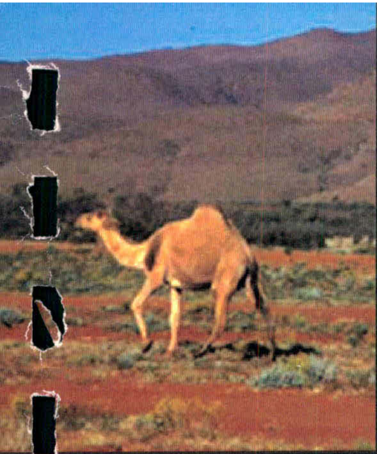

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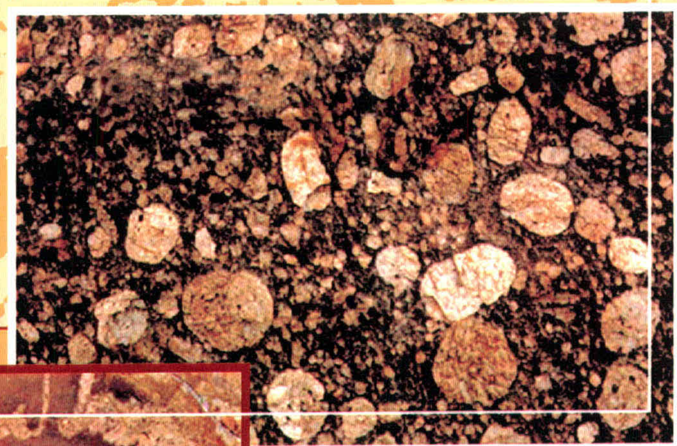

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The traditional owners of the Papunya area are thanked for permitting access to the western Arunta.

Abstract

Field investigations by Geoscience Australia in late 2000, as part of a National Geoscience Agreement with the Northern Territory Geological Survey (NTGS), evaluated the geological setting of Proterozoic mafic-ultramafic intrusions in the Arunta Province of central Australia. The major aims of this regional study were to constrain the various mafic-ultramafic magmatic systems within the event chronology of the Arunta Province, and to provide a geoscientific framework for assessing the prospectivity and resource potential of the intrusions.

This report summarises the field relationships and mineralisation features of the major mafic-ultramafic intrusions in the Arunta Province. They form large homogeneous gabbroic bodies, folded high-level mafic sills, steeply dipping amphibolite sheets and relatively undeformed ultramafic plugs with alkaline and tholeiitic affinities. Metamorphic grades range from granulite to sub-amphibolite facies. Chilled and contaminated margins and net-vein complexes resulting from the commingling of mafic and felsic magmas indicate that most intrusions crystallised *in situ* and were not tectonically emplaced.

The intrusions were subdivided into western, central and eastern groups on the basis of lithology, metamorphic-structural history, degree of fractionation and limited geochronology. The field investigations described here and preliminary geochemical data (see Hoatson 2001) indicate that the western and central intrusions have some potential for Ni-Cu-Co sulphide deposits, whereas the eastern intrusions appear to be more prospective for platinum-group element (PGE) mineralisation. The recent emerging evidence that the eastern Arunta is prospective for PGE mineralisation is supported by exploration companies defining anomalous PGE-Cu-Au concentrations in hydrothermal veins hosted by the Riddock Amphibolite and in magnetite layers of the Attutra Metagabbro. These results, for the first time, highlight geographical differences in the mineral prospectivity of mafic-ultramafic rocks in the Arunta Province.

Introduction, methods of study and nomenclature

The Arunta Province has historically been regarded as having low potential for mineral deposits associated with mafic-ultramafic rocks, because of its high metamorphic grade and protracted tectonothermal history spanning more than 1500 Ma (Collins 2000). Intermittent phases of exploration during the last three decades have been restricted to a few mafic-ultramafic intrusions. This is in contrast to other Proterozoic provinces in Australia (Halls Creek Orogen, Albany-Fraser Orogen, Musgrave Block), where more extensive exploration of mafic-ultramafic intrusions has defined a range of magmatic and hydrothermal deposits of PGEs, Cr, Ni, Cu, Co, Ti, V, and Au (Hoatson & Blake 2000). Preliminary airborne geophysical (magnetics and/or electromagnetics) and geochemical investigations by exploration companies have been carried out on some large mafic bodies in the central (e.g. Mount Hay) and western Arunta (Andrew Young Hills) and a few small ultramafic and alkaline bodies in the eastern Arunta (Mordor). In most cases, detailed follow up testing of geophysical-geochemical anomalies by drilling was not carried out. The Mordor Igneous Complex is one of the few intrusions that has been relatively well investigated during a number of exploration programs that involved satellite imagery, airborne and ground geophysics, detailed mapping, diamond drilling and rock geochemistry.

Documented precious-metal mineralisation associated with the Arunta intrusions is sparse with some occurrences restricted to mafic rocks in the eastern Arunta. Hydrothermal felsic veins containing local high concentrations of PGEs occur in altered variants of the Riddock Amphibolite, and minor concentrations of PGEs have been reported in Ti-V-bearing magnetite layers in the upper parts of the Attutra Metagabbro. Other styles of mineralisation, such as PGEs hosted by chromitite layers and basal accumulations of Ni-Cu-Co sulphides have not been recorded. In general, most intrusions in the Arunta Province have not been thoroughly assessed for orthomagmatic or hydrothermal mineralisation, particularly at depth or under shallow cover.

Despite comprehensive government mapping programs undertaken in the Arunta Province from the 1960s to the mid-1990s, the geological setting and economic potential of the Proterozoic mafic-ultramafic intrusions are poorly known. In late 2000, Geoscience Australia, in collaboration with the Northern Territory Geological Survey (NTGS), commenced field investigations of the major occurrences of mafic and ultramafic rocks in the Arunta Province. The major objectives of the regional study were to constrain the various mafic-ultramafic magmatic systems within the event chronology of the Arunta Province, and to assess the prospectivity and resource potential of the intrusions. Field work was undertaken from August to October 2000. Sixteen mafic, ultramafic, and alkaline bodies were sampled from a 150 km north-south by 600 km east-west rectangular area covering the central and northern parts of the Arunta Province (Fig. 1). This area encompasses the MOUNT DOREEN[1] (Young et al. 1996), MOUNT LIEBIG (Wells et al. 1968), NAPPERBY (Stewart et al. 1982), HERMANNSBURG (Shaw et al. 1995), ALCOOTA (Shaw et al. 1975), ALICE SPRINGS (Shaw et al. 1983) and HUCKITTA (Freeman 1986a) sheets. The collection of samples along type traverses across each body was facilitated by geophysical data and Landsat-5 Thematic Mapper imagery. In addition to the mafic-ultramafic intrusions themselves, co-mingled felsic rocks, cross-cutting felsic intrusions, dolerite dykes and country rocks were sampled for U-Pb zircon and baddeleyite geochronology.

Sample traverses across the mafic-ultramafic intrusions were plotted on vertical colour (1:25 000 scale) and RC9 black/white aerial photographs (1:80 000 scale). Open-file company reports from the NTGS and published scientific papers were used in conjunction with geological map commentaries and accompanying maps at 1:250 000 (listed above) and 1:100 000 scales [three special sheets: Geology of the Arltunga-Harts Range Region (Shaw et al. 1984b), Geology of the Reynolds Range Region (Stewart et al. 1981), Geology of the Strangways Range Region (Shaw et al. 1984c)]. Various airborne geophysical and remote-sensing techniques, such as gradient-enhanced magnetics, gamma-ray spectrometrics and Landsat-5 Thematic Mapper imagery greatly assisted sample selection. Aeromagnetics in association with magnetic susceptibility data of surface samples were used to determine the regional extent, geometry and younging-fractionation directions (due to the presence of primary magnetite) of evolved mafic bodies (Andrew Young Hills, Papunya gabbro, Kanandra Granulite). Composite gamma-ray spectrometric images defined the size and shape of large mafic granulite bodies (Mount Chapple, Mount Hay) where low concentrations of K, Th and U in the mafic rocks (expressed as dark tones) contrast markedly with the stronger spectrometric signatures of interlayered felsic gneisses, metasedimentary and granitic country rocks. Landsat-5 Thematic Mapper imagery (bands 4, 5, 7; 5/7, 5/3, 5; various principal components) was helpful in differentiating major rock groups of contrasting composition (Anburla Anorthosite, Riddock Amphibolite) and in providing

[1] 1:250 000 sheet names throughout this report are printed in capitals to avoid confusion with identical place names and to distinguish them from 1:100 000 sheet names.

information on structural features. The Landsat-5 Thematic Mapper imagery also depicted regions of alteration, geobotanical signatures (black organic coatings on rocks of specific composition) and cultural-natural influences (fireburns). Landsat-5 Thematic Mapper imagery and gamma-ray spectrometrics were generally the most useful techniques for assisting the ground sampling.

One hundred and sixty mafic and ultramafic rock samples (Appendix 1) were collected for petrographic and geochemical studies. Samples were obtained at 50 to 500 m spacing across the bodies to determine cumulus crystallisation sequences and stratigraphic levels of S saturation and, where needed, to establish geochemically the younging direction of rock sequences. Similar strategies of geochemical sections across mafic-ultramafic bodies have been successfully used in other Precambrian terrains, such as the Pilbara Craton (Hoatson et al. 1992) and Halls Creek Orogen (Hoatson & Blake 2000), Western Australia. Locations for all samples are indicated in Appendix 1 and on the geological maps in this report. The ten-digit sample numbers comprise four digits for the year (2000), two digits for the project code (08) and four digits for the sample (1001 to 1160). Eleven major elements and 43 trace elements were determined by X-ray fluorescence spectrometry (XRFS) and inductively coupled plasma-mass spectrometry (ICP–MS) at Geoscience Australia in Canberra. Analytical procedures and detection limits for these techniques are described in Appendix 1 of Hoatson & Blake (2000). On the basis of geochemistry and petrography, 100 samples were selected for Pt, Pd and Au analysis by fire assay, lead concentration, ICP–MS, at ANALABS in Perth. Results of the petrography and whole-rock geochemistry will be presented in future reports.

High-Zr mafic granulite, fractionated gabbros and associated felsic rocks were collected from 12 bodies throughout the Arunta Province for U-Pb zircon and baddeleyite geochronology. The 27 geochronology samples have ten-digit numbers that are prefixed by 20000812 (Appendix 2). Prior to bulk sampling, small (100–200 g) representative rock samples were submitted to the Geoscience Australia laboratories for Zr analysis to target those samples potentially containing zircon or baddeleyite. Similar geochronological programs that successfully used Zr geochemistry as a guide for sampling mafic rocks were undertaken in the East Kimberleys (Page & Hoatson 2000). Anorthositic rocks in the upper parts of some Arunta bodies (Anburla Anorthosite, Harry Anorthositic Gabbro) contained less than 10 ppm Zr and were clearly unsuitable for U-Pb geochronology. In contrast, fractionated gabbro and mafic granulite for most bodies often had relatively high abundances of Zr (80 to 220 ppm). Large (~ 30 kg) samples of these high-Zr mafic rocks were obtained by sledge hammer and drilling. Homogeneous rocks with no felsic sweats or veins were carefully selected and weathering skins removed in the field. Zircons of variable abundance and morphology have been obtained from 12 mafic samples that were crushed in the Geoscience Australia geochronology laboratories. Crushed 10 kg splits for 11 of the 12 samples provided enough zircon grains for analysis. The only sample that did not contain a statistically meaningful amount of zircon grains was from the Johannsen Metagabbro (7 grains from 20 kg sample). The geochronological data for the Arunta mafic rocks will be reported elsewhere.

Locations of sample sites were recorded using a Global Positioning System (GPS) instrument (accuracy of up to 80 m) as well as the aerial photographs. WGS 84 (similar co-ordinates to GDA 94) geoid co-ordinates are used for all samples in this report. Various components of the field data are available for purchase in hard-copy and digital formats from Geoscience Australia's geological databases, including structural and field data (OZROX), geochronology (OZCHRON) and whole-rock geochemistry (OZCHEM).

Igneous rocks were classified using the traditional classification of plutonic rocks based on modal mineral contents as recommended by the IUGS Subcommission on the Systematics of Igneous Rocks (Streckeisen 1973, 1976). Although most igneous rocks reported here are metamorphosed, the prefix ‘meta’ (e.g. meta-anorthosite) has been deleted for convenience. Names of metamorphic rocks are based on criteria applicable in the field—mineral composition and texture (see Appendix in Shaw et al. 1984a). The mineral assemblages of metamorphic rocks are arranged in ascending modal abundance.

Geological setting and classification

The mafic-ultramafic intrusions of the Arunta Province (Fig. 1, Table 1) have been provisionally subdivided into three broad geographical groups (western, central and eastern) on the basis of lithology, metamorphic-structural history, degree of fractionation and limited geochronology. This subdivision will be refined when further geochronology-geochemical data become available. Mafic intrusions generally displaying tholeiitic fractionation trends dominate throughout the province, with some small ultramafic and alkaline bodies restricted to the western and eastern Arunta. The well-preserved intrusions form large homogeneous gabbroic bodies, folded high-level mafic sills, steeply dipping amphibolite sheets and relatively undeformed ultramafic plugs with alkaline and tholeiitic affinities. Metamorphic grades range from granulite to sub-amphibolite facies. Chilled and contaminated margins and net-vein complexes resulting from the commingling of mafic and felsic magmas indicate that most intrusions crystallised *in situ* and were not tectonically emplaced. With the exception of the Riddock Amphibolite and possibly the Kanandra Granulite, most bodies investigated are considered to be of intrusive origin. The identification of protoliths to large mafic granulite bodes (e.g. Mount Hay and Mount Chapple) is made difficult by the predominance of fine-grained recrystallised rock types, scarcity of preserved primary textures, and poor exposures of contact relationships with country rocks. In contrast to intrusions from other Proterozoic provinces (East Kimberleys, Musgrave Block), the Arunta bodies are generally more homogeneous in composition and are poorly layered. Moreover, olivine-dominant ultramafic rocks such as peridotite and dunite are rare, pyroxenites are restricted to a few small bodies, and chromitites have not been documented.

Intrusions of the western group (Andrew Young Hills, Papunya gabbro, Papunya ultramafic, South Papunya gabbro, West Papunya gabbro) are generally small, evolved bodies that display variable amounts of crustal contamination. The Andrew Young Hills intrusion is a high-level gabbronorite-tonalite body strongly contaminated with felsic crustal material and enriched in S, and the Papunya ultramafic intrusion is an ovoid plagioclase pyroxenite body—one of the few ultramafic bodies in the Arunta Province. Recent mapping by the NTGS suggests that most intrusions of the western group are coeval with the ~1635±9 Ma Andrew Young Igneous Complex (Young et al. 1995a, b; Edgoose et al. 2001). Intrusions of the central group (Anburla Anorthosite, Enbra Granulite, Harry Anorthositic Gabbro, Johannsen Metagabbro, Mount Chapple Metamorphics, Mount Hay Granulite, Mount Stafford dolerite) are typically medium to large homogeneous mafic-felsic bodies emplaced before the main granulite events that affected the Mount Hay and Strangways regions at ~1780–1760 Ma and ~1730–1720 Ma (Pietsch 2001). The mafic granulites locally contain well-preserved medium-grained 'intergranular' textures, rare compositional layering and mafic pillows associated with hybrid felsic rocks that indicate the protoliths were probably homogeneous sequences of gabbros that commingled with felsic magmas. Relatively thin anorthositic sequences (Anburla Anorthosite, Harry Anorthositic Gabbro) are spatially associated with the Mount Hay Granulite and Johannsen Metagabbro. Stacked sequences of mafic dykes and sills (Mount Stafford dolerite and Johannsen Metagabbro) represent the smallest bodies in the central group. The eastern group comprises both pre-orogenic (Attutra Metagabbro, Kanandra Granulite, Riddock Amphibolite) and relatively undeformed (Mordor Complex) intrusions of variable form and composition. Weakly recrystallised gabbro and pyroxenite host thin magnetite-ilmenite lenses in the Attutra Metagabbro, folded concordant sheets of amphibolite up to 70 km long characterise the Riddock Amphibolite, and the Mordor Complex consists of a cluster of small undeformed differentiated alkaline plugs emplaced in the Mesoproterozoic.

The following section summarises the major field relationships and mineralisation features of the sixteen intrusions investigated during this field study. The intrusions are described in alphabetical order within the western, central and eastern groups.

Western group of intrusions

Andrew Young Hills (Figs 1 & 2)

Centre of exposure and collection of samples. MOUNT DOREEN (SF 52–12): Gurner (5052) at AMG ~^{6}96000 and ^{74}75000. The Andrew Young Hills intrusion (equivalent to the Andrew Young Igneous Complex of Young et al 1995a, but excluding the felsic igneous rock component) south of the Ngalia Basin in the west Arunta is the most westerly body investigated in this study. Samples were collected throughout the intrusion (Fig. 2).

Age. U-Pb zircon ages of ~1625 Ma for gabbronorite (C.M. Fanning, unpublished data in Young et al. 1995a, b) and 1635±9 Ma for a coarse-grained granite body that is hosted by, and considered to be to coeval to, a gabbronorite (Young et al. 1995b). Results of U-Pb zircon geochronology of gabbronorite (115 ppm Zr) from this program (Appendix 2) will be reported elsewhere.

Form, structure and areal extent. A group of five prominent gabbro hills that rise abruptly above a sand plain west of Lake Bennett constitute the Andrew Young Hills. The hills reach a maximum height of 642 m above sea level and cover a total area of 4.5 by 6.5 km. They have a regional arcuate alignment that swings from east-west to south-southeast towards the east. This alignment is parallel to ?moderate- to steeply dipping macroscopic layering trends in the mafic rocks that are evident on aerial photographs and aeromagnetics, but are not readily seen on the ground. The exposed part of the intrusion occurs at the northern end of a large east-trending arcuate magnetic high.

Interpretation of aeromagnetics by A. Meixner (Geoscience Australia):

Preliminary modelling of the Andrew Young Hills magnetic anomaly and adjacent anomalies has been carried out using point-located aeromagnetic line data (1998 NTGS survey) and magnetic susceptibility data of surface samples. The magnetic signature of the intrusion comprises high-amplitude (up to 2000 nT) curvilinear anomalies that generally strike east-west. The subsurface extent far exceeds its outcrop extent and measures approximately 32 km east-west and 13 km north-south. The structure is interpreted as a broad inclined synform, with the fold axis plunging to the south. Southerly dips of the magnetic units range through steep to vertical on the western side of the intrusion, shallowing to approximately 30° in the centre, then steeping again to approximately 80° on the eastern side of the body. Magnetic susceptibilities range from 20 000–80 000 (SI (10^{-6})) for the bulk of the body with extreme susceptibilities up to 200 000 (SI (10^{-6})) for the maximum amplitude anomalies. Only a small portion of the body crops out, the rest is buried by surficial sediments that are estimated to be up to 150 m thick.

There are two prominent magnetic high regions, on the southern edge of MOUNT DOREEN, with similar magnetic character to that produced by the Andrew Young Hills mafic intrusion. These anomalous regions are interpreted as being produced by similar mafic intrusive bodies to the Andrew Young Hills intrusion. One body, approximately 15 km to the southeast, with dimensions of 9 km east-west and 6 km north-south, lies less than 200 m from the surface. The other body, approximately 15 km to the southwest, with near surface dimensions of 18 km east-west and 13 km north-south, lies at less than 150 m depth below the surface. Further magnetic anomalies, which extend to the southwest into MOUNT RENNIE, are of similar character and may also be caused by similar rock types to the Andrew Young Hills body.

Thickness. Unknown. Potentially thick (> 5 km).

Stratigraphy and major rock types. Consists of a homogeneous mafic sequence of fine- to medium-grained gabbronorite, magnetite gabbronorite, biotite gabbronorite, gabbro, hornblende tonalite and diorite. The rocks contain well-preserved igneous features (mafic pillows, commingling of magmas, zoned xenocrysts), are not foliated or strongly recrystallised and are of ?sub-amphibolite metamorphic facies (Fig. 3 A–D). Contacts between rock types tend to be diffuse and gradational, and the absence of distinctive marker layers and compositional layering prohibits subdivision of the mafic rocks. The most marked variation relates to the degree of felsic contamination the magma(s) experienced during ascent into the crust. The patchy contamination ranges from uncontaminated gabbronorite, to biotite gabbronorite and biotite tonalite hosting small (up to 5 mm) isolated resorbed quartz xenocrysts, to more hybrid dioritic and tonalitic variants containing thin discontinuous trains of quartz xenocrysts and clusters of large (up to 3 cm) resorbed alkali feldspar xenocrysts. The later xenocrysts are often zoned from a core of alkali feldspar to a thinner rim comprising fine myrmekitic intergrowths of quartz and feldspar.

Magnetic susceptibility of rock types (SI (10^{-6})). Moderate to high: gabbros (16 000–45 000).

Field relationships. The gabbroic rocks are not seen in contact with country rocks although high-grade migmatitic gneisses of the Lander Rock beds are shown on MOUNT DOREEN to the west and south of the intrusion. Granite, pegmatite and aplite veins in the gabbros are generally aligned parallel to the regional arcuate trend of the intrusion implying some structural control on the emplacement of the dykes. Leucocratic biotite granite and biotite-hornblende granite locally form large (up to 20 by 80 m) isolated blocks or smaller irregular pods within gabbro, particularly in the two easternmost hills. The larger blocks, which are generally undeformed and have sharp contacts with the gabbro, may be rafts of country rock detached from the ?roof of the intrusion. Mafic pillows with intricate liquid-liquid-type contacts and net-vein commingling features characterise some of the smaller granite pods (Young et al. 1995a). Such mixing features, which generally indicate coeval mafic and felsic magmas or partial remelting of pre-existing felsic rocks by hotter mafic magmas, are typical of many other Australian Proterozoic and Phanerozoic igneous provinces (Blake & Hoatson 1993).

Mineralisation. Unknown.

Other comments. The exposed part of the Andrew Young Hills intrusion represents a high-level (possibly near the roof zone) fractionated gabbronorite-tonalite body that was strongly contaminated with felsic crustal material. Lower stratigraphic levels that are concealed by alluvial cover have potential for accumulations of massive and disseminated Ni-Cu-Co sulphides near the basal contact and/or within the feeder conduit. Airborne electromagnetics, gravity and drilling could be used to explore these prospective environments.

Reference(s). Young et al. (1995a, b).

Papunya gabbro[2] (Figs 1 & 4)

Centre of exposure and collection of samples. MOUNT LIEBIG (SF 52–16): Haast Bluff (5251) at AMG ~^{7}76000 and ^{74}23300. Samples were collected along a northerly traverse near the centre of the intrusion (Fig. 4).

Age. Correlated with the ~1625 Ma Andrew Young Hills intrusion. Results of U-Pb zircon geochronology of gabbro (221 ppm Zr) from this program (Appendix 2) will be reported elsewhere.

Form, structure and areal extent. East-trending elongated mafic body that forms low rugged deeply incised hills over an area of 0.5 by 3 km. The general contact regions of this sill-like body with country rock gneisses are exposed on all margins except for the northwestern side, which is covered by shallow alluvium. A foliation in the gabbros defined by aligned prismatic pyroxene and magnetite grains generally dips moderately to the north. Younging directions for the body are not clear, but increasing fractionation trends to the north are implied by the consistently increasing magnetic susceptibilities of the gabbros (due to magnetite) towards the north (1150→6700→12 000→24 000→71 600 SI [10^{-6}]). This is consistent with rare primitive plagioclase pyroxenite forming small conical hills near the southern central contact.

Thickness. 400 m.

Stratigraphy and major rock types. Comprises a homogeneous mafic sequence of fine-grained recrystallised gabbro, magnetite gabbro, gabbronorite, amphibolite and rare plagioclase pyroxenite. The gabbros are not compositionally layered, generally foliated and of ?upper amphibolite to granulite metamorphic facies (to be confirmed by later petrographic studies).

Magnetic susceptibility of rock types (SI (10^{-6})). Very variable, ranging from low to high: gabbros (1150–71 600). The most magnetic rock (2000081133) sampled in this study is a chilled magnetite gabbro from the northern central contact of the intrusion.

Field relationships. The intrusion appears to be concordant with enclosing foliated felsic gneiss, quartzofeldspathic biotite migmatite, gneissic granite, biotite schist and biotite-garnet-sillimanite schist interpreted by the NTGS to be part of the ?1680–1640 Ma Yaya Metamorphics. Chilled gabbros along parts of the northern and southern contacts indicate that the intrusion has not been tectonically emplaced. Large irregular discontinuous sheets of banded gneissic granite, aplitic

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[2] Intrusion names marked thus are informal only.

granite and other felsic rocks are intercalated with gabbros in the central part of the intrusion, whereas smaller felsic bodies are abundant at the eastern and western ends of the intrusion. Individual sheets are up to 600 m long and 80 m wide. They rapidly thicken, thin, and anastomose parallel to the margins of the intrusion. The felsic sheets may represent a stacked sequence of granitic veins emplaced into the lower parts of the intrusion prior to deformation, or they are deformed screens/rafts derived from the country rocks. Dolerite, pegmatite, quartz, aplite and aplitic granite dykes also cut the gabbros.

Mineralisation. Unknown.

Other comments. The Papunya gabbro intrusion may represent the upper, more fractionated part of the nearby Papunya ultramafic intrusion.

Papunya ultramafic[2] (Figs 1 & 4)

Centre of exposure and collection of samples. MOUNT LIEBIG (SF 52–16): Haast Bluff (5251) at AMG ~^{7}76000 and ^{74}21800. Samples were collected throughout the intrusion (Fig. 4).

Age. Correlated with the ~1625 Ma Andrew Young Hills intrusion. Results of U-Pb zircon geochronology of plagioclase websterite (43 ppm Zr) from this program (Appendix 2) will be reported elsewhere.

Form, structure and areal extent. This poorly-exposed recessive ovoid pyroxenite body located 1.5 km south of the Papunya gabbro intrusion is one of the few ultramafic intrusions, *sensu stricto*, in the west Arunta Province. The east-northeast-trending tear-drop-shaped body covers an area of 0.8 by 1.8 km. The margins of the intrusion appear to be concordant with the foliated country rocks and the intrusion has a similar ovoid geometry to the nearby West Papunya gabbro body. Rubbly outcrop is largely restricted to a 10 m-high northeast-trending pyroxenite ridge at the eastern end of the intrusion and along parts of the northern contact of the intrusion. Rare isolated mafic rocks and granite also crop out on a colluvium and black soil plain that covers the western two-thirds of the intrusion. The western extent of the intrusion is defined by an abrupt break in topographic relief from this plain to the ridge-forming country rocks and a botanical anomaly characterised by different species of low- to medium-height grasses. Massive milky white carbonate alteration in gullies traversing the ridge-forming country rocks also defines the northern contact of the intrusion. The most primitive exposed part of the intrusion correlates with the pyroxenites at the eastern end of the intrusion, thus the intrusion appears to young to the west.

Thickness. ?1 km.

Stratigraphy and major rock types. Dominant rocks are weakly recrystallised fine- to medium-grained massive plagioclase websterite and websterite with minor gabbronorite and gabbro. Pyroxenites are dominant in the eastern and northern parts of the intrusion, whereas rare gabbro occurs in the west. No peridotites or olivine-bearing gabbros were found in the intrusion; this is characteristic of most Arunta intrusions. The pyroxenite ridge consists of unaltered and uralitised pyroxenite, and chilled plagioclase websterite occurs at the northeastern contact of this ridge with the felsic country rocks. The southeastern side of the pyroxenite ridge contains a thin (5 m wide) mafic zone of gabbro, pegmatitic gabbro and plagioclase pyroxenite. These rocks show limited lateral continuity, rapid changes in grainsize and contain traces of fine-grained disseminated sulphides and limonite spots after oxidised sulphides. The basal contact of these rocks with the country rocks is masked by alluvium and colluvium.

Magnetic susceptibility of rock types (SI (10^{-6})). Low: pyroxenites (280–480).

Field relationships. Country rocks are mainly quartzose metasediment, psammite, metapelite and felsic gneiss interpreted by the NTGS to be part of the ?1680–1640 Ma Yaya Metamorphics. A regional west-northwest-trending fault separates these rocks from the higher-grade gneissic country rocks of the Papunya gabbro intrusion farther north. The general concordant character of the Papunya ultramafic body is disrupted in the northeastern corner by a northeast-trending sinistral fault that has truncated the pyroxenite ridge and displaced a thin slice of metasediments towards the centre of the intrusion. Discontinuous granite veins and felsic dykes are particularly common in the northern half of the alluvial plain covering the western part of the intrusion.

Mineralisation. Unknown.

Other comments. The presence of evolved mafic rocks near the basal contact is a feature common to many Proterozoic and Archaean mafic-ultramafic intrusions (Hoatson et al. 1992; Hoatson & Blake 2000). They often form a thin border series discordant to the overlying more primitive ultramafic sequences, and their formation is generally related to contamination and/or supercooling of the primitive magma with the country rocks. Significantly, the marginal gabbroic rocks sometimes host economic concentrations of disseminated and massive Ni-Cu-Co sulphides. If the Papunya ultramafic intrusion is S saturated, then the unexposed basal contact region east of the pyroxenite ridge is prospective for base-metal sulphides. Favourable environments that concentrate massive sulphides, such as depressions and fault embayments along this contact, particularly those below the thickest sequence of mafic-ultramafic rocks, and feeder conduits should be investigated by geophysics and drilling.

South Papunya gabbro[2] (Figs 1 & 5)

Centre of exposure and collection of samples. MOUNT LIEBIG (SF 52–16): Haast Bluff (5251) at AMG ~^{7}89000 and ^{74}20000. Samples were collected along a northwest-trending traverse near the centre of the intrusion (Fig. 5).

Age. Results of U-Pb zircon geochronology of gabbro (35 ppm Zr) from this program (Appendix 2) will be reported elsewhere.

Form, structure and areal extent. Northeast-trending elongated metagabbroic body that covers an area of 1.0 by 3.8 km. This well-exposed intrusion on the northwestern side of Beantree Creek consists of a cluster of steep conical hills separated by recessive sheets and veins of granite. A number of small isolated gabbroic hills separated by shallow alluvium characterise the northeastern end of the body. The ?shallow-dipping metagabbroic sequence forms dark massive units that cap the tops of the hills. The intrusion occurs along a regional contact between deformed granite and leucogranite to the northwest, and felsic gneiss, quartzofeldspathic migmatite, and metapelite of the ?1680–1640 Ma Yaya Metamorphics to the southeast. The southeastern margin region is largely covered by alluvium.

Thickness. ?0.5 km.

Stratigraphy and major rock types. Composed of a homogeneous sequence of fine- to medium-grained gabbros of ?granulite metamorphic facies. In the northern half of the intrusion, a variety of contaminated hybrid variants comprising biotite gabbro, quartz gabbro and biotite tonalite occur near the contacts of the gabbros and large irregular bodies of leucocratic biotite granite (Fig. 3 E–F). The hybrid rocks contain small (less than 1 cm) squat feldspar xenocrysts that become more abundant towards the granite contacts, and thin irregular granitic veins and veinlets. Similar hybridisation, commingling and net-veining features are associated with granite bodies and lower-grade gabbros in the Andrew Young Hills intrusion.

Magnetic susceptibility of rock types (SI (10^{-6})). Low: gabbros (260–340).

Field relationships. Most contacts are covered by red sand and alluvium associated with a system of creeks that encircles most of the intrusion. The gabbros become progressively more foliated and sheared towards the northwestern contact of the intrusion with the deformed country rock granites. The foliation dips moderately towards the northwest and parallels both the margin of the intrusion and deformational structures in the country rock granites. Irregular bodies of leucogranite and spatially associated felsic dykes are localised along east-northeast-trending structures in the northern half of the intrusion. East-trending dolerite dykes cut the central part of the intrusion and the country rock granites.

Mineralisation. Unknown. Trace disseminated sulphides (mainly ?metamorphic pyrite) occur in gabbro from the northern part of the intrusion.

West Papunya gabbro[2] (Figs 1 & 6)

Centre of exposure and collection of samples. MOUNT LIEBIG (SF 52–16): Haast Bluff (5251) at AMG ~^{7}63300 and ^{74}25000. Samples were collected throughout the intrusion (Fig. 6).

Age. Correlated with the ~1625 Ma Andrew Young Hills intrusion.

Form, structure and areal extent. Small north-trending ovoid mafic body covering an area of 260 by 400 m. This well-exposed intrusion forms a slightly raised flat-topped hill covered with rubbly outcrop. The attitude of the sill-like body cannot be determined due to the absence of internal structures, but the consistent increase of magnetic susceptibility values towards the west (380→800→3280→3400 SI [10^{-6}]) in response to increasing amounts of magnetite in the gabbros implies a younging direction to the west. The foliation of the felsic gneissic country rocks, which wraps around the sill, has moderate dips of 30 to 60° towards the west, southwest and northwest. The intrusion resembles a concordant 'boudin pip' within the foliated country rocks. The original contact relationships (e.g. chilled contacts) are preserved in the 'pressure shadows' on the north side of the boudin.

Thickness. ?200 m.

Stratigraphy and major rock types. Homogeneous mafic sequence of fine- to medium-grained gabbronorite and gabbro.

Magnetic susceptibility of rock types (SI (10^{-6})). Low: gabbros (380–3400).

Field relationships. A 2 to 5 m-wide chilled zone of fine-grained gabbro and doleritic gabbro defines parts of the northern contact between the intrusion and felsic gneisses interpreted by the NTGS to be part of the ?1680–1640 Ma Yaya Metamorphics. The chilled margin—a common feature of the Papunya intrusions—and the occurrence of stepped contacts and fine-grained gabbros containing xenoliths of gneiss along the western margin support an intrusive rather than a tectonic emplacement for the intrusion.

Mineralisation. Unknown.

Other comments. The West Papunya gabbro intrusion is too small to have any economic significance, but it highlights the orthopyroxene-bearing compositions of the mafic rocks (gabbronorite rather than gabbro) that characterise the intrusions of the Papunya district. It has been tentatively correlated in age with the Andrew Young Hills, Papunya gabbro, and Papunya ultramafic intrusions.

Central group of intrusions

Anburla Anorthosite (Figs 1, 14 & 15)

Centre of exposure and collection of samples. HERMANNSBURG (SF 53–13): Anburla (5551) at AMG ~^{3}13000 and ^{74}07000. Samples were collected from the northern end of the north-northeast-trending traverse east of Mount Hay (Fig. 14) and from the Hamilton Downs Homestead body.

Age. Palaeoproterozoic.

Form, structure and areal extent. Three separate bodies are equidistant along a 38 km-long belt that extends southeast from the northeastern side of the Mount Hay Granulite intrusion to near the Redbank Thrust Zone. The largest body, east-southeast of Valley Bore, forms a series of parallel strike ridges covering an area of 1 by 10 km, the second is a 1 by 1.5 km ovoid body east of Hamilton Downs Homestead, and the most southeastern occurrence is a 1 by 5 km arcuate body east of Blackhill Dam (not investigated due to denial of access). The body near Valley Bore is a laterally continuous sheet that has moderate to steep (45^0 to 80^0) dips towards the south-southwest. Large smooth spheroidal boulders (up to 3 m across) and rubbly outcrop typically flanks the slopes of low rises and steep-sided hills (Fig. 9 A).

Thickness. < 1 km.

Stratigraphy and major rock types. Rock types near Valley Bore range in composition from monomineralic plagioclase rocks (anorthosite), to more mafic variants containing up to 30 per cent ferromagnesian minerals (two pyroxenes and hornblende: leucogabbro), to plagioclase-bearing mafic granulite (metagabbro). Deformed plagioclase-rich rocks have a metamorphic foliation defined by wispy lenses and discontinuous layers of black amphibole (replacing late-crystallising ?clinopyroxene) in a medium-grained recrystallised matrix of plagioclase. In the less deformed rocks, a 'primary' inch-scale compositional layering/banding is developed where the ferromagnesian layers are laterally more continuous and are of similar thickness (1 to 5 cm) to the plagioclase-rich layers (Fig. 9 B–C). The anorthositic rocks are devoid of sulphide and have very low magnetite contents. The body mapped at Hamilton Downs Homestead is more mafic than at Valley Bore. Anorthosites were not observed, and leucogabbro forms a minor component (25%) of the mafic-dominated stratigraphy. The leucogabbros have a distinctive brown knobbly surface expression due to clots of pyroxene replaced by amphibole in a granoblastic plagioclase matrix.

Magnetic susceptibility of rock types (SI (10^{-6})). Low: anorthosites (60–2100).

Field relationships. Deformed and metamorphosed to granulite or upper amphibolite facies during events that affected the Mount Hay and Strangways regions at ~1780–1760 Ma and ~1730–1720 Ma. The anorthositic sequence near Valley Bore forms the northeastern limb of a synformal body comprising overlying garnet quartzofeldspathic gneiss, mafic granulite and minor gabbro. The synform is probably faulted against the large Mount Hay Granulite intrusion to the southwest. The inferred southeast-trending fault separating the two bodies is obscured by shallow alluvium. In contrast to associated mafic granulites and metasediments, anorthosites show no migmatisation or little intrusion by felsic veins. Anorthosite east of Blackhill Dam is faulted against Bunghara Metamorphics, and the Hamilton Downs Homestead body is surrounded by alluvium.

Mineralisation. Unknown.

Reference(s). Glikson (1984); Watt (1992); Warren (1995); Warren & Shaw (1995).

Enbra Granulite (Figs 1, 7 & 8)

Centre of exposure and collection of samples. ALICE SPRINGS (SF 53–14): Burt (5651) at AMG ~^{3}85000 and ^{74}34000. Samples were collected along a northeast-trending traverse near the centre of the intrusion (Fig. 7).

Age. ?Palaeoproterozoic to Mesoproterozoic. Results of U-Pb zircon geochronology of mafic granulite (93 ppm Zr) from this program (Appendix 2) will be reported elsewhere.

Form, structure and areal extent. Fault-bounded wedge-shaped granulite body consisting of a group of isolated hills that cover an area of 8 by 15 km on the Burt Plain. Aeromagnetics indicate that the granulites extend farther west under sand plain to the Stuart Highway with the overall dimensions of the body about 10 by 22 km. The outcrop pattern of the faulted wedge appears to have a closure to the east suggesting a macroscopic folded structure with an east-trending axial plane. A locally well-developed foliation defined by aligned prismatic pyroxene and/or hornblende in the mafic granulites dips steeply (72–85°) towards the north in the eastern part of the body, whereas vertical and steep (80–85°) dips to the south characterise the western end. The southern and northern margins of the body appear to be bounded by faults splaying off the east-trending Harry Creek Deformed Zone that has greater surface expression to the southeast of the nearby Harry Anorthositic Gabbro intrusion. Landsat-5 Thematic Mapper imagery (Fig. 8) highlights the homogeneous compositions of the mafic granulites and the extensive development of calcareous deposits along the southern margin. These deposits may have formed by fluid movement during shearing of the mafic rocks along the southern bounding fault.

A possible younging direction of the body to the north is indicated by the occurrence of anorthosite and anorthositic gabbro near the northern margin (samples 2000081008/1009/1010 in Fig. 7). Cyclic trends of magnetic susceptibility values across the body imply open fractionation systems involving regular new pulses of primitive magma into an evolving chamber.

Thickness. Unknown.

Stratigraphy and major rock types. Comprises a homogeneous mafic granulite sequence ?overlain by more fractionated felsic rocks in the north. Mafic granulites are the dominant rock type (80%), with irregular felsic granulite, garnet-biotite-feldspar-quartz paragneiss and migmatitic paragneiss (20%) bodies interlayered with the mafic granulites abundant in the central part of the body. The mafic granulites are fine- to medium-grained foliated rocks containing thin segregations (sweats) of felsic granulite. A primary modal layering defined by thin alternating pyroxene-rich and plagioclase-rich laminae is locally preserved. Flattened mafic pillows, stacked sequences of alternating mafic and felsic granulite layers, and intricate net-vein textures involving *in-situ* commingling of mafic and felsic magmas support an intrusive origin for the mafic granulites (Fig. 9 D–E). Such magma-magma relationships are found in other mafic-felsic granulite bodies of the central group, including Mount Hay and Mount Chapple. Medium-grained plagioclase-rich mafic granulite and anorthositic rocks are associated with mafic granulites about

1 km south of Snake Well on the northern margin of the body (Fig. 9 F). Minor garnet is associated with these felsic rocks.

Magnetic susceptibility of rock types (SI (10^{-6})). Variable, low to moderate: mafic granulites (80–16 800).

Field relationships. A east-trending fault-bounded wedge is situated between the Sliding Rock metamorphics to the south and the Erontonga metamorphics to the north. Contacts with the country rocks are covered by sand plains.

Mineralisation. Unknown.

Other comments. The sheared southern contact significantly downgrades the potential for accumulations of massive Ni-Cu-Co sulphides that may occur in depressions along the basal contact and in feeder conduits. The Enbra Granulite has similar rock types and mafic-felsic magma relationships to the Mount Hay Granulite located 90 km to the southwest. Both granulite bodies occur near, and on opposite sides of, the Harry Creek Deformed Zone. Detailed geochemical-geochronological data and an understanding of the movement dynamics along this poorly-exposed regional fault system are required to establish if the Enbra Granulite body is a transposed fragment of the Mount Hay Granulite body.

Reference(s). Shaw & Wells (1983); Shaw & Langworthy (1984).

Harry Anorthositic Gabbro (Figs 1 & 10)

Centre of exposure and collection of samples. ALICE SPRINGS (SF 53–14): Laughlen (5751) at AMG ~^{4}05000 and ^{74}29500. Samples were collected throughout the intrusion (Fig. 10).

Age. ?Palaeoproterozoic to Mesoproterozoic. Results of U-Pb zircon geochronology of tonalite (93 ppm Zr) and dolerite dyke (Fig. 13 A)—?Stuart Dyke Swarm—(85 ppm Zr) both cutting the Harry Anorthositic Gabbro from this program (Appendix 2) will be reported elsewhere.

Form, structure and areal extent. East-trending elongated bodies, 3 km southwest of Johannsen's Phlogopite Mine, crop out in a 2 by 6 km area of subdued relief in the southern foothills of the Utnalanama Range. The anorthositic gabbro bodies have lobate outcrop patterns that interfinger along strike with younger discordant bodies of massive brown tonalite and diorite. The anorthositic gabbro bodies show rapid changes in width along strike, with the eastern end of the largest body just west of the Johannsen Mine track having a maximum width of 1 km. Bouldery outcrop is patchy on low slopes that have flatter topographic profile gradients than the neighbouring ridge-forming tonalite and mafic granulite (Johannsen Metagabbro) rocks. Most rocks have a distinctive thin dark brown to black weathering skin. Weak aeromagnetic signatures comprising long narrow arcuate magnetic highs separated by broad lows define a similar area to the outcrop.

Thickness. ?1 km.

Stratigraphy and major rock types. The dominant rock type is a medium- to coarse-grained uralitised anorthositic gabbro metamorphosed to granulite facies. The most distinctive feature is a blotchy mottled texture due to centimetre-sized black clots of prismatic amphibole (after late-crystallising ?clinopyroxene) in a recrystallised matrix of sericitised plagioclase. More deformed variants have flattened amphibole clots that form plates and lenses in a pervasive foliation. Associated rocks include minor metamorphosed anorthosite, quartz anorthosite, leucogabbro, gabbro and rare pyroxenite. The most plagioclase-rich rocks (anorthosite) were observed near the western end of the body (sample 2000081084). Anorthositic gabbro in contact with tonalite contains trace amounts of quartz, and all rocks have very low abundances of magnetite and are devoid of sulphides.

Magnetic susceptibility of rock types (SI (10^{-6})). Low: anorthositic gabbro and anorthosite (160–3400).

Field relationships. Possible single mafic body separated into at least five smaller lenticular bodies by thin irregular parallel bodies of younger massive tonalite and diorite. The latter bodies show shallow-angle discordance with the margins of the anorthositic gabbros, and tonalite veins and veinlets cut the amphibole clots of the anorthositic gabbros (Fig. 13 B). Felsic granulites of the ?Utnalanama Granulite form a minor countryrock component to the anorthositic gabbro and tonalites. The anorthositic gabbro bodies have long curvilinear boundaries that truncate the radiating dykes of the Johannsen Metagabbro to the north, and are themselves cut by porphyritic biotite granite of the 990±13 Ma Gumtree Granite (Rb-Sr age by Allen & Black 1979), aphanitic dolerite dykes (?Stuart Dyke Swarm) and coarse feldspar pegmatite dykes. Shallow alluvial cover largely masks the southern contact of the intrusion with the east-trending Harry Creek Deformed Zone.

Mineralisation. Unknown.

Other comments. Similar metamorphosed anorthositic and plagioclase-rich gabbroic sequences abutting homogeneous mafic granulites occur in the Mount Hay-Anburla Anorthosite and Enbra Granulite intrusions.

Reference(s). Stewart et al. (1980); Shaw & Wells (1983); Shaw & Langworthy (1984).

Johannsen Metagabbro (Figs 1 & 10)

Centre of exposure and collection of samples. ALICE SPRINGS (SF 53–14): Laughlen (5751) at AMG ~^{4}05000 and ^{74}31500. Samples were collected along a northeasterly traverse west of Johannsen's Phlogopite Mine (Fig. 10).

Age. ?Palaeoproterozoic to Mesoproterozoic. Results of U-Pb zircon geochronology of mafic granulite (57 ppm Zr) from this program (Appendix 2) will be reported elsewhere.

Form, structure and areal extent. Mafic granulite dyke swarm that forms the rugged, deeply incised hills of the Utnalanama Range. The dykes (?metamorphosed dolerites) typically crop out as distinctive black ridge cappings and strike ridges on the slopes of the hills. At least ten individual dykes that cover a total area of 5 by 6 km radiate outwards from an apparent confluence point 2 km southwest of Johannsen's Phlogopite Mine. Aeromagnetics show a radiating array of narrow discontinuous magnetic ridges and no significant sub-surface extensions of the dykes. The dykes have parallel arcuate trends and constant widths of 50 to 250 m along their strike extents that attain 6 km. Distances between the radiating dykes consistently increase from less than 100 m in the east to 800 m in the west. Southwest-trending strike-slip faults have locally disrupted their orientation and caused sinistral displacements of tens to hundreds of metres.

Thickness. < 250 m.

Stratigraphy and major rock types. Dominant rocks include homogeneous coarse-grained mafic granulite, granoblastic gabbro and felsic granulite. The mafic granulites have a distinctive black colour and spheroidal weathering. They generally have sharp contacts with the Harry Anorthositic Gabbro and felsic granulite country rocks. The latter felsic granulites are very homogeneous in composition suggesting that they may be metamorphosed granitic sheets. In contrast to the sulphide-poor rocks of the Harry Anorthositic Gabbro, the mafic granulites contain trace disseminated pyrite. Mafic granulites south of The Garden Homestead track are cut by numerous east-trending epidote-quartz-bearing shears, dolerite dykes and boudinaged granitic and pegmatitic veins that reflect the proximity of the Harry Creek Deformed Zone to the south. Brecciated and complexly folded calc-silicate rocks of the ?Ankala gneiss (Fig. 13 C) also occur near this deformation corridor.

Magnetic susceptibility of rock types (SI (10^{-6})). Variable, low to moderate: mafic granulites (4120–29 500).

Field relationships. The southeastern extent of the dykes appears to be truncated by a large east-trending body of Harry Anorthositic Gabbro, and the dykes are also cut by porphyritic biotite granite of the 990±13 Ma Gumtree Granite (Rb-Sr age by Allen & Black 1979), massive tonalite, aphanitic dolerite dykes (?Stuart Dyke Swarm) and coarse feldspar pegmatite dykes. The dykes intrude homogeneous felsic granulite of the Utnalanama Granulite and layered felsic granulite and cordierite quartzofeldspathic granulite of the Erontonga Metamorphics farther north. Metapelitic rocks, mafic granulite and small pods and lenses of serpentinised ultramafic rocks and sapphirine-bearing silica-undersaturated rocks are interlayered with felsic granulites near Johannsen's Phlogopite Mine along the eastern flank of the dyke swarm.

Mineralisation. Unknown. The mafic bodies are generally too small for hosting significant Ni-Cu-Co sulphide mineralisation.

Other comments. The spatial distribution and dimensions of the dykes and associated cordierite metapelites are features also common to the Mount Stafford dolerites, located 200 km to the northwest in the Yundurbulu Range. About 3.6 tonnes of phlogopite was mined from the hangingwall of Johannsen's Phlogopite Mine in 1942–1944. Much of the phlogopite is fluorine-rich and contains inclusions of euhedral magnetite, which made it unsuitable for industrial use, but it has specimen value (Shaw & Langworthy 1984).

Reference(s). Stewart et al. (1980); Shaw & Wells (1983); Shaw & Langworthy (1984).

Mount Chapple Metamorphics (Figs 1, 11 & 12)

Centre of exposure and collection of samples. HERMANNSBURG (SF 53–13): Narwietooma (5451) at AMG ~^{2}80000 and ^{74}20000. Samples were collected along a north-northeast-trending traverse near the centre of the intrusion between No 10 and No 13 Bores (Fig. 11).

Age. Palaeoproterozoic. Results of U-Pb zircon geochronology of mafic granulite (182 ppm Zr) from this program (Appendix 2) will be reported elsewhere.

Form, structure and areal extent. Large composite mafic-intermediate-felsic granulite body that forms a ~ 62 km-long narrow ridge and chain of hills extending from near Narwietooma Homestead in the west to Karanji Bore in the east. The east-trending ridge and hills maintain a height of 300 to 400 m above the surrounding sand plain, and the highest point, Mount Chapple (1206 m), is at the western end of the main ridge. The exposed width of the body consistently decreases eastwards from its maximum width of ~ 9 km near the centre of the body. Structural trends defined by compositional banding and foliation in granulites vary from northwest to east to east-northeast. Foliations dip steeply (70–86°) towards the north and northeast in the western part of the body, and steeply towards the north or south in the eastern part. Foliations are generally parallel to compositional banding. Glikson (1984) noted that penetrative lineation sets, expressed as feldspar-quartz rodding on foliation planes plunging steeply eastward, correspond to the axes of reclined isoclinal folds. Collins (2000) described lineations and foliations that are folded into upright, east-trending structures. The upright shallowly plunging folds formed during peak granulite facies metamorphism at < 1600 Ma, which contrasts with the sheath-like structures at Mount Hay that formed at ~1770 Ma. Structural and fractionation trends along the sample traverse show that the mafic granulites near the centre of the body generally young to the north. Faults separating the different granulite lithologies are often parallel to the structural trends and the regional arcuate pattern of the outcrops. Aeromagnetics reveal that the exposed granulites represent the southern part of a much larger strongly magnetic elongated body centred farther north. Magnetic ridges along strike to the west of this large body suggest that magnetite-bearing granulites are widespread under cover in the northwestern corner of HERMANNSBURG.

Thickness. Unknown.

Stratigraphy and major rock types. Compared with the more homogeneous mafic composition of the nearby Mount Hay Granulite body, the Mount Chapple body contains a higher proportion of intermediate and felsic granulites relative to the mafic granulites and a greater abundance and variety of metasediments. These rock types comprise the Mount Chapple Metamorphics—a component of the regionally extensive Narwietooma Metamorphic Complex (Warren & Shaw 1995). The central part of Mount Chapple is dominated by mafic granulite, whereas the western and eastern parts contain large bodies of quartzofeldspathic gneiss, felsic granulite, intermediate gneiss, orthopyroxene-bearing gneissic granite (charnockite) and various migmatitic metasediments. The mafic granulites form fine-grained, massive to foliated dark brown to dark grey outcrops that are generally devoid of igneous textures. In places they show compositional banding comprising alternating segregations of ferromagnesian minerals with feldspar and quartz. Most mafic granulites contain clinopyroxene, orthopyroxene, plagioclase, minor garnet, biotite, magnetite and quartz. Secondary aggregates of clinoamphibole after pyroxene indicate variable retrogression to amphibolite facies assemblages. Trace disseminated pyrite and chalcopyrite grains are more abundant towards the southern end of the sample traverse. Fine- to locally medium-grained felsic and intermediate granulites with orange to pale brown outcrop colours generally have sharp contacts with the mafic granulites. They form small to large irregular bodies or centimetre- to metre-wide parallel layers within the mafic granulites (Fig. 13 D–E). Amphibole and garnet become dominant ferromagnesian minerals in the felsic rocks at the expense of pyroxene. Pods, lenses, enclaves and fragments of mafic granulite are locally abundant in the felsic granulites (Glikson 1984). Large bodies of charnockite and quartzofeldspathic gneiss are shown on HERMANNSBURG near the western end of the body, and metasediments are more abundant in the eastern chain of hills. Stocks, pods and veins of augen gneiss and gneissic granite intrude granulites in the central and eastern parts of the complex. Mafic granulite pillows are locally chilled against fine-grained leucogranite (Fig. 13 F).

Magnetic susceptibility of rock types (SI (10^{-6})). Very variable, low to high: mafic granulites (470–48 000).

Field relationships. Relationships between the granulites are difficult to determine, as they generally form poorly-defined irregular bodies that are commonly fault-bounded and complexly folded. Landsat-5 Thematic Mapper imagery (Fig. 12) also failed to discriminate the different rock types or regional structures using techniques such as band ratios and directed principal component analysis.

Mineralisation. Unknown. The presence of trace sulphides on the southern side of the complex indicates the rocks are S saturated and there is potential for concentrations of Ni-Cu Co sulphides in structural embayments and depressions along the basal contact. The southern contact of the mafic granulites with the country rocks is under shallow cover and would need to be defined by geophysics.

Other comments. The Mount Chapple and Mount Hay granulite bodies are separated from each other by the Harry Creek Deformed Zone, which may explain their different lithological assemblages, structures and deformational histories.

Reference(s). Glikson (1984); Watt (1992); Warren (1995); Warren & Shaw (1995).

Mount Hay Granulite (Figs 1, 14 & 15)

Centre of exposure and collection of samples. HERMANNSBURG (SF 53–13): Anburla (5551) at AMG ~^{3}05000 and ^{74}04000. Samples were collected along two north-northeast-trending traverses across different stratigraphic levels of the intrusion (Fig. 14). The longer traverse (~11 km) over mainly mafic granulite is located 3 km west of the Mount Hay trig point, and the shorter traverse (~5 km) crosses an intercalated sequence of mafic granulite, garnet gneiss and anorthosite in the northeast of the body. Landsat-5 Thematic Mapper imagery (Fig. 15) clearly differentiates the homogeneous mafic granulites, which form the main part of the Mount Hay body, from the intercalated mafic-felsic sequence further north.

Age. Palaeoproterozoic. U-Pb dating of metamorphic zircon from mafic and intermediate granulites, and of zircon rims from nearby granites yield an age of 1770 Ma for the timing of peak metamorphism (unpublished data of Collins & Williams in Collins & Sawyer 1996). Results of U-Pb zircon geochronology of mafic granulite (118 ppm Zr) from this program (Appendix 2) will be reported elsewhere.

Form, structure and areal extent. The Mount Hay Granulite body forms one of the most prominent landform features on the Burt Plain (Fig. 18 A). The highest point of Mount Hay (1252 m) is situated near the middle of a large elongated east-southeast-trending body that rises 600 m above a pediment of black clay and sandy alluvium. Farther to the northeast is a lower ridge-forming body, which contains a variety of interlayered rock types (including type section of the Anburla Anorthosite: see description at start of 'Central group of intrusions'), and is separated from the main body by a narrow valley. Collectively the two bodies are 35 km long by 4 to 9 km wide. A stacked series of parallel linear aeromagnetic anomalies northeast of the Anburla Anorthosite sequence suggest the cyclic occurrence of magnetic units (mafic granulite or gneiss) under cover.

Mapping by Glikson et al. (1983), Collins & Sawyer (1996) and this study shows that the main body is a large antiformal sheath fold. Aeromagnetic data indicates that it is faulted against a smaller synformal body of interlayered mafic granulite, garnet gneiss and anorthosite (Anburla Anorthosite) to the northeast. Collins and Sawyer's map shows both southwest and northeast limbs of the sheath fold dipping northeast at about 60°, which implies that the fold is a somewhat flattened parallel-sided pipe plunging northeast. The present study, however, found:

- southwest-dipping foliations 2 km north of Mount Hay trig point and so the northeast-plunging lineations depicted in this area by Collins & Sawyer cannot be related to the southwest-dipping foliation;
- southeast-dipping foliations on the northern margin of the body; and
- east-dipping foliations 5–6 km west-northwest of Mount Hay trig point.

These data indicate that the western half of the body is synformal, and only the eastern half antiformal. Figure 16 is a longitudinal section of the intrusion, and Figure 17 shows transverse cross-sections through the intrusion. Rather than being a northeast-plunging pipe, the sheath fold is interpreted as a large subhorizontal elongate balloon-like body. The present ground level cuts up-section from the lower, synformal portion of the balloon in the west to the upper, antiformal portion in the east. At its eastern end, the balloon plunges down to the northeast at about 60°. The shape of the fold seems to suggest west-directed growth, possibly by mobilisation of parts of the mafic granulite fold core—a notion consistent with the presence of several regions of massive (structureless) rock in the body, one of which encloses a raft of foliated mafic granulite on the southeastern side of the Mount Hay trig point.

Thickness. About 3 km at the centre; unknown (but >3 km) at the eastern end, where the body plunges below ground level.

Stratigraphy and major rock types. The Mount Hay Granulite body—part of the regionally extensive Narwietooma Metamorphic Complex (Warren & Shaw 1995)—comprises dominantly mafic granulite (~60%), felsic and intermediate granulite (~25%), anorthositic rocks (~5%), migmatitic metasediments (~5%), and various felsic igneous rocks (~5%), such as charnockite, leucogranite, and pegmatite (Fig. 18 B–F). The dark brown to black mafic granulites are generally fine-grained, massive to foliated and have strong mineral elongation lineations. Medium-grained variants with ?primary intergranular textures and rare compositional layering on a centimetre scale are preserved locally, particularly near the central axis of the main body. The dominant minerals include plagioclase, clinopyroxene, orthopyroxene and hornblende associated with variable minor amounts of biotite, garnet, magnetite and quartz. The mafic granulites appear to be homogeneous in composition on a macroscale, but they are heterogeneous at outcrop scale, containing numerous thin quartzofeldspathic and tonalitic leucosomes and charnockite veins and stringers. Intermediate and felsic granulites have similar granoblastic mineral assemblages to the mafic granulites, except for greater abundances of quartz and feldspar. Metasediments showing different stages of migmatisation are locally prominent near the margins of the main body (e.g. northwestern region) and as thicker layers intercalated with mafic granulites. Metapelite, psammite and garnet-sillimanite gneiss are most common. Diopside-rich calc-silicate rocks, bands of wollastonite and scapolite-rich pods within mafic granulites have been reported at the eastern end of the body on the north side of Ceilidh Hill (Watt 1992). Glikson (1984) and Bonnay et al. (2000) provide comprehensive mineralogical summaries of the various granulite and vein rocks.

Magnetic susceptibility of rock types (SI (10^{-6})). Very variable, low to high: mafic granulites (350–58 000).

Field relationships. The temporal and genetic relationships of the magmas that produced the mafic and felsic rocks are complex and have been the subject of much discussion in recent years. Collins & Sawyer (1996) suggested that granite magma emplacement occurred through the lower crust during compressive deformation of the mafic rocks at granulite metamorphic facies. However, Wiebe (in Bonnay et al. 2000) proposes that the granitic rock crystallised at low pressures before the high-P metamorphism, and that the mafic granulites are not country rocks to the granites, but rather formed by injections of tholeiitic basaltic magmas into chambers of felsic magma at low pressure (1–2 kb). The mafic layers represent basaltic magma ponding on and spreading across the floor of the chamber, and the interlayered felsic rocks crystallised from crystal mush accumulated on the chamber floor between pulses of mafic magma.

Mineralisation. Unknown. Very rare fine disseminated sulphides occur in mafic granulites.

Other comments. Glikson's (1984) mineral chemistry study of granulite rocks from Mount Hay indicates equilibration of two-pyroxene granulite at ~ 6.5 kb and ~ 900° C, garnet-two pyroxene granulite at ~7.3–8.1 kb and ~ 680–770° C, sillimanite-garnet gneiss at ~ 8.8 kb and ~ 670° C and felsic bands in mafic granulite at ~ 5.9 kb and ~ 670° C. Shaw & Black (1991) used metapelite and garnet-bearing mafic granulite to determine metamorphic conditions of 7–8 kb and 700–800° C. These granulite metamorphic facies determinations are consistent with Harley et al's. (1994) inferred estimates of > 6 kb and 780–850° C based on garnet coronas on scapolite, and Bonnay et al's. (2000) estimates of 6.4±2.5 kb and 825–875° C based on clinopyroxene-plagioclase assemblages and metapelitic assemblages, respectively. Collins (2000) proposed two granulite facies events at ~1770 Ma and ~1600 Ma on the basis of the ages of megacrystic granite and granulite rocks and textural evidence (coronas).

Reference(s). Glikson (1984); Watt (1992); Warren (1995); Warren & Shaw (1995); Collins & Sawyer (1996); Bonnay et al. (2000).

Mount Stafford dolerite (Figs 1 & 19)

Centre of exposure and collection of samples. NAPPERBY (SF 53–9): Reynolds Range (5453) at AMG ~ ^{2}58000 and ^{75}64000. The Mount Stafford dolerites in the Yundurbulu Range (northwestern part of the Anmatjira-Reynolds Ranges) of the northern Arunta are the most northerly intrusions investigated in this study. Samples were collected along a westerly traverse near the northern end of the dolerite sills (Fig. 19).

Age. ?Palaeoproterozoic. Sills and dykes intrude spotted and layered cordierite hornfelses of the Palaeoproterozoic (Orosirian: 2050–1800 Ma) Mount Stafford beds. These metasediments are regarded by Stewart (1981) as a markedly pelitic facies variant of the Lander Rock beds.

Form, structure and areal extent. Stacked sequence of hypabyssal sills and associated dykes tightly folded around northwest- to north-northeast-trending axes. The dolerites form rubbly outcrop along strike ridges of steeply sloping hills in the highest part of the Yundurbulu Range (Fig. 20 A). They cover a total area of ~ 6 by 7 km, with individual sills composed of isolated outcrops along arcuate concordant trends within the metasediments. The sills crop out for distances of up to 3 km along strike, and their thicknesses range from 10 to 120 m, with a maximum thickness of 200 m. At least eight sills were identified at different stratigraphic levels in the metasediments, with distances between the sills being tens to hundreds of metres.

Thickness. ? < 0.2 km.

Stratigraphy and major rock types. The most common rock types of dolerite, doleritic gabbro, gabbro and gabbronorite are generally fine-grained, massive, weakly recrystallised, and weakly magnetic. Despite being affected by the same metamorphic-deformational event(s) that produced the surrounding folded hornfelses, the metadolerites still have preserved primary sub-ophitic and fine-grained intergranular textures. Compositional layering is absent and there are no obvious lithological-mineralogical variations within the sills to indicate fractionation trends. Contacts with the metasediments are generally sharp and the absence of thick chilled zones indicates that the country rocks were probably hot during their emplacement. Dolerites near the eastern contact with the granitic rocks contain trace pyrite as disseminated grains and in veinlets.

Magnetic susceptibility of rock types (SI (10^{-6})). Low to rarely moderate: gabbros (510–17 000).

Field relationships. The Mount Stafford region in the Anmatjira Range is part of a multiply deformed Palaeoproterozoic to Mesoproterozoic terrain containing mostly metasediments and granites metamorphosed under high temperature (≥750° C) and low-pressure (2.5±0.6 kb) conditions (Clarke et al. 1990). The Mount Stafford dolerite bodies occur within a ~1300 m-thick intercalated assemblage of thin- to thick-bedded metapelitic hornfelses and minor psammites of the Mount Stafford beds. Metamorphic textures range from spotted layered variants containing small clots of cordierite or chlorite-sericite after cordierite, biotite, andalusite, microcline, plagioclase and quartz to higher-grade composite variants containing irregular bodies of partially mobilised ('stewed') interfingering pelitic and psammitic components (Fig. 20 B). Stewart (1981) documented sillimanite and garnet in spotted hornfels and hypersthene in dark layers of layered hornfels typical of the pyroxene hornfels facies of thermal metamorphism. Porphyritic granitic gneiss and rapakivi granite of the Palaeoproterozoic Anmatjira Orthogneiss intrudes the eastern and northern flanks of the Mount Stafford beds and dolerites. Fine-grained tourmaline-bearing granite variants crop out along the northeastern margin and form dykes along fault zones in the Mount Stafford beds to the southwest. Quartz, aplite and pegmatite veins also cut the metasediments of the Mount Stafford beds.

Mineralisation. Unknown.

Other comments. The dolerite dykes and sills in the Mount Stafford region are too evolved to host PGE-Cr mineralisation, and individually are too small for significant Ni-Cu-Co sulphide mineralisation. However, if it can be determined that they represent part of a much larger dynamic magmatic system, such as a network of feeder conduits to overlying magma chamber(s) that have since been removed by tectonism or erosion, then the sills at depth may have some potential for Voisey's Bay (Canada)-type Ni-Cu mineralisation.

Reference(s). Stewart et al. (1980); Stewart (1981); Clarke et al. (1990); Vernon et al. (1990); Buick et al. (1999).

Eastern group of intrusions

Attutra Metagabbro (Figs 1& 21)

Centre of exposure and collection of samples. HUCKITTA (SF 53–11): Jervois Range (6152) at AMG ~ ^{6}36000 and ^{74}99000. The Attutra Metagabbro intrusion immediately southeast of the Jervois Range in the northeast Arunta is the most easterly body investigated in this study. Samples were collected throughout the intrusion (Fig. 21).

Age. A broad Proterozoic age (~2050 to 545 Ma) is indicated by gabbros from the western margin of the intrusion (^{6}35230, ^{74}99425) being chilled against metapsammite and metapelite of the Palaeoproterozoic (Orosirian: 2050–1800 Ma) Bonya Schist, and to the north, the gabbros are unconformably overlain by basal Neoproterozoic (Neoproterozoic III: 650-545 Ma) sediments of the Georgina Basin. Results of U-Pb zircon geochronology of chilled gabbro (153 ppm Zr) from this program (Appendix 2) will be reported elsewhere.

Form, structure and areal extent. This wedge-shaped body consists of a group of 5 to 20 m-high rounded hills (Fig. 20 C), sinuous strike ridges, and isolated tors on plains that cover a total area of approximately 4 by 5 km. The northern extent of the body is covered by shallow-dipping Neoproterozoic sediments (Elyuah and Grant Bluff Formations) of the Georgina Basin, and the eastern and southern margins are masked by Quaternary alluvium. An aeromagnetic ridge flanked by a north-northwest-trending regional fault (Lucy Creek Fault Zone on HUCKITTA), 2 km east of the Attutra Metagabbro, implies subsurface gabbroic rocks under shallow alluvium. The distribution of the Attutra Metagabbro shown on HUCKITTA is over-represented. Northeast-trending outcrops assigned to the Attutra Metagabbro, 5 km southwest of Unka Bore, are low ridges of porphyritic and amygdaloidal metabasalt, and smaller isolated outcrops of fine-grained gabbro and metadolerite between this bore and the Lucy Creek Homestead-Jervois Mine road belong to an unrelated mafic intrusion (here referred to as Unnamed gabbro). A prominent aeromagnetic high correlates with these outcrops and small gabbro outcrops north of Jervois Mine.

Most strike ridges throughout the intrusion have east-northeast to east-west orientations that are subparallel to discontinuous magnetite layers. These trends are generally discordant to the dominant north to northeast structures in the Bonya Schist country rocks. Granitic dykes (Fig. 20 D) cutting the gabbros have dominant northerly strikes. Hunter

Resources Limited (1988) described gabbros having a north-south strike and vertical dips near the northern apex of the body close to the unconformity with the Georgina Basin sediments. They interpreted the body as an irregular steep-sided lopolith with concordant metasedimentary screens, which behaved as a semi-rigid block with ductile enclaves, during deformation and metamorphism to amphibolite grade.

Thickness. Unknown.

Stratigraphy and major rock types. Comprises a homogeneous, weakly recrystallised mafic sequence of medium- to coarse-grained gabbro, magnetite gabbro, magnetitite (Fig. 20 E), with lesser leucogabbro, pyroxenite and amphibolite. Most rock types are generally equigranular, massive and unfoliated, and there is no obvious cyclicity or compositional layering. Pervasive uralitisation alteration imparts a green to green-black colour to the gabbros. The general uniformity of rock compositions and abundance of oxide-rich rocks suggests a ?shallow-dipping mafic sequence from the upper part of an evolved tholeiitic intrusion.

Magnetic susceptibility of rock types (SI (10^{-6})). Low: gabbro (180–5030); high: magnetitite (36 000–38 000).

Field relationships. The intrusive western contact of the intrusion consists of a ~15 m-wide chilled marginal zone of fine-grained massive gabbro abutting psammite and metapelite of the Bonya Schist. Enclaves of metapsammite, metapelite, chlorite schist, calc-silicate rock and amphibolite are associated with the marginal gabbros. Abundant medium-grained tonalite (similar to that cutting the Harry Anorthositic Gabbro), granite, pegmatite and aphanitic dolerite dykes cut the coarse-grained and chilled marginal gabbros and schists of the Bonya Schist (Fig. 20 F). The margins of the thicker felsic dykes are chilled in places, and have commingled net-vein features that involved hybridisation of mafic and felsic magmas.

Mineralisation. Small bodies of massive vanadiferous magnetite are associated with fractionated mafic rocks in the northern and southern parts of the intrusion. The coarse-grained magnetite typically forms 0.5 to 1 m-thick (maximum thickness 3 m) lenses, bands, pods and stacked sequences comprising magnetite lenses separated by magnetite-free gabbro and amphibolite. They have strike extents of a few metres, but their distributions are indicated by concentrations of alluvial oxides in the shallow drainage systems. Abundant blocks of magnetite and maghemite (?replacement-hydrothermal origin) occur with massive epidote and quartz near altered shear zones on ridges and on scree slopes. Small isolated outcrops of vanadiferous magnetite stained with malachite also occur on the plain southeast of the intrusion north of Unka Bore (mineral occurrences 128 and 129 on HUCKITTA). Anomalous V (1.1%), Cu (1.4%), Pd (215 ppb), Pt (28 ppb) and Au (104 ppb) concentrations are associated with the magnetites (Wright 1974, Hunter Resources Limited 1988).

Other comments. The anomalous PGE concentrations in the magnetite-bearing rocks indicate that the Attutra Metagabbro body is probably derived from S-undersaturated magma(s). If this is correct then more primitive parts of the body, if present at depth, have potential for orthomagmatic and structurally-controlled hydrothermal styles of PGE mineralisation. The association of Pd and Pt with magnetite-bearing gabbroic rocks is unusual for Australian mafic intrusions, although Western Mining Corporation Ltd announced magnetite-ilmenite horizons containing elevated concentrations of PGEs and Au (up to 1 ppm) in the Giles intrusions of the west Musgrave Block, Western Australia (WMC website: 30 June 2000).

Reference(s). Wright (1974); Freeman (1986b); Hunter Resources Limited (1988).

Kanandra Granulite (Figs 1, 22 & 23)

Centre of exposure and collection of samples. ALCOOTA (SF 53–10): Delny (5852) at AMG ~^{4}90000 and ^{74}85000. Samples were collected along a northeast-trending traverse midway between Mount Swan and Kanandra Dam.

Age. Palaeoproterozoic, with maximum deposition age of 1817 Ma (Scrimgeour & Raith 2001).

Form, structure and areal extent. Areally extensive poorly-exposed body that extends ~100 km eastwards from near the eastern margin of ALCOOTA to the central part of HUCKITTA. The largest exposed part of the body northwest of Kanandra Dam (Fig. 22) covers an area of ~15 by 30 km on ALCOOTA, whereas a narrow east-trending fault-bounded corridor is wedged between the Entire Point Shear Zone and the Delny Shear Zone on HUCKITTA. Much of the outcrop is obscured by Cainozoic sediments, but its extent is delineated by a characteristic highly variable, but intense aeromagnetic pattern of southeast-trending magnetic ridges and lows. The aeromagnetics show that significant extensions of the mafic granulites persist under Tertiary sediments. In particular, the granulite body is continuous at depth from the large granulite body on ALCOOTA, to the granulite outcrops near Bundey Highway, and to the narrow fault slivers on central HUCKITTA; a distance of ~100 km. Landsat-5 Thematic Mapper imagery (Fig. 23) is particularly useful for indicating the distribution of mafic granulites and differentiating the different Cainozoic silcrete, laterite and carbonate (e.g. Waite Formation) units that are deeply incised along drainage systems.

The mafic granulites along the sample traverse near Mount Swan form ridge cappings and low rubbly outcrop on the slopes of low rounded hills. Trend lines northwest of Mount Swan show that the mafic granulites and associated metasediments are tightly folded about northwest- and north-northwest-trending axial planes. The mafic granulites southeast of Mount Swan show increasing magnetic susceptibility values towards the southwest (380→800→3280→3400 SI [10^{-6}]) due to increasing amounts of magnetite, implying a general younging direction to the southwest.

Thickness. Unknown.

Stratigraphy and major rock types. Various mafic and pelitic rock types (part of Strangways Metamorphic Complex) are metamorphosed to upper amphibolite or hornblende granulite facies. In the Mount Swan region, the dominant rock type is a fine-grained massive mafic granulite that is interlayered with medium-grained layered quartzofeldspathic gneiss, migmatitic garnet quartzofeldspathic gneiss and minor biotite-garnet gneiss and hornblende gneiss (Fig. 24 A–B). The fine grainsize (< 0.5 mm) and complete recrystallisation of the mafic granulites, abundance of interlayered aluminous metasediments and absence of chilled margins and igneous layering suggests that the mafic granulites were originally basaltic lava flows or shallow hypabyssal sills. Coarse-grained ?pyroxenite pods and lenses with distinctive dimpled weathering surfaces are locally associated with the mafic granulite in the central and northern parts of the body. Kanandra Granulite rock types on HUCKITTA experienced high-grade metamorphism (700–800° C and 5–7 kb) during the Late Strangways event at ~1730 Ma (Scrimgeour & Raith 2001).

Magnetic susceptibility of rock types (SI (10^{-6})). Variable, low to high: mafic granulites (340–32 700).

Field relationships. Aeromagnetics indicate that the northern and southern margins of the large Kanandra granulite body on ALCOOTA are bounded by regional east- and southeast-trending shear zones, respectively. The granulites in the north are faulted against a large pluton of Mount Swan Granite (Statherian: 1800–1600 Ma), and the southern contact is masked by Cainozoic sediments. These include Tertiary chalcedonic limestone, sandstone, mudstone and sandy conglomerate of the Waite Formation, and Lower Tertiary weathered rocks, laterite and silcrete.

Small gneissic biotite granite bosses of the Mount Swan Granite are concentrated in the northern half of the granulite body (Fig. 22).

Mineralisation. Unknown.

Other comments. The Kanandra Granulite is equivalent to Mount Bleechmore Granulite, which is the oldest unit exposed on ALCOOTA. If the mafic granulites near Mount Swan represent an extrusive system then the potential for precious metal and base-metal mineralisation can be significantly downgraded.

Reference(s). Shaw & Warren (1975); Shaw et al (1975): Freeman (1986b); Scrimgeour & Raith (2001).

Mordor Complex (Figs 1 & 25)

Centre of exposure and collection of samples. ALICE SPRINGS (SF 53–14): Laughlen (5751) at AMG ~ ^{4}46000 and ^{74}08000. Samples were collected throughout the intrusion (Fig. 25).

Age. Whole-rock Rb-Sr isochron age of 1180±90 Ma, and mineral Rb-Sr isochron ages of 1128±20 Ma and 1118±17 Ma (Langworthy & Black 1978: recalculated by Nelson et al. 1989). Sm-Nd isochron age of 1100±280 Ma (Nelson et al. 1989). Results of U-Pb zircon geochronology of plagioclase pyroxenite (112 ppm Zr) from this program (Appendix 2) will be reported elsewhere.

Form, structure and areal extent. Composite undeformed plug-like alkaline body that crops out over 6 by 6 km inside Mordor Pound, a region of low relief surrounded by sheer cliffs of sandstone and conglomerate (Heavitree Quartzite). These cliffs form a distinctive rectangular pound that is open-ended to the southwest. The felsic rocks of the intrusion typically form weathered rubbly gravel and low outcrops on sandy plains that are broken by prominent dark conical hills of ultramafic intrusive rocks (Fig. 24 C–D). Contacts between rock types, particularly along the eastern margin, are generally obscured by alluvium. The ultramafic rocks are restricted to the eastern half of the intrusion where they form homogeneous lobate and more irregular bodies with curvilinear contacts. They increase in abundance towards the north, with the largest body (0.5 by 1.2 km) near the right centre of the intrusion flanked to the east by a curvilinear cluster of outcrops that resemble ?radial dykes. The ultramafic bodies occur mainly in shonkinite or monzonite, or along the contacts between these rock types. There is no obvious internal zoning of lithologies or rock textures. A prominent aeromagnetic high anomaly comprising low, moderate and high components reveals a composite plug-like body similar in size to the outcrop. High-magnetic components in the southeastern corner of the anomaly appear to correlate with ultramafic rocks. Gamma-ray spectrometrics (especially potassium band) clearly define the distributions of the felsic rock types and indicate that the phlogopite-olivine-bearing ultramafic rocks make up less than 5% of the intrusion.

Thickness. < 1.2 km (ultramafic bodies).

Stratigraphy and major rock types. The intrusion can be broadly subdivided into a western zone of homogeneous syenite and an eastern zone comprising a highly fractionated comagmatic suite of alkaline felsic-mafic rocks spatially associated with phlogopite-bearing ultramafic rocks. Syenite, monzonite, melamonzonite and shonkinite are the dominant felsic-mafic rocks, whereas the ultramafic rocks comprise wehrlite, olivine clinopyroxenite, lherzolite, dunite and pyroxenite. The medium- to coarse-grained ultramafic rock types contain large (up to 2 cm) plates of phlogopite, show no compositional layering or metamorphic recrystallisation, and have well-preserved primary minerals and cumulus igneous textures. In contrast to the massive ultramafic rocks, shonkinite and syenite locally have a strong ?flow lamination defined by the alignment of large tabular alkali feldspar phenocrysts. All mafic and ultramafic rocks have trace amounts of disseminated magmatic sulphides (pyrite, pyrrhotite, chalcopyrite) that form lobate aggregates interstitial to coarser-grained silicate minerals and magnetite-ilmenite (Gole 1996). Remobilised anhedral pentlandite grains are associated with serpentinised olivine.

Swarms of pegmatite, quartz and aplite dykes, and narrow veinlets of carbonate breccia cut felsic and ultramafic rocks in the eastern zone and are rarely found in syenite of the western zone. They have parallel northeast to east arcuate trends across the total width of the eastern zone that reflect a regional pervasive structural control. The carbonate-rich veinlets appear to be of secondary origin related to leaching of ultramafic rocks by groundwater, rather than being primary carbonatite.

Gole (1996) suggested on the basis of field relationships (generations of dykes and rafts) that the order of emplacement for the major rock groups was ultramafics, shonkinite, followed by syenite, which is the opposite proposed by Langworthy & Black (1978). This study documented plagioclase pyroxenite dykes (sample 2000081159 in Fig. 25) with 0.5 m-wide chilled margins intruding syenite in the northeast corner of the intrusion. The dykes can be traced westwards to a nearby silicified-capped peridotite hill, 20 m west of the main access track. The contact relationships of other ultramafic bodies throughout the intrusion would need to be determined to confirm the ultramafic bodies generally postdate the felsic rocks.

Field relationships, igneous textures, gradational relationships between rock types, restricted range of SiO_2 contents (42.7%–52.7%) and continuous smooth chemical variation trends indicate that the Mordor rocks formed from magmatic differentiation of a K-rich magma (Langworthy & Black 1978). The rocks are unusually rich in K, Al, Rb, Ba, Sr and La, and have low Mg/Fe^{2+} and high K_2O/Na_2O ratios. Sr isotopes and geochemical data demonstrate that the magma did not experience extensive contamination by country rocks.

Magnetic susceptibility of rock types (SI (10^{-6})). Variable, low to moderate: pyroxenites and peridotites (1530–23 500).

Field relationships. Intrudes granitic gneiss and quartzofeldspathic gneiss of the Mesoproterozoic Jennings Granitic Gneiss and is unconformably overlain by sandstone, siltstone and conglomerate of the Neoproterozoic Heavitree Quartzite.

Mineralisation. The intrusion and associated carbonate veins have generated exploration interest for Ni, Cu, Cr, PGEs, diamonds, vermiculitic phlogopite, U and rare-earth elements. The NTGS have investigated minor occurrences of Ni and Cu (Barraclough 1976), and uranium and thorium silicates, including brannerite and uranophane have been reported in some plagioclase-rich rocks (Kostlin 1971). Ultramafic rocks contain trace amounts of chrome spinel. Carbonate veins cutting the intrusion have low rare-earth element contents and appear to be unrelated to carbonatite. The possible kimberlitic affinities (Langworthy & Black 1978) of the intrusion downgrade the potential for Ni-Cu sulphide mineralisation.

Other comments. The Mordor Complex and the smaller Mud Tank Carbonatite (Knutson & Currie 1990), 52 km to the north-northwest, occur near the Woolanga Lineament—a deep-seated crustal dislocation that may have facilitated the emplacement of these unusual plug-like bodies. The younger emplacement of the Mud Tank Carbonatite (U-Pb zircon age of 732±5 Ma: Black & Gulson 1978) relative to the Mordor Complex may indicate reactivation along this regional lineament or associated fault structures.

Reference(s). Kostlin (1971); Barraclough (1976); Langworthy & Black (1978); Stewart et al. (1980); Shaw & Wells (1983); Shaw & Langworthy (1984); Nelson et al. (1989); Gole (1996).

Riddock[3] Amphibolite (Figs 1, 26 & 27)

Centre of exposure and collection of samples. ALICE SPRINGS (SF 53–14): Riddoch (5851) at AMG ~ ^{4}90000 and ^{74}46000. Samples were collected along a southeasterly traverse midway between Mount Campbell and Mount Mabel (Fig. 26).

Age. Late Neoproterozoic to Cambrian for the Harts Range Group (Hand et al. (1999 a, b) and Mawby et al. (1999) refer to this group as the Irindina Supracrustal Assemblage and the Riddock Amphibolite Member as part of the Harts Range Igneous Complex).

Form, structure and areal extent. Composite ?volcano-sedimentary sequence comprising folded concordant mafic sheets within laterally continuous pelitic, calcareous and quartzose schists and gneisses of the Irindina Gneiss (Harts Range Group). The amphibolites form the topographic backbone of the Harts Range Block, a broad elevated area west of the Entia Dome and north of the White Lady Block and Oonagalabi Dome. Long steep-sided strike ridges with several prominent peaks (Mount Riddoch–1094 m, Mount Mabel–1070 m, Mount Brassey–1203 m) rise more than 500 m above the sand plains to the north. The moderately to steeply dipping amphibolite sheets have a regional east-west trend from near Mount Riddoch to Mount Brady, and this abruptly changes to south along the western flank of the Entia Dome towards Mount Ruby. The amphibolites are laterally continuous for about 70 km and have a maximum width of 6 to 8 km. Thicknesses of individual bodies range from a few metres up to ?2 km. Aeromagnetics reveal a very weak linear trend of parallel narrow magnetic ridges and lows up to 10 km long, which contrasts with the intense magnetic signature of the Strangways Metamorphic Complex further south. Landsat-5 Thematic Mapper imagery (Fig. 27) highlights the lateral continuity and folded character of the different mafic and felsic units that comprise the Riddock Amphibolite Member. The Riddock Amphibolite is cut by a parallel series of northwest-trending faults (see right central part of Figure 27) that may be important for vein-type mineralisation (see Mineralisation below).

Amphibolite units between Mount Riddoch and Mount Mabel are affected by upright, east-west-trending isoclinal folds, which formed during north-south contraction, assigned by Ding & James (1985) and James & Ding (1988) to a mid-Proterozoic deformation they called the Harts Range Orogeny. Recent work by Mawby et al. (1999) and Hand et al. (1999a) considered this

[3] The formal spelling of the stratigraphic and homestead names is Mount Riddock, whereas the spelling of the topographic feature is Mount Riddoch and the 1:100 000 sheet is Riddoch.

folding to have occurred during the Devonian to Carboniferous Alice Springs Orogeny. These authors assign the high-grade layer-parallel fabrics in the rocks to an earlier period of extensional movement which took place in the early Ordovician, rather than in the mid-Proterozoic as proposed by Ding & James (1985). Sivell & Foden (1985) considered that the dominant regional layering fabrics south of Mount Brady developed during a recumbent tectonothermal event (upper amphibolite facies) which also caused flattening and parallelism of all previous discordancies into a well layered laterally continuous parallel package of rock types.

Thickness. ? < 2 km.

Stratigraphy and major rock types. Composite sequence of compositionally layered and massive amphibolite interlayered with garnet quartzofeldspathic gneiss, biotite gneiss, garnet-biotite gneiss, sillimanite gneiss and hornblende- or clinopyroxene-bearing plagioclase-rich gneiss. Intrusive ultramafic rocks and gabbros form a minor component. Metamorphic grade ranges from upper amphibolite to locally granulite facies. Layering in the amphibolites consists of alternating basaltic and tonalitic bands concordant with a penetrative foliation and wrapping around mafic boudins (Fig. 24 E–F). Layer-parallel fabrics with strong linear components characterise most lithologies. Garnet is more abundant in heterogeneous packages of layered amphibolite relative to more massive homogeneous amphibolite. Sivell and Foden (1985) recognised the following succession (from base to top) south of Mount Brady: lower amphibolite (< 40 m); metapelite (< 2 m); anorthositic gneiss (50 m); metapelite (10 m); and upper amphibolite (> 500 m). Isolated boudins and conformable lenses (< 5 m thick) of hornblende-rich anorthositic gabbro and peridotite occur within anorthositic gneiss. In addition, they identified younger unfoliated norite and gabbro pods discordant with the enclosing pelitic gneisses. Sivell & McCulloch (1991) sub-divided the amphibolites on the basis of rare-earth-element geochemistry and isotopes. The southern basal metatholeiitic sequence is depleted in light-rare-earth elements (LREE) and has uniformly high ε_{Nd} values of +8.2 to +6.9. In contrast, metatholeiites from higher in the sequence to the north are LREE-enriched, with variable, but lower ε_{Nd} values of +6.3 to +2.8.

Magnetic susceptibility of rock types (SI (10^{-6})). Low: amphibolites (150–610).

Field relationships. Sivell & Foden (1985) used the absence of chilled margins, igneous layering and pillow structures, the presence of concordant calc-silicate bands, the recrystallised nature of the amphibolites and the preservation of original igneous textures in associated norite and gabbro to indicate that the amphibolites were originally fine-grained lava flows. The lateral continuity of the thin amphibolite sheets and their association with intercalated quartzofeldspathic gneisses (felsic metavolcanics?) also support an extrusive origin for the mafic rocks. Sivell & Foden (1985) interpreted the amphibolite sequence as a complexly folded and metamorphosed basalt-tonalite suite formed at a rifted continental margin or intra-cratonic rift.

Mineralisation. High-grade Pt-Pd-Au-Cu mineralisation occurs in felsic-carbonate veins hosted by amphibolite units south and southeast of Mount Riddoch (Tanami Gold NL 2000). PNC Exploration (Australia) discovered the mineralised veins during their U-exploration programs in the mid-1990s. Four major prospects have now been defined within the Florence Creek shear zone–a regional northwest-trending structural corridor cutting the Harts Range Block and Strangways Metamorphic Complex. The Kongo Prospect, ~ 4 km northwest of the Copper Queen mine (Fig. 26), consists of mineralised quartz-carbonate-tourmaline veins associated with chlorite-hematite altered amphibolite (Tanami Gold NL 2000). The veins contain up to 0.6 ppm Pt, 1.4 ppm Pd, 5.8 ppm Au, 6.8% Cu and 12 ppm Ag. High-grade mineralisation (maximum of 38.5 ppm Au, 4.8 ppm Pd, 0.1 ppm Pt) has also been reported at the Copper King (~800 m southeast of Kongo Prospect), Pegma and Copper Hill (both ~ 2.4 km southeast of Kongo Prospect) prospects (MiningNews.net July 2001). The polymetallic character of the vein systems, associated Fe alteration and erratic metal ratios are features common to other hydrothermal Au-PGE deposits, such as Coronation Hill and El Sherana in the Pine Creek Inlier, Northern Territory.

The Selins Cu-Zn prospect (Fig. 26), 4.5 km south-southwest of Mount Riddock homestead, consists of atacamite, chalcanthite and malachite in anthophyllite rock, garnet-hornblende rock and calc-silicate rock. These distinctive magnesium-calcium-rich rocks occur in a unit of garnet quartzite and garnet quartzofeldspathic gneiss hosted by the Riddock Amphibolite Member. Shaw et al. (1984a) reported traces of Cu (5000 ppm) and Zn (1000 ppm: AMDEL Report AC 3245/79).

The Virgina Cu prospect, 12 km southeast of Mount Riddock homestead, consists of copper carbonate-stained garnet quartzite in association with quartzofeldspathic gneiss and migmatitic garnet-quartz-rich hornblende rock. The mineralised zone contains quartz veins, and is more schistose than the host rock, which is again the Riddock Amphibolite Member (Shaw et al. 1984a).

Amphibolites south of Mount Brady host several pegmatitic veins that contain small quantities of mica, titanite, corundum and epidote. Ruby was mined from a plagioclase-rich variant of the Riddock Amphibolite Member at the Hillrise mine south of Mt Brady.

Prospects and mines in the Harts Range region are described in detail by Joklik (1955a, b), Stewart & Warren (1977), Warren (1980) and Shaw & Freeman (1985).

Other comments. The hydrothermal PGE mineralisation near Mount Riddoch takes on considerable significance in view of the radical revision being recently proposed for the tectonothermal history of the Harts Range region. U-Pb and Sm-Nd geochronological studies (Hand et al. 1999a, Mawby et al. 1999) suggest that sediments and igneous rocks of the Harts Range Group (Irindina Supracrustal Assemblage) represent a rift sequence that was 'deposited' during the late Neoproterozoic to Cambrian and was metamorphosed to granulite facies in an extensional intraplate setting during the early Ordovician (480–460 Ma). The igneous rocks include basalt, volcaniclastics, anorthosite and ultramafic intrusives (Buick et al. 2001). The Harts Range region therefore appears to be a new sub-province characterised by relatively young rifting, extensional, metamorphic, and therefore mineralisation processes quite distinct from those documented elsewhere in the Arunta. The variety and abundance of mafic-ultramafic rocks in a tectonically dynamic part of the Arunta and the known mineralisation near Mount Riddoch (and Attutra) enhances the prospectivity of this region for PGEs.

Reference(s). Shaw & Wells (1983); Shaw et al. (1984a); Shaw & Freeman (1985); Sivell & Foden (1985); Sivell & McCulloch (1991); Hand et al. (1999a, b).

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Table 1. Mafic and mafic-ultramafic intrusions investigated in the Arunta Province.

Intrusion	*Areal extent (km)*	*Approximate thickness (km)*	*Form*	*Surrounding rocks*	*Major rock types*	*Metamorphic grade*
Western group						
Andrew Young Hills	4.5 x 6.5	> 5	Plunging synform	Migmatitic gneiss, granite	Gabn, MtGabn, BiotGabn, Gab, Ton, Dior	Sub-amphibolite
Papunya gabbro	0.5 x 3	0.4	Dipping sill	Felsic gneiss, gneissic granite, schist	Gab, MtGab, Gabn, Amph, PlPx	Upper amphibolite to granulite
Papunya ultramafic	0.8 x 1.8	?1	Ultramafic ?plug	Psammite, metapelite, felsic gneiss	PlWeb, Web, Gabn, Gab	?Amphibolite
South Papunya gabbro	1 x 3.8	?0.5	Shallow-dipping ?sill	Granite	Gab, BiotGab, QtzGab, BiotTon	Granulite
West Papunya gabbro	0.3 x 0.4	?0.2	Dipping sill	Felsic gneiss	Gabn, Gab	?Amphibolite
Central group						
Anburla Anorthosite	1 x 10	< 1	Folded sheet	Mafic granulite, garnet gneiss	An, AnGab, LGab, Gab, PlPx	Upper amphibolite to granulite
Enbra Granulite	8 x 15	?	Dipping ?folded sheet	Felsic granulite, migmatitic gneiss	MGran, LGab, AnGab, An	Granulite
Harry Anorthositic Gabbro	2 x 6	?1	Elongated bodies	Tonalite, mafic granulite	AnGab, An, QtzAn, LGab, Px	Granulite
Johannsen Metagabbro	5 x 6	< 0.3	Dyke swarm	Felsic granulite, tonalite, anorthositic gabbro	MGran, Gab	Granulite
Mount Chapple Metamorphics	7 x 62	?	Folded sheets	Migmatitic metasediment, felsic gneiss, granite	MGran, Gab, Char	Granulite
Mount Hay Granulite	9 x 35	3	Antiformal sheath fold	Migmatitic metasediment, garnet gneiss	MGran, Gab, Char, LGab, An	Granulite
Mount Stafford dolerite	6 x 7	0.2	Folded dykes and sills	Metapelitic hornfels, psammite	Dol, Gab, Gabn	Amphibolite
Eastern group						
Attutra Metagabbro	4 x 5	?	Dipping sheets	Psammite, metapelite, tonalite, granite	Gab, MtGab, Mt, LGab, Px, Amph	Amphibolite
Kanandra Granulite	15 x > 30	?	Fault-bounded sheets	Quartzofeldspathic gneiss, felsic granulite	MGran, Px	Upper amphibolite to granulite
Mordor Igneous Complex	6 x 6	< 1.2	Alkaline ultramafic plugs	Granitic gneiss, quartzofeldspathic gneiss	Syen, Monz, Shon, Wehr, OlCpx, Lherz, Dun	Sub-amphibolite
Riddock Amphibolite	6 x 70	< 2	Concordant folded sheets	Metapelite, carbonate, schist, gneiss	Amph, Ton, AnGab, An, Per	Upper amphibolite to granulite

Major rock types are arranged in approximate order of decreasing abundance. The prefix 'meta' has been deleted from all metamorphosed rock types. Amph = amphibolite; An = anorthosite; AnGab = anorthositic gabbro; BiotGab = Biotite gabbro; BiotGabn = biotite gabbronorite; BiotTon = biotite tonalite; Char = charnockite; Dior = diorite; Dol = dolerite; Dun = dunite; Gab = Gabbro; Gabn = gabbronorite; LGab = leucogabbro; Lherz = lherzolite; MGran =mafic granulite; Monz = monzonite; Mt = magnetitite; MtGab = magnetite gabbro; MtGabn = magnetite gabbronorite; OlCpx = olivine clinopyroxenite; Per = peridotite; PlPx = plagioclase pyroxenite; PlWeb = plagioclase websterite; Px = pyroxenite; QtzGab = quartz gabbro; Shon = shonkinite; Syen = syenite; Ton = tonalite; Web = websterite; Wehr = wehrlite.

Appendix 1. Rock samples collected from the Arunta Province.

Intrusion	*1:100 000 Sheet*	*Easting*	*Northing*	*Rock type*	*Traverse height (m)*	*Mag susc (SI(10^{-6}))*
Enbra Granulite						
2000081001	Burt	383033	7429429	Mafic granulite	50	1360
2000081002	Burt	381645	7432034	Mafic granulite	1200	550
2000081003	Burt	382622	7432203	Mafic granulite	1600	10 200
2000081004	Burt	383160	7432775	Mafic granulite	2200	330
2000081005	Burt	383477	7433235	Mafic granulite	2800	2660
2000081006	Burt	383467	7433969	Mafic granulite	3500	250
2000081007	Burt	384092	7434343	Mafic granulite	4000	840
2000081008	Burt	384278	7434664	Anorthositic granulite	4300	16 800
2000081009	Burt	385219	7434613	Anorthosite	4800	80
2000081010	Burt	385678	7434793	Anorthositic gabbro	5400	9990
2000081011	Burt	384363	7434635	Felsic granulite		7260
Mount Hay Granulite						
2000081012	Anburla	299221	7402270	Mafic granulite	830	3480
2000081013	Anburla	299246	7402470	Mafic granulite	1100	2950
2000081014	Anburla	299593	7402886	Mafic granulite	1680	2430
2000081015	Anburla	299669	7403248	Mafic granulite	2260	3600
2000081016	Anburla	300037	7404147	Mafic granulite	3560	23 000
2000081017	Anburla	300463	7404527	Mafic granulite	4050	1450
2000081018	Anburla	300490	7405182	Mafic granulite	4800	1700
2000081019	Anburla	300582	7405559	Mafic granulite	5380	430
2000081020	Anburla	300586	7406030	Leucogabbro	6020	1350
2000081021	Anburla	300685	7406540	Leucogabbro	6660	4000
2000081022	Anburla	300897	7406901	Mafic granulite	7150	5300
2000081023	Anburla	300975	7407259	Mafic granulite	7760	9350
2000081024	Anburla	301067	7407482	Mafic granulite	8110	730
2000081025	Anburla	301123	7407786	Mafic granulite	8570	2230
2000081026	Anburla	301244	7408166	Mafic granulite	8800	950
2000081027	Anburla	301698	7408671	Mafic granulite	9290	1350
2000081028	Anburla	301952	7409055	Mafic granulite?	9990	14 600
2000081029	Anburla	302266	7409893	Mafic granulite	11 200	4250
2000081030	Anburla	300867	7401169	Mafic granulite	50	5000
2000081031	Anburla	300776	7401515	Mafic granulite	690	3870
2000081032	Anburla	296313	7408940	Chilled mafic granulite	1	4900
2000081033	Anburla	313659	7403395	Mafic granulite	200	58 000
2000081034	Anburla	313689	7403454	Mafic granulite	580	2400

2000081035	Anburla	314044	7403767	Mafic granulite	1160	1050
2000081036	Anburla	314404	7404218	Mafic granulite	1710	1080
2000081037	Anburla	314556	7404542	Mafic granulite	2230	1450
2000081038	Anburla	314671	7404934	Mafic granulite	2750	550
2000081039	Anburla	314777	7405400	Mafic granulite	3160	3200
2000081040	Anburla	314921	7405607	Mafic granulite	3680	360
2000081041	Anburla	315272	7405858	Mafic granulite	4120	350
Anburla Anorthosite						
2000081042	Anburla	315373	7405974	Anorthosite	4440	60
2000081043	Anburla	315515	7406194	Anorthosite	4820	170
2000081044	Anburla	315793	7406387	Anorthosite	5170	120
Mount Hay Granulite						
2000081045	Anburla	317814	7404312	Gabbro		3500
2000081046	Anburla	317817	7404266	Leucogabbro		4150
2000081047	Anburla	317773	7403835	Anorthosite		2100
2000081048	Anburla	298170	7404377	Charnockite		4000
Anburla Anorthosite						
2000081049	Macdonnell Ranges	325070	7399334	Leucogabbro		240
Mount Chapple Metamorphics						
2000081050	Narwietooma	270173	7414054	Mafic granulite	440	1170
2000081051	Narwietooma	270533	7414335	Mafic granulite	1140	1100
2000081052	Narwietooma	271150	7414480	Mafic granulite	1630	37 500
2000081053	Narwietooma	271870	7414920	Mafic granulite	2650	48 000
2000081054	Narwietooma	272310	7415530	Mafic granulite	3460	18 600
2000081055	Narwietooma	272570	7416640	Mafic granulite	5260	2020
2000081056	Narwietooma	272530	7416990	Mafic granulite	5750	840
2000081057	Narwietooma	272620	7417385	Mafic granulite	6270	7040
2000081058	Narwietooma	272750	7417620	Mafic granulite	6700	550
2000081059	Narwietooma	272890	7417940	Mafic granulite	7020	470
2000081060	Narwietooma	273480	7418190	Mafic granulite	7250	20 200
2000081061	Narwietooma	273514	7418618	Mafic granulite	7690	4500
2000081062	Narwietooma	273600	7418972	Mafic granulite	8180	3250
Mount Stafford dolerite						
2000081063	Reynolds Range	260595	7563682	Dolerite		510
2000081064	Reynolds Range	260395	7563685	Dolerite		730
2000081065	Reynolds Range	260224	7563653	Dolerite		520
2000081066	Reynolds Range	259160	7563740	Dolerite		17 000
2000081067	Reynolds Range	258390	7563700	Dolerite		540

2000081068	Reynolds Range	257930	7563090	Dolerite	790
2000081069	Reynolds Range	257690	7563960	Dolerite	650
2000081070	Reynolds Range	257190	7563815	Dolerite	620
Unnamed tonalite and dolerite					
2000081071	Laughlen	404449	7429436	Tonalite	19 000
2000081072	Laughlen	404377	7429359	Dolerite (?Stuart Dyke Swarm)	59 000
Johannsen Metagabbro					
2000081073	Laughlen	405706	7429005	Mafic granulite	13 100
Harry Anorthositic Gabbro					
2000081074	Laughlen	405678	7429115	Leucogabbro	480
2000081075	Laughlen	405876	7429445	Leucogabbro	1910
Johannsen Metagabbro					
2000081076	Laughlen	405980	7429721	Mafic granulite	7520
2000081077	Laughlen	406229	7430425	Mafic granulite	18 100
2000081078	Laughlen	406589	7430721	Mafic granulite	6100
2000081079	Laughlen	407099	7431210	Mafic granulite	4120
2000081080	Laughlen	407289	7430781	Mafic granulite	29 500
Harry Anorthositic Gabbro					
2000081081	Laughlen	406846	7429008	Leucogabbro	210
2000081082	Laughlen	407414	7429576	Leucogabbro	160
2000081083	Laughlen	407426	7429736	Leucogabbro	330
2000081084	Laughlen	403611	7429422	Anorthosite	3400
Mordor Igneous Complex					
2000081085	Laughlen	447960	7407885	Phlogopite olivine pyroxenite	21 500
2000081086	Laughlen	447766	7406856	Phlogopite lherzolite	10 200
2000081087	Laughlen	447050	7407955	Phlogopite olivine pyroxenite	11 500
2000081088	Laughlen	446880	7407705	Phlogopite lherzolite	18 900
2000081089	Laughlen	446680	7407445	Phlogopite lherzolite	23 500
2000081090	Laughlen	446695	7407120	Phlogopite pyroxenite	10 700
2000081091	Laughlen	445437	7409590	?Shonkinite	2600
2000081092	Laughlen	448651	7408367	Phlogopite plagioclase pyroxenite	1530
Attutra Metagabbro					
2000081093	Jervois Range	637094	7499889	Gabbro	240
2000081094	Jervois Range	636677	7499678	Gabbro	180
2000081095	Jervois Range	636196	7499031	Gabbro	5030
2000081096	Jervois Range	635576	7499527	Gabbro	36 000
2000081097	Jervois Range	636506	7501302	Gabbro	380
2000081098	Jervois Range	635931	7501851	Gabbro	200

2000081099	Jervois Range	635962	7501847	Gabbro	38 000
2000081100	Jervois Range	636218	7500967	Gabbro	280
2000081101	Jervois Range	636794	7497963	Gabbro	3500
2000081102	Jervois Range	638706	7498003	Gabbro	260
2000081103	Jervois Range	635228	7499425	Chilled gabbro	470
Unnamed gabbro					
2000081104	Jervois Range	633815	7490915	Gabbro	300
2000081105	Jervois Range	633642	7489381	Quartz leucogabbro	14 500
Riddock Amphibolite					
2000081106	Riddoch	473876	7448611	Amphibolite	420
2000081107	Riddoch	474383	7447369	Amphibolite	370
2000081108	Riddoch	474471	7446713	Amphibolite	150
2000081109	Riddoch	475406	7446454	Amphibolite	160
2000081110	Riddoch	475507	7446080	Amphibolite	240
2000081111	Riddoch	476160	7445455	Dolerite	610
2000081112	Riddoch	476742	7444396	Amphibolite	370
Andrew Young Hills					
2000081113	Gurner	693905	7476231	Gabbronorite	32 200
2000081114	Gurner	693796	7475837	Gabbro	38 000
2000081115	Gurner	693834	7475300	Gabbronorite	16 000
2000081116	Gurner	694617	7475328	Gabbro	22 500
2000081117	Gurner	695283	7475178	Gabbronorite	40 000
2000081118	Gurner	695734	7475508	Gabbro	40 500
2000081119	Gurner	696401	7476064	Gabbro	30 300
2000081120	Gurner	695905	7475188	Gabbronorite	21 000
2000081121	Gurner	696417	7474932	Gabbro	32 000
2000081122	Gurner	696528	7474517	Gabbronorite	38 300
2000081123	Gurner	696750	7474349	Gabbronorite	45 000
2000081124	Gurner	698060	7474824	Gabbronorite	17 500
2000081125	Gurner	698181	7474345	Gabbronorite	22 500
2000081126	Gurner	697877	7474096	Gabbro	35 600
2000081127	Gurner	697364	7473982	Gabbronorite	18 600
2000081128	Gurner	697090	7473550	Gabbronorite	27 700
2000081129	Gurner	697740	7473640	Gabbronorite	34 700
2000081130	Gurner	698265	7473490	Gabbronorite	28 700
2000081131	Gurner	695930	7472324	Gabbronorite	17 300
2000081132	Gurner	697394	7474000	Gabbronorite	19 300
Papunya gabbro					

2000081133	Haast Bluff	775879	7423495	Gabbro	2	71 600
2000081134	Haast Bluff	775952	7423467	Gabbronorite	80	1740
2000081135	Haast Bluff	775948	7423386	Gabbronorite	200	24 000
2000081136	Haast Bluff	776022	7423282	Gabbronorite	350	12 000
2000081137	Haast Bluff	776091	7423189	Chilled gabbro	480	6700
2000081138	Haast Bluff	776089	7423093	Gabbro	550	1150
Papunya ultramafic						
2000081139	Haast Bluff	776385	7421767	Plagioclase websterite		450
2000081140	Haast Bluff	776269	7421730	Microgabbronorite		430
2000081141	Haast Bluff	776216	7421736	Plagioclase websterite		440
2000081142	Haast Bluff	776631	7422135	Chilled plagioclase websterite		480
2000081143	Haast Bluff	776109	7422128	Plagioclase websterite		470
2000081144	Haast Bluff	775446	7421767	Gabbro		280
West Papunya gabbro						
2000081145	Haast Bluff	763360	7425070	Chilled gabbro		3400
2000081146	Haast Bluff	763180	7425010	Gabbronorite		3280
2000081147	Haast Bluff	763330	7424998	Gabbronorite		800
2000081148	Haast Bluff	763430	7424946	Gabbronorite		380
South Papunya gabbro						
2000081149	Haast Bluff	789617	7420123	Gabbro		340
2000081150	Haast Bluff	789315	7420354	Gabbro		330
2000081151	Haast Bluff	789162	7420481	Gabbro		260
Kanandra Granulite				Gabbro		
2000081152	Delny	493566	7482145	Gabbro	50	26 400
2000081153	Delny	493372	7482929	Gabbro	1000	32 700
2000081154	Delny	493562	7483253	Gabbro	1400	25 500
2000081155	Delny	494177	7483597	Gabbro	1900	17 100
2000081156	Delny	494243	7483953	Gabbro	2400	5950
2000081157	Delny	494487	7484157	Gabbro	2700	340
Attutra Metagabbro (extra)						
2000081158	Jervois Range	635230	7499435	Gabbro		550
Mordor Complex (extra)						
2000081159	Laughlen	448683	7408367	Chilled pyroxenite		6400
2000081160	Laughlen	447620	7408870	Phlogopite olivine pyroxenite		14 200

Appendix 2. Mafic and felsic rocks sampled for U-Pb geochronology.

Pr	*Intrusion (1:250 000 sheet)* *Geochronology sample number*	*Rock type*	*Easting* (*GDA 94 ~ WGS 84)*	*Northing*	*Equivalent geochemical sample in OZCHEM (Zr content)*
	1 Papunya ultramafic (MT LIEBIG)				
b	2000081201	Pegmatitic gabbro	776280	7421753	
a	2000081202	Gabbro	776315	7421751	
	2 Papunya gabbro (MT LIEBIG)				
a	2000081203	Gabbro	775879	7423495	2000081133 (221 ppm)
b	2000081204	Aplite dyke cutting gabbro	775922	7423448	
b	2000081205	Gneiss country rock	775887	7423828	
	3 South Papunya gabbro (MT LIEBIG)				
a	2000081206	Gabbro	789617	7420123	2000081149 (35 ppm)
b	2000081207	Granite (coeval melt or later intrusion)	789617	7420123	
b	2000081208	Gneiss country rock	789773	7419983	
	4 Mount Chapple Metamorphics (HERMANNSBURG)				
b	2000081209	Mafic granulite	273514	7418618	2000081061 (145 ppm)
d	2000081210	Felsic granulite interlayer	273509	7418654	
a	2000081211	Mafic granulite	273600	7418972	2000081062 (182 ppm)
c	2000081212	Granite melt coeval to #211	273600	7418972	
	5 Mount Hay (HERMANNSBURG)				
a	2000081213	Mafic granulite	300975	7407259	2000081023 (118 ppm)
b	2000081214	Mafic granulite	301952	7409055	2000081028 (102 ppm)
	6 Attutra Metagabbro (HUCKITTA)				
a	2000081215	Gabbro chilled margin	635228	7499425	2000081103 (153 ppm)
c	2000081216	Tonalite cutting #215	635228	7499425	
c	2000081217	Psammitic schist country rock	635184	7499424	
b	2000081218	Felsic melt coeval to #215	635283	7499321	
c	2000081219	Granite dyke cutting #215	635342	7499278	
	7 Johannsen Metagabbro (ALICE SPRINGS)				
a	2000081220	Mafic granulite	406229	7430425	2000081077 (57 ppm)
	9 'Stuart Dyke' (ALICE SPRINGS)				
a	2000081221	Dolerite dyke cutting Harry Anorthositic Gabbro and associated tonalite	404377	7429359	2000081072 (85 ppm)
	8 Harry Anorthositic Gabbro (ALICE SPRINGS)				
a	2000081222	Tonalite cutting Harry Anorthositic Gabbro	404449	7429436	2000081071 (93 ppm)
	10 Mordor Igneous Complex (ALICE SPRINGS)				
a	2000081223	Pyroxenite cutting syenite	448651	7408367	2000081092 (112 ppm)
b	2000081224	Syenite	448685	7408367	
	11 Enbra Granulite (ALICE SPRINGS)				
b	2000081225	Mafic granulite	382622	7432203	2000081003 (83 ppm)
a	2000081226	Mafic granulite (with coeval felsic melts)	383477	7433235	2000081005 (93 ppm)
	12 Andrew Young Hills (MT DOREEN)				
a	2000081227	Gabbronorite	697394	7474000	2000081132 (115 ppm)

Pr = priority of sample for U-Pb zircon geochronology: a>b>c.

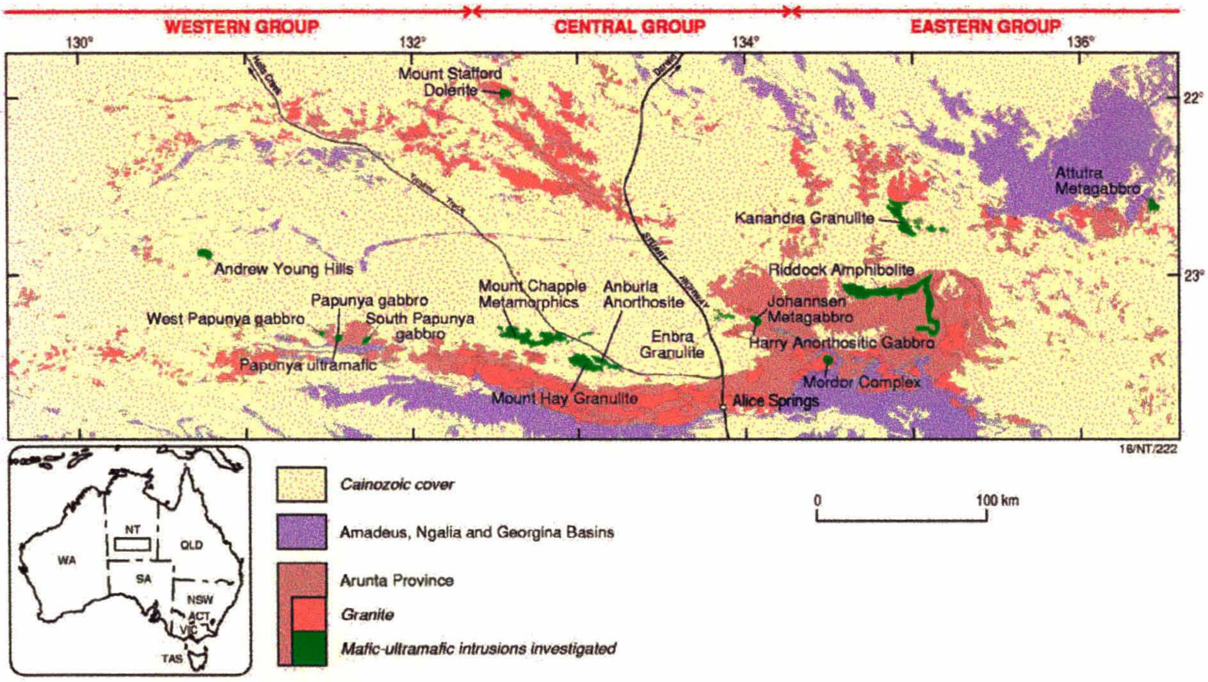

Figure 1. Mafic-ultramafic intrusions investigated in the Arunta Province.

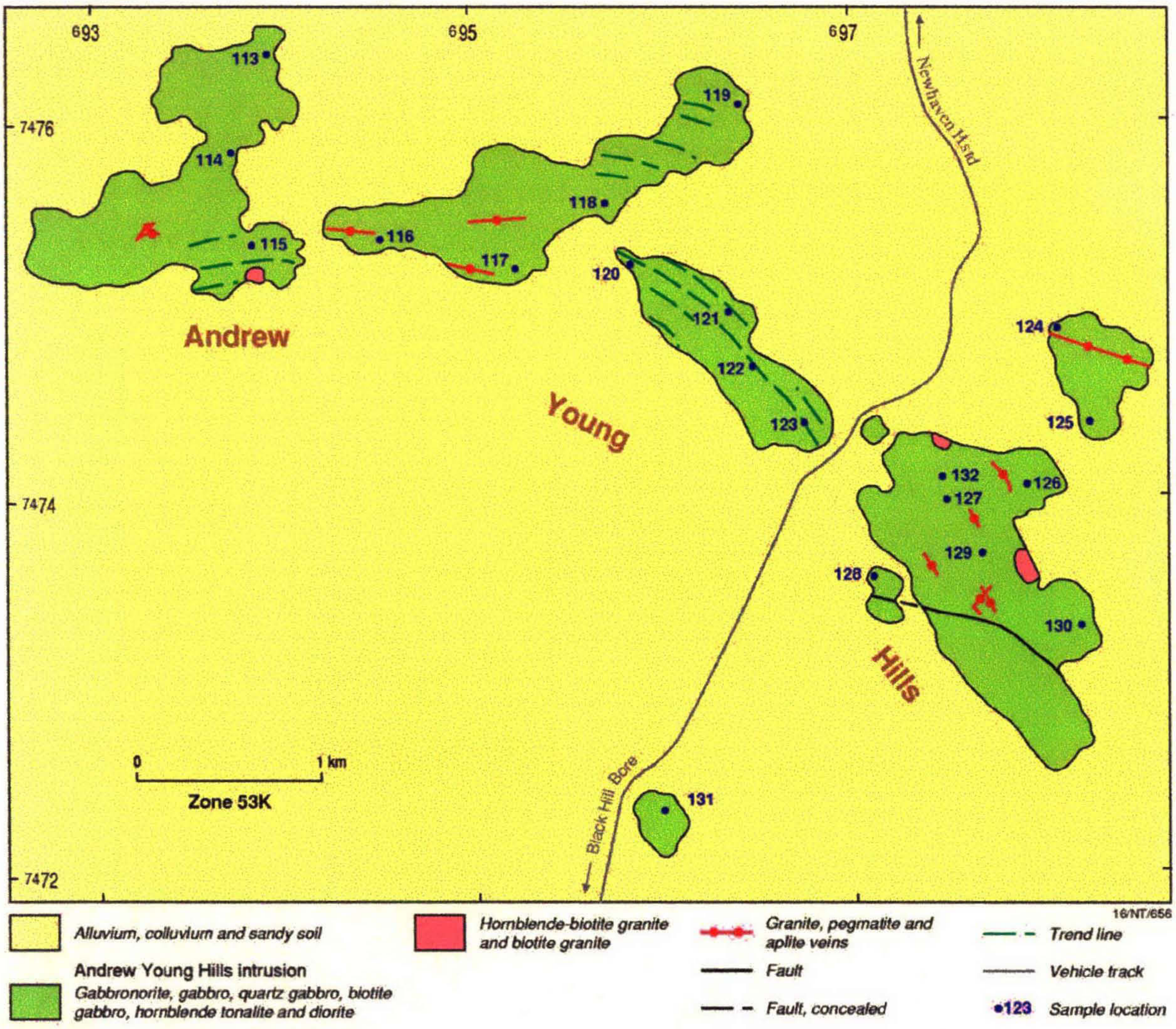

Figure 2. Geological map of the Andrew Young Hills mafic intrusion.

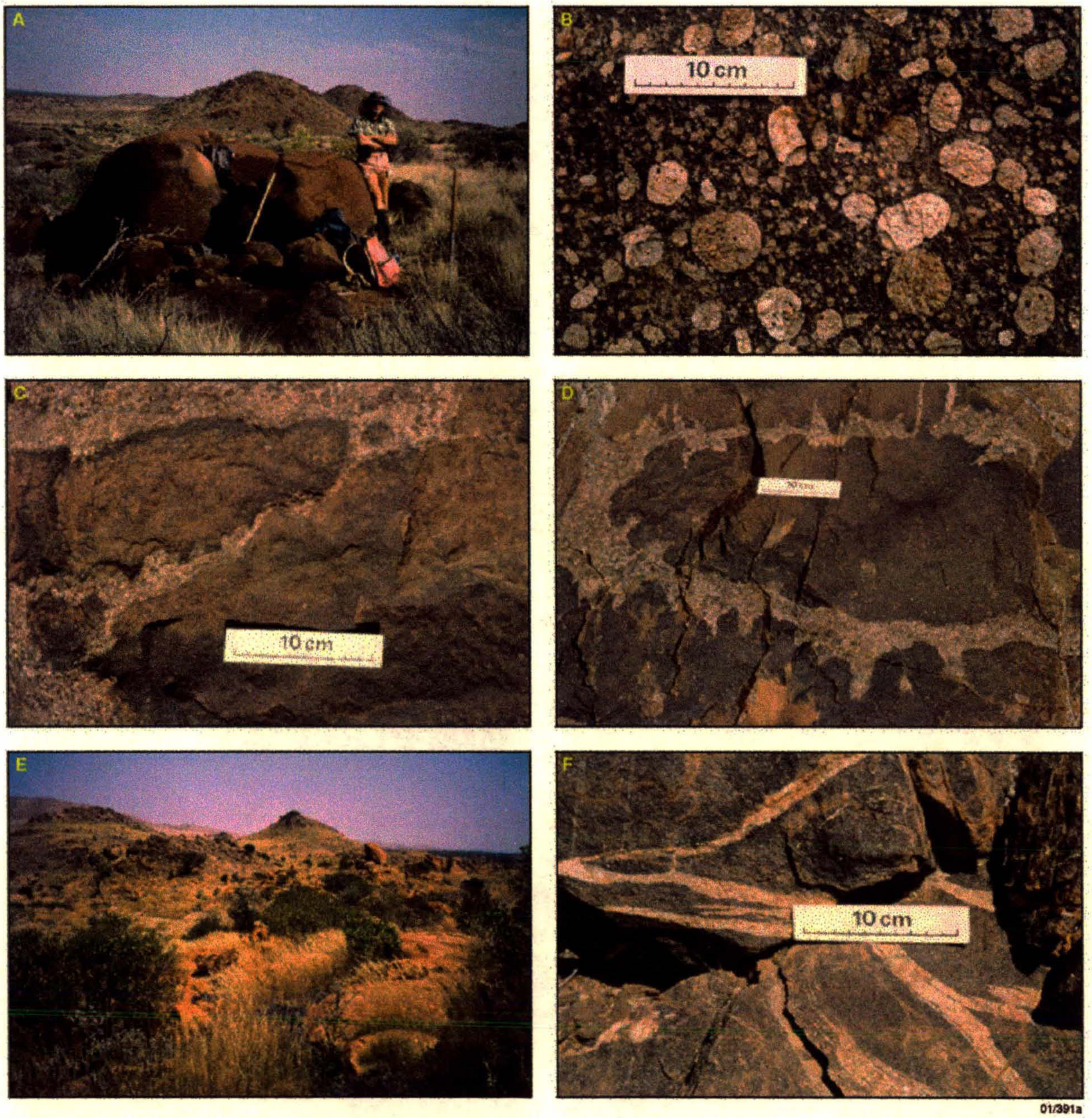

Figure 3A–F. Field relationships of western group of intrusions.

A. Typical outcrop of gabbro and hills, Andrew Young Hills. Site of U-Pb zircon geochronology sample 2000081227 (AMG ^{6}97394 ^{74}74000: Appendix 2).

B. Resorbed alkali feldspar xenocrysts in hybrid tonalite, Andrew Young Hills (near AMG ^{6}97394 ^{74}74000).

C. Mafic pillow with cuspate and contaminated margins enclosed in fine-grained granite, Andrew Young Hills (AMG ^{6}93740 ^{74}75728).

D. Mafic pillow with cuspate and contaminated margins enclosed in fine-grained granite, Andrew Young Hills (small granite body ~200 m north of sample 2000081132 on Fig. 2).

E. View looking southwest across granite sheets (foreground) intruding gabbro (dark hills), South Papunya gabbro.

F. Irregular granite veins and veinlets intruding contaminated gabbro, South Papunya gabbro. Site of U-Pb zircon geochronology sample 2000081207 (AMG ^{7}89617 ^{74}20123: Appendix 2).

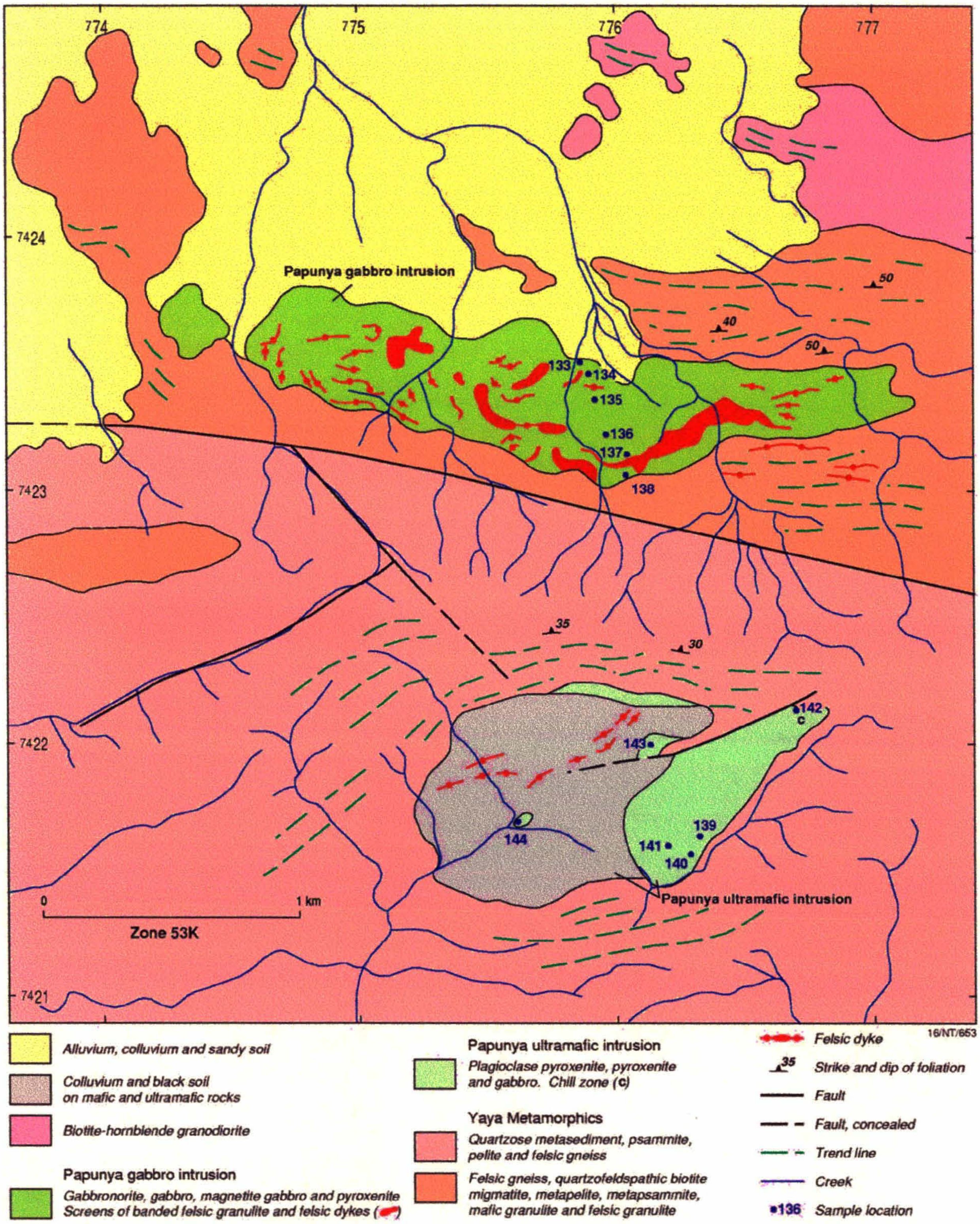

Figure 4. Geological map of the Papunya gabbro and Papunya ultramafic intrusions.

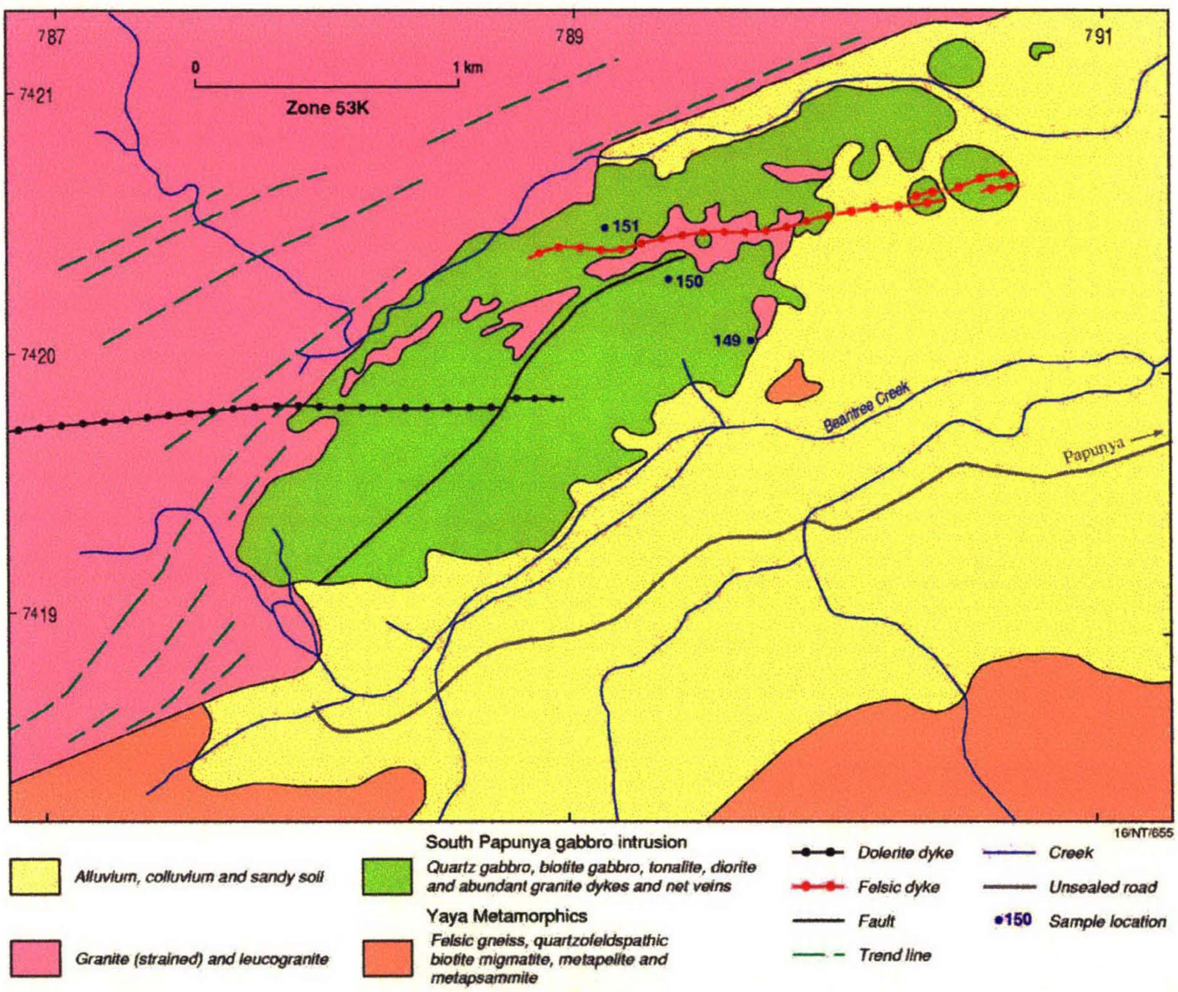

Figure 5. Geological map of the South Papunya gabbro intrusion.

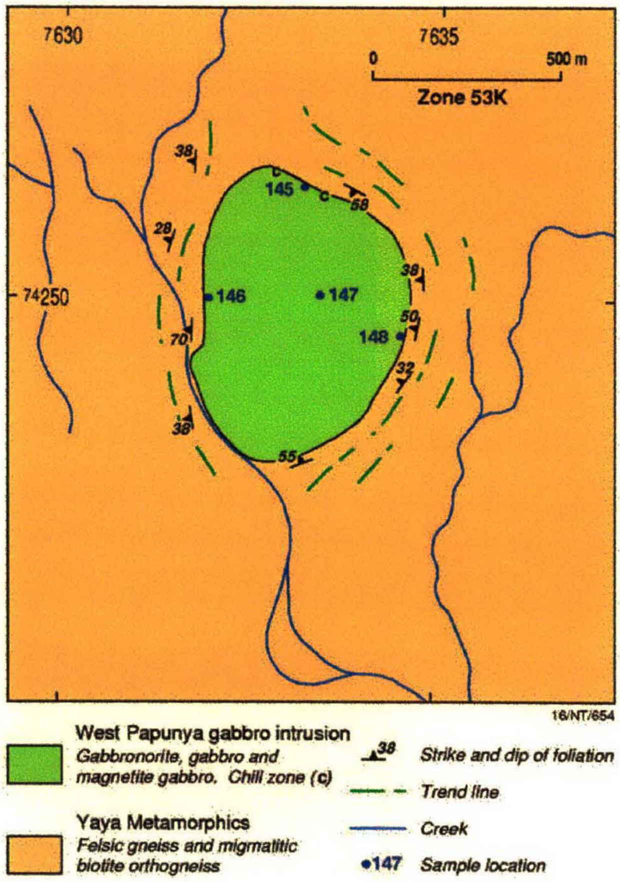

Figure 6. Geological map of the West Papunya gabbro intrusion.

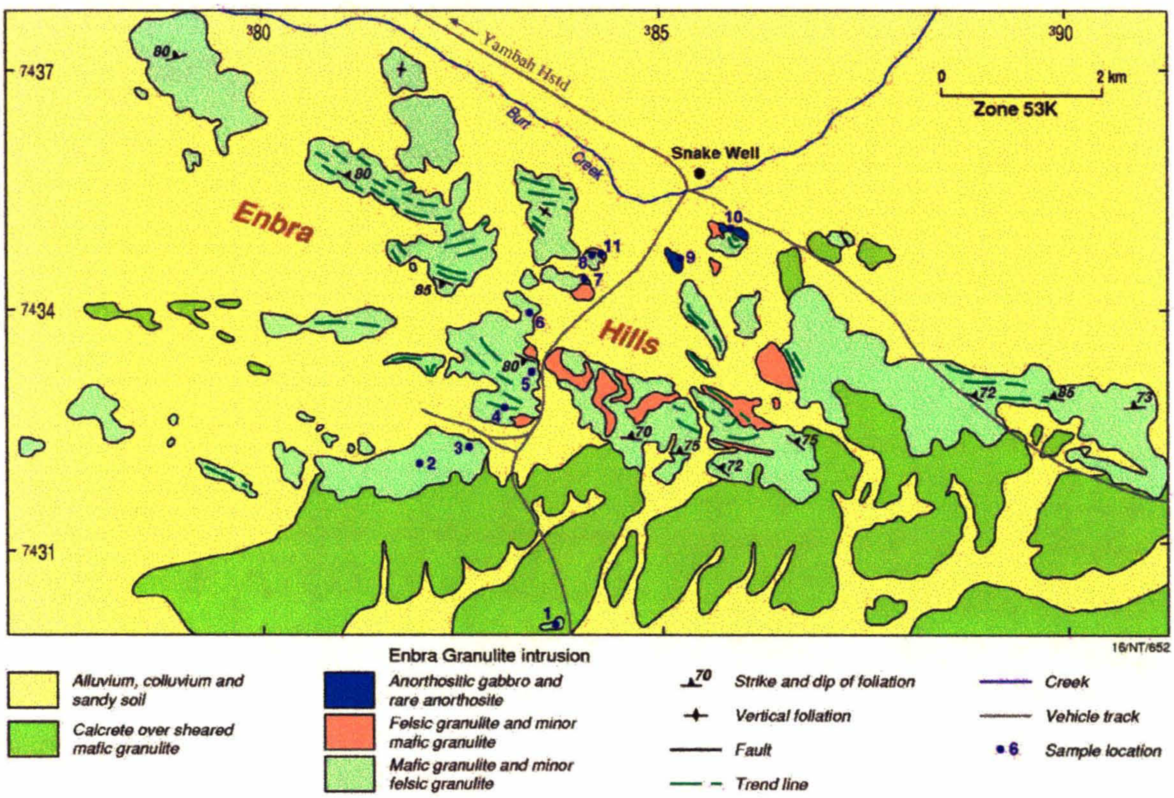

Figure 7. Geological map of the Enbra Granulite intrusion (modified after Shaw et al. 1983).

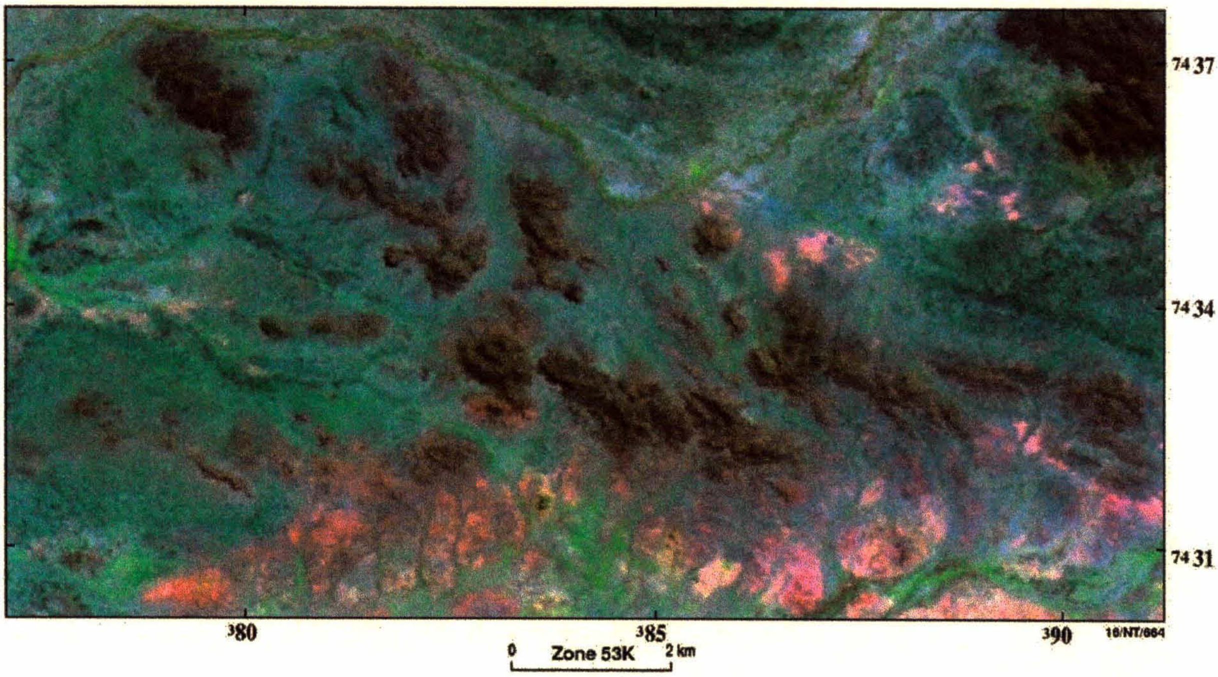

Figure 8. Landsat-5 Thematic Mapper colour composite image of the Enbra Granulite intrusion using bands 1, 4 and 7 displayed as red, green and blue, respectively. The area shown is the same as that for the geological map of Figure 7.

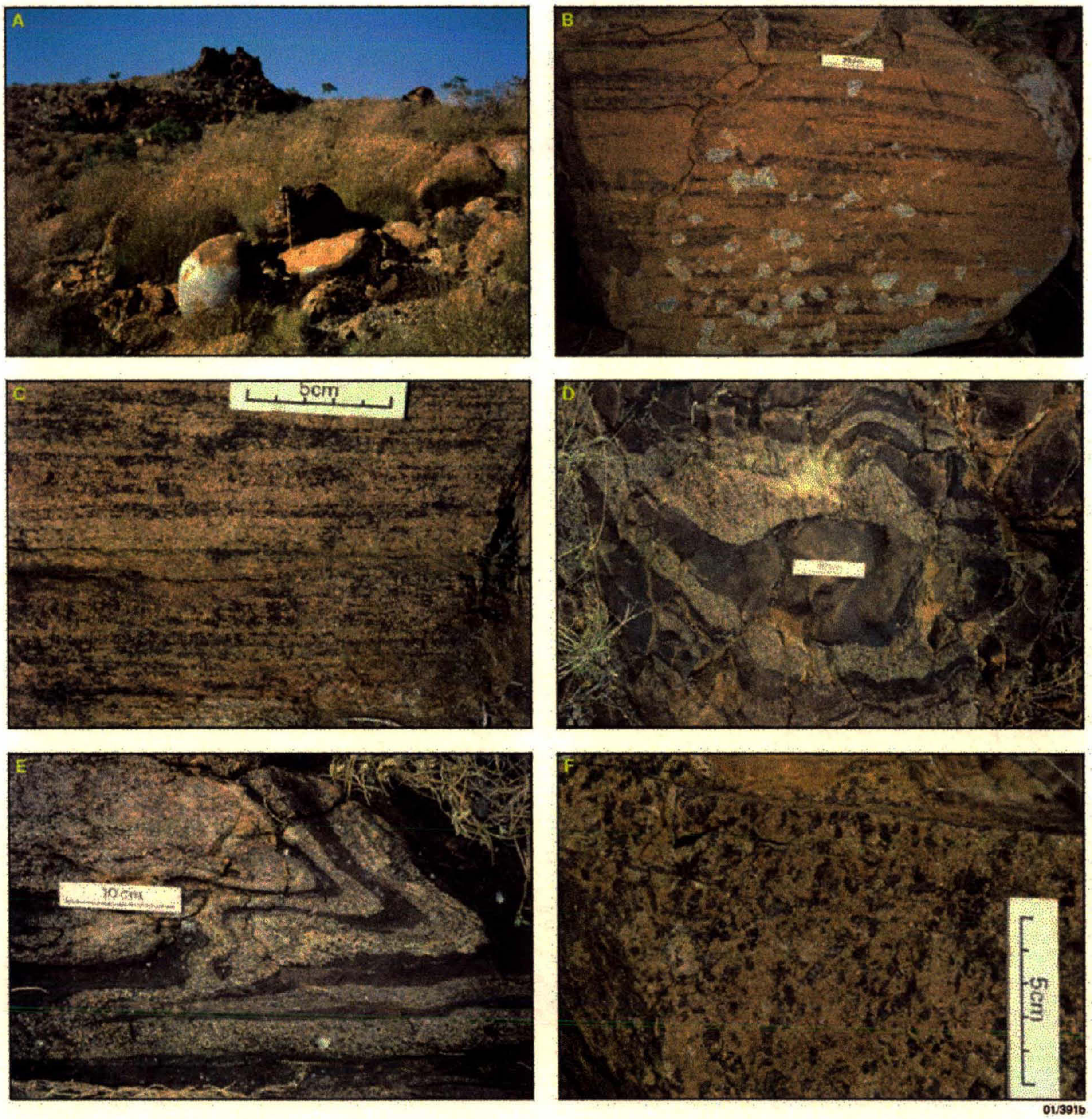

Figure 9A–F. Field relationships of central group of intrusions.

A. Typical bouldery outcrop of anorthosite, Anburla Anorthosite (near sample 2000081044 on Fig. 14).

B. Wispy compositional layering/banding in Anburla Anorthosite (near AMG ^{3}15793 ^{74}06387).

C. Compositional layering/banding in Anburla Anorthosite (near AMG ^{3}15793 ^{74}06387).

D. Irregular mafic granulite pillow and layers in felsic granulite, Enbra Granulite (near AMG ^{3}83477 ^{74}33235).

E. Folded mafic and felsic granulite layers, Enbra Granulite (near AMG ^{3}83477 ^{74}33235).

F. Amphibole leucogabbro, Enbra Granulite (AMG ^{3}85219 ^{74}34613).

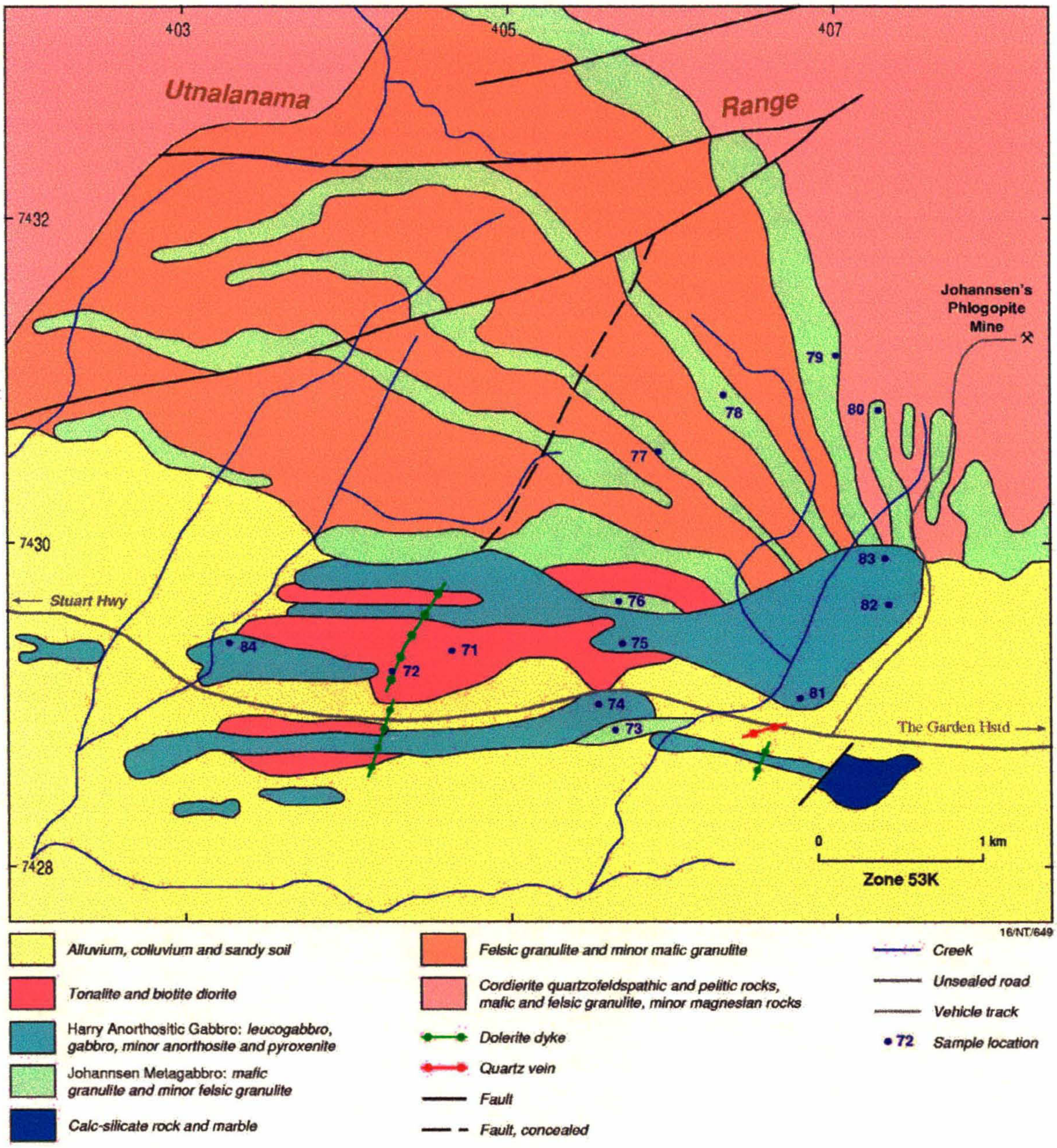

Figure 10. Geological map of the Harry Anorthositic Gabbro and Johannsen Metagabbro intrusions (modified after Shaw et al. 1983).

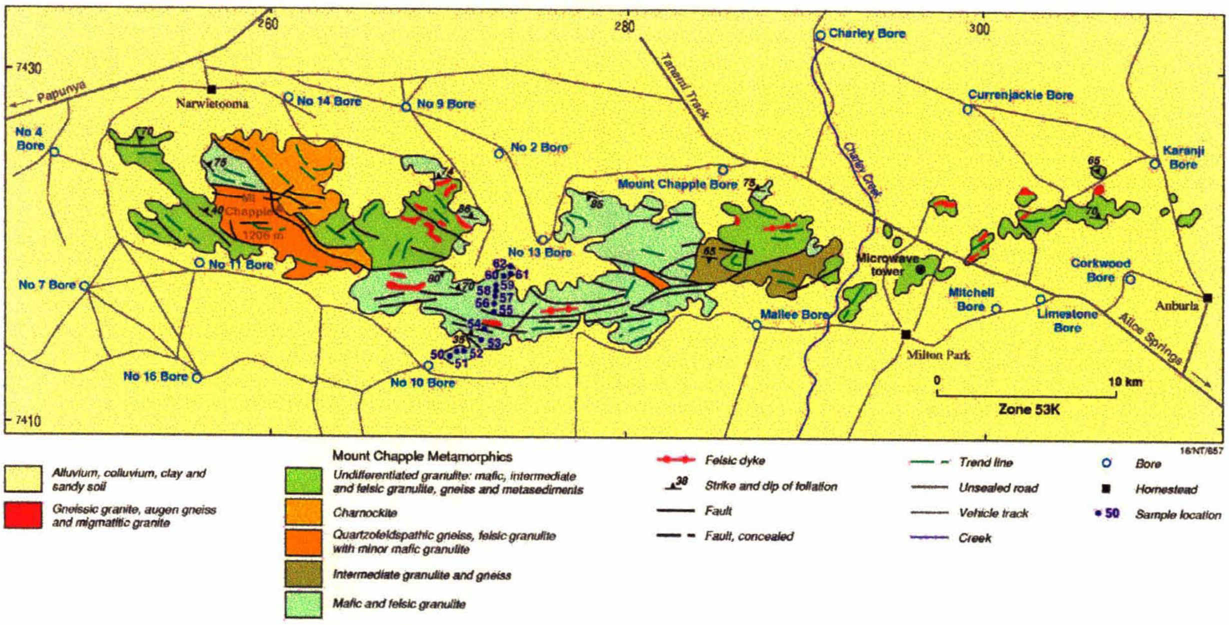

Figure 11. Geological map of the Mount Chapple Metamorphics (modified after Glikson et al. 1983 and Shaw et al. 1995).

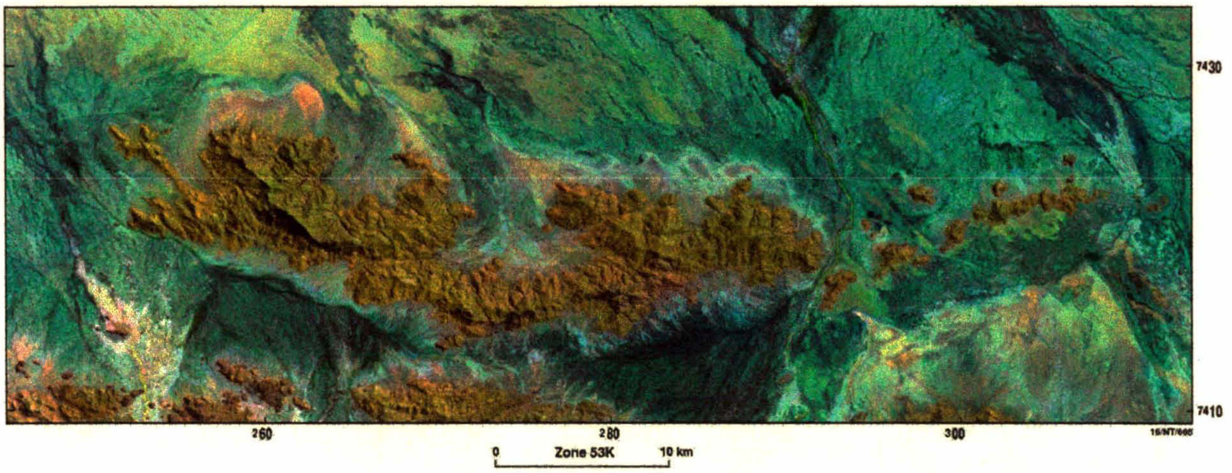

Figure 12. Landsat-5 Thematic Mapper colour composite image of the Mount Chapple Metamorphics using bands 1, 4 and 7 displayed as red, green and blue, respectively. The area shown is the same as that for the geological map of Figure 11.

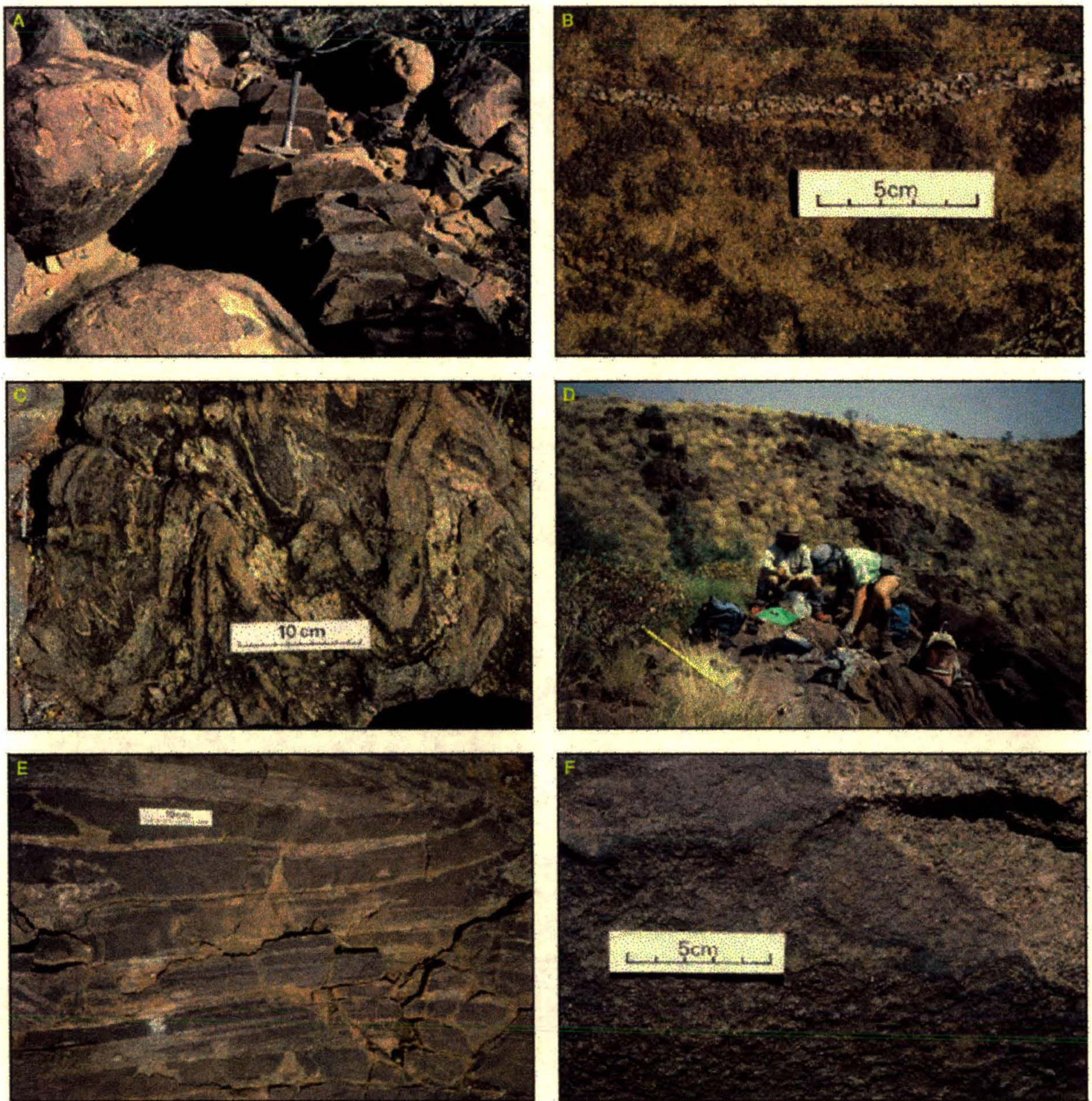

Figure 13A–F. Field relationships of central group of intrusions.
A. Jointed dolerite dyke (hammer) intruding massive tonalite and Harry Anorthositic Gabbro. Near site of U-Pb zircon geochronology sample 2000081221 (AMG $^{4}04377$ $^{74}29359$: Appendix 2).
B. Thin tonalite vein cutting clots of amphibole (after ?clinopyroxene) in mottled anorthosite, Harry Anorthositic Gabbro (AMG $^{4}05876$ $^{74}29445$).
C. Strongly folded calc-silicate rocks and psammitic metasediments (?Ankala gneiss), southeast of Harry Anorthositic Gabbro (near AMG $^{4}06910$ $^{74}28770$).
D. Strike ridges of interlayered mafic and felsic granulite, Mount Chapple Metamorphics. Site of U-Pb zircon geochronology sample 2000081210 (AMG $^{2}73509$ $^{74}18654$: Appendix 2).
E. Interlayered mafic and felsic granulite, Mount Chapple Metamorphics (near AMG $^{2}73514$ $^{74}18618$).
F. Chilled margin of mafic granulite pillow against fine-grained granite, Mount Chapple Metamorphics. Site of U-Pb zircon geochronology sample 2000081211 (AMG $^{2}73600$ $^{74}18972$: Appendix 2).

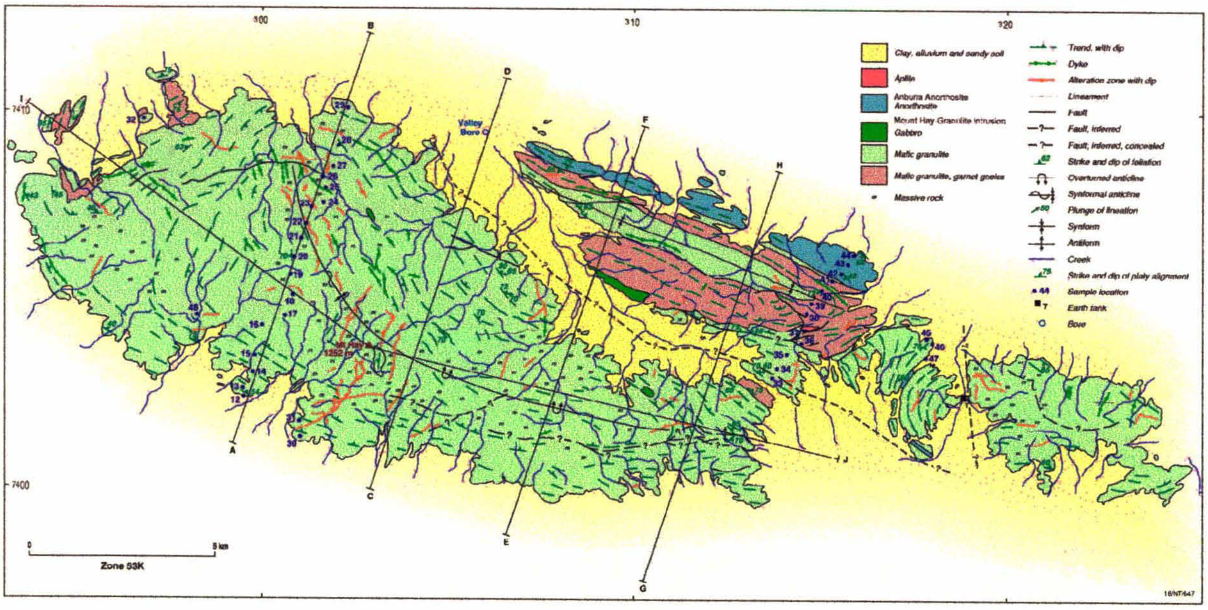

Figure 14. Geological map of the Mount Hay Granulite and Anburla Anorthosite mafic intrusions (modified after Glikson et al. 1983 and Shaw et al. 1995).

Figure 15. Landsat-5 Thematic Mapper colour composite image of the Mount Hay Granulite and Anburla Anorthosite mafic intrusions using bands 1, 4 and 7 displayed as red, green and blue, respectively. The area shown is the same as that for the geological map of Figure 14.

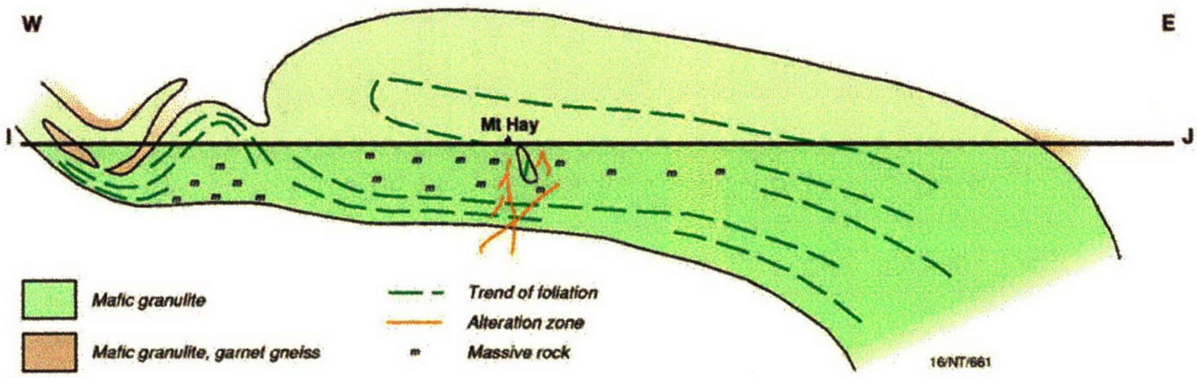

Figure 16. Longitudinal section of the Mount Hay Granulite and Anburla Anorthosite mafic intrusions.

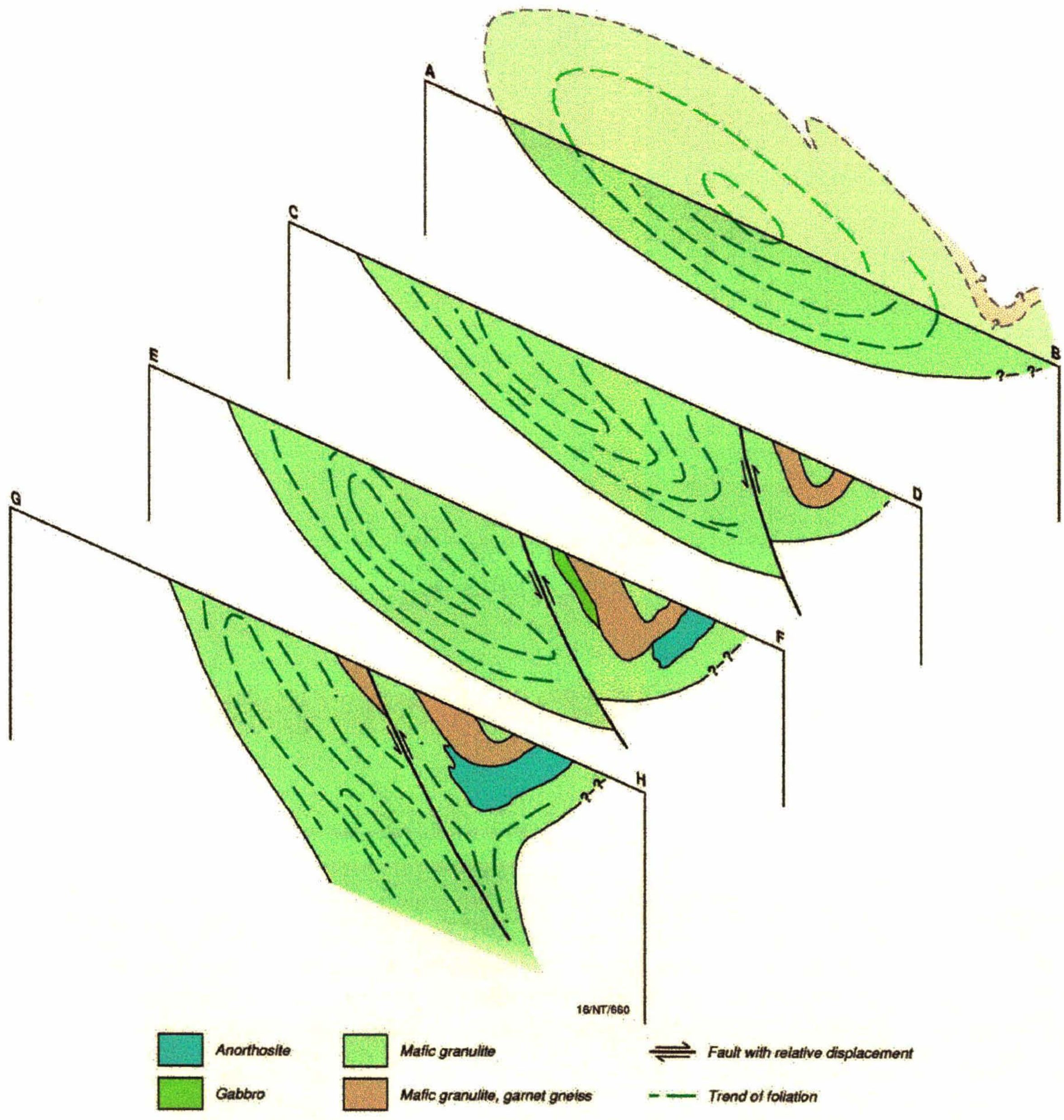

Figure 17. Perspective cross-sections (looking southwest) of the Mount Hay Granulite and Anburla Anorthosite mafic intrusions.

Figure 18A–F. Field relationships of central group of intrusions.

A. View looking southeast across central part of Mount Hay Granulite.

B. High-Zr mafic granulite (geochronology sample 2000081213: Appendix 2) used for U-Pb zircon geochronology (AMG ^{3}00975 ^{74}07259).

C. Wispy layered mafic granulite and leucogabbro, Mount Hay Granulite (AMG ^{3}00582 ^{74}05559).

D. Stacked sequence of mafic granulite (dark) and charnockite (light) layers, Mount Hay Granulite (near AMG ^{2}97962 ^{74}04300).

E. Deformed mafic granulite ?pillow and lenses in felsic granulite, Mount Hay Granulite (near AMG ^{2}97984 ^{74}04238).

F. Deformed mafic granulite ?pillows in felsic granulite, Mount Hay Granulite (near AMG ^{2}97984 ^{74}04238).

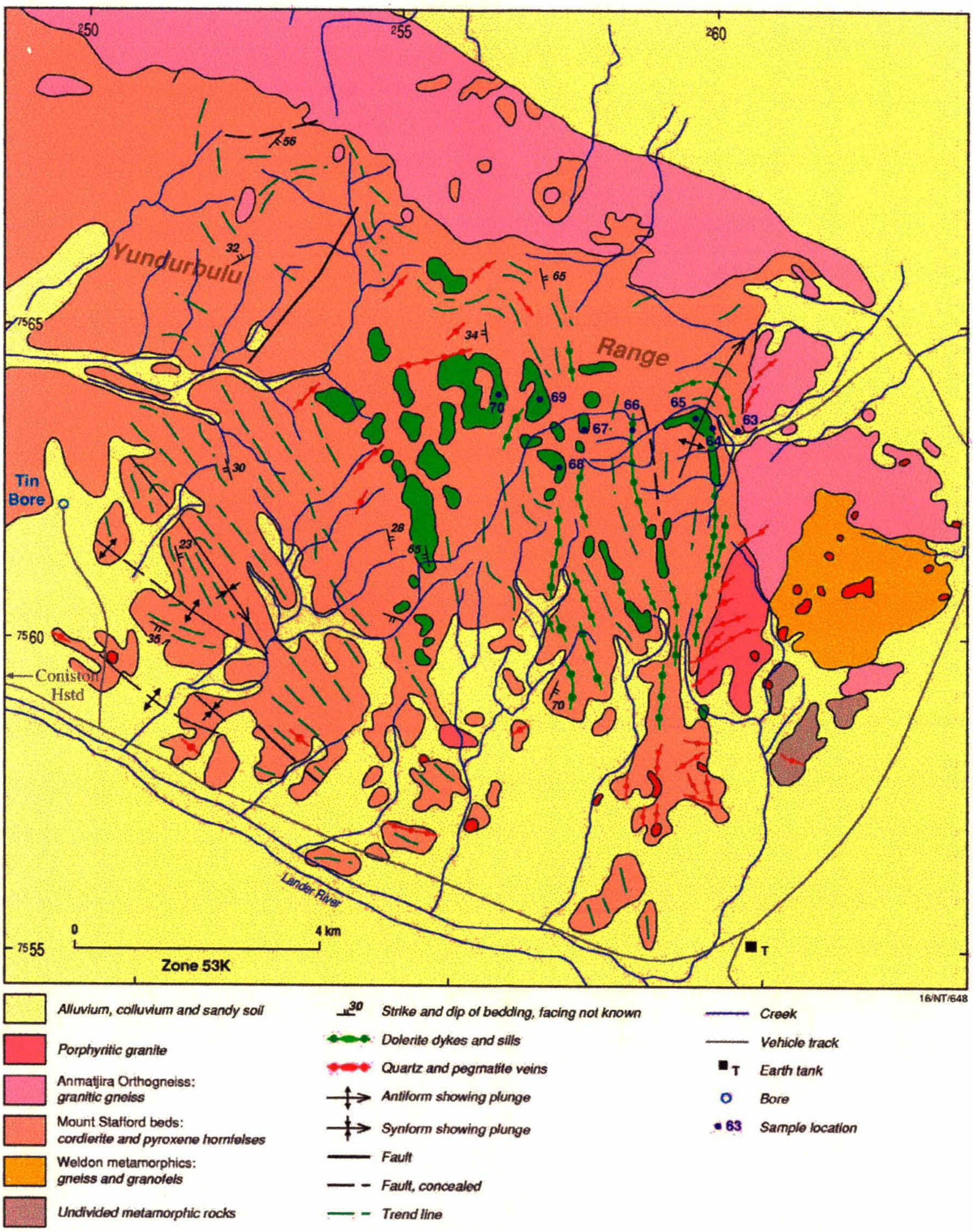

Figure 19. Geological map of the Mount Stafford dolerite intrusions (shown as green bodies on map face; modified after Stewart et al. 1981).

Figure 20A–F. Field relationships of central and eastern groups of intrusions.
A. View looking south along strike of dolerite dykes (dark ridges) of Mount Stafford dolerite.
B. Swirly partially melted metapelite (dark) and psammite (light) country rocks to Mount Stafford dolerite (in creek bed ~200 m north of sample 2000081065: Fig. 19).
C. View looking north across typical bouldery outcrop of gabbro, Attutra Metagabbro (near AMG ^{6}36218 ^{75}00967). Shallow-dipping sediments of the Georgina Basin are in the background.
D. Zoned granitic veins cutting massive gabbro, Attutra Metagabbro (AMG ^{6}37094 ^{74}99889).
E. Folded magnetitite shell (dark rock under hammer) of the Attutra Metagabbro enclosing fractured metapelite raft (brown) of Bonya Schist (AMG ^{6}35962 ^{75}01847).
F. Granite vein cutting metapelite of Bonya Schist (near AMG ^{6}35342 ^{74}99278).

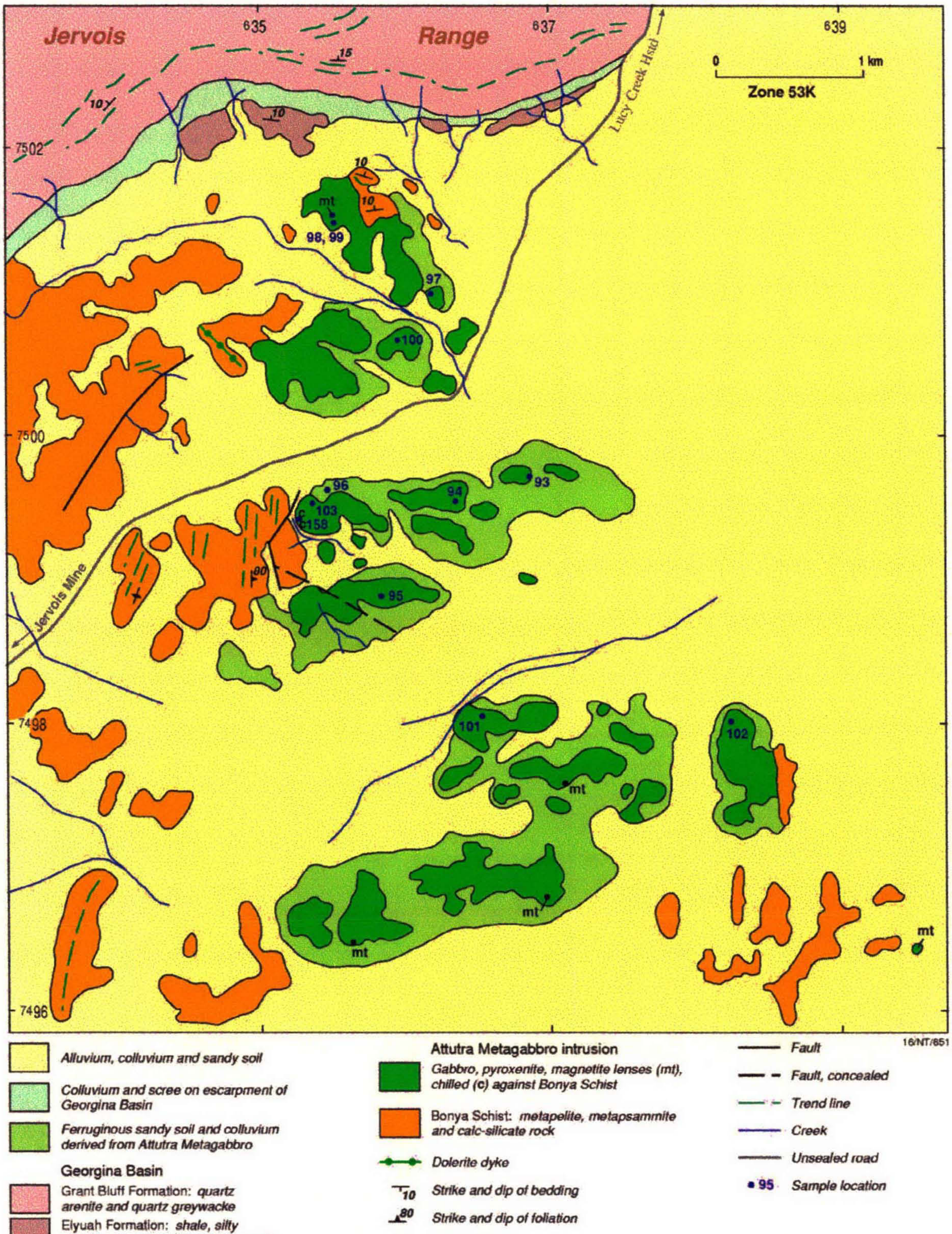

Figure 21. Geological map of the Attutra Metagabbro intrusion (modified after Freeman 1986a).

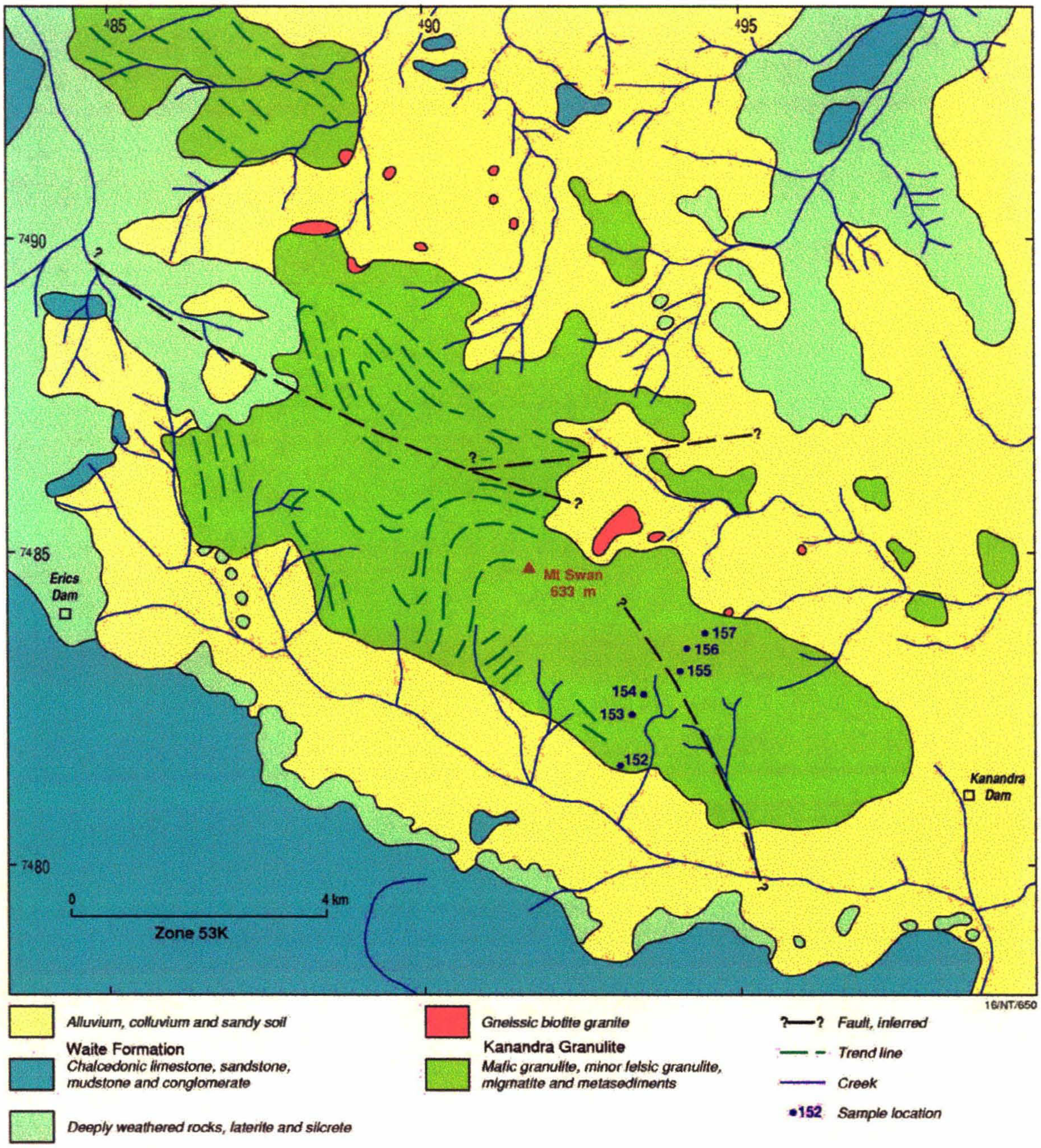

Figure 22. Geological map of the western part of the Kanandra Granulite (modified after Shaw et al. 1975).

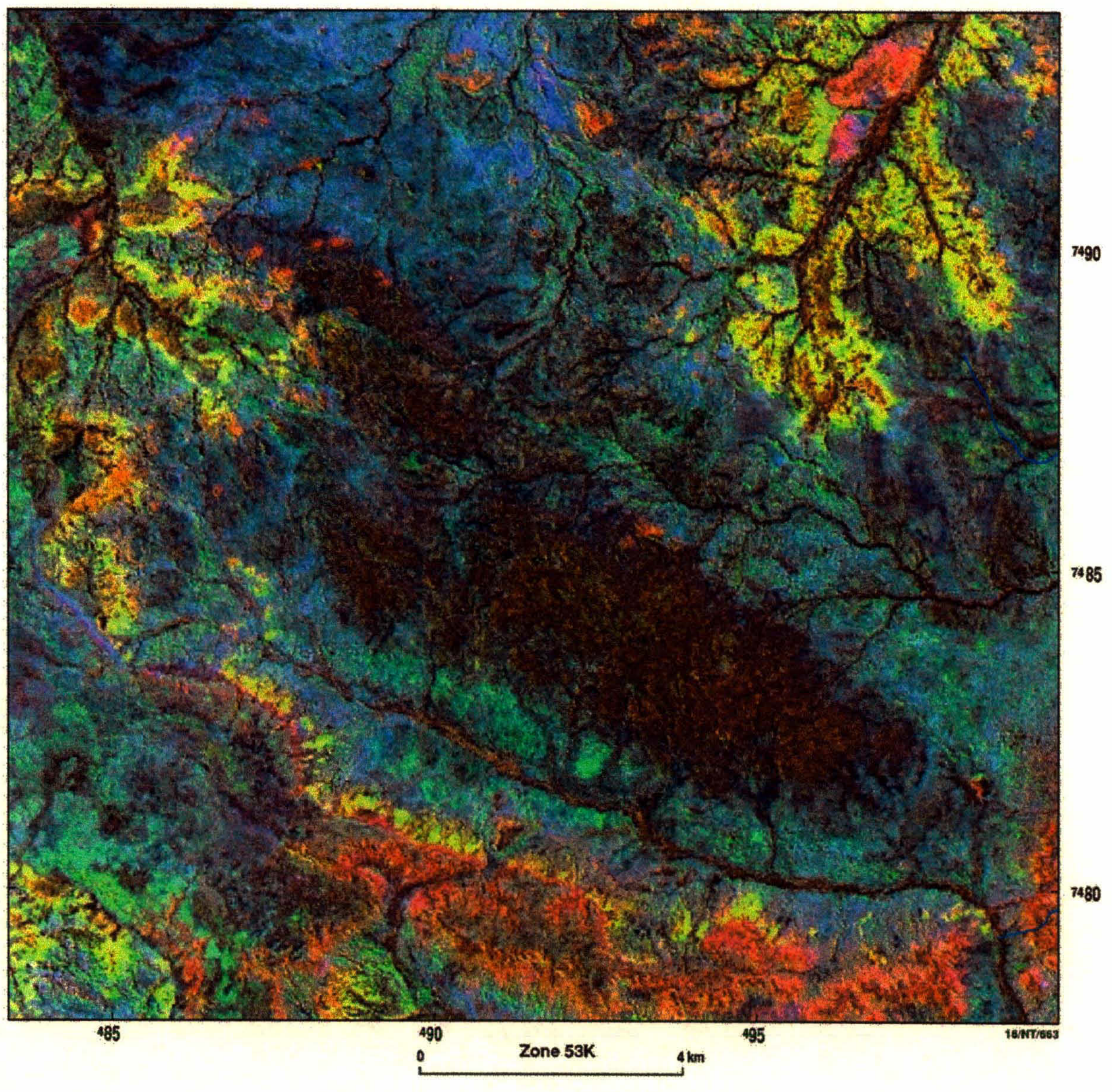

Figure 23. Landsat-5 Thematic Mapper spectrally-enhanced colour image of the Kanandra Granulite displaying 'clays' (red), 'iron oxides' (green) and 'silica' (blue). The area shown is the same as that for the geological map of Figure 22.

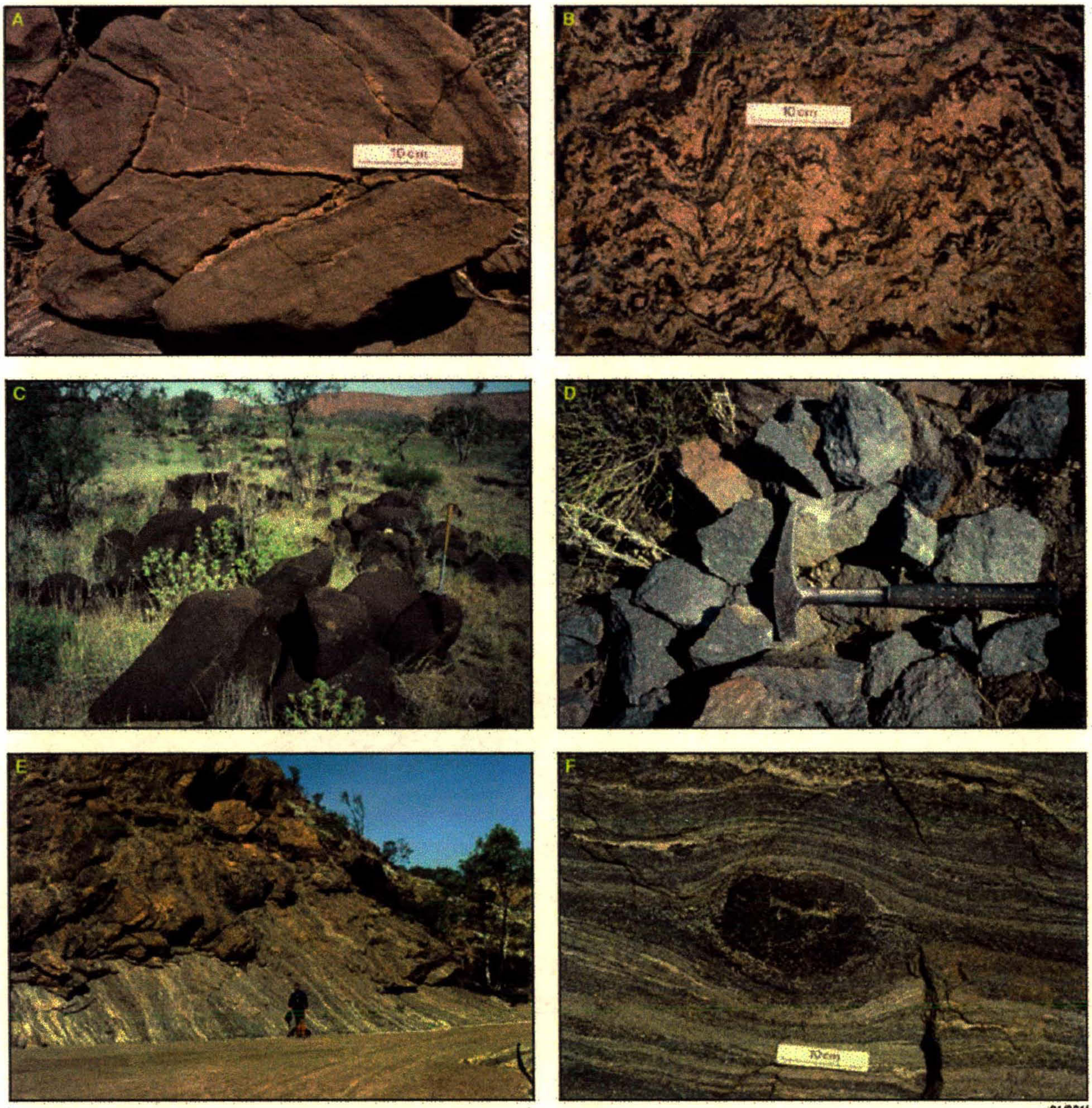

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Figure 24A–F. Field relationships of eastern group of intrusions.
A. Folded mafic granulite, Kanandra Granulite (AMG ^{4}94177 ^{74}83597).
B. Garnet-bearing migmatitic gneiss country rock to Kanandra Granulite (near ?AMG ^{4}94487 ^{74}84157).
C. Typical bouldery outcrop of phlogopite olivine pyroxenite, Mordor Igneous Complex (AMG ^{4}47960 ^{74}07885). Ridge of Heavitree Quartzite in background.
D. High-Zr phlogopite plagioclase pyroxenite (geochronology sample 2000081223: Appendix 2) used for U-Pb zircon geochronology (AMG ^{4}48651 ^{74}08367).
E. Steeply dipping, well-layered amphibolite, Riddoch Amphibolite Member (AMG ^{4}76125 ^{74}45626).
F. Mafic boudin in amphibolite sequence shown in Fig 24E.

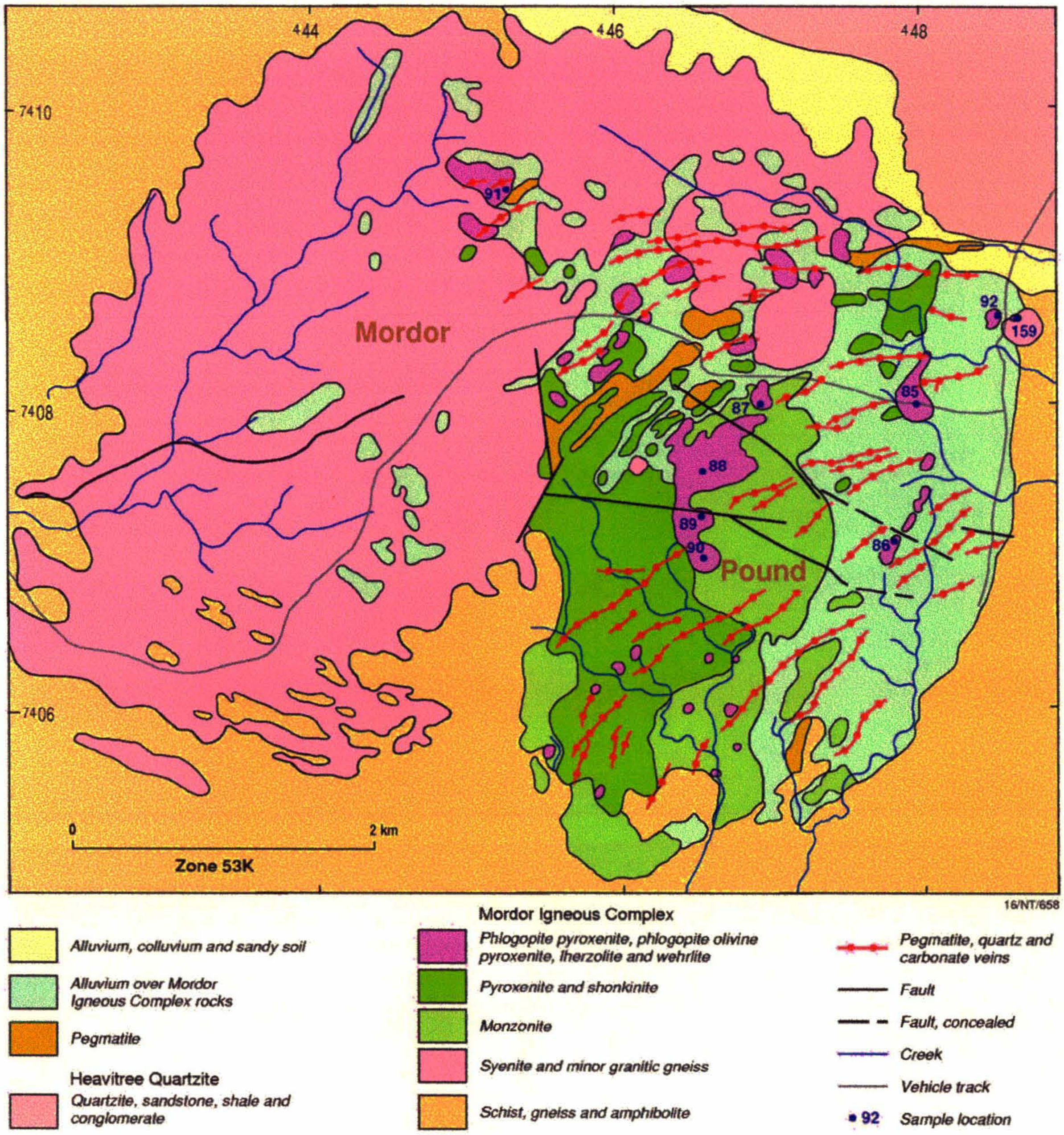

Figure 25. Geological map of the Mordor Igneous Complex (modified after Langworthy & Black 1978).

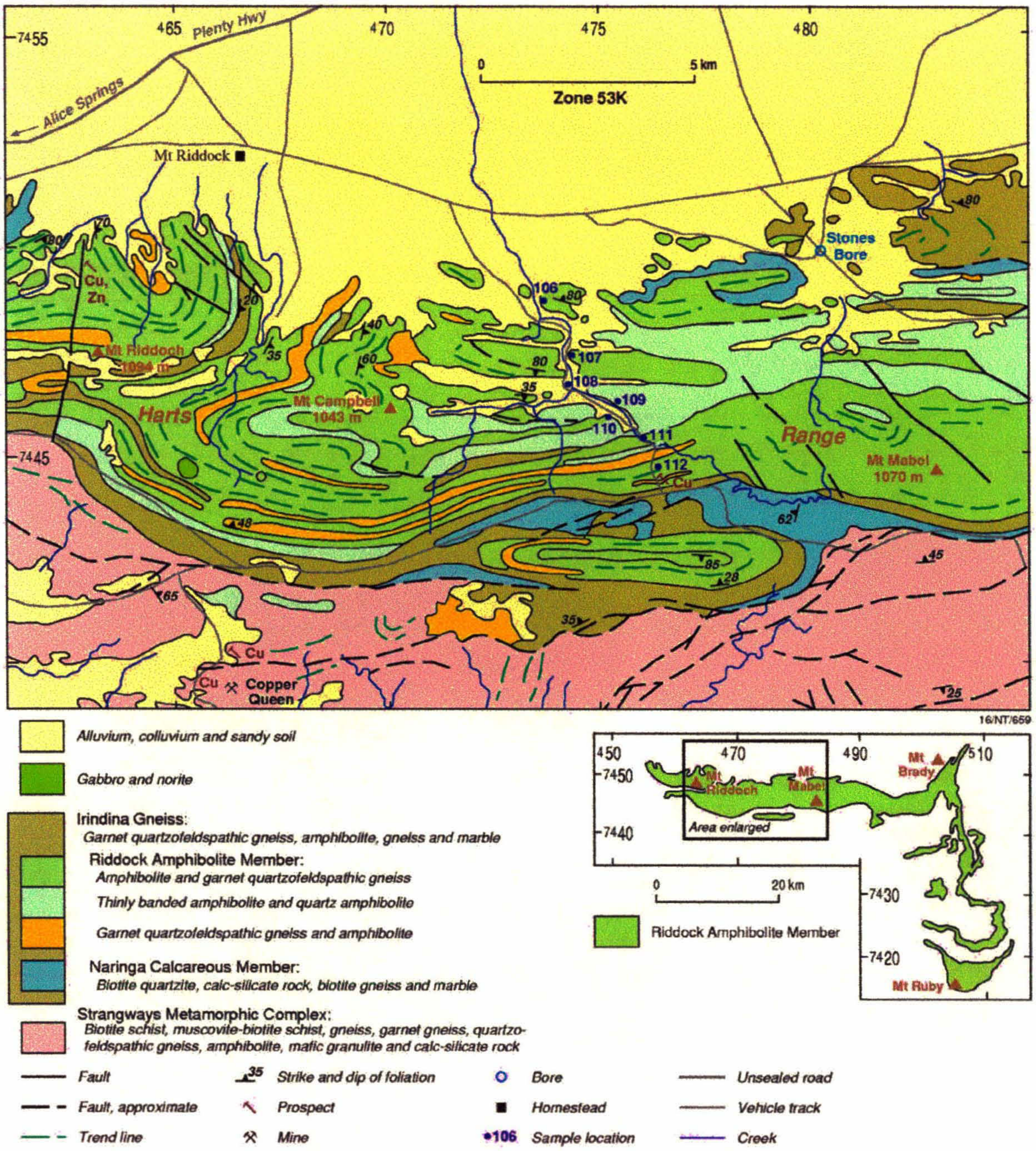

Figure 26. Geological map of the western part of the Riddock Amphibolite (modified after Shaw et al. 1984b).

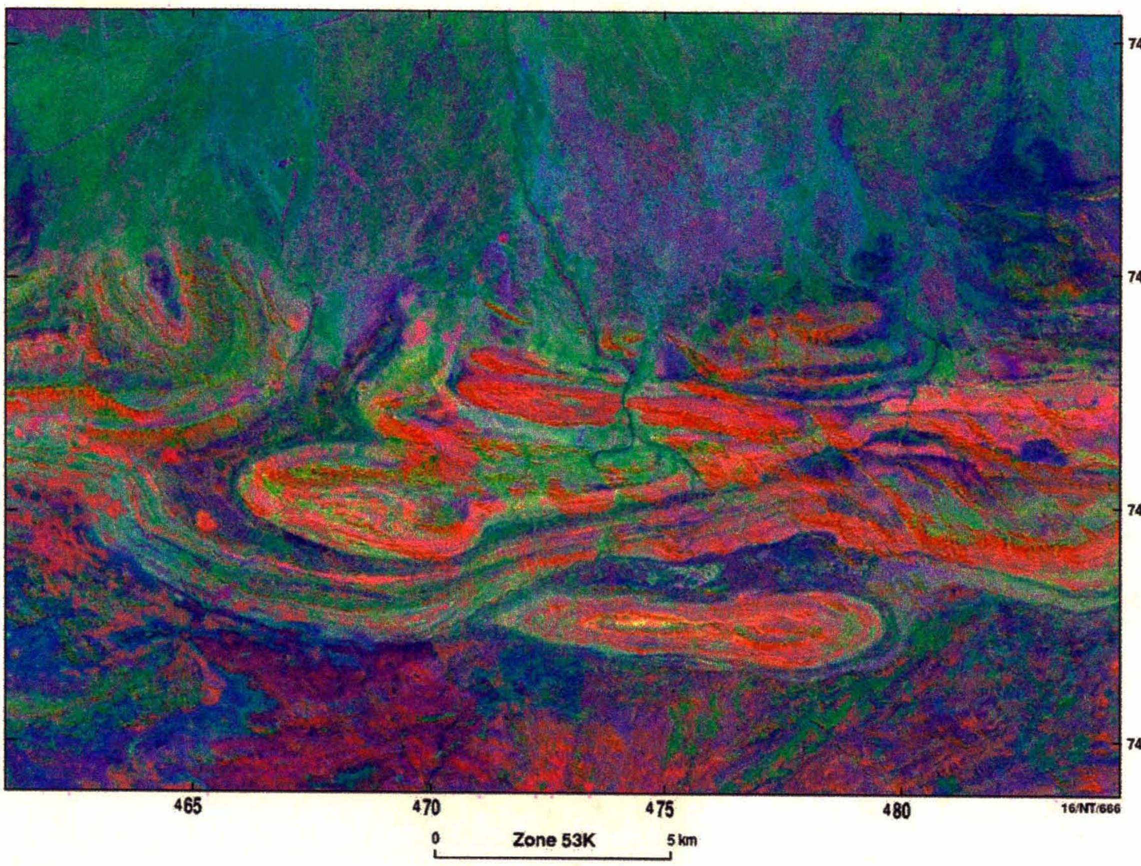

Figure 27. Landsat Enhanced Thematic Mapper-7+ spectrally-enhanced colour image of the western part of the Riddock Amphibolite displaying 'clays' (red), 'iron oxides' (green) and 'silica' (blue). The area shown is the same as that for the geological map of Figure 26.