# THE GEOCHEMISTRY AND MINERALOGY OF ZIRCONS FROM SRI LANKA

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A total of 51 sediment samples and 40 rock samples from the main gem fields of Sri Lanka have been analysed for their Zr contents. The results indicated a marked enrichment of Zr in the sediments as against the probable source rocks. Fortynine zircon separates from the gem-bearing sediments were analysed by electron microprobe and neutron activation for their trace and rare-earth element concentrations. Of the green, yellow, violet and rose zircon varieties studied, the green zircons showed relatively high enrichment in Th, U and Hf. Chondrite-normalized REE plots for five zircon separates revealed markedly similar patterns with HREE enrichments. The similarity of the plots could well indicate a similar source of origin for the zircons. Seven zoned zircons were also studied for their elemental composition. Even though there were periodic changes in the elemental composition within one zone, there were, on an average, no distinct elemental variations from the rim to the core of the zircon grain.

Key words: sediments, rocks, zircon, chemical composition, rare earths, Sri Lanka, Ratnapura, Elahera.

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## Introduction

Zircon has been studied extensively as an accessory mineral in rocks. Being much used as an indicator of petrogenesis, zircons are studied for their ages, REE concentrations, shapes and colours, as well as concentrations of many trace elements. Numerous attempts have been made to correlate the trace element chemistry of zircons and other accessory minerals with their geological environments (Fleischer and Altschuler 1969; Puchelt and Emmermann 1976; Exley 1980; Murali *et al.* 1983). Further, zircon is also considered to be a gem mineral and certain varieties are often subjected to detailed physical and chemical investigations.

The gem-bearing sediments of Sri Lanka are well-known throughout the world for their diversity of gemstones, especially varieties of corundum, chrysoberyl, spinel, garnet, tourmaline and topaz. Zircon is ubiquitous in these gem-bearing sediments, and yellow, green, violet and rose varieties are often observed. However, very little work has been done so far on the trace element geochemistry and mineralogy of these zircons from Sri Lanka.

This paper highlights the significant mineralogy, and the trace element concentrations and

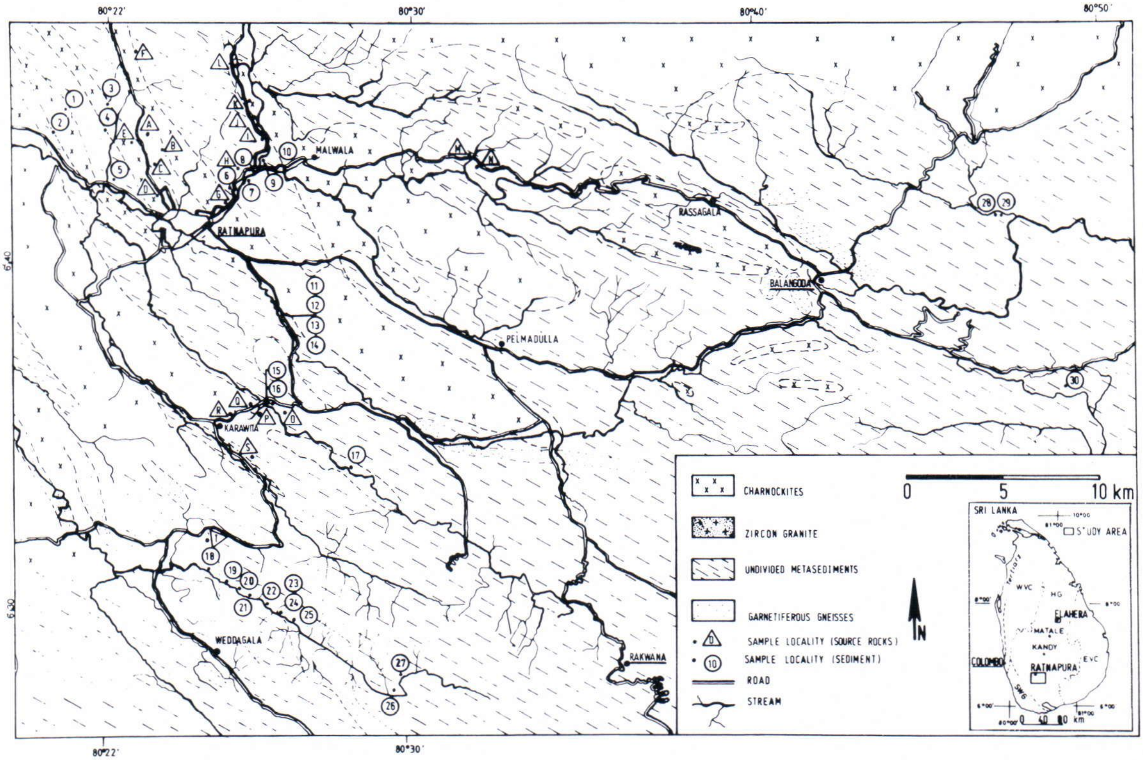


Fig. 1. The geology of the Ratnapura gem field of Sri Lanka showing sampling locations. The inset shows the study areas with respect to the main geological divisions of Sri Lanka.

their variations in the zoned and ordinary zircon minerals from the gem-bearing sediments of Sri Lanka.

## Study areas

Figure 1 (see inset) shows the location of the study areas with respect to the major geological divisions of Sri Lanka. The bulk of the island is composed of Precambrian metamorphic rocks, which are subdivided into the following major divisions (Cooray, 1978):

(a) Highland Group (Pyroxene-granulite facies) consisting of charnockites, quartzites, marbles, garnetiferous gneisses, hornblende gneisses, granulites and pegmatites;

(b) Vijayan Complex (amphibolite-granulite facies) consisting of hornblende biotite gneisses, migmatites and granites;

(c) South-West Group (cordierite-granulite facies) composed of cordierite gneisses, wollastonite scapolite rocks and calc gneisses.

Figure 1 illustrates the geology of the Ratnapura, Rakwana and Balangoda areas. Except for scattered patches of alluvium, the areas included in the Ratnapura and Rakwana topographic sheets consist of Precambrian metamorphic rocks of the charnockite-metasedimentary type. The major rock types are charnockites, garnet-sillimanite granulites, amphibolite and perthite-bearing garnet-biotite granulitic gneisses, with charnockites and the pelitic garnet-sillimanite granulites being the dominant types. Also of importance are intrusive rocks of the zircon granite type, and vein quartz and pegmatites.

The Ratnapura and Rakwana gem field is an expanse of Pleistocene or sub-recent alluvium containing patches or streaks of gravel of Heavy

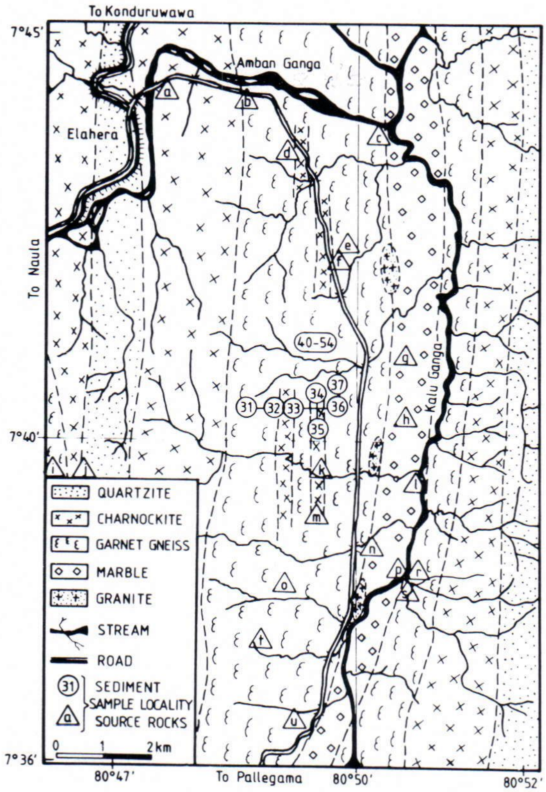


Fig. 2. The geology of the Elahera gem-bearing area showing the sampling locations.

minerals laid down in the beds of streams, in flood plains, in the beds of abandoned tributaries or in talus fans at the foot of the steep slopes of hillsides (Wadia and Fernando 1945). Lenses of layers of gravel deposited during periods of intense flooding carry with them numerous heavy minerals, including gems denuded from an extensive catchment area.

Figure 2 shows the geology of the Elahera gem field in northeastern Sri Lanka, which is characterized by ridge and valley topography in a plunging synclinal structure. Silva (1976) reported the occurrence of granites and pegmatites in the area. The general rock types consist of quartzite, marbles and garnet-sillimanite biotite gneisses with tourmaline and charnockites. Tourmalinization of the garnetiferous gneisses is especially pronounced. The gem-bearing surficial material in the area consists predominantly of laterites but also of sandy gravel.

## Sampling and analytical techniques

Fifty-one sediment samples and 40 fresh rock samples were collected from the localities shown in Fig. 1 and 2. All the sediment samples were extracted from existing gem pits dug into buried river beds in the region. The pay gravel layers, or »Illams» as they are known locally in Sinhalese, are usually composed of rounded or subangular pebbles or boulders of quartz, heavy minerals and gem stones.

Fifteen to 25 buckets of »Illam» were taken from each pit and washed until the clay was removed. The remaining portion, locally termed »Nambuwa», was placed in polythene bags. An average sample weighed from 10 to 15 kg.

Fresh rock samples weighing about 5 kg were collected from quarries, road cutting and natural outcrops in the area.

In the separation of Zircon from other minerals in the »Nambuwa», the following techniques and instruments were used in addition to visual identification:

— Geiger-Müller counter
— density measurements
— RI (refractive index) measurements
— X-ray diffractometer.

For the chemical analyses, sediment samples and rock samples were crushed and sieved, carefully avoiding all possible contamination. The $<0.063$ mm size fractions were dissolved in order to analyse them with Inductively Coupled Plasma spectrometry (ICP) using a Bausch-Lomb ARL instrument. The analytical accuracy, checked against standard sediment samples, gave a relative standard deviation of $\pm 5$ %.

About 50 zircon grains were divided into four different colours, green, yellow, rose and violet. These sets were mounted in brass rings and analysed using a CAMECA CAMEBAX MICROBEAM (Microprobe). At least three points

Table 1. The contents of Zr and other elements in the Ratnapura gem-bearing sediments (see Fig. 1 for locations)

| RATNAPURA sed. sample | Li ppm | $Na_2O$ % | $K_2O$ % | Rb ppm | Be ppm | MgO % | CaO % | Sr ppm | Ba ppm | $Al_2O_3$ % | Zr ppm | $TiO_2$ % | V ppm | Cr ppm | Mn ppm | $Fe_2O_3$ % | Co ppm | Ni ppm | Cu ppm | Zn ppm | $SiO_2$ % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 51 | 0.55 | 2.31 | 112 | 7 | 2.81 | 2.32 | 100 | 370 | 21.92 | 971 | 2.07 | 263 | 319 | 364 | 9.88 | 43 | 337 | 114 | 242 | 43.65 |
| 2 | 36 | 0.38 | 1.94 | 75 | 6 | 0.93 | 1.01 | 85 | 694 | 18.97 | 620 | 2.47 | 194 | 187 | 298 | 8.44 | 35 | 136 | 54 | 215 | n.a. |
| 3 | 29 | 0.54 | 3.54 | 92 | 7 | 0.63 | 0.46 | 141 | 1228 | 20.92 | 707 | 2.25 | 185 | 381 | 1007 | 17.00 | 82 | 182 | 40 | 254 | n.a. |
| 4 | 46 | 0.34 | 2.64 | 258 | 11 | 0.32 | 0.25 | 84 | 811 | 24.90 | 500 | 1.30 | 179 | 305 | 309 | 6.25 | 67 | 119 | 45 | 158 | 54.84 |
| 5 | 64 | 0.32 | 2.12 | 168 | 6 | 0.65 | 0.36 | 76 | 643 | 26.06 | 536 | 1.32 | 264 | 251 | 301 | 6.52 | 43 | 238 | 87 | 263 | 44.48 |
| 6 | 52 | 0.41 | 4.70 | 175 | 7 | 0.44 | 0.23 | 93 | 937 | 23.05 | 298 | 0.39 | 134 | 136 | 264 | 12.60 | 45 | 130 | 54 | 205 | 43.10 |
| 7 | 20 | 0.65 | 1.89 | 75 | 4 | 0.48 | 0.46 | 141 | 540 | 22.22 | 560 | 0.82 | 248 | 363 | 279 | 19.81 | 48 | 172 | 121 | 240 | 43.53 |
| 8 | 23 | 0.11 | 1.73 | 140 | 5 | 0.50 | 0.19 | 80 | 558 | 21.65 | 503 | 1.18 | 203 | 257 | 604 | 13.13 | 62 | 105 | 79 | 185 | 47.44 |
| 9 | 23 | 0.13 | 1.14 | 90 | 13 | 0.84 | 0.07 | 80 | 425 | 35.75 | 226 | 1.25 | 230 | 200 | 291 | 7.35 | 12 | 112 | 49 | 120 | 43.49 |
| 10 | 30 | 0.46 | 2.55 | 84 | 4 | 0.55 | 0.21 | 82 | 522 | 22.26 | 491 | 1.28 | 220 | 168 | 293 | 12.64 | 20 | 140 | 53 | 140 | 42.94 |
| 11 | 26 | 1.02 | 0.86 | 161 | 5 | 1.00 | 0.77 | 79 | 487 | 18.12 | 201 | 0.43 | 210 | 116 | 273 | 14.09 | 52 | 182 | 41 | 342 | 50.81 |
| 12 | 29 | 0.11 | 0.87 | 102 | 8 | 0.21 | 0.40 | 61 | 168 | 27.74 | 446 | 2.05 | 424 | 342 | 308 | 14.83 | 17 | 280 | 57 | 177 | 42.73 |
| 13 | 21 | 0.10 | 0.65 | 34 | 4 | 0.05 | 0.06 | 84 | 192 | 20.41 | 507 | 1.11 | 270 | 158 | 347 | 15.36 | 30 | 107 | 92 | 164 | 50.42 |
| 14 | 33 | 0.09 | 0.29 | 150 | 8 | 0.27 | 0.58 | 100 | 170 | 32.61 | 465 | 1.78 | 363 | 240 | 703 | 18.38 | 28 | 202 | 117 | 205 | 35.86 |
| 15 | 49 | 0.70 | 1.02 | 58 | 7 | 3.52 | 2.42 | 57 | 616 | 17.31 | 385 | 0.51 | 113 | 81 | 3415 | 18.59 | 40 | 191 | 82 | 237 | 42.91 |
| 16 | 64 | 0.45 | 1.29 | 92 | 11 | 3.39 | 2.63 | 150 | 999 | 17.95 | 242 | 0.71 | 130 | 155 | 3833 | 16.59 | 54 | 156 | 100 | 301 | 47.07 |
| 17 | 30 | 0.19 | 0.95 | 126 | 4 | 0.24 | 1.26 | 101 | 667 | 23.58 | 414 | 1.04 | 271 | 333 | 527 | 10.34 | 104 | 179 | 117 | 399 | 48.28 |
| 18 | 49 | 0.24 | 2.24 | 40 | 9 | 0.15 | 0.18 | 84 | 669 | 25.36 | 691 | 2.29 | 216 | 251 | 375 | 8.09 | 100 | 203 | 56 | 389 | 47.07 |
| 19 | 59 | 0.66 | 1.99 | 109 | 5 | 0.81 | 0.46 | 127 | 1100 | 28.70 | 842 | 0.73 | 140 | 105 | 941 | 13.91 | 120 | 166 | 88 | 458 | 41.90 |
| 20 | 31 | 0.11 | 0.81 | 60 | 2 | 0.29 | 0.20 | 109 | 184 | 28.76 | 285 | 1.06 | 174 | 165 | 351 | 16.92 | 24 | 117 | 63 | 145 | 29.10 |
| 21 | 15 | 0.05 | 0.32 | 19 | 6 | 0.08 | 0.06 | 50 | 201 | 30.69 | 614 | 1.46 | 218 | 154 | 60 | 6.96 | 4 | 155 | 47 | 25 | 45.16 |
| 22 | 34 | 0.67 | 1.72 | 103 | 3 | 0.66 | 0.63 | 89 | 712 | 26.15 | 314 | 1.47 | 237 | 212 | 2454 | 13.11 | 146 | 152 | 53 | 157 | 36.76 |
| 23 | 16 | 0.32 | 4.42 | 186 | 2 | 0.07 | 0.07 | 131 | 1025 | 26.08 | 469 | 0.53 | 92 | 82 | 297 | 12.31 | 13 | 161 | 51 | 119 | 46.98 |
| 24 | 28 | 0.11 | 1.24 | 48 | 9 | 0.38 | 0.06 | 80 | 659 | 27.78 | 290 | 1.03 | 184 | 161 | 308 | 17.49 | 18 | 84 | 67 | 138 | 31.34 |
| 25 | 22 | 0.09 | 1.10 | 69 | 12 | 0.16 | 0.09 | 30 | 330 | 31.38 | 436 | 1.00 | 185 | 129 | 290 | 3.58 | 6 | 103 | 38 | 93 | 47.22 |
| 26 | 18 | 0.12 | 0.59 | 114 | 3 | 0.11 | 0.11 | 103 | 301 | 25.26 | 344 | 1.00 | 281 | 400 | 1251 | 20.41 | 107 | 199 | 192 | 199 | 36.30 |
| 27 | 20 | 0.08 | 0.35 | 39 | 5 | 0.17 | 0.08 | 51 | 217 | 35.16 | 295 | 1.97 | 253 | 182 | 302 | 7.87 | 9 | 96 | 127 | 87 | 40.29 |
| 28 | 11 | 0.07 | 0.52 | 227 | 3 | 0.05 | 0.05 | 118 | 207 | 23.43 | 292 | 0.92 | 284 | 256 | 727 | 20.11 | 55 | 150 | 135 | 135 | 36.62 |
| 29 | 17 | 0.89 | 2.65 | 98 | 4 | 0.78 | 0.55 | 143 | 662 | 21.39 | 368 | 0.72 | 185 | 335 | 372 | 12.05 | 30 | 192 | 94 | 174 | 48.98 |
| 30 | 29 | 0.45 | 5.34 | 275 | 4 | 0.87 | 0.69 | 136 | 1458 | 21.16 | 202 | 0.62 | 65 | 110 | 421 | 6.19 | 23 | 79 | 13 | 109 | 47.79 |
| Ø | 33 | 0.35 | 1.79 | 112 | 6.13 | 0.71 | 0.59 | 95 | 592 | 24.89 | 450 | 1.22 | 214 | 218 | 719 | 12.69 | 48 | 161 | 77 | 203 | 43.46 |
| Av.sed./Av.shale | 0.29 | 0.27 | 0.46 | 0.63 | 1.52 | 0.37 | 1.96 | 0.61 | 0.82 | 1.21 | 2.57 | 1.31 | 2.07 | 2.72 | 1.71 | 1.83 | 3.68 | 4.02 | 1.54 | 2.13 | 0.72 |
| Av.sed./Av.rock | 1.53 | 0.12 | 0.63 | 0.63 | 2.92 | 0.55 | 0.17 | 0.58 | 0.83 | 2.04 | 4.33 | 1.91 | 2.51 | 10.45 | 1.13 | 2.22 | 4.48 | 7.07 | 2.96 | 1.57 | 0.74 |

Table 2. The contents of Zr and other elements in the Elahera gem-bearing sediments (see Fig. 2 for locations)

| ELAHERA sed. sample | Li ppm | $Na_2O$ % | $K_2O$ % | Rb ppm | Be ppm | MgO % | CaO % | Sr ppm | Ba ppm | $Al_2O_3$ % | Zr ppm | $TiO_2$ % | V ppm | Cr ppm | Mn ppm | $Fe_2O_3$ % | Co ppm | Ni ppm | Cu ppm | Zn ppm | $SiO_2$ % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 31 | 29 | 0.16 | 1.58 | 112 | 6 | 0.91 | 0.39 | 32 | 306 | 32.56 | 440 | 0.86 | 120 | 111 | 1506 | 10.02 | 29 | 107 | 34 | 82 | 40.53 |
| 32 | 68 | 0.22 | 1.05 | 56 | 5 | 0.26 | 0.12 | 10 | 457 | 25.87 | 473 | 0.80 | 156 | 124 | 1865 | 12.66 | 58 | 84 | 36 | 89 | 43.06 |
| 33 | 38 | 0.39 | 3.38 | 99 | 5 | 0.70 | 0.43 | 35 | 412 | 25.09 | 320 | 0.78 | 117 | 110 | 651 | 8.91 | 27 | 95 | 39 | 105 | 47.07 |
| 34 | 46 | 0.24 | 2.49 | 111 | 5 | 1.14 | 0.31 | 47 | 336 | 25.41 | 142 | 0.68 | 148 | 133 | 567 | 13.37 | 36 | 99 | 38 | 160 | 42.78 |
| 35 | 29 | 0.68 | 2.37 | 103 | 5 | 2.43 | 1.87 | 37 | 784 | 19.41 | 397 | 0.67 | 91 | 130 | 2749 | 7.78 | 45 | 105 | 22 | 90 | 49.20 |
| 36 | 25 | 0.81 | 4.73 | 183 | 5 | 0.59 | 0.39 | 28 | 425 | 18.57 | 375 | 0.65 | 107 | 196 | 1332 | 11.20 | 34 | 120 | 32 | 180 | 49.11 |
| 40 | 39 | 0.11 | 0.69 | 448 | 4 | 0.83 | 0.11 | 13 | 197 | 18.02 | 167 | 0.78 | 131 | 177 | 160 | 12.83 | 27 | 67 | 127 | 132 | n.a. |
| 41 | 43 | 0.11 | 0.77 | 435 | 4 | 0.17 | 0.15 | 13 | 391 | 21.80 | 119 | 0.78 | 139 | 127 | 230 | 11.68 | 40 | 66 | 106 | 268 | n.a. |
| 42 | 52 | 0.14 | 0.95 | 571 | 4 | 1.73 | 0.59 | 29 | 1078 | 21.67 | 128 | 0.72 | 130 | 115 | 1110 | 13.12 | 81 | 75 | 111 | 117 | n.a. |
| 43 | 5 | 0.09 | 0.81 | 569 | 4 | 0.32 | 0.21 | 16 | 571 | 22.91 | 136 | 0.80 | 134 | 125 | 650 | 12.63 | 62 | 74 | 96 | 99 | n.a. |
| 44 | 45 | 0.12 | 1.04 | 558 | 4 | 0.32 | 0.20 | 21 | 278 | 27.68 | 141 | 0.78 | 126 | 126 | 200 | 11.78 | 29 | 64 | 61 | 70 | 55.93 |
| 45 | 45 | 0.14 | 1.10 | 269 | 4 | 0.36 | 0.29 | 30 | 394 | 29.93 | 112 | 0.65 | 124 | 99 | 290 | 11.88 | 36 | 55 | 81 | 209 | 53.67 |
| 46 | 39 | 0.08 | 0.43 | 566 | 3 | 0.22 | 0.18 | 10 | 336 | 21.25 | 119 | 0.82 | 159 | 150 | 240 | 14.49 | 53 | 70 | 64 | 102 | 59.55 |
| 47 | 44 | 0.12 | 0.95 | 536 | 3 | 1.00 | 0.13 | 19 | 259 | 22.99 | 132 | 0.78 | 129 | 106 | 250 | 11.76 | 49 | 69 | 58 | 79 | n.a. |
| 48 | 46 | 0.09 | 0.71 | 544 | 4 | 0.32 | 0.15 | 14 | 462 | 24.20 | 106 | 0.82 | 143 | 164 | 400 | 13.54 | 48 | 74 | 135 | 193 | 54.78 |
| 49 | 31 | 0.57 | 0.30 | 104 | 2 | 1.00 | 0.22 | 29 | 549 | 24.41 | 121 | 0.63 | 151 | 130 | 400 | 13.30 | 78 | 49 | 80 | 303 | n.a. |
| 50 | 36 | 0.08 | 0.35 | 525 | 2 | 0.17 | 0.17 | 8 | 357 | 17.85 | 108 | 0.75 | 137 | 126 | 260 | 13.06 | 33 | 59 | 251 | 213 | n.a. |
| 51 | 39 | 0.15 | 0.51 | 488 | 5 | 0.30 | 0.22 | 14 | 250 | 25.88 | 128 | 0.70 | 129 | 171 | 240 | 13.83 | 35 | 60 | 232 | 196 | n.a. |
| 52 | 50 | 0.11 | 0.96 | 569 | 4 | 0.34 | 0.20 | 29 | 405 | 23.93 | 133 | 0.93 | 140 | 146 | 320 | 12.91 | 57 | 81 | 76 | 257 | n.a. |
| 53 | 47 | 0.22 | 0.65 | 163 | 3 | 0.18 | 0.22 | 35 | 278 | 26.26 | 137 | 0.70 | 117 | 117 | 230 | 11.94 | 34 | 61 | 270 | 393 | n.a. |
| 54 | 56 | 0.14 | 1.11 | 567 | 4 | 0.46 | 0.25 | 24 | 330 | 23.75 | 117 | 0.88 | 116 | 106 | 210 | 11.02 | 24 | 70 | 61 | 76 | n.a. |
| Ø | 41 | 0.23 | 1.28 | 360 | 4 | 0.65 | 0.33 | 23 | 422 | 23.78 | 193 | 0.76 | 130 | 133 | 660 | 12.08 | 44 | 76 | 96 | 163 | 49.57 |
| Av.sed./Av.shale | 0.36 | 0.18 | 0.33 | 2.1 | 1 | 0.34 | 1.10 | 0.15 | 0.58 | 1.16 | 1.10 | 0.82 | 1.23 | 1.66 | 1.67 | 1.73 | 3.35 | 1.91 | 1.91 | 1.71 | 0.83 |
| Av.sed./Av.rock | 1.40 | 0.13 | 0.35 | 5.2 | 3 | 0.22 | 0.04 | 0.17 | 0.53 | 2.13 | 1.25 | 1.62 | 1.33 | 14.15 | 0.53 | 2.74 | 0.77 | 1.79 | 8.76 | 0.98 | 0.91 |

sample no. 40—54, data adopted from Henn (1983)

Table 3. The contents of Zr and other elements in the rocks of the Ratnapura gem field

| RATNAPURA Rock samples | | Class 1 | | | | | Class 2 | | | Class 3 | Class 4 | | | | | Class 5 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Li | $Na_2O$ | $K_2O$ | Rb | Be | MgO | CaO | Sr | Ba | $Al_2O_3$ | Zr | $TiO_2$ | V | Cr | Mn | $Fe_2O_3$ | Co | Ni | Cu | Zn | $SiO_2$ |
| | ppm | % | % | ppm | ppm | % | % | ppm | ppm | % | ppm | % | ppm | ppm | ppm | % | ppm | ppm | ppm | ppm | % |
| D | 14 | 3.27 | 4.80 | 294 | 3 | 0.54 | 1.25 | 136 | 590 | 12.04 | 188 | 0.35 | 26 | 16 | 407 | 3.29 | 0 | 16 | 7 | 164 | 71.35 |
| G | 21 | 3.16 | 4.76 | 253 | 2 | 0.54 | 1.49 | 91 | 412 | 11.55 | 113 | 0.36 | 20 | 9 | 330 | 3.13 | 0 | 6 | 4 | 172 | 70.59 |
| J | 22 | 3.47 | 2.52 | 59 | 1 | 0.42 | 2.32 | 219 | 767 | 11.28 | 30 | 0.20 | 14 | 1 | 191 | 1.92 | 0 | 0 | 80 | 88 | 71.70 |
| M | 16 | 3.42 | 5.59 | 344 | 3 | 0.58 | 1.27 | 123 | 536 | 12.66 | 231 | 0.42 | 26 | 5 | 329 | 2.89 | 0 | 11 | 3 | 102 | 69.67 |
| N | 11 | 4.22 | 3.07 | 103 | 2 | 1.25 | 2.19 | 628 | 895 | 14.36 | 335 | 0.31 | 37 | 27 | 302 | 3.53 | 4 | 13 | 48 | 78 | 67.21 |
| O | 20 | 2.41 | 5.44 | 288 | 0.8 | 0.11 | 0.53 | 43 | 180 | 9.14 | 127 | 0.21 | 11 | 4 | 169 | 1.57 | 0 | 10 | 6 | 52 | 75.69 |
| S | 17 | 2.67 | 2.74 | 322 | 5 | 0.06 | 1.27 | 64 | 852 | 11.46 | 129 | 0.40 | 2 | 0 | 611 | 4.91 | 0 | 12 | 5 | 186 | 70.22 |
| C | 15 | 2.81 | 0.47 | 2.2 | 2 | 4.22 | 6.89 | 148 | 41 | 11.85 | 24 | 0.89 | 199 | 52 | 1203 | 9.93 | 30 | 30 | 64 | 103 | 58.80 |
| E | 36 | 2.30 | 0.30 | 0.6 | 0.4 | 6.06 | 10.66 | 148 | 30 | 14.15 | 7 | 0.78 | 284 | 12 | 1659 | 12.37 | 40 | 63 | 30 | 297 | 50.90 |
| K | 10 | 2.51 | 0.95 | 8.0 | 0.1 | 3.07 | 8.11 | 169 | 162 | 10.47 | 14 | 1.52 | 285 | 33 | 1740 | 13.99 | 34 | 30 | 40 | 330 | 59.71 |
| L | 7 | 2.20 | 0.87 | 7.7 | 1 | 2.53 | 7.05 | 197 | 135 | 9.21 | 16 | 1.42 | 311 | 30 | 1322 | 13.42 | 31 | 24 | 23 | 174 | 59.77 |
| Q | 28 | 2.23 | 0.70 | 15 | 0 | 2.00 | 7.58 | 45 | 37 | 12.47 | 44 | 0.96 | 233 | 136 | 1100 | 13.67 | 27 | 70 | 43 | 145 | 58.28 |
| R | 51 | 1.71 | 0.37 | 2.3 | 0 | 1.83 | 6.53 | 230 | 158 | 11.26 | 27 | 2.74 | 234 | 63 | 1454 | 15.25 | 44 | 84 | 99 | 176 | 57.86 |
| I | 35 | 2.97 | 2.40 | 259 | 2 | 0.45 | 1.52 | 113 | 461 | 13.07 | 129 | 0.27 | 15 | 7 | 286 | 2.67 | 0 | 8 | 7 | 61 | 71.64 |
| P | 58 | 2.83 | 3.30 | 161 | 1 | 0.61 | 3.03 | 332 | 3428 | 18.12 | 77 | 0.55 | 26 | 5 | 558 | 5.18 | 0 | 9 | 26 | 114 | 61.20 |
| A | 13 | 3.25 | 5.06 | 321 | 3 | 0.44 | 1.13 | 118 | 514 | 11.26 | 224 | 0.36 | 28 | 8 | 255 | 2.64 | 0.8 | 22 | 3 | 62 | 70.67 |
| B | 15 | 2.98 | 4.41 | 267 | 3 | 0.68 | 1.67 | 141 | 594 | 11.00 | 162 | 0.33 | 27 | 10 | 229 | 2.47 | 2 | 17 | 6 | 81 | 72.53 |
| T | 12 | 2.39 | 5.96 | 344 | 1 | 0.41 | 1.30 | 86 | 440 | 11.59 | 251 | 0.57 | 11 | 4 | 293 | 4.22 | 0 | 21 | 2 | 169 | 69.77 |
| F | 14 | 3.99 | 0.54 | 278 | 3 | 0.07 | 1.00 | 162 | 690 | 13.58 | 170 | 0.10 | 6 | 4 | 127 | 0.60 | 0 | 8 | 6 | 84 | 76.80 |
| H | 28 | 2.85 | 2.93 | 264 | 2 | 0.14 | 1.02 | 83 | 426 | 12.57 | 88 | 0.09 | 6 | 1 | 109 | 1.07 | 0 | 0.6 | 22 | 52 | 78.30 |
| Ø | 22 | 2.87 | 2.86 | 179 | 2 | 1.30 | 3.39 | 164 | 567 | 12.15 | 104 | 0.64 | 85 | 21 | 634 | 5.72 | 11 | 23 | 26 | 135 | 66.87 |
| Av.rock. / Av.granite | 0.62 | 0.71 | 0.64 | 1.7 | 0.83 | 1.70 | 1.72 | 0.34 | 0.30 | 0.80 | 0.35 | 1.30 | 2.36 | 2.33 | 2.44 | 2.13 | 2.39 | 4.6 | 2.36 | 1.59 | 0.97 |
| Av.rock. / Av.sed. | 0.67 | 8.20 | 1.60 | 1.59 | 0.33 | 1.83 | 5.75 | 1.73 | 0.96 | 0.49 | 0.23 | 0.52 | 0.40 | 0.10 | 0.88 | 0.45 | 0.23 | 0.14 | 0.34 | 0.67 | 1.52 |

D, G, J, M, N, O, S, acid charnockite. C, E, K, L, Q, R, basic charnockite. I, P, intermedate charnockite. A, B, T, biotite gneiss. F, H, qtz. fsp.gneiss

Table 4. The contents of Zr and other elements in the rocks of the Elahera gem field

| ELAHERA Rock sample | Li | $Na_2O$ | $K_2O$ | Rb | Be | MgO | CaO | Sr | Ba | $Al_2O_3$ | Zr | $TiO_2$ | V | Cr | Mn | $Fe_2O_3$ | Co | Ni | Cu | Zn | $SiO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ppm | % | % | ppm | ppm | % | % | ppm | ppm | % | ppm | % | ppm | ppm | ppm | % | ppm | ppm | ppm | ppm | % |
| u | 14.0 | 1.03 | 2.56 | 171 | 0.0 | 3.97 | 1.48 | 111 | 439 | 14.5 | 145 | 0.29 | 136 | 21 | 1699 | 9.46 | 100 | 56 | 21 | 110 | 61.77 |
| n | 92.5 | 3.04 | 1.17 | n.a. | 3.4 | 3.58 | 6.49 | 298 | 612 | 13.3 | 205 | 2.95 | 155 | 0.0 | 1374 | 15.50 | 51 | 11 | 0.0 | 1275 | 51.85 |
| s | 19.9 | 0.85 | 0.27 | 8 | 3.2 | 2.19 | 8.19 | 159 | 314 | 14.2 | 119 | 0.56 | 110 | 36 | 1061 | 4.72 | 84 | 43 | 0.0 | 103 | 67.28 |
| r | 47.5 | 0.37 | 0.15 | 0.7 | 0.0 | 5.64 | 18.08 | 247 | 639 | 11.4 | 314 | 0.58 | 175 | 0.0 | 6305 | 7.21 | 33 | 73 | 0.0 | 137 | 51.80 |
| t | 0.0 | 2.88 | 9.35 | 374 | 1.9 | 0.00 | 0.29 | 140 | 1350 | 14.6 | 0.0 | 0.00 | 3 | 0.0 | 211 | 0.08 | 60 | 3 | 0.0 | 54 | 71.02 |
| o | 5.8 | 2.58 | 4.12 | 112 | 0.7 | 0.48 | 1.95 | 148 | 792 | 13.1 | 119 | 0.23 | 32 | 0.0 | 374 | 2.31 | 88 | 27 | 0.0 | 92 | 73.34 |
| m | 35.5 | 3.39 | 5.02 | n.a. | 7.0 | 0.15 | 1.25 | 33 | 771 | 13.5 | 131 | 0.03 | 12 | 0.0 | 271 | 0.39 | 93 | 9 | 0.0 | 33 | 74.29 |
| i | 0.0 | 2.74 | 5.07 | 150 | 0.6 | 0.66 | 1.72 | 170 | 455 | 12.6 | 212 | 0.25 | 46 | 0.0 | 359 | 3.63 | 77 | 21 | 0.0 | 48 | 73.06 |
| c | 6.5 | 2.32 | 8.46 | n.a. | 0.8 | 0.00 | 1.76 | 182 | 666 | 13.9 | 118 | 0.01 | 14 | 3 | 291 | 0.29 | 38 | 9 | 0.0 | 52 | 72.33 |
| b | 0.0 | 2.58 | 4.12 | 98 | 1.5 | 1.18 | 1.94 | 166 | 597 | 14.7 | 71 | 0.67 | 70 | 84 | 1437 | 6.89 | 82 | 31 | 0.5 | 84 | 64.63 |
| e | 0.0 | 2.85 | 7.87 | n.a. | 0.7 | 0.00 | 0.73 | 248 | 2048 | 13.8 | 194 | 0.07 | 8 | 0.0 | 238 | 0.54 | 71 | 4 | 0.0 | 52 | 72.11 |
| p | 66.5 | 0.01 | 0.64 | n.a. | 0.0 | 9.05 | 23.77 | 424 | 697 | 2.0 | 45 | 0.19 | 147 | 0.1 | 1930 | 0.97 | 0.0 | 0.0 | 76 | 8 | 10.17 |
| g | 42.3 | 0.29 | 1.90 | n.a. | 1.0 | 1.59 | 20.28 | 237 | 430 | 6.1 | 381 | 0.35 | 178 | 36 | 1410 | 4.64 | 9 | 70 | 0.0 | 807 | 22.58 |
| h | 72.3 | 0.02 | 0.81 | 11 | 0.0 | 3.26 | 19.56 | 212 | 493 | 2.1 | 149 | 0.14 | 128 | 0.0 | 1197 | 0.58 | 0.0 | 63 | 0.0 | 103 | 6.31 |
| l | 76.6 | 0.11 | 0.06 | n.a. | 0.0 | 11.30 | 24.43 | 137 | 401 | 1.1 | 4 | 0.10 | 134 | 0.0 | 1718 | 0.86 | 0.0 | 79 | 0.0 | 4 | 2.11 |
| j | 36.7 | 1.57 | 6.57 | n.a. | 0.6 | 4.39 | 7.46 | 229 | 180 | 12.4 | 75 | 0.89 | 252 | 0.0 | 1833 | 12.90 | 89 | 31 | 57 | 99 | 56.06 |
| k | 9.0 | 2.97 | 4.15 | 93 | 1.3 | 1.21 | 3.25 | 255 | 862 | 14.5 | 191 | 0.45 | 56 | 0.0 | 555 | 3.11 | 83 | 25 | 0.0 | 65 | 70.07 |
| b | 51.2 | 0.24 | 1.36 | 67 | 0.0 | 8.59 | 16.64 | 250 | 478 | 9.6 | 46 | 0.80 | 210 | 0.0 | 1826 | 7.67 | 36 | 97 | 54 | 58 | 49.08 |
| a | 10.1 | 2.50 | 6.29 | 230 | 0.9 | 0.61 | 1.93 | 384 | 3059 | 12.8 | 196 | 0.24 | 36 | 7 | 300 | 2.23 | 79 | 185 | 11 | 59 | 71.31 |
| f | 00.0 | 3.40 | 4.01 | n.a. | 1.7 | 0.57 | 2.33 | 272 | 1281 | 12.5 | 167 | 0.61 | 43 | 0.0 | 628 | 3.79 | 65 | 13 | 0.0 | 74 | 71.46 |
| Ø | 29.3 | 1.79 | 3.70 | 69 | 1.3 | 2.92 | 8.18 | 215 | 793 | 11.1 | 154 | 0.47 | 97 | 9 | 1251 | 4.40 | 57 | 42 | 11 | 166 | 54.63 |
| Av.rock. / Av.sed. | 0.71 | 7.78 | 2.89 | 0.19 | 0.33 | 4.49 | 24.79 | 9.34 | 1.88 | 0.47 | 0.8 | 0.62 | 0.75 | 0.07 | 1.9 | 0.36 | 1.3 | 0.56 | 0.11 | 1.02 | 1.10 |

Gneiss — u, n, s, r, t, o, m, i, c, b, c  Marble — p, g, h, l  Charnockite — j, k, b, a, f  data adopted from Asadi (1985)

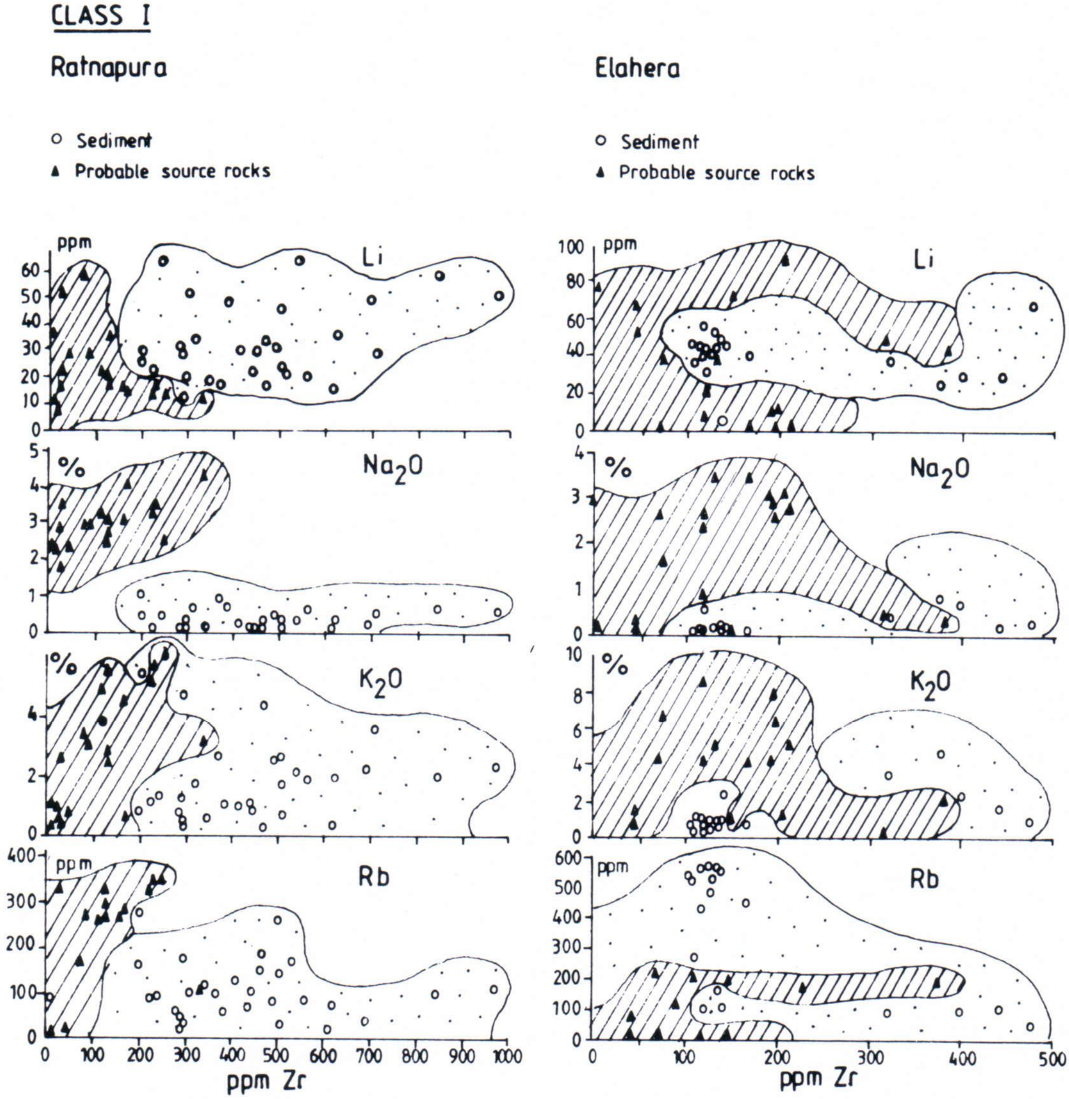


Fig. 3. Variation in Zr versus class 1 elements in sediments and rocks.

on each grain were analysed, taking great care to avoid inclusions and tiny voids.

In zoned zircons, planes cut normal to the c-axes were selected, and three points in each zone were analysed.

Precleaned zircon crystals were irradiated with thermal neutrons for six hours in the TRIGA reactor of Mainz University, West Germany, using a $7.10^{11}$ n $cm^{-2}$ $sec^{-1}$, neutron flux. The grain weights were in the range 0.3—0.5 g. Since the irradiation was not followed by a cooling period, the zircon crystals were transferred immediately to a Ge (Li) detector where the intensities of the X-ray spectra were determined. For details of the method, see Wänke *et al.* (1977) and Blum (1977). The samples were irradiated for

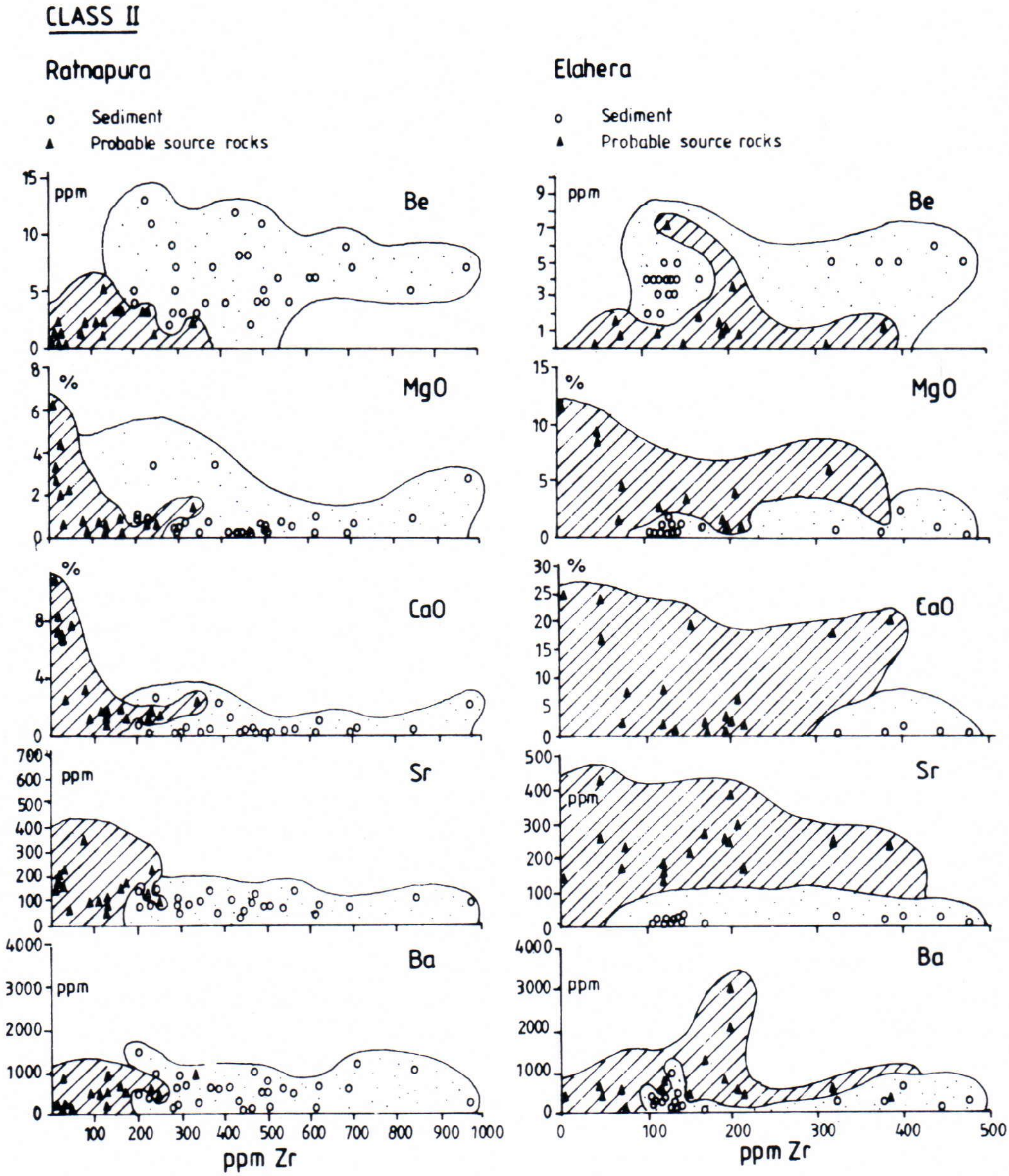


Fig. 4. Variation in Zr versus class 2 elements in sediments and rocks.

exactly the same length of time and in the same position in the reactor.

Element standards were included to check the specific activities of the elements determined in the unknown samples. The zonation in the zircon crystals was studied with scanning electron microscopy.

## Results and discussion

### *The geochemistry of Zr in gem-bearing sediments and rocks*

Table 1—4 shows the contents of Zr and other elements in the sediments and rocks of the two main gem fields of Sri Lanka, Ratnapura

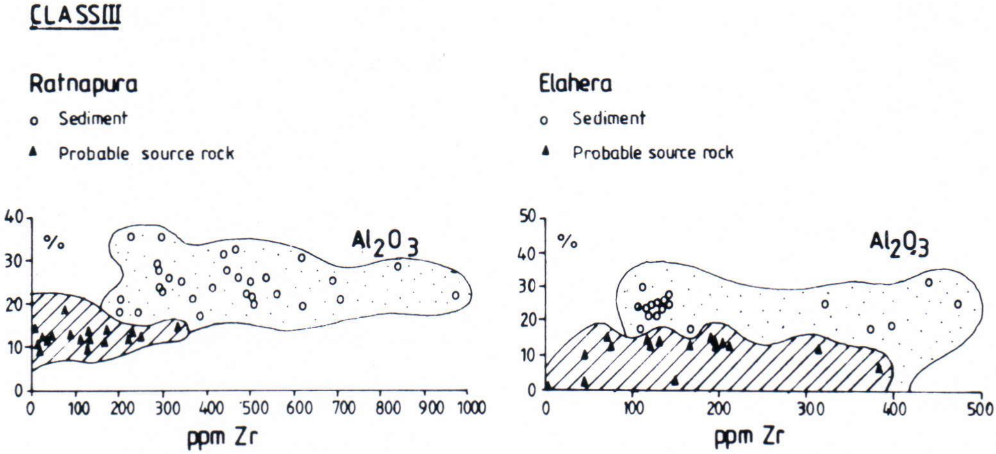


Fig. 5. Variation in Zr versus class 3 elements in sediments and rocks.

and Elahera. The average Zr content of the Ratnapura gem sediments is 450 ppm as against 193 ppm in the Elahera gem field. The enrichment factors denoted as average sediment/average shale and average sediment/average rock for the Ratnapura sediments are 2.57 and 4.33, respectively. At Elahera they are 1.10 and 1.85, respectively, indicating a marked enrichment of Zr in the Ratnapura gem-bearing sediments. The difference in the geochemical behaviour of Zr in the probable source rocks and gem-bearing sediments is best illustrated by plots showing the variation of Zr versus the other elements. These elements could be grouped into four classes as follows:

Class 1: Li, Na, K, Rb
Class 2: Be, Mg, Ca, Sr, Ba
Class 3: Al
Class 4: Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn

Figure 3 gives the variation diagrams for Zr versus the class 1 elements Li, Na, K and Rb for the Ratnapura and Elahera gem fields. The clusters for the sediments and the probable source rocks for these alkali elements are clearly demarked, particularly for the Ratnapura gem field. In general, the element to Zr ratio is much greater in the rocks owing to their smaller Zr concentration.

Figure 4 shows the variation diagram for Zr versus the class 2 elements Be, Mg, Ca, Sr and Ba. As with the class 1 elements, there is a marked difference in trends, Mg, Ca and Sr in particular showing that the behaviour of these elements with Zr is not the same in the sediments as in the rocks. The class 3 element Al shows a positive variation with Zr in both sediments and rocks (Fig. 5).

The transition elements, all in class 4, show similar geochemical behaviour with Zr. In the Ratnapura sediments in particular, these elements exhibit an apparently negative correlation in the probable source rocks, whereas in the sediments the correlation is positive. The Elahera trends, however, are less conspicuous than the Ratnapura ones (Fig. 6).

## Electron microprobe analysis of zircons

A total of 49 zircon samples comprising 21 green, 11 violet, 12 yellow and five rose varieties were analysed by electron microprobe. At a rate of three points per sample, a total of 147 points were analysed for Si, Fe, Zr, Hf, Th and U. As shown in Table 5, the four colour varieties have different concentrations of the elements studied. The green zircons are relatively enriched in Hf,

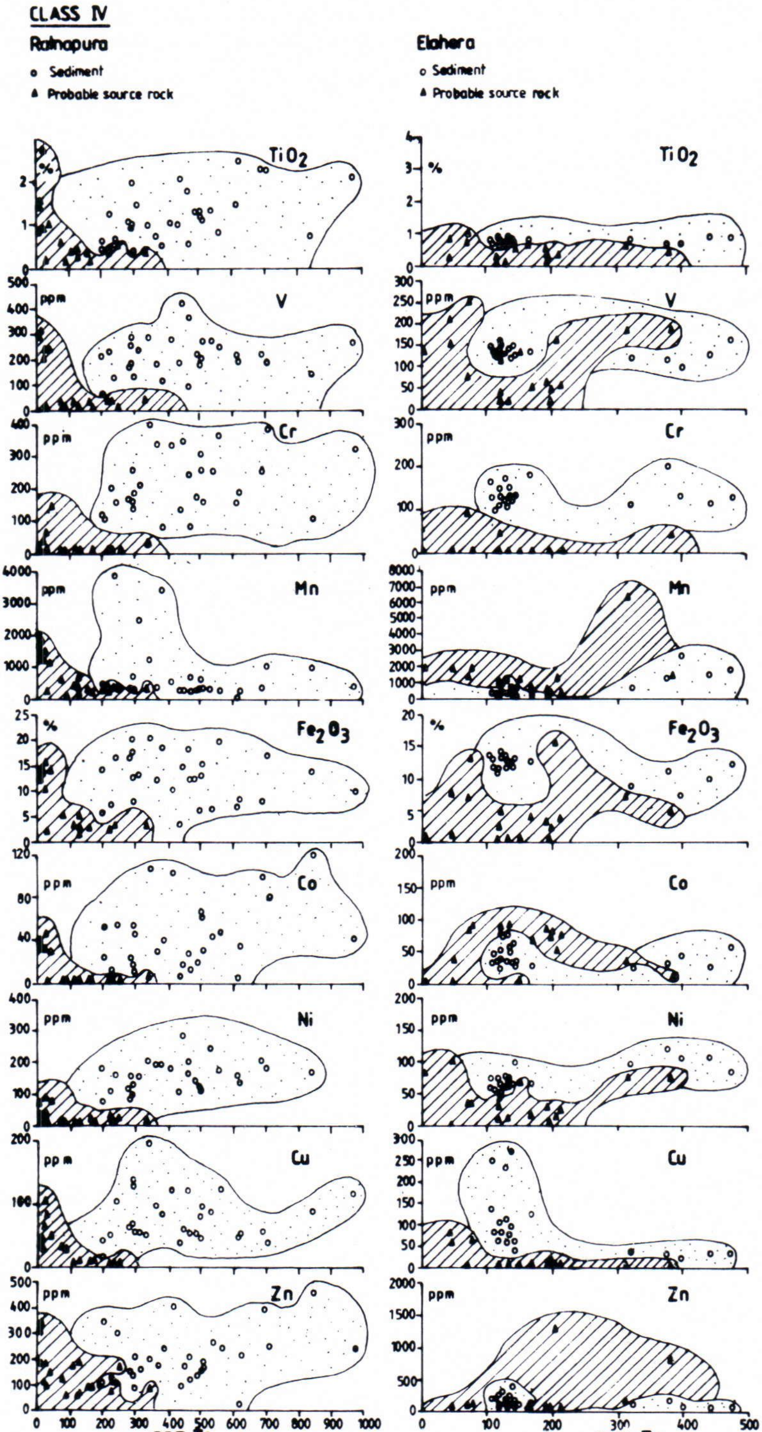


Fig. 6. Variation in Zr versus class 4 elements in sediments and rocks.

Table 5. Elemental composition of the four varieties of 49 zircons from Sri Lanka

| | Si % | Fe % | Zr % | Hf % | Th % | U % | U/Fe | Zr/Hf |
|---|---|---|---|---|---|---|---|---|
| Green | 15.87 | 0.067 | 47.69 | 1.436 | 0.112 | 0.410 | 6.139 | 33.21 |
| Violet | 16.02 | 0.017 | 48.64 | 1.007 | 0.084 | 0.113 | 6.653 | 48.31 |
| Yellow | 15.67 | 0.021 | 48.25 | 1.193 | 0.074 | 0.136 | 6.476 | 40.44 |
| Rose | 15.82 | 0.025 | 48.64 | 1.084 | 0.060 | 0.119 | 4.760 | 44.87 |
| | Zr/Th | Zr/U | Th/U | Hf/Th | Hf/U | Zr/Si | Zr/Fe | Th/Fe |
| Green | 426.7 | 116.5 | 0.273 | 12.84 | 3.51 | 3.00 | 751 | 1.672 |
| Violet | 579.1 | 430.1 | 0.742 | 11.99 | 8.90 | 3.04 | 2861 | 4.941 |
| Yellow | 652.0 | 354.8 | 0.574 | 16.12 | 8.77 | 3.08 | 2298 | 3.524 |
| Rose | 810.6 | 408.7 | 0.504 | 18.07 | 9.11 | 3.07 | 1946 | 2.400 |

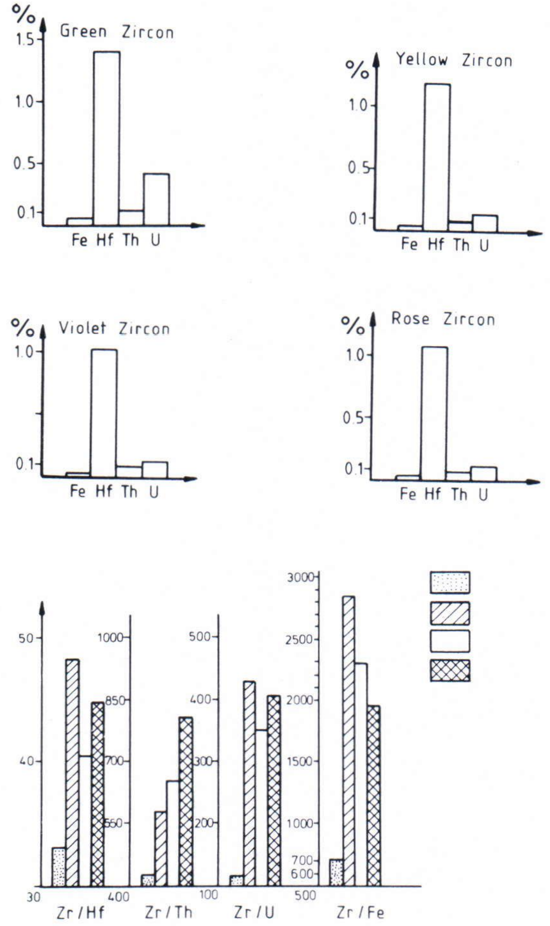


Fig. 7. Histograms showing the Fe, Hf, Th and U contents and their ratios to Zr in the four varieties of zircons.

Th and U, whereas the rose and violet varieties show low Hf, Th and U concentrations. The average Zr/Hf ratio of terrestrial rocks is approximately 40 (Brooks 1970), which is known to increase with differentiation, increasing alkalinity, volatile content and silica undersaturation (Pavlenko *et al.* 1957). As shown in Table 5 and Fig. 7, the green variety has the lowest Zr/Hf ratio of 33, and the violet type the highest ratio

Table 6. The REE contents of some zircons from Sri Lanka

| Sample* | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Ce | — | — | — | — | — |
| Pr | — | — | — | — | — |
| Nd | — | — | — | — | — |
| Sm | 0.25 | 1.12 | 1.34 | — | — |
| Eu | 0.08 | 0.27 | 0.35 | 0.51 | 0.48 |
| Gd | — | — | — | — | — |
| Tb | 0.16 | 0.55 | 0.63 | 2.20 | 1.80 |
| Dy | 1.42 | 6.68 | 5.14 | 19.40 | 17.78 |
| Ho | 0.50 | 2.42 | 1.92 | 8.30 | 5.30 |
| Er | 2.40 | 9.71 | 7.14 | — | — |
| Tm | — | — | — | — | — |
| Yb | 3.58 | 10.74 | 9.33 | 74.00 | 34.58 |
| Lu | 0.70 | 2.05 | 1.41 | 16.00 | 6.11 |
| La | — | — | — | 0.40 | 0.37 |
| Σ REE | 9.09 | 33.54 | 27.26 | 120.81 | 45.42 |
| Sc | 35.04 | 90.78 | 91.03 | 11.60 | 18.12 |
| Mn | 0.41 | 0.28 | 0.49 | 4.00 | 6.06 |
| Ta | 2.11 | 2.32 | 2.05 | 1.00 | 2.12 |
| U | 6.68 | 18.50 | 14.32 | 2410.00 | 1168.61 |
| Th | 12.18 | 8.50 | 7.43 | 425.00 | 761.00 |
| Hf | 1.14% | 0.90% | 1.13% | 2.00% | 1.76 |
| Co | — | — | 0.34 | — | — |
| W | — | 0.91 | 2.76 | — | — |
| Ga | — | 0.25 | — | — | 6.9 |
| Ir | — | — | 0.85 | — | — |
| Fe | 0.002% | 0.002% | 0.002% | 0.01% | 0.02% |
| Na | — | — | — | 6.00 | 19.00 |
| K | — | — | — | 15.00 | — |
| Zr | n.a. | n.a. | n.a. | 46.90% | 47.25% |

* content in ppm unless marked otherwise
n.a. — not analysed
1, 2, 3 — Analyst Schwarz, D
4, 5 — Analyst Rupasinghe, M.S.

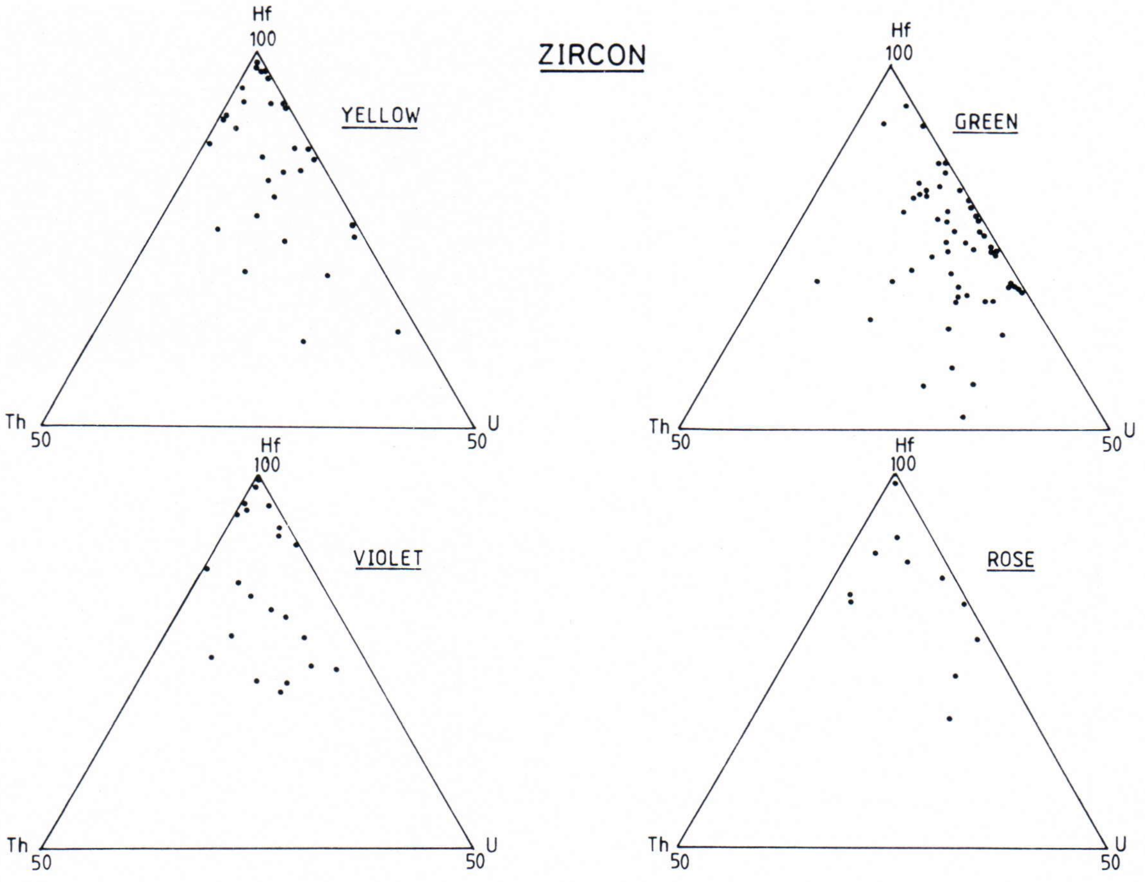


Fig. 8. Hf — Th — U ternary diagrams for the four varieties of zircons.

of 48. Further, the green zircons exhibit the lowest Zr/Th and Zr/U ratios in contrast to the rose and violet types. A noteworthy feature of the green zircons is their low Hf/U ratio of 3.51 as against 9.11 in the rose type, a decrease by a factor of three. The variations in Th, U and Hf are illustrated in the ternary diagrams (Fig. 8).

## REE and other trace elements

Table 6 shows the REE contents of some Sri Lanka zircons. As expected there is a general preference for HREE (Eu—Lu) and the total REE content varies from 9.09 to 120.81. Figure 9 illustrates the chondrite-normalized REE plots for the samples studied. Work by Nagasawa (1970), Puchelt and Enmermann (1976), and Irving and Frey (1978) have shown that the same mineral — whether zircon, garnet or apatite — from different rock types exhibits different mineral/chondrite REE patterns. The differences in the REE content of a specific mineral reflect differences in the bulk rock REE content and variations in REE partition coefficients as a function of pressure, temperature and composition (Murali *et al.* 1983). Accordingly, the similarity between REE plots of the zircons in this study indicates a common source for the gem-bearing sediments.

On account of its similar ionic radius, co-ordination number and electronegativity, scandium, $Sc^{3+}$ tends to substitute for $Zr^{4+}$ and $Hf^{4+}$ in

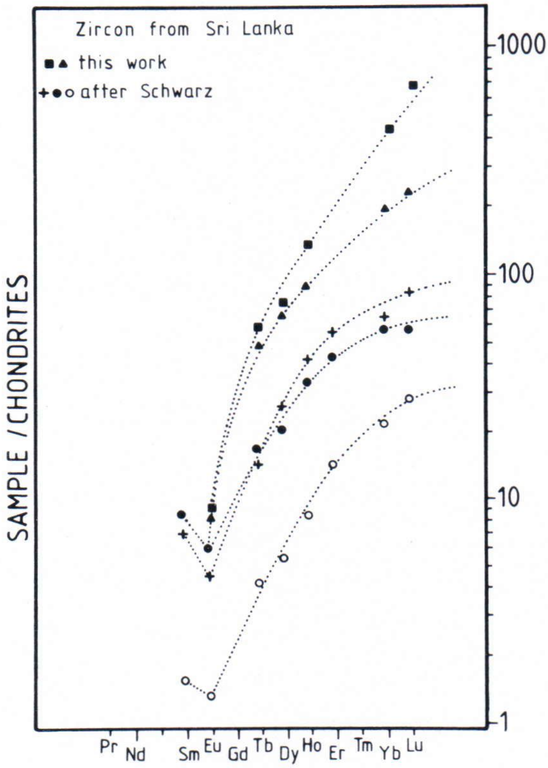


Fig. 9. Chondrite-normalized rare earth elements plots for some zircons in Sri Lanka.

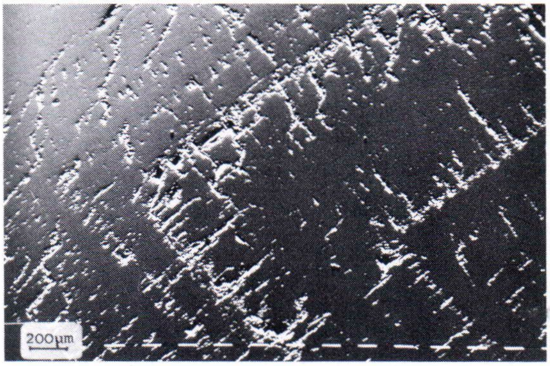


Fig. 10. Electron microscope image of zoned zircon from Sri Lanka.

Table 7. The correlation matrix for elements in zoned and ordinary zircons. Zircon from Sri Lanka, correlation coefficients

| | Si | Fe | Zr | Hf | Th | U |
|---|---|---|---|---|---|---|
| Si | 1.000 | | | | | |
| Fe | 0.287 | 1.000 | | | | |
| Zr | —0.308 | —0.329 | 1.000 | | | |
| Hf | —0.128 | —0.024 | —0.171 | 1.000 | | |
| Th | —0.007 | 0.017 | 0.010 | —0.068 | 1.000 | |
| U | —0.049 | —0.041 | —0.166 | 0.455 | 0.040 | 1.000 |

Zr- and Hf-bearing minerals (Vlasov 1966). The Sc content of the zircons studied varies from 18 to 91. Zircon samples 4 and 5 (Table 5) display a very high concentration of Th, U and Hf and, in this respect, it is of interest to note that some of the placer monazites of Sri Lanka are among the world's most thorium-rich monazites (Overstreet 1967; Rupasinghe *et al.* 1984). Some granitic bodies of Sri Lanka are also known to be rich in uranium.

## Zoned zircons

A total of seven zoned zircons (Fig. 10) were selected for electron microprobe study. Approximately three points per zone were analysed in a total of 159 points. Table 7 shows the correlation matrix for the zoned and normal zircons, there being no significant correlation between any of the element pairs. Figures 11 and 12 illustrate the surface distribution of the elements and their ratios. Note that, although the elements studied exhibit periodic highs and lows of element concentrations within a zone, there is no strong increase or decrease towards the core of the zircon.

## Conclusions

Zircons found ubiquitously in the gem-bearing sediments of Sri Lanka are relatively rich in Th, U and Hf. The green, yellow, violet and rose varieties analysed had varying trace element concentrations, with the green zircons having the highest Th, U and Hf contents. Geochemical

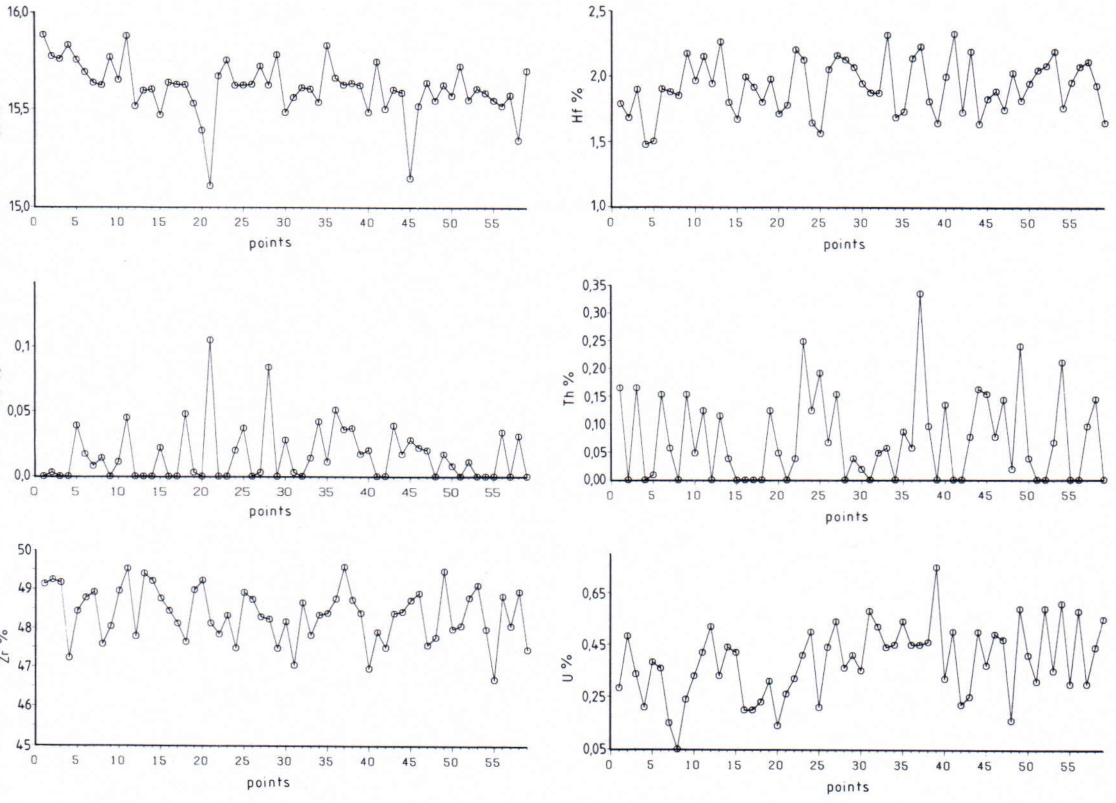


Fig. 11. Elemental variations in zoned zircons.

studies reveal markedly different geochemical behaviour of Zr with respect to other elements in the gem-bearing sediments and in the probable source rocks. In the Ratnapura gem field the Zr contents of the gem sediments are enriched by a factor of four as against the rocks of the gem fields. In the Elahera region, however, this factor is approximately two.

Chondrite — normalized REE plots for selected zircons show a similar pattern with enrichments of the heavy rare-earth elements.

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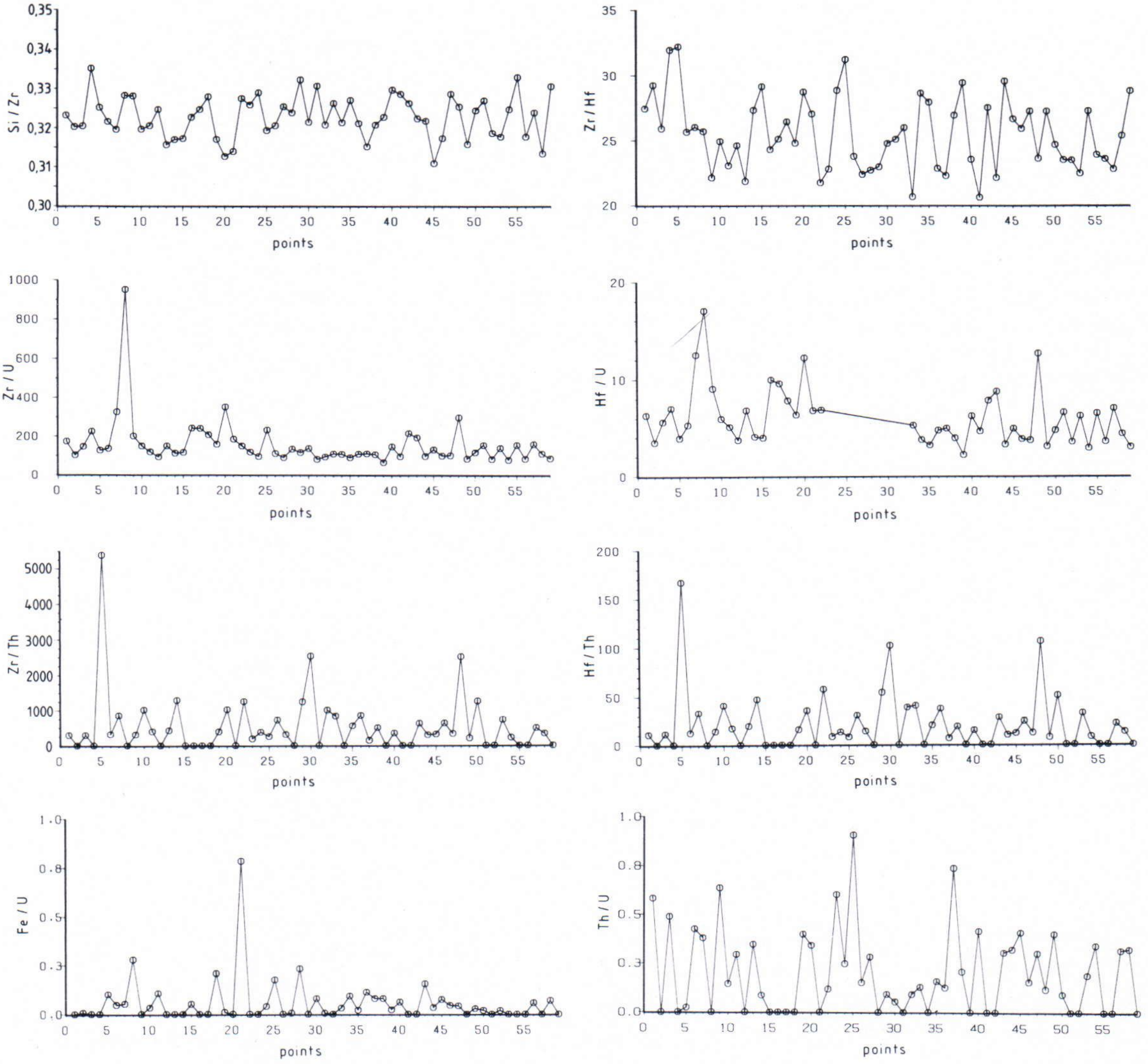


Fig. 12. Variation in elemental ratios in zoned zircons.

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