1. INTRODUCTION

The late Precambrian Damara Orogen of Namibia forms part of the Pan African belt. Models of its evolution - probably on a rifting continental crust - as well as studies on its tectonic, metamorphic and geochemical character are discussed in two monographs edited by Martin and Eder (1983) and Miller (1983). The orogen was affected by only one major regional metamorphism which occurred late-to post-tectonically as shown by the isograds which cut all tectonic structures (Hoffer, 1977). The high-grade Central Zone of the orogen is characterized by low pressure/high temperature metamorphism (anatexis at 2,5-3 kb, Hoffer, 1977; Puhan, 1979) and by the intrusion of numerous large granite plutons whose Rb-Sr whole rock ages lie between 459 and 553 Ma (Haack et al., 1983a, b). This Central Zone contains an abundance of small and large pegmatites some of which are mineralized with Be, Nb, Ta, Li, Sn and U. Their occurrence in the granite-rich zone suggests genetic links with these magmatic rocks either by differentiation or as products of the same thermal event. It is the purpose of this paper to examine Rb-Sr data on the pegmatites and nearby granites in order to test the possible genetic relationship.

2. ANALYTICAL RESULTS

The analytical procedure is described in detail elsewhere (Haack et al., 1980). The calculations are based on the following constants: \( \lambda_{Rb} = 1.42 \times 10^{-11} \text{ a}^{-1} \), common \( \frac{86\text{Sr}}{88\text{Sr}} = 0.1194 \), common \( \frac{84\text{Sr}}{86\text{Sr}} = 0.0572 \), common \( \frac{85\text{Rb}}{87\text{Rb}} = 2.593 \). The value obtained for the Sr standard NBS SRM 987 was 0.71039 ± 0.00022. The Sr ratios were corrected by the factor 0.71014/0.71039. Unless otherwise stated, all errors are 2σ (either the analytical precision or the scatter error, whichever is the larger one).

2.1 Pegmatites associated with the Donkerhuk Granite

The Donkerhuk Granite and its associated white and pink pegmatites were studied, amongst others, by Faulpel (1974), Nieberding (1976) and Sawyer (1978). The pegmatites are of two types: white dykes with abundant

### TABLE 1: Pegmatites associated with Donkerhuk Granite

<table>
<thead>
<tr>
<th>Sample</th>
<th>Type</th>
<th>(^{87}\text{Rb}/^{87}\text{Sr})</th>
<th>(^{87}\text{Sr}/^{86}\text{Sr})</th>
<th>Rb (ppm)</th>
<th>Sr (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R89</td>
<td>white pegmatite</td>
<td>18.59 ± 0.03</td>
<td>0.8534 ± 0.0005</td>
<td>186</td>
<td>28.8</td>
</tr>
<tr>
<td>R82</td>
<td>white pegmatite</td>
<td>20.31 ± 0.05</td>
<td>0.8647 ± 0.0005</td>
<td>246</td>
<td>34.7</td>
</tr>
<tr>
<td>R66</td>
<td>white pegmatite</td>
<td>22.84 ± 0.05</td>
<td>0.8935 ± 0.0002</td>
<td>192</td>
<td>24.5</td>
</tr>
<tr>
<td>R106</td>
<td>white pegmatite</td>
<td>27.76 ± 0.02</td>
<td>0.9209 ± 0.0003</td>
<td>159</td>
<td>16.9</td>
</tr>
<tr>
<td>R97</td>
<td>pink pegmatite</td>
<td>88.58 ± 0.03</td>
<td>1.3583 ± 0.0004</td>
<td>270</td>
<td>9.4</td>
</tr>
<tr>
<td>R56</td>
<td>pink pegmatite</td>
<td>84.0 ± 1.5</td>
<td>1.324 ± 0.0003</td>
<td>244</td>
<td>8.9</td>
</tr>
</tbody>
</table>

Overall analytical precision (2σ) ± 1.2% ± 0.12%

Donkerhuk Granite (Blaxland et al., 1979)

- R110: 2.527, 0.73089, 150, 172.1
- R114: 7.63, 0.76805, 240, 91.5
- R115: 6.118, 0.75756, 174, 83.0
- R116: 2.676, 0.73251, 173, 174.8
- R113: 5.775, 0.78437, 255, 75.9

Age R89–R106 white pegmatites: 533 ± 40 Ma (2σ), \( R_1 = 0.708 ± 0.012 \) (2σ); MSWD = 0.39.

R97 and R568 pink pegmatites: model ages (with \( R_1 = 0.708 \)) 618 Ma.

For comparison: age of Donkerhuk Granite 621 ± 15 Ma, \( R_1 = 0.712 ± 0.001 \) (Blaxland et al., 1979).

Donkerhuk Granite + white pegmatites: 527 ± 6 Ma (2σ), \( R_1 = 0.7113 ± 0.0007 \) (2σ); MSWD = 0.840.
coarse muscovite and spessartine-rich garnet (up to 4 mm in diameter) and pink dykes with only some small thin flakes of muscovite and small garnets (about 1 mm in diameter).

In some of the pegmatites beryl or columbite/tantalite are occasionally found, but most of them are not mineralized. Pegmatites analysed in this study are barren and occur on the farm Onanis along the road from Swakopmund via Anschluß to Windhoek and include material from several different pegmatite veins. The data for the white pegmatites (see Fig. 1, Table 1) plot on an isochron whose slope corresponds to an age of 538 ± 40 Ma with an initial (\(^{87}\)Sr/\(^{86}\)Sr) ratio of 0.708 ± 0.012. Within the limits of error this cannot be distinguished from the result for the Donkerhuk Granite whose age is 521 ± 14 Ma and whose initial (\(^{87}\)Sr/\(^{86}\)Sr) ratio is 0.711 ± 0.001 (Blaxland et al., 1979). If the data points for the granite and the white pegmatites are regressed together the result is: \(t = 527 ± 3\) Ma (2\(\sigma\)), \(R = 0.7113 ± 0.0007\) (2\(\sigma\)), MSWD = 0.84 (analytical error on \(^{87}\)Sr/\(^{86}\)Sr ≤ 0.05 %, on \(^{87}\)Rb/\(^{86}\)Sr ≤ 1 %). The data for the pink pegmatites (triangles in Fig. 1) do not fall on this isochron and were not used for the regression. However, this observation is not necessarily proof of a different origin because they plot only slightly below the isochron. Perhaps some Sr was lost from these samples which consist mainly of feldspar with only very little mica. Therefore, it will be assumed that all pegmatites of the area are cogenetic.

2.2 Li-pegmatite of the Rubicon mine

The Rubicon pegmatite occurs in a medium- to high-grade metamorphic environment south-east of Karibib. It is the largest of several pegmatites which contain abundant Li minerals but also minerals of Be, Bi, Cs, Nb, Ta and a host of rare phosphates. A detailed description is given by Roering and Gevers (1964) and Roering (1964). The main ore bodies at Rubicon are a discontinuous zone of rich Li and Be mineralization stretching for a total length of almost 1 km and, on average, 30-45 m wide. Roering (1964) considers the Rubicon pegmatite as late tectonic and related in space and

**TABLE 2: Data on the Rubicon pegmatite**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Mineral</th>
<th>(^{87})Rb/(^{86})Sr</th>
<th>(^{87})Sr/(^{86})Sr</th>
<th>Rb (ppm)</th>
<th>Sr (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L189</td>
<td>albite</td>
<td>0.07039 ± 0.00008</td>
<td>0.7363 ± 0.0003</td>
<td>1.38</td>
<td>55.8</td>
</tr>
<tr>
<td>L180</td>
<td>k-feldspar</td>
<td>1.5046 ± 0.0022</td>
<td>4.9642 ± 0.0005</td>
<td>5.19</td>
<td>14.1</td>
</tr>
<tr>
<td>L186</td>
<td>muscovite</td>
<td>2057.6 ± 1.8</td>
<td>16.353 ± 0.004</td>
<td>6.834</td>
<td>31.4</td>
</tr>
<tr>
<td>L183</td>
<td>muscovite</td>
<td>24419 ± 161</td>
<td>171.7 ± 0.28</td>
<td>13.192</td>
<td>28.0</td>
</tr>
</tbody>
</table>

Overall analytical precision ± 2% ± 0.32%

Ages: pair K-feldspar/albite: 502 ± 11 Ma, \(R = 0.736 ± 0.002\); pair K-feldspar/muscovite: 493 ± 11 Ma, \(R = 1.69 ± 0.45\); pair muscovite/albite: 497 ± 10 Ma, \(R = 0.736 ± 0.002\).

For comparison: age of nearby Gose Granite 515 ± 20 Ma and \(R = 0.716 ± 0.0006\) (Blaxland et al., 1979).
time to late-tectonic intrusive granites. He concurs with Smith (1965, p. 68) who thinks that the pegmatites of the central Damara Orogen, although locally intrusive, are in general derived from the sediments in their immediate environment.

The minerals of the Rubicon pegmatite are all of gigantic size. Therefore, only minerals, never whole rocks could be analysed. The data are listed in Table 2 and plotted in Fig. 2. The data for amblygonite, K-feldspar and muscovite plot on one straight line whose slope corresponds to an age of 515 ± 36 Ma. The initial (\(^{87}\)Sr/\(^{87}\)Sr) ratio of 0.736 is essentially given by amblygonite. It is remarkable how well this Li-phosphate discriminates against Rb in a Rb-rich environment. As often observed, the point for apatite lies above the intercept indicating that apatite acted as a Sr acceptor for some time after its crystallization. The age of 515 Ma is approximately the mean of the values obtained for the mineral pairs and the same as that for the nearby Salem-type granite on Goas (Blaxland et al., 1976). However, differentiation from the latter is excluded because the initial (\(^{87}\)Sr/\(^{87}\)Sr) ratio of 0.736 of the pegmatite is far too high. It cannot be directly derived by any equilibrium process from the Damaran metasediments either because 515 Ma ago their (\(^{87}\)Sr/\(^{87}\)Sr) ratio was only about 0.717 ± 0.004 (data collected in Table 1, Haack et al., 1983a). On the other hand, derivation from the basement as represented by the Fransfontein and the Abbabis inliers as well as the Etusis Formation is excluded because 515 Ma ago their Sr isotope ratios were between 0.77 and 0.85, i.e. far too high to be the protoliths of the pegmatites (see data collected in Table 4).

### 2.3 Tin pegmatite of the Uis mine

Uis is the only tin deposit of Namibia which is exploited. It consists of several bodies of white pegmatite mineralized with cassiterite. The pegmatite is post-tectonic. The samples which all come from the same pit (K5) consist mainly of large crystals of K-feldspar and muscovite plot on one straight line whose slope corresponds to an age of 496 ± 30 Ma. The Rb-Sr age of 496 ± 30 Ma (Fig. 3) might suggest differentiation from a granite of the type Sorris-Sorris which was dated by Hawkesworth et al. (1983) as 495 ± 15 Ma old. However, this hypothesis has to be rejected because the initial Sr isotope ratios of 0.737 for the pegmatite and 0.709 for the Sorris-Sorris Granite are too different (see Table 3). Calculations show also that it cannot have differentiated from one of the other northern granites either, even if one supposes that the age of 496 is not the intrusion age but indicates some stage of cooling. Even assuming that its real age is 530 Ma does not lower the initial (\(^{87}\)Sr/\(^{87}\)Sr) sufficiently to make this hypothesis plausible. As in the case of the Rubicon pegmatite derivation from the basement is highly improbable for similar reasons.

### 3. DISCUSSION

Dating pegmatites by the Rb-Sr method is notorious for unreliable results because of the loss and redistribution of Sr from the feldspars. However, even if the ages obtained should not necessarily be taken at their face value the data do permit hypotheses on the origin of...
the pegmatites either from granites or from other source rocks.

The data on the barren pegmatites in the vicinity of the Donkerhuk Granite are compatible with the hypothesis that they are differentiates of this granite. For the giant mineralized pegmatite of Rubicon and Uis a similar genetic relationship with nearby granites is excluded. Likewise, any model involving equilibrium partial melting of basement, Etusis or Kuiseb Formation cannot provide melts with an initial Sr isotope ratio of around 0.736. On the other hand, Roering (1964), Roering and Gevers (1964) and Smith (1965) put forward arguments to support the idea that the pegmatites, although locally intrusive, are in general derived from their immediate environment which is the Kuiseb Formation.

How can these mutually exclusive views be reconciled with one another and how can it be explained that the pegmatites are broadly coeval with their nearby granites? One way to raise the initial ratio of the pegmatites is to assume that they existed for 1-2 Ma as separate melts in magma chambers and thus achieved internal Sr equilibration at a high ratio because of their extremely high Rb/Sr ratios. If this is at all a viable possibility, it requires a very static and quiet geological environment. Otherwise such large volumes of liquid could not be kept in a sort of magma chamber for any appreciable length of time and would always escape. The surroundings into which the pegmatites intruded were not static. The area was, on the contrary, in rapid uplift at that time (Haack, 1976). We do, therefore, not favour the model that the pegmatites existed long enough as liquids to allow Sr equilibration. However, this possibility seems unlikely in view of the large size of the crystals (the analysed amphibolite fragment, e.g. was more than 10 cm long and 5 x 3 cm thick).

We propose here a different way to obtain a highly radiogenic initial (87Sr/86Sr) ratio. If a reaction decomposes biotite and the reaction product is removed before it can completely equilibrate its Sr with the restite, an easy way is provided to obtain melts or solutions with highly radiogenic Sr. Biotite does not readily accept Sr but is rich in Rb. Typical (87Rb/86Sr) ratios are 200-1,500. It therefore quickly accumulates radiogenic Sr which will be released to a melt or solution on the decomposition of the biotite. Biotite decomposition reactions occur during high grade metamorphism when cordierite, K-feldspar and melt are formed. The following model calculations may serve to illustrate the point. Let us assume a biotite with the typical (87Rb/86Sr) ratio of 800 had existed for 20 Ma before it decomposed 515 Ma ago. Its (87Sr/86Sr) ratio had increased from 0.715 to 0.942 by then and the whole-rock (B7Sr/86Sr) ratio to 0.717 (initial ratio of granite). Under these assumptions 8% of the total Sr is derived from the biotite. If muscovite is the main decomposing mineral, the proportion of muscovite-derived Sr must be several times higher, because the (87Rb/86Sr) ratios of muscovite generally are <100, often <50.

The proposed mechanism can also explain the high concentration of rare metals in pegmatites because in most rocks these metals are concentrated in biotite (Haack, 1969). Hence, it is the ideal mineral whose decomposition can yield fluids with highly radiogenic Sr which at the same time are enriched in rare elements. In addition, this model explains the contemporaneity with the granites. Both can be derived from the same source rock by the same thermal event, i.e. the peak of regional metamorphism. The difference is that the granites comprise at least a major portion of the parent rock and presumably have more or less equilibrated with their restites. The pegmatites originated from a highly selective disequilibrium process like incipient incongruent melting or high-grade biotite (muscovite) decomposition reactions with a quick removal of the liquid.

4. CONCLUSIONS

Rb-Sr data on granites and associated pegmatites permit evaluation of the differentiation hypothesis. Comparable initial (87Sr/86Sr) ratios suggest that the barren pegmatites associated with the Donkerhuk Granite are most probably differentiates. In contrast, the economically important Sn-pegmatite of Uis and Li-pegmatite of Rubicon cannot be differentiates of nearby granites. They probably owe their origin to the decomposition of biotite (or perhaps muscovite) from metasediments either by melting or by K-feldspar-forming reactions during high-grade regional metamorphism. It might then be asked whether the precondition for the concentration of rare elements in these pegmatites is the presence of a metasediment in which the rare elements were already enriched or whether quite normal concentrations of Li, Be, Sn, etc., are sufficient to form deposits, provided the melts or solutions can accumulate. Perhaps a greater

---

TABLE 4: Data on basement rocks (granitic gneiss) from the 1-2 Ga old Abbabis inlier

<table>
<thead>
<tr>
<th></th>
<th>87Rb/86Sr</th>
<th>87Sr/86Sr (ppm)</th>
<th>Rb (ppm)</th>
<th>Sr (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S159</td>
<td>7.387</td>
<td>0.8991</td>
<td>303.0</td>
<td>121.1</td>
</tr>
<tr>
<td>S163</td>
<td>7.594</td>
<td>0.9080</td>
<td>302.9</td>
<td>117.8</td>
</tr>
<tr>
<td>S164</td>
<td>7.472</td>
<td>0.9034</td>
<td>307.4</td>
<td>121.5</td>
</tr>
<tr>
<td>S165</td>
<td>9.531</td>
<td>0.9207</td>
<td>326.6</td>
<td>101.5</td>
</tr>
</tbody>
</table>

Arithmetic mean 7.996 0.907

Mean (87Sr/86Sr) 515 Maago: 0.849.

For comparison: Mean (87Sr/86Sr) of granitic Fransfontein basement inlier in the North of the central zone 515 Ma ago was 0.786 (based on data by Clifford et al., 1969).

Rb/Sr ages of this inlier 1.547 ± 20 Ma, R = 0.708.

Mean (87Sr/86Sr) ratio of a migmatite of the Etusis formation overlying the Abbabis inlier 515 Ma ago was 0.775 (based on data by Downing and Coward, 1981).
volume of metasediment has to be processed in the case of economic pegmatites.

5. ACKNOWLEDGEMENTS

The major part of this work was conducted as part of the research programme of the Sonderforschungsbereich 48, financed by the Deutsche Forschungsgemeinschaft. The mass spectrometric measurements were made possible by the generous support given to us by the Zentralaboratorium für Geochronologie, University of Münster. We thank especially Prof. Dr B. Grauert and Dr B. Hansen for much help. We thank also Mr F.W. Ekart, Rubicon and Mr T.R. Richards, Uis, for their permission to collect samples. Discussions with R. Brandt and H. Martin and a review by D.L. Reid were of great help.

6. REFERENCES