Sphene, Sri Lanka's newest gemstone

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Three cut sphenes, originating from the Tissamaharama area in Sri Lanka, are described. Their properties are compared with those of gem quality sphenes from Capelinha, Brazil. There is hardly any difference between the chemical data of the major elements and physical properties of the specimens of these two sources. Even the inclusions are very similar. It is the first time that fine gem quality sphene has been reported from Sri Lanka.

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Introduction

During a recent visit to Sri Lanka the authors bought three cut sphenes from the well-known gem dealer Mr Faust A. Saheed in Colombo. According to him they originate from the Tissamaharama area in the southern part of the island and they are the first sphenes of good gem quality found in Sri Lanka. Gem mining has started very recently in this area and a good production may be expected based on the results of the exploration during the last years (see Fig. 1).

Although sphene is a very common accessory mineral in many rock types, due to its large stability field (Ribbe, 1980), material of gem quality is known from a few localities only, the most important being Brazil, California, and the Alps. The sphenes from the Austrian Alps being of better quality than

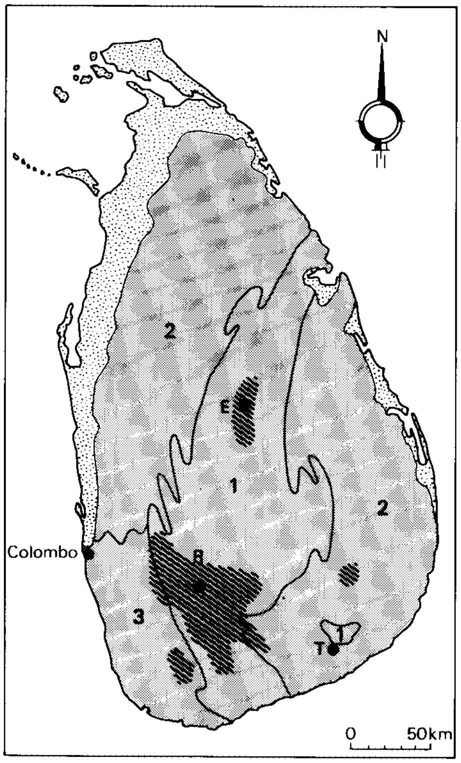

Fig. 1. Geological sketchmap of Sri Lanka with main gem producing areas.
1: Highland Group
2: Vijayan Complex
3: Southwestern Group

E: Elahera
R: Ratnapura
T: Tissamaharama

▨ Precambrian rocks
░ Cenozoic sediments
▧ gem mining areas

those from Switzerland, as far as the suitability for cutting is concerned. Those from Brazil are mainly from Capelinha in Minas Gerais, while the sphenes from Conquista in Bahia are less well-known. Sphenes from Baja California (Mexico) are of good gem quality, but they are only scarcely met with.

The first announcement of sphene, suitable for cutting, from Sri Lanka is therefore of considerable interest. According to the above mentioned gem dealer, the production of the Tissamaharama area will not be restricted to these three stones alone. More material will come on the market in due course.

The stones to be described here, are stored in the collection of the Rijksmuseum van Geologie en Mineralogie, Leiden. They are registered with numbers prefixed with RGM. Preliminary investigations have been carried out on the Sri Lanka sphenes and on stones from Brazil for comparison.

For the measurement of the refractive indices use was made of a refractometer provided with a cubic zirconia prism and a scale recalculated by one of the authors (Zwaan). Due to the high figures for sphene only α could be observed.

The chemical data on the major elements in combination with density measurements offered the possibility to calculate the mean refractive index of the sphenes using the Gladstone - Dale relationship (Mandarino, 1976, 1979).

Specific gravity measurements were carried out by means of a hydrostatic balance using both ethylene dibromide and alcohol as immersion liquids and coils of silver wire to hold the specimens. The data obtained are the average of replicate measurements.

The X-ray investigation was carried out by means of powder photographs, using Fe-radiation and a Debye - Scherrer camera with a diameter of 114.6 mm. In the case of cut stones, use was made of the so-called 'sphere' method of Hiemstra (1956).

Electron microprobe analyses on four sphenes were performed at the electron microprobe laboratory of the Instituut voor Aardwetenschappen, Vrije Universiteit, Amsterdam, with financial and personnel support by ZWO - WACOM (Research Group for Analytical Chemistry of Minerals and Rocks subsidized by the Netherlands Organization for the Advancement of Pure Research).

Although the name *titanite* has been officially accepted by IMA's Commission on New Minerals and Mineral Names in 1966, the authors have used the name *sphene* because it is preferably used by gemmologists.

A number of investigations have been dedicated to the crystal structure and geochemistry of sphene from different geological deposits, e.g. Sahama (1946), Zabavnikova (1957), Černy & Sanseverino (1972), Higgins & Ribbe (1976), and Ribbe (1980), but from the gemmological point of view not very much has been published on this mineral.

Cassedanne & Cassedanne (1971, 1974) reported on sphene of gem quality from Campo do Boa, Capelinha municipality, Minas Gerais State in Brazil. In these papers crystallographic properties are given besides density data, details about accompanying minerals and a comparison with other sphene deposits in the world. As far as the authors are aware the only available chemical data of sphene from Capelinha have been published by Higgins & Ribbe (1976, table 1).

The aim of this paper is first to draw the attention to the discovery of a new gem quality mineral in Sri Lanka and further to compare the properties of these stones with those of sphenes from Capelinha in Brazil.

Acknowledgements

The authors are much indebted to Dr P. Maaskant of ZWO-WACOM for the electron microprobe analyses and to Mrs R. C. Litjens who carried out the density measurements. They also highly appreciated the critical considerations of Dr R. P. Kuijper regarding the measurements of the properties.

Properties

Available for investigation were three cut stones from Sri Lanka (see Fig. 2), and seven cut and one rough stone from Brazil. Four of the cut sphenes from Brazil are not in the collection of the museum but were kindly loaned for investigation by the Netherlands Gem Laboratory (NEL), which is housed in the museum.

RGM 151 854 is a brownish yellow oval cut stone, weighing 4.94 carats. Its size is 11.8 × 9.5 × 6.1 mm, the specific gravity 3.5354 ± 0.0008.

RGM 151 855 is mixed cut and has a honey-brown colour. Its weight is 6.48 carats, its size 11.7 × 11.7 × 6.8 mm and its density 3.538.

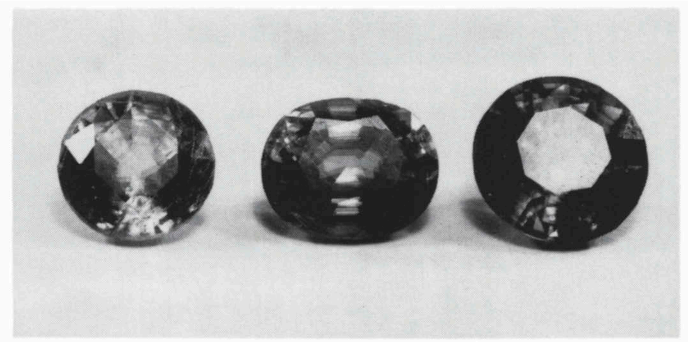

Fig. 2. The three cut sphenes from the Tissamaharama area, Sri Lanka; from left to right: RGM 151 856, RGM 151 854 and RGM 151 855, all × 2.

RGM 151 856 is yellowish green, mixed cut and weighs 4.60 carats. The size of the stone is 10.3 × 10.3 × 6.4 mm, its specific gravity 3.5276 ± 0.0008.

Apart from these three Sri Lanka stones three Brazilian cut sphenes are in the museum collection.

RGM 151 800 is a brownish yellow oval stone, weighing 3.15 carats. Its size is 9.8 × 7.6 × 5.1 mm, and the density is 3.527.

RGM 151 801 is yellowish brown and emerald cut. It weighs 4.61 carats and is 10.8 × 7.6 × 5.3 mm. The density is 3.533 ± 0.001.

RGM 151 858 is yellow-green, it is brilliant cut and has a weight of 2.15 carats. The size is 8.2 × 8.2 × 4.9 mm, the density is 3.529.

The remaining stones, available for investigation, have similar colours with weights between 2.17 and 9.96 carats. The one weighing 2.17 carats, NEL-S2, has a greenish colour and has been analyzed together with three museum stones.

In Table 1 the results of electron microprobe analyses of five sphenes are given. Two of them are from Sri Lanka, the three others from Brazil. The latter, belonging to a sphene from Malacacheta not far away from Capelinha, is in the collection of the analyst Dr P. Maaskant.

Standards used were olivine (Mg, Fe, Ni), gehlenite (Al), diopside (Si, Ca), ilmenite (Ti, Mn), spinel (V, Cr, Zn), and V_2O_3 (V). For Si and Ca reference standards were gehlenite, åkermanite and andradite. The Ca- and Si-values are corrected after both diopside, gehlenite and åkermanite, the average values are taken. Differences obtained with the different standards are about 0.5%. If present, the contents of Na, Mg, Ni, and Zn are less than 0.01%. Analyses on three different spots per stone did not reveal significant differences in major and minor element contents of the sphenes. The results of the major element analyses compare well with those in the literature (e.g. Deer et al., 1962; Higgins & Ribbe, 1976).

The general chemical formula of pure sphene is Ca TiO $[SiO_4]$, but in nature all sphenes show a variable range of isomorphic replacements. These diadochic substitutions are isovalent or heterovalent. An example of the latter, most common among natural sphenes, are the coupled substitutions of $(Fe, Al)^{3+} + (F,OH)^{-} \leftrightarrows Ti^{4+} + O^{2-}$ (Higgins & Ribbe, 1976). Other important substitutions are rare earth elements and alkalis for Ca. From the above it follows that the general formula of natural sphene should be expressed as follows (Zabavnikova, 1957):

Table 1. Results of electron microprobe analyses and unit cell contents of two sphenes from Sri Lanka and three from Brazil.

	RGM 151 854 Sri Lanka	RGM 151 856 Sri Lanka	RGM 151 801 Brazil	NEL-S2 Brazil	VUA Brazil
CaO	28.4	28.7	28.7	28.7	28.6
MnO	0.07	0.04	0.04	0.03	0.04
TiO_2	38.4	38.6	38.5	38.3	38.2
Al_2O_3	1.25	1.11	1.00	1.12	1.37
Fe_2O_3	0.70	0.60	0.66	0.84	0.41
V_2O_3	—	—	0.10	0.16	—
Cr_2O_3	0.015	—	0.045	0.025	0.015
SiO_2	30.4	30.4	30.4	30.4	30.4
totals	99.2	99.5	99.4	99.6	99.0
	Unit cell contents on the basis of 19 O				
Ca	3.80 } 3.81	3.84	3.73	3.84	3.84
Mn	0.01	—	—	—	—
Ti	3.61	3.62	3.64	3.59	3.60
Al	0.18 } 3.86	0.17 } 3.85	0.15 } 3.86	0.17 } 3.85	0.20 } 3.84
Fe	0.07	0.06	0.06	0.08	0.04
V	—	—	0.01	0.01	—
Cr	—	—	—	—	—
Si	3.80	3.79	3.82	3.79	3.81
totals	11.47	11.48	11.41	11.48	11.49

(Ca,X)(Ti,Y) $[SiO_4]$ (O,Z),

where: X = rare earth elements, Na, K, Mn, Sr, (Ba, Pb)
Y = Al, Fe, Nb, Ta, Mg, Zr, (V, Cr)
Z = OH, F, (Cl)

Trace element analyses, e.g. rare earth and other elements, could not be performed without damaging the faceted stones. They will be performed soon after rough specimens of the Tissamaharama area are available. These additional data are necessary because the present geochemical and physical data of the sphenes do not allow to draw a conclusion on their mode of origin. However, these data are compared with the results of Zabavnikova (1957). As a consequence it seems probable that the sphenes from Sri Lanka originate from (retrograde metamorphic) ultramafic or mafic rocks. On the other hand the very similar Brazilian gem quality sphenes have developed within druses in quartz-albite-epidote-hornblende-sphene-bearing calcsilicate bands intercalated in a terrain of low grade metamorphic pelites and quartzites (Cassedanne & Cassedanne, 1971, 1974).

With the aid of chemical analyses and densities it is possible to calculate the mean refractive index ($\bar{n}$) of minerals, using the Gladstone - Dale relationship (Mandarino, 1976, 1979): $K = \frac{\bar{n}-1}{D}$, in which: K is the specific refractive energy of a mineral, D the density, and $\bar{n}$ the mean refractive index. For a biaxial mineral like sphene $\bar{n} = \frac{\alpha + \beta + \gamma}{3}$.

In this case the chemically derived refractive energy (K_c) is concerned and

$$K_c = \frac{k_1 p_1}{100} + \frac{k_2 p_2}{100} + \dots\dots\dots + \frac{k_n p_n}{100},$$

Table 2. Refractive indices of four cut sphenes obtained by calculation (Gladstone-Dale relationship) and refractometer (cubic zirconia prism) measurement.

No.	analysis	K_c[1] Gladstone-Dale	ñ	n(α′) refractometer	D measured
RGM	Fe^{3+}	0.2804	1.9913		
151 854	Fe^{2+}	0.2798	1.9892	1.912	3.5354
Sri Lanka	Fe^{3+}; OH	0.2807	1.9889	±0.001	±0.0008
	Fe^{2+}; OH	0.2801	1.9903		
RGM	Fe^{3+}	0.2807	1.9902		
151 856	Fe^{2+}	0.2802	1.9884	1.910	3.5276
Sri Lanka	Fe^{3+}; OH	0.2809	1.9909	±0.001	±0.0008
	Fe^{2+}; OH	0.2804	1.9891		
RGM	Fe^{3+}	0.2786	1.9843		
151 801	Fe^{2+}	0.2780	1.9822	1.911	3.533
Brazil	Fe^{3+}; OH	0.2788	1.9850	±0.001	±0.001
	Fe^{2+}; OH	0.2782	1.9829		
NEL	Fe^{3+}	0.2792	1.9904		
S2	Fe^{2+}	0.2784	1.9875	1.909	3.532
Brazil	Fe^{3+}; OH	0.2799	1.9907	±0.001	±0.004
	Fe^{2+}; OH	0.2791	1.9879		

1) after correction to 100 wt%

in which: k_1, k_2, etc., are the specific refractive energies of the components of sphene and p_1, p_2, etc., the weight percentages of the components.

The k-values are called Gladstone - Dale constants, they have recently been recalculated by Mandarino (1976).

The results of the K_c calculations are listed in Table 2. Four ñ-values have been calculated from each of the analyses. The first one is directly derived from the chemical analysis, in which all Fe has been considered trivalent. In the second calculation all Fe has been considered divalent. In fact sphene may contain both divalent and trivalent iron, either separately or together (Deer et al., 1962; Zabavnikova, 1957). Sphene contains generally some OH and F as replacement for O, the contents of which could not be identified by the electron microprobe. As the totals of the analyses are not 100% exactly, it is evident that an important part of the lacking percentages can be ascribed to such a substition of oxygen. In the third and fourth calculations of ñ about half of the lacking percentage is taken to belong to OH.

Besides these calculations, the refractive indices of all available cut stones were also measured with the aid of a refractometer provided with a cubic zirconia prism and highly refractive liquids (Table 2). Although such a prism will make it possible to get readings up to about 2.06, it was only possible to get a shadow-edge near 1.910, which is apparently the lowest figure corresponding with $\alpha' \geqslant \alpha$. Some of the stones gave two readings on the table facet but these could only be related to the double refraction in the direction of observation, like for instance 1.935 (α') and 2.030 (β').

By applying Duc de Chaulnes law (Phillips, 1971) the refractive indices of the cut sphenes were calculated from the ratios between the real en apparent depth in a direction perpendicular to the table facet. Though not very accurate the results were in general accordance with optical data of sphene.

Table 3. X-ray powder diffraction data for two sphenes.

	RGM 151 855 Sri Lanka		RGM 151 858 Brazil	
hkl	d (obs.)	I	d (obs.)	I
$\bar{1}11$	4.93	1	4.91	½
111 002	3.22	10	3.21	10
$\bar{2}02$	2.98	8	2.98	8
200	2.84	1	2.84	½
$\bar{2}21$ 022	2.59	9	2.59	9
$\bar{1}13$ 220	2.36	½	2.34	½
112 $\bar{1}32$	2.27	6	2.27	6
131	2.22	½	2.21	½
$\bar{3}12$	2.11	½	2.11	½
311	2.06	5	2.06	5
221	1.972	½	1.972	½
$\bar{3}13$	1.942	2	1.942	2
$\bar{2}04$ 310	1.850	½	1.850	½
042 $\bar{2}41$	1.802	½	1.802	½
$\bar{3}32$	1.741	1	1.741	1
$\bar{2}24$	1.703	6	1.704	6
$\bar{3}33$	1.641	7	1.641	7
151 241	1.553	4	1.553	4
043 $\bar{1}34$	1.528	2	1.527	2
133	1.492	7	1.495	7
400	1.419	5	1.418	5
	1.345	5	1.345	5
	1.303	4	1.303	3
	1.272	3	1.271	3
	1.223	1	1.223	1
	1.201	½	1.202	½
	1.143	½	1.143	½
	1.133	4	1.133	4
	1.114	1	1.114	1
	1.107	4	1.107	4
	1.077	2	1.076	2
	1.063	½	1.063	½
	1.040	½	1.040	½
	1.029	½	1.028	½
	1.014	½	1.014	½
	0.997	½	0.997	½

Comparing the calculated values with those obtained on the Cubic Zirconia Refractometer, it is clear that all sphenes have α near 1.910 and $\bar{n}$ near 1.9881. This means that they have very similar properties, which can also be seen from the chemical analyses in Table 1.

All specimens have a strong pleochroism in tones of yellow-green, yellow-brown, orange-brown, and light green, depending on the colour of the stone. Generally the sphenes with a colour in which yellow-green dominates

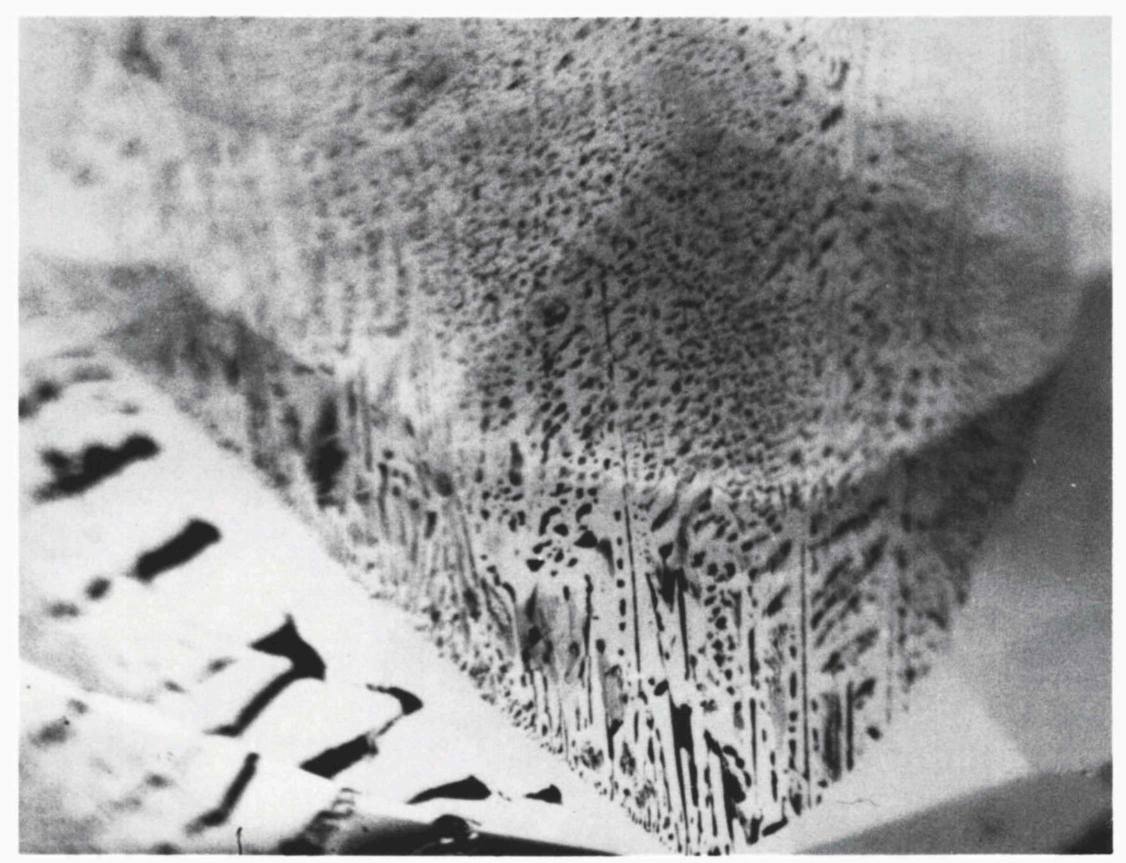

Fig. 3. Liquid inclusions in sphene RGM 151 800 from Capelinha, Brazil, × 25.

have light green and yellowish brown pleochroic colours, while those with a brownish yellow colour have a pleochroism in tones of orange-brown and yellow-green. Due to the enormous birefringence in all stones double facet edges at the base side are to be observed while looking through the table, in some cases even with the naked eye.

The absorption spectra of these sphenes are, as might be expected, due to the content of rare earths. It was seen that the brownish yellow stones have distinct absorption spectra with sharp intensive lines at 586 and 582 nm, in particular specimen RGM 151 854 has a very well developed spectrum. In these stones five lines can be seen in the yellow part of the spectrum at 599, 586, 582, 580, and 575 nm, while three absorption lines may be observed at 534, 530 and 528 nm, the strongest of them being the two lines in the yellow as mentioned above and the 530 nm in the green.

This 'didymium' spectrum, due to the presence of the rare earth elements neodymium and praseodymium, is less developed in the yellowish green stones. They have ill-defined lines in both the yellow and the green part of the absorption spectrum. It is evident, moreover, that the quality of the spectrum is not only due to the colour but also to the intensity of that colour.

X-ray diffraction has been used to prepare powder photographs of all cut stones as well as of the rough sphene from Brazil available for investiga-

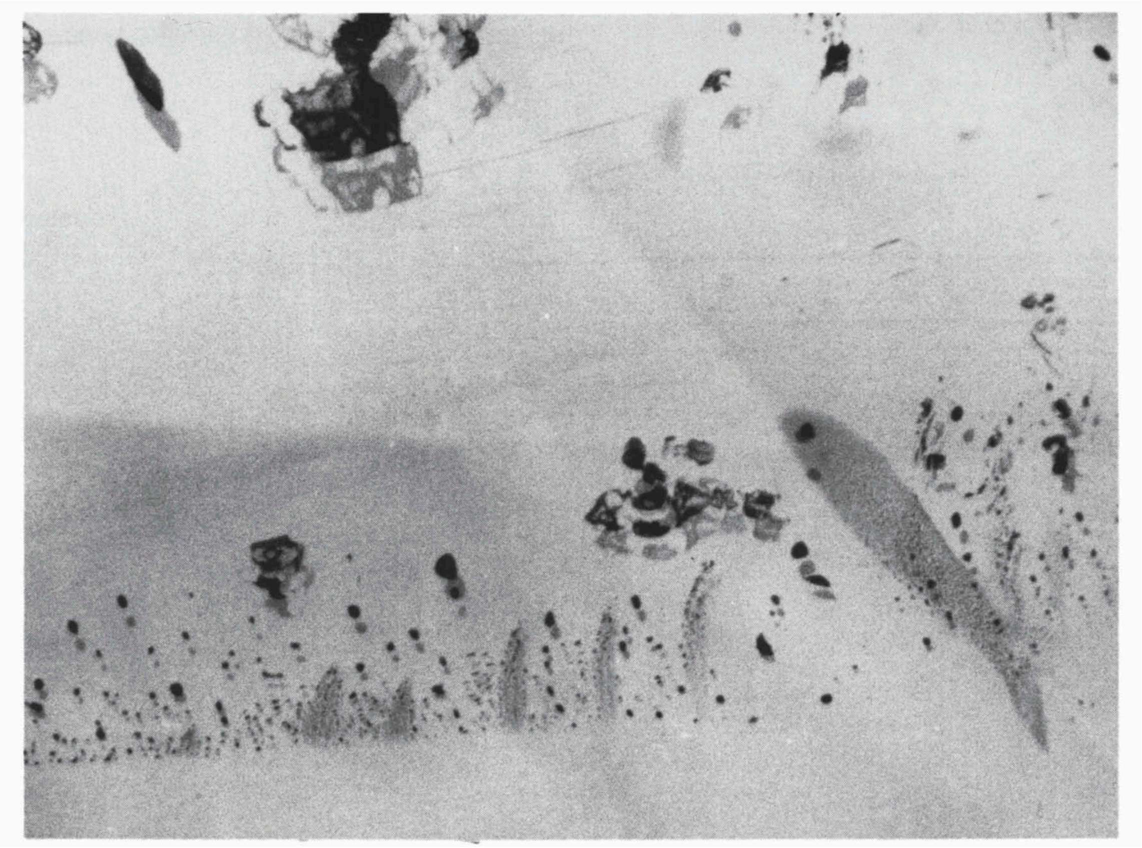

Fig. 4. Liquid inclusions in sphene RGM 151 855 from Sri Lanka, × 25. Note the strong doubling of the inclusions.

tion. The X-ray powder diffraction data for two sphenes, from Sri Lanka and Brazil respectively, are given in Table 3. It is evident that there are hardly any differences between these data, which indicates once more that the sphenes examined have very similar properties.

Inclusions

All specimens, available for investigation, contain inclusions and the most striking is a type of liquid feathers comparable with those occurring in tourmalines. This may be observed in sphene RGM 151 800 from Capelinha, Brazil, in particular at the left side of the photomicrograph (see Fig. 3).

Also another type of liquid inclusions in the same Brazilian sphene can be seen in Fig. 3, it is very similar to the liquid feathers which are characteristic for corundums from Sri Lanka.

In Fig. 4 inclusions are to be seen in RGM 151 855, a sphene from Sri Lanka. It is difficult to identify the nature of these inclusions, but they most

Fig. 5. Crystal inclusion (probably apatite) in sphene RGM 151 858 from Capelinha, Brazil, × 25.

probably are both liquid inclusions and healed fissures, the strong doubling of the inclusions, due to the enormous birefringence of the stone, being very striking.

A characteristic type of inclusions is found in RGM 151 858, a sphene from Brazil. In this stone crystals are included, which from their habits and optical properties, as far as these could be observed, very likely are apatite crystals (see Fig. 5). Although apatite is rather common in several gemstones from Sri Lanka, it has not yet been found in the three stones from that country, available for investigation.

Most of the sphenes contain one or more of the types of inclusions described above, except for the apatite crystals which only are found in RGM 151 858. Some stones do also have two-phase inclusions.

From the observations made, no indications can be obtained with regard to differences between Brazilian sphenes and those from Sri Lanka. Neither can the conditions under which the mineral has been formed be derived from these data.

Conclusions

The physical properties of the available sphenes from the Tissamaharama area in Sri Lanka are very similar to those of investigated sphenes from Capelinha in Brazil. From electron microprobe analyses, it is clear that the compositions of the sphenes are also very similar. It will be interesting to analyse the rare earth and other trace element contents of sphenes from both sources, because it is not unlikely that these data will make it possible to differentiate between stones from the two sources.

The absorption spectra of the specimens examined seem to confirm this idea as in some of the specimens an excellent intensive spectrum can be observed, while others have very vague absorption lines.

Examination of the inclusions indicates that there are no real differences in the nature of them. Sphenes from both sources may contain the same type of inclusions.

It is impossible to differentiate between the sphenes of both localities as long as no more data are available. This means that further work on more material from Sri Lanka will be necessary to draw more definite conclusions. One may hope, moreover, that a greater amount of this mineral will be found in Sri Lanka, because it is a very attractive stone of high gem quality.

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