1997; 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, uranopyrochlore; 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-sapphire-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 sapphire was recorded in Bo Rai ruby by Koivula and Fryer (1997) 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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The late A.W. Chubb of Gloucester, New South Wales, provided material from the Barrington-Gloucester Tops area. R.E. Pogson, G. Avern, B.J. Barron, S. Folwell and R. Springthorpe, Australian Museum, assisted in preparation of mineral data and the script. The Australian Museum Trust supplied funds through the Geodiversity Research Group. P. Kennewell, Cluff Resources, Sydney, provided lapidary assistance. C. Nockolds, University of Sydney, arranged New South Wales Department of Mineral Industry of New South Wales, provided material from sources below these basaltic fields.

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John R. Führbach, B.Sc., FGA, CG
Amarillo, Texas, USA

ABSTRACT: An extinct volcano’s alkali 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.

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
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
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; J. Geom., 1998, 26, 2, 86-102).
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.

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:

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

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.
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...
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$_2$SiO$_4$ to fayalite, Fe$_2$SiO$_4$. The general formula is (Mg,Fe)$_2$SiO$_4$. 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.
Therefore, in the large phenocrysts, one mineral becomes progressively richer in iron and 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 $\alpha$, $\beta$ and $\gamma$ 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 1 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.

### 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

| Table 1: Gemmological properties and chemical compositions of three representative samples of Black Rock Summit lava flow peridot. |
|---|---|---|---|
| Properties and elements | BRP#1 | BRP#2 | BRP#3 |
| RI $\alpha$ | 1.6595 | 1.658 | 1.656 |
| $\beta$ | 1.6725 | 1.676 | 1.676 |
| $\gamma$ | 1.6930 | 1.694 | 1.696 |
| SG | n.d. | 3.351 | 3.388 |
| Wt. % | | | |
| SiO$_2$ | 40.55 | 40.05 | 37.90 |
| Al$_2$O$_3$ | 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$_2$O$_3$ | n.d. | n.d. | 0.034 |
| ZnO | n.d. | n.d. | 0.008 |
| Total | 100.03 | 99.92 | 99.992 |

*Chemical analysis performed by M. Coller, Department of Geology, Indiana University. (From Vitaliano and Harvey, 1965.)

*Electron microprobe analysis by David E. Lang, Harvard University.

*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.

### 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.
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 1). 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 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.

![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.](image)

**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.

**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).
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 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.

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 Pryer, 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.

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<th>SG</th>
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<tr>
<td>Sri Lanka</td>
<td>1.651</td>
<td>1.660</td>
<td>1.690</td>
<td>0.039</td>
<td>B+</td>
</tr>
<tr>
<td>Synthetic</td>
<td>1.65</td>
<td>1.68</td>
<td>0.03</td>
<td>B</td>
<td>3.30</td>
</tr>
<tr>
<td>Tanzania-Kenya (border)</td>
<td>1.650</td>
<td>1.658</td>
<td>1.684</td>
<td>0.034</td>
<td>B+</td>
</tr>
<tr>
<td>Unknown (cat's-eye)</td>
<td>No data available</td>
<td></td>
<td></td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>Vietnam</td>
<td>1.650</td>
<td>1.666</td>
<td>1.688</td>
<td>0.038</td>
<td>B+</td>
</tr>
<tr>
<td>Zarbargad</td>
<td>1.652</td>
<td>1.668</td>
<td>1.690</td>
<td>0.035</td>
<td>B-</td>
</tr>
</tbody>
</table>

Notes:
- OC Optical character
- B Biaxial positive or negative
- P 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 Koivula, 1986
- 12 Stockton, Manson, 1983
- 13 Wilson, Hendy, Taylor, 1974
- 14 Führbach, 1995
- 15 Larson, Thompson, 1994
- 16 Naess, 1994
- 17 Thompson, 1994
- 18 Sinukkas, Koivula, Becker, 1992
- 19 Koivula, Fryer, 1986
- 20 Koivula, Kammerling and Fritsch, 1993

Peridot from the Black Rock Summit lava flow, Nye County, Nevada, USA
were found by X-ray diffraction to be pyrrhotite \((\text{Fe}_{1-x}\text{S})\) where \(x\) is between 0.0 and 0.2. Other similar-appearing spheres, but non-magnetic, were found to be pentlandite \((\text{Fe},\text{Ni})_2\text{S}_8\). Note the variation in colour between the two peridots photographed.

*Paint-brush strokes: dark orange-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.

**Acknowledgements**

The author would like to thank Dr Cornelius Hurlbut, Professor of Mineralogy Emeritus, Department of Earth and Planetary Science, Harvard University. He is co-author with Robert Kammerling of the book *Gemmology*.

John I. Koivula and Dr Edward J. Gübelin furnished photographs of inclusions, and David E. Lang, Harvard University, the electron microprobe analysis. Djon Doughter is thanked for the spectroscopy, EDXRF analysis, and infrared spectrometry, and Maja DeMaggio for the photographs of the faceted gems and crystal in matrix. Special thanks to Patricia Robertson-Führbach for her companionship and tireless collecting of specimens and especially Chris Führbach for his countless hours of removing specimen material from the lava by hammer and chisel.

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Peridot from the Black Rock Summit lava flow, Nye County, Nevada, USA
Rubies and pink sapphires from the Pamir Mountain Range in Tajikistan, former USSR

Christopher P. Smith
Managing Director, Special Projects, Gübelin AG, Lucerne, Switzerland

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

<table>
<thead>
<tr>
<th>Property</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual appearance</td>
<td>Highly transparent with richly saturated hues ranging from purplish-pink to purplish-red</td>
</tr>
<tr>
<td>Refractive index</td>
<td>Ne = 1.761–1.762</td>
</tr>
<tr>
<td></td>
<td>No = 1.770</td>
</tr>
<tr>
<td>Birefringence</td>
<td>0.008–0.009</td>
</tr>
<tr>
<td>Optic character</td>
<td>Uniaxial negative</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>3.99–4.02</td>
</tr>
<tr>
<td>Pleochroism</td>
<td>Moderate to strong dichroism; pinkish/reddish-orange to red-orange parallel to the c-axis</td>
</tr>
<tr>
<td></td>
<td>Purple-pink to purple-red perpendicular to the c-axis</td>
</tr>
<tr>
<td>UV luminescence</td>
<td>Long-wave (365 nm): strong to very strong, slightly orangy-red to red</td>
</tr>
<tr>
<td></td>
<td>Short-wave (254 nm): very weak to medium red</td>
</tr>
<tr>
<td>Visible absorption spectrum</td>
<td>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</td>
</tr>
<tr>
<td>Internal features</td>
<td>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</td>
</tr>
</tbody>
</table>
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 (1011) crystal faces and dominant c.o (14 14 28 3) or v (4481) crystal faces, and (b) Habits composed of subordinate basal pinacoid c (0001) and positive rhombohedral r (1011) crystal faces, with dominant dipyramidal z (2241) crystal faces.

Rubies and pink sapphires from the Pamir Mountain Range in Tajikistan, former USSR.
The internal growth characteristics were classified using a specially designed stoneholder 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 Lambda 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 28 3) or υ (4481) and positive rhombohedral r (1011) crystal faces. A dipyramidal crystal habit composed of subordinate c (0001) and r (1011), with dominant ω (14 14 28 3) or υ (4481) 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 (1011), with dominant dipyramidal ω (14 14 28 3) or υ (4481) 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 (1011) 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...
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

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, 40x.

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, 30x.

Absorption spectra

The spectra of the rubies and pink sapphires from the Pamir mountains are dominated by Cr³⁺ absorption, with broad bands centred at approximately 405 and 550 nm, and weak to moderate sharp bands at approximately 468, 475, 476, 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).
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

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

<table>
<thead>
<tr>
<th>Oxide</th>
<th>0.30 ct</th>
<th>0.38 ct</th>
<th>0.44 ct</th>
<th>0.56 ct</th>
<th>0.80 ct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al₂O₃</td>
<td>99.5</td>
<td>99.3</td>
<td>99.4</td>
<td>99.5</td>
<td>99.6</td>
</tr>
<tr>
<td>Cr₂O₃</td>
<td>0.224</td>
<td>0.516</td>
<td>0.498</td>
<td>0.286</td>
<td>0.185</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.156</td>
<td>0.047</td>
<td>0.017</td>
<td>0.091</td>
<td>0.068</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.018</td>
<td>0.011</td>
<td>0.006</td>
<td>0.007</td>
<td>0.004</td>
</tr>
<tr>
<td>V₂O₅</td>
<td>0.024</td>
<td>0.015</td>
<td>0.025</td>
<td>0.025</td>
<td>0.016</td>
</tr>
<tr>
<td>Ga₂O₃</td>
<td>0.012</td>
<td>0.014</td>
<td>0.013</td>
<td>0.012</td>
<td>0.010</td>
</tr>
</tbody>
</table>

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

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.

Discussion

The Pamir mountains which extend along the southern perimeter of Tajikistan, in the former Soviet Union, are probably most well...
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 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.

Acknowledgements

The author wishes to express his appreciation to Nicole Surdez, Gübelin Gemmological Laboratory, Lucerne, Switzerland, and Professor W.B. Stern, Institute of Mineralogy and Petrography, University of Basel, Switzerland, for providing semi-quantitative chemical analysis; Dr Suzanne Schmidt, Institute of Mineralogy and Petrography, University of Basel, and Dr H.-D. von Schultz, SUVA, Lucerne, Switzerland, for performing scanning electron microscope analysis; also Ivan M. Polarevski, president of Bulgaria Gems, Sofia, Bulgaria, for providing the samples and useful information. All photographs are by the author unless otherwise noted.

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Gemstone deposits of the former Soviet Union

Ernst M. Spiridonov
Geology Department, Moscow State University, Moscow, Russia

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 Tютчев 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 ...'

[TTranls. M.O'D]

Nature is neither blind nor spiritless as you implied but includes freedom and love: nor is it without soul or feeling.' [Tranls. 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 Batobinskaya [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
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.
Gemstone deposits of the former Soviet Union

...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 clinopyroxene.

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...
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

GLOSSARY OF SOME GEOLOGICAL TERMS USED IN THIS REVIEW

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anorthosite</td>
<td>Rock composed mainly of plagioclase feldspar</td>
</tr>
<tr>
<td>Boudin</td>
<td>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</td>
</tr>
<tr>
<td>Breccia</td>
<td>Rock composed of angular fragments mixed with finer material</td>
</tr>
<tr>
<td>Facies</td>
<td>Group term for a range of rocks formed under a specified range of chemical, pressure, temperature or other physical conditions</td>
</tr>
<tr>
<td>Granitoid</td>
<td>Rock with granitic character but not necessarily a granite in the strict sense</td>
</tr>
<tr>
<td>Hydromica</td>
<td>Mineral with a structure like mica but altered to accommodate more OH groups or water molecules</td>
</tr>
<tr>
<td>Jadeite</td>
<td>Petrologists’ term for rock consisting largely of jadeite the mineral</td>
</tr>
<tr>
<td>Karst</td>
<td>Countryside formed on limestone which has suffered solution by groundwater to form caves and underground drainage</td>
</tr>
<tr>
<td>Leucogranite</td>
<td>Granite consisting mainly of light-coloured minerals</td>
</tr>
<tr>
<td>Meta</td>
<td>Abbreviation for metamorphosed</td>
</tr>
<tr>
<td>Metasomatism</td>
<td>Process of alteration by action on rocks of fluids from an external source</td>
</tr>
<tr>
<td>Metasomatite</td>
<td>Rock formed as a result of metasomatic processes</td>
</tr>
<tr>
<td>Miarolitic</td>
<td>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</td>
</tr>
<tr>
<td>Protolith</td>
<td>Rock which is subsequently altered in some way – for example, by metamorphism or metasomatism</td>
</tr>
<tr>
<td>Septaria</td>
<td>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</td>
</tr>
<tr>
<td>Supergene</td>
<td>Adjective describing processes involving water percolating downwards from the earth’s surface; involves solution, reaction and deposition of minerals</td>
</tr>
<tr>
<td>Ultrabasite</td>
<td>Ultrabasic rock, one generally low in silica content, lower than basic rocks such as most basalts</td>
</tr>
</tbody>
</table>
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 Zapadnokievskoe 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 leuconorite 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 leuconorite 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.

**Beryl – heliodor, aquamarine, morganite.** Miarolitic pegmatites of the central Urals and in particular the Murzinskoe [18], Alabaschko [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-Ady 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

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Gemstone deposits of the former Soviet Union

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*Figure 3: Verdelite crystals from a granitic pegmatite in the Pamirs. Long dimension of the image is 9 cm. Photo by M.A. Bogomolov.*
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-tsilaisite composition. Fine rubellite, verdelite, indicolite and polychrome tourmalines are distributed in the miarolitic pegmatites in the centre of Transbaikalia in the Borschovchyn [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 × 0.5 × 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 × 2 × 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].

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.
Post-magmatic high-temperature metasomatites of alkaline magmatites - fentites

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 northeastern Transbaikalia. In this contact zone, fluids replaced the limestone and quartz sandstone. Charoite is a layered silicate with separate segregations up to 50 cm in size and occurs in patches in coarse-grained 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.

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.

Chrome diopside

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-Ial 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-Ial 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 haüyne 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 Sludyanskoie [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 northeast 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$_6$Ca$_2$Al$_5$Si$_6$O$_{24}$(SO$_4$)$_{1.95}$C$_{0.45}$(CO$_3$)$_{0.15}$Cl$_{0.1}$L 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...
The metasomatite is accompanied by phenakite and Be margarite were formed. Carbonate rock was infiltrated, zwitter-glimmerite containing Li-Cs phlogopite, chrome-magnetite (e.g. serpentinite, talc-carbonate rock) was infiltrated, zwitter-glimmerite containing Li-Cs phlogopite, 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 Kazakhstan. 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. serpentine, 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

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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 Fe³⁺ 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-granodiorite 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 Adyu [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.

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.
Jet also occurs in lignite and soft coal deposits in low-grade zeolite metasedimentary bodies. Occurrences are at Beschuevskoe [53] in the Crimea, Tkvarchely [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 Altai (Kolyvan [60] and others). They are also found in central Asia and Kazakhstan.

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 crosscut 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 chromitite are filled by carbonates, uvarovite, chrome-chlorite, quartz and pumpellyite with chrome titanite, rutile, diaspor and 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 sphen 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.](image)

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
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 plagioclases hosted in meta-ultrabasites.

Experiments indicate that at a high CO\textsubscript{2} fugacity spinel breaks down according to the reaction MgAl\textsubscript{2}O\textsubscript{4} + CO\textsubscript{2} \rightarrow Al\textsubscript{2}O\textsubscript{3} + MgCO\textsubscript{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\textsubscript{3}\textsuperscript{2-} and S\textsuperscript{2-}.

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.

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.
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 serpentinitized 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 boulders of jadeitite are found within Alpine basite-ultrabasite massifs in the zones of deep faults. Large deposits are at Itmuryndy [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 a plagiogranoid 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], northern Kazakhstan, occurs as small grains averaging approximately 30 μm in size (microdiamonds). Some crystals are cubeshaped. 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 Mednorudyansko deposit reaches an exceptional 450 t.

Diopside, 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 Biriuzaakan [84], in Uzbekistan (Kyzyilkumskoe [85] and Kalmakyrskoe [86]), Armenia (Tekhuteskoe [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 Eabastuz, 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 Sarykoublordo 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 Voznesensko 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.

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### Further Reading


Modern diamond cutting and polishing.

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.

Gem Trade Lab notes.

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.

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

Two cameoos 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 cameoos themselves and the way they were produced closely resemble genuine Roman gems - the materials used, however, showed they to be fakes.

Broken Hill.

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.
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. Lapid. 22(7/8), 1997, 59-79, 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, J.A. POLENOV, V.J. GERNAKOV AND A.V. SAMSONOV. Lapid. 22(7/8), 1997, 44-58, illus. in colour, 2 maps.

Superb crystals of emerald and alexandrite with a marked colour-change are described from Pridorozhnoje in the Russian Polar Urals. Occurring in Alpine clift-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-Malsyshche.
J.V. BURLAKOV, J.A. POLENOV, V.J. GERNAKOV AND A.V. SAMSONOV. Lapid. 22(7/8), 1997, 44-58, illus. in colour, 2 maps.

Yellow-green chrysoberyl is also found. Other minerals of Pakistan, from Madagascar, Nepal, Mozambique, California and Brazil are described and illustrated. M.O'D.

Minerali in vetrina: alcune tormaline della collezione Giazotto [second part].
Tourmaline crystals from pegmatites of the Gilgit area of Pakistan, from Madagascar, Nepal, Mozambique, California and Brazil are described and illustrated. M.O'D.

Rubies and fancy coloured sapphires from Nepal.

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 white tourmaline; distinct colour zoning is common and there are bicolour stones with red and violet-blue zones in thick or wedge-shaped bands; also there are almost colourless haloes surrounded by mineral inclusions.

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

**Gemmological Kurzinformationen.**

**Short gemmological notes.**


The emeralds come from Malipo, 300 km south of Kunming, near the Vietnamese border. The samples occur in mica schists with quartz and feldspar; 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 0.017-0.008, SG 2.68-2.71. Apart from the tourmaline inclusions, fine cracks as well as distinct growth zoning were visible under the microscope.


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.

**Gem news from Tucson 1997.**


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 ‘tourmaline’ inclusions were observed.

An unusual trapezoid 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 tough 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 regular, with the thinner inclusions appearing red, while the thicker inclusions appear black and opaque. Aventurine 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.

**Brazilianische Opale aus Pedro II.**


The Piauí 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, orange, 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.


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 polylaminite (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 Lagerstatten des Urals.


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 Murinsk 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.


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.


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.


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.


Diopside and tremolite are reported and described from rocks of the Grenville geological province, a belt of igneous and metamorphic rocks extending from southeastern 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 Inland, Snowdon Township, Haliburton County, Ontario: constants are given. Both minerals are near to end-member composition.

M.O.D.

Neuer spektakulärer Amethystfund aus SüdNorwegen.


Large well-formed crystals of amethyst are reported from Holmenstrand, 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.


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, 1.584–1.587, n, 1.590–1.594) and a high SG (2.73–2.77). Most stones contain fibrous amphibole, both actinolite and cummingite. Fluid inclusions are not common and are usually present as partially healed fractures. The absorption spectra show broad bands around 450 nm, 670 nm (ordinary ray) and a sharp peak at 833 nm. Chemical analyses show these emeralds have a high Cr content (0.6–1.3 wt%) together with high MgO and Na₂O contents. The above characteristics and the constant properties of Sandawana emeralds are distinctive. J.J.

Growth mechanism of 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.

Structural analysis on flux grown emerald crystals.


Crystals of synthetic emerald grown by a V₂O₅–PbO flux had the composition SiO₂, 66.31, BeO 13.70, Al₂O₃ 19.42, Cr₂O₅ 0.70, V₂O₅ 0.04 = 100.17 giving the formula Al₅.₉₂Cr₀.₀₈Be₀.₃₅Sis.₉₅0.₈; their structure was refined to R1.5% (c 9.203, å 9.172 Â, space group P6₃/mmc, Dₐ = 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 BeO₄ 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 (0,0,0.290) and (0,0,0.290). The centre of these two positions is (0,0,0.14) 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.


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


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 surrounding a growth crystal is numerically simulated, satisfactorily explaining the growth nature.


Two synthetic phenakites and their structure analysis.


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$_2$SiO$_4$, but the coloured one contains 0.3 wt% of V impurities. Both are trigonal, space group P3; 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 (1.499%). 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.

Réflexions sur des techniques lapidaires mogholes.


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

Short information about gemmological science and practice.

V.V. Indutny and L.I. Vishnevskaya. 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 Bouweelen, 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.

Diamants: la synthèse a une histoire.


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

Abstracts - Techniques and Applications
Discover opals.

S. ARACIC, 1996. The Author [P.O. Box 143, Lightning Ridge, NSW 2834, Australia], pp 352, illus. in colour, hardcover. SA100.00. 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 and there are also 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 pseudomorphs after fossils, the first discovery of opal, cut and polished, 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 fields 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, 1985). Aracic's beautifully produced 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.


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.

Encyclopaedia of mineral names.


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.


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.

1990. Bergbau- und Industriemuseum Ostbayern, Königsmünster. pp 294. illus. in colour, hardback. DM44 including postage and packing. ISBN 3 925690 33 6. (The Museum is at Schloss Thurnen, Portnerstrasse 1, 92245 Königsmünster, 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.


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 disaderatum is the absence of a species index, so that the searcher for ‘edelstal’
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.


With excellent photographs by Maggie Campbell Pedersen and at a reasonable 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.


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 confluence 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.


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 Lingan 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.


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 hassonite, 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.
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.

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 Association 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.

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 pipeline.

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.

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 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 collecting gemstones in Scotland.

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 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

Baizan, 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, Nasapu, 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
Li Xin, Wuhan, Hubei, P.R. China
Li Yung Ching, Taipei, Taiwan, R.O. China
Liule, Cigdem, Ankara, Turkey
Marolla, Marianne, 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

Qualified

Balzan, Cortney G., San Francisco, Calif., USA
Chan Kwong Chi, Hong Kong
Chen Lili, Wuhan, Hubei, PR. China
Gandhi, Amar A.A., Stanmore, Middlesex
Gao Bin, Wuhan, Hubei, PR. China
Huang Yichun, Beijing, PR. China
Huang Yizhi, Wuhan, Hubei, PR. China
Iannicelli, Marco, Salerno, Italy
Kabangi, Nasapu, Leyton, London
Karim, Zapherali, Leicester
Kemp, Margaret A., Backwell, Somerset
Li Hongjun, Wuhan, Hubei, PR. China
Li Li, Beijing, PR. China
Li Li, Wuhan, Hubei, PR. China
Li Xin, Wuhan, Hubei, PR. China
Li Yung Ching, Taipei, Taiwan, RO. China
Liule, Cigdem, Ankara, Turkey
Marolla, Marianne, Athens, Greece
Mitchell, Susannah, Newton by Tattenhall, Cheshire
Panagopoulou, Anastasia, Athens, Greece
Qu Li, Beijing, PR. China
Renard-Richard, Joelle M., Ruislip, Middlesex
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Sun Jingyu, Wuhan, Hubei, PR. China
Tang Yun Hing, Frances, Hong Kong
Webster, Paul T., Greenford, Middlesex
Wong Ti Yin, Heather, Hong Kong
Yang Hong, Beijing, PR. China
Zhu Ling, Wuhan, Hubei, PR. China
FORTHCOMING EVENTS

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.
3 October  Trade Dinner. To be held at the Café Royal, Regent Street, London. Guest speaker: Geoffrey C. Munn.
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 GEMMOLGY

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 qualified, 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 Xiaotao, Wuhan, Hubei, P.R. China
- Davidge, Elizabeth A., Pimlico, London
- Draper, Zoe S., Upper Abbeywood, London
- Fan Liying, Shanghai, P.R. China
- Ho Chuan-Hsiang, Taipei, Taiwan, R.O. China
- Holt, Judith A., Darwen, Lancashire
- Hsieh Pao Lien, Hong Kong
- Hu Chuan-Hsiang, Taipei, Taiwan, R.O. China
- Ho, Judith A., Darwen, Lancashire
- Htun Han, Yangon, Myanmar
- Hsu Chin-Ching, Taipei, Taiwan, R.O. China
- Iannicelli, Marco, Salerno, Italy
- Jacquart, Stephane, Geneva, Switzerland
- Ji Tianxi, Shanghai, P.R. China
- 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 Yun, Shanghai, P.R. China
- Rammens, Catharina M.C., Lindhoven, The Netherlands
- Rowntree, Josephine, Knaresborough, North Yorkshire
- Sandar Win, Yangon, Myanmar
- Song, Ruohan, Shanghai, P.R. China
- Tinnuyun, Emma J., Kensal Green, London
- Tong Tsoi, Guilin, Guangxi, P.R. China
- Tupper, Michael L., 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
- Blathertwick, Clare, London
- Brown, Vanessa, Sittingbourne, Kent
- Browne, Diane, Battersea, London
- Chan Kam Wai, Carolyn, Hong Kong
- Chen Pai-Rong, Taipei, Taiwan, R.O. China
- Cheong-Ly Karine, London
- Cho, Chung-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
- Eggerbatt, Pauline, Sundbyberg, Sweden
- Fan Liying, Shanghai, P.R. China
- Fris, Arnold, Goedereede, The Netherlands
- Fujin, Motoko, London
- Fung Wai Man, Winnie, Shaukeiwan, Hong Kong
- Garrett, Frances S.J., Crawley, West Sussex
- Grech, Carriean, Richmond, Surrey
- Greenfield, Dawn M., Eynsford, Kent
- Guimondson, Inger M., Lamnavaara, 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 Swie 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., Eindhoven, The Netherlands
- Koh, Hock Heng, Singapore
- Konstandopoulos, Garoufalia, London
- Lai Hoi Shan, Kowloon, Hong Kong
- Lanz, Ernst, Veytaux, Switzerland

J. Gemm., 1998, 26, 2, 135-141
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- Diploma Theory Review: 1 June
- Four-day Diploma Workshop: 1-4 June
- Two-day Diploma Practical Workshop: 6-7 June
- Weekend Diamond Grading Revision: 6-7 June

For further details contact the GAGTL Education Department
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Loe Shue Mon, Taipei, Taiwan, R.O. China
Long Chu, Guilin, Guangxi, P.R. China
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Maung Aung Min, Yangon, Myanmar
Myo Thaw Lin, Yangon, Myanmar
Nang Latt Latt Htun, Yangon, Myanmar
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Okamoto, Chizuko, London
Ono, Shiho, London
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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, Mohammmad 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
Soo Moe Naing, Yangon, Myanmar
Srihthai, Boonarika, 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
Tsalanika, Christina, Athens, Greece
Tulo, Karen, London
Van Spaendonck, Anouk D., The Hague, The Netherlands
Vasilevskaya, Polina, San Francisco, Calif., USA
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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 25
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, Tooru, 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
Blatterwick, Clare, London
Castoro, Loretta, New York, N.Y., USA
Finlay, Louden B., London
Gupta, Ashwani Kumar, Windsor, Berkshire
Hasegawa, Takako, Toyama City, Osaka, Japan
Hashiguchi, Naoko, Sendai City, Kagoshima Pref.,
Japan
Higashi, Moritomi, Yao City, Osaka, Japan
Higo, Chizuyo, Ueda-gun, Nagano 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, Yoshi, 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
Murats, Hiroto, Naka City, Osaka, Japan
Nemoto, Ko, Yoku-Tanabe City, Kyoto, Japan
Nichol, Douglas, Wrexham, North Wales
Nilsson, Paul Graham, Auckland, New Zealand
Nishimura, Yoko, Nara City, MicPref., 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, Osaka City, Sija Pref., Japan
Sanui, Atsuko, Kawanishi City, Hyogo Pref., Japan
Smith, Christopher, Lucerne, Switzerland
Tanayama, Rie, Kyoto City, Kyoto, Japan
Tanimura, Hiromi, Osaka City, Osaka, Japan
Taylor, Duncan Lawrence, Stowting, Near
Ashford, Kent
Thoresen, Lisbet, Santa Monica, Calif., USA
Tsutsu, Masao, Higashi-Hiroshima City,
Hyogo Pref., Japan
Yamamoto, Hiroko, 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
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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)
Van der Molen, Wouter Nicolaas, Zwolle, The
Netherlands. 1996

Ordinary Membership
Bell-Burrow, Brioni, London
de Vries, Marius Leonardus, South Kensington,
London
Dube, Nokuthula, Cambridge, Cambs
Flynn, Matthew, Amersham, Bucks
Gillary, Adam Jason, Woodley, Reading Berks.
Huddleston, Jonathan David, London
Kendall, David Carl, Addiscombe, Croydon,
Surrey
Kneip, John Richard, London
Massera, Dezith-Baka, Stratford, London
Michael, Marius, Stockwell, London

J. Gemm., 1998, 26, 2, 135–141
Morrison, Maxine, Cold Ash, Berks.
Okutu, Yula, London
O'Neill, Vince, Dorchester, Dorset
Orsak, Jane, Wassenaar, The Netherlands
Patel, Purnima, Kintbury, Berks.
Pinter, Max, London
Roth, Joan Martin, London
Taylor, C. Russell, Gorseinon, Wales
Téte, Nair Cristina, London
Van Dievoet, Daniel, Antwerp, Belgium
Yuka, Fujiwara, London

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 ...

ADVERTISING IN THE JOURNAL OF GEMMOLOGY

The Editors of the Journal invite advertisements from gemstone and mineral dealers, publishers and others with interests in the gemmological, mineralogical, lapidary and jewellery fields.

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Contents

Distinctive gem corundum suites from discrete 65
basalt fields: a comparative study of
Barrington, Australia, and West Pailin,
Cambodia, gemfields
F.L. Sutherland, D. Schwarz, E.A. Jobbins,
R.R. Coenraads and G. Webb

Peridot from the Black Rock Summit lava flow, 86
Nye County, Nevada, USA
J.R. Führbach

Rubies and pink sapphires from the Pamir 103
Mountain Range in Tajikistan, former USSR
C.P. Smith

Gemstone deposits of the former Soviet Union 111
E.M. Spiridonov

Abstracts 126

Book Reviews 132

Proceedings of the Gemmological Association and 135
Gem Testing Laboratory of Great Britain and
Notices

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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