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Application of Rb–Sr ratios to gem exploration in the granulite belt of Sri Lanka

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ABSTRACT

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The geochemical distribution of rubidium and strontium in the central granulite belt of Sri Lanka, where many of the gem deposits are found, was studied. The Rb–Sr ratios, particularly in the stream sediments, were found to be useful in delineating gem-bearing areas from the non gem-bearing or low potential areas. Among the main gem minerals that are mined at present are corundum, spinel, zircon and tourmaline. It was observed that higher Rb–Sr ratios correspond to high gem potential and, even within areas of good potential, barren areas could be delineated using these ratios. During pegmatite formation, Rb is enriched, and there is a marked depletion of Sr yielding a high Rb–Sr ratio. Pegmatites, granites and other magmatic bodies are associated with gem formation under granulite facies conditions and, when used in conjunction with geology, structure, and mineralogy, the Rb–Sr ratio could be used effectively to delineate target areas for further exploration.

INTRODUCTION

The gem minerals of Sri Lanka have attracted the attention of mineralogists the world over because of their uniqueness and because they are found in a wide variety. Gemstones are by far the most important mineral commodity in Sri Lanka and have a mining history of over 2500 years. Of the 5% mineral export earnings, 60% come from gemstones (Natural Resources of Sri Lanka, 1991). Recent research (Dissanayake, 1991) has shown that nearly 25% of the total land area of Sri Lanka is potentially gem-bearing, making Sri Lanka the most dense gem-bearing country in the world. The gem minerals mined at present include corundum, spinel, zircon and tourmaline.

Despite the seemingly vast gem mineral resources in the country, new discoveries are always based on "hearsay" methods and are chance findings. Gem

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mining in Sri Lanka is therefore still confined to the traditional gem mining areas around the well-known gem fields. Much of the reluctance on the part of gem miners to explore for gems in the non-traditional areas is therefore due to lack of information on their gem potential.

This paper discusses the use of Rb–Sr ratios in the stream sediments and rocks to delineate areas of good gem potential and poor to no gem potential in the gem mineral-rich central granulite belt of Sri Lanka.

GEOLOGICAL SETTING

Ninety percent of Sri Lanka's land is underlain with metamorphic rocks of the Precambrian Age. These rocks form two major divisions, namely the Highland Group and the Vijayan Complex (Cooray, 1978). The Highland Group has a metamorphic sub-division termed the Southwest Group. The Vijayan Complex is geographically separated into the Western and Eastern Vijayan Complex by the linear arcuate fold belt of the Highland Group (Fig. 1).

A suite of metasedimentary and possibly metavolcanic rocks formed under granulite facies conditions comprises the Highland Group. The prominent rock types of the Highland Group found are charnockites (acid, intermediate, basic); undifferentiated metasediments (garnetiferous granulites, garnetiferous biotite gneisses, garnet–sillimanite–biotite gneisses); khondalites (quartz–feldspar–garnet–sillimanite–graphite schist); quartzites, crystalline limestones, calc–gneisses and calc granulites, amphibole granulites and amphibolites. The rocks are found closely associated with one another in an interbanded relationship. The charnockites form a major percentage of the Highland Group rocks and the key observation is that most of the gem deposits of Sri Lanka are confined to the Highland Group, particularly to the Southwest Group. The latter consists mainly of calciphyres, charnockites and cordierite bearing gneisses.

Except for the transported alluvial gemstones, the Vijayan Complex is devoid of major gem deposits. The Western Vijayan consists of leucocratic biotite gneisses and migmatites, pink granitic gneisses and granitoids varying from granitic, syenitic to granodioritic. The Eastern Vijayan is composed of biotite/hornblende gneisses, granitic gneisses and scattered bands of metasediments and charnockitic gneisses.

The largest gem fields in Sri Lanka are located in the Sabaragamuwa Province in the Southwest in the areas around Avissawella, Balangoda, Rakwana, and Ratnapura. The other gem fields of interest lie in the regions around Elahera, Okkampitiya and Hasalaka. The gem-bearing beds are classified into three types: (1) residual, (2) eluvial, and (3) alluvial (Dahanayake et al., 1970). The residual beds bear gem minerals mostly deposited in-situ, whereas eluvial beds have minerals transported along slopes of ridges and deposited

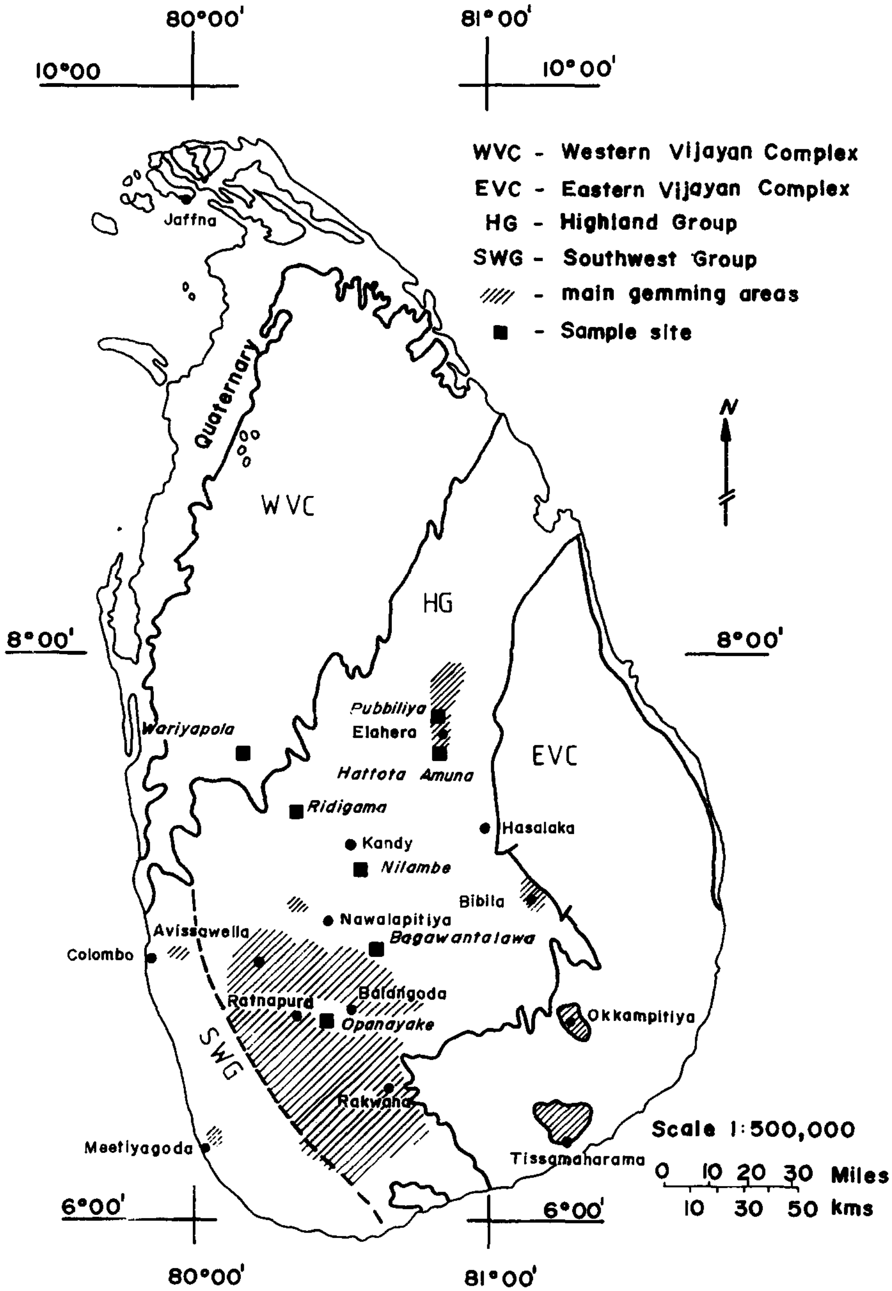

Fig. 1. Map of Sri Lanka showing main geological groups, gemming areas and sample sites.

away from the parent rock. The alluvial beds on the other hand contain gem minerals transported along streams and deposited at a greater distance from the parent rock.

MATERIALS AND METHODS

The basic assumption in the use of stream sediments in gem mineral exploration is that the gem minerals found in stream sediments are derived from adjacent bedrock that form the hillsides of the alluvium-filled valleys. Consequently, the mineralogy and chemistry of a particular sediment, gem-bearing or otherwise, should reflect its nearby provenance and the processes of weathering, erosion, solution, transportation and deposition that resulted in the sediment. Therefore, gem-bearing sediments should be characterized chemically and mineralogically to distinguish them from those with low potential for gems. It is also desirable to characterize the types of bedrock from which sediments of high, moderate, and low gem potential have been derived.

A total of 675 samples from 7 different areas was collected and analysed for Rb and Sr by X-ray fluorescence spectrometry at the Laurentian University , Canada. Sampling involved both stream sediments and bedrock. The seven areas, shown in Fig. 1, represent different levels of known (or assumed) gem potential, as follows:

(i) Areas of known high potential; Opanayake and Hattota Amuna. Both areas are underlain with rocks of the Highland Group. Extensive gem production in these areas is derived from stream sediments.

(ii) Areas of moderate potential from which some gem occurrences have been reported, but in which no significant production has taken place; e.g., Bogawantalawa and Pubbiliya. These areas are also underlain with rocks of the Highland Group.

(iii) Areas of low, very low or no potential; Nilambe and Ridigama. Both areas are underlain with rocks of the Highland Group. This category also includes Wariyapola, an area underlain with rocks of the Western Vijayan Group, assumed to lack potential for gems.

In the Opanayake area, a prolific gem-bearing region with extensive production of sapphire, the bedrock consists dominantly of charnockite and undifferentiated metasediments, with lesser garnet sillimanite gneiss, quartzite and marble. Bedrock sampled during the present study included a variety of garnetiferous gneisses containing pyroxene, hornblende or biotite, granulites, acid charnockites pegmatites, marble and pyroxenite.

The Hattota Amuna area, an area of proven potential for gem quality corundum and garnet, is underlain with garnetiferous gneisses (some of which are graphitic), granulites and charnockites, marble, skarn and pegmatite. Gem-quality garnets appear to be associated mainly with garnet-graphitic gneisses rather than with garnet gneisses lacking graphite. High-quality corundum appears to be restricted to areas of massive, medium- to coarse-grained crystalline limestone.

At Bogawantalawa, an area from which some gems have been reported and which is considered to be of moderate potential, charnockites, charnockitic gneiss and a variety of garnetiferous gneisses were observed. At Pubbiliya, the bedrock consists largely of garnet gneisses, some of which are graphitic. Like Bogawantalawa, Pubbiliya is considered to be an area of moderate potential.

The Nilambe and Ridigama areas, assumed to be of low potential, are underlain with garnetiferous gneisses. The western part of the Ridigama area is underlain with rocks of the Western Vijayan where no gems have been found. These areas were included in the present study for comparison with the areas underlain with rocks of the Highland Group.

Stream sediments were collected by auger or shovel and were dried, disaggregated and sieved. The fine fraction (<65 mesh) was ground further and material <250 mesh was made into pressed powder pellets for analysis by X-ray fluorescence spectrometry.

Comparison with the analytical data obtained by the analysis of reference standard sample GSP-1 gave a standard deviation of 1.47 for Rb and 0.99 for Sr.

USE OF Rb–Sr RATIOS IN GEM EXPLORATION

Rb–Sr ratios in stream sediments

The analytical results showed that the concentrations of Rb and Sr in the stream sediments varied significantly among areas, whereas within each subarea, the variation was small. However, the more important observation made was that the Rb–Sr ratio appeared to be characteristic for a particular area, bearing in mind that the gem deposits of Sri Lanka are located in a metamorphic terrain of granulite facies grade. In general, however, lower values for this ratio were found in non gem-bearing areas, whereas the areas known for their high gem potential had higher ratios.

Table 1 shows the results obtained from the geochemical survey. It is worthy of note that even within a particular gem-bearing region, in some locations, for certain geological and structural reasons, no gems could be found and the Rb–Sr ratios still differed. In the Opanayake area, well known as a gem field in Sri Lanka, high Rb–Sr ratios were observed for the gem-bearing parts west and southwest of Opanayake. Most of the prominent gem-bearing locations had an Rb–Sr ratio of around 1.0 or more, particularly in the gem pits. In the stream sediments, a value of approximately 0.4 could be used as a rough guide in the delineation of target areas for detailed gem exploration. Generally, marked differences were not observed in the Rb and Sr contents of the rocks and overlying soils or sediments of the adjacent streams.

TABLE 1

The Rb–Sr ratios in the stream sediments in areas of varying gem potential

Area	No. of sediments samples	Mean Rb ppm	Mean Sr ppm	Mean Rb/Sr	Remarks
Hattota Amuna Gem pit sediment	18	44	58	1.56	High gem bearing
Hattota Amuna Stream sediment	33	113	82	0.46	High gem bearing
Opanayake West	16	54	45	1.11	High gem bearing
Opanayake North and East	80	60	295	0.30	Only a few gems found
Pubbiliya Gem pit sediment	5	76	199	0.38	Moderately gem bearing
Pubbiliya Stream sediment	43	67	298	0.24	Moderately gem bearing
Nilambe Stream sediment	53	56	78	0.85	Not explored but of high potential
Ridigama Stream sediment	98	62	356	0.19	Low gem bearing
Wariyapola Stream sediment	50	39	357	0.12	Low to non-gem bearing

In the Opanayake area, gem fields exist towards the west and south of the town of Opanayake. Only a few gems have been reported by the miners, towards the east, beyond Opanayake, the town being located in the extreme eastern corner of the gem field. Fewer gems are found in the headwater streams of the northern part of the Opanayake area, except at a few localities. This feature is compatible with the value of the Rb–Sr ratios as considerably lower values for Rb–Sr ratios were observed for the sediments and rocks of the northern headwater streams. In the headwater streams, relatively high values were observed at the places where gem minerals (garnets, spinels, corundum, etc.) were found. Towards the western side, very high values of Rb–Sr ratios were observed the stream sediments, gem-pit sediments and rocks; this is compatible with the high potential for gemstones in the western part of the area.

The Hattota Amuna area, well known for the abundance of gem-quality corundum, tourmaline, garnets and spinel, shows high Rb–Sr ratios. In the gem pits, a sharp decrease in the Sr content and an increase in the Rb content give rise to very high values of Rb–Sr ratios.

About 30 profile samples from four gem pits have been analyzed to determine the Rb–Sr ratio. Profile samples included sediments, weathered rocks, and fresh rocks. The most interesting feature found in this area was the value of the Rb–Sr ratio *in illam* (gem gravel) samples. This value was greater than one for the analyzed *in illam* samples. It was noted that in gem pits with high concentrations of gems, the ratio was even greater than 2.0.

Even though the Pubbiliya area is close to Hattota Amuna, very few gems have been reported from this area. The Rb–Sr ratio is 0.24 for sediments. There are several residual pits in this area that contain mostly garnets. The Rb content was found to be high in these pits giving somewhat higher values (0.38) for the Rb–Sr ratio.

The Bogawantalawa area is of moderate potential for gem stones. The Rb–Sr ratio is found to be generally high for the whole area. About 60 stream sediment samples from this area have been analyzed.

The Wariyapola area is located outside the Highland Group and no gems have been reported to date. A high Sr content and a relatively low Rb–Sr ratio were observed for this area.

Although only a few gems have been reported from around Nilambe, there are good possibilities for the occurrence of gems in this area. Generally, both Sr and Rb contents are low in this area. It is worthy of note that though the ratio is considerably high for the whole area, the Rb content is very low compared to that in other prominent gem-bearing areas. Garnets, tourmalines and amethyst have been reported from several localities of this area.

In the southwest part of the Ridigama area Rb–Sr ratios are low and are

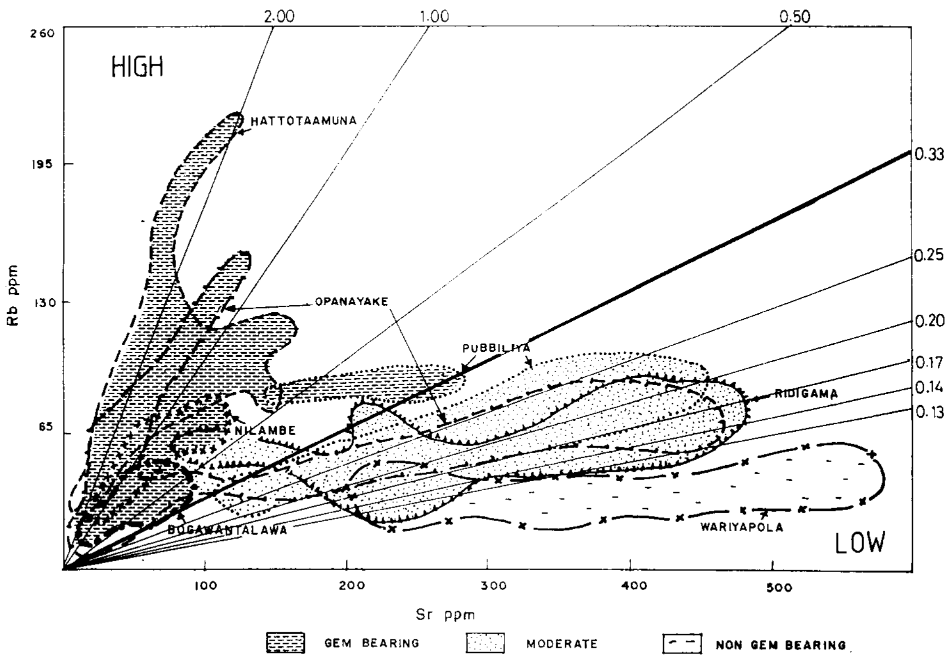

Fig. 2. Rb–Sr plots for the stream sediments.

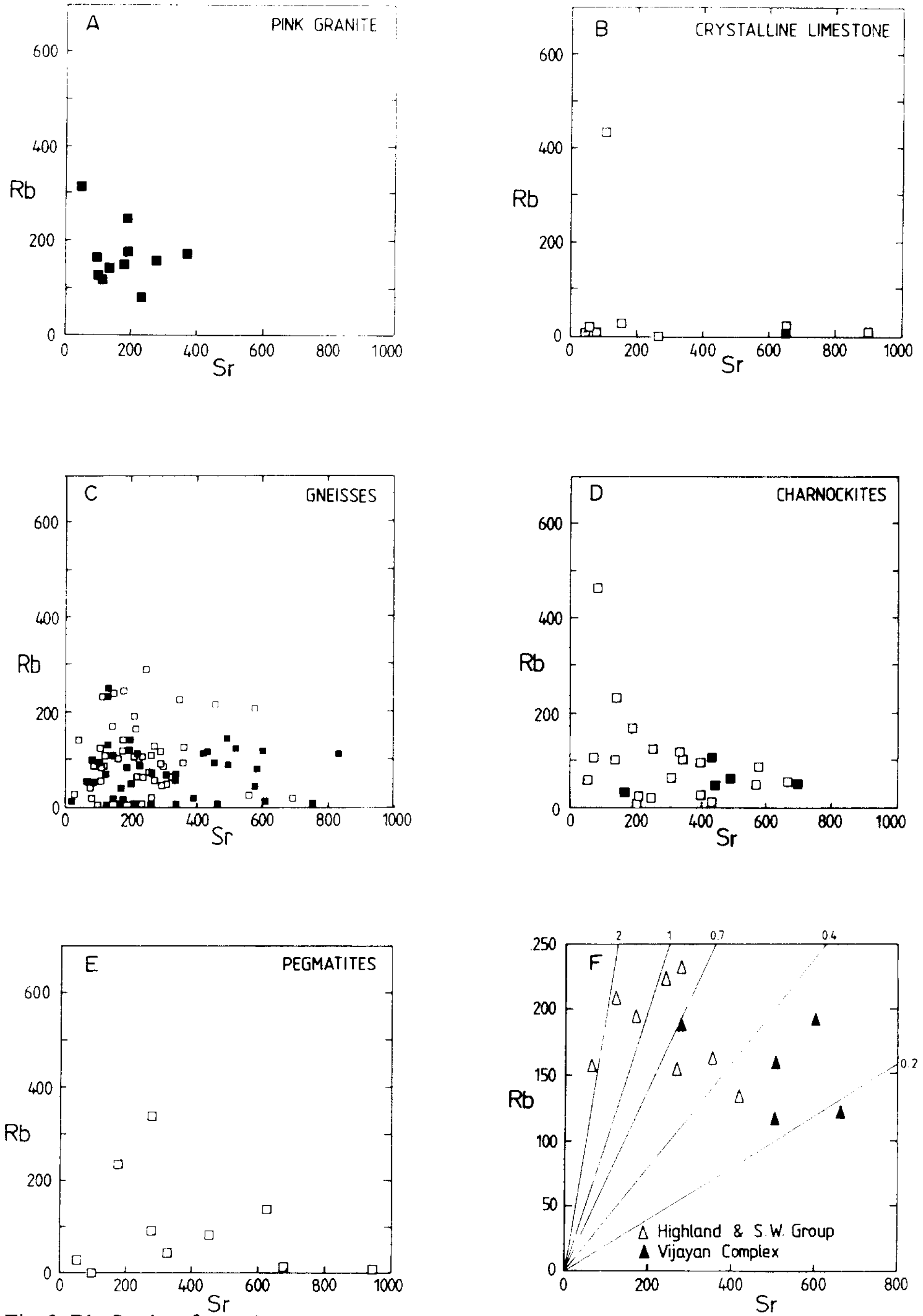

Fig. 3. Rb–Sr plots for rocks.

comparable to those in the Wariyapola region. The southwest part of Ridigama, like its western area, is underlain by rocks of the western Vijayan Complex. In the northeast part, Rb–Sr ratios are relatively high in a few places where a few good-quality garnets have been found.

Figure 2 illustrates the Rb-Sr plots for the areas of differing gem potential. It is observed that even though there is a certain degree of overlap between the fields, there is a clear variation of the Rb–Sr ratios in moving across from high gem-bearing to low gem-bearing regions. It was also observed that in a particular gem-bearing area, the Rb–Sr ratio in gem-pit sediment samples was generally higher than that in stream sediments in the same area.

Rb–Sr RATIOS IN ROCKS

The rocks in the gem-bearing areas studied in the Highland and Southwest Groups are mainly gneisses, charnockites, marbles, quartzites, granites and granitoid intrusives. The plots of Rb–Sr (Fig. 3) show that there is wide scatter for the metamorphic rocks, particularly the gneisses. The marbles have very low Rb–Sr ratios whereas the pink granites have markedly higher Rb–Sr ratios. The pegmatites and the charnockites on the other hand exhibit a wide range of Rb–Sr ratios.

Even though the potential for using the Rb–Sr ratios of the different rocks in the main gem-bearing and non gem-bearing rocks may appear to be limited, an understanding of the role of the magmatic rocks in the genesis of the gem minerals, as discussed in the next section, may enhance their use.

Figure 3F illustrates this point clearly. The Rb–Sr ratios obtained for the granitoid intrusives in the Highland and Southwest Groups (Pohl and Emmermann, 1991) (known to be gem-bearing) and the Western Vijayan Complex (known to be non gem-bearing) show markedly different Rb–Sr ratios. Further detailed geochemical work on these rocks is therefore necessary to develop the use of Rb–Sr ratios as a tool in tracing the source rocks of gem minerals.

DISCUSSION

The apparent relationship between the Rb–Sr ratio and the gem potential of an area is seemingly governed by the behaviour of a Rb–Sr open system. The loss of Sr during pegmatite and related magmatic phases has resulted in higher Rb–Sr ratios in areas associated with such magmatic activity.

The origin of gem minerals of Sri Lanka has been studied by Katz (1972), Munasinghe and Dissanayake (1981), Rupasinghe and Dissanayake (1985), and Hapuarachchi (1989). Katz (1972) suggested that the Ratnapura type gem deposits were derived from cordierite gneisses and associated rocks. In the early literature a pegmatitic origin had been advocated by Coates (1935) and Wadia and Fernando (1945). Munasinghe and Dissanayake (1981) emphasized the role played by basic and ultrabasic igneous rocks in the desilication of pelitic rocks forming corundum and spinel on a large scale. Silva and Siriwardena (1988) described the geology and origin of the corundum-bearing skarn at Bakamuna. They concluded that the deposit was formed by the reaction of late magmatic fluids with the marble which eventually enriched the fluids in Al, causing Al_2O_3 to precipitate as corundum.

Inherent in all these hypotheses is the active role played by a magmatic fluid. Pollard (1989) discussed the geochemistry of granites associated with tantalum and niobium mineralization and recognized three major varieties of granites:

(1) Alkali granites containing alkali pyroxenes and/or amphiboles which are characterised by high Rb, among other elements and low Sr along with Ca and Ba.
(2) Biotite and/or muscovite granites characterised by high Rb among other elements and low Sr, Ca and Ba.
(3) Lepidolite albite granites often containing topaz characterised by high Rb among other elements and low Sr and Ba.

It is thus seen that the Rb–Sr ratio is low in all these granites associated with mineralisation. Crystal and/or liquid fractionation during magma evolution and/or postmagmatic alteration by interaction with fluorine rich hydrothermal fluids may be the cause for such trends.

The work of Walraven et al. (1990) on the Rb–Sr open system behaviour and its application as a pathfinder for Sn mineralisation in granites of the Bushveld Complex showed evidence for a radiogenic Sr loss model. In their model, late-stage, low-temperature hydrothermal fluids responsible for mineralization form part of an extremely long-lived hydrothermal system.

In view of the role played by magmatic fluids in the formation of gem minerals under granulite facies conditions, such an Sr loss model may well be applicable to the gem-bearing granulite belt of Sri Lanka. The variable loss of Sr during gem mineral formation changes the Rb–Sr ratio leaving a geochemical signature indicative of the potential for gem mineral formation. Due to the fractionation in the parental granite, the last fluids are highly enriched in Rb with concomitant depletion of Sr resulting in a high Rb–Sr ratio. Moller (1989) explained the variation of Rb-Sr ratios by the superimposition of three effects:

(1) Fractionation of Rb and Sr during solidification of the parental granite.
(2) Fractionation during crystallisation of the pegmatite.
(3) Inhomogeneous pegmatite fluid due to mixing of liquids with greatly differing Rb–Sr ratios.

In some instances of pegmatite formation, Rb is enriched by a factor of two and Sr is decreased by a factor of five. It is seen from this study that the Vijayan Complex which does not yield much gemstones consistently gives low

Rb–Sr ratios when compared to the central granulite belt which produces most of Sri Lanka's gemstones.

It should, however, be borne in mind that even though there are complicating factors controlling the Rb–Sr fractionation during hydrothermal processes, when used in conjunction with geological, structural and mineralogical factors of gem mineral formation and distribution, Rb–Sr ratios could be used as an effective tool in the exploration for gems in granulite facies terrain.

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