Metallogenic potential of mafic-ultramafic intrusions in the Arunta Province, central Australia

Some new insights

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Recent field investigations by AGSO, as part of the National Geoscience Agreement with the Northern Territory Geological Survey, evaluated the geological setting and economic potential of Proterozoic mafic-ultramafic intrusions in the Arunta Province of central Australia. Historically, the Arunta Province was generally thought to have low potential for mineralising systems associated with mafic-ultramafic rocks, because of its high-grade metamorphic character and protracted tectonothermal history spanning more than 1500 million years.[1] Field observations and new preliminary geochemical data, however, indicate that intrusions from the western and central Arunta have some potential for Ni-Cu-Co sulphide deposits, and the eastern Arunta could be prospective for platinum-group element (PGE) mineralisation. These results highlight, for the first time, geographical differences in mineral prospectivity, and the PGE potential of the eastern Arunta.

A regional geochemical study undertaken in late 2000 involved sampling 16 mafic-ultramafic bodies from a 90 000 square kilometre area encompassing most of the central and northern parts of the Arunta (figure 1). The Arunta is a geologist's Mecca for examining the intrusions, for they are generally well exposed, and differential movements along province-scale fault systems have allowed their exposure from different levels in the crust. The collection of samples along type traverses across each body was facilitated by aeromagnetic and gamma-ray spectrometric data and Landsat 5 Thematic Imagery. In addition to the mafic-ultramafic intrusions themselves, co-mingled felsic rocks, cross-cutting intrusions, and country rocks have been sampled for detailed U-Pb zircon and baddeleyite geochronology. This will be used to place the various mafic-ultramafic magmatic systems within the event chronology of the Arunta. Mineral separates from the first 12 high Zr-bearing (80 to 220 ppm) mafic samples crushed have yielded zircon of variable abundance and morphology. The geochronological data will be incorporated with whole-rock geochemical and Sm-Nd isotopic studies for information on the timing of magmatic/metamorphic events, tectonic environments, and economic potential.

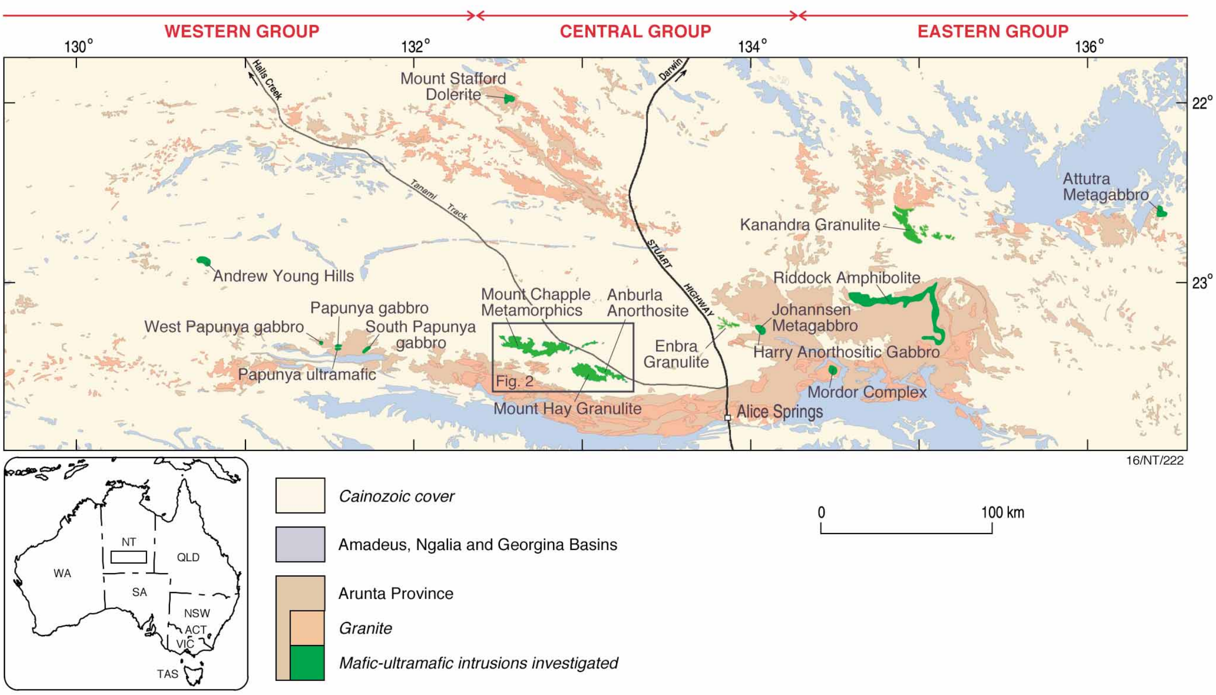

Figure 1. Mafic-ultramafic intrusions investigated in the Arunta Province

Geological setting and classification

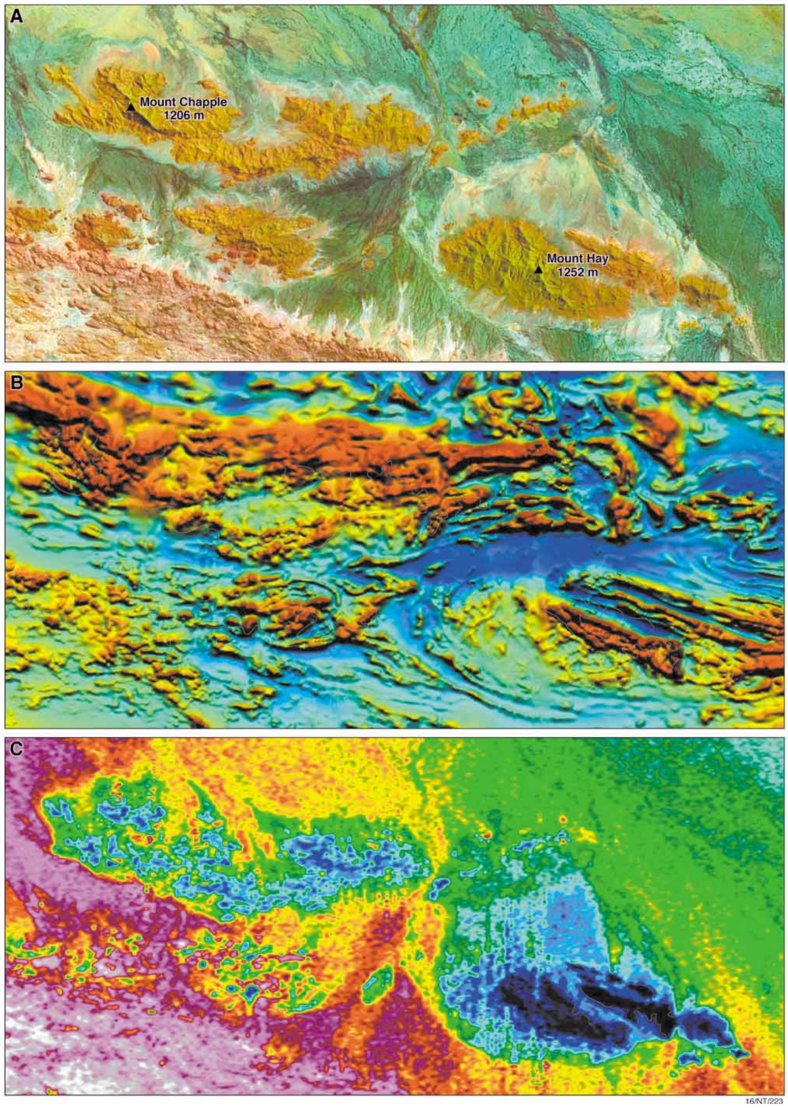

Figure 2. Remote sensing and geophysical images that highlight the uniform compositions of the Mount Hay and Mount Chapple granulite bodies. **A:** Landsat 5 Thematic Mapper (using bands 1, 4 and 7 displayed as red, green and blue, respectively). **B:** Total Magnetic Intensity (reduced to pole, northerly illumination). **C:** Gamma-ray spectrometrics (potassium band)

The mafic-ultramafic intrusions have been provisionally subdivided into three broad geographical groups (western, central and eastern) on the basis of lithologies, metamorphic-structural histories, degree of fractionation, and limited geochronology. This classification will be refined when further geochemical-isotopic data become available. The intrusions form large homogeneous metagabbroic 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—the results of comingling mafic and felsic magmas—indicate that most intrusions crystallised *in situ* and were not tectonically emplaced. In contrast to intrusions from other nearby Proterozoic provinces (East Kimberleys, Musgrave Block), the Arunta bodies are generally more homogeneous in composition and are poorly layered. Moreover, primitive ultramafic rocks are rare 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 mafic bodies that display variable amounts of crustal contamination. Andrew Young Hills is a high-level gabbronorite-tonalite body strongly contaminated with felsic crustal material and enriched in sulphur. Papunya ultramafic is a rare ultramafic ovoid body of plagioclase pyroxenite. Recent mapping by the NTGS suggest that the intrusions of the western group are related to the ~1635±9 Ma Andrew Young Igneous Complex.[2,3] Intrusions of the central group (Enbra Granulite, Johannsen Metagabbro, Mount Chapple Metamorphics, Mount Hay Granulite: figure 2) are typically medium to large homogeneous mafic-felsic bodies emplaced prior to the main granulite events that affected the Mount Hay and Strangways regions at ~1780–1760 Ma and ~1730–1720 Ma.[4] 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 comingled with felsic magmas (figure 3). Relatively thin anorthositic sequences (Anburla Anorthosite, Harry Anorthositic Gabbro) are in places spatially associated with the mafic granulites. 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; moderately dipping concordant sheets of amphibolite and metasediments up to 70 kilometres long characterise the Riddock Amphibolite; and the Mordor Complex consists of a cluster of small differentiated alkaline plugs emplaced at ~1150 Ma.[5]

Regional mineral prospectivity

The timing of S saturation in evolving mafic-ultramafic magmas in part determines the type of mineralisation in layered intrusions. PGE-bearing stratabound layers (e.g., Merensky Reef, Bushveld Complex; Great Dyke of Zimbabwe) are generally favoured by PGE-enriched primitive magmas that were S undersaturated prior to emplacement in the magma chamber. If these magmas attain S saturation too early in their evolution (i.e., in the mantle or during their ascent through the crust), the PGEs will be rapidly depleted in

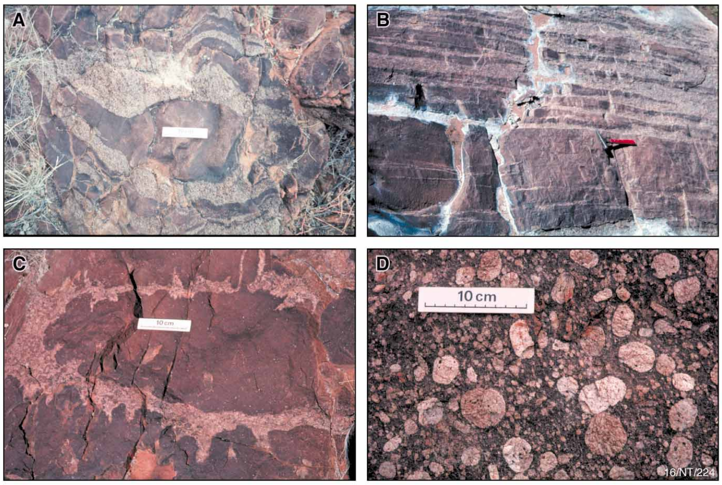

Figure 3. Contact relationships of mafic and felsic magmas. **A:** Irregular mafic granulite pillow and layers, Enbra Granulite (scale bar = 10 cm). **B:** Stacked sequence of mafic granulite (dark) and charnockite (light) layers, Mount Hay Granulite. **C:** Mafic pillow with cuspate and contaminated margins, Andrew Young Hills (scale bar = 10 cm). **D:** Resorbed alkali feldspar xenocrysts in tonalite, Andrew Young Hills

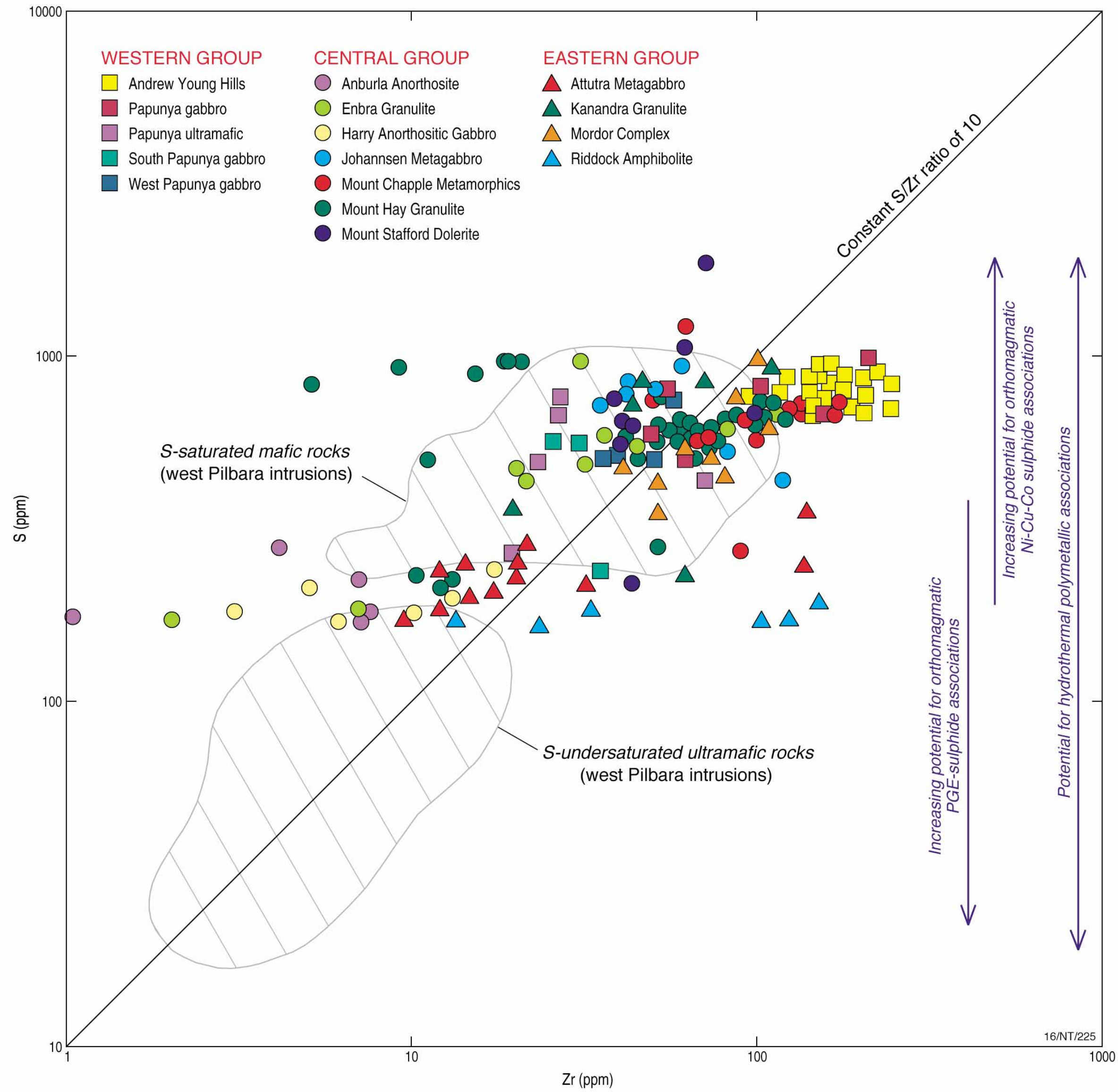

Figure 4. Logarithmic plot of whole-rock S and Zr concentrations in mafic and ultramafic rocks from the Arunta Province. The fields for S-saturated and S-undersaturated rocks from mineralised intrusions in the west Pilbara Craton[16] are also shown.

the magmas owing to their extremely high sulphide melt/silicate melt partition coefficients (about 10^3–10^5)[6], and fail to form PGE-enriched layers in the chamber. In contrast, massive concentrations of Ni-Cu-Co sulphides in embayments along basal contacts or in feeder conduits (e.g., Voisey's Bay, Canada) are generally associated with magmas that attained early S saturation through such processes as crustal contamination. These deposits are favoured by dynamic feeder systems, S-bearing country rocks, and a structural framework that facilitates the rapid emplacement of voluminous amounts of hot primitive magmas not depleted in Ni by early protracted olivine crystallisation.[7]

The economic implications of the Arunta intrusions can be broadly assessed by comparing concentrations of S with an incompatible element that provides an index of fractionation, such as Zr. Figure 4 shows that the Arunta intrusions fall into two major geochemical groups:

1. a S-rich group (~300 to 1200 ppm S) from the western and central Arunta that has some potential for orthomagmatic Ni-Cu-Co sulphide associations; and
2. a relatively S-poor (<300 ppm S), slightly more primitive group from the eastern Arunta that has greater potential for orthomagmatic PGE-sulphide associations. Of this group, the Riddock Amphibolite and Attutra Metagabbro appear to have the most favourable low S concentrations for PGE mineralisation.

Both groups have potential for hydrothermal polymetallic deposits of PGEs-Cu-Au±Ag±Pb spatially associated with the intrusions. However, the absence of thick sequences of primitive rocks (peridotite, orthopyroxenite) throughout the Arunta downgrades the potential for PGE-chromite associations.

The recent emerging evidence that the eastern Arunta is prospective for PGE mineralisation is supported by company investigations at two locations. Tanami Gold NL noted that hydrothermal quartz-carbonate-tourmaline veins associated with chlorite-hematite altered amphibolite near Mount Riddoch contained up to 0.6 ppm Pt, 1.4 ppm Pd, 5.8 ppm Au, 6.8 per cent Cu, and 12 ppm Ag.[8] Hunter Resources reported anomalous Pd (up to 215 ppb), Au (up to 104 ppb), and Cu (up to 2400 ppm) concentrations in massive magnetite hosted by gabbro of the Attutra Metagabbro.[9] Interestingly, Western Mining have also documented elevated concentrations of PGEs and Au (up to 1 ppm) in magnetite-ilmenite horizons near their recently discovered Ni-Cu-Co sulphide deposit in the west Musgrave Block (WMC website: June 30, 2000).

Exploration challenges

The occurrence of hydrothermal and orthomagmatic PGEs in the eastern Arunta 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 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 setting during the early Ordovician (480–460 Ma).[10,11] The igneous rocks include basalt, volcaniclastics, anorthosite, and ultramafic intrusives.[12] 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.

A major challenge in exploring for Ni-Cu-Co sulphide deposits in the Arunta is to locate feeder conduits or depressions within the basal contact that may be covered by shallow alluvial cover. The identification of these favourable environments in large prospective bodies such as Andrew Young Hills, Mount Chapple and Mount Hay will be most likely achieved through sophisticated geophysical (airborne electromagnetic) and remote-sensing techniques in association with diamond drilling, petrological information, and possibly an element of luck. For example, the Discovery Hill gossan at Voisey's Bay was found fortuitously during a regional stream-sampling program for diamond indicator minerals. A follow-up horizontal-loop electromagnetic survey of the gossan indicated a 1200-metre-long continuous conductor at depth. Airborne magnetics indicate that the more prospective primitive parts of Andrew Young Hills and Mount Chapple appear to be under alluvium several kilometres distant from the main outcropping parts of the bodies.

The granulite metamorphic overprint in the central group of Arunta intrusions should not be regarded as a major impediment for exploration, since Ni-Cu-Co sulphide deposits at similar high metamorphic grades are preserved in the East Kimberley (Bow River, Corkwood, Keller Creek, Norton[13]) and overseas.[14,15] In some of these deposits, metal grades have been enhanced by the remobilisation and recrystallisation of sulphides into low-stress areas.

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Rapid mapping of soils and salt stores

Using airborne radiometrics and digital elevation models

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Salinisation of land and rivers is a major problem throughout Australia's agricultural regions. There is a pressing need to map or predict where the salt is, and to understand the nature of salt stores and the conduits through which salt and water are delivered to streams and the land surface.

This article describes a new method (an integrated, catchment-based approach) of modelling natural gamma-ray emissions from the Earth's surface for soil/regolith mapping, and combining the results with topographic indices to delineate salt stores and salt outbreaks in the landscape. Modelled thematic maps produced using this approach allow catchments to be ranked according to their salinity risk, or potential risk, for prioritising remedial management.

Large areas of land in Australia are affected by dryland salinity with more than 240 000 hectares affected in New South Wales and Victoria alone.[1,2] In the next 50 years this area is likely to increase substantially. In Australia, annual damage and loss in production caused by dryland salinity has been estimated at 270 million dollars.[3]

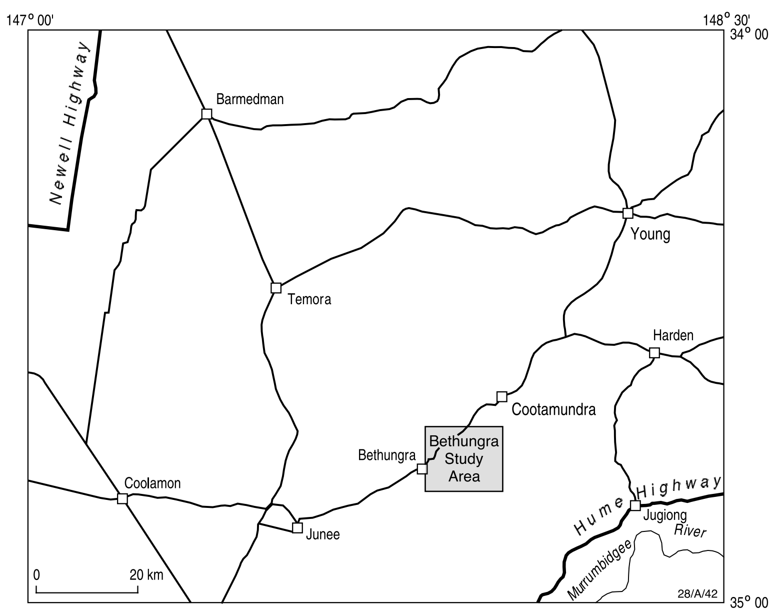

Figure 1. Location of study area within the Cootamundra 1:250 000 map sheet