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GRANITIOD-SERIES EVOLUTION OF THE ARCHAEAN JOHANNESBURG DOME GRANITOIDS, SOUTH AFRICA

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by

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ABSTRACT

Archaean granitoids of the Johannesburg Dome were evaluated in terms of the granitoid series using Fe_2O_3/FeO ratios of bulk chemistry and magnetic susceptibility data. The Fe_2O_3/FeO ratios range between 0.05 and 0.72 and are generally below 0.5, implying that they belong mostly to reduced, ilmenite-series granitoids. Magnetic susceptibility was measured on 122 samples of TTG suite granitoids and 239 samples of calc-alkaline suite granitoids collected on the 700km^2 granitic inlier constituting the Johannesburg Dome in the central part of the Kaapvaal Craton, South Africa. From the measurements it was established that the TTG suite consists of 78 % ilmenite-series granitoids and 22 % magnetite-series granitoids, while the calc-alkaline suite consists of 83 % ilmenite-series and 17 % magnetite-series granitic rocks. Magnetite-series granitoids tend to occur sporadically in the central part of the Dome at the interface between the TTG and calc-alkaline granitoids. The granitoids are generally seen to be of a reduced type, the reducing conditions most likely being partly the result of assimilation of the country rocks into which the granitic rocks intruded.

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INTRODUCTION

Measurement of magnetic susceptibility is a powerful tool in field studies of granitic rocks. The magnetite content can readily be ascertained and provides important information on the redox state of any given granitoids. Magnetic susceptibility studies have been applied to the Phanerozoic granitoids of Japan (Kanaya and Ishihara, 1973; Ishihara, 1979), South Korea (Ishihara et al., 1981; Jin et al., 2001), South and North China (Ishihara and Wang, 1999; Ishihara et al., 2001), the Malay Peninsula (Ishihara et al., 1979), the Lachlan Fold Belt of Australia (Tainosho et al., 1988), the Sierra Nevada batholith (Bateman et al., 1991), the Peninsular Range batholith (Gastil et al., 1990), Northern Chile (Ishihara et al., 1984) and granitoids of coastal Peru (Ishihara et al., 2000). Regional variations have been revealed in these studies that reflect the intrinsic redox state of the granitic magmas.

In this study, magnetic susceptibility investigations were applied to the *c.*3340-3000Ma Archaean granitic rocks exposed on the Johannesburg Dome situated in the central part of the Kaapvaal Craton in South Africa (Fig. 1). The Johannesburg Dome, which occurs as an ovoid inlier surrounded by Archaean and Proterozoic sediments and volcanic rocks occupies an area of approximately 700 km^2 and constitutes one of a number of domical "windows" of ancient granitic basement on the Kaapvaal Craton. Susceptibility measurements were performed using a portable KT-5 magnetic susceptibility meter. Measurements were made both on field outcrops as well as on an extensive collection of granitoid samples housed at the Economic Geology Research Institute at the University of the Witwatersrand, Johannesburg.

The nature of the rock surface is important when undertaking susceptibility measurements with the portable KT-5 device. If the surface of the outcrop or measured samples is uneven correction factors need to be applied to normalize the measured values to those obtained on flat surfaces. The following correction factors were applied in this study: Surface unevenness 1 mm, correcting factor, k=1.07; 2 mm, k=1.15; 3 mm, k=1.24; 4 mm, k=1.35; 5 mm, k=1.44; 6 mm, k=1.55; and 7 mm, k=1.66.

The redox state of the Johannesburg Dome granitoids was initially evaluated using published Fe_2O_3 and FeO data. These results supplement the magnetic susceptibility measurements presented in this paper. It should be noted that the magnetite- and ilmenite-series granitoids, as originally defined by Ishihara (1977), can be distinguished using a separation value of 0.5 of Fe_2O_3/FeO (wt %) and 3.0 x 10^{-3} SI units of magnetic susceptibility, precisely at 70 wt % SiO_2 (Fig. 2).

JOHANNESBURG DOME GRANITOIDS

Archaean granitoids on the Kaapvaal Craton are best exposed and widely distributed in the Barberton granite-greenstone terrane located approximately 400km east of Johannesburg (Robb and Anhaeusser, 1983). Archaean granitoid rocks also occur north of Johannesburg where they intrude the Archaean mafic and ultramafic volcanic and plutonic greenstones in the area (Anhaeusser, 1977, 1978, 1992, 1999). These mafic and ultramafic rocks have been equated with similar rocks found in the Barberton Supergroup (formerly referred to as the Swaziland Supergroup). Anhaeusser (1973) divided the granitoid rocks of the Johannesburg Dome into several types (Fig. 1) and further provided bulk chemical analyses, including Fe_2O_3 and FeO contents, for representatives of the granitic varieties found on the Dome.

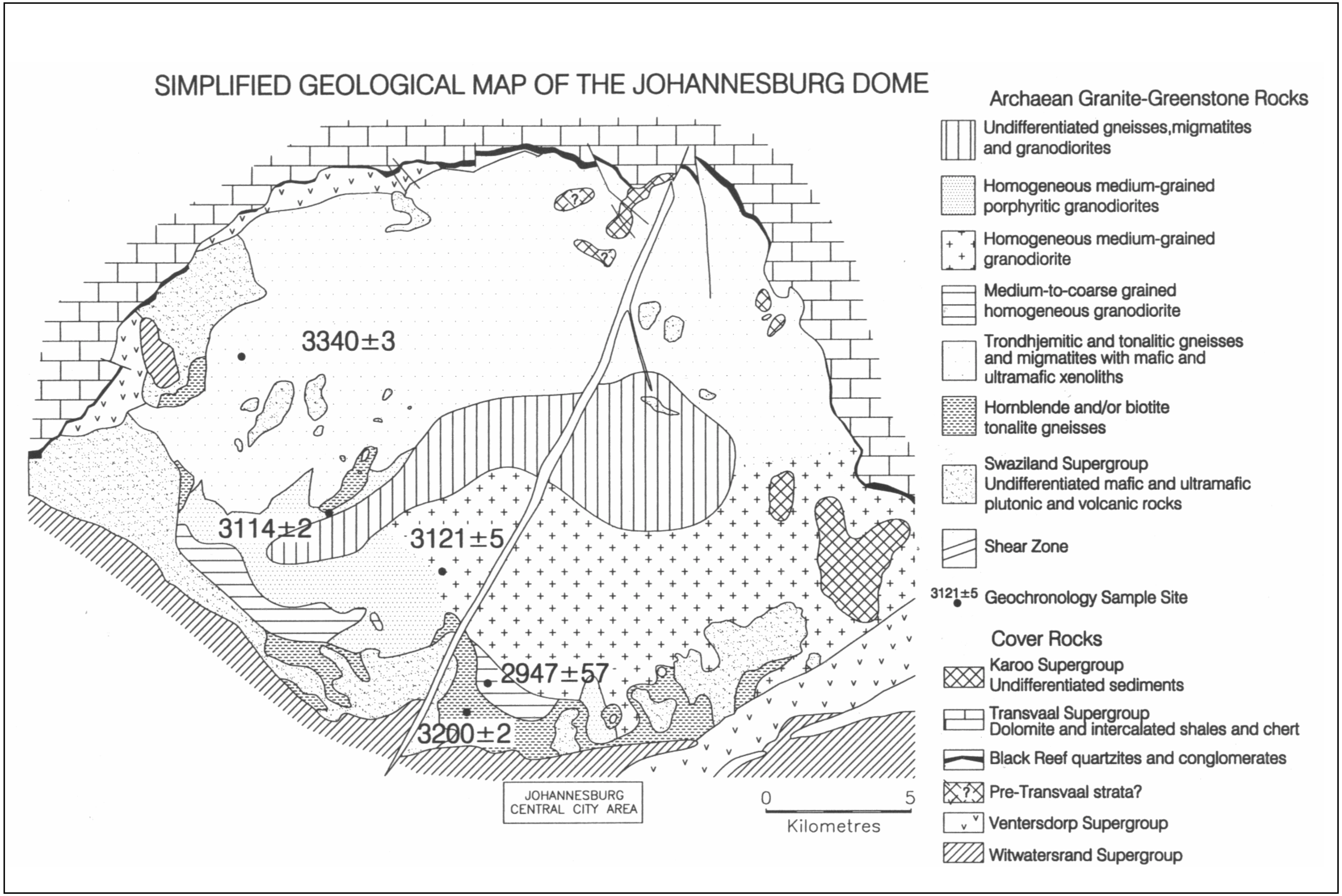

Figure 1: *Simplified geological map of the Johannesburg Dome (modified after Anhaeusser, 1973). U-Pb zircon ages of the main granitiod types on the Dome after Poujol and Anhaeusser (2001).*

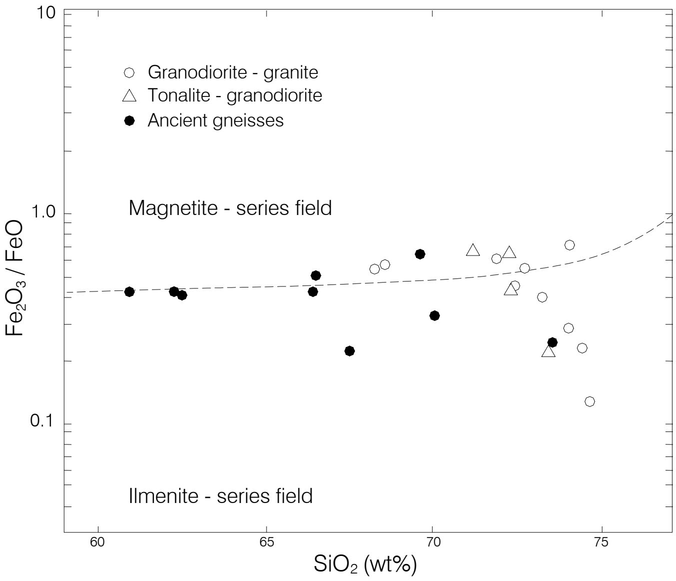

Figure 2: *Fe_2O_3/FeO ratios plotted against SiO_2 of the Johannesburg Dome granitoids.*

The granitoid rocks of the dome are unconformably overlain by sedimentary rocks of the Witwatersrand Supergroup as well as volcanic and sedimentary rocks of the Ventersdorp and Transvaal Supergroups. Anhaeusser (1973, 1999) subdivided the granitic rocks into essentially two varieties: (1) ancient tonalitic gneisses and leuco-trondhjemite-granodiorite gneisses – the so-called "TTG suite"; and (2) homogeneous, and in places porphyritic granodiorites and adamellites - hereafter termed the "calc-alkaline suite". The tonalitic and trondhjemitic gneisses, which occupy most of the northern half of the dome as well as areas around the southern margins of the dome (Fig.1), contain numerous greenstone remnants or xenoliths, together with migmatites produced as a result of granite-greenstone intermixing.

U-Pb zircon age determinations by Poujol and Anhaeusser (2001) indicated several stages of granitoid intrusion (refer to Fig. 1): (1) leuco-biotite trondhjemitic gneisses of *c.*3340 Ma age in the north; (2) *c.*3200 Ma hornblende-tonalite gneisses in the far south; (3) calc-alkaline granitoids (granodiorite-adamellite) of *c.*3120-3114 Ma in the south-central part of the dome; and (4) potassic pegmatites of *c.* 3000 Ma representing late-stage granitoids associated with the calc-alkaline granitic rocks. The TTG suite includes a variety of biotite- and hornblende-bearing tonalitic and trondhjemitic granitoids and gneisses (Fig.1), grading locally into dioritic, granodioritic and quartz-dioritic gneisses, and including a variety of metamorphosed and metasomatised mafic and ultramafic rocks (Anhaeusser, 1999). The calc-alkaline suite (i.e., calcic in the sense of Peacock, 1931), whose alkali-lime index has been calculated to be 62.5 from the chemical data of Anhaeusser (1973), can be further subdivided into tonalite-granodiorite and granodiorite-granite.

BULK Fe_2O_3/FeO RATIO

The magnetite-series/ ilmenite-series granitoids have been empirically separated at 0.5 of bulk Fe_2O_3/FeO ratio at 70 wt % SiO_2 on granitoid rocks from Japan (Ishihara, 1977). It was established that the bulk Fe_2O_3/FeO ratio of any given granitoids generally increases with

SiO_2 content. Such a trend was based on the average chemical compositions of the Japanese granitoids, and is represented by the broken line in Figure 2. This line, with 0.5 Fe_2O_3/FeO and 70% SiO_2, is used to separate the magnetite-ilmenite series granitoids sampled on the Johannesburg Dome.

Within the TTG suite, the mesocratic hornblende-biotite tonalites and tonalitic gneisses have Fe_2O_3/FeO ratios of 0.42 - 0.43 (n=3, Table 1, Anhaeusser, 1973), which are lower than the limiting value of 0.5. Thus, these gneisses are considered to be part of the ilmenite series. The leuco-biotite tonalitic gneisses and biotite trondhjemites of the northern half of the dome have Fe_2O_3/FeO ratios of 0.23 - 0.66 (n=6, Table 2, Anhaeusser, 1973). Four of these samples show ilmenite-series values (0.23, 0.25, 0.34, 0.43) with two falling into the magnetite-series category (0.51, 0.66). Taken together, the TTG rock suite is composed of 78 % ilmenite series and 22 % magnetite series rock types (n=9, Fig. 2).

The calc-alkaline suite, consisting of homogeneous, medium-to-coarse grained, pinkish-grey granodiorites (in places grading into tonalites - Table 3, Anhaeusser, 1973) have Fe_2O_3/FeO ratios of 0.23, 0.44, 0.65 and 0.70. These granitoids comprise equal amounts of ilmenite- and magnetite-series granitoids with a low average Fe_2O_3/FeO ratio of 0.51 (n=4). The homogeneous, medium-grained, grey granodioritic-to-granitic suite (including also the porphyritic granodiorites) have Fe_2O_3/FeO ratios of 0.05, 0.29, 0.46, 0.55 and 0.72 (Table 4, Anhaeusser, 1973). Thus, they are made up of 60 % ilmenite series and 40 % magnetite series rocks with an average Fe_2O_3/FeO value of 0.41 (n=5). Porphyritic granites, possibly influenced by the intrusion into them of Pilanesberg dykes (Table 5, Anhaeusser, 1973), have Fe_2O_3/FeO ratios of 0.13 and 0.55 (average 0.34, n=2).

Between the TTG granitoids in the north and the homogeneous-to-porphyritic calc-alkaline granodiorites in the south-central part of the dome is a zone referred to by Anhaeusser (1973) as a "Transitional-Zone". This transitional or central sector of the dome contains rocks consisting of a mixed zone of migmatites and gneisses, together with homogeneous and porphyritic granodiorites (i. e., a suite of granitic rocks comprising remnants of both the early - *c.* 3340 Ma - trondhjemitic gneisses and the later intrusive phases belonging to the *c.* 3121 - 3114 Ma granodiorites and porpyritic granodiorites). A number of granitic tors are developed in this central area of the dome. The rocks in the Transitional Zone have low Fe_2O_3/FeO ratios of 0.23, 0.40, 0.56 and 0.62 (average 0.45, n=4 - Table 6, Anhaeusser, 1973). Fine-grained foliated diorite from the western edge of the dome (Fig.1, near the Witwatersrand outlier known as Zwartkop) has a very low Fe_2O_3/FeO ratio of 0.26 (Table 8, Anhaeusser, 1973).

As a general conclusion the Fe_2O_3/FeO ratios of both the TTG suite (average 0.41; n=9) and the calc-alkaline granitoids (average 0.43; n=16) are very similar and all these granitic rocks appear to be of a generally reduced character (Fig.2).

MAGNETIC SUSCEPTIBILITY

Measured values of the magnetic susceptibility of the Johannesburg Dome granitoids are shown graphically in Figures 3 and 4. Granitoids of the TTG suite occur mainly along the southern margin and in the north-central part of the dome. There is no clear magnetic susceptibility difference between granitoids of the TTG suite and the calc-alkaline suite. The magnetic susceptibility values are, however, lower in the southwestern and southeastern

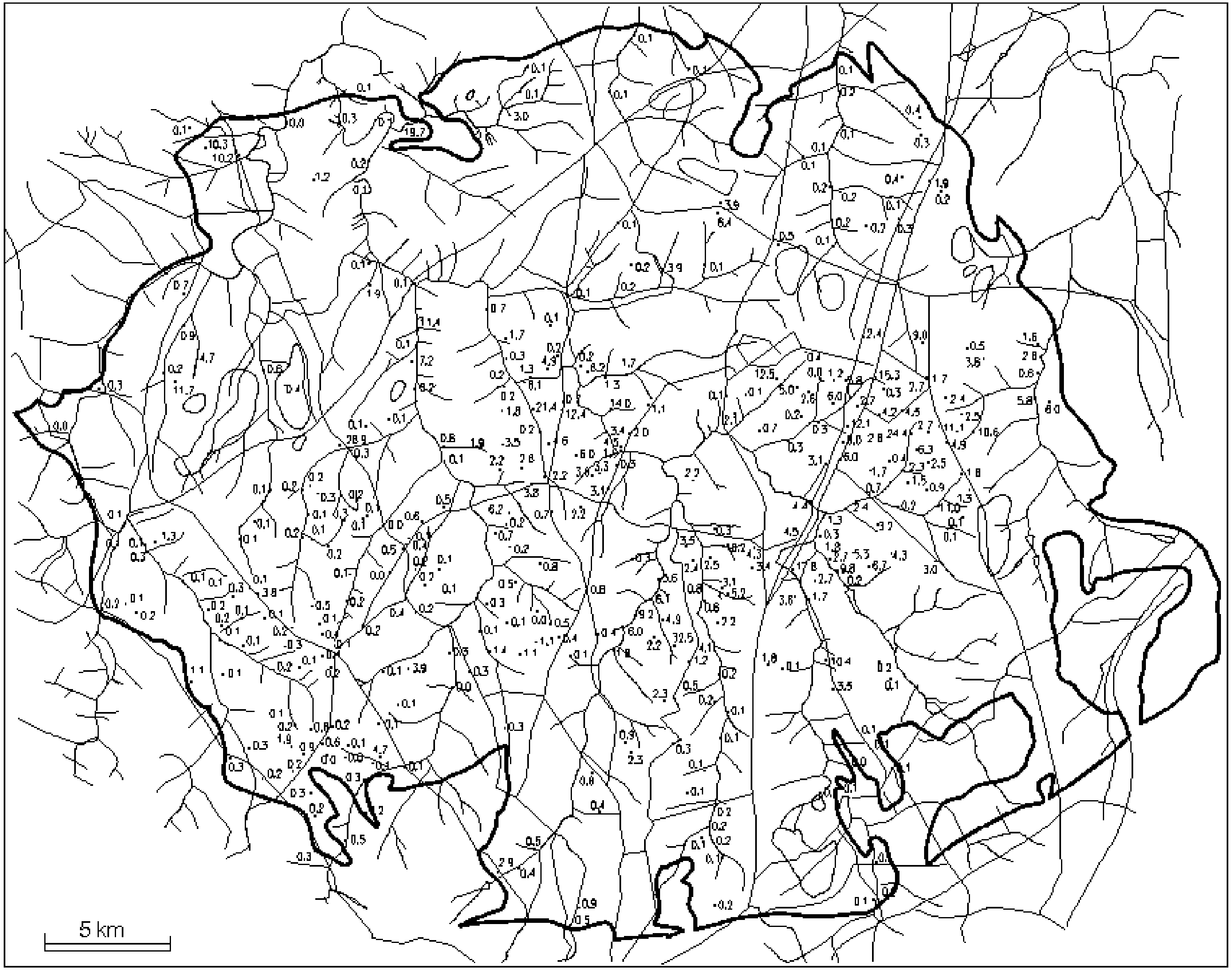

Figure 3: *Localities and magnetic susceptibility values of the granitoids studied on the Johannesburg Dome. The values are in x10^{-3} SI units*

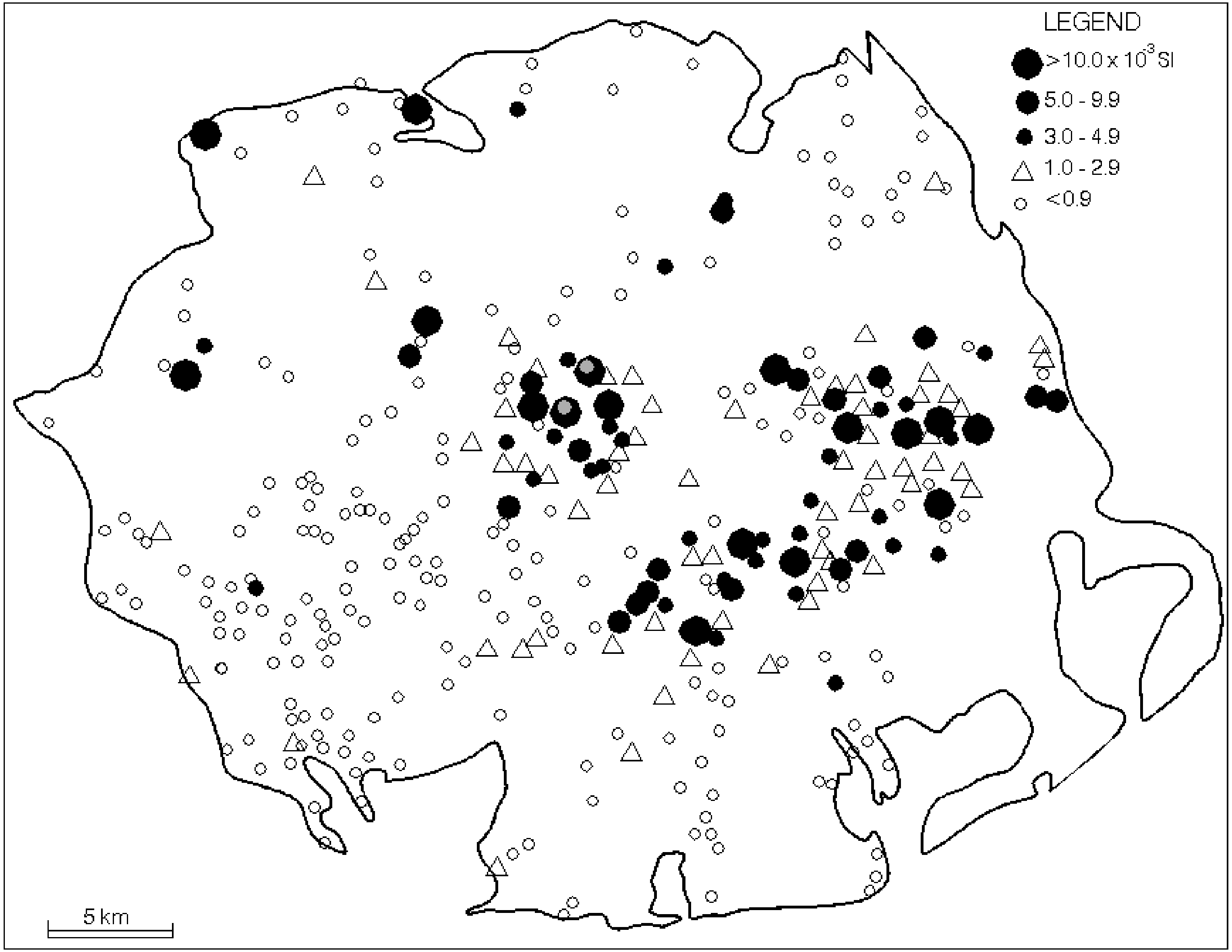

Figure 4: *Sample distribution and intensity of magnetic susceptibility of the Johannesburg Dome granitoids. Solid circles = TTG suite; open circles = calc-alkaline suite.*

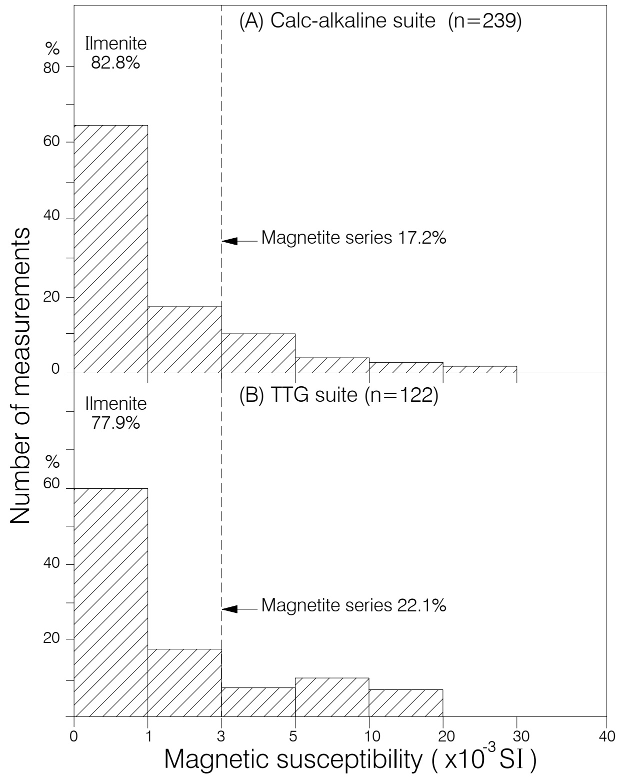

***Figure 5:** Histograms of magnetic susceptibility of the Johannesburg Dome granitoids. A = calc-alkaline suite; B = TTG suite.*

sectors of the dome where the remnants of the mafic and ultramafic greenstones are exposed. Within the granitic terrane, particularly on the northern half of the dome the greenstones remnants occur as xenoliths and the granitoids in their vicinity tend to record low magnetic susceptibility values. By contrast, high magnetic susceptibility values occur sporadically in the central part of the dome and show an east-west trend (Fig. 4), the latter corresponding with the granitoid rocks grouped within the Transitional Zone.

It is evident in Figure 4 that low magnetic susceptibility values also occur intimately juxtaposed with high values. This mixed occurrence of high and low values has not been recorded in Phanerozoic granitoids (such as those of the Japanese Islands) and can be considered as a notable characteristic of the Archaean granitoids investigated in this study. Magnetic susceptibility data from the Johannesburg Dome granitoids are also shown in histograms in Figure 5. In this diagram the granitoids are divided into TTG suite and calc-alkaline suite granitoids. The TTG rocks have magnetic susceptibilities of < 0.1- 12.8×10^{-3} SI units. They show mostly ilmenite-series values (77.9 %, n = 95 samples) and partly magnetite-series values (22.1 %, n = 27 samples). The calc-alkaline suite has a wider variation of up to 36.9×10^{-3} SI units, but the general histogram pattern is similar to that of the TTG suite (Fig. 5). The calc-alkaline granitoids are composed mostly of ilmenite-series rocks (82.8 %, n = 198 samples) and lesser magnetite-series rocks (17.2 %, n= 41 samples). Moreover, the intensity of the magnetic susceptibility is similar to that of intermediate series granitoids described by Ishihara et al. (1984). Thus, the Archaean granitoids of the Johannesburg Dome are generally composed of reduced-species granitoids, a conclusion also supported by the Fe_2O_3/FeO ratios.

CONCLUDING REMARKS

It was found that the majority (*c*. 80 %) of the Johannesburg Dome granitic rocks fall into the category of ilmenite-series granitoids. Magnetite-series granitoids also occur sporadically in the central part of the granitic dome. Marginal granitoid rocks, namely those in contact with mafic and ultramafic greenstone remnants are all of the ilmenite-series type. This may imply that the reduced granitic magmas were formed partly as a result of the interaction or assimilation of the mafic-ultramafic country rocks. It is to be expected that these predominantly volcanic and plutonic rocks were of a reduced nature because the source upper mantle during Archaean times may also have been reduced. For example, Ringwood (1966) estimated Fe_2O_3/FeO ratios of 0.06 for the pyrolite mantle. Observed Fe_2O_3/FeO ratios of the Onverwacht Group komatiitic and basaltic komatiitic volcanic rocks of the Barberton greenstone belt range from 0.03 to 0.41 and their averages are 0.28 (n =14, Viljoen and Viljoen, 1969b) and 0.21 (n =10, Hawkesworth and O'nions, 1977). Archaean clastic sediments are also reduced, as is shown by Fe_2O_3/FeO ratios of 0.16 for greywackes and 0.19 for shales of the Fig Tree Group, also in the Barberton greenstone belt (Viljoen and Viljoen, 1969a). Sporadic magnetite-series granitoids occurring in the central part of the Johannesburg Dome indicate the localized existence of oxidized magmas during this period of early Archaean plutonism. Further detailed studies are needed on the Fe-Ti oxides and mafic silicate minerals in Archaean terranes to understand the genesis of the local fO_2 increases such as that recorded by the Johannesburg Dome granitoids.

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