Inverell *Exploration NSW* geophysics — new data for exploration and geological investigations in the northern New England area of New South Wales

**ABSTRACT**

Interpretation of new airborne magnetic and radiometric data covering much of the eastern Inverell and western Grafton 1:250 000 map sheet areas (the Inverell survey area) has demonstrated the value of high-resolution airborne geophysics. These new data were collected as part of the *Exploration NSW* initiative over a geologically diverse part of the New England region. Preliminary interpretation of the data has resulted in a greatly enhanced understanding of the structure; lithological distribution; origin of felsic volcanic rocks; and controls on mineralisation of the region.

The Inverell survey area in the New England Orogen hosts known mineralisation — including granite-related cassiterite, tungsten, molybdenum, gold, silexite (quartz–topaz greisen) and silver-rich lead, zinc and copper; seafloor manganese oxide–rhodonite and copper–lead–zinc; and alluvial deposits of tin, sapphires and diamonds. Interpretation of the geophysical data has improved understanding of relationships between structurally controlled granite-related mineralisation and various fault and fracture sets, and between the occurrence of sapphires and Tertiary volcanic rocks.

Airborne magnetic data have indicated the presence of large, circular magnetic bodies with characteristics resembling calderas. These bodies represent the source of much of the felsic Wandsworth Volcanic Group in the area and may have potential for epithermal mineralisation. The aeromagnetic data have also proved useful for identifying concealed granite plutons, dykes and plugs and major crustal fractures. Radiometric data provide a valuable tool distinguishing major Tertiary eruptive suites in the region, including areally extensive younger volcanic rocks in the west, and an older corundum-associated suite in the east. The radiometric data are also useful for interpreting the surface geology, for identifying previously recognised geological units and relationships, and for distinguishing some pluton phases.

**Keywords:** New England Orogen, *Exploration NSW*, aeromagnetic data, radiometric data, Inverell, Glen Innes, Ashford, Emmaville, Torrington, Copeton, regional geology, mineralisation, tectonic units, tin, diamond, sapphire, lead, zinc, copper, silver, molybdenum, tungsten, silexite

**INTRODUCTION**

The Inverell airborne geophysical survey area is the third high-resolution survey flown by the former Department of Mineral Resources in the New England region. The Inverell survey area is an extension to the Peel airborne geophysical survey area which was released in early 1999 (Brown 2001). The area covers part of the eastern Inverell, part of the western Grafton and a little of the Manilla 1:250 000 map sheet areas (Figure 1).

*Exploration NSW* projects are undertaken with the aim of integrating detailed geophysical data with a synthesis of known geology and recent mineral exploration data. Survey areas typically lack detailed geological mapping and/or include extensive regolith cover. The *Exploration NSW* datasets are intended to promote and assist better-directed exploration.

The Inverell survey area was selected to provide high-resolution geophysical data to facilitate the reinterpretation of the geological units and structures adjoining, and to the...
north of the Peel survey area (Figure 1). The Inverell survey area hosts many granite-related tin, arsenic and silver-rich polymetallic vein occurrences (Figures 2 and 3), including the Tingha, Elsmore, Emmaville and Torrington tin fields; and the Conrad, Webbs Consols, Webbs silver mine polymetallic lodes and Ottery arsenic mine. Diamonds have been mined from alluvial deposits in the Copeton area, and sapphires have been extracted from alluvial deposits throughout the Inverell and Glen Innes areas. The former Department of Mineral Resources metallogenic mapping program (Brown & Stroud 1997; Henley et al. 2001a, b) described and classified the mineral occurrences of the survey area. With the exception of scattered Honours and post-graduate student mapping, only regional-scale geological mapping is available in this region.

The Inverell survey area has undergone intermittent mining activity since the discovery of alluvial tin in the Tingha, Emmaville and Torrington areas in 1871 (Brown & Stroud 1997). Alluvial and lode tin production figures are inaccurate, but total production from 1871 to the early 1980s probably exceed 160 000 tonnes of concentrate (Brown & Stroud 1997). The Taronga tin prospect (Figure 2) was developed to pre-mining status in the early 1980s and hosts about 47 Mt of mineralisation grading 0.145% tin (Endeavour Resources Ltd & Newmont Holdings Pty Ltd 1984). Silver-rich polymetallic veins were mined from the early 1880s to 1970s, with more than 200 000 t of ore produced. About 30 000 t of lead- and zinc-rich mineralisation was identified in the Tangoa prospect (Figure 2) in the early 1980s.

Diamond mining in deep leads and water courses at Copeton (Figure 2) has produced >200 000 carats from the early 1870s to 1997 (Brown & Stroud, 1997). Arsenic became a sought-after commodity from the 1880s to the 1920s, resulting in the production of more than 1900 t of ore, mainly from the Ottery mine (Figure 2). Emeralds were discovered near Emmaville in 1890 and have been worked from several sources for >28 000 carats of emerald and beryl. Tungsten mining in the Torrington district commenced in the late 1890s and by the late 1970s had produced more than 49 000 t of ore. More than 500 000 000 carats of sapphire have been mined from 1919 to 2003 from alluvial deposits in the Inverell and Glen Innes areas.

The Inverell survey area is under-explored by modern geophysical, geochemical and remote sensing techniques. Most activity has been centred on historical alluvial and lode tin prospects in the Emmaville–Torrington and Tingha areas. Exploration has been hampered by a lack of understanding of mineralisation controls and conceptual models, has been of limited extent and has focused mostly on areas of historical production. An interpretation of the previous low-resolution airborne and gravity data of the area was undertaken by Webster, Scheibner and Green (1983).
Figure 1 Location of the Inverell Exploration NSW area. The Peel and Peel South survey areas are also shown (Brown 2001; 2003a), as are major structural blocks of the New England Orogen and 1:250,000 map sheet areas.
The Survey

The Inverell airborne geophysical survey was flown by Fugro Airborne Surveys in May, June and July 2002 using fixed-wing aircraft and global positioning system (GPS) control. The survey utilised east–west flight lines with 250 m interline spacing at a nominal 60 m ground clearance. The survey acquired potassium, thorium and uranium radiometric data; magnetic, and digital elevation data.

Magnetic data were acquired by a split beam Scintrex CS2 Caesium magnetometer with a resolution of 0.001 nT, and a cycle time of 0.1 second that gave a mean sample interval of 7 m. The radiometric data were collected using a 256-channel Exploranium GR-820 spectrometer having a crystal volume of 56 litres. To assist in a continuous count rate over the survey area, self-calibrating crystals were used, with twice-daily calibration checks. With a cycle time of 1.0 second, the mean sample interval was 70 m. From the GPS and altitude data a Digital Terrain Model (DTM) was calculated.

Geoscience data package

Geoscience data from the Inverell survey area have been compiled for presentation on a CDROM (Brown 2003b). The CDROM is a compilation of geophysical images and a range of spatial datasets that include geographical, geological, exploration and mineral occurrence data. The information is in two GIS formats: ArcView 3.2 and MapInfo 6.5. The Inverell dataset includes a total of 2962 mineral occurrences, geochemistry of 1208 stream sediment samples, data on 268 drillholes, 867 whole rock analyses, 929 assays of mineralised grab samples, and 1292 petrological sample descriptions.

REGIONAL GEOLOGY

The Inverell survey area encompasses rocks of the southern New England Orogen (NEO) (Figure 1). Within the survey area, rocks of the NEO comprise one major structural block: the Central or Woolomin–Texas Block. The Central Block consists of complexly deformed rocks that are unconformably overlain by felsic volcanic rocks and intruded by granitic plutons and dykes. The complexly deformed rocks are Early Carboniferous and Late Permian to Early Triassic I-type leucogranites, granites and monzogranites (Flood 1971; Shaw & Flood 1981). Some of the leucogranites are highly fractionated and are responsible for most of the region’s tin, molybdenum, tungsten, bismuth, arsenic and base metal mineralisation (Brown, Brownlow & Krynen 1992, Brown & Stroud 1997; Henley et al. 2001a; Brown, Henley & Stroud 2001).

Late Permian–early Triassic calcalkaline volcanic rocks occur throughout the central portion of the survey area. They are predominantly rhyolitic to rhyodacitic crystal–lithic ignimbrites (Barnes et al. 1991). A detailed study of these rocks to the east of Ashford was undertaken by Adams (2004) using the Inverell geophysical images as a mapping tool.

Tertiary volcanic and intrusive rocks and sediments occur extensively throughout the survey area. The volcanic rocks are predominantly basaltic lavas ranging in age from about 36 to 18 Ma (Wilkinson 1962, 1969; Duggan 1972; Coenraads, Sutherland & Kinny 1990; Sutherland, Pogson & Hollis 1993). Volcaniclastic units make up a subordinate proportion of the Tertiary volcanic pile (Cotton 1915; Sutherland 1985; Brown & Pecover 1986a, b; Sutherland, Pogson & Hollis 1993; Oakes, Barron & Lishmund 1996). Mafic intrusions include dykes and plugs, commonly rich in accidental high-pressure xenoliths and mineral inclusions (Coenraads, Sutherland & Kinny 1990; Sutherland, Pogson & Hollis 1993). Remnants of an extensive Tertiary regolith are preserved as deep lateritic weathering profiles and fluvioglacial and lacustrine sediments — both in deep leads and as uncapped exposures. Some of the region’s most significant mineral occurrences are developed in these sediments, including alluvial cassiterite, diamonds and rare sapphire deposits (Brown & Stroud 1997; Henley et al. 2001a).

Veneers of Quaternary sediments blanket much of the survey area. Significant fluvioglacial deposits also occur along major rivers, creeks and floodplains. Mineral occurrences locally present in these sediments include cassiterite, sapphires and diamonds (Brown & Stroud 1997; Henley et al. 2001a).

RADIOOMETRIC AND MAGNETIC INTERPRETATION

Preliminary interpretations of the airborne radiometric and magnetic data of the Inverell survey area were undertaken by Rob Barnes, Bob Brown, Jeff Brownlow, Mark Dawson, Harvey Henley, Roger McEvilly, Dave Robson, Peter Ruszkowski and Frances Spiller — geoscientists of the former Department of Mineral Resources. Paul Ashley of the University of New England also participated in the interpretative exercise.

The interpretation was undertaken as a workshop in November 2002. Images at a scale of 1:100 000 were used for interpretation and included grey-tone images of the first and second derivative (reduced to pole) magnetic data, and colour composite K–Th–U and individual potassium, thorium and uranium radiometric images. The workshop group was split into three teams who were responsible for separate, overlapping areas. The resultant interpretative maps were digitised by Phil Kennedy and the resultant ArcView shape file
Figure 2: Images of the first vertical derivative (IVD) of the total magnetic intensity (a) and RGB radiometric data (b) for the Inverell survey area. The images have been incorporated with the Peel survey data of Figure 1. The distribution of selected mineral occurrences in the Inverell survey area is also shown.
was attributed by the author, with polygon topology built using ArcInfo software by Phil Kennedy. Three spatial datasets were produced: radiometric and magnetic domains; radiometric and magnetic structures; and radiometric and magnetic polygon areas. Subdivisions shown on the domain map (Figure 3) used existing stratigraphic nomenclature (Stroud & Brown 1998; Henley et al. 2001b) to assist with correlations of geophysical and geological features.

Three days of field checking in selected areas was undertaken following completion of the initial radiometric and magnetic interpretation. Magnetic susceptibility measurements were recorded and limited traverse mapping completed.

Subsequent to the workshop a series of filtered magnetic images produced by Vector Research Pty Ltd was used for additional interpretation. These images were derived from a filtering process (Overburden Filter™, a registered trade mark of Vector Research Pty Ltd) which produces various subsets of long- and short- wavelength magnetic intensity (Vector Research Pty Ltd 2004). The process generates images representative of shallow to deep magnetic sources. The images are valuable for differentiating between shallow (<2 km) and deep (>5 km) magnetic bodies, and for enhancing both shallow and deep features. Portions of some of these images are reproduced herein. These images are referred to as either TMI shallow 1 or TMI deep 15, the number 15 relating to the number of flightlines utilised in each filter pass.

The Inverell high resolution geophysical data provide an excellent tool for bedrock geological interpretation. The magnetic data (Figure 2a) are excellent for distinguishing and differentiating some surface geological units, and for identifying units with magnetic contrasts at depth and in outcrop. Many major faults and fractures have been identified from the magnetic data.

Reasonably good outcrop over most of the survey area has facilitated optimal radiometric responses (Figure 2b) and has greatly assisted in the surface geological interpretation. Local areas of high soil moisture content, water bodies, and possibly some vegetation types have produced anomalous radiometric responses. For example, high soil moisture depresses the radiometric response, whereas water bodies return negligible response.

Geophysical domains

The geophysical domains illustrated in Figure 3 were defined on the basis of their distinctive aeromagnetic and/or radiometric data characteristics. In general, an approximate correlation is apparent between previous geological mapping and the domains described herein. Significantly, interpretation of the Inverell geophysical imagery has indicated the following features.

1. Previously unrecognised cupolas are present within, and below, the westerly extent of the Wandsworth Volcanic Group.

2. Presently recognised subdivisions of the Wandsworth Volcanic Group are confirmed; and further subdivisions are possible.

3. Tertiary lavas are subdivisible into two major and one minor domains.

4. The Bundarra Supersuite is subdivisible into two major, and several minor, variants.

5. Previously unidentified folds and gross bedding trends have been recognised within the Texas beds.

6. Unmapped, mafic to intermediate dykes and plugs occur throughout the area — these include the newly recognised ‘Willowrie diorite’ plug and associated radial dyke swarm.

7. A number of small, buried granitoid plutons are interpreted to be present throughout the area.

8. The extent of the structure controlling emplacement of the Conrad lode is apparent, with similarly oriented structures within close proximity.

9. Structures controlling the Webbs silver mine (Collisons mine), Webbs Consols and Tangoa prospects are identified within a broad structural domain.

10. A broad belt of fracturing or faulting is developed above the shallow-dipping, buried upper surface of the Mole Granite, with those structures exhibiting a dominant strike subparallel to the outcrop boundary of the Mole Granite.

11. A lack of radiometric or magnetic contrast has resulted in some stratigraphic units remaining indistinguishable.

CENTRAL BLOCK METASEDIMENTARY AND VOLCANIC ROCKS

Metasedimentary rocks

The Peel and Peel South airborne geophysical data (Brown 2001, 2003a) demonstrated the advances possible in mapping facies, structures and boundaries in Central Block metasedimentary assemblages. Similar advances can be made using the Inverell data and imagery.

The Whitlow Formation (Cws) is exposed as several small inliers in the west of the survey area (Figure 3). This unit exhibits significant radiometric contrast with adjacent Tertiary rocks and the Dumboy-Gragn Granite. Its interpreted distribution correlates reasonably well with previous mapping. Boundary discrepancies relate to local masking by Tertiary regolith.

The Texas beds (Ctx) occur within a major, north-trending belt in the central western half of the survey area (Figure 3). This metasediment-rich unit is characterised by a relatively uniform internal radiometric and magnetic response with locally contrasting linear anomalies corresponding to bedding. The unit contrasts strongly with adjacent granitoids and felsic and mafic volcanic rocks. The geophysical data indicate a general southeast and south-southeast strike within the Texas beds.
Local, open geometry, regional-scale folds are apparent to the south of Ashford (Figure 2). A north-trending, unmapped fault cuts the Texas beds to the southeast of Ashford. The fault has apparently developed local monoclinal folding on its western flank. The geophysical imagery suggests that no internal subdivision of the Texas beds is appropriate in the survey area.

The Sandon beds (Csx) occur as a number of small inliers in the southwestern half of the survey area (Figure 3). This unit exhibits similar geophysical characteristics to those of the Texas beds and contrasts strongly with adjacent granitoids and volcanic rocks. The geophysical data suggest that previous mapping of this unit requires significant local modification.

The Torrington pendant (Pxh) is an extensive metasedimentary roof pendant within the Mole Granite north of Torrington. A small proportion of the pendant is present in the northeastern corner of the survey area. Its extent is obscured by the abundance of silexite mineral occurrence symbols in Figure 3. The pendant is of economic significance for the numerous tungsten, beryl and silexite occurrences hosted by the metasedimentary rocks. Previous mapping of the pendant margins correlate closely with the pendant margins interpreted from the radiometric images. Several small pendants have been previously mapped in a belt extending eastward from Torrington village. The radiometric and magnetic data suggest that a single, large pendant is present, extending for about 3.5 km east from Torrington. Field checking of this pendant has indicated that the pendant zone consists of sparse, small outcrops of metasedimentary rock, widespread granite, and large areas of no outcrop associated with intermittently swampy or wet ground. Several significant cassiterite lodes and rare silexite occur within the zone. The radiometric and magnetic characteristics of the pendant are very similar to those of Early Permian metasediments (Px) exposed south of the Mole Granite outcrop. Imagery of the radiometric data suggests that numerous small pendants up to 300 m across may be present within the Mole Granite between the Torrington pendant and Torrington village.

Unnamed, Early Permian metasedimentary rocks (Px, Pc, Pb) are widely distributed to the south of the Mole Granite and to the north of Emmaville (Figures 2, 3 and 4). The radiometric characteristics of these rocks contrast strongly with those of the adjacent Mole Granite and felsic to mafic volcanic rocks. They show significant magnetic contrast with the mafic rocks and variable, inconsistent contrast with the felsic volcanic rocks (Figure 4). Their boundary is generally relatively accurate, with regolith locally obscuring contact relationships. Internal stratification in the Palaeozoic rocks is generally not well defined by the geophysical data. Several mapped conglomeratic Pc in Figure 4) and metabasaltic (not illustrated in Figure 4) units correlate well with magnetic and radiometric features (Figures 2 and 4).

A well-developed set of magnetic lineations are apparent in the 1VD image (Figure 4). The lineations strike subparallel to the metasediment–Mole Granite contact and are normal to bedding. No explanation for the lineations is apparent in the radiometric data. It is proposed that the lineation may relate to fracturing and possible deep-seated granitoid dyke emplacement associated with granite upwelling.

The Early Permian Ashford Coal Measures are exposed within the survey area as a small, hook-shaped outlier developed on the Texas beds to the south of Ashford. The Coal Measures exhibit no apparent radiometric or magnetic contrast with the Texas beds and are not identifiable in the geophysical images. The boundaries of the Coal Measures are possibly weakly defined in the image of the 1VD magnetic data.

**Wandsworth Volcanic Group**

The Wandsworth Volcanic Group (Barnes et al. 1991) are exposed extensively throughout the eastern half of the survey area (Figure 3). The Group represents part of a Late Permian to Early Triassic episode of igneous activity. The volcanic units occur predominantly as flat to shallow-dipping sheets of rhyolitic to rhyodacitic and minor andesitic ignimbrites and subordinate lavas. They have been deposited on basement metasedimentary sequences, and have been locally intruded by high-level plutons. Radial dips are common and provide vectors to calderas (Godden 1982; Meldrum 1983; Shaw, Flood & Vernon 1988). The volcanic units were recently mapped to the east of Ashford (Figures 1 and 2) by Adams (2004).

Previous mapping within the area has developed a three-fold subdivision of these rocks.

1. The Emmaville Volcanics (Pwevl–3 in Figure 3)
2. The Tent Hill Volcanics (Pwtr in Figure 3)
3. The Dundee Rhyodacite (Pwddr in Figure 3)

Interpretation of the Inverell geophysical data confirms the validity of this subdivision. Each of the Wandsworth Volcanic Group subunits are characterised by distinctive magnetic and/or radiometric features. The geophysical data provide additional insights into this volcanic group which have not previously been mapped or described, including:

- recognition of individual bedded units;
- identification of caldera structures; and
- additional possible subdivisions of the Emmaville Volcanics.

**Emmaville Volcanics**

This regionally extensive sequence of flat-lying, rhyolitic to rhyodacitic ignimbritic flows and minor lavas and epiclastic rocks is characterised by a moderate to high radiometric response and low to high magnetic intensity (Figures 2 and 5). They are distinguished from the Tent Hill Volcanics by the latter’s high magnetic intensity with prominent linear features. The Dundee Rhyodacite is distinguished by a characteristically uniform, high magnetic intensity, and a uniformly moderate radiometric response.
Figure 3 Interpreted magnetic and radiometric domains, structures and mineral occurrences in the Inverell survey area. To assist with correlations between mapped geology (shown in some subsequent figures) and the interpreted geophysical domains, stratigraphic names have been applied to the domains to demonstrate equivalence. (Legend on following pages)
Uralla Supersuite

Early Triassic
Rtg1 Tingha Monzogranite: very high K, low to high Th and U responses; low, featureless magnetic response
Rtg2 Tingha Monzogranite: low to high K and Th responses, very low to moderately high; low, featureless magnetic response

Late Permian to Early Triassic
PRUd Wollingrove Granodiorite: moderate to high K and low Th and U responses; low magnetic response
PRWg Wards Mistletoe Monzogranite: moderate K and Th; moderate to high U responses; moderate magnetic intensity

Bundarra Supersuite (Pbg)

Early Permian
Pbg1 Bundarra Supersuite: very high K and high Th and U responses; uniformly low to moderate, featureless magnetic response
Pbg2 Bundarra Supersuite: moderately low K and high K responses with mottled texture; magnetically identical to Pbg1
Pbg3 Bundarra Supersuite: high to very high radiometric response, K response lower than Pbg1; magnetically identical to Pbg1
Pbg4 Bundarra Supersuite: strongly weathered; low K, high Th responses, moderate to high U; magnetically identical to Pbg1

Wandsworth Volcanic Group (Pw)

Late Permian to Early Triassic
Pwdr Dundee Rhyodacite: moderate, mottled radiometric response with higher K; uniformly strongly magnetic with prominent linear anomalies related to jointing
Pwcv1 Emmawill Volcanics: moderate Th and U and high K responses with linear texture; high intensity magnetic response with abundant subparallel linear anomalies
Pwcv2 Emmawill Volcanics: high radiometric response; moderate to high magnetic intensity
Pwcv3 Emmawill Volcanics: high to very high Th and K, moderate to high U response; uniformly low magnetic intensity
Pwr Tent Hill Volcanics: high radiometric response with persistent linear features; moderate magnetic response with linear anomalies

Early Permian
Pb Unnamed metabasalt: low radiometric response; low to moderate magnetic intensity with medium intensity curvilinear anomalies
Pc Unnamed conglomerate: moderate to high K and low to high Th and U responses; moderate to high mottled magnetic response
Px Unnamed sedimentary rocks: moderate K and Th and low to moderate U responses; low to moderate mottled magnetic response with higher intensity linear anomalies
Pxn Torington pendant: low to moderate Th, low to very low K and U response; low magnetic intensity with linear anomalies

Early Carboniferous
Csx Sandon beds: distinctive medium Th response defining lithological units; medium to low magnetic response defining some discontinuous units
Ctx Texas beds: moderate to high K and low to moderate Th and U responses; low magnetic response with localised, discontinuous striping defining lithological units
Cwx Wilhoo Formation: low to moderate radiometric response; low, featureless magnetic response
The Emmaville Volcanics exhibit prominent magnetic and radiometric lineations attributable to discrete flows or epiclastic beds (Figures 2 and 5). Analysis of the imagery should enable calculations of bedding thicknesses, and would provide an estimate of the number of ash flows within the local volcanic pile. Interpreted layering wraps about the outcrop extent of the Tent Hill Volcanics and Dundee Rhyodacite and transgresses topography, suggesting that the Emmaville Volcanics dip beneath the other Wandsworth Volcanic Group units.

Mapping by Adams (2004) in the Pindari Dam area to the east of Emmaville Volcanics in the Inverell–Emmaville–Glen Innes area. The bodies increase in size southward. Contact geometry indicates a succession from north to south, with the northern margin of each body penetrating the southern edge of its neighbour. Overburden Filter™ images by Vector Research Pty Ltd demonstrate limited depth persistence of the bodies, with the TMI shallow 15 image (Figure 5) clearly defining the boundary geometry of the bodies. The correlation of linear features in the TMI and RGB radiometric images (Figure 5) confirms that the bodies are exposed, whilst the extension of magnetic features beyond the extent of outcrop of the volcanic rocks (Figure 5, inset) may indicate that the bodies dip beneath the Texas beds to the west. The bodies have been interpreted by Larry Barron (pers. comm. 2003) as exposed and shallow (buried) calderas. The size relationships and geometry of the calderas demonstrate an evolutionary series from the oldest in the north to the youngest in the south. The interpreted calderas may have been sources for the extensive ashflow deposits and rare lavas of the youngest in the south. The interpreted calderas may have been sources for the extensive ashflow deposits and rare lavas of the youngest in the south. The interpreted calderas may have been sources for the extensive ashflow deposits and rare lavas of the youngest in the south.

Magnetic and radiometric imagery indicate the presence of at least three large, approximately hemispherical, zoned bodies within and beneath the western extent of outcropping Emmaville Volcanics (Figures 2 and 5). The bodies increase in size southward. Contact geometry indicates a succession from north to south, with the northern margin of each body penetrating the southern edge of its neighbour. Overburden Filter™ images by Vector Research Pty Ltd demonstrate limited depth persistence of the bodies, with the TMI shallow 15 image (Figure 5) clearly defining the boundary geometry of the bodies. The correlation of linear features in the TMI and RGB radiometric images (Figure 5) confirms that the bodies are exposed, whilst the extension of magnetic features beyond the extent of outcrop of the volcanic rocks (Figure 5, inset) may indicate that the bodies dip beneath the Texas beds to the west. The bodies have been interpreted by Larry Barron (pers. comm. 2003) as exposed and shallow (buried) calderas. The size relationships and geometry of the calderas demonstrate an evolutionary series from the oldest in the north to the youngest in the south. The interpreted calderas may have been sources for the extensive ashflow deposits and rare lavas of the Emmaville Volcanics in the Inverell–Emmaville–Glen Innes area.

Mapping by Adams (2004) in the Pindari Dam area to the east of Ashford was unable to confirm the presence of calderas in that area. Adams (2004) reported the following observations as supporting local calderas.

- Geophysical imagery indicates the approximate geometry of a nested caldera complex.
- Flow-laminated felsic lavas, felsic pyroclastic units and relatively abundant dykes would be expected within, or adjacent to, a caldera.
- Fiamme orientations within ash flow volcanioclastic units in some areas exhibit an approximately radial dip.

Adams (2004) rendered the following observations as counter-suggestive of local calderas.

- No ring faults were mapped.
- There is an absence of collapse breccias.
- Dip angles of fiamme in the centre of the apparent caldera structures were about 33°–35°, which is too steep for intracaldera rocks unless they have been tilted after emplacement.

Adams (2004) was unable to satisfactorily explain the caldera-like geometry illustrated on the geophysical images. Despite the apparent evidence against local calderas, the combination of geophysical images suggesting a nested caldera geometry and the abundance of proximal felsic volcanic rocks and felsic dykes are compelling supporting evidence.

The recognition of (volcanic) calderas at the present ground level has implications for proposing erosion depths since the Late Permian. From a geophysical study of Quaternary volcanism, Iyer (1984) demonstrated that magma chambers beneath volcanic centres of significant size are more than four or five kilometres below ground level. This implies that a thickness of about four or five kilometres of Wandsworth Volcanic Group rocks has been eroded in the survey area.

The Inverell radiometric data demonstrate that additional subdivision of the Emmaville Volcanics is possible (Figures 2 and 3). At least one new, regionally extensive unit is recognisable, characterised by contrasting radiometric and magnetic characteristics. Further, localised subdivision is also possible within the calderas, where strongly contrasting magnetic and radiometric responses identify laterally persistent lithological associations.

**Tent Hill Volcanics**

The Tent Hill Volcanics (Godden 1982) are comprised predominantly of interbedded porphyritic, rhyolitic to andesitic ignimbrite and lava. They occur as an envelope about the Dundee Rhyodacite (Figure 3), stratigraphically above the Emmaville Volcanics. The earliest studies of the Tent Hill Volcanics (Andrews, Mingaye & Card 1907; Lawrence 1969; Godden 1982) proposed a ring-like intrusive origin. Godden (1982) also proposed an alternative stratigraphic origin, and Baillie (1983) suggested a conformable contact with the Emmaville Volcanics and a possible disconformable contact with the Dundee Rhyodacite. Shaw, Flood and Vernon (1988) considered that the Tent Hill Volcanics are largely indistinguishable from the Emmaville Volcanics, and recommended that the unit be redefined or eliminated. Barnes and Willis (1989) noted that the Tent Hill Volcanics are geochemically similar to the Dundee Rhyodacite and distinct from the Emmaville Volcanics.

The Inverell geophysical data provide new insights into the relationships between the Tent Hill Volcanics and Emmaville Volcanics and the Dundee Rhyodacite (Figure 6). The composite K–Th–U radiometric data highlight a distinct belt of volcanic rocks generally coincident with the previously mapped extent of the Tent Hill Volcanics. The composite image suggests a closer affinity between the Tent Hill Volcanics and Emmaville Volcanics than between the Tent Hill Volcanics and the Dundee Rhyodacite. Individual radiometric channels portray a slightly different interpretation, with potassium data for the Tent Hill Volcanics being intermediate in response between the
Dundee Rhyodacite and Emmaville Volcanics and the thorium and uranium data being indistinguishable from the Emmaville Volcanics. Images of the radiometric data exhibit prominent, laterally persistent, parallel belts probably attributable to lithological layering in the Emmaville Volcanics and Tent Hill Volcanics. These belts are absent in the mapped Dundee Rhyodacite.

Measured magnetic susceptibility data show a strong contrast between the weakly magnetic local Emmaville Volcanics \((6 \times 10^{-5} \text{ to } 47 \times 10^{-5} \text{ SI})\) and the more strongly magnetic Tent Hill Volcanics \((248 \times 10^{-5} \text{ to } 552 \times 10^{-5} \text{ SI})\) and Dundee Rhyodacite \((588 \times 10^{-5} \text{ to } 1080 \times 10^{-5} \text{ SI})\). Both the Tent Hill Volcanics and Emmaville Volcanics exhibit well-developed, parallel linear magnetic anomalies corresponding with the radiometric striping described above. There is little or no indication of similar features in the Dundee Rhyodacite.

Interpretation of the aforementioned geophysical characteristics yields the following conclusions.

- The Tent Hill Volcanics is a distinct, mappable unit. Its extent approximately correlates with what has previously been mapped although the unit boundaries can be significantly refined and extended eastward using the images of the airborne geophysical data.
- The airborne geophysical data demonstrate internal stratification which is coplanar with that in the Emmaville Volcanics. No coherent stratification is evident in the Dundee Rhyodacite.
- The Tent Hill Volcanics are radiometrically similar to the Emmaville Volcanics in thorium and uranium but not consistently similar in potassium. This suggests variation in K-feldspar:plagioclase ratios and K-feldspar volume between the two units in an assemblage of otherwise generally similar composition. This conflicts with previous observations that the average mineralogical composition of Tent Hill Volcanics lithologies falls within the range of the Dundee Rhyodacite (Godden 1982) and that the whole-rock chemistry is more basic than that of the Emmaville Volcanics and not significantly different from that of the Dundee Rhyodacite (Barnes & Willis 1989).
- The Dundee Rhyodacite and Tent Hill Volcanics are magnetically similar, with the latter being slightly less magnetic than the former. The Tent Hill Volcanics is magnetically distinct from the nearby Emmaville Volcanics.

**Dundee Rhyodacite**

The Dundee Rhyodacite (Flood et al. 1977) is exposed as an angular, semicircular mass in the northeast corner of the survey area (Figures 3 and 6). Previous studies have demonstrated that this strongly porphyritic rhyodacitic ignimbrite occupies a structural basin which systematically dips towards its centre on its eastern, northern and southern margins (Shaw, Flood & Vernon 1988). The unit is remarkable for its lack of regional textural and compositional variation (Flood et al. 1977; Godden 1982; McPhie 1988). Its basal relationships are uncertain, with recent researchers concluding either a disconformable or conformable contact.

The Inverell geophysical images provide useful data for interpreting the Dundee Rhyodacite. Images of the radiometric data confirm a likely conformable or local, low-angle disconformable relationship with the Tent Hill Volcanics. The regional homogeneity of the Dundee Rhyodacite is confirmed by the paucity of apparent lithological layering and very limited variation in radiometric response across the unit. The potassium and thorium response of the rhyodacite is greater than that of the adjacent Emmaville Volcanics, whereas the rhyodacite exhibits a lower uranium response.

The magnetic data confirm the homogeneity of the Dundee Rhyodacite, with very few linear magnetic anomalies attributable to lithological layering or original compositional variants. As described above, the rhyodacite exhibits a similar magnetic intensity to the Tent Hill Volcanics, and is of significantly higher intensity than the Emmaville Volcanics. A response to a pervasive north-northeast-striking fracture pattern is recorded in the magnetic images (Figure 6). The parallel fracture set is developed throughout the rhyodacite and is developed to a lesser extent in the Tent Hill Volcanics.

The airborne geophysical data demonstrate that the boundaries of the Dundee Rhyodacite are reasonably accurately mapped. Minor local inaccuracies could be corrected using the radiometric images.

**CENTRAL BLOCK GRANITOIDS**

Preliminary interpretation of the Inverell airborne geophysical data suggests that some significant revisions in mapping and subdivision of the granitoids in the survey area are possible. Several new variants of major bodies have been recognised from the imagery, and several deeply buried non-exposed granitoid bodies are inferred. However, some mapped outcropping bodies cannot be distinguished in the magnetic or radiometric imagery because of either a lack of geophysical contrast, or to partial masking by regolith.

**Bundarra Supersuite**

The northern extremity of the Early Permian, S-type, Bundarra Supersuite mass is exposed near the western margin of the survey area (Figures 2 and 3). This large body consists of distinctly coarse-grained, porphyritic monzogranite with abundant K-feldspar megacrysts. It is characterised by a uniformly low magnetic susceptibility \((2 \times 10^{-5} \text{ to } 11 \times 10^{-5} \text{ SI})\) and a variable, medium to high radiometric response.

Previous mapping and attempts at subdivision have been confined to the southern extremity of the pluton beyond the Inverell survey area (eg. O’Neill, Shaw & Flood 1977; Chappell...
Figure 4 First vertical derivative (IVD) image (upper) and interpretation and lineament map (lower) of the Early Permian metasediments (Px, Pc) of the Emmaville area. Rimu = Mole Granite, Tb = Tertiary volcanic rocks, Pw = Wandsworth Volcanic Group.
Figure 5 TMI shallow 15 image (upper) and RGB radiometric image (lower) of the Wandsworth Volcanic Group in the survey area. The inset is a composite of the TMI and RGB images showing the relationships between radiometric and magnetic features as well as the extension of magnetic features beyond the surface exposures of the volcanic rocks.

The pluton trends approximately north–south. A significant area of the pluton is concealed beneath Tertiary volcanic rocks.

The Inverell airborne geophysical imagery suggests potential for refinement of boundaries, and for subdivision of the otherwise undifferentiated pluton. The magnetic imagery also demonstrates the presence of significant, structurally controlled, magnetic dyke swarms within the pluton (Figures 2, 3 and 7) and has revealed the presence of the ‘Willowrie diorite’ (see below and Figures 2 and 7).

Interpretation of the geophysical images has resulted in a four-fold subdivision of the Bundarra Supersuite into units Pbg1, Pbg2, Pbg3 and Pbg4 (Figure 3). The subdivision is based on relative radiometric abundances (Figure 2). None of these variants has been previously mapped as discrete phases.

Unit Pbg1 is restricted to the northern half of the pluton within the survey area, and to small inliers within the Tertiary volcanic sheet (Figure 3). The dominant lithology is a coarse-grained, massive, megacrystic biotite monzogranite with locally abundant, relict cordierite crystals visible in hand specimen. The unit is characterised by a relatively very high potassium response, and relatively high thorium and uranium response.

An elongate, north-trending body which exhibits geophysical characteristics similar to Pbg1 is hosted by the Texas beds to the southeast of Ashford (Pxg in Figure 3). Mapping by Adams (2004) has identified this body as a Bundarra Supersuite correlative.

Unit Pbg2 is exposed along the eastern margin of the pluton and as scattered bodies throughout the pluton mass. It is characterised by (relatively) moderately low thorium and uranium and high potassium response with a mottled texture. Limited field observation failed to identify any significant hand specimen difference between this unit and the surrounding variants. A close correlation between areas of Pbg2 and subdued topography suggests that this unit is possibly an artefact of deeper or more advanced weathering, or of partial blanketing by regolith. The high potassium and low thorium response supports the regolith blanket model rather than the deep weathering alternative as deep weathering would usually result in depletion of potassium.

Unit Pbg3 is a distinctive lithology of very coarse-grained, euhedral white K-feldspar megacrysts in a coarse-grained biotite monzogranite. This areally widespread unit is characterised by a relatively high to very high radiometric response but with potassium concentrations lower than Pbg1 to the north.

Unit Pbg4 is restricted to the central and southern section of the Bundarra Supersuite in the survey area. The unit is characterised by relatively low concentrations of potassium with high thorium and moderate to high uranium concentrations. It is locally associated with Tertiary regolith and volcanic rocks. Its setting close to the relict Tertiary weathering surface and its low potassium response is consistent with the unit representing a leached, weathered variant of the Bundarra Supersuite.

Units Pbg1 and Pbg3 are regionally extensive bodies distinguishable lithologically and geophysically. Their contact is concealed beneath Tertiary volcanic rocks. Both units are exposed over wide areas in the survey area and display relative internal uniformity. It is recommended that they should be formally recognised as mappable units of the Bundarra Supersuite.

Uralla Supersuite

The Late Permian to Early Triassic I-type Uralla Supersuite occurs as scattered bodies throughout the eastern half of the survey area. This Supersuite has been the subject of numerous petrographic and geochemical studies (eg, Cotton 1910; Connor 1972; Flinter, Hesp & Rigby 1972; Mikulski 1973; Pogson & Hitchins 1973; Want 1973; Juniper 1974; Street 1974; Jones 1976; Stolz 1976; Cook 1986; Barnes & Willis 1989; Shaw & Flood 1993). Consequently, many Uralla Suite intrusions are relatively well mapped and their characteristics thoroughly documented. The Inverell geophysical data indicate that some bodies require minor adjustments to mapped boundaries.

**Tingha Monzogranite**

The Tingha Monzogranite (Figure 3) is characterised by a uniformly low magnetic intensity and a low to very high radiometric response. Two units (Rutg1 and Rutg2) have been recognised based on their radiometric features. The two variants share similar, relatively low to high thorium and uranium concentrations, with the most widespread variant characterised by low to high potassium concentrations and the more restricted variant exhibiting very high potassium concentrations. The high-potassium variant is developed directly adjacent to the Gilgai Granite (Rlu on Figure 3) and may represent any of the following alternatives:

- a phase of the Tingha Monzogranite;
- localised Gilgai Granite-derived regolith cover over Tingha Monzogranite;
- intrusion of numerous small bodies of Gilgai Granite into the Tingha Monzogranite; or
- assimilation, or partial assimilation, of Tingha Monzogranite into the younger Gilgai Granite.

The radiometric images indicate that previous mapping of the boundary between the Gilgai Granite and Tingha Monzogranite locally requires re-examination. Field investigation has demonstrated that the boundary is difficult to identify locally, with apparent hybrid variants indicating varying degrees of assimilation or digestion of the Tingha Monzogranite by the Gilgai Granite.
Figure 6 K-Th-U radiometric (left) and 1VD total magnetic intensity reduced to pole (right) images of the Dundee Rhyodacite and the Tent Hill Volcanics showing published geological boundaries (Herley et al. 2001b). Trend lines facilitate correlation between images. Letter symbols for Tb, Rimu and Prew are simplified from Figure 3.

Figure 7 1VD RTP magnetic image showing the oval magnetic (pink) anomaly corresponding with the ‘Willowie diorite’ and its associated radial magnetic dyke swarm.
The eastern extent of the Tingha Monzogranite is locally at variance with previous mapping (Figure 8). Many small inliers of the monzogranite are also absent in the geophysical images. The correspondence of hilly terrain and extensive Tertiary basalt has resulted in the dispersal of Tertiary regolith which has locally obscured the monzogranite’s radiometric signature. The high magnetic intensity of the basalts has also masked the boundary and numerous small monzogranite inliers. Images of the radiometric data indicate that at least several small outliers previously mapped as Tingha Monzogranite may be Gilgai Granite. It is also apparent that several previously unmapped, outcropping granitoid outliers are present in this eastern area. Filtering of the TMI RTP data by Vector Research Pty Ltd (Figure 8 — TMI deep 15) has indicated the presence of deeply buried magnetic masses with a homogeneous magnetic response near the eastern extent of exposed Tingha Monzogranite and Gilgai Granite. A deeply buried magnetic mass with a similar response occurs beneath the main area of outcrop of these granitoids (Figure 8) to the west. It is possible that the deeply buried eastern masses represent persistence of one or both of these granitoids for many kilometres further east and northeast beyond the area of outcrop. The magnetic response of the buried granitoid implies an affinity with the high magnetic intensity variants of the Gilgai Granite (see later discussion).

**Wards Mistake Monzogranite**

The Wards Mistake Monzogranite (PRuwg in Figure 3) is exposed over a small outcrop area in the southeastern corner of the survey area in the vicinity of Glen Innes. Previous mapping has identified four scattered bodies of this intrusion in the survey area. Only one body has been interpreted from the geophysical data, with all others lacking sufficient geophysical contrast to be distinguishable.

**Wellingrove Granodiorite**

The Wellingrove Granodiorite (PRuld in Figure 3) occurs as a set of northwest-striking, dyke-like and irregular masses about 20 km northwest of Glen Innes. The granodiorite is characterised by a relatively moderate to high potassium and low thorium and uranium response, and a low magnetic intensity. The granodiorite is hosted by the Emmaville Volcanics, from which it is distinguished by its lower magnetic intensity and lower thorium response. Regolith derived from the Emmaville Volcanics has masked a large area of the exposed granodiorite, hindering the use of radiometric data as a tool for mapping the intrusion. Filtered TMI RTP images by Vector Research Pty Ltd suggest that the granodiorite is not present as a large mass at depth. It is possible that the dyke-like geometry of the granodiorite bodies represents the base of an eroded pluton which has intruded a northwest-trending structural corridor.

**Leucocratic granitoids**

A number of the most significant mineralising silica-rich, fractionated I-type leucogranitoid bodies in the southern New England Orogen crop out in the Inverell survey area. The leucogranites generally occur as coarse- to very coarse-grained quartz–feldspar–biotite rocks containing 74% to 77% SiO₂. These include the Early Triassic Mole Granite (Rlmu), Gilgai Granite (Rliu) and Elsmore Granite (Rlfu), and the less significant Webbs Consols Leucogranite (Rlwu) and Dumboy-Grarin Granite (Rllu). These granitoids have been interpreted as sources for the Tingha–Gilgai, Vegetable Creek, Torrington and Stannum tin fields and the Conrad, Webbs Consols and Webbs silver mine silver-rich polymetallic deposits (Ashley et al. 1996; Brown & Stroud 1997; Henley et al. 2001a). Regionally important tungsten, beryl, emerald, silexite (quartz–topaz greisen), kaolinite and arsenic occurrences are also derived from these rocks.

**Mole Granite**

The southern half of the outcropping Mole Granite (Rlmu) is exposed in the Inverell survey area (Figures 3 and 9). The granite is characterised by a relatively high to very high radiometric response and a low to moderate magnetic intensity. The Inverell geophysical images confirm that previous mapping of this granite has been accurate, with very close correlation between the mapped boundaries and the images of the radiometric and magnetic data. However, although the radiometric data images suggest that the granite margins are accurate, it is apparent that numerous metasedimentary roof pendants are present between Torrington and the previously mapped Torrington pendant (Figure 9). These pendants have been described above (in discussion of the metasedimentary rocks).

Three variants of the Mole Granite have been recognised from the airborne geophysical data (Figure 3). These have been subdivided on the basis of different radiometric and magnetic characteristics. The variants form elongate zones parallel to the southern outcrop margin of the Mole Granite. The broadest zone (Rlmu2) extends northward from the outcrop boundary and is interpreted as a carapace.

Filtering of the TMI RTP data by Vector Research Pty Ltd to enhance broad-wavelength, deep-sourced features has demonstrated the subsurface persistence of the Mole Granite (Figure 9) southwest from its outcrop area. The filtered magnetic data image shows the granite persisting as an orthogonal (or near-orthogonal) mass with a structurally controlled eastern boundary. The granite may be present in the subsurface for as much as 32 km beyond the southern outcrop margin. This interpretation is in accord with the inferred subsurface geometry of the Mole Granite proposed by Henley et al. (2001a, figure 25). Their model was based on the extent and clustering of mineral occurrences exhibiting characteristics considered diagnostic of Mole Granite parentage. Confirmation of their model is significant as it reinforces the prospectivity of the region above the buried granite, particularly in granite surface ridges and cupolas.

Intrusion of the sill-like or laccolith-like Mole Granite pluton has apparently resulted in the development of widespread...
different to the main mass of leucogranite, and may be altered suggests that the other mapped bodies are compositionally could not be identified in the geophysical imagery. This both hosts. The other, smaller mapped bodies of leucogranite Emmaville Volcanics, and a prominent magnetic contrast with sedimentary rocks, a low radiometric contrast with the Early Permian prominent radiometric contrast with the Early Permian granite. The leucogranite has intruded the Emmaville Volcanics and southern margin (Figure 2), but elsewhere is of low magnetic intensity.

The Inverell airborne geophysical data indicate that previous mapping of the outer margin of the Gilgai Granite is of very good to poor reliability. An assessment of the granite contact with the Tingha Monzogranite, and the potential for significant eastward subsurface persistence has been described above.

**Gilgai Granite**

The northern edge of the Gilgai Granite (Rliu) outcrop is exposed in the Inverell survey area (Figure 3). The granite is characterised by a relatively high to extremely high radiometric response and a low to high magnetic intensity. The Gilgai Granite exhibits a high magnetic intensity rim along its western and southern margin (Figure 2), but elsewhere is of low magnetic intensity.

The Inverell airborne geophysical data indicate that previous mapping of the outer margin of the Gilgai Granite is of very good to poor reliability. An assessment of the granite contact with the Tingha Monzogranite, and the potential for significant eastward subsurface persistence has been described above.

**Elsmore Granite**

This intensely tin-mineralised granitoid (Rlfu1, Rlfu2) occurs as two small bosses about 20 km southeast of Inverell (Figures 2 and 3). The granite is characterised by a relatively very high radiometric response and a uniformly low magnetic intensity. Areas of very low to moderate potassium concentrations (Rlfu2 in Figure 3) have been subdivided from the major granite variant. The low-potassium variant corresponds with areas of deep kaolinisation adjacent to areas of intense greisenisation (Brown & Stroud 1997). More than 60 000 tonnes of high-grade kaolin were identified in the westernmost body.

Images of the radiometric data demonstrate good agreement with the previous mapping of the external boundaries. Areas of kaolinisation in both granite bodies represent potential vectors to tin mineralisation, and may have potential for additional viable kaolin deposits.

**Webbs Consols Leucogranite**

The Webbs Consols Leucogranite (Rlwu) is a fine- to coarse-grained, coarsely porphyritic to equigranular, leucocratic granite. The leucogranite has intruded the Emmaville Volcanics and unnamed Early Permian sedimentary rocks as four small, irregular bodies about 10 km southwest of Emmaville.

The largest previously mapped body of the leucogranite is characterised by a relatively high potassium and uranium response, with a very high thorium response and a relatively low magnetic intensity (Figure 3). This body exhibits a prominent radiometric contrast with the Early Permian sedimentary rocks, a low radiometric contrast with the Emmaville Volcanics, and a prominent magnetic contrast with both hosts. The other, smaller mapped bodies of leucogranite could not be identified in the geophysical imagery. This suggests that the other mapped bodies are compositionally different to the main mass of leucogranite, and may be altered or not related to the Webbs Consols Leucogranite.

The Inverell radiometric data indicate that mappable variants are present within the major body of leucogranite. The western lobe of the leucogranite exhibits significantly lower uranium and slightly lower thorium response than the eastern lobe.

**Dumboy-Gragin Granite**

The easternmost extent of the Dumboy-Gragin Granite (Rluu) is exposed near the western edge of the Inverell survey area (Figure 3). The granite was previously described by Stroud (1992); Vickery (1993); and Vickery, Ashley and Fanning (1997). This leucocratic, medium- to coarse-grained syenogranite with K-feldspar megacrysts has intruded the Early Carboniferous Whitlow Formation and is overlain by the Early Triassic Gragin Conglomerate and Tertiary volcanic rocks. The granite is exposed as numerous inliers. The clarification of subsurface relationships between inliers is hindered by the overlying strata.

The granite is characterised by a (relatively) extremely high radiometric response and a uniformly low magnetic intensity. The incorporation of significant volumes of relatively fresh Dumboy-Gragin Granite detritus into the Gragin Conglomerate renders radiometric differentiation of the two units difficult or impossible. Dispersal of detritus from these units, and from the Tertiary volcanic rocks has resulted in significant discrepancies between previous mapping and the interpretation illustrated in Figure 3.

**Undifferentiated granitoids**

Previous mapping in the Inverell survey area has identified a number of undifferentiated granitoid stocks and dykes (Stroud & Brown 1998; Henley et al. 2001b). Many of these have intruded rocks of the Wandsworth Volcanic Group with which they share similar radiometric and magnetic characteristics. These geophysical similarities have resulted in most mapped undifferentiated granitoids not being identified in the geophysical data.

The similarity of geophysical characteristics between the Wandsworth Volcanic Group and various undifferentiated granitoids may be of relevance to the parentage of both units. It is possible that they may be cognamic.

**Miscellaneous intrusions**

A number of previously unrecognised intrusions have been identified during interpretation of the Inverell geophysical images. These intrusions include:

- a plug-like diorite body southwest of Ashford;
- magnetic dyke swarms within the Bundarra Supersuite; and
- buried plutons in the Glen Innes and other areas.

A circular, relatively high-intensity magnetic anomaly located centrally within an area of radial linear magnetic anomalies occurs within the Bundarra Supersuite about 14 km southwest of Ashford (Figures 2 and 7). The central anomaly is oval in plan, with linear margins suggesting rectilinear structural control.
Figure 8: Previously mapped geology, ternary radiometric image (RGB), filtered TMI RTP image (TMI deep 15) and first vertical derivative reduced to pole (IVD) image of the eastern extent of the Tingha Monzogranite (Pug) and Gilgai Granite (Riu). The TMI image suggests the presence of a deeply buried pluton (shown as solid red colour) in the central east which is not present in outcrop. The extent of outcrop of the Tingha Monzogranite is shown as an outline on the RGB, TMI deep 15 and IVD images. For key to letter symbols (some abbreviated here), see Figure 3.
Figure 9 The mapped geology south of the outcropping Mole Granite (Geology), and ternary radiometric image (RGB), filtered TMI RTP image (TMI deep 13) and the first vertical derivative reduced to pole (TVD) image of the same area. The filtered TMI image suggests the possible depth extension of the Mole Granite to the southwest. For key to letter symbols (some abbreviated here), see Figure 3.
Field examination of the area of the anomaly has defined a prominently outcropping body of fine- to medium-grained diorite and microdiorite. The body has been informally termed the ‘Willowrie diorite’. The diorite crops out as tors over an area extending about 1300 m north–south, and 1200 m east–west. Local gullies draining the area of diorite outcrop are rich in fine-grained detrital magnetite. Magnetic susceptibility recordings along a traverse from the approximate core of the body to its eastern contact with the Bundarra Supersuite ranged from $203 \times 10^{-5}$ to $3780 \times 10^{-5}$ SI. The core of the body yielded higher magnetic susceptibility values, ranging from $569 \times 10^{-5}$ to $3780 \times 10^{-5}$ SI, whereas the outermost 200 m of the body ranged from $203 \times 10^{-5}$ to $530 \times 10^{-5}$ SI.

The ‘Willowrie diorite’ exhibits hand specimen, field and geophysical characteristics similar to the Fox Tor Diorite (Stonestreet 2002; Brown 2003a; Stonestreet et al. in prep) from the Watsons Creek district in the Peel South geophysical area (Brown 2001). The Fox Tor Diorite was subsequently dated by the author using the K–Ar technique at 239.7 ± 6.7 Ma (i.e. Late Permian). A similar K–Ar date of 244.5 ± 2.6 Ma was obtained for the ‘Willowrie diorite’ by M Dawson (2004, pers. comm.). The Fox Tor Diorite exhibits an average magnetic susceptibility of $900 \times 10^{-5}$ SI and also intrudes the Bundarra Supersuite.

Brown (2003a) attempted to correlate the Fox Tor Diorite with the New England plutonic suites. Based on a comparison of compositional variants and magnetic susceptibilities it was considered that the closest correlate is the Moonbi Supersuite. Stonestreet et al. (in prep) have also concluded that the oxidation state and magnetic characteristics of the Fox Tor Diorite are more typical of lower-K, mafic Moonbi Supersuite bodies, although the geochemical characteristics are more similar to magnetic, mafic members of the Uralla Supersuite. The 240-Ma age of the Fox Tor Diorite falls within the age ranges of the Moonbi and Uralla Supersuites.

The airborne magnetic data have identified the presence of many non-outcropping dyke swarms throughout the western half of the survey area (Figure 3). These include:

- a north- to north-northeast-trending swarm;
- localised northeast-trending dykes; and
- a swarm extending radially from the ‘Willowrie diorite’ plug.

The dykes correspond to a variable-intensity cluster of linear to arcuate, positive magnetic anomalies. They range in length from several hundred metres to about 10 km. The dykes exhibit no radiometric response, suggesting that they do not crop out. Almost all dykes interpreted from the magnetic imagery have intruded the Bundarra Supersuite. A few dykes have apparently intruded the Texas beds as part of the radial swarm about the ‘Willowrie diorite’. The relationship of the dykes to the Tertiary volcanic rocks is uncertain. In most areas the intense magnetic character of the Tertiary lavas has masked the linear dyke signature. However, in some areas, such as north of Copeton (Figure 10), a poorly-defined magnetic linear trace can be projected northwards through the Tertiary lavas from individual dykes within the Bundarra Supersuite. This latter observation can be interpreted as either:

- some dykes have intruded the Tertiary lavas; or
- reactivation of the fractures or faults hosting the dykes has penetrated the lavas; or
- the magnetic signature of the dykes is visible where the lavas are thinner.

Doleritic dykes have been observed as basement intrusions within underground deep lead mine workings in the Copeton area (Barron & Brown 1994; Brown & Stroud 1997). A deeply weathered dolerite dyke is present in Pyke and O’Donnells adit, where it has intruded along a fault plane in granite (Photographs 1 and 2). The fault has subsequently been reactivated, resulting in offsetting of all boundaries. Slickensides are evident along the fault plane in the Tertiary sediments, dyke and granitoid. The dyke predates the sedimentary deposits and was evidently deeply weathered at the time of erosion (Barron & Brown 1994).

It is apparent that the non-radial dykes occupy a major, north-to north-northeast-trending regional fracture zone. In the Inverell survey area the zone is up to 8 km wide and persists with apparent continuity for at least 105 km. A similar swarm is present in the Watsons Creek district within the Peel South Survey area (Brown 2003a). Overall, the fracture zone extends from the Tamworth area (south of the area in Figure 1) to at least the northern boundary of the Inverell survey area with an extent of at least 170 km long and 100 km wide.

The radial dyke swarm associated with the ‘Willowrie diorite’ occurs within a 20 km × 13 km area (Figures 3 and 7). The dykes have intruded the Bundarra Supersuite and Texas beds. Persistence of the host radial fractures beyond the dykes is apparent in the magnetic images, particularly to the south and southeast of Ashford. The radial geometry of the dykes is diagnostic of the plug-like origin of the ‘Willowrie diorite’. Although no outcrop of the radial dykes was observed in the field in this study, it would be reasonable to assume that at least some of the dykes are related to the ‘Willowrie diorite’, or to the magmatic event which produced the plug. Three petrographic samples were collected by DJ Bourke in 1974 from a site which correlates with the surface trace of a radial dyke (GDA 56 grid reference 303706mN 6749888mE). The samples were identified as olivine basalt dykes in coarse granite by the collector. This is of significance as it demonstrates that at least some of the dykes are basaltic rather than doleritic or dioritic. It also suggests that at least some of the fractures hosting the dykes have been utilised by intrusions of very different ages. This may also apply to the ‘Willowrie diorite’ plug, which may also host younger, more mafic lithologies at depth or in subcrop.
Figure 10: 2D magnetic image (left) and previous geological mapping (right) of the Copeton area. For key to lithological letter symbols (abbreviated here), mineral occurrence symbols and other symbols see Figure 3.
The filtered magnetic data by Vector Research Pty Ltd indicate the presence of several buried plutons. One possible body occurs to the southwest of Glen Innes (Figure 11) near several small areas of outcropping Wards Mistake Monzogranite. The body lies beneath two small stockwork mineral occurrences.

A possible 12 km × 7 km pluton is thought to lie beneath the Wandsworth Volcanic Group calderas described above (Figure 12). The possible pluton is developed adjacent to an outcropping body of undifferentiated granitoid which may represent the surface expression of the buried pluton. The rectilinear margins of the feature suggest structural control on emplacement. The possible genetic relationship between the inferred pluton and the calderas requires investigation.

Another possible pluton could lie beneath the Dundee Rhyodacite to the east of Emmaville (Figure 9). No granitoids crop out close to this feature. The body may represent a magma chamber to the Dundee Rhyodacite.

The Wellingrove Granodiorite crops out to the east of a possible buried pluton south of Emmaville (Figure 9). The possible body may represent a magma chamber for the dyke-like Wellingrove Granodiorite bodies.

SURAT BASIN AND WARIALDA TROUGH

Rocks of the New England Orogen are overlain by continental sedimentary rocks of the Early to Middle Triassic Warialda Trough and Jurassic Surat Basin in the Inverell area. The Warialda Trough is represented by the Early to Middle Triassic Gunnee Formation and Gragin Conglomerate. The Late Jurassic Pilliga Sandstone is the single representative of the Surat Basin present in the Inverell survey area (Figure 3).

The mixed sedimentary sequence representative of the Gunnee Formation was not identified from the geophysical data. The unit shares radiometric characteristics similar to Tertiary basalt-derived regolith, and has a low magnetic intensity similar to the locally exposed Whitlow Formation and Dumboy-Gragin Granite.

The Gragin Conglomerate was not distinguished from the Dumboy-Gragin Granite in the survey area (Figure 3). Both share similar radiometric and magnetic responses, with a high potassium response suggesting an arkosic component in the Gragin Conglomerate.

The Pilliga Sandstone is a quartzose sandstone characterised by a very low potassium and low to high thorium and uranium response and uniformly low magnetic intensity. The low potassium response is attributable to the quartz-dominant, feldspar-poor mineralogy. Locally (relatively) elevated thorium and uranium response may confirm the presence of locally significant concentrations of detrital heavy minerals, including monazite and zircon. An alternative explanation for thorium-enrichment (PM Ashley 2004, pers. comm.) relates to pre-basaltic, deep weathering and ferruginisation which is prevalent throughout the Inverell region. The sandstone contrasts well with the geophysical response of the surrounding Tertiary volcanic units in the area. Previously unmapped inliers of Pilliga Sandstone are apparent in the northwestern corner of the Inverell survey area.

TERTIARY SEDIMENTS, REGOLITH, VOLCANICLASTIC UNITS AND LAVAS

The Inverell geophysical dataset is a tool which provides assistance for identifying the presence of, and for differentiating between, Tertiary rocks. Preliminary examination of the data has resulted in the following observations.

- The radiometric data confirm the presence of two major volcanic compositional suites.
- Selective re-imaging of the radiometric data may prove useful for identifying Tertiary volcaniclastic units.
- Many anomalous features in the radiometric images cannot be readily explained by observed rock or soil types, vegetation or landforms.
- Identified volcanic centres in the Kings Plains, Swan Peak and Elsmore areas are not apparent in the magnetic data — although Swan Peak is visible in the radiometric images.
- Some Tertiary deep lead palaeochannels are recognisable in the magnetic images.

Perhaps one of the most significant uses of the Inverell survey data is the differentiation of eastern and western compositional suites of Tertiary basalts (Figure 13). Although the suites are characterised by low to very low thorium and uranium responses they are differentiated on their potassium response. The western suite exhibits low to very low potassium, and the eastern suite low to moderate potassium (Figure 13d).
Previous studies have identified the presence of an older (32–38 Ma), eastern sapphire-rich province (e.g., Coenraads 1990; Coenraads, Sutherland & Kinny 1990) and a younger (19–23 Ma), western sapphire-poor province. Sutherland, Pogson and Hollis (1993) used pre-existing data plus new fission track and K–Ar dates on zircons and evolved rocks to further subdivide the Tertiary volcanic units of the survey area into age fields (Figure 13). Their data confirmed the general subdivision into eastern and western suites, and recognised domains of more specific age ranges within the suites.

The Inverell radiometric data are a potentially useful tool for subdividing areas of Tertiary basalts into compositional domains. It may also prove possible, with appropriate image stretching, to recognise domains corresponding to localised volcanic centres and to specific age ranges.

The Inverell radiometric data have confirmed the local subdivision of the Tertiary volcanic rocks in the Inverell area proposed by Duggan (1972). In particular, Duggan (1972) mapped an area of ultra-alkaline basalts about 5 km west of Inverell which are identifiable as an anomalous domain on the radiometric images (Figure 2 and unit Tb3 in Figure 3). The ultra-alkaline lithologies are characterised by very low to moderate potassium, very high thorium and low to high uranium responses.

A tentative attempt was undertaken to correlate geophysical characteristics with mapped areas of Tertiary volcaniclastic units. This attempt was of limited success, with the volcaniclastic rocks exhibiting geophysical characteristics ranging from basalt to basaltic soil. Areas of possible Tertiary volcaniclastic rocks (Txl, Tx2) are interpreted in Figure 3, but from limited field examination have generally proved to be basalt-derived soils. These areas are characterised by low to very low potassium, thorium and uranium concentrations, with a low to high magnetic intensity. The magnetic susceptibility of Tertiary volcaniclastic rocks is highly variable, with recordings ranging from $14 \times 10^{-5}$ to $920 \times 10^{-5}$ SI. This is similar to Tertiary basaltic lavas from the survey area, which range from $48 \times 10^{-5}$ to $696 \times 10^{-5}$ SI.

In many areas, basaltic outcrop and soil cover exhibit anomalous radiometric responses indicating strong weathering and regolith development. The most widespread anomaly type relates to areas of elevated thorium and uranium and depleted potassium concentrations (relative to the surrounding basaltic response). This is regarded as a regolith feature because weathering of basalt would result in depletion of potassium with retention and possible elevation of the initially low uranium and thorium concentrations. This anomaly type occupies areas ranging in size from several hundred square metres to many square kilometres. The anomalies are apparent in Figure 13 as very dark brown to black areas. They occur along the margins of the volcanic sheet in some areas, and in others occur throughout the basaltic domain. A belt of these anomalies occurs between the northern and southern outcropping masses of the Bundarra Supersuite.

Field examination of the anomalous response has resulted in the following observations:

- the anomaly occurs in a variety of geological settings, from deep basaltic soil to fresh, abundant basalt outcrop;
- no transported minerals or lithologies are apparently present at the surface;
- there is no apparent variation in land use between areas of anomalous and non-anomalous response; and
- the anomalous areas occupy a variety of landforms, from hilltops to alluvial flats.

Possible explanations tendered to explain the anomalous radiometric response include:

- the elevated uranium and thorium response represents transported accumulations of basalt-derived, uranium- and thorium-bearing mineral species resulting from prolonged weathering and erosion of the basaltic pile;
- the radiometric response is related to agricultural practices, landforms or vegetation;
- the anomaly results from introduced regolith minerals from non-basaltic sources, possible redistributed palaeochannels or unroofed Tertiary deep leads; or
- the anomalies represent primary lava or volcaniclastic compositional variants.

Although some individual anomalous areas may be explained by one or more of these suggestions, no single explanation for the anomalies covers all of the observed field data. The preliminary interpretation of the radiometric and field data presented here is inadequate to reach a final conclusion. Possibly the most likely cause of the anomalies is...
Figure 11  Mapped geology (Geology), ternary radiometric image (RGB), filtered TM1 RTP image (TM1 deep 15) and first vertical derivative reduced to pole (IVD) image of the Glen Innes area. The TM1 image has been filtered to enhance long wavelength (ie, deeply buried) features. Note the presence of stockwork mineral occurrences (Figure 3) above the eastern margin of the possible pluton (solid red area). For a key to letter symbols (abbreviated here), see Figure 3.
Figure 12  Mapped geology (Geology), ternary radiometric image (RGB), filtered TM1 RTP image (TM1deep 15) and the first vertical derivative reduced to pole (1VD) image of an area of Wandsworth Volcanic Group east of Ashford. The TM1 image has been filtered to enhance long wavelength (i.e. deeply buried) features. Note the possible pluton (shown as solid red colour) in the central top of the TM1deep 15 image. For a key to letter symbols (abbreviated here) and mineral occurrence symbols, see Figure 5.
a primary compositional difference. Further geochemical and petrographic study is warranted.

Four significant basaltic eruptive centres (Pecover 1993) are present within, or adjacent to, the Inverell survey area (Figure 13d): Swan Peak; Elsmore; Stony Knob; and Maybole (located outside of the survey area but shown in Figure 13d). Several significant plugs occur close to but outside the survey area and are not shown in Figure 13d. These include Balfours Peak and Gragin Peak to the west, and Spring Mountain and Waterloo Sugarloaf to the southeast.

The Elsmore centre exhibits no obvious geophysical characteristics. The area about the centre is associated with an apparent discrete tongue of volcanic rocks exhibiting similar geophysical characteristics to the western province of younger rocks (Figure 13d). However, the Elsmore area falls within the oldest age field of Sutherland, Pogson and Hollis (1993). This anomaly requires further investigation. The centre is not associated with an apparent magnetic anomaly.

The Swan Peak plug is one of several prominent plugs within the Swan Brook–Kings Plains vent complex (Pecover 1993). The plug is associated with a radiometric anomaly characterised by high potassium and thorium and high to very high uranium concentrations and exhibits no apparent magnetic anomaly (Figure 14). From a regional petrographic study, Barron (1987) regarded Swan Peak as phonolithic. This observation makes Swan Peak lithologically anomalous in the Tertiary volcanic rocks of the Inverell–Glen Innes region. The elevated radiometric response of Swan Peak is consistent with that expected for a typical phonolithic lithology with about 5% potassium.

Stony Knob (Figure 14) is a prominent hawaiite plug recognised by Pecover (1993) as part of the Swan Brook–Kings Plains vent complex. The plug exhibits no identifiable radiometric or magnetic anomaly in the Inverell geophysical data. Two elliptical radiometric features are apparent in the radiometric data (Figure 13). The features are at least 12 km long on their combined east–west axis. The interpreted geometry of the features indicates that an older, eastern feature has been succeeded by the western structure. Both lie in the headwaters of Kings Plains Creek. Pecover (1993) considered that coarse-grained teschenitic ankaramite and partly overlying alkali basalts at the headwaters of the western branch of Kings Plains Creek may represent an in-vent domal structure. The radiometric data support Pecover’s (1993) observation and suggest that a domal vent structure is present at the head of the western branch. The possible eastern, older dome has not previously been identified and may reflect greater complexity of the Swan Brook–Kings Plains vent complex than previously thought.

The Maybole Volcano (Pecover 1987) is an eroded, basaltic shield volcano southwest of Glen Innes, outside the Inverell survey area. The volcano is marked by radial drainage and a central breccia pipe. Dating of associated rock types and a zircon from the breccia has demonstrated an eruptive age of 33 to 38 Ma (Sutherland, Pogson & Hollis 1993). The Inverell radiometric data show the northwestern and western extent of the eruptive apron from the Maybole Volcano (Figure 13). Most sapphire occurrences in the region are associated with this apron, suggesting that the Maybole Volcano, and earlier maars along its flanks, represent the source of sapphire-bearing volcaniclastic rocks and lavas.

Interpretation of the Inverell magnetic data offers the possibility of inferring buried Tertiary deep lead channels. Some of the region’s most significant tin mineralisation is hosted by deep leads (Figure 3), including the Vegetable Creek deep lead near Emmaville (Henley et al. 2001a), the Gilgai–Tingha deep leads south of Inverell and the Elsmore–Newstead deep leads (Brown & Stroud 1997). Tin- and diamond-bearing deep leads occur throughout the Copeton area, and a sapphire-bearing deep lead is present near Elsmore. Although some deep leads have been unoofed, most preserved leads occur beneath basaltic sheets. Mineral-bearing palaeochannels may be buried many tens of metres beneath surface, requiring ground geophysics and follow-up drilling for evaluation.

Preliminary examination of the depth filtered TMI RTP data has demonstrated that some deep lead channels are recognisable. A well-developed sinuous palaeochannel has been identified about 25 km northwest of Glen Innes from the Vector Research Pty Ltd TMI shallow 15 image (Figure 15). This palaeochannel was not apparent in the unfiltered data. This image has enhanced short-wavelength features and excluded deeper, long-wavelength features. Further filtering and stretching of the imagery could result in the identification of other, potentially mineral-bearing deep leads.

**ENHANCED PROSPECTIVITY**

Interpretation of the Inverell airborne geophysical data has provided new insights into the origin and controls on mineralisation in the survey area. These include:

- the spatial relationship of a mafic dyke swarm to alluvial diamond occurrences at Copeton and Ashford;
- structural controls on mineralisation in the Conrad mine area and in the Webbs Consols–Webbs silver mine area;
- confirmation of the distribution of sapphires with volcanic rocks derived from the Maybole Volcano and associated maars, and with edifices associated with the Swan Brook–Kings Plains vent complex; and
- possible discovery of new deep leads, and enhancement of the geometry of known deep leads.

The association of dolerite dykes and alluvial diamonds has been recognised from the earliest periods of mining at Copeton (Sutherland 1996; Barron et al. 1996; Brown & Stroud 1997). Several xenocrysts of diamond were recovered from a
Figure 13 Interpretative maps of Tertiary geology (a, b, c) and RGB radiometric image (d) showing age range fields, major plugs, and petrology, whole-rock geochemistry sites classified into alkaline or tholeitic associations and major sapphire occurrences. The RGB image has been enhanced for subdivision of Tertiary units. Age range fields are after Sutherland, Fogson, and Hollic (1995). Petrology and geochemistry data are sourced from Department of Primary Industries databases. For a key to letter symbols see Figure 3.
Figure 14 Enhanced RGB image (top) and interpretative map (bottom) of the Kings Plains area. Interpreted radiometric lineaments indicate the presence of two elliptical structures, possibly concentric extrusive aprons about volcanic vents.
Figure 15: Filtered TMI RTP image by Vector Research Pty Ltd (top) and RGB radiometric image (bottom) of an interpreted deep lead channel beneath basalt. The previously unrecognised palaeochannel is about 25 km northwest of Glen Innes. The interpreted palaeochannel axis is shown as a blue line on the RGB image.
dolerite dyke at Copeton (Brown & Stroud 1997), confirming the relationship between at least some of the alluvial diamonds and local dolerite dykes. The Inverell magnetic images indicate the presence of a significant magnetic dyke swarm through the Copeton diamond field (Figure 10). The data also indicate several small plugs to the south of the major area of deep leads. Radiometric data indicate that these dykes and possible plugs do not cross out. Although the presence of the dykes was realised from their exposure in underground deep lead workings, the extent of the dyke swarm has not previously been realised. The dykes and possible plugs constitute a potential exploration target and warrant computer modelling and ground investigations.

A similar magnetic dyke swarm in the Ashford area (described above) also warrants investigation for diamonds. Several occurrences of diamond are reported from the Ashford–Gruman area in the general region about the 'Willowrie diorite' plug and dyke swarm. This area has not previously attracted diamond exploration.

The Conrad mine is developed on a structurally controlled hydrothermal vein (the Conrad lode. Brown & Stroud 1997) within the Gilgai Granite (Rliu) and Tingha Monzogranite (Rutg) (Figure 16). The vein has been worked discontinuously for more than 7.5 km along strike and to a depth of 300 m for a production of more than 175 000 t of ore. Mineralisation is polymetallic, with lead, zinc, silver, copper, tin and arsenic dominant. About 90 geochemically similar veins occur throughout the Gilgai Granite within about 5 km of the Conrad lode. The Inverell magnetic data show the trace of some of the structures controlling the mineralisation, and reveal some structures with no recorded mineralisation. Further enhancement and interpretation of the magnetic data could potentially identify structural targets suitable for exploration, including fractures parallel to the Conrad lode, fracture intersections, dilational jogs and extensions to known mineralised fractures.

A north-trending linear cluster of polymetallic silver-and base-metal-rich veins occurs to the south of the outcropping Mole Granite about eight kilometres west of Emmaville (Figures 2, 3 and 17). The veins include the Webbs Consols mine, which has produced more than 19 000 t of ore; the Tangoa prospect, with at least 30 000 t of 'pre-resource mineralisation'; and Webbs silver mine, which produced 22 t of arsenic, 9.3 t of copper and 5.5 t of silver (Brown & Stroud 1997; Henley et al. 2001a). Numerous smaller occurrences occur in this group — referred to as the Webbs mineralised line (Henley et al. 2001a). Interpretation of the Inverell magnetic data provides a framework for clarifying the structural setting of this mineralised group (Figure 17). An approximately north-trending group of fractures or hard-linked faults (ie, fault segments whose terminations have been bridged or linked by shorter cross fractures to form irregular fault traces which work kinematically as a single longer fault; Peacock & Sanderson 1991) is developed throughout a corridor about 12 km wide and at least 25 km long (Figure 17). A large proportion of the identified mineral occurrences in this corridor lie along structures identifiable from the magnetic data. Detailed analysis and further enhancement of the magnetic images should refine the structural model for this area and assist with exploration target generation in this under-explored, highly prospective zone.

The sapphire prospectivity of the region has been enhanced by the relatively precise definition of the extent of prospective volcanic rocks — as indicated by the radiometric data. These data provide a useful tool for excluding areas exhibiting unsuitable radiometric responses, such as the domain of western, younger volcanic rocks. Enhancing and stretching the radiometric images may result in the development of a ‘fingerprint’ useful in identifying exposures of basal, sapphire-bearing volcaniclastic rocks and thereby identifying new areas that may host economic alluvial concentrations of sapphires.

The extensive Tertiary basalt sheets throughout the region potentially obscure numerous deep leads, some of which may host economically significant accumulations of sapphire, diamond and/or tin. Numerous deep leads have been identified by mining in the Emmaville, Inverell and Elsmore regions (Brown & Stroud 1997; Henley et al. 2001a). However, little is known of the extent of these leads beyond the worked areas. Filtering of the data to remove very short wavelength and long wavelength features from the data may assist with enhancing images of unidentified deep leads, or previously undiscovered branches of exploited deep leads.

**CONCLUSIONS**

The Inverell high-resolution airborne geophysical data have assisted in the identification of lithological units and tectonic structures. Across most of the Inverell survey area the aeromagnetic and radiometric data have proved of value for the identification of geological boundaries; for recognising compositional variation within lithological or stratigraphic units; and for identifying buried intrusions, stratigraphic units and tectonic structures. The data have failed in some areas to identify previously mapped stratigraphic units and lithologies where there is no contrast in radiometric or magnetic characteristics between adjacent rock types.

Preliminary interpretation of the Inverell geophysical data has resulted in a range of significant conclusions that have contributed to improved understanding of the geology, geological history and prospectivity of the area.

- **The radiometric data distinguish the eastern and western domains of Tertiary volcanic rocks.** The domains correspond with older and younger compositional suites which have been recognised by previous workers, but whose areal extent has not been accurately constrained.
- **The westerly extent of the Late Permian Wandsworth Volcanic Group is interpreted to be associated with a series of**
Figure 16 Geological map (top) and IVD image (bottom) of the Conrad mine area. Major fractures interpreted from the magnetic image are overlain as dotted lines on the geological map. For the key to lithological letter symbols (abbreviated here) and mineral occurrence symbols, see Figure 3.
Figure 17 Geological map (top) and 1VU magnetic image (bottom) of the region about the Webbs Consols mine, Tangra prospect and Webbs silver mine. Fractures interpreted from the magnetic image are superimposed on the geology as dotted lines. For the key to lithological letter symbols (abbreviated here) and mineral occurrence symbols, see Figure 3.
previously unrecognised, interpreted granite cupolas which have been progressively emplaced from north to south.

- Major subdivisions within the Wandsworth Volcanic Group are confirmed and additional possible subdivisions are possible, particularly in the region associated with the cupolas.

- The granitic Bundarra Supersuite is divisible into two major, previously unrecognised variants.

- The existence of the ‘Willowrie diorite’ plug has been established, and interpreted to be related to a radial mafic dyke swarm.

- Numerous unmapped mafic to intermediate dykes and several plugs are present in the vicinity of the Copeton diamond field.

- Proprietary filtering of the magnetic data has allowed interpretation of a number of small, shallow (buried) granitoid plutons.

- Previously unidentifiable folds and bedding trends have been identified in the Texas beds.

- Structural controls on the Conrad lode south of Inverell and on the Webbs silver mine, Webbs Consols mine and Tangoa prospects near Emmaville have been confirmed, and additional structures interpreted in both areas.

- A broad belt of fracturing or faulting is developed above the buried (upper) surface of the Mole Granite.

- Tertiary and post-Tertiary weathering effects and variable regolith development are apparent throughout the area.

The Inverell geophysical data will prove an invaluable tool for exploration and research studies in the region. Radiometric data will assist in the identification and differentiation of surface geology. Magnetic data will complement the usefulness of the radiometric data and will assist with the identification of concealed intrusions and structures.

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REFERENCES


IYER H.M. 1984. Geophysical evidence for the locations, shapes and sizes, and internal structures of magma chambers beneath regions of Quaternary volcanism. Royal Society of London, Philosophical Transactions A310, 473–510.


