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Physical Property Variations within Archaean Granite-Greenstone Terrane of the Yilgarn Craton, Western Australia: The Influence of Metamorphic Grade

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Abstract

Petrophysical properties (magnetic susceptibility, density) and gravity data are presented from greenstone belts of the Yilgarn Craton which have been subjected to greenschist and amphibolite facies metamorphism. The study areas were the Weebo/Wildara greenstone belt (greenschist facies) and Southern Cross greenstone belt (amphibolite facies). Comparison of similar rock types from these areas reveals systematic changes in their magnetic susceptibility and density interpreted as reflecting mineralogical changes associated with metamorphism. Bulk rock chemical analyses from each area are similar.

Increased density of ultramafic rocks from greenschist to amphibolite facies results from replacement of serpentine/talc (2.7 g/cm^3) by olivine (3.3 g/cm^3). The prograde reaction of actinolite/tremolite and plagioclase to hornblende causes increased density of the mafic rocks.

Changes in magnetic susceptibility are closely related to magnetite abundance and therefore extremely sensitive to local alteration processes (e.g. talc-carbonate alteration of ultramafic rocks). In this study, an increase in magnetic susceptibility with increasing metamorphic grade is noted for both mafic and ultramafic rocks. These effects may reflect increased magnetite content of the amphibolite facies rocks of approximately 0.005 volume % and 0.5 volume %, respectively. Additionally, the average grainsize of magnetite was observed to increase with metamorphic grade, thereby further increasing the magnetic susceptibility.

Gravity modelling suggests a maximum vertical thickness of mafic greenstones of <2 km at Weebo/Wildara and Southern Cross. The absence of a thick mafic pile below the Weebo/Wildara greenstone belt is interpreted to reflect tectonic detachment at shallow depth.

Key words: Yilgarn, Weebo/Wildara, Southern Cross, greenstone, magnetic susceptibility, density.

Introduction

Attention has recently been focussed upon the three-dimensional structure of granite-greenstone terrane within the Archaean Yilgarn Craton, Western Australia, given its high mineral endowment, economic importance and future mineral potential. In this regard, various geophysical methods may provide information not readily determined from surface geology. Recent examples include deep seismic sounding (Goleby *et al.*, 1993) and gravity modelling (Dentith *et al.*, 1992; Trench *et al.*, this volume). Similarly, geophysical methods can be used as a geological mapping tool and are of particular importance when surface outcrop is limited. Recent examples include detailed multiclient aeromagnetic surveys (Isles *et al.*, 1990) and airborne electromagnetic surveys (WMC proprietary data) capable of mapping bedrock and regolith lithologies.

In order that correct interpretations of such geophysical data can be undertaken, detailed petrophysical information (e.g. magnetic susceptibility, magnetic remanence, electrical conductivity, density) are required wherever possible. For example, in gravity interpretation of greenstone belt structure, uncertainty in the magnitude of the mean density contrast between greenstone and granite may result in possible errors of kilometres in determining the depth and geometry of the greenstone basin.

This paper documents the results of petrophysical investigations aimed at determining the characteristic magnetic susceptibility and density of two greenstone sequences, metamorphosed to greenschist and amphibolite facies, respectively. The Southern Cross (amphibolite facies, Ahmat, 1986) and Weebo/Wildara (greenschist — upper greenschist facies, Hallberg, 1985) greenstone belts were chosen for this purpose (Fig. 1). In addition, the results of gravity modelling of transects crossing each belt are reported.

Geophysical Background

Several previous studies have reported on the variation of magnetic susceptibility and density with metamorphic grade for a variety of rock types and field areas. A brief summary of the main conclusions of these studies is given in Figs 2 and 3.

Density in igneous and metamorphic rocks primarily reflects mineral composition. Magnetic susceptibility is a function of

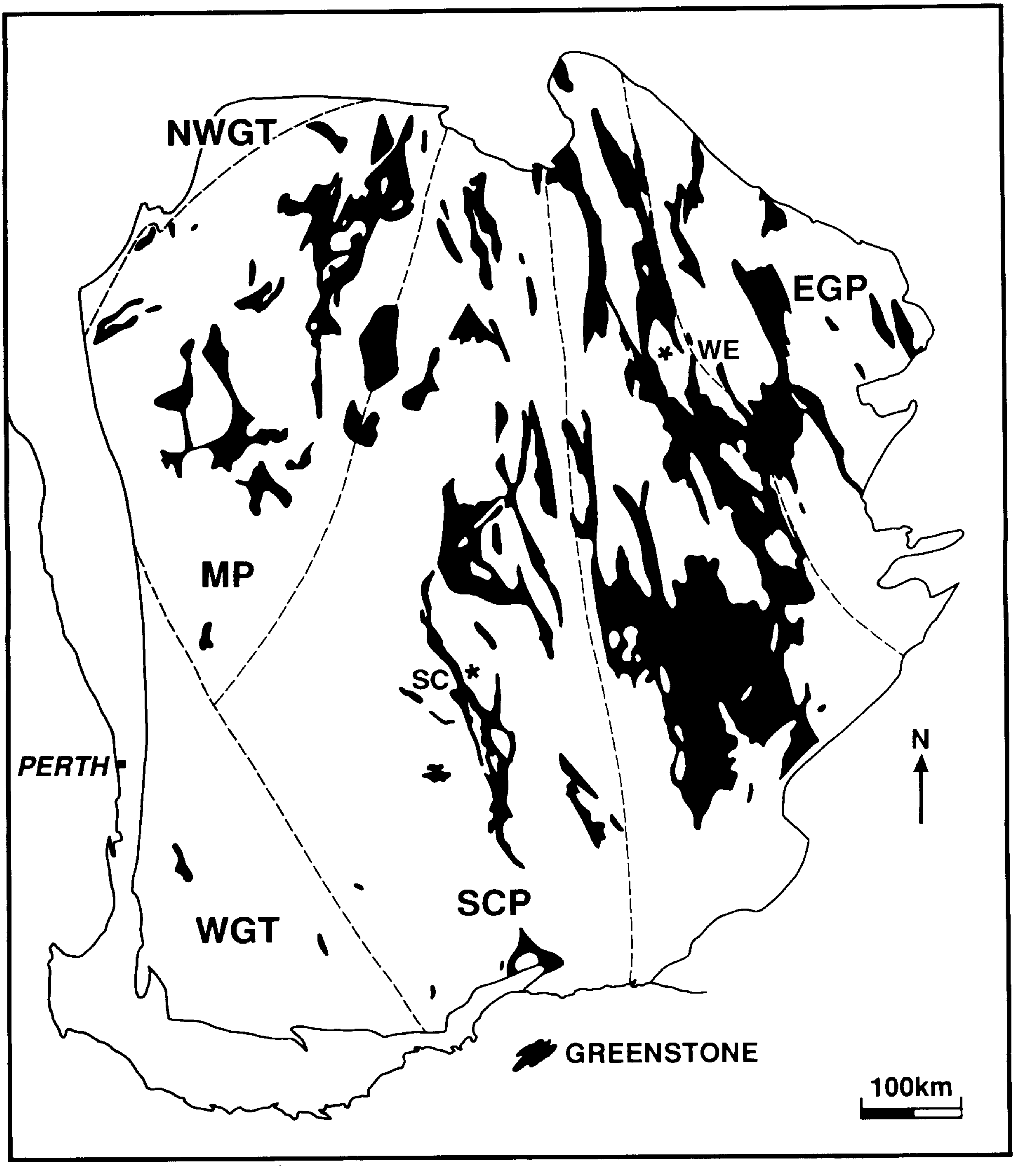

FIGURE 1
Locality map showing the Weebo-Wildara (WE) and Southern Cross survey areas (SC). Other divisions of the Yilgarn Block are as follows: WGT — Western Gneiss Terrane, NWGT — Northwest Gneiss Terrane, MP — Murchison Province, SCP — Southern Cross Province, EGP — Eastern Goldfields and Northeastern Goldfields.

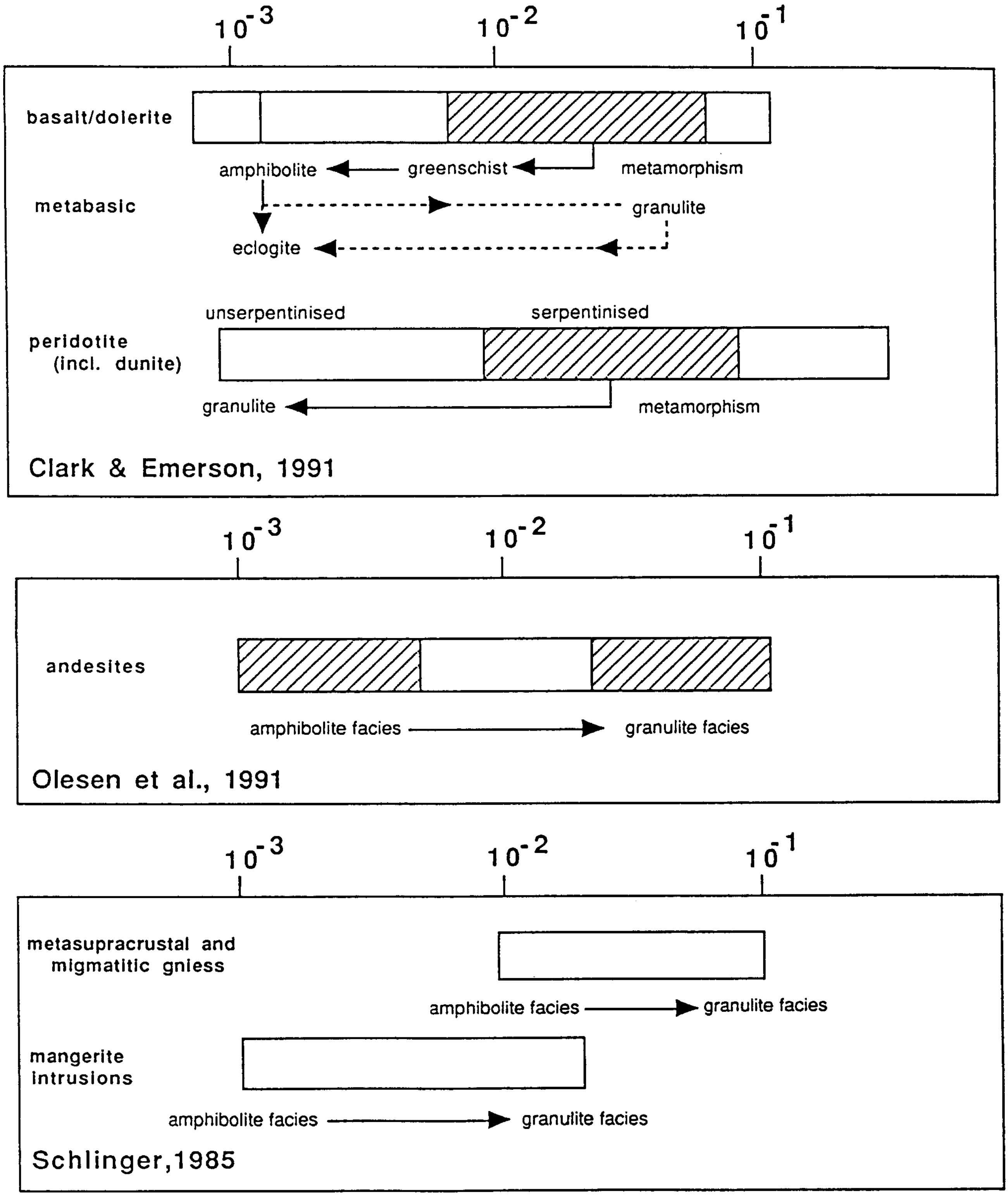

FIGURE 2
Examples of the effect of metamorphism on the magnetic susceptibility (S.I.) of different rock types. Bars represent total ranges. Hatched areas indicate dominant values.

mainly magnetite content, which is in turn dependent upon original host rock geochemistry and oxygen fugacity (Haggerty, 1979; Grant, 1985; Clark *et al*., 1992). During metamorphism, magnetite may be either produced or resorbed during reactions involving iron/magnesium silicates. The total magnetite production is limited by the total iron content and the oxidation state which controls iron partitioning between oxide, sulphide and silicate phases. Alteration processes, particularly in ultramafic rocks (Donaldson, 1981; 1983), can further modify the magnetite content and therefore magnetic properties of greenstones.

Data Acquisition and Methods

Densities reported in this paper are wet grain densities (Emerson, 1990), measured at 20°C, and determined from cut samples (typically 1 cm^3 to 4 cm^3) of water-saturated fresh rock. Each *sample* density represents the average of several *specimen* densities cut from a single hand sample. Wherever possible, samples were collected from unmineralised rocks in open pits to minimise the effects of surface weathering, which has a tendency to reduce observed density (Paish, 1991), and alteration processes.

Magnetic susceptibilities were measured in the field using a Microkappa KT-5 hand-held meter. Every effort was taken to use flat, open pit exposure where possible to minimise the negative effects of weathering and surface roughness. No correction has been applied to the data to account for possible surface effects and the data are therefore strictly *apparent* susceptibilities.

Gravity data were acquired using a Sodin 410 series gravity

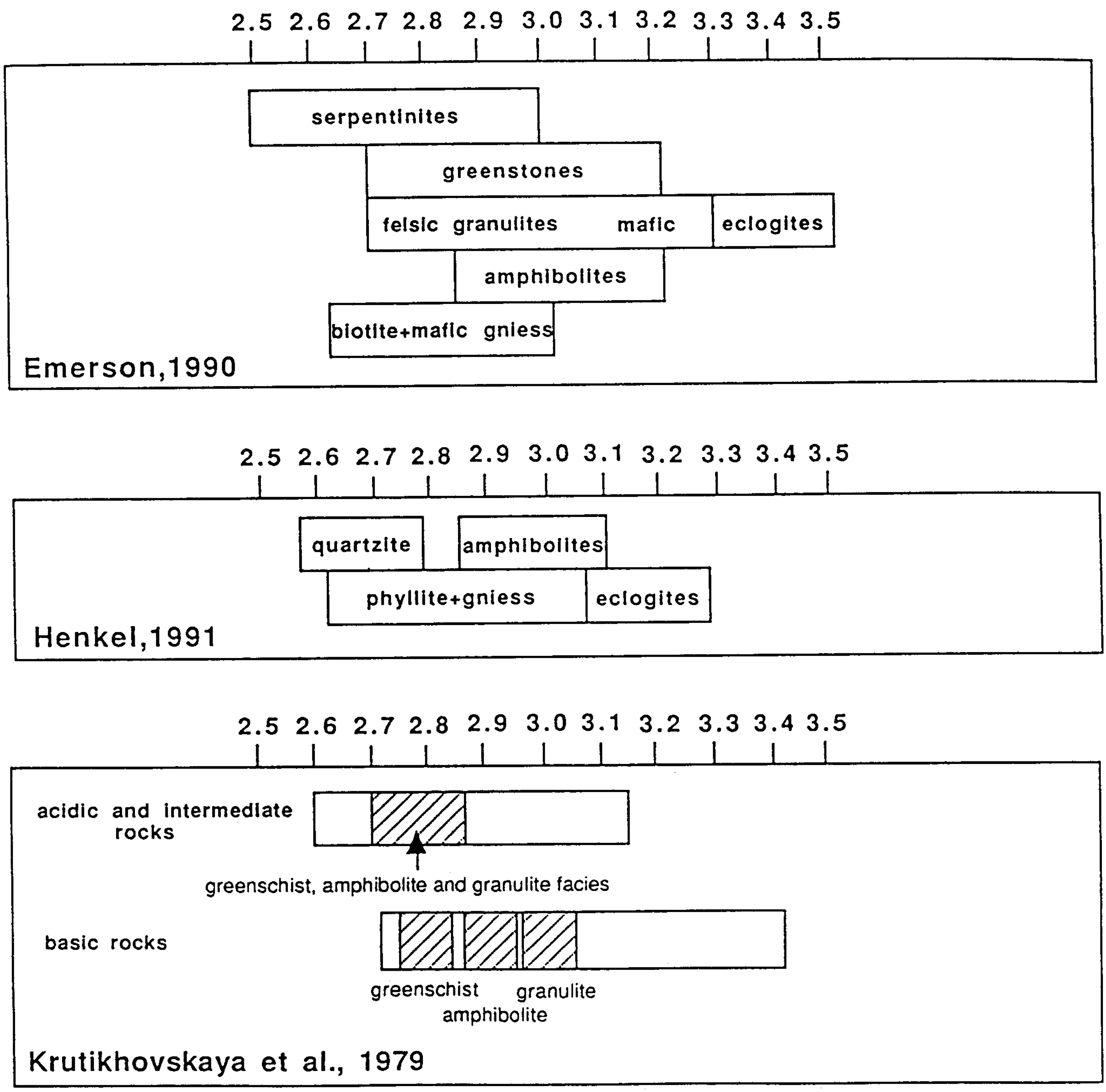

FIGURE 3
Examples of the effect of metamorphism on the densities of different rock types (g/cm^3). Bars represent total ranges. Hatched areas represent dominant values.

meter. Elevations were determined by levelling between benchmarks. All data and survey procedure are fully listed in Bourne (1992).

Bulk rock chemical analyses (Fig. 4) are similar for mafic and ultramafic lithologies of each belt making a comparison of their physical properties meaningful.

Results and Discussion

Frequency histograms showing the density distributions of mafic and ultramafic rocks at greenschist and amphibolite facies are shown in Figs 5 and 6. Magnetic susceptibility distributions (logarithmic scale) for ultramafic and mafic rocks are shown in Figs. 7 and 8.

The density of ultramafic rocks shows a significant increase with metamorphic grade — in the order of 0.2 g/cm^3. Thin section analyses suggest this increase is attributable to the prograde reaction of serpentine and talc (typical S.G. 2.7 g/cm^3) to form olivine (typical S.G. 3.3 g/cm^3). The density of mafic rocks also shows significant increase from greenschist to amphibolite facies in the order of 0.1 g/cm^3. Thin section studies suggest the consumption of plagioclase (S.G. 2.61 g/cm^3 to 2.77 g/cm^3) during the reaction of actinolite/tremolite (S.G. 3.02 g/cm^3 to 3.44 g/cm^3) to produce hornblende (S.G. 3.02 g/cm^3 to 3.45 g/cm^3) can account for the observed trend.

The magnetic susceptibility of mafic rocks shows a slight increase with increasing metamorphic grade (0.2×10^{-3} S.I.). The magnetic susceptibility of ultramafic rocks shows a more profound increase in the order of 20×10^{-3} S.I. — these effects can be interpreted to reflect increased magnetite content of the amphibolite facies rocks in comparison to their greenschist counterparts of approximately 0.005 volume % and 0.5 volume %, respectively. Additionally, the average grainsize of magnetite was observed to increase with metamorphic grade, thereby further increasing the low-field magnetic susceptibility. Assessment of the relative importance of prograde metamorphism and subsequent alteration of ultramafic rocks upon their magnetic properties is complex and involves competing reactions, as shown below.

Magnetite constructive : Serpentinisation

$$\underset{\text{(olivine)}}{Mg_{1.8}Fe_{0.2}SiO_4} + \underset{\text{(fluids)}}{H_2O} = \underset{\text{(serpentine)}}{Mg_3Si_2O_3(OH)_4} + \underset{\text{(magnetite)}}{Fe_3O_4} + \underset{\text{(brucite / chlorite)}}{MgO + (H_2 \text{ or } Fe)}$$

Magnetite destructive : Talc-carbonate alteration

$$\underset{\text{(serpentine)}}{Mg_3SiO_3(OH)_4} + \underset{\text{(magnetite)}}{Fe_3O_4} + \underset{\text{(fluids)}}{CO_2} = \underset{\text{(talc)}}{Mg_3Si_4O_{10}(OH)_2} + \underset{\text{(magnesite)}}{Mg_{0.9}Fe_{0.1}CO_3} + H_2O + O_2$$

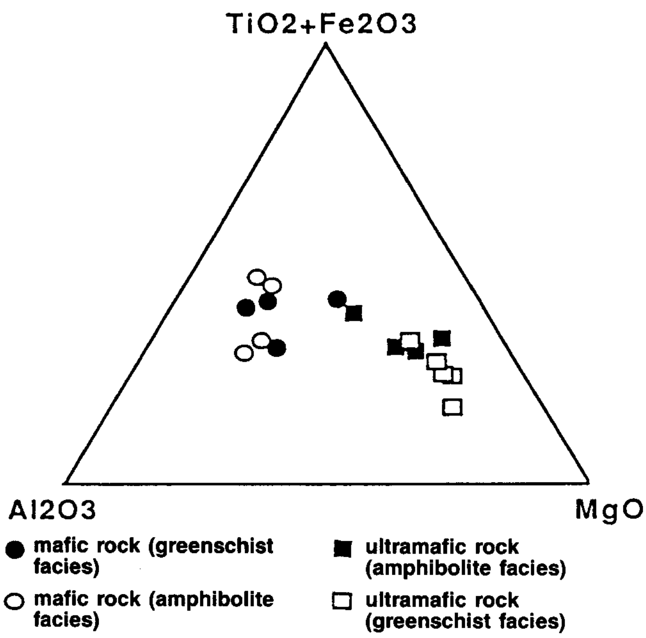

FIGURE 4
Bulk rock chemical compositions of mafic and ultramafic rocks from the Southern Cross (amphibolite) and Weebo-Wildara (greenschist) belts.

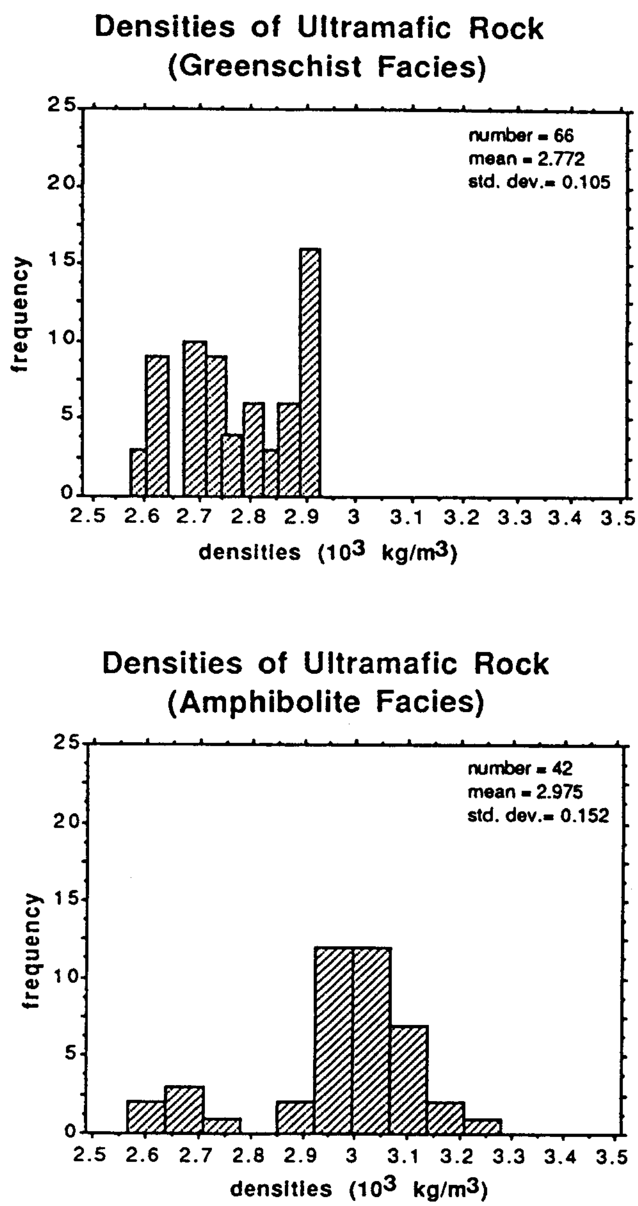

FIGURE 5
Frequency histogram showing observed densities of ultramafic rocks which have undergone greenschist and amphibolite facies metamorphism.

The influence of talc-carbonate alteration is likely to be more prevalent at greenschist facies conditions due to the decreasing stability of carbonate minerals with increasing temperature (Yardley, 1989, p. 138). For example, the lower peak of the bimodal susceptibility distribution of ultramafic rocks at greenschist facies (Fig. 7) may result from local talc-carbonate alteration.

This trend with metamorphism is noted to be the opposite to that observed by Clark *et al.* (1992), along the Agnew-Wiluna Belt of the Yilgarn Block and it is therefore inferred that a change has occurred in dominance of magnetite constructive/destructive reactions and/or grain-size effects between the contrasting study areas and rock types.

Gravity models, using the reported density measurements and additional data from other lithologies (granite = 2.64 g/cm^3 for both study areas), are shown for both greenstone belts in Figs 9 and 10. The models are intentionally simple and attempt only to obtain an overall geometry for each belt. Density contrasts between individual lithologies were based upon laboratory measurements. In both cases, greenstones are interpreted to terminate at relatively shallow depths of as much as 2 km. Given that the metamorphic grade of the exposed greenstones at Weebo/Wildara is greenschist, there is no evidence for an extensive sequence of concealed greenstones metamorphosed to amphibolite facies below the present level of erosion. A possible explanation for this might involve the loss of greenstone stratigraphy by a detachment fault (e.g. Hammond and Nisbet, 1992).

Conclusions

Density and magnetic susceptibility measurements of both ultramafic and mafic greenstones are found to increase with increasing metamorphic grade from greenschist to amphibolite facies. These contrasts are interpreted to reflect mineralogical changes associated with metamorphism and

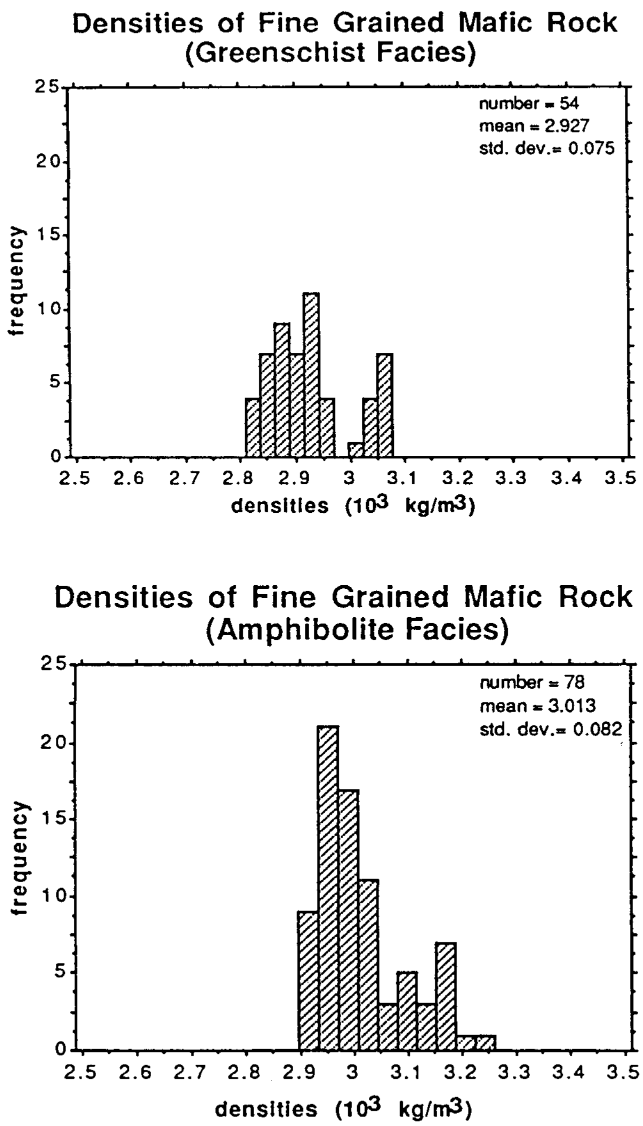

FIGURE 6
Frequency histogram showing observed densities of fine-grained mafic rocks which have undergone greenschist and amphibolite facies metamorphism.

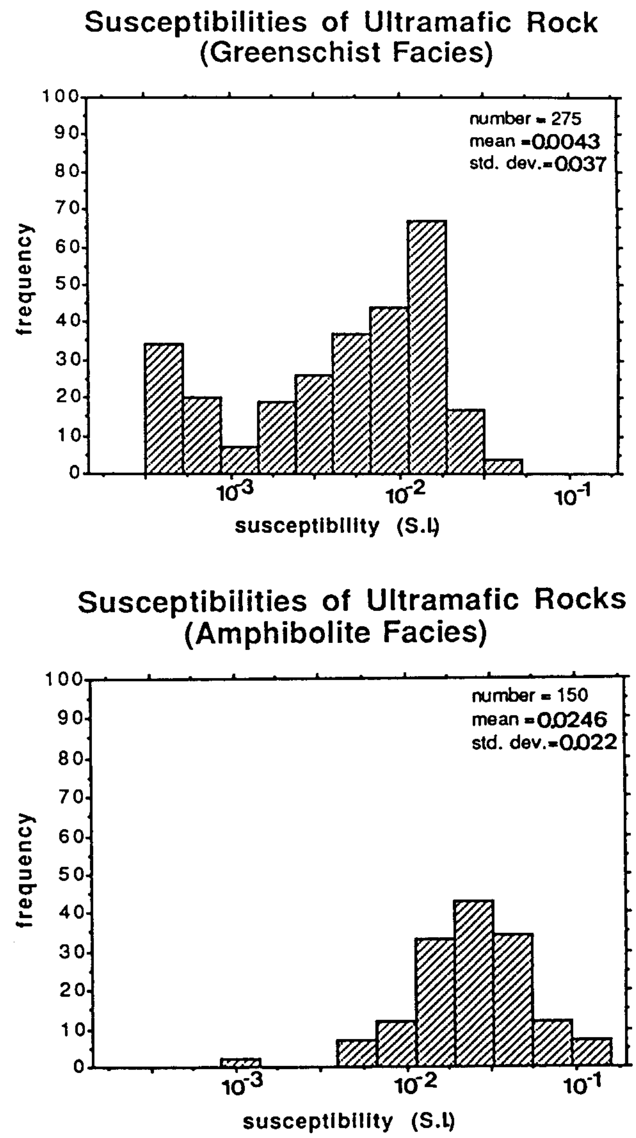

FIGURE 7
Frequency histogram showing observed magnetic susceptibilities (logarithmic scale) of ultramafic rocks following greenschist and amphibolite facies metamorphism.

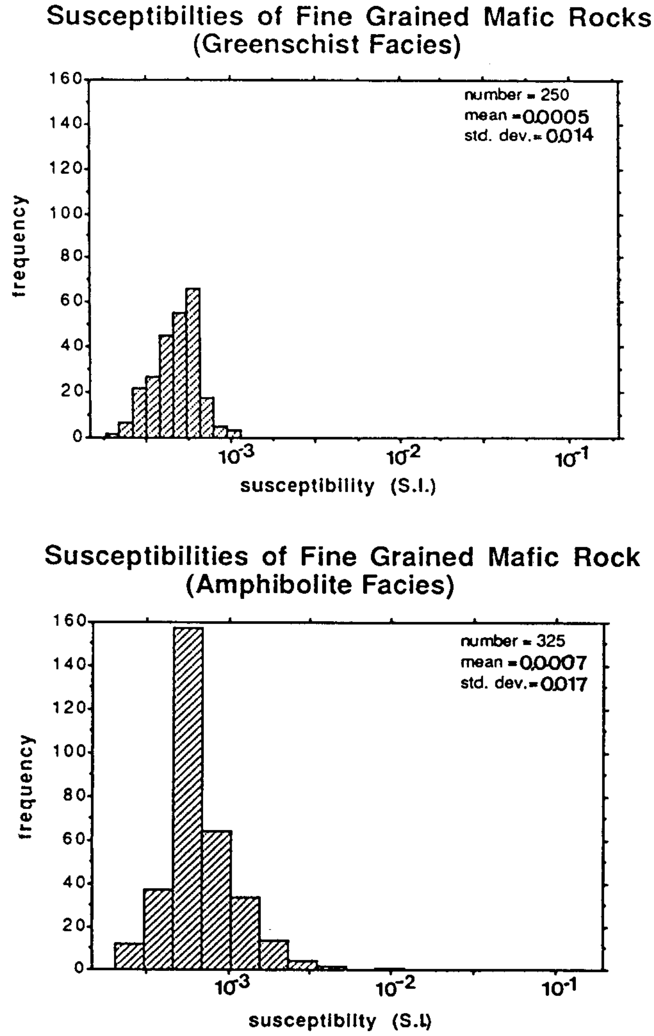

FIGURE 8
Frequency histogram showing observed magnetic susceptibilities (logarithmic scale) of fine-grained mafic rocks following greenschist and amphibolite facies metamorphism.

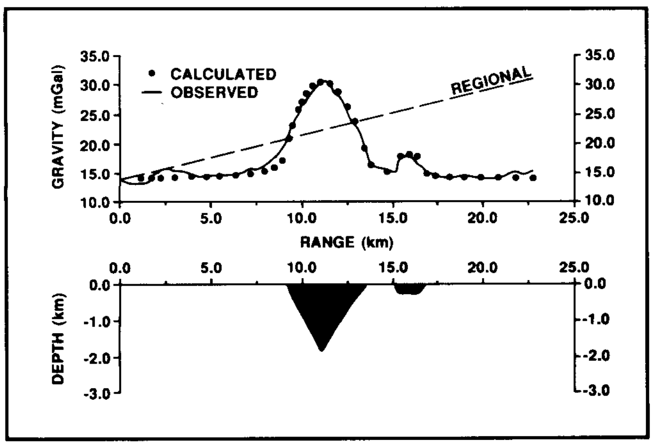

FIGURE 9
Gravity model of the Weebo/Wildara Greenstone Belt (greenschist facies). Note that a vertical exaggeration of X2 has been used in the diagram.

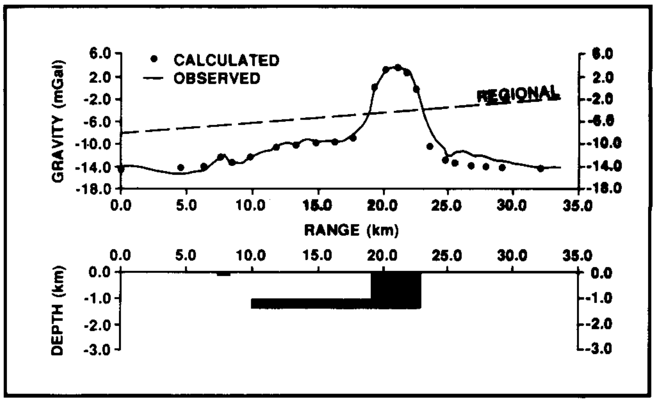

FIGURE 10
Gravity model of the Southern Cross Greenstone Belt (amphibolite facies) updated from Dentith *et al.* (1992). Note that a vertical exaggeration of X2 has been used in the diagram.

are of sufficient magnitude to require consideration in gravity and magnetic modelling of greenstone belts.

Gravity data from the Weebo/Wildara and Southern Cross greenstone belts reveal positive Bouguer anomalies up to 15 mGal. Two-dimensional modelling of these data, using the observed density data, suggests that mafic stratigraphy in each belt is unlikely to greatly exceed 2 km vertical extent. In the case of the Weebo/Wildara greenstone belt, the data preclude the presence of a deeper segment of the belt metamorphosed to higher grade.

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