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IN THIS ISSUE

- Heavenly Bounty - Impact Metallogeny
- Evolution of Eastern Ghats Belt
- Geoelectric Resistivity Survey
- Himalayan Catastrophe
- Trabeoles in Assilina Exponens
- GIS Based Landslide Susceptibility Mapping
RESEARCH PAPERS

Himalayan Catastrophe that Enveloped North Bihar, Vishwas S. Kale .................................................................................. 713

Evolution of the Eastern Ghats Belt, India: A Plate Tectonic Perspective, K. Viswan Kuman and C. Lalganandam .................................................................................................................. 720

Trabeceules in Axillina expansa (Sowerby) (Foraminifera) – A Preliminary Report, S. Sengupta and S. Mukhopadhyay ..................................................................................................................... 750


GIS Based Landslide Susceptibility Mapping- A Study from Darjeeling-Kalimpong Area, Eastern Himalaya, India. T.B. Ghoshal, N.K. Saksar, Nabab Gohshi and M. Serejendaranath ......................................................................................................................... 763

Gastrochaenolites Bioerosion in the Kalyangpur Limestone (Pliocene) of Dwarka Area, Kathiawar, Gujarat. Kantikar G. Kulkarni, V.D. Borse and Tejasri Petkar ............................................................................................................................................... 774


Tectono-Provenance and Diagenesis of Habo Dome Sandstone, Chari Formation, Kachchh, Western India. A.H.M. Ahmad, S. Bhat, Neeraj Jain, A.F. Khan and Asgeri Maite .............................................................................................................................................. 790

Evidence of Ductile Deformation along the Ramgarh Thrust in Kumaun Lesser Himalaya. Suman Jeevan .................................................................................................................................................. 801


Pegmatites Derived from Fractionation of a Melt: An Example from Pegmatites in the Owala-Kaikawala Area, Matale, Sri Lanka

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Abstract: Vertically and sub-vertically intruded syenite and granitic pegmatites, which carry many industrial minerals are found in the Owala-Kaikawala area in the central parts of Sri Lanka. The field setting, petrography and chemical composition of feldspars of these rocks illustrate that they have been derived from a single magmatic source formed by crustal anastasis. The enrichment of compatible elements in feldspars of the fluorspar-bearing syenitic pegmatite and incompatible elements in granitic pegmatites can best be explained by the chemical evolution of the extremely fractionated melt. The initial fractionation of a volatile enriched, silica-under saturated melt from the parental magma resulted into the fluorspar-bearing syenitic pegmatite. The remaining melt, that is rich in silica, fractionated again slightly and was emplaced into eastern parts of the area as granitic pegmatite. The fractionations of the flux rich melt took place frequently until the crystallization of minerals.

Keywords: Pegmatite, Geochemistry of feldspars, Incompatible elements, Fractionation, Sri Lanka.

INTRODUCTION

Traditionally, the origin, evolution and classification of pegmatites are evaluated from detailed studies on major, minor and accessory mineral constituents. However, studies carried out in the last 25 years revealed that the chemical composition of K-feldspars can provide valuable information on the petrogenetic evolution of pegmatites (Shmakov, 1979; Cerny, 1982; Cerny and Brittin, 1982; de Silva et al. 1995; Quenemour and Lagache, 1995; Kontak et al. 2002) and their chemical evolution (Trumbull, 1995). Further, K-feldspar can be used as an indicator mineral for the exploration of mineralized pegmatites (Trueman and Cerny, 1982; Smeds, 1990; Hallaran and Russell, 1992; Singh and Sharma, 1997). Rb is a minor element that substitutes extensively for the K+ site in K-bearing minerals. This close geochemical association leads to the use of K/Rb ratios of K-feldspars as a good indicator of pegmatite evolution (Cerny, 1982; Quenemour and Lagache, 1999).

The distributions of the trace elements Ca, Sr, Ba, Pb in K-feldspars, which also substitute for the alkali site, can be coupled with Rb in order to study the origin and the evolution of coexisting pegmatite forming melt. Ba, Sr and Pb have two positive charges and a substitution of K is only possible when additionally Si is replaced by Al. The ionic radii of Ba²⁺ and Sr²⁺ are close to K⁺ and since they have two positive charges they have a higher ionic potential than K⁺ and should be partitioned preferentially into K-feldspar. Pb⁴⁺ has a smaller ionic radius and additionally a different electronegativity than K. Based on Goldschmidt’s rules, Ba²⁺ and Sr²⁺ behave compatible whereas all other trace elements behave incompatible at different levels compared to K for K-feldspar – granitic melt distribution. Ga³⁺ and Fe³⁺ can substitute Al³⁺ in feldspars. Phosphorus, which substitutes for the T-site in the K-feldspars, is also used as an indicator of pegmatite evolution together with the above trace elements (Breiner et al. 2002).

GEOLOGICAL SETTING OF SRI LANKA

The Proterozoic high-grade basement of Sri Lanka covers more than 80% of the country and consists of four major crustal blocks (see Fig. 1a) namely (1) Highland Complex (HC), (2) Vijayan Complex (VC), (3) Wanni Complex, and (4) Kadagamawa Complex (KC) (Kröner et al. 1991; Cooray 1994). In the northwestern coastal strip, Miocene to recent sedimentary rocks and sediments are found. Pegmatites,
dolerites, carbonatites and granites are the only post metamorphic igneous bodies found within in the high-grade terrane (less than 1%) of Sri Lanka (Coreray 1984). Although the pegmatites are minor rocks by volume, they are found as disseminated bodies in many parts of the country providing quartz, feldspars and mica for many local industries. Further, it is believed that they are the source rocks of some gem minerals as most of them are located close to the presently gem mining areas. Even though the pegmatites in the country provide us many economic minerals, we have a little knowledge on the genesis, economic potential and mode of occurrences of them.

Mode of Occurrences and Petrography of Pegmatites

Pegmatites of Owalla – Kaikawala area, in the Matale District of Sri Lanka are located within the H.C., which underwent high-grade metamorphism during Pan-African Orogeny at ca. 550 Ma (Kröner and Williams, 1993). The study area is characterized by marbles, garnet-sillimanite gneisses, charnockitic gneisses and quartzites having their general trend of NW-SE. Two sets of fractures are dominant in the area and they are mainly trending NNW-SSE and E-W (see Fig. 1b).

Pegmatites in the study area are found mainly as vertical or sub vertical bodies that are commonly intermingled with host marbles and quartzites with sharp contacts. Although geochronological studies on pegmatites of Sri Lanka have not yet been done, field investigations clearly show that the emplacement of pegmatite plutons took place after the major phase of metamorphic events. Most of studied pegmatites in the study area have been mined for quartz and feldspars. The weathered zones of the granitic pegmatites have presently been mined for topaz. The Polwatta area, a well-known topaz deposit in Sri Lanka, is located towards the east of the granitic pegmatites at Kaikawala (see Fig. 1b).

Dissimilarities in terms of geometry, zoning and model distribution of major and minor minerals of the pegmatites show that the Owalla-Kaikawala area is characterized by two groups of pegmatites, which have granitic and syenitic compositions. A fluorite-bearing syenitic pegmatite is present in the western part of the study area. The granitic
Fig. 2. Simplified cross section of the syenitic pegmatite at Owala. The intermediate zone, which is enclosed by the thin shell of outer zone, is the largest unit of the body. The core zones are mainly made up of fluorite which occurs as massive vertical bodies within the intermediate zone. Locations of samples collected from the pegmatite are shown by triangles.

Pegmatites are concentrated in the eastern part of the area (see Fig. 1b). The syenitic pegmatite is a comparatively large (covers about 0.2 km²), isolated, oval-shaped intrusion, comprising of systematically defined zones (Fig. 2). The outer zone consists of decimetric crystals of microcline, coarse-grained flakes of mica having different orientations and medium to fine-grained accessory quartz (Fig. 3a). A sharp transition is noticed towards the intermediate zone that comprises exclusively coarse-grained perthitic K-feldspars with accessory microcline and mica (Fig. 3b). The rare occurrences of medium-grained graphic granites together with fine to medium-grained muscovite are found as patches and lenses within outer and intermediate zones. Several vertical, massive fluorite bodies are found in the core zone. Fluorite, having deep-violet colour, is euhedral to subhedral crystals (Fig. 3c).

In contrast to the syenitic pegmatite body, the granitic pegmatites found at Kaikawula, Gurubabila and Koswana areas are smaller, irregularly zoned with narrow elongated exposures (average width less than 100 m) which comprise of very coarse-grained perthitic K-feldspars, amazonite and quartz as well as quartz-feldspar intergrowths. The accessory minerals are biotite, phlogopite, amazonite, tourmaline and topaz. Amazonite and topaz-bearing pegmatites are located close to the syenitic suite whereas pegmatites with accessory tourmaline are found in the more southeastern parts.

Fig. 3. Field appearance of the syenitic pegmatite at Owala. (a) The photograph shows the sharp boundary between outer zone and intermediate zone. Large grains of white coloured K-feldspars in the intermediate zone clearly demarcate the outer zone made mainly of mica and microcline. (b) The photograph shows the occurrence of accessory microcline and biotite mica within the perthitic groundmass in the intermediate zone. (c) Strongly zoned, vertically oriented fluorite masses (dark coloured area) in the core.
Sampling and Analytical Methods

K-feldspars were collected from the different zones of the syenitic pegmatite and from granite pegmatites (see Figs. 1b and 2). Inclusion free samples were powdered and analyzed by a Bruker Pionier S4 X-ray fluorescence spectrometer at the Department of Earth Sciences, University of Graz, Austria, for major and minor elements. One gram of sample was mixed with seven grams of di-lithium tetraborate and a glass bead was fused at c. 1300°C with the automatic fusion machine VAA20M of HD-Elektronik und Elektrotechnik GmbH. About 40 international reference materials were used for calibration and the feldspar standard SARM AL-1 was analyzed as unknown sample and could be reproduced within errors.

RESULTS

Major Element and Trace Element Chemistry

The compositions of K-feldspars are summarized in Tables 1 and 2. Feldspars from the syenitic pegmatite have a compositional range of Or0.40–0.70 Ab27–38 An69–32. Most of the K-feldspars from the granite pegmatites are sodium poorer with an average composition of Or44–67 Ab25–35 An28–34. In contrast, K-feldspars from Gurubabila where two sodium rich K-feldspars were sampled with a composition of Or28–55 Ab29–40 An41–45.

Table 1: Chemical composition of potassium feldspar from granite pegmatites from Kailawala, Koswana, Gurubabila

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</table>

Rb, Ba, Sr, Pb, Fe and Ga are the dominant trace elements in K-feldspars in syenitic and granitic pegmatites. The granitic pegmatite body containing amazonite at Kailawala is more enriched in Rb (3486–7680 ppm) and in Pb (148–233 ppm) than the other granitic pegmatites lacking amazonite. The occurrences at Koswana and Gurubabila consist mainly of perthite K-feldspar with Rb values in the range of 1044–2501 ppm and Pb concentration from 66 to 134 ppm. The lowest Rb contents are recorded in feldspars from the syenitic pegmatite (652–775 ppm). In contrast, the syenitic pegmatites are more enriched in Ba (Ba = 291–372 ppm) and Sr (Sr = 67–97 ppm) than the granitic pegmatites. However, K-feldspars from the granitic pegmatites at Koswana (Ba = 180–333 ppm and Sr = 48–105 ppm) and Gurubabila (Ba = 128–161 ppm, Sr = 51–57 ppm) are more enriched in Ba and Sr than from the pegmatitic body at Kailawala (Ba = 15–47 ppm, Sr = 21–33 ppm). While Rb, Sr, Ba, and Pb substitute the K site in K-feldspar, Ga and Fe can fill the tetrahedral aluminum site. The highest values of Ga (26–62 ppm) are seen in the granitic pegmatites while the Ga content in syenitic pegmatites is 21–23 ppm. Fe concentration is highest in the syenitic pegmatites (Fe₂O₃ = 0.12–0.29 wt%) compared to 0.06–0.11 wt% Fe₂O₃ in granitic pegmatites.

K-feldspars from the studied pegmatites comprise low values of P₂O₅, ranging from 0.02–0.03 weight percent and 0.02–0.03 weight percent.
Table 2. Chemical composition of potassium feldspar from syenitic pegmatites from Owala

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<td>0.48</td>
<td>0.53</td>
<td>0.42</td>
<td>0.40</td>
<td>0.29</td>
<td>0.24</td>
<td></td>
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</tbody>
</table>

Major and minor elements in (wt%), trace elements in (ppm)

do not show any variation between syenitic and granitic pegmatites (Tables 1 and 2).

**DISCUSSION**

Two well-known hypotheses explain the formation of pegmatitic melts: (1) they are the direct product of partial melting (anatectic) or (2) the products of extended fractional crystallization of granitic magmas. In the vicinity of the study area, even within the region, granites are absent. Therefore, it can be assumed that the parental magma of the present pegmatite bodies does not have any link to granitic rocks and it can be assumed that the pegmatitic melt may have derived from partial melting (anatexis) of crustal material.

The syenitic pegmatite in the west is a systematically zoned body. In contrast, granitic pegmatites in the east are irregularly zoned bodies. Petrography of the pegmatites clearly indicates that the chemical fractionation of the parental melt has taken place prior to the emplacement. Less siliceous conditions of pegmatites can develop under H₂O undersaturated and F-enriched conditions (Christiansen et al. 1984; London et al. 1989; London, 2005). Therefore, the fluorite bearing syenitic pegmatite indicates that the body crystallized under SiO₂ undersaturated and volatile saturated conditions derived from a silica-undersaturated fluorine-rich melt. The residual melt of the fluorine depleted, silica enriched melt was emplaced in the eastern part of the area around Kaikawala, Gurusabila and Koswana resulting in a K-rich pegmatite.

![Fig.4. K/Rb versus Rb concentration in K-feldspars of studied pegmatites compared with published data of pegmatites from Cap de Creus (Alfonsì et al. 2003), from southern Norway (Larsen, 2002) and from Tin Mountains, South Dakota, U.S.A. (Walke et al. 1989). Note that the pegmatites in Owala-Kaikawala contain very primitive compositions.](https://example.com/fig4)
Fig. 5. Distribution of various compatible and incompatible elements in K-feldspars. (a and b) Chemical fractionation of the source is clearly marked by the enrichment of the compatible elements Ba and Sr in the syenitic pegmatite at Owala. (c and d) Rb and Pb are enriched in the evolved pegmatites from Kalkazwa and Gansbahla. (e and f) Al/Ga ratio and Fe concentration are highest in primitive pegmatites.
in granitic pegmatites. The distribution of trace elements in K-feldspars within these pegmatites supports this hypothesis.

The trace element concentration in K-feldspar in the study area is very low compared to the other pegmatites elsewhere (e.g. Truem and Cerny, 1982). Therefore, the pegmatite in the study area can be classified as infertile pegmatites, which do not have potential to form economic minerals other than the presently mined industrial minerals. Correlation of K/Rb vs. Rb of K-feldspars (Fig. 4) indicates that the pegmatites from the study area except Kaikawala bodies are relatively primitive compared to other pegmatite bodies (Walker et al. 1986; Larsen, 2002; Alfonso et al. 2003). This nature also indicates the formation of the melt through the anatexis processes (Norton and Redden, 1990).

Distribution of Rb, Sr, Ba, K, Pb, Ga and Fe in feldspars have been used to evaluate the degree of evolution of pegmatites (Kontak et al. 2002; Alfonso et al. 2003; Ren, 2004). Ba and Sr which are compatible elements in K-feldspar are enriched in syenitic pegmatite (Figs. 5a and b). In contrast, incompatible elements, Rb and Pb are enriched in granitic pegmatites (Figs. 5c and d). As the compatible elements concentrate during the early stages of the magmatic differentiation, the above results clearly indicate that the syenitic pegmatite were derived at an early stage from the parental feldspar while the granitic pegmatites are products of the later residual portion of the parental melt. Ga and Fe are present in small quantities in these pegmatites. Ga, which usually behaves geochemically similar to Al should not vary considerably since the Al2O3 content is about constant. This is true for the syenitic pegmatites but is systematically varying in granitic pegmatites. The Al2O3 content in syenitic pegmatites is c. 4800 which is similar to an average crustal ratio. The Al2O3 content increases in granitic pegmatites with increasing incompatible elements, which means the more the pegmatite is evolved the higher the Ga concentration (Fig. 5e). A similar picture is seen in Fe. Although the Fe contents vary considerably in syenitic pegmatites, the lowest Fe values are found in the most evolved granitic pegmatites (Fig. 5f). The variation in Fe concentration in K-feldspar is most likely related to the crystallization of Fe- and Fe-Ti oxides and biotite.

The K/Rb and the Rb/Sr ratios of feldspars are commonly used to evaluate the degree of evolution of the pegmatites. The pegmatites formed by undifferentiated magmatic source have the highest K/Rb ratio while pegmatites formed by the more differentiated magma have the highest Rb/Sr ratio (Larsen, 2002). Figure 6 illustrates the highest K/Rb ratios from syenitic pegmatite and the highest Rb/Sr ratios from granitic pegmatites from the Kaikawala area which may have formed in the final stage of the magmatic process. These results confirm the chemical fractionation process of the pegmatitic melt.

CONCLUSIONS

The chemical composition of studied feldspars of the syenitic pegmatite is mostly homogeneous all over the body. In contrast, the granitic pegmatites are made up of relatively inhomogeneous feldspars. This may indicate that the conditions of crystallization of these pegmatites of different compositions were not identical. The low trace element contents in K-feldspars illustrate that all studied bodies do not carry any economic minerals other than presently mined industrial minerals and topaz. The Rb and Pb contents of feldspars from granitic pegmatites are relatively high but the syenitic pegmatite is more enriched in Fe, Ba and Sr.

Considering this fact along with other chemical characteristics of feldspars, it can be suggested that chemical fractionation resulted in forming the syenitic pegmatite at the initial stage. Further, the obtained chemical data show that the parental magma of the present pegmatite was primitive. Field relationships and the correlation of K/Rb vs. Rb of feldspars suggest that the studied pegmatites may have derived from crustal anatexis processes and are the product of a single source.

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