NSW DPI

Quarterly Notes

Geological Survey of New South Wales

October 2006 No 122

The Fox Tor Diorite, a newly recognised intrusion within the New England Batholith, northern New South Wales

ABSTRACT

The Fox Tor Diorite is a newly recognised intrusion with an I-type intermediate composition. It is totally enclosed by the S-type Pringles Monzogranite, a member of the Bundarra Supersuite of the New England Batholith. The intrusion was initially detected by its strong aeromagnetic signature and subsequent mapping showed that there are six separate outcrops covering 84 hectares within an area of 2.6 km north–south and 1.2 km east–west. Field relationships imply intrusive contacts against the Pringles Monzogranite, with localised contamination of the diorite at the contact. Modelling of magnetic data indicates that the intrusive mass is steep-sided and extends to considerable depth. K–Ar geochronology on the Fox Tor Diorite gave an age of 239.7±6.7 Ma, a result that overlaps with age determinations for the Uralla and Moonbi Supersuites in the southern New England Orogen, but is approximately 50 Ma younger than granitoids of the Bundarra Supersuite. Rocks of the Fox Tor Diorite are medium-grained, with early crystallised orthopyroxene, clinopyroxene and plagioclase, and subsequent crystallisation of minor hornblende, biotite, K-feldspar and quartz. The intrusion is characteristically magnetic, with susceptibilities of 900×10^{-5} to 2800×10^{-5} SI. Although ilmenite is present, magnetite is more abundant and the magnetic (and oxidation state) characteristics are more typical of the Moonbi Supersuite granitoids, rather than those of the Uralla Supersuite. On the other hand, geochemical characteristics of the Fox Tor Diorite, such as contents of K_2O, P_2O_5, Rb, Sr, Nb and Zr, accord better with mafic members of the Uralla Supersuite. Geochemical and mineralogical criteria indicate that the Fox Tor Diorite magma had a significant mantle-derived component and that it has undergone fractionation, perhaps largely by precipitation of pyroxenes and possibly plagioclase.

Keywords: Fox Tor Diorite, New England Batholith, Uralla Supersuite, Moonbi Supersuite, Bundarra Supersuite, aeromagnetic imagery, radiometric imagery, geochemistry

AUTHORS

P G Stonestreet[1]

P M Ashley[1]

R E Brown[2]

W J Sivell[1]

1. Earth Sciences, University of New England, Armidale
2. Geological Survey of New South Wales, Armidale

NSW DEPARTMENT OF
PRIMARY INDUSTRIES

Papers in Quarterly Notes are subject to external review. External reviewer for this issue was Phil Blevin. His assistance is appreciated.

Quarterly Notes is published to give wide circulation to results of studies in the Geological Survey of New South Wales. Papers are also welcome that arise from team studies with external researchers.
Contact: john.watkins@dpi.nsw.gov.au

ISSN 0155-3410

INTRODUCTION

The New England Batholith of northeastern New South Wales and southern Queensland (Shaw & Flood 1981) contains more than one hundred and sixty discrete plutons based on variations in field, mineralogical, geochemical and geophysical criteria. The area of exposed granitoids (15 000 km^2), petrological diversity and the large range of genetically associated mineral deposits in the New England Batholith has led to many detailed geological studies and reviews (e.g. Wilkinson 1969; Flood 1971; Flood & Shaw 1975, 1977; Chappell 1978, 1994; Shaw & Flood 1981, 1993; Hensel et al. 1985; Barnes et al. 1988; Brown et al. 1992; Gilligan et al. 1992; Blevin & Chappell 1993; Kent 1994; Landenberger et al. 1995; Ashley et al. 1996; Brown & Stroud 1997; Bryant, Arculus & Chappell 1997; Bryant, Chappell & Blevin 2003; Stroud et al. 1999; Henley et al. 2001).

The New England Batholith has been subdivided into five distinct plutonic suites (Shaw & Flood 1981) – more recently termed supersuites by Chappell (1994), on the basis of petrological variations. These are the Late Carboniferous to Early Permian Bundarra and Hillgrove Supersuites and the Late Permian to Early Triassic Moonbi, Uralla and Clarence River

CONTENTS

Production co-ordination: *Simone Meakin*

Copy editing: *Richard Facer*

Geospatial information: *Cheryl Hormann*
Phillip Carter

Layout: *Simone Madigan*

NSW DEPARTMENT OF
PRIMARY INDUSTRIES

Supersuites. The two former suites are composed of S-type granitoids, whereas the latter three consist of I-type granitoids (Shaw & Flood 1981; Chappell 1994). The Uralla Supersuite displays certain characteristics transitional between I-type and S-type granitoids (O'Neil et al. 1977; Shaw & Flood 1981; Hensel et al. 1985). Members of the Moonbi Supersuite in particular display fractionation trends into highly evolved leucogranite with which are associated abundant and diverse mineralisation types (Blevin & Chappell 1993, 1996; Brown & Stroud 1993; Henley, Brown & Stroud 1999; Henley et al. 2001).

The acquisition of new geophysical datasets over parts of the New England region by the Geological Survey of New South Wales has allowed further refinement of geological boundaries and clarified many geological relationships. Specifically, the Peel airborne geophysical survey area (Brown 2001) and Peel South airborne geophysical survey area (Brown 2003) have provided high-quality magnetic and radiometric results that have significantly improved the understanding of relationships within and between granitoids of the New England Batholith in the southwestern portion of the New England Orogen. In the Peel and Peel South survey areas, granitoids of the Bundarra, Moonbi and Uralla Supersuites are geophysically distinct, and in many cases, individual plutons can be readily discerned on the basis of differences in their magnetic (total magnetic intensity, TMI, and first vertical derivative, 1VD) and radiometric (total count radioelement or individual K, U or Th) responses (Brown 2001; 2003).

A result from the Peel South survey was the identification of a prominent keyhole-shaped magnetic anomaly in the centre of the large southern lobe of the Bundarra Supersuite granitoids approximately 35 km WSW of Uralla (Brown 2003) (Figure 1). Previous mapping, compiled by Brown et al. (1992), indicated that the region was underlain by the Pringles Monzogranite of the Bundarra Supersuite. However, the character of the magnetic anomaly implied a shallow (perhaps outcropping) source, quite different to the magnetically bland Bundarra Supersuite (Figure 1, lower left). Initial field reconnaissance at the area of the magnetic anomaly by R.E. Brown located outcrops of medium- to coarse-grained diorite with moderate to high magnetic susceptibilities, surrounded by coarse, porphyritic granite typical of the Bundarra Supersuite. Subsequently, the area was investigated in more detail by Stonestreet (2002). This geological note details results of mapping, petrography and geochemical analyses, relating these data to the geophysical responses of the diorite. The age and affinities of the diorite have also been investigated, as has its possible relationship to the southern part of the New England Orogen.

LOCATION, DEFINITION AND METHODS USED IN STUDY

The prominent magnetic anomaly is centred 34 km WSW of Uralla and 20 km north of Bendemeer. It is in the Manilla–Narrabri 1: 250 000 metallogenic map area (Brown et al.

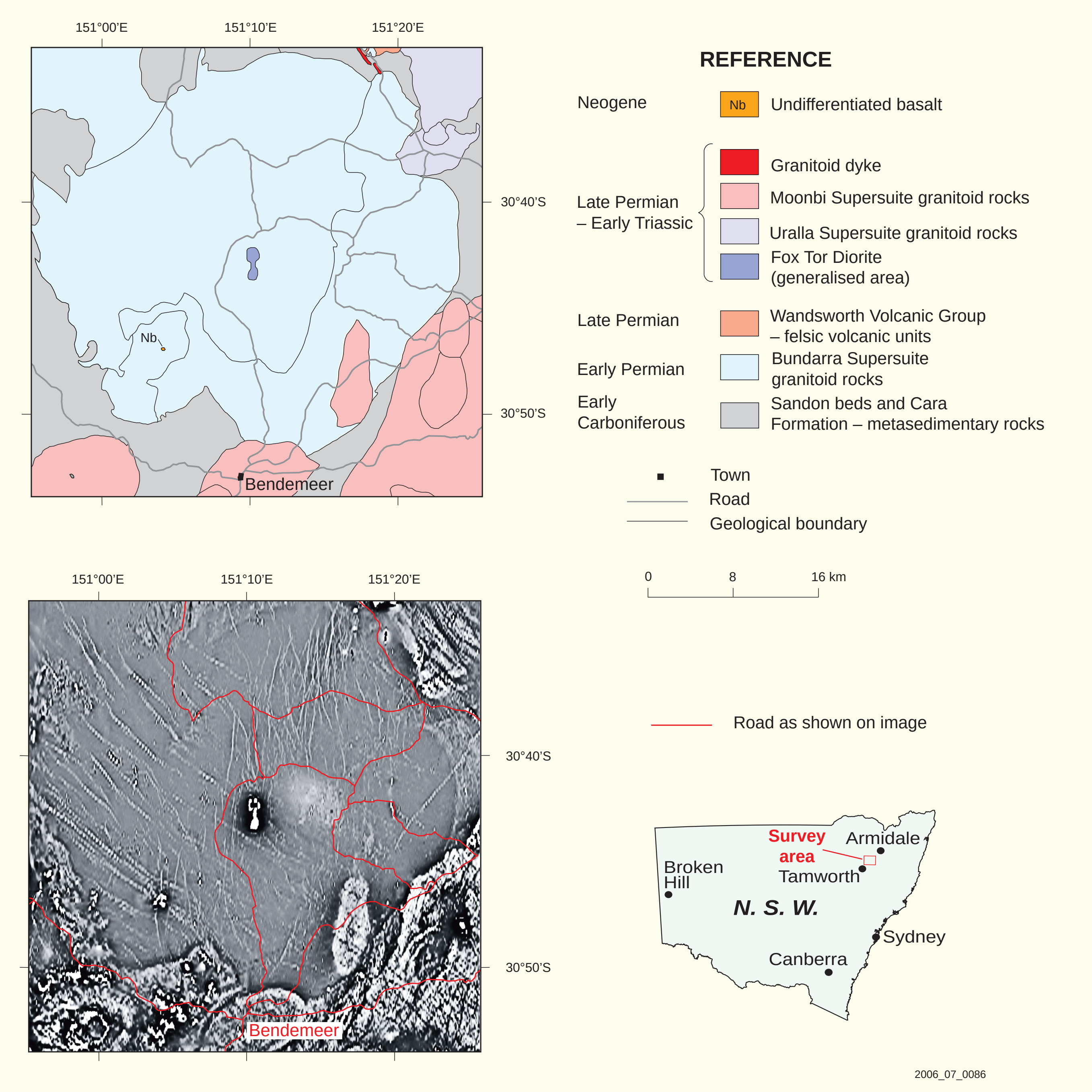


Figure 1 Regional location, geological setting and first vertical derivative of the total magnetic intensity response for the Fox Tor Diorite. Cadastral data from the NSW Department of Lands.

1992) and the Watsons Creek 1:25 000 topographic map area (9136-IV-S). The AMG (1966) coordinates for the central point of the anomaly are 324600mE, 6601650mN (Zone 56). Mapping by Stonestreet (2002) resolved the diorite into six discrete outcrop areas that correlated well with the geophysical imagery (Brown 2003). The outcrop areas are located mainly on the property 'Fox Tor' and hence the name *Fox Tor Diorite* is proposed for the body (see Appendix).

An area of approximately 6 km^2 covering the magnetic anomaly was mapped at a scale of 1:15 000 (Stonestreet 2002) and results related to the aeromagnetic and radiometric imagery from the Peel South survey. Samples collected during mapping were measured for magnetic susceptibility using a GMS-2 magnetic susceptibility meter and subsequently examined petrographically. Ten samples of diorite were selected for whole-rock geochemical analyses and these were subsequently analysed for major element oxides and trace elements at Macquarie University by Professor Bruce Chappell (eight samples) and the University of New England by John Bedford (two samples) using X-ray fluorescence spectrometry. One of the geochemically analysed samples was subsequently submitted to Actlabs Pacific Pty Ltd, Perth, for K–Ar geochronology. In the dated sample, K was determined by ICP and argon analysis was performed by the isotope dilution procedure on noble gas spectrometry. Mineral chemical analyses were performed on polished thin sections by electron probe microanalysis (EPMA) at the Electron Microscope Unit, University of New England, using a JEOL5800 electron microprobe with energy dispersive system. Samples referred to in the paper are housed in the collection of Earth Sciences at the University of New England.

GEOLOGICAL SETTING AND FIELD DESCRIPTION

The Fox Tor Diorite crops out near the centre of the large southern lobe of the Bundarra Supersuite granitoids (Figure 1). This lobe is approximately 35 km in diameter and is evidently composite, with discrete phases having been defined (Chappell 1978; Brown 2003; cf. Brown et al. 1992). In this region, the Bundarra Supersuite has been intruded by younger plutons of the Moonbi Supersuite (Flood 1971; Chappell 1978; Brown 2003). Granitoids of the Bundarra Supersuite have intruded metasedimentary rocks of the southern New England Orogen (Anaiwan tectonostratigraphic terrane of Flood & Aitchison 1988). The metasedimentary rocks are part of the accretionary complex forming the central portion of the southern New England Orogen and in the Uralla–Bendemeer region are elements of the Sandon beds and the Cara Formation (Brown et al. 1992; Brown 2003).

Outcrop of the Fox Tor Diorite occurs in six discrete irregular to lobate masses over an area extending approximately 2.6 km north–south and up to 1.2 km east–west (Figure 2). Each mass is surrounded by granitoids assigned to the Pringles Monzogranite. The total area covered by the diorite masses is approximately 84 ha, with the southernmost mass being the largest with an outcrop area of approximately 49 ha (Figure 2). There is a close relationship between the mapped outcrops of diorite and the position of aeromagnetic anomalies (Figure 3). Outcrop over the diorite and surrounding monzogranite is extensive in hilly terrain, but less prominent elsewhere. The rocks are fresh in blocky to tor-like outcrops, although saprock development occurs in regions of subdued outcrop.

Samples of the Fox Tor Diorite are grey, mesocratic, relatively equigranular and medium-grained. Plagioclase, biotite and hornblende are conspicuous macroscopic phases. Typical grainsize ranges from ~0.5 mm to ~2 mm; locally there is a tendency for development of aggregates of ferromagnesian minerals and phenocrystal plagioclase up to 5 to 7 mm across. No consistent relationship was noted between grainsize and contacts of the diorite. All samples are magnetic, with magnetic susceptibility ranging from 900×10^{-5} SI to 2800×10^{-5} SI (average 1600×10^{-5} SI). There is little evidence of hydrothermal alteration in the diorite and the primary igneous minerals are generally fresh.

Rare dykes occur within, or are closely associated with, the Fox Tor Diorite (Figure 2). A single dyke in the northwestern mass (AMG 1966: 324150mE, 6602600mN) strikes northwesterly for about 100 m, is up to 4 m wide and is composed of a fine- to medium-grained, non-magnetic rock that is more felsic than the diorite. It was given the field name 'microgranodiorite'. Float of a fine grained, grey, porphyritic and non-magnetic rock, probably representing a dyke, also occurs near the northern end of this mass (at AMG 1966: 324400mE, 6602750mN). Another single dyke with a northwesterly strike crops out near the southeastern margin of the southern mass of Fox Tor Diorite (AMG 1966: 324800mE, 6600200mN). This dyke is non-magnetic, grey, fine-grained and microporphyritic, up to 2 m wide and crops out for about 20 m. The latter two occurrences were given the field name 'microdiorite'.

The dominant rock type surrounding the Fox Tor Diorite masses is a relatively leucocratic, medium- to coarse-grained and somewhat megacrystic biotite monzogranite. K-feldspar megacrysts up to 1.5 cm across are present and there are a few rectangular pseudomorphic aggregates after former cordierite. This rock type is non-magnetic. Around the southern margin of the southern Fox Tor Diorite mass, the monzogranite contains rare spheroidal enclaves up to 20 cm across. These are equigranular and finer grained and more biotite-rich than the host.

In places along the eastern margin of the northwestern mass of the Fox Tor Diorite, the monzogranite is texturally different, being medium-grained and porphyritic in K-feldspar and quartz. There are also several dykes within the monzogranite – these have strikes that vary from northwest to north to northeast (Figure 2) and range up to a few metres wide.

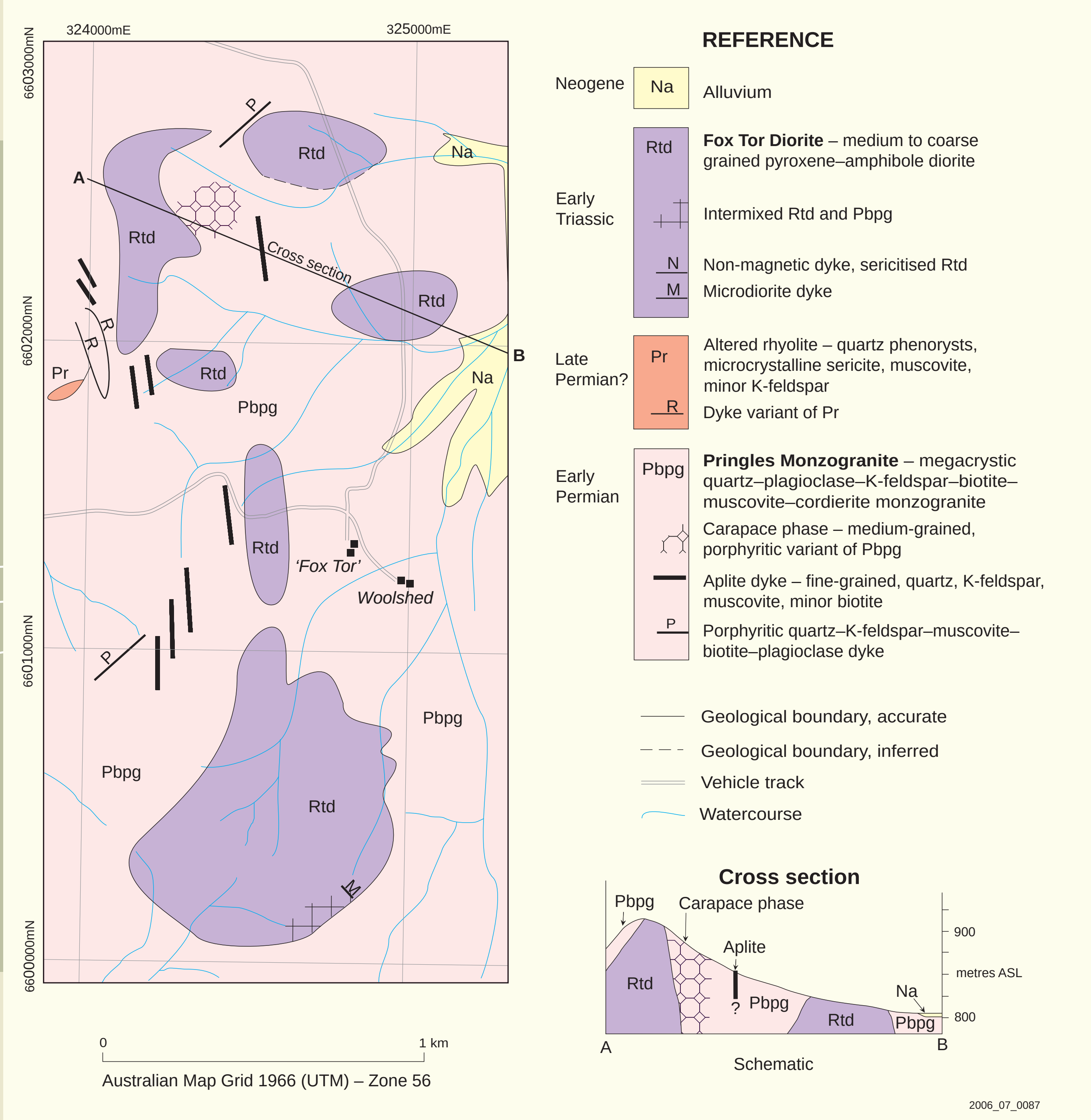
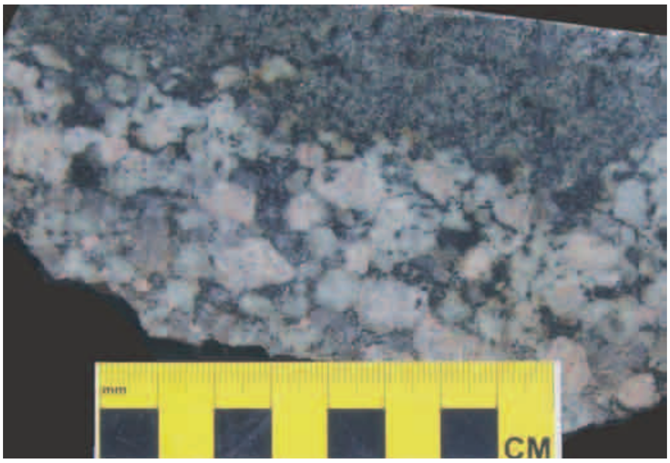


Figure 2 Geological map and cross section of the Fox Tor Diorite – geological interpretation and map after Stonestreet (2002). Topographic data from the NSW Department of Lands.

They include: sparsely porphyritic and locally flow-foliated rhyolite; quartz–feldspar porphyry; and fine- to medium-grained, relatively equigranular microgranite (aplite). All of the felsic dyke types are non-magnetic and none of the above types occur in the diorite.

Adjacent to the southeastern margin of the southern diorite mass (centred on AMG 1966: 324900mE, 6600400mN), there has been textural modification of the monzogranite within a few metres of the contact. There, localised apparent 'infiltration' and possible reaction of the diorite with monzogranite has occurred, which created a rock with large feldspar grains surrounded by medium-grained biotite, hornblende, feldspars and quartz. This type of material is moderately magnetic, with susceptibilities of 100×10^{-5} SI to 300×10^{-5} SI. Rare contacts between the diorite and the apparent reaction phase are sharp, but intricate (Photograph 1). There are also rare rounded xenoliths of monzogranite up to 15 cm across in diorite immediately adjacent to the contact.



Photograph 1 Sample R81911 showing contact between medium-grained diorite (lower) and 'mixed' phase (upper) adjacent to the contact with Pringles Monzogranite. The 'mixed' phase contains coarse-grained plagioclase (white), partly replaced by K-feldspar (pale pink), with interstitial ferromagnesian minerals. Scale is in centimetres. (Photographer P.M. Ashley)

GEOPHYSICAL RESPONSES

Magnetic characteristics

The Fox Tor Diorite was initially recognised and informally termed the Fox Tor diorite by Brown (2003, p. 22) due to its contrasting, intense positive magnetic anomaly within the otherwise bland, low-intensity Pringles Monzogranite (Figures 1, 3a and 3b). The total magnetic intensity anomaly is approximately keyhole-shaped with an elongate axis striking north–south for about 3000 m (Figure 3a, 3b). The anomaly can be resolved into an aggregate of five, and perhaps six, closely spaced pod-like domains that correlate closely with outcropping areas of the Fox Tor Diorite. The anomaly profile is approximately symmetrical across its long axis, with a peak value of 56 100 nT and amplitude of 600–700 nT.

Modelling of the magnetic data by Peter Ruszkowski (pers. comm. 2003) indicated that the Fox Tor Diorite is a tabular mass dipping at about 80° to the west (Figure 4). The body extends to depths probably in excess of 3 km. The close correlation of outcrop areas and portions of the magnetic anomaly could indicate that the diorite occurs as a number of closely spaced, steeply dipping, irregular tabular and rod-like masses.

The magnetic images (Figure 3a, 3b) exhibit two apparent dyke swarms within the Pringles Monzogranite. The dykes are evident as positive linear anomalies striking north–south and northeast–southwest with peak intensity values below that of the Fox Tor Diorite. Their relationships to the diorite are not apparent from the magnetic data.

Radiometric characteristics

The Fox Tor Diorite does not exhibit a distinctive radiometric response in the South Peel geophysical dataset. Consequently, the K, Th, U and total count radiometric images are inadequate for accurately distinguishing the Fox Tor Diorite from the Pringles Monzogranite (Figure 3c). This possibly relates to terrain clearance errors or spectrometer resolution, or could be due to mantling by granite-derived regolith, particularly in the northern half of the diorite outcrop area. A region of K response that is lower than that over the Pringles Monzogranite correlates approximately with the Fox Tor diorite. Subtle, non-systematic variations in U and Th are apparent throughout the Fox Tor Diorite.

PETROGRAPHY AND MINERAL CHEMISTRY

Fox Tor Diorite

The Fox Tor Diorite intrusion is composed essentially of a single rock type, viz. a two-pyroxene–hornblende–biotite–quartz diorite. There are, however, considerable textural variations and minor modal variations (Photographs 2, 3, 4), but all samples examined are unstrained and unrecrystallised. The diorite ranges from medium-grained (average 0.5 mm; Photograph 4) to medium- to coarse-grained (average 2 mm; Photographs 2, 3), with all being hypidiomorphic granular and the coarser types tending to be slightly porphyritic, with scattered plagioclase laths up to 5 mm long (Photograph 3). In some of the medium-grained samples, weak alignment of plagioclase laths is apparent (Photograph 4). Glomeroporphyritic aggregates of ferromagnesian minerals up to 7 mm across are scattered in both finer and coarser types. Plagioclase is the most abundant mineral (50–70 modal %) and has crystallised at both early and later stages. Normal and oscillatory compositional zoning is characteristic and EPMA has indicated a range of An_{23-62}. Pyroxenes are present in most samples, but in some have been replaced by alteration aggregates. They constitute up to 20 modal % as discrete grains and as components of composite ferromagnesian aggregates. Clinopyroxene (augite: $Ca_{25.5-38.2}$

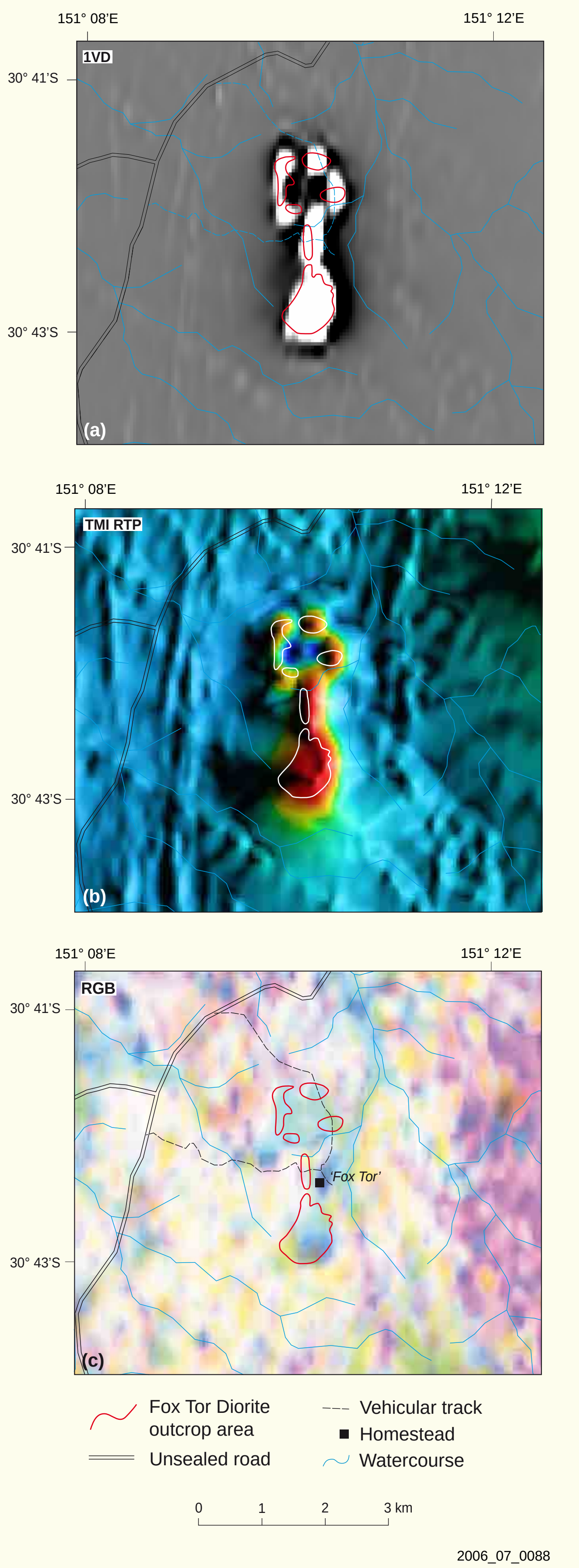


Figure 3 (a) First vertical derivative image, (b) pseudocolour total magnetic intensity reduced to pole image and (c) ternary RGB radiometric image of the Fox Tor Diorite and immediate area. Images are from Brown (2002), using data collected as part of the Exploration NSW initiative. Topographic data from the NSW Department of Lands.

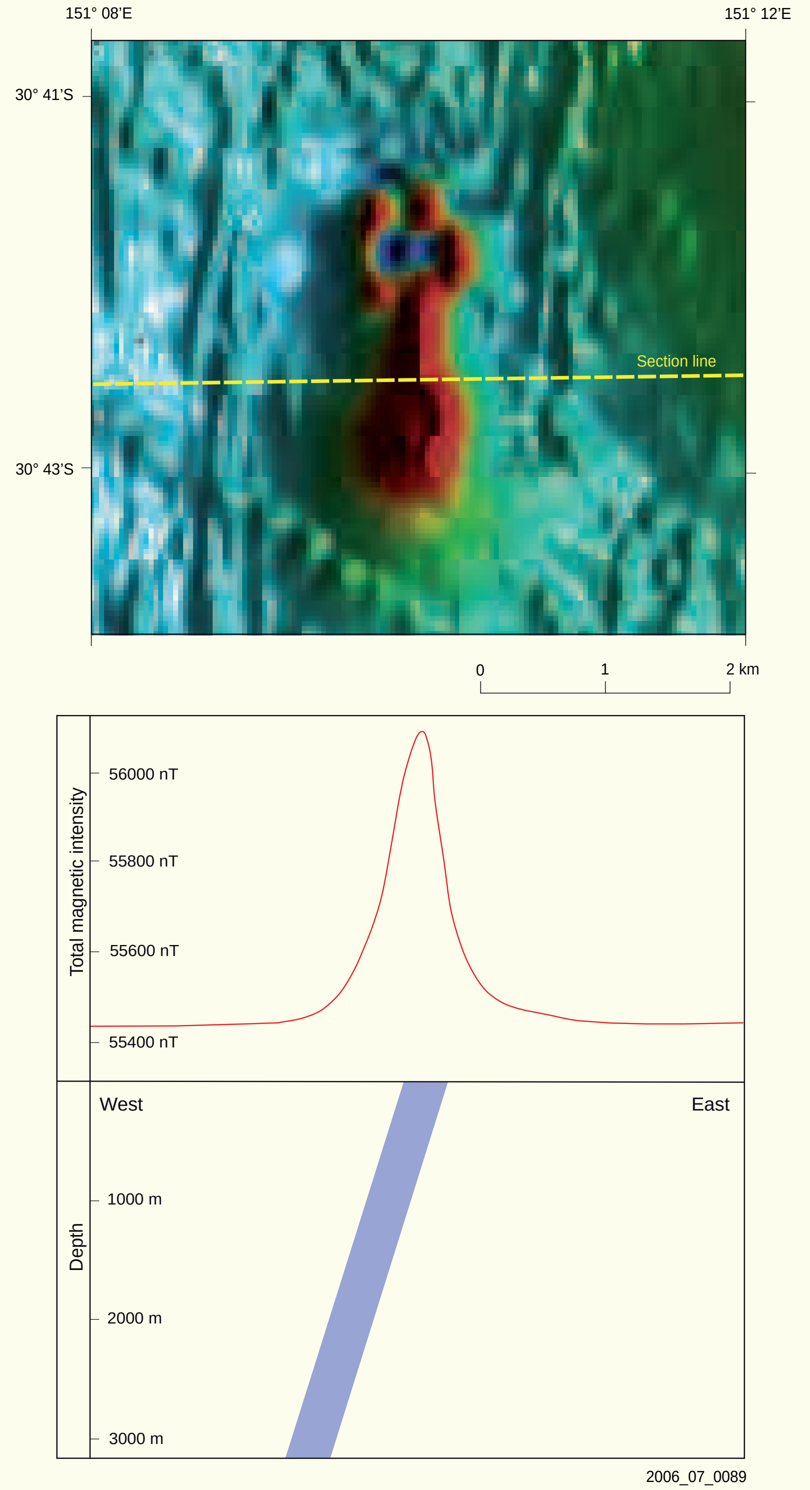
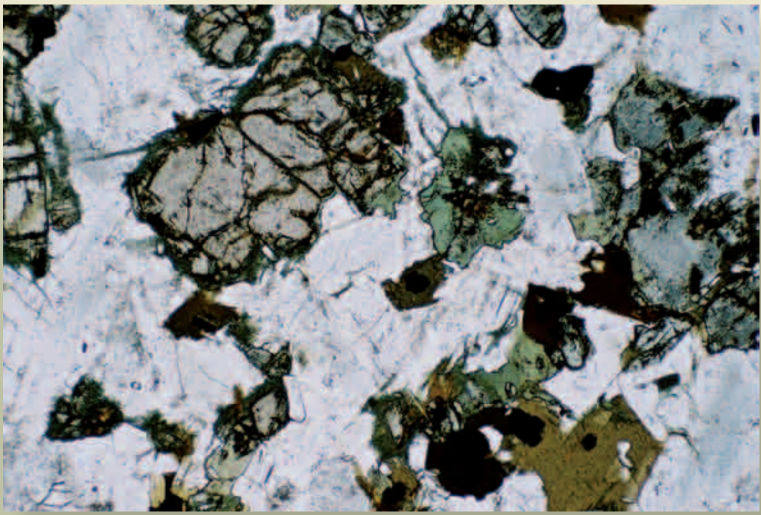
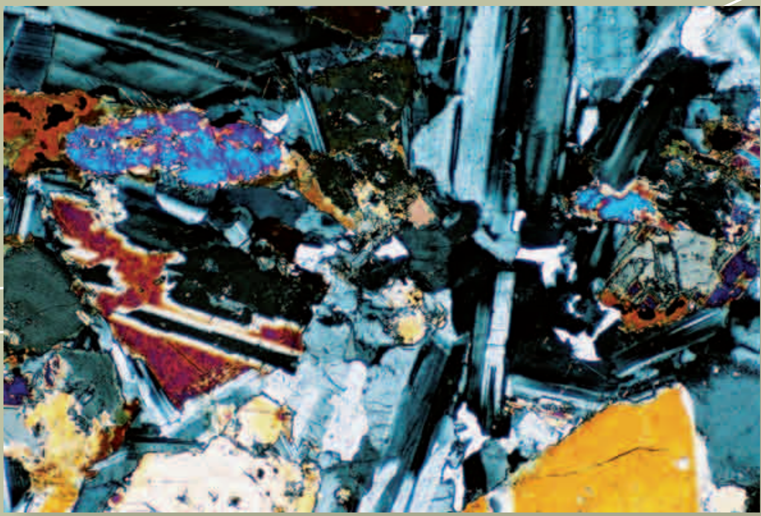


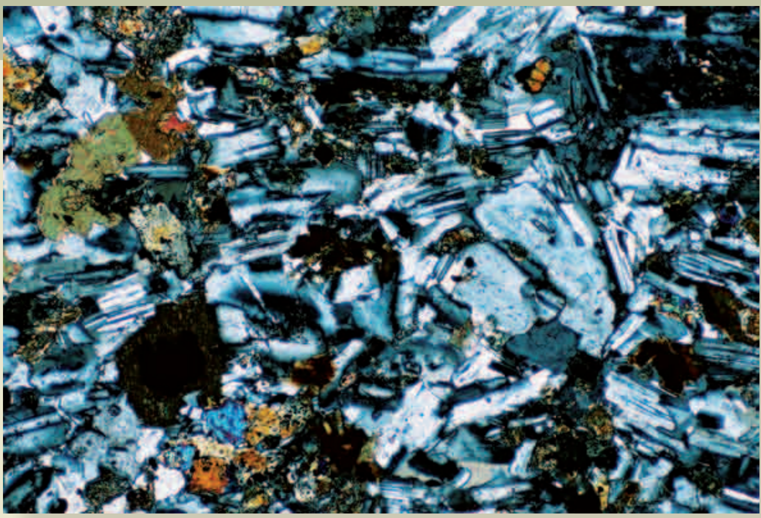
Figure 4 Total magnetic intensity reduced to pole (TMI RTP) aeromagnetic image of the Fox Tor Diorite (top) with total magnetic intensity profile and corresponding geophysical model. The section line for the profile is shown on the TMI RTP image. Profile and model after Peter Ruszkowski (pers. comm. 2003).



Photograph 2 Sample R79438. Typical texture and mineral assemblage in medium-grained Fox Tor Diorite. Scattered grains of orthopyroxene (pinkish) and clinopyroxene (pale grey) occur with hornblende (green), biotite (brown) and Fe–Ti oxides (black), hosted in plagioclase and minor quartz (clear). Plane polarised transmitted light, field of view 2.5 mm across. (Photographer P.M. Ashley)



Photograph 3 Sample R79440. Coarse-grained pyroxene diorite. Most strongly coloured grains are clinopyroxene (in places twinned), intergrown with twinned plagioclase and a little quartz, biotite and orthopyroxene. Transmitted light, crossed polars, field of view 2.5 mm across. (Photographer P.M. Ashley)



Photograph 4 Sample R79432. Fine-grained diorite, with abundant aligned plagioclase grains, plus minor biotite (brown), pyroxenes (multicoloured), quartz (white) and Fe–Ti oxide (black). Transmitted light, crossed polars, field of view 2.5 mm across. (Photographer P.M. Ashley)

$Mg_{44.3-49.5}Fe_{14.5-29.3}$) has a similar abundance to orthopyroxene ($Ca_{2.4-4.3}Mg_{47.4-74.4}Fe_{21.5-50.1}$). The two minerals may be mutually intergrown but, in places clinopyroxene rims orthopyroxene. In one sample (R79440), orthopyroxene hosts pseudomorphs after former olivine. Hornblende occurs in all samples, with a range of 1–15 modal %. It occurs as discrete anhedral to prismatic grains and most commonly as rims on pyroxenes. In the rims, hornblende could have formed by late magmatic replacement of pyroxenes. Hornblende is green to green–brown and EPMA indicates that compositions are all magnesio-hornblende in the classification of Leake et al. (1997) with 5.5–8.8% Al_2O_3 and 0.5–1.95% TiO_2. Biotite is a common, minor phase, constituting 1–10 modal %. It occurs discretely, but also as a component of ferromagnesian aggregates with pyroxenes and hornblende, plus oxide minerals, and it characteristically encloses oxide minerals. Biotite is relatively Ti-rich (3.3–4.7%) and Fe-rich (Mg/Mg + Fe^{2+} = 47.8–60.3).

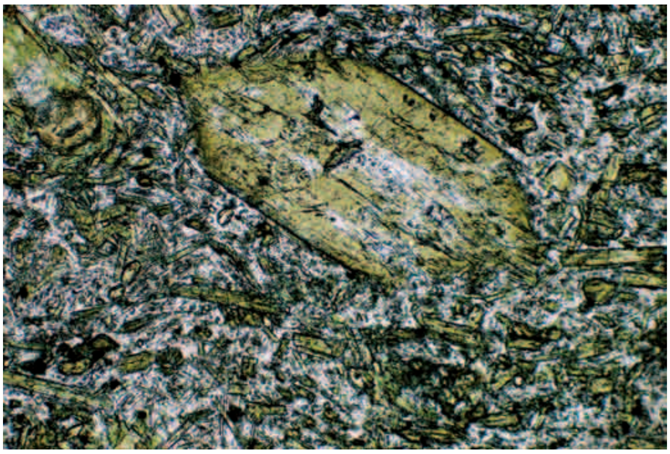
Iron–titanium oxide minerals constitute 1–3 modal % and are commonly associated with ferromagnesian minerals, forming individual grains and aggregates. Magnetite (with 2.1–10.2 mol. % ülvospinel and 1.8–2.1 % V_2O_3) commonly coexists with less abundant ilmenite. K-feldspar (orthoclase) and quartz are minor (1–10 modal %) phases that occur interstitially to plagioclase and ferromagnesian minerals. Apatite is the most common accessory phase (typically enclosed in plagioclase) and there are tiny traces of chalcopyrite, zircon and titanite.

The petrographic characteristics of the Fox Tor Diorite conform to those indicated for mafic I-type granitoids (e.g. Chappell & White 2001). In particular: the presence of pyroxenes, in places surrounded by hornblende; and the relative abundance of magnetite; are characteristic. On the other hand, the oxidation state of the Fox Tor Diorite is not as high as in many I-type granitoids, as pink K-feldspar is absent and ilmenite is a common accessory phase (up to 1 modal %).

Alteration effects imposed on the primary igneous minerals range from minor to moderate. Several samples display replacement of orthopyroxene by near-colourless twinned amphibole, identified as cummingtonite by EPMA. The replacement could have occurred under sub-solidus conditions. Clinopyroxene and hornblende have locally been retrogressed to actinolite, with all ferromagnesian phases displaying local late alteration to chlorite and carbonate. Plagioclase in a few samples is flecked by fine–grained sericite and clinozoisite.

Dykes associated with Fox Tor Diorite

The 'microgranodiorite' dyke in the northwestern mass of Fox Tor Diorite is medium-grained and porphyritic, with phenocrysts of plagioclase and minor biotite up to 2 mm across. K-feldspar and subordinate biotite and quartz, with a trace of allanite, are interstitial to plagioclase. A line of float of porphyritic 'microdiorite' near the northern margin of the same mass petrographically displays pseudomorphs after former



Photograph 5 Sample R79446. is a lamprophyre (vogesite) from a dyke in the Fox Tor Diorite which displays phenocrysts of brown hornblende in a finer grained feldspathic groundmass. Plane polarised transmitted light, field of view 2.5 mm across. (Photographer P.M. Ashley)

phenocrysts of ?clinopyroxene up to 3 mm across set in a fine- to medium-grained groundmass of brown–green hornblende, biotite, plagioclase and minor K-feldspar. Texturally and mineralogically, this rock is a lamprophyre and its interpreted primary assemblage conforms to a spessartite. Former ?clinopyroxene phenocrysts have been replaced by pale green amphibole, but preserve tiny relict grains of chromian spinel. Moderate alteration in this rock has resulted in replacement by actinolite, chlorite, sericite, carbonate and a trace of titanite. The dyke of 'microdiorite' in the southern mass of the Fox Tor Diorite is also a type of lamprophyre. It contains prismatic to acicular phenocrysts of brown hornblende in a finer grained groundmass of hornblende, K-feldspar and plagioclase, conforming to vogesite composition (Photograph 5). This rock is also moderately altered, with replacement by carbonate, chlorite, actinolite, epidote and titanite.

Monzogranite and related dykes and enclaves

Typical monzogranite surrounding the Fox Tor Diorite is medium- to coarse-grained and inequigranular to porphyritic (megacrystic). It contains large grains of K-feldspar (microcline), with intergrown quartz, plagioclase, minor biotite and a little tourmaline, sericitised ?cordierite and traces of apatite, ilmenite and zircon. In places, micrographic K-feldspar–quartz intergrowths are present. The porphyritic monzogranite phase along the eastern margin of the northwestern mass of the Fox Tor Diorite has large K-feldspar grains and is more quartz-rich than typical monzogranite. It is also hydrothermally altered, with substantial replacement of feldspars and biotite by muscovite/sericite.

Dykes in the monzogranite include: medium-grained micrographic-textured microgranite (with minor muscovite and biotite); strongly porphyritic rhyolite (quartz–feldspar porphyry) that contains phenocrysts of quartz and K-feldspar and altered phenocrysts of plagioclase and biotite in a fine-grained altered feldspathic groundmass (alteration in this rock is to muscovite/sericite); and sparsely porphyritic and strongly altered rhyolite. This rock type has sparse quartz phenocrysts in an altered feldspathic groundmass largely replaced by fine-grained muscovite and quartz, plus traces of pyrite.

Rare enclaves in the monzogranite near the southern mass of Fox Tor Diorite are medium-grained and inequigranular. Although rich in quartz, plagioclase and K-feldspar, they contain substantially more biotite (brown and green types) than the enclosing monzogranite, in places in pseudomorphic aggregates after a former ?ferromagnesian phase, as well as a few grains of garnet up to 1 mm across. Such enclaves are peraluminous (as expected by the presence of garnet) and might represent restite material, formerly of metasedimentary origin.

Contact rock

Monzogranite has apparently locally reacted with invading diorite magma, resulting in a 'mixed' or 'mutually contaminated' rock up to a few centimetres in thickness. The latter contains scattered large anhedral grains of plagioclase and K-feldspar, with lesser amounts of quartz, biotite, hornblende and uncommon pyroxenes and a minor amount of oxide minerals. Texturally, the rock has similarities with the surrounding monzogranite, but mineralogically is closely akin to the diorite (Photograph 1). Large plagioclase phenocrysts appear to have been partly replaced by K-feldspar and minor quartz, and there has been considerable apparent reaction of pyroxenes to form hornblende and biotite. The replacement textures could have formed at the late magmatic stage or under subsolidus conditions.

GEOCHRONOLOGY

Following petrographic examination of the suite of samples from the Fox Tor Diorite, one sample of fresh, unstrained, medium-grained two-pyroxene (–biotite–hornblende–quartz) diorite (sample R79431) was selected and crushed for whole-rock K–Ar geochronology. The crushed sample was submitted to Actlabs Pacific Pty Ltd, Perth. Results are shown in Table 1. A Triassic age of approximately 240 Ma was obtained.

Table 1 Result of K–Ar radiometric analysis of sample R79431 from the Fox Tor Diorite

Sample type	Two-pyroxene (–biotite–hornblende–quartz) diorite (whole rock)
AMG 1966 Easting, m	324300
AMG 1966 Northing, m	6600150
K wt %	2.030
Rad ^{40}Ar, 10^{-9} mol/g	19.84
$\%^{40}Ar_{air}$	27.4
Calculated age (Ma)	239.7
Calculated error (Ma)	6.7

Analyst: Y. Kapusta, Actlabs. Decay constants are $\lambda_e = 5.81 \times 10^{-10} y^{-1}$ and $\lambda_\beta = 4.962 \times 10^{-10} y^{-1}$.
Sample R79431 is housed at Earth Sciences, University of New England.

GEOCHEMISTRY

Ten representative samples of fresh Fox Tor Diorite were geochemically analysed for major element oxides and trace elements. Eight samples were from the southern mass (R79430, R79431, R81906–11), one from the northwestern mass (R79432) and one from the northern mass (R79440). In the analyses, total Fe is expressed as Fe_2O_3T (where T = total). CIPW norms were subsequently calculated with apportioning of Fe in the ratio of $Fe_2O_3/FeO = 0.2$. Values of 'Mg ratio' (Mg#) have been similarly calculated as $100Mg/(Mg+Fe^{2+})$ where Fe^{2+} is adjusted on the basis of $Fe_2O_3/FeO=0.2$.

Results confirm the intermediate composition of the intrusion, with a limited SiO_2 range from 55.6% to 61.6%, but with a significant correlative variation in Mg# from 68.1 to 47.8 (Table 2). Mimicking the antithetic variation in SiO_2 and Mg# are decreases in Fe_2O_3T, MgO, CaO, TiO_2, CaO/Al_2O_3, Cr, Ni, V, Cu and Zn, and increases in total alkalies, Zr and Nb (Figure 5, Table 2). Although there are variations in Na_2O/K_2O of 1.1–3.0 and Rb/Sr of 0.11–0.26, there are only weak relationships with SiO_2 content and Mg#. Despite the limited analytical data, there is an apparent change in chemical trends at ~58% SiO_2 for the Fox Tor Diorite and at an Mg# value of ~54 (Figure 5c) perhaps reflecting pyroxene-controlled magmatic crystal accumulation processes in the more mafic examples. These chemical trends clearly reflect the modal variations in ferromagnesian and oxide minerals versus feldspars and quartz. Most samples are metaluminous and values of the Aluminium Saturation Index (ASI) (e.g. Chappell & White 1974; 2001) range from 0.71 to 1.01 (Table 2). Normative compositions (Table 2) indicate the presence of minor quartz that is consistent with modal observations. The majority are diopside-normative and only the 'mixed phase' has significant normative corundum (0.8%) (this may reflect the replacement of primary igneous minerals by ?subsolidus phases). All samples have considerable normative magnetite and this characteristic, together with ASI values below 1.1, accord with I-type compositions.

DISCUSSION

Implications of field relationships and geochronology

Field relationships indicate that the Fox Tor Diorite has intruded the surrounding Pringles Monzogranite. The latter is a member of the S-type Bundarra Supersuite that was emplaced at approximately 286 Ma (e.g. Scheibner & Basden 1998). In the general region of the Fox Tor Diorite, the Pringles Monzogranite has been intruded by dyke swarms that display northerly and

Table 2 Whole-rock geochemical analyses of Fox Tor Diorite

Sample	R79430	R79431	R79432	R79440	R81906	R81907	R81908	R81909	R81910	R81911
Easting (AMG1966)	324700	324300	324100	324800	324800	324770	324760	324900	324600	324780
Northing (AMG1966)	6600200	6600150	6602500	6602700	6600290	6600280	6600240	6600400	6600400	6600210
Rock type	diorite	diorite	diorite	diorite	porph. diorite	porph. diorite	diorite	diorite	diorite	'mixed phase'
SiO_2	56.21	55.58	56.70	55.90	60.80	59.54	58.59	56.50	55.63	61.56
TiO_2	1.00	0.97	0.87	0.88	0.93	0.81	0.80	1.05	0.96	0.78
Al_2O_3	15.59	17.62	16.63	14.84	17.25	17.05	17.40	17.68	16.22	18.65
Fe_2O_3T	7.76	8.10	7.49	7.67	5.78	5.72	6.09	7.99	7.71	4.23
MnO	0.13	0.13	0.14	0.13	0.12	0.10	0.10	0.14	0.13	0.09
MgO	5.23	4.11	4.72	7.04	2.27	2.80	3.00	3.77	5.13	1.77
CaO	7.01	7.34	6.81	7.55	4.48	5.25	5.94	6.45	7.28	4.60
Na_2O	2.93	3.23	3.29	2.93	3.88	3.42	3.51	3.79	3.01	4.63
K_2O	2.25	2.17	2.35	2.31	3.14	3.23	2.64	1.27	2.15	2.35
P_2O_5	0.30	0.20	0.24	0.23	0.34	0.23	0.22	0.30	0.33	0.18
S	0.03	0.02	0.04	0.05	0.02	0.01	0.02	0.03	0.02	<0.01
H_2O^+	1.79	0.67	*0.44	*0.17	1.00	1.44	1.10	0.89	1.57	1.10
H_2O^-	0.19	0.17			0.12	0.22	0.21	0.24	0.14	0.12
CO_2	0.10	0.10			0.08	0.48	0.22	0.12	0.10	0.09
less O=S	0.01	0.01	0.02	0.02	0.01	0.00	0.01	0.01	0.01	0.00
Total	**100.53**	**100.42**	**99.74**	**99.72**	**100.21**	**100.30**	**99.85**	**100.23**	**100.39**	**100.15**
Mg#	61.1	54.2	59.5	68.1	47.8	53.3	53.5	52.4	60.8	49.4
ASI	0.78	0.84	0.82	0.71	0.96	0.91	0.90	0.91	0.79	1.01
Trace elements										
V	193	190	158	178	82	124	147	179	200	50
Cr	175	13	77	257	43	67	49	75	165	29
Ni	45	8	25	83	11	15	17	23	44	9
Cu	31	21	28	45	23	23	22	28	36	2
Zn	73	72	67	64	66	59	70	82	70	47
Ga	17.4	19.3	20	16	19.2	17.3	18.7	19.7	18.1	21.3
As	1.2	8.9	8	11	4.6	2.1	3.8	5.5	1.0	2.2
Rb	83	85	93	94	117	117	91	58	79	81
Sr	563	507	499	429	483	454	508	540	585	572
Y	21	22	21	21	26	21	21	19	20	15
Zr	137	141	156	168	296	185	107	128	128	322
Nb	5.8	4.6	7	6	7.5	6.7	5.8	6.8	5.4	6.8
Mo	0.6	0.8			0.5	0.6	0.7	0.7	0.6	0.3
Cd	0.5	0.2			0.5	0.5	0.5	0.2	0.3	<0.2
Sn	2.3	1.8			3.9	3.1	2.3	1.2	2.0	1.7
Sb	0.7	0.4			0.9	0.5	0.7	<0.5	<0.5	0.5
Cs	6.8	6.4			9.6	10.8	7.0	4.6	4.8	5.5
Ba	1040	778	866	873	2156	1598	1280	837	1190	906
La	21	19	20	20	19	22	24	28	22	24
Ce	50	45	40	43	47	53	57	60	52	46
Hf	3.5	4.1			7.2	5.0	3.8	3.7	3.8	9.3
Tl	1.2	1.0			0.6	0.8	0.8	0.5	0.8	1.0
Pb	25	26	26	30	25	24	31	22	22	25
Th	12.4	12.5	14	16	8.9	14.4	13.6	8.9	11.6	13.6
U	1.5	3.5	1	2	0.8	1.9	1.6	1.9	1.4	0.7
CIPW Norm										
Q	7.06	4.99	5.81	3.58	11.66	11.03	9.66	7.94	5.94	12.01
C					0.32	0.04				0.81
or	13.30	12.82	13.89	13.65	18.56	19.09	15.60	7.51	12.71	13.89
ab	24.79	27.33	27.84	24.79	32.83	28.94	29.70	32.07	25.47	39.18
an	22.74	27.17	23.67	20.52	19.50	21.51	23.92	27.48	24.40	20.95
di	7.65	5.97	6.43	11.93			2.24	0.86	7.24	
hy	17.75	16.24	16.95	20.31	11.69	13.11	12.98	17.62	17.70	8.66
mt	1.71	1.80	1.65	1.70	1.28	1.26	1.35	1.77	1.71	0.94
il	1.90	1.84	1.65	1.67	1.77	1.54	1.52	1.99	1.82	1.48
ap	0.70	0.46	0.56	0.53	0.79	0.53	0.51	0.70	0.76	0.42
pr	0.06	0.04	0.08	0.10	0.02	0.02	0.04	0.06	0.04	
cc	0.25	0.25			0.18	1.09	0.50	0.55	0.23	0.21
H_2O	1.79	0.67	0.44	0.17	1.00	1.44	1.10	0.89	1.57	1.10
Total	**99.70**	**99.58**	**98.97**	**98.95**	**99.60**	**99.60**	**99.12**	**99.44**	**99.59**	**99.65**

Analysts: B.W. Chappell, Macquarie University, J. Bedford, University of New England (R79432, R79440).
Total Fe as Fe_2O_3, *H_2O^+ value is loss-on-ignition
Mg# = Mg ratio: 100Mg/(Mg + Fe^{2+}) where Fe^{2+} (atomic) is adjusted on the basis of Fe_2O_3/FeO = 0.2.
ASI = aluminium saturation index molecular Al_2O_3/(Na_2O + K_2O + CaO)

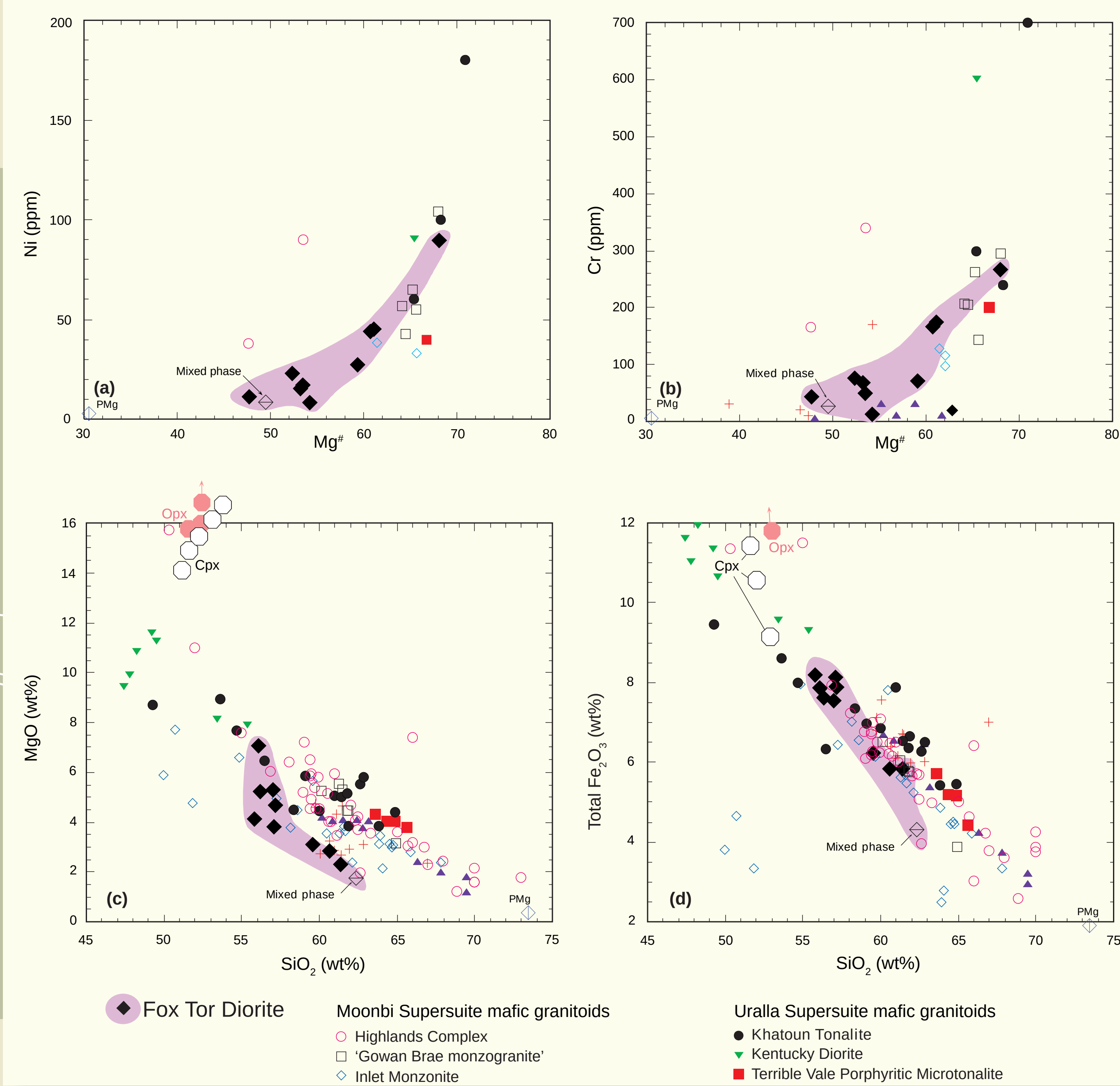


Figure 5 Geochemical variation plots for the Fox Tor Diorite and mafic Uralla and Moonbi granitoids. (a) Ni–Mg#, (b) Cr–Mg#, (c) MgO–SiO_2, (d) Total Fe_2O_3–SiO_2. Shaded area represents the field for Fox Tor Diorite. Also shown is PMg = average composition of Pringles Monzogranite(surrounding the Fox Tor Diorite). Data point for Pringles Monzogranite (PMg) is from the whole-rock analysis digital data base of the Geological Survey of New South Wales. Open and closed octagons represent clinopyroxene and orthopyroxene electron microprobe analyses, respectively, of samples of Fox Tor Diorite. Data points for Uralla and Moonbi Supersuites mafic granitoids are from the northeastern New South Wales whole-rock analysis digital data base of the Geological Survey of New South Wales.

northwesterly strike directions (Brown 2003). These bodies are magnetic and it has been inferred (Brown 2003) that they are most probably of mafic composition, although outcrops are extremely rare. There is no evidence from the aeromagnetic imagery, or from field mapping, that such dykes cut across the Fox Tor Diorite. In general, there is also little evidence that the dyke swarms post-date plutons of the Uralla and Moonbi Supersuites in the region. The Pringles Monzogranite hosts several non-magnetic dykes of microgranite and rhyolite (Figure 2), none of which have been observed in the Fox Tor Diorite. It is interpreted that these felsic dykes may be genetically related to, and of similar age to, the Bundarra Supersuite granitoids.

The K–Ar age determination on the Fox Tor Diorite (239.7±6.7 Ma, Table 1) indicates that the body post-dates the emplacement of the Bundarra Supersuite by 40–50 Ma. It is therefore most unlikely that there is any relationship between the Fox Tor Diorite and intermediate to mafic intrusive rocks that are spatially and temporally associated with the ~300 Ma Hillgrove Supersuite granitoids, e.g. the Bakers Creek Diorite Complex, east of Armidale (e.g. Jenkins et al. 2002). The K–Ar age determined for the Fox Tor Diorite overlaps with that determined recently on the petrographically and chemically similar Willowie Diorite in the Ashford area (244.3±2.5 Ma) (M. Dawson pers. comm. 2004). Superficially, the age of the Fox Tor Diorite is slightly younger than those determined on individual plutons of the Uralla and Moonbi Supersuites (243–251 Ma; Shaw & Flood 1993), but the age uncertainties result in considerable potential age overlap. Shaw and Flood (1993) considered that their biotite Rb–Sr age determinations may have had realistic age uncertainties of >1% (e.g. at least ±3 Ma). Therefore, the intrusion of the Fox Tor Diorite could be approximately coeval with the emplacement of the main event of I-type granitoids forming the southern part of the New England Batholith. Rare dykes of lamprophyre and microgranodiorite in the Fox Tor Diorite must post-date emplacement of the latter. By analogy with similar dykes elsewhere in the southern part of the New England Orogen that have age ranges between 261 ± 6 Ma and 246±5 Ma (Rowley 1975; Ashley, Cook et al. 1994; Kent 1994), it is unlikely that they are significantly younger than 240 Ma.

Geophysical signature of Fox Tor Diorite and relation to mineralogical and chemical constitution

The prominent aeromagnetic anomaly over the Fox Tor Diorite led to its initial recognition (Brown 2003). Measurements of magnetic susceptibility on the Fox Tor Diorite confirm its contrast with that of the surrounding Bundarra Supersuite (Table 3). This is due to the Fox Tor Diorite containing up to 2 modal % disseminated magnetite, with magnetite generally being more abundant than ilmenite. Granitoids of the Bundarra Supersuite contain ilmenite as the only significant Fe–Ti oxide phase. The magnetic properties of the Fox Tor Diorite also contrast with those of the Uralla Supersuite, including the most mafic plutons of the latter. Despite having rock compositions ranging from granodiorite to gabbro, the Fe–Ti oxide mineralogy of the Uralla Supersuite is dominated by ilmenite and the most melanocratic rocks only have magnetic susceptibilities up to 170×10^{-5} SI (Table 3). On the other hand, the magnetic susceptibility values of the Fox Tor Diorite overlap (and commonly exceed) those measured on mafic members of the Moonbi Supersuite (Table 3). It can be concluded that the redox state of the Fox Tor Diorite is moderately oxidised, similar to that of the Moonbi Supersuite, but contrasting with the moderately reduced Uralla Supersuite (cf. Blevin 2003; Bryant, Chappell & Blevin 2003).

Table 3 Geophysical responses of granitoids of the New England Batholith in the Armidale–Tamworth region

Granitoid mass	Aeromagnetic response*. Magnetic susceptibility (10^{-5} SI)	Radiometric response
Fox Tor Diorite	High, well-defined. Mag sus 900–2800	Moderate K, low U and Th
Bundarra Supersuite	Very low, bland on imagery. Mag sus <10	High to very high K, high to low Th and U
Moonbi Supersuite (mafic)	Moderate–high. Mag sus <50–1100	High, uniform K, Th and U
Moonbi Supersuite (felsic)	Low–moderate. Mag sus 50–300	High K, high to low Th and U
Uralla Supersuite (mafic)	Low, diffusely moderate. Mag sus 20–170	Low to high K, low to moderate Th and U
Uralla Supersuite (felsic)	Very low–low. Mag sus <10–40	High to very high K, Th and U

*This table includes magnetic susceptibility data obtained by measurement of samples from Flood (1971) and Kilpatrick (1986).

The Fox Tor Diorite only gives a subtly contrasting radiometric response (Figure 3c), perhaps because of the relatively small size of the diorite masses and the local dispersion of transported granitic regolith from the surrounding Pringles Monzogranite over the Fox Tor Diorite. However, it would be expected that the K response over the Fox Tor Diorite would be lower than that of the enclosing rocks as its K_2O content is only about half the value of the Pringles Monzogranite and Bundarra Supersuite granitoids generally (cf. Table 2 and Chappell 1978). Similarly, values of Th and U in typical Bundarra Supersuite granitoids (e.g. Chappell 1978) imply that the latter would have a higher Th and U response than that of the Fox Tor Diorite (Table 3). The Fox Tor Diorite would have a significantly lower K–Th–U response than Moonbi Supersuite granitoids, including the mafic members, due to lower values of these elements in the former (cf. Flood 1971; Chappell 1978; Kilpatrick 1986; Kent 1994; Table 3). Compared with the more mafic members of the Uralla Supersuite, the Fox Tor Diorite has a similar K and Th radiometric response, as values of K_2O and Th overlap with those of the former. However, the Fox Tor Diorite would have a lower U response as U values are low (e.g. Table 2; Table 3; cf. Flood 1971).

Mineralogical, geochemical and genetic affinities of the Fox Tor Diorite

The Fox Tor Diorite displays neither chemical nor mineralogical affinities with the enclosing Pringles Monzogranite, a member of the peraluminous S-type Bundarra Supersuite (cf. Chappell 1978). Since the Fox Tor mass is likely to be a significantly younger intrusion and has I-type compositional characteristics (see discussion above), it is most unlikely to have any genetic association with the Pringles Monzogranite. Mineralogically, the Fox Tor Diorite has affinities with the more mafic members of the Uralla and Moonbi Supersuites (cf. Flood 1971; Chappell 1978; Kent 1994), with early crystallised pyroxenes and plagioclase, followed by hornblende, biotite and late crystallising minor K-feldspar and quartz (Table 4). Compared with the mafic Uralla Supersuite granitoids, the Fox Tor Diorite contains significant accessory magnetite, similar to the amount in mafic Moonbi Supersuite granitoids, but lacks the accessory titanite found in some of the latter rocks (Table 4). Again, in contrast to most of the mafic Moonbi Supersuite examples, K-feldspar in the Fox Tor Diorite is white–grey in colour, rather than pink.

The Fox Tor Diorite has strong geochemical similarity to mafic Uralla Supersuite granitoids. It is distinguished from many of the mafic Moonbi Supersuite granitoids by the commonly lower values of K_2O, P_2O_5, Rb, Sr, Nb and Zr (Table 4; Figure 6). The Fox Tor Diorite geochemical data tend to overlap with the mafic Uralla Supersuite Shalimar Tonalite and Khatoun Tonalite plutons (e.g. Flood 1971). However, it is more felsic than the Kentucky Diorite (Figure 6). Trends demonstrated in Mg# and CaO/Al_2O_3 relationships and between Mg#, SiO_2 and Fe_2O_3T, MgO, TiO_2, Cr, Ni and V by the Fox Tor Diorite and mafic granitoids of the Uralla and Moonbi Supersuites (Figures 5, 6) are consistent with the early accumulation of pyroxenes and (calcic) plagioclase, followed by crystallisation of Fe–Ti oxides and more sodic plagioclase.

Data from this preliminary study of the Fox Tor Diorite imply that the intrusion has a significant mantle-derived component (e.g. relatively high Mg# and Cr and Ni values; Table 2, Figure 5). However, it displays a strong fractionation trend with increasing SiO_2, alkalies and Zr, and decreasing Mg#, CaO/Al_2O_3, Fe_2O_3T, MgO, CaO, TiO_2, Cr, Ni and V contents. These geochemical concepts need to be further confirmed by additional geochemical studies – for example, by using radiogenic

Table 4 Mineralogical and chemical comparison of the Fox Tor Diorite with mafic members of the Uralla and Moonbi Supersuites

Criterion	Fox Tor Diorite	Uralla Supersuite mafic plutons*	Moonbi Supersuite mafic plutons *
Dominant minerals	plag, cpx, opx, hb, bi (Kf, qz)	plag, hb, cpx, bi (opx, qz, Kf)	plag, Kf, hb, bi, cpx (opx, qz)
Fe–Ti oxides	mt > ilm	ilm >> mt	mt > ilm
Titanite	trace	trace to accessory	accessory
K-feldspar colour	white–grey	white–grey	pink to white–grey
K_2O at 55–62% SiO_2	1.3–3.2%	2.5–3.5%	2.8–6.0%
P_2O_5 at 55–62% SiO_2	0.18–0.34%	0.14–0.51%	0.29–0.62%
Rb, Sr, Nb, Zr	values overlap with mafic Uralla Supersuite plutons	generally lower than mafic Moonbi Supersuite plutons	generally higher than mafic Uralla Supersuite plutons
Mg#	48–68	48–71	38–78

*Mafic Uralla Supersuite plutons include Kentucky Diorite, Terrible Vale Porphyritic Microtonalite, Shalimar Tonalite, Khatoun Tonalite and mafic Moonbi Supersuite plutons include Inlet Quartz Monzonite, Back Creek Tonalite, Walcha Road Monzogranite, Highlands Complex, Gowan Brae Quartz Monzonite.
Data is from Flood (1971), Chappell (1978), Kilpatrick (1986) and Kent (1994).

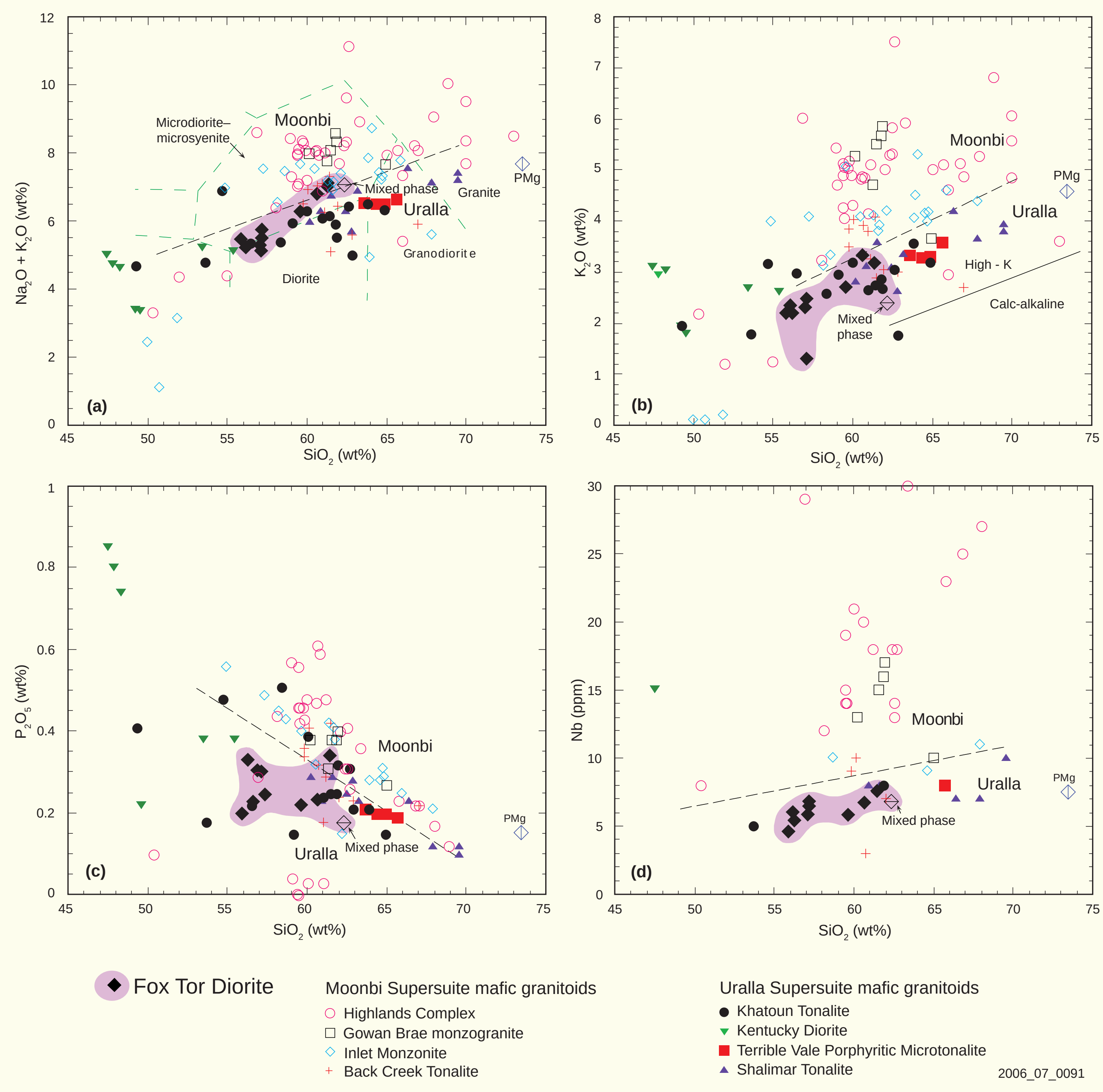


Figure 6 Geochemical variation plots for Fox Tor Diorite samples and Uralla and Moonbi Supersuites mafic granitoids: (a) $(Na_2O+K_2O)–SiO_2$, (b) $K_2O–SiO_2$, (c) $P_2O_5–SiO_2$, (d) Nb–SiO_2. The plots are selected to highlight chemical distinction between mafic Uralla Supersuite and mafic Moonbi Supersuite granitoids. The dashed line separates Uralla and Moonbi mafic granitoids. The solid line is between high-K and calc-alkaline igneous rock compositions (Peccerillo & Taylor 1976). The shaded area represents the field for the Fox Tor Diorite. Also shown is PMg = average composition of Pringles Monzogranite (surrounding the Fox Tor Diorite). Data points for Uralla and Moonbi Supersuite mafic granitoids are from the northeastern New South Wales whole rock analysis digital data base of the Geological Survey of New South Wales.

isotopic methods. Although there are broad mineralogical and geochemical links between the Fox Tor Diorite and mafic granitoids of the Uralla and Moonbi Supersuites, the closest links are with the Uralla Supersuite. On the other hand, the magnetic properties and Fe–Ti oxide mineralogy imply an oxidation state more akin to that demonstrated in many Moonbi Supersuite granitoids.

CONCLUSIONS

Aeromagnetic imagery from the Peel South airborne geophysical survey area (Brown 2003) demonstrated the presence of a strongly magnetic body within the large southern lobe of the magnetically bland Bundarra Supersuite granitoids. Subsequent field mapping resolved the presence of six, previously unrecognised, outcropping bodies of diorite covering a total area of approximately 84 ha, enclosed by the S-type Pringles Monzogranite. These bodies have been termed the Fox Tor Diorite. Magnetic modelling implies that the Fox Tor Diorite forms a steep, west-dipping series of tabular to rod-like bodies. The diorite is medium- to coarse-grained, locally weakly porphyritic and has a sharp contact with surrounding monzogranite. It is composed of dominant plagioclase, with lesser amounts of orthopyroxene, clinopyroxene, hornblende, biotite, magnetite and ilmenite, plus interstitial K-feldspar and quartz. In general, later alteration effects are absent to minor. A few thin dykes of microgranodiorite and lamprophyre have intruded the Fox Tor Diorite, but dykes of rhyolite, quartz–feldspar porphyry and microgranite that occur in the enclosing Pringles Monzogranite have not been recognised within the diorite.

A K–Ar age determination of 239.7±6.7 Ma has been made on the Fox Tor Diorite. This age overlaps with those determined on members of the Uralla and Moonbi Supersuite granitoids in the southern part of the New England Orogen, but is approximately 50 Ma younger than granitoids of the Bundarra Supersuite. The geochronological data indicate that the Fox Tor Diorite has intruded the Pringles Monzogranite. Although field observations are sparse, it is apparent that there has been local interaction between the diorite and monzogranite, as well as incorporation of rare xenoliths of the latter into the former. Geochemically, the Fox Tor Diorite is an intermediate I-type pluton, with a range of SiO_2 between 55% and 62% and Mg# between 68 and 48. It has strong geochemical affinities with the more mafic granitoids of the Uralla Supersuite and lower values of K_2O, P_2O_5, Rb, Sr, Nb and Zr than most of the mafic granitoids of the Moonbi Supersuite. The early crystallising pyroxenes and plagioclase, together with relatively high values of Mg#, Cr and Ni imply that the magma source for the Fox Tor Diorite involved a mantle-derived contribution.

The Fox Tor Diorite has broad temporal, mineralogical and geochemical affinities with mafic granitoids of the Uralla and Moonbi Supersuites, but has strongest links to the Uralla Supersuite, despite being significantly more oxidised.

ACKNOWLEDGMENTS

Professor Bruce Chappell of Macquarie University and John Bedford of the University of New England are thanked for providing whole rock geochemical analyses for this paper. David Keith provided his characteristically high-quality petrographic sections. PMA wishes to thank Dr Adam Kent of Oregon State University for access to a sane work environment where the paper was partly prepared. Geophysicist Peter Ruszkowski, formerly with the Department of Mineral Resources (now NSW Department of Primary Industries) is acknowledged for his dedicated and timely modelling of the Fox Tor aeromagnetic data. The manuscript was capably reviewed by Dr Phil Blevin.

REFERENCES

Ashley P.M., Cook N.D.J., Hill R.L. & Kent A.J.R. 1994. Shoshonitic lamprophyre dykes and their relation to mesothermal Au–Sb veins at Hillgrove, New South Wales, Australia. *Lithos* 32, 249–272.

Ashley P.M., Barnes R.G., Golding S.D. & Stephens C.J. 1996. Metallogenesis related to Triassic magmatism in the New England Orogen. *Geological Society of Australia, Abstracts* 43, 34–42.

Barnes R.G., Brown R.E., Brownlow J.W., Gilligan L.B., Krynen J. & Willis I.L. 1988. A review of the mineral deposits of the New England Orogen in New South Wales. pp. 211–227 *In:* Kleeman J.D. ed. *New England Orogen: tectonics and metallogenesis.* Department of Geology and Geophysics, University of New England, Armidale.

Blevin P.L. 2003. Metallogeny of granitic rocks. pp. 1–4 *In:* Blevin P., Jones M. & Chappell B. eds. *Magmas to mineralisation: the Ishihara symposium.* Geoscience Australia Record 2003/14.

Blevin P.L. & Chappell B.W. 1993. The influence of fractionation and magma redox on the distribution of mineralisation associated with the New England Batholith. pp. 423–429 *In:* Flood P.G. & Aitchison J.C. eds. *New England Orogen, eastern Australia.* Department of Geology and Geophysics, University of New England, Armidale.

Blevin P.L. & Chappell B.W. 1996. Internal evolution and metallogeny of Permo-Triassic high-K granites in the Tenterfield–Stanthorpe region, southern New England Orogen, Australia. *Geological Society of Australia, Abstracts* 43, 94–100.

Brown R.E. 2001. Peel Discovery 2000 geophysics – providing keys to exploration in the western New England region of New South Wales. *Geological Survey of New South Wales, Quarterly Notes* 111, 1–15.

Brown R.E. (compiler) 2002. Peel South Geoscience Data Package, CD–ROM Version 1. Geological Survey of New South Wales, Sydney.

Brown R.E. 2003. Peel South Exploration NSW geophysics – interpretation of new data for exploration and geological investigations in the western New England region of New South Wales. *Geological Survey of New South Wales, Quarterly Notes* **114**, 1–27.

Brown R.E., Brownlow J.W. & Krynen J.P. 1992. *Manilla–Narrabri 1:250 000 metallogenic map SH/56–9, SH/55–12: metallogenic study and mineral deposit data sheets.* Geological Survey of New South Wales, Sydney, 319 pp.

Brown R.E. & Stroud W.J. 1993. Mineral deposits of the Inverell 1:100 000 sheet. *Geological Survey of New South Wales, Quarterly Notes* **91**, 11–33.

Brown R.E. & Stroud W.J. (compilers) 1997. *Inverell 1:250 000 metallogenic map SH/56–5: metallogenic study and mineral deposit data sheets.* Geological Survey of New South Wales, Sydney, 576 pp.

Bryant C.J., Arculus R.J. & Chappell B.W. 1997. Clarence River Supersuite: 250 Ma cordilleran tonalitic I–type intrusions in eastern Australia. *Journal of Petrology* **38**, 975–1001.

Bryant C.J., Chappell B.W. & Blevin P.L. 2003. Granites of the southern New England Orogen. pp. 9–11 *In:* Blevin P., Jones M. & Chappell B. eds. *Magmas to mineralisation: the Ishihara symposium*. Geoscience Australia Record **2003/14**.

Chappell B.W. 1978. Granitoids from the Moonbi district, New England Batholith, eastern Australia. *Geological Society of Australia, Journal* **25**, 267–285.

Chappell B.W. 1994. Lachlan and New England: fold belts of contrasting magmatic and tectonic development. *Royal Society of New South Wales, Journal and Proceedings* **127**, 47–59.

Chappell B.W. & White A.J.R. 1974. Two contrasting granite types. *Pacific Geology* **8**, 173–174.

Chappell B.W. & White A.J.R. 2001. Two contrasting granite types: 25 years later. *Australian Journal of Earth Sciences* **48**, 489–499.

Flood P.G. & Aitchison J.C. 1988. Tectonostratigraphic terranes of the southern part of the New England Orogen. pp. 7–10. *In:* Kleeman J.D. ed. *New England Orogen – tectonics and metallogenesis.* Department of Geology and Geophysics, University of New England, Armidale.

Flood R.H. 1971. A study of part of the New England Batholith, New South Wales. PhD thesis, University of New England, Armidale (unpubl.).

Flood R.H. & Shaw S.E. 1975. A cordierite-bearing granite suite from the New England Batholith, NSW, Australia. *Contributions to Mineralogy and Petrology* **52**, 157–164.

Flood R.H. & Shaw S.E. 1977. Two 'S-type' granite suites with low initial $^{87}Sr/^{86}Sr$ ratios from the New England Batholith, Australia. *Contributions to Mineralogy and Petrology* **61**, 163–173.

Gilligan L.B., Brownlow J.W., Cameron R.G. & Henley, H.F. 1992. *Dorrigo–Coffs Harbour 1:250 000 metallogenic map SH/56–10, SH/56–11: metallogenic study and mineral deposit data sheets.* Geological Survey of New South Wales, Sydney, 509 pp.

Henley H.F., Brown R.E. & Stroud W.J. 1999. The Mole Granite – extent of mineralisation and exploration potential. *In:* Flood P.G. ed. *New England Orogen*, pp. 385–392. Earth Sciences, University of New England, Armidale.

Henley H.F., Brown R.E., Brownlow J.W., Barnes R.G. & Stroud W.J. 2001. *Grafton-Maclean 1:250 000 metallogenic map SH/56–6, SH/56–7: metallogenic study and mineral deposit data sheets.* Geological Survey of New South Wales, Sydney, 292 pp.

Hensel H.D., McCulloch M.T. & Chappell B.W. 1985. The New England Batholith: constraints on its derivation from Nd and Sr isotopic studies of granitoids and country rock. *Geochimica et Cosmochimica Acta* **49**, 369–384.

Jenkins R.B., Landenberger B. & Collins W.J. 2002. Late Palaeozoic retreating and advancing subduction boundary in the New England Fold Belt, New South Wales. *Australian Journal of Earth Sciences* **49**, 467–489.

Kent A.J.R. 1994. Geochronology and geochemistry of Palaeozoic intrusive rocks in the Rockvale region, southern New England Orogen, New South Wales. *Australian Journal of Earth Sciences* **41**, 365–379.

Kilpatrick J.A. 1986. The Highlands Igneous Complex. BSc (Hons) thesis, University of New England, Armidale (unpubl.).

Landenberger B., Farrell T.R., Offler R., Collins W.J. & Whitford D.J. 1995. Tectonic implications of Rb–Sr biotite ages for the Hillgrove Plutonic Suite, New England Fold Belt, N.S.W., Australia. *Precambrian Research* **71**, 251–263.

Leake B.E., Woolley A.R. & 20 others 1997. Nomenclature of amphiboles: report of the Subcommittee on Amphiboles of the International Mineralogical Association, Commission on New Minerals and Mineral Names. *American Mineralogist* **82**, 1019–1037.

O'Neil J.R., Shaw S.E. & Flood R.H. 1977. Oxygen and hydrogen isotope compositions as indicators of granite genesis in the New England Batholith, Australia. *Contributions to Mineralogy and Petrology* **62**, 313–328.

Peccerillo A. & Taylor S.R. 1976. Geochemistry of Eocene calc-alkaline volcanic rocks from the Kastamonu area, northern Turkey. *Contributions to Mineralogy and Petrology* **58**, 63–81.

Rowley D.K. 1975. Potassium–argon dating of seven samples from New South Wales. Geological Survey of New South Wales Report **GS1975/187** (unpubl.).

Scheibner E. & Basden H. (ed.) 1998. Geology of New South Wales – synthesis. Volume 2 Geological evolution. *Geological Survey of New South Wales, Memoir Geology* **13(2)**, 666 pp.

SHAW S.E. & FLOOD R.H. 1981. The New England Batholith, eastern Australia: geochemical variations in time and space. *Journal of Geophysical Research* 86, 10530–10544.

SHAW S.E. & FLOOD R.H. 1993. A compilation of Late Permian and Triassic biotite Rb–Sr data from the New England Batholith and areas to the southeast. *In:* Carr P.F. ed. *Centre for Isotope Studies Research Report* 1991–92, pp. 151–155. Centre for Isotope Studies, CSIRO Minerals Research Laboratories, Sydney.

STONESTREET P. 2002. The Fox Tor Diorite – a previously unrecognised I-type intrusion within the S-type Bundarra granitoid pluton. GEOL308 project, University of New England, Armidale (unpubl.).

STROUD W.J., BARNES R.G., BROWN R.E., BROWNLOW J.W. & HENLEY, H.F. 1999. Some aspects of the metallogenesis of the southern New England Fold Belt. *In:* Flood P.G. ed. *New England Orogen*, pp. 365–371. Earth Sciences, University of New England, Armidale.

WILKINSON J.F.G. 1969. Intrusive rocks: the New England Batholith. pp. 271–278. *In:* Packham G.H. ed. The geology of New South Wales. *Geological Society of Australia, Journal* 16 (1).

APPENDIX

Fox Tor Diorite – formal stratigraphic definition	
NAME OF UNIT	Fox Tor Diorite (new name)
STATE	New South Wales
PROPOSERS	P.G. Stonestreet, P.M. Ashley, R.E. Brown & W.J. Sivell
RESERVED IN REGISTER OF STRATIGRAPHIC NAMES*	Yes
RESERVATION DATED	13 November 2003
PROPOSED PUBLICATION	Quarterly Notes of the Geological Survey of New South Wales
DEFINITION	Strongly magnetic, grey, mesocratic, relatively equigranular, medium- to coarse-grained, I-type diorite intruding coarse-grained felsic granitoid of the Bundarra Supersuite.
DERIVATION OF NAME	Fox Tor homestead, located near the centre of the intrusion exposure
SYNONYMY	NA
CONSTITUENT UNITS	NA
DISTRIBUTION	Six discrete irregular to lobate masses over an area extending approximately 2.6 km north–south and up to 1.2 km east–west
GEOMORPHIC EXPRESSION	Crops out on hills and adjacent flat terrain
TYPE LOCALITY (with Lat. & Long.)	Approximately 750 m south–southwest of 'Fox Tor' homestead; Lat 151°10′05″E Long 30°42′51″S
THICKNESS	Extends over a surface area of 2.6×1.2 km, and modelled to a depth of at least 3 km.
LITHOLOGY	Strongly magnetic, grey, mesocratic, relatively equigranular, medium-to coarse-grained plagioclase–biotite–hornblende diorite
DEPOSITIONAL ENVIRONMENT	NA
FOSSILS (if relevant)	NA
DIASTEMS OR HIATUSES	NA
RELATIONSHIPS & BOUNDARY CRITERIA	Intrusive contact with Bundarra Supersuite (Pringles Monzogranite). Local areas of apparent partial assimilation of granitoid by intrusive diorite body.
AGE & EVIDENCE	K–Ar 239.7±6.7 Ma
CORRELATIVES	A similar diorite body, the 'Willowrie diorite', recognised by Brown (in prep) in the Ashford area, is similarly hosted by the Bundarra Supersuite.
COMMENTS	NA
REFERENCES	Stonestreet P. 2002. The Fox Tor Diorite – a previously unrecognised I-type intrusion within the S-type Bundarra granitoid pluton. GEOL308 project, University of New England, Armidale (unpublished).

*maintained by Geoscience Australia

Forthcoming issues:

'Cainozoic igneous rocks in the Bingara to Inverell area, northeastern NSW' by M.W. Dawson, N.M. Vickery, W.J. Sivell, K.R. Malloch & W.J. Dunlap

'Mineral resource potential of the continental shelf, NSW' by J. Whitehouse

6760 06/06

NSW DEPARTMENT OF PRIMARY INDUSTRIES

NSW Department of Primary Industries, Mineral Resources
516 High Street, Maitland NSW 2320
PO Box 344 Hunter Region Mail Centre NSW 2310.
T: 1300 736 122 T: (02) 4931 6666

www.dpi.nsw.gov.au