Petrochemical and mineralogical relationships in the Koperberg Suite, Namaqualand, South Africa

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Abstract

The anorthositic to noritic Koperberg Suite is distinguished by a dispersed mode of occurrence and by primary copper sulfides. Petrographic variation is mainly caused by change in the relative proportions of three rock-forming minerals: andesine, orthopyroxene, and brown mica. Average major-element chemical compositions are calculated for the principal rock types: anorthosite (A), leucodiorite (LD), leuconorite (LN), mica diorite (MD), norite (N), orthopyroxenite (OP), and glimmerite or micaite (GL). The different igneous rock types are petrochemically distinct and not gradationally related, although intimate association in multiple intrusions is common. Two genetically related differentiation series are recognized, one characterized by orthopyroxene (LN, N, OP) and the other typified by brown mica and lack of orthopyroxene (LD, MD, GL). Mineral analyses from the different rock types disclose negligible variation in mineral chemistry for the suite as a whole, with the possible exception of some of the brown mica. The mafic to ultramafic members of both series tend to contain brown mica that is more magnesian (phlogopitic) than the prevalent biotite of the other rock types. The Koperberg Suite probably originated as a mantle-derived basaltic melt that underwent considerable crustal contamination and differentiation at an intermediate level, prior to multiple injection into favorable structures at high level.

Introduction

The Koperberg Suite comprises a swarm of small intrusive bodies, which vary in composition from mafic to intermediate and which occur in a portion of the northwestern part of the Cape Province (Namaqualand), South Africa (Fig. 1). In the past, these occurrences were often collectively referred to as norites or noritoids, even though the most prevalent rock types are anorthosite and diorite. The relatively recent formal term "Koperberg Suite" (Marais, 1980) is derived from the name of a historical hill near the town of Springbok, where a small amount of copper ore was recovered in 1685 from one of the bodies. Excellent detailed geologic and geophysical maps of the entire region of interest have been compiled by the O'okiep Copper Company over many decades and have been summarized by Lombaard et al. (1986).

The overall anorthositic-noritic character of the Koperberg Suite argues for categorization with massif-type anorthosite complexes. Additional features that support such a classification are the age and sequence of intrusion, as well as the high-grade metamorphic environment (Conradie and Schoch, 1986a). However, the Koperberg Suite is distinguished by (1) a dispersed mode of occurrence (numerous small bodies concentrated in an area of 3000 km²), (2) primary copper sulfide ores associated with mafic members of the suite, and (3) mica-rich assemblages such as mica diorite and glimmerite (micaite, biotite perknite), which are associated with the anorthositic-noritic rocks.

Various aspects of the Koperberg Suite were discussed in previous papers, including field relationships (Lombaard and Schreuder, 1978; Lombaard et al., 1986), petrography (Van Zyl, 1967; Conradie, 1983; McIver et al., 1983; Conradie and Schoch, 1986a), ore petrography (Latsky, 1942), isotopic relations (Clifford et al., 1975; Koeppel, 1980; Clifford et al., 1981), mineral chemistry (Stumpfl et al., 1976; Conradie and Schoch, 1986a, 1986b), and REE geochemistry (Conradie and Schoch, 1988). This paper summarizes the chemical and mineralogical properties of the suite as a whole.

Geological setting and field relationships

The Koperberg Suite is exposed in an area of 3000 km² known as the Okiep Copper District (Fig. 1). The suite is manifested as a swarm of short dikes and pipelike bodies that intruded into gneissic granite and metasedimentary rocks of the Proterozoic Namaqua mobile belt. The peak of the regional Namaqua metamorphism reached upper amphibolite to granulite facies and has been dated as ca. 1200 Ma (U-Pb zircon dating, Clifford et al., 1981). Zircon ages of about 1100 Ma for the Koperberg Suite (Stumpfl et al., 1976; Koeppel, 1980; Conradie, 1983) suggest posttectonic or late syntectonic emplacement. Contacts with country-rock gneiss are invariably sharp,
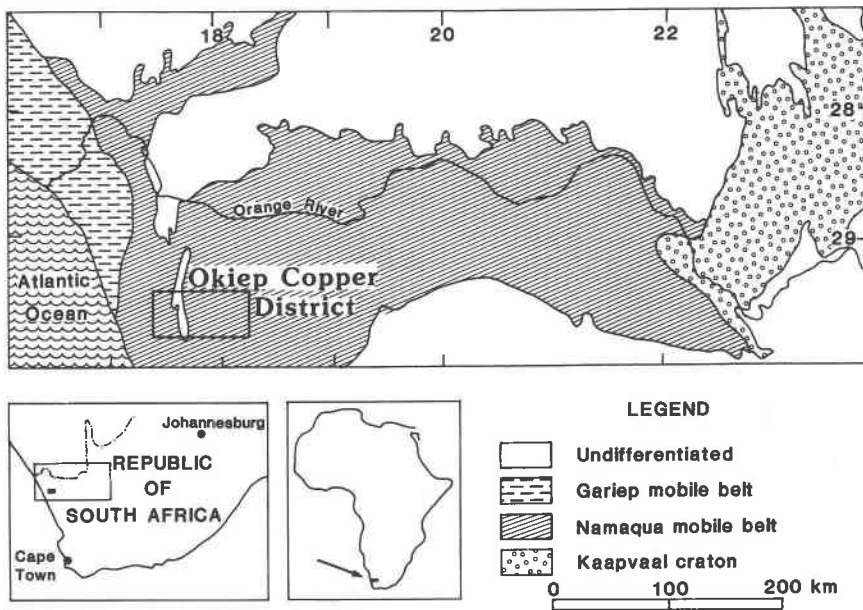
Fig. 1. Locality map. The Koperberg Suite occurs as approximately 1500 intrusive bodies (scale <1 km) dispersed through the Okiep Copper District.

and the absence of chilled margins testifies to the low thermal contrast between magma and environment. In multiple intrusions, the junctions between different members are sharp rather than gradational. Xenoliths of country-rock gneiss are common in the mafic rocks. Autoliths of anorthosite, leuconorite, and leucodiorite often occur in norite, orthopyroxenite, and glimmerite, revealing the intrusive sequence.

The outcrop pattern of the mafic suite reflects plugs and east-northeasterly–trending dikes, prevalently with widths of 50 to 100 m and along-strike dimensions of less than 1 km. The common occurrence of pinch-and-swell structures has been demonstrated by exploration drilling. Although many intrusions appear to taper out at depth, one occurrence (Carolusberg mine, deep ore body) has been traced to almost 2 km beneath the surface. It is still uncertain whether all the intrusives are individually connected to a deep-seated source or whether secondary dispersion occurred from a few primary intrusive centers.

PETROLOGICAL RELATIONS

The petrographical properties of the different intrusive rock types were discussed in detail elsewhere (Conradie and Schoch, 1986a). In summary, the Koperberg Suite is composed of plagioclase, orthopyroxene, and brown mica, with subordinate iron-titanium oxides, apatite, and sulfides. Amphibole and clinopyroxene are virtually absent. Different proportions of plagioclase and ferromagnesian minerals constitute a series of discrete rock types displayed in multiple intrusions. The petrographic classification employed is fundamentally based on the mineral proportions originally proposed by Johannsen (1931).

Thus, for instance, is leuconorite (<22.5% mafic minerals) distinguished from norite (>22.5% mafic minerals).

A recent regional sampling program revealed that anorthosite (andesinite), leuconorite (hypersthene leucodiorite), and biotite leucodiorite are present in roughly equal volume proportions, constituting some 85% of the intrusive suite. The remaining 15% consists of more mafic assemblages such as norite, orthopyroxenite (hypersthenite), biotite diorite, and glimmerite (micaite). The latter term is reserved for rocks with phlogopite in excess of 60 vol%. Rocks that are enriched in iron-titanium oxides and relatively depleted in mafic silicates, including ferrodiorites, occur sporadically. Such assemblages are highly variable in composition, and it is not yet clear whether they represent discrete magma pulses or in situ differentiates. Some iron-titanium oxide rocks also contain abundant apatite and resemble nelsonite (Kolker, 1982). All known ore bodies (±35) are associated with the mafic assemblages, which constitute only 15% of the Koperberg Suite.

In broad perspective, the Koperberg Suite comprises anorthosite associated with two distinct rock series characterized by either orthopyroxene (leuconorite, norite, orthopyroxenite) or brown mica (leucodiorite, mica diorite, glimmerite). The orthopyroxene-bearing rocks invariably contain small amounts of mica, whereas the mica-rich varieties are practically devoid of orthopyroxene.

MINERAL COMPOSITION

The results of detailed petrographic study of all the rock types were discussed elsewhere (Conradie and Schoch, 1986a). The Koperberg Suite is constituted of
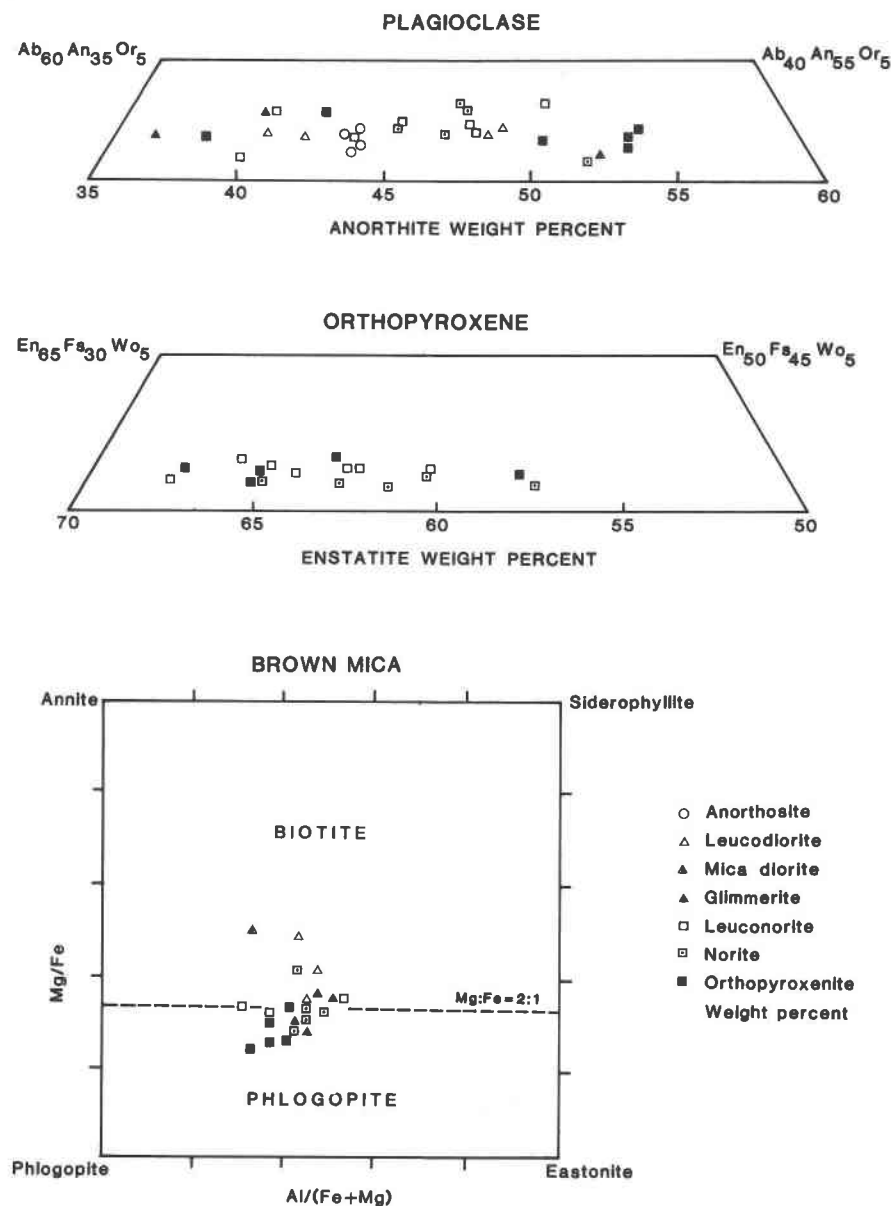
Fig. 2. Diagrams illustrating the restricted variation in chemical composition of rock-forming minerals from various rock types of the Koperberg Suite in terms of end-members.

only a few rock-forming minerals, with apatite and magnetite as the principal accessory minerals. Electron-microprobe analyses of rock-forming and some accessory minerals (plagioclase, orthopyroxene, brown mica, magnetite, ilmenite) for selected samples were made with a JEOL-JXA and a CAMECA CAMEBAX MICROBEAM apparatus. It was previously reported that the variation in mineral composition of the Koperberg Suite is remarkably limited and that the different petrographic types cannot be distinguished in terms of mineral chemistry (Conradie and Schoch, 1986a, 1986b). These conclusions have not changed with the addition of new data. The limited variation in mineral composition is summarized in Figure 2.

The only possible exception is the tendency of the ultramafic rock types (orthopyroxenite, glimmerite) to contain micas that are more phlogopitic, whereas the sheet silicate in the other petrographic units is more biotitic. Preliminary results obtained from detailed study of the glimmerite (Boer, 1989), however, suggest that the brown mica may be predominantly biotitic also in this rock type. The biotite of all rock types is very Ti-rich (TiO$_2$ weight percent varies between 4.5 and 4.9) and has high F/Cl ratios.

CHEMICAL COMPOSITION

Representative samples, collected from about 160 occurrences of Koperberg Suite rocks, were chemically ana-

TABLE 1.   Average compositions of Koperberg Suite rock types

	A n = 16	LN n = 31	LD n = 24	N n = 27	MD n = 9	OP n = 6	GL n = 6
SiO_2	56.88(0.21)	52.29(0.97)	51.45(0.60)	45.11(1.40)	43.62(1.67)	46.09(1.37)	36.87(2.89)
TiO_2	0.09(0.03)	0.46(0.10)	0.74(0.08)	1.46(0.27)	2.41(0.26)	0.47(0.11)	3.52(0.44)
Al_2O_3	24.69(0.23)	21.27(0.66)	21.68(0.40)	14.92(0.61)	15.95(1.30)	4.76(0.79)	13.76(1.03)
Fe_2O_3	0.58(0.14)	2.86(0.74)	2.46(0.35)	7.10(1.14)	5.21(1.01)	7.40(1.47)	3.76(1.36)
FeO	0.64(0.15)	4.55(0.65)	4.10(0.26)	12.26(1.07)	9.88(1.42)	16.08(3.84)	12.18(1.71)
MnO	0.02(0.01)	0.09(0.01)	0.08(0.02)	0.23(0.02)	0.14(0.03)	0.41(0.10)	0.10(0.01)
MgO	0.33(0.19)	2.77(0.33)	1.99(0.18)	6.69(0.59)	5.44(0.81)	17.24(2.05)	10.10(1.05)
CaO	7.58(0.21)	7.40(0.22)	7.39(0.24)	5.79(0.36)	6.20(0.48)	2.58(0.30)	5.15(0.55)
Na_2O	5.66(0.11)	3.81(0.31)	3.75(0.21)	2.17(0.24)	1.78(0.20)	0.46(0.09)	0.72(0.30)
K_2O	1.11(0.07)	0.85(0.06)	1.63(0.14)	0.68(0.06)	2.74(0.38)	0.30(0.04)	5.72(0.53)
P_2O_5	0.03(0.01)	0.23(0.07)	0.29(0.04)	0.64(0.12)	1.24(0.25)	0.99(0.46)	2.39(0.67)
H_2O^+	0.53(0.06)	0.87(0.18)	0.88(0.09)	1.37(0.21)	1.02(0.20)	0.37(0.17)	1.50(0.36)
CO_2	0.19(0.08)	0.39(0.12)	0.71(0.11)	0.66(0.12)	1.17(0.06)	0.60(0.21)	0.61(0.15)
CuO	0.03(0.01)	0.23(0.08)	0.20(0.05)	1.32(0.30)	0.80(0.28)	1.06(0.45)	2.03(0.73)
S	0.01(0.00)	0.09(0.03)	0.13(0.03)	0.96(0.38)	0.76(0.21)	0.50(0.14)	0.82(0.10)
F	0.10	0.10	0.18	0.13	0.14	—	0.64
Total	98.47	98.19	97.48	101.36	98.36	99.31	99.23
S ≡ O	0.00	0.04	0.06	0.48	0.38	0.25	0.41
F ≡ O	0.08	0.08	0.15	0.11	0.12	—	0.54
Total	98.39	98.07	97.27	100.77	97.86	99.06	98.28

Note: n = number of samples. Standard error of the mean, $\sigma/\sqrt{n}$, given in parentheses. A = anorthosite, LN = leuconorite, LD = leucodiorite, MD = mica diorite, N = norite, OP = orthopyroxenite, GL = glimmerite. Average values for H_2O^- and LOI are not considered to be useful and were not calculated. The values for *n* are for all components except Fe_2O_3, FeO, CuO, S, and F, for which fewer values were available. For F, standard errors of the mean are not significant.

lyzed by XRF using a Phillips PW1410 spectrometer and were used for the compilation of Table 1 and Table 2. Major elements were determined on fused discs by aid of the Norrish method (Norrish and Hutton, 1969). The values for Na and trace elements were obtained from pressed briquettes. Average values for volumetrically relatively minor petrographic types such as ferrodiorite have not been calculated because the data are not yet statistically significant.

Because the various petrographic types are mainly distinguished by the relative proportions of mafic minerals, a chemical mafic index (MI) should, in principle, be able to discriminate between them. For this reason, it was decided to employ a mafic index MI = $100(Fe_{Tot} + Mg + Mn + Ti)/(Al + Fe_{Tot} + Mg + Mn + Ti)$ in terms of cation proportions, where Fe_{Tot} represents total Fe. The

TABLE 2.   CIPW norms of average compositions of Koperberg Suite rock types

	A	LN	LD	N	MD	OP	GL
Q	2.79	5.08	3.40	2.63	0.27	3.18	0.00
C	0.47	1.18	1.01	1.62	1.75	1.36	2.74
Lc	—	—	—	—	—	—	4.89
Or	6.56	5.02	9.63	4.02	16.19	1.79	27.57
Ab	47.89	32.24	31.73	18.36	15.06	3.89	0.00
An	37.41	35.21	34.77	24.54	22.66	6.33	9.94
Ne	—	—	—	—	—	—	3.30
Ol	—	—	—	—	—	—	28.15
Hy	—	12.30	7.38	31.32	23.66	66.32	—
Mt	0.04	4.15	3.57	10.29	7.55	10.72	5.45
Ilm	0.17	0.87	1.40	2.77	4.58	0.89	6.68
Ap	2.93	2.34	0.68	1.51	2.93	2.34	5.64

Note: The corresponding major-element compositions are given in Table 1. A = anorthosite, LN = leuconorite, LD = leucodiorite, N = norite, MD = mica diorite, OP = orthopyroxenite, GL = glimmerite.

different petrographic types are well separated with respect to this parameter (Fig. 3). Thus, indices of 15 and 45 discriminate anorthosite from leuconorite and leuconorite from norite, respectively. The correspondence between leuconorite of the orthopyroxene-bearing series (Fig. 3A) and leucodiorite of the mica-rich series (Fig. 3B) is also demonstrated. The chemical data corroborate the impression gained from the petrographic study that the principal petrographic types are distinct rather than gradationally related. Thus, the major rock types are each represented by discrete peaks in Figure 3. The limitations of MI are illustrated, however, by its failure to discriminate between glimmerite and mica diorite, reflecting the relatively high Al content of the sheet silicate.

When the accumulated data for all Koperberg Suite samples are plotted in a single frequency diagram in terms of MI (Fig. 4), the results show four fundamental nodes: (1) anorthosite, (2) leuconorite-leucodiorite, (3) norite–mica diorite–glimmerite, and (4) orthopyroxenite. The samples were collected in an unbiased manner to represent the Koperberg Suite rather than specific rock types. The results of the subsequent petrographic study could not possibly have been anticipated during sampling. The quadrimodal distribution is real and interpreted to be of fundamental petrogenetic significance. The intermediate peaks are emphasized in Figure 4 because of the similarity between the orthopyroxene-bearing series and the mica-rich series.

Calcuation of average chemical compositions for the major petrographic types is justified because of the demonstrated chemical clustering. The results (Table 1) make it possible to compare the orthopyroxene-bearing series quantitatively to the mica-rich series. The average com-
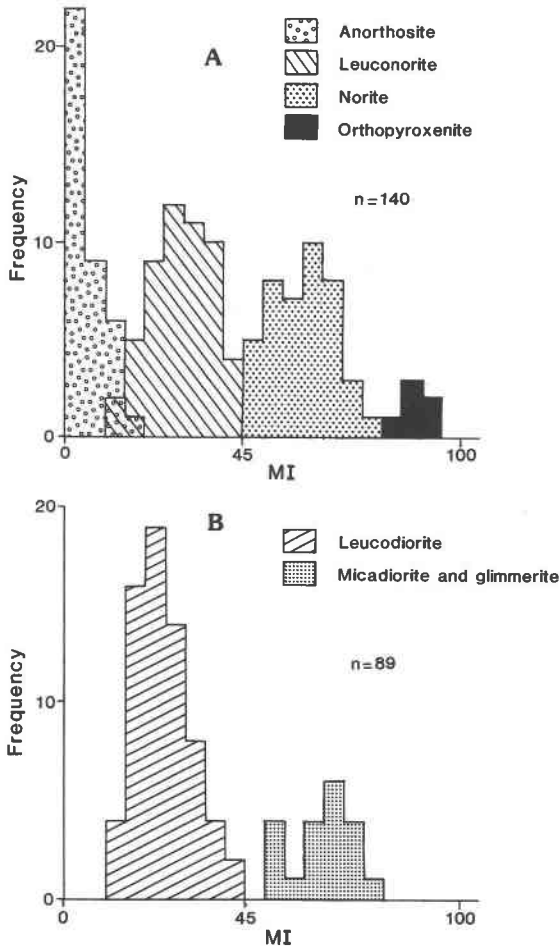
Fig. 3. Histograms illustrating the relationship between frequency of occurrence in terms of mafic index (MI) and Koperberg Suite petrographic types. The mafic index is calculated from cation proportions of major-element whole-rock analyses and is defined as $MI = 100(Fe_{Tot} + Mg + Mn + Ti)/(Al + Fe_{Tot} + Mg + Mn + Ti)$. (A) Rocks characterized by the presence of orthopyroxene. (B) Rocks characterized by the presence of biotite and the absence of orthopyroxene.
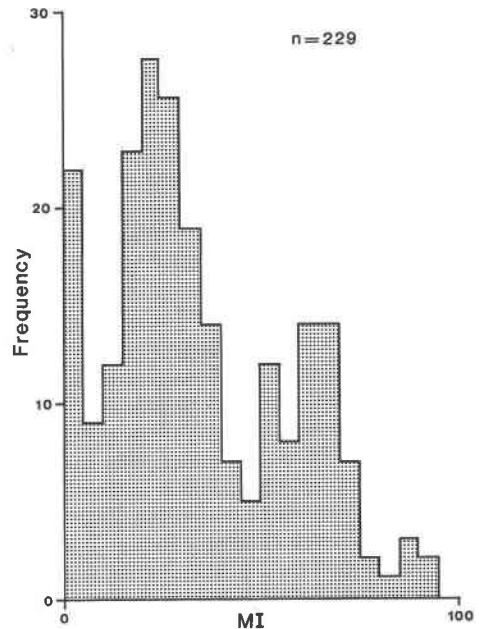

Fig. 4. Accumulative histogram of all chemically analyzed samples in terms of mafic index (MI). The details of the same data set are shown in Fig. 3.

positions of leuconorite and leucodiorite prove to be remarkably similar. The only significant differences are, predictably, the higher K_2O and TiO_2 values of the mica-rich rock. The same close correspondence and limited differences appear for norite and mica diorite, with the addition of higher P_2O_5 in the latter. When the ultramafic representatives of the two series, orthopyroxenite and glimmerite, are compared, however, large differences are apparent in terms of SiO_2, TiO_2, Al_2O_3, K_2O, and P_2O_5. Nevertheless, the correspondences are better than predicted by Figure 3, which grouped the glimmerite incorrectly with norite owing to the importance of Al in the brown mica. The major-element chemical differences between comparable members of the orthopyroxene-bearing series and the mica-rich series can clearly be attributed to variation in the amount of mica and apatite. The

positive correlation between copper mineralization and basicity, proven by mining experience in the Copper district, is also reflected by the average CuO values (Table 1). Since these are averaged values for samples from a variety of localities, most of which are not situated near mines, the syngenetic character of the sulfide component, deduced from petrographic study, is corroborated by the chemical evidence for both rock series.

In essence, variation in the proportions of only three rock-forming minerals (i.e., plagioclase, orthopyroxene, and brown mica) accounts for the diversity of Koperberg Suite rock types. It should therefore be possible to display relatively undistorted evolutionary trends on binary chemographic diagrams, provided that the plotted positions of the applicable end-members (rock-forming minerals) are well separated. Because of the similarity between the Koperberg Suite and massif-type anorthosite complexes, the diagram should also allow undistorted comparison with probable precursors such as basaltic-liquid compositions. The critical planes in the haplobasaltic system (Yoder and Tilley, 1962; La Roche, 1978) are well suited for this purpose. For the Koperberg Suite, the critical plane of silica saturation, containing orthopyroxene and plagioclase but not olivine and clinopyroxene, is a better plane of reference than the critical plane of silica undersaturation. In the multicomponent haplobasaltic tetrahedron of La Roche (1978), the four apices are Al, Si, Mg + Fe + Ti, and Ca + (11/6)(Na + K). The equation for the critical plane of silica saturation is given by $F_1 = 4(Mg + Fe + Ti) + 6Ca + 11(Na + K) + Al - 4Si$. Samples that plot near to the plane have F_1 values near zero. Silica-oversaturated samples yield neg-
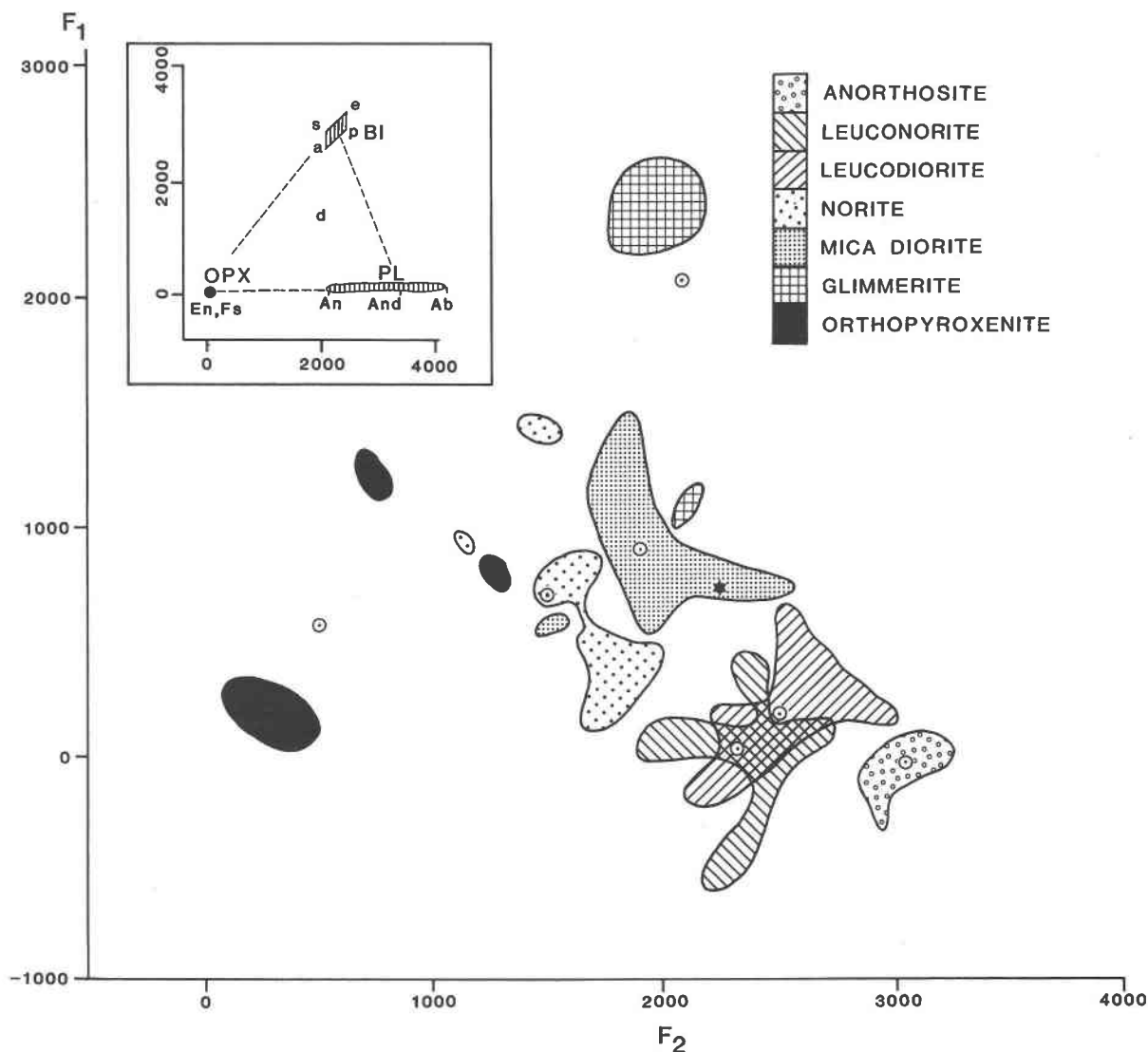
Fig. 5. Binary diagram illustrating the relationship between major-element compositions and petrographic types for the Koperberg Suite. Factor $F_1 = 4(Mg + Fe + Ti) + 6Ca + 11(Na + K) + Al - 4Si$ primarily reflects the biotite content and a value of $F_1 = 0$ represents positions on the critical plane of silica supersaturation in the haplobasaltic system. Factor $F_2 = 6Ca + 11(Na + K)$ primarily reflects the orthopyroxene : plagioclase ratio. All values used for the calculation of factors are cation proportions × 1000. The circled points represent the average compositions of the major petrographic types listed in Table 1. The star represents the world average basalt (Le Maitre, 1976). The inset (upper left-hand corner) shows the extent of the chemographic dispersion space (d) in terms of the three prevalent rock-forming minerals: orthopyroxene, andesine, and biotite. (OPX = orthopyroxene, En = enstatite, Fs = ferrosilite, PL = plagioclase, An = anorthite, And = andesine, Ab = albite, BI = biotite, a = annite, s = siderophyllite, p = phlogopite, e = eastonite.)

ative values of F_1, and silica-saturated to silica-undersaturated specimens give positive values.

Critical minerals, such as olivine, which indicate silica undersaturation and which would result in positive F_1 values, are not present in the Koperberg Suite. However, all of the end-members of the biotite series plot well within the undersaturation volume of the haplobasaltic model. This means that the F_1 values of the samples mainly reflect the ratio of biotite to orthopyroxene plus plagio-

clase. This parameter considers the chemical variation along one direction only, perpendicular to the critical plane of silica saturation. For a more comprehensive chemographic compilation, alternative projection planes should also be employed. Within the haplobasaltic tetrahedron, a convenient reference plane that intersects the plane of silica saturation ($F_1 = 0$) at a high angle is given by $F_2 = 6Ca + 11(Na + K)$. In terms of this parameter, rocks rich in orthopyroxene plot near zero whereas increasing
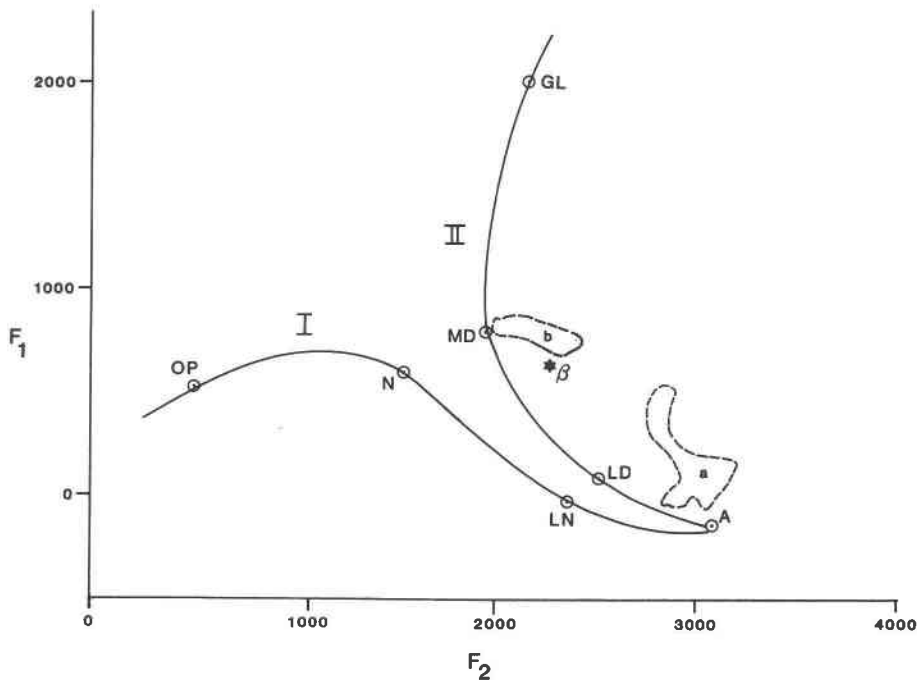
Fig. 6.   Average analyses of the principal Koperberg Suite petrographic types (Table 1) plotted in terms of F_1 and F_2 as explained in Fig. 5. (A = anorthosite, LD = leucodiorite, LN = leuconorite, MD = mica diorite, N = norite, GL = glimmerite, OP = orthopyroxenite. β = world average basalt of Le Maitre (1976). For comparison, a = field of anorthosite and noritic anorthosite, Laramie Complex, and b = field of norite, Laramie Complex, Wyoming, calculated from data of Fountain et al., 1981.) Two converging trends are identified: (I) rocks characterized by orthopyroxene and (II) rocks with biotite but no orthopyroxene.

amounts of the other rock-forming minerals (plagioclase and brown mica) result in increasing positive values of F_2. Figure 5 shows variation of the Koperberg Suite analytical data in terms of F_1 and F_2. This diagram may be regarded as a maximum-dispersion chemographic display for rock series in which the petrographic trends are caused by variation in the proportions of the three minerals plagioclase, orthopyroxene, and brown mica. It is clear that we are dealing with two distinct trends that converge on anorthosite.

When the principal trends are constructed using average values (Table 1), the increase in dissimiliarity between comparable representatives of the two rock series with increasing basicity is clearly illustrated (Fig. 6). For trend I, the orthopyroxene-bearing series, F_2 is a realistic differentiation index, but not for trend II, the mica-rich series. For the latter, F_1 provides a better representation of the differentiation trend.

Average concentration values for selected trace elements are provided in Table 3. The mica-rich series proves to be enriched in Ba, F, and Rb with respect to the orthopyroxene-bearing series. Figure 7 shows the variations in trace-element content in terms of F_1 and F_2 values for a few of the trace elements. The high values of Rb in the mica-rich series are clearly shown for individual samples, particularly in the glimmerite. As can be expected, Sr is relatively high in feldspar-rich specimens belonging to both series. Zr tends to be higher in the mica-rich series

than in the orthopyroxene-bearing series, but the variation in Y and Nb values is complex, as could have been predicted from the intricate REE patterns previously described in Conradie and Schoch (1988).

DISCUSSION

The constituent minerals as well as the different members of the Koperberg Suite are characterized more by their chemical similarities than by their differences. This is true in spite of the presence of an impressive array of

TABLE 3.   Average trace-element compositions (ppm) of Koperberg Suite rock types

	A n = 17	LN n = 27	LD n = 24	N n = 20	MD n = 8	OP n = 3	GL n = 6
F	994	960	1764	1290	1380	—	6360
Ba	393	331	571	181	1521	304	4993
Rb	19	19	79	28	152	26	356
Sr	659	741	739	425	939	138	237
Y	8	22	30	55	86	100	70
Zr	80	86	288	212	690	25	281
Nb	1	3	8	8	21	2	24
Zn	29	64	108	104	273	182	192
Pb	24	35	46	54	83	29	80
Ni	40	71	78	189	228	225	440

Note: The corresponding major-element compositions are given in Table 1. A = anorthosite, LN = leuconorite, LD = leucodiorite, N = norite, MD = mica diorite, OP = orthopyroxenite, GL = glimmerite, n = number of analyses. For F, the values of n are, from left to right, 34, 42, 51, 14, 3, and 5. For Ba, corresponding values are 2, 6, 7, 9, 1, 2, and 2.
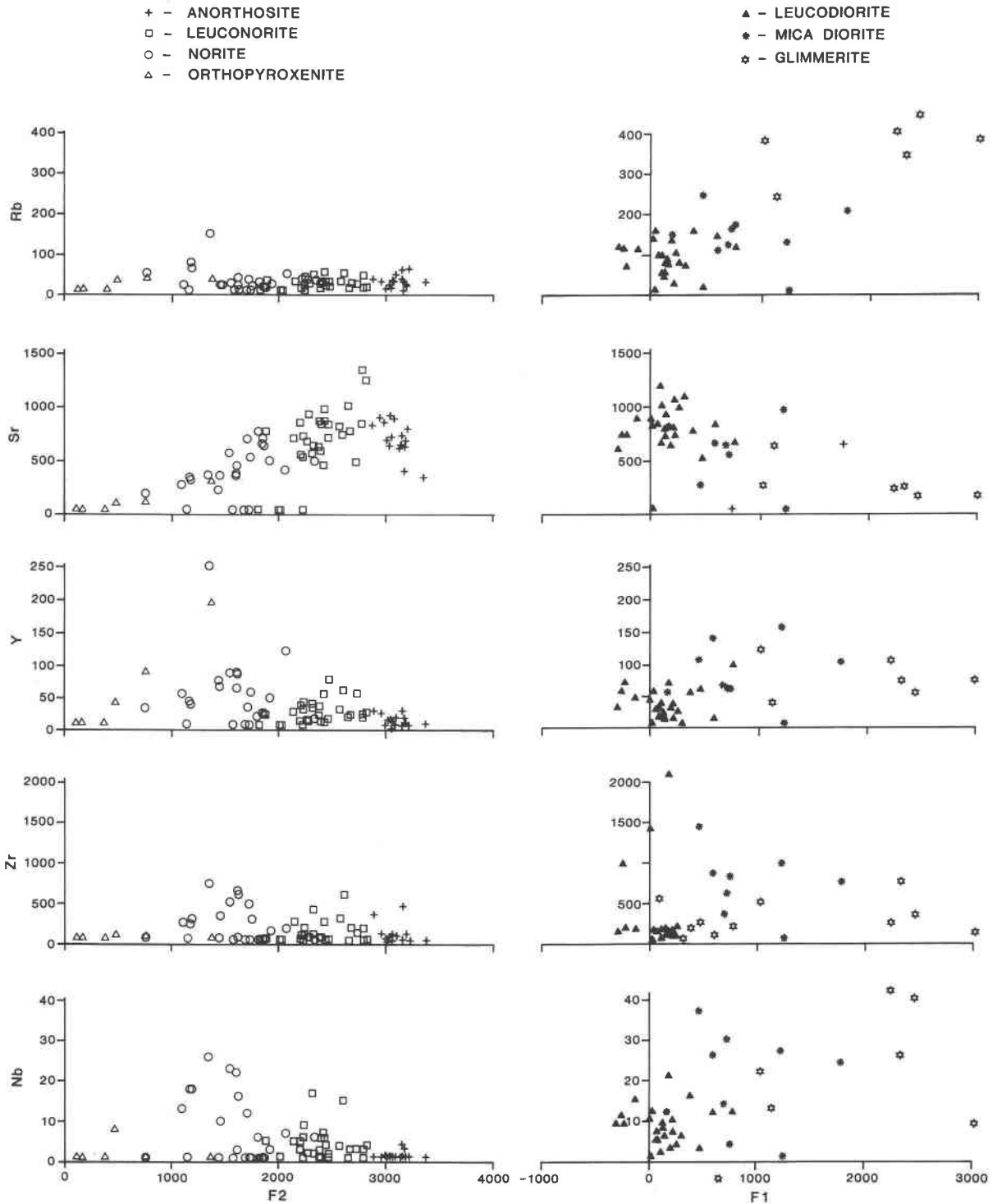
Fig. 7.   Variation in trace-element compositions (ppm) for individual samples. The basicity indices used as absissa labels are calculated from cation values ($\times$ 1000) in terms of $F_1 = 4(Mg + Fe + Ti) + 6Ca + 11(Na + K) + Al - 4Si$ for the mica-rich series and in terms of $F_2 = 6Ca + 11(Na + K)$ for the orthopyroxene-bearing series.

rock types representing a large variation in basicity and in spite of the evidence for sequential emplacement. The various rock types have strong consanguineous characteristics so that multiple-stage genetic models cannot be regarded as realistic for this suite. Nonetheless, a considerable amount of petrographical and geochemical evidence supports two discrete differentiation trends, respectively characterized by orthopyroxene and brown mica. According to Gray (1987), orthopyroxene (as opposed to olivine) in anorthosite complexes reflects crustal contamination of a mantle-derived basaltic precursor. Although well-constrained initial Sr and Nd ratios are not yet available for the Koperberg Suite, the known data (Stumpfl et al., 1976) point to exceptionally high values of both ratios, supporting crustal contamination. It is therefore proposed that a significant amount of crustal contamination took place during the evolution of the Koperberg magmas.

The problem of the origin of the mica-dominated series and its genetic similarities with the orthopyroxene series remains unresolved. The development of the former certainly involves the addition or retention of volatile components (K, H_2O, and P). However, the general similarity in REE compositions for comparable members from both series (Conradie and Schoch, 1988) argues for a common precursor. The well-defined petrochemical character of the major rock types indicates that efficient differentiation processes must have interceded prior to emplacement. The primary source of the Koperberg magmas could have been similar to those deduced for the other major anorthosite complexes, i.e., in the mantle below a thickened portion of the crust (e.g., Emslie, 1978, 1985). There is a distinct possibility that the mantle for the region under discussion had anomalous properties, such as enrichment in K, rare-earth elements, and P (KREEP). However, the divergence of the suites indicates that considerable differentiation must have taken place at some intermediate crustal level prior to relatively high level emplacement in structurally favorable zones characterized by anticlinal flexures ("steep structures") and megabreccias. The close temporal association of the Koperberg Suite with cryptoexplosion features (megabreccias, Lombaard and Schreuder, 1978), the occurrence of internal xenolithic swarms, and the prevalence of protoclastic features such as marginal granulation of plagioclase megacrysts (Conradie and Schoch, 1986a) suggest fast emplacement of each intrusive pulse. Relatively rapid decompression played a major role during the development of the Koperberg Suite from differentiated products of a mantle source. Magmatic differentiation was probably a more fundamental factor for the observed petrochemical diversification than crustal contamination.

ACKNOWLEDGMENTS

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