Past activities

-Geological Society of America meeting (October 16-19, Salt Lake City, USA) - G. Beaudoin
-UNESCO/Geochim 2005/SGA (September 5-19, 2005 Prague and Dolní Rožínka, Czech Republic) – J. Pašava
-The 20th World Mining Congress (November 7-11, 2005 Tehran, Iran)- G. Borg, M. Yazdi
-New Zealand Minerals Conference (13-16 November, 2005) – F. Bierlein

Future activities

-Conference on the Geology of the Middle East (March 20-23, 2006 Al-Ain, United Arab Emirates)-M.Yazdi
-MDSG (January 5-6, 2006) – R. Herrington
-Gold Short Course (June 4-7, 2006 Munich, Germany) – Hagemann et al.
-The 12th IAGOD Quadrennial Symposium (August 2006 Moscow, Russia) – J. Pašava, H. Frimmel
-The XXV Latinamerican Course of Metallogeny (Antofagasta, Chile, 2006) – F. Tornos et al.
-UNESCO/Geochim 2006/SGA – Postgraduate training course in geochemical exploration methods and their environmental applications (September 4-18, 2006 Prague and Dolní Rožínka, Czech Republic) – J. Pašava, D. Mašek
-Fremont Meeting (September 13-15, 2006 London, UK)
-Deuxieme Journees de Launay: Nouvelles Approaches de la Recherche et de l ´Exploration Minueres (October 25-26, 2006 Marrakech, Morroco) – D. Leach – keynote speaker
-The 10th GOLDSCHMIDT 2006 (Australia) – SGA will only have a booth there – F. Bierlein, H. Stein, G. Borg
-SGA presence at the 2008 IGC (Oslo, Norway) – invitation from P. Weihed
-A joint meeting with the GAC and MAC in 2008 (May, Quebec City, Canada)
SGA activities (G. Beaudoin)

>>> page 1 Mineralisation associated with the Giles mafic-ultramafic intrusions, Australia

South Australia and the southwest corner of the Northern Territory to Western Australia (Figs. 2 and 3). Aspects of the geology of the intrusions are discussed in numerous publications, inlcuding Nesbitt et al. (1970), Daniels (1974), Goode (1977a and b, 1978), Goode and Moore (1975), Ballhaus and Glikson (1989), Gray and Goode (1989), Major and Connor (1993), Glikson (1995), Glikson et al. (1996; and references therein), and Sun and Sheraton (1997). The Giles intrusions comprise gabbro, anorthosite, troctolite, gabbronorite, norite, pyroxenite (both clino- and ortho-), dunite and peridotite. Granophyres are present as dykes and as masses up to 60 m thick, locally form cappings of the layered gabbros (Myers, 1990).

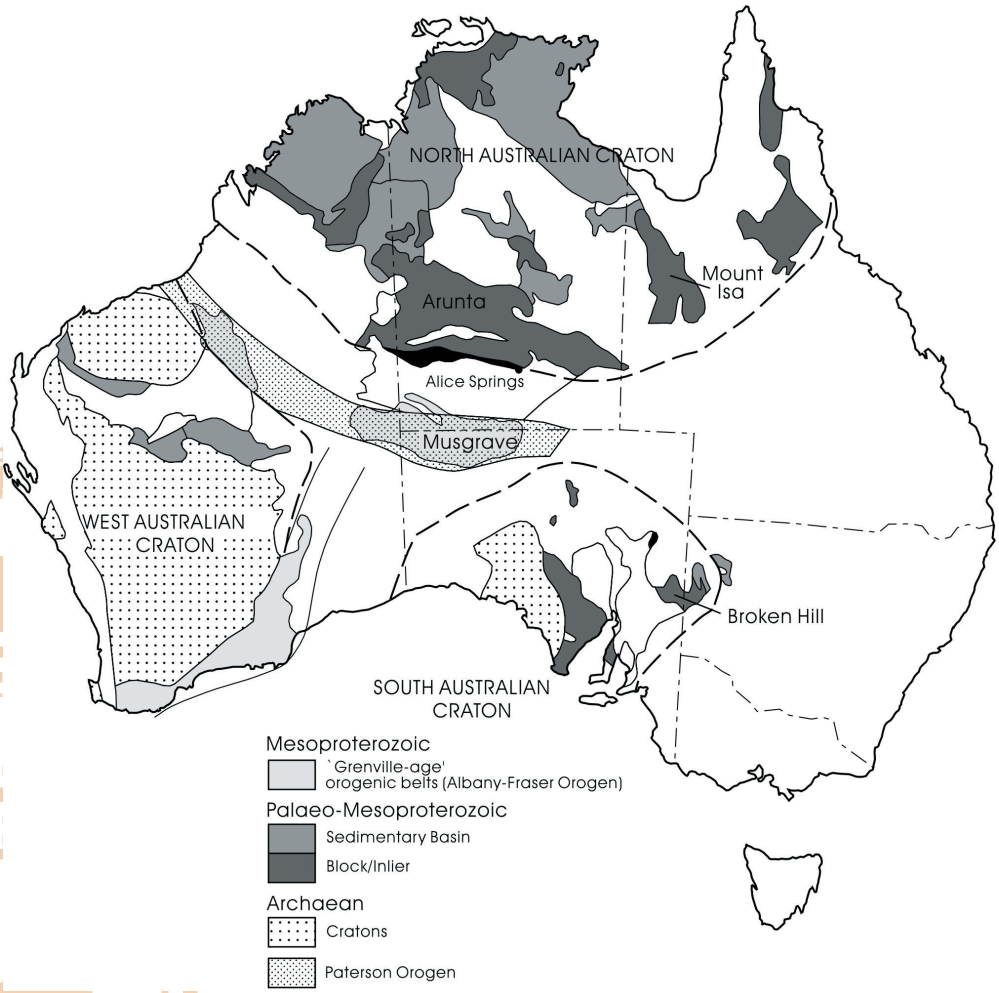

Figure 1: Main tectonic elements of central and western Australia, showing the Paterson Orogen and position of the Musgrave Complex. Modified from Edgoose et al. (2003).

Ballhaus and Glikson (1995) distinguished three main lithotypes in the Giles intrusions: 1) ultramafic olivine-clinopyroxene rich cumulate sequences; 2) mafic, clinopyroxene-plagioclase sequences, and 3) more evolved troctolite and magnetite-rich sequences. These authors also suggested that most ultramafic dominated intrusions (Murray Range, Wingellina Hills, Ewerarra, Kalka, Claude Hills) tend to be concentrated along the northern periphery of the zone of Giles intrusions, whereas the gabbro and troctolite dominated intrusions tend to occur in the central parts and in the south, respectively. The bimodal volcanic rocks of the Bentley Supergroup (including the Tollu Group and Cassidy Group), represent the highest level of the magmatic system.

The mineral assemblages of several of the Giles intrusions, commonly exhibit reaction coronas, such as ol + plag ± opx + cpx/spinel symplectite; opx + plag ±ß grt, indicative of pressures in the range of 8-13 kb (Nesbitt et al., 1970). Intrusions in the central areas (eg Michael Hills, Hinckley Range, Mt Davies, Kalka) were emplaced into the lower crust during granulite facies metamorphism and crystallised under high-pressure conditions. Intrusions further west (eg Jameson, Cavenagh and Blackstone) were emplaced at higher levels and volcanic equivalents are found in the same area (Tollu Group bimodal volcanics; Bentley Supergroup).

Nesbitt et al. (1970) described the Giles mafic-ultramafic intrusions as a series of variably deformed sheets, which form isolated bodies scattered over an area of some 25 000 km2. However, recent gravity surveys in Western Australia, suggest that at least some of these intrusions may be linked below the surface (Shevchenko, in press). The Giles intrusions have their best exposures and development in the Jameson, Blackstone, Bell Rock, Cavenagh, Hinckley Ranges, Wingellina Hills, Mt Davies, Mount West, Michael Hills and Latitude Hills in Western Australia and the Ewarara, Kalka and Mt Caroline (Tomkison and Musgrave Ranges) in South Australia (Fig. 3). Below we briefly describe selected intrusive bodies (Fig. 3).

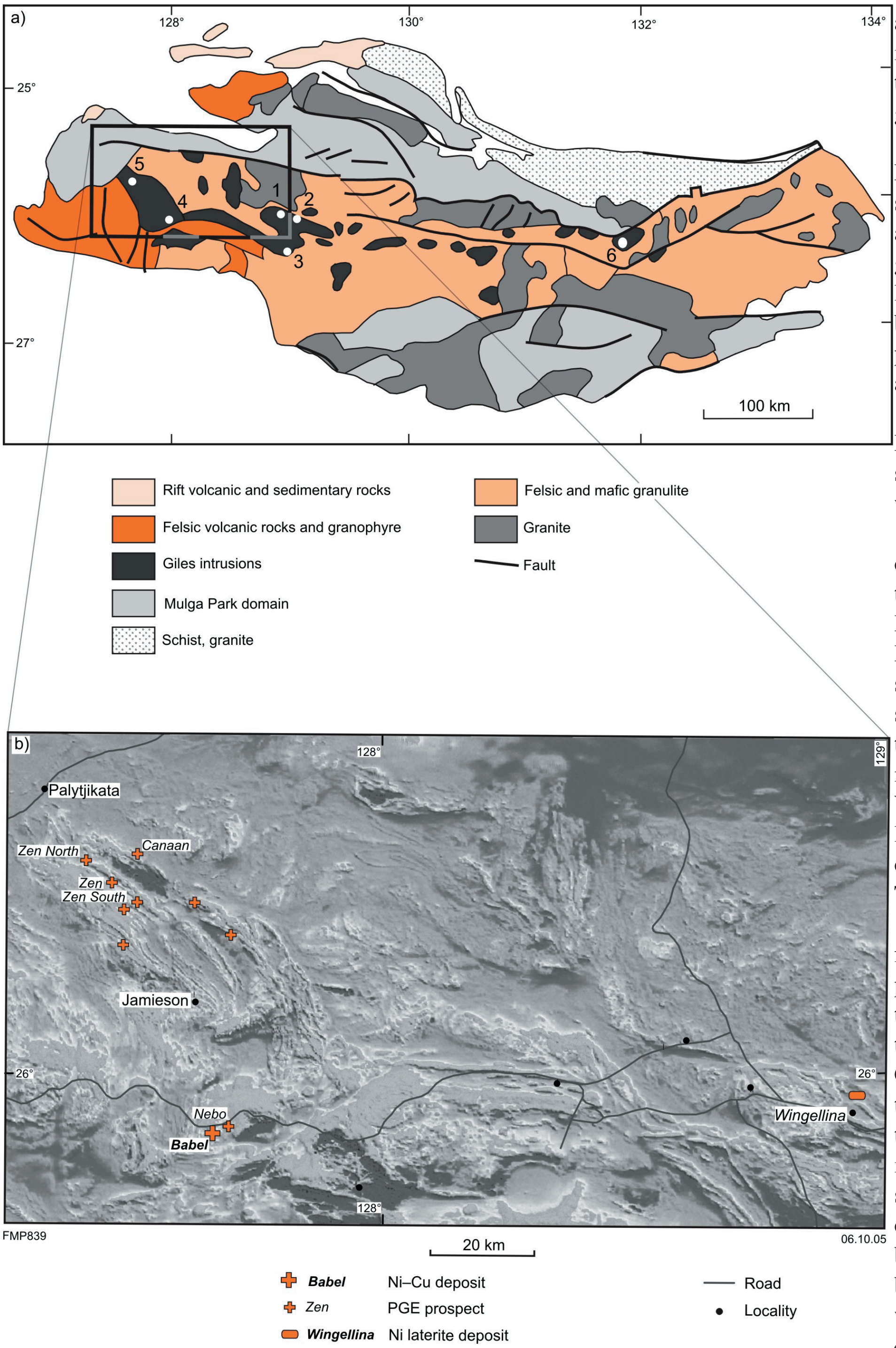

Figure 2: A) Simplified geological map of the Musgrave Complex (adapted from Conor et al.; 2002), showing distribution of Giles intrusions and associated principal ore deposits; 1) Wingellina; 2) Claude Hills; 3) Bell Rock; 4) Nebo-Babel; 5); Zen-Canaan group; 6) Mt Caroline. B) Grey scale TMI image of area outlined in (A) showing distribution of Ni, Ni-Cu and PGE deposits; the Zen-Canaan group in the NW are PGE prospects currently being assessed.

The Jameson Range intrusion was subdivided into 4 zones with a total thickness of about 5500 m (Daniels 1974). Zone 1 contains olivine gabbro and is the 460 m thick basal zone of the intrusion. Zone 2 is 320 m thick and consist mainly of lherzolite with titaniferous magnetite bands. Zone 3 is a 760 m-thick sequence of troctolites, anorthosite and anorthositic gabbro with primary igneous banding and structures such as cross-bedding and ripple marks. Zone 4 is a well-layered 3000 m thick sequence of troctolite, olivine gabbro and hypersthene gabbro.

The Blackstone-Bell Rock-Cavenagh Ranges intrusions are probably part of the same intrusive body and consist of gabbro and troctolite, interlayered with thin magnetite lenses and ultramafic rocks. The layered rocks of this sheet exhibit cross-bedding structures and the layers are expressed topographically as a series of ridges and valleys.

The Hinckley Ranges and Wingellina Hills intrusions possibly represent the same sheet and may form a synclinal structure with an east-trending axis (Nesbitt et al. 1970). However, these authors also pointed out that lithological correlation between the two is difficult, because the Wingellina Hills have ultramafic layers not found in the Hinckley Ranges. A 400 m-wide shear zone separates the two ranges and is characterised by an anastomosing network of mylonites and pseudotachylite veins and breccias, mostly developed in gabbroic rocks. The Wingellina Hills intrusion is economically important because of its nickeliferous ochres, as discussed in more detail below. This intrusive body has a thickness of about 1600 m and consists of a cyclic succession, from bottom to top, of olivine gabbro with pyroxenite bands, pyroxenite and peridotite, olivine gabbro, peridotite-pyroxenite layers, and gabbronorite (Ballhaus and Glikson, 1989). A 500m diamond drillhole through parts of the Wingellina Hills intrusion by Acclaim Exploration in 2003 intersected, between 250 and 506 m below surface, peridotite and olivine gabbronorite overlying a layered series composed of gabbro, dunite, olivine cumulates with dunite bands, and clinopyroxene orthocumulate with intercumulus olivine and dunite (Fig. 4).

The Hinckley Range intrusion is one of the largest of the Giles intrusions. The Range is about 38 km long, rising to 1015 m a.s.l. at Mt. Hinckley, up to 12 km wide,

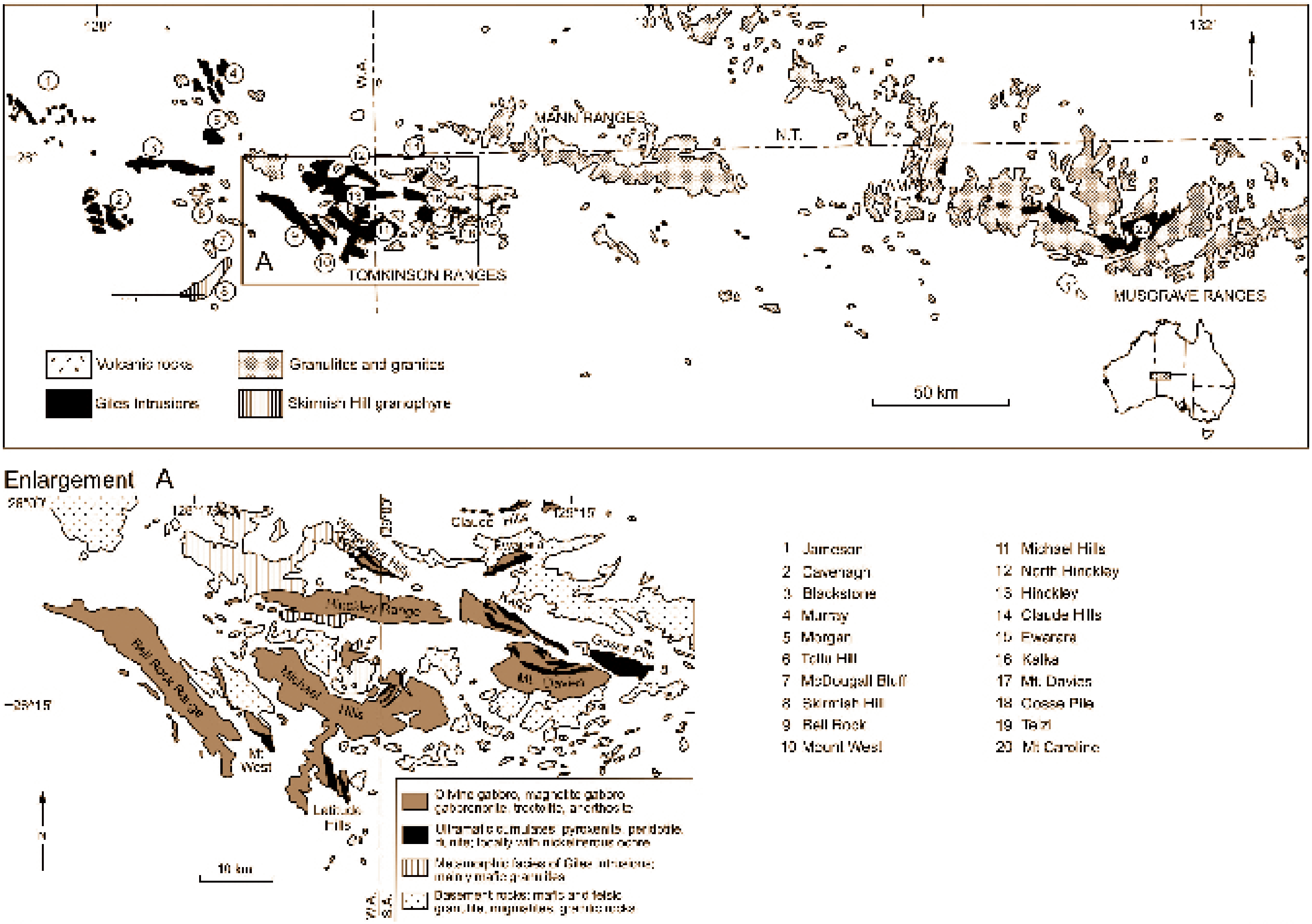

Figure 3: Map showing outcrop distribution of Giles intrusions and country rocks of the Musgrave Complex. Adapted from Nesbitt et al. (1970).

and forms a north-dipping layered intrusion estimated to be 4800 m thick. The intrusion consists of gabbro, gabbronorite, troctolite, anorthosite and lesser pyroxenite. These rocks are associated with dykes and sills of microgabbro, which intruded during a late magmatic stage into the mafic-ultramafic pile whilst this was not yet fully consolidated. The anorthosite layers seem to be concentrated in the eastern sector, where they are associated with thin magnetite seams.

The Mt. Davies intrusion is divided into an overturned southern zone and a northern zone truncated by the Hinckley Fault. The southern zone is 4000 m thick and consists of a basal section of alternating olivine clinopyroxenite, olivine gabbro, anorthosite and norite.

The Michael Hills intrusion is a 6400 m thick gabbro sheet which extends across the state border into South Australia. The intrusion is possibly folded into an anticlinal structure in which Daniels (1970) recognised four zones, as follows. The base is Zone 1, with a 1500 m thich succession of leucocratic gabbro, anorthosite and pyroxenite. Zone 2 is about 2000 m thick, forms most of the elevated topography of the hills, and consists predominantly of hypersthene gabbro. Zone 3 is 365 m thick and also consists of well-banded hypersthene gabbro with common cross-bedding structures. Zone 4 is 2300 m thick and contains a fine-grained gabbronorite with associated minor intrusions of gabbro, pegmatitic troctolite and ultramafic rocks.

The Michael Hills intrusion is in structural contact with the Latitude Hills intrusion, which is characterised by west-dipping alternating leucogabbro and pyroxenite layers with lesser anorthosite units. The nature of the relationship between the two intrusion is yet to be determined.

The Ewarara intrusion in South Australia is a small flat-lying ultramafic body about 6 km long and 200 m thick intruded into granulite rocks (Goode, 1977a; 2002), and is interpreted as the basal remnant of a larger intrusive body. The layered sequence consists of a lower bronzitite zone and an upper pyroxenite zone, with partially preserved cumulate textures (Goode, 2002). An unusual feature of the Giles intrusions in the Ewarara area is the presence of olivine-bearing plugs and dykes, characterised by cumulate textures and including picrite, dunite and gabbro. Sixteen of these plugs and dykes exposed near the base of the Ewarara intrusions, which consist of olivine-bronzite cumulates, locally with disseminated sulphides.

The Kalka intrusion (South Australia) is about 12 km long and comprises 6000 m of cumulate rocks (Goode, 2002). The layered sequence of the Kalka intrusive body, from the base upward, contains up to 450 m of orthopyroxenites, grading upward into websterites and with orthopyroxene as the main cumulus phase. This is followed by a norite zone. Finally, an anorthosite zone, with a maximum thickness of 800 m, comprises leucogabbro, olivine-bearing anorthosite, leucotroctolite and a distinctive olivine-magnetitite unit in the northern part. Locally, magnetite-ilmenite rich layers (up to 10% by volume) are present. The Kalka intrusion was thought to be the only outcropping component of the Giles intrusions known to contain a complete succession from pyroxenite to anorthosite (Goode, 1977a, b). However, our recent mapping in the Wingellina Hills and Hinckley Range suggests that these intrusions may also have a complete succession from basal dunite to

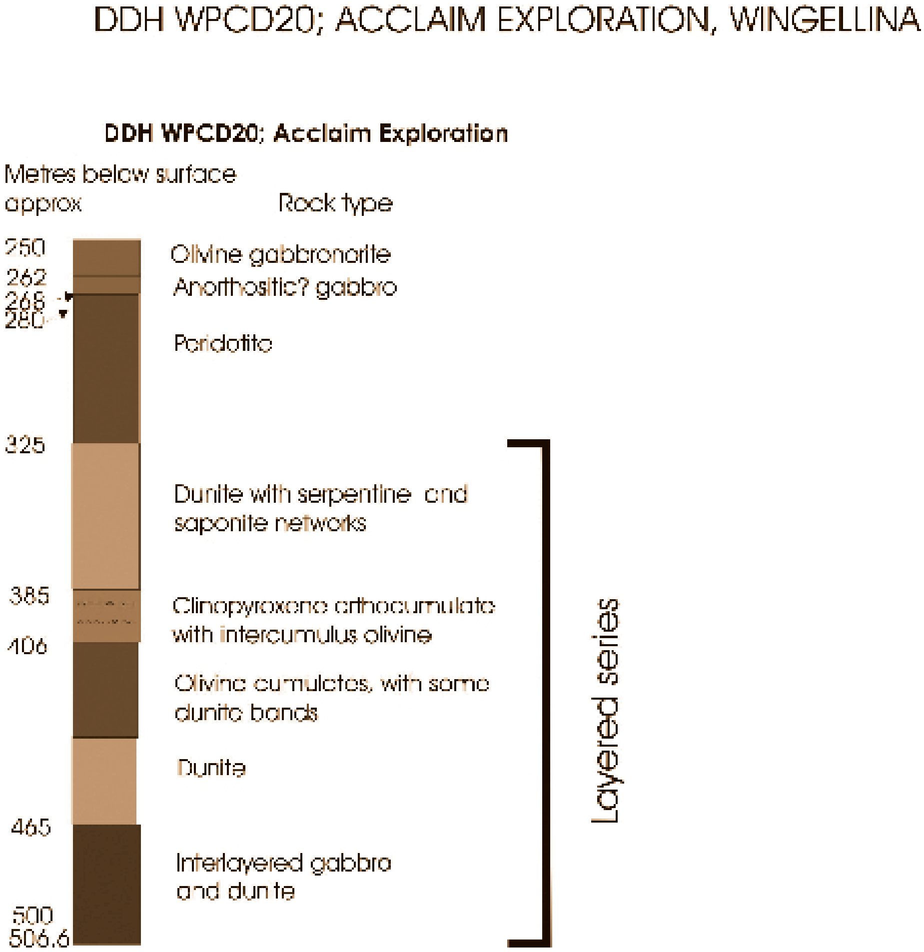

Figure 4: Simplified log of drill core showing the Wingellina ultramafic sequence between 250 and 500 m below surface. Where weathered and lateritised this sequence contains nickeliferous limonitic ochre.

anorthosite.

The Mt Caroline intrusion (South Australia) consists of gabbro-norite with interlayered pyroxenite and olivine-gabbro, forming a series of discontinuos outcrops along an E-W strike of about 9 km. Aeromagnetic data suggest that these outcrops are part of a single layered intrusion (Woodhouse and Gum, 2005).

Mineralisation

Among the original goals of the Society, The Ni-Cu and PGE potential of the Giles intrusions has attracted the interest of exploration companies. The distribution of Ni-Cu sulphide and lateritic Ni occurrences in the Giles intrusions is shown in Fig. 2.

To date, economically significant mineral deposits in the Musgrave Complex are:

- Wingellina Hills Ni lateritic ochre deposit containing 227 Mt @ 1% Ni and 0.07% Co (Acclaim Exploration, 2003)
- Claude Hills Ni lateritic ochre deposit containing 4.6 Mt @ 1.3% Ni (Acclaim Exploration, 2003), in South Australia (Fig. 2A)
- Jameson Range stratiform vanadiferous magnetite deposits, estimated at 100 Mt @ 1% V2O5 (Daniels, 1974)
- Nebo-Babel disseminated to semi-massive Ni-Cu-PGE sulphides hosted by a layered gabbronorite intrusion, south of the Jameson Range (Seat et al. 2005; Baker and Waugh, 2005).
- At Mt Caroline in South Australia (Fig. 3), are Ni-Cu disseminations hosted in olivine gabbro (Woodhouse and Gum, 2005).

Wingellina nickeliferous ochres and chrysoprase

Yellow-brown to dark brown ochre material in the Wingellina area is nickeliferous. This deposit was discovered by INCO in 1956. The ochre material is composed of goethite, manganese oxides, gibbsite and kaolinite and is derived from the weathering of dunite and peridotite of the layered Wingellina Hills intrusion. The ochre material is best developed at the base of the Wingellina Hills, where lateritic weathering extends to a depth of at least 200 m (Acclaim Exploration, 2003). The ochres formed by selective leaching of SiO2 and MgO, which is especially pronounced along shear zones, and the resulting passive concentration of residual alumina, Fe oxides and Ni. Locally the lateritic material is cut by the semiprecious pale green chrysoprase. The metal resources of the Wingellina deposit are reported at 227 Mt at 1% Ni and 0.07% Co, with a 2.3 Mt of contained metal.

Limonitic ochre material is also present in the southeastern part of the Bell Rock intrusion. At this locality, excavations exposed laterite, ochre and chalcedonic veins above a zone of saprolite. This zone of laterite and ochre has an east-west trend. A grab sample of the ochre material assayed 1.2 % Ni.

Ni-Cu-(PGE) and the Nebo-Babel deposit

The Nebo-Babel Ni-Cu-PGE deposit is located approximately 30 km west of the Cavenagh Range (Fig. 2)

In April 2002, Western Mining Corporation announced a drill intersection of 26 m @ 2.45% Ni, 1.78% Cu and 0.09% Co at the Nebo-Babel prospect (Figs. 2, 3, 5). To-date this deposit represents the largest Ni sulphide discovery since Voisey's Bay in Canada (Seat et al., 2005). The Nebo-Babel deposits were discovered by conventional deflation lag geochemical sampling (Baker and Waugh, 2005). Little is known about the geology of the deposits and the only information is provided by Seat et al. (2005) from whom the following summary is taken.

The Nebo-Babel mineralisation is hosted in a tube-like mafic intrusion, with a cross-section of about 1 x 0.5 km, emplaced within granulite facies intermediate to granitic gneiss country rocks. Nebo and Babel refer to two mineralised zones of the same intrusion, offset by a fault that cuts the tube-like intrusion into a western and eastern sectors (Fig. 5). Sulphide mineralisation is massive at Nebo (eastern sector) and net-textured and disseminated at Babel (western sector). Mineralogical and geochemical trends suggest that the intrusion may be overturned.

The Babel part of the tube-like intrusion consist of five gabbronorite (GN) units (top to bottom and terminology used in Seat et al., 2005)): 1) variably-textured leuco-GN1; 2) mineralised GN; 3) variably-textured GN2; 4) barren GN; and 5) variably-textured leucoGN3. These gabbronorite units generally have ≤ 80% plagioclase, ≤15% orthopyroxene and lesser clinopyroxene, with olivine being restricted to the variably-textured units. Along the upper contact of the intrusion a breccia zone contains fragments of country rocks, variably-textured gabbronorite and sulphide xenoliths in a matrix of massive sulphides.

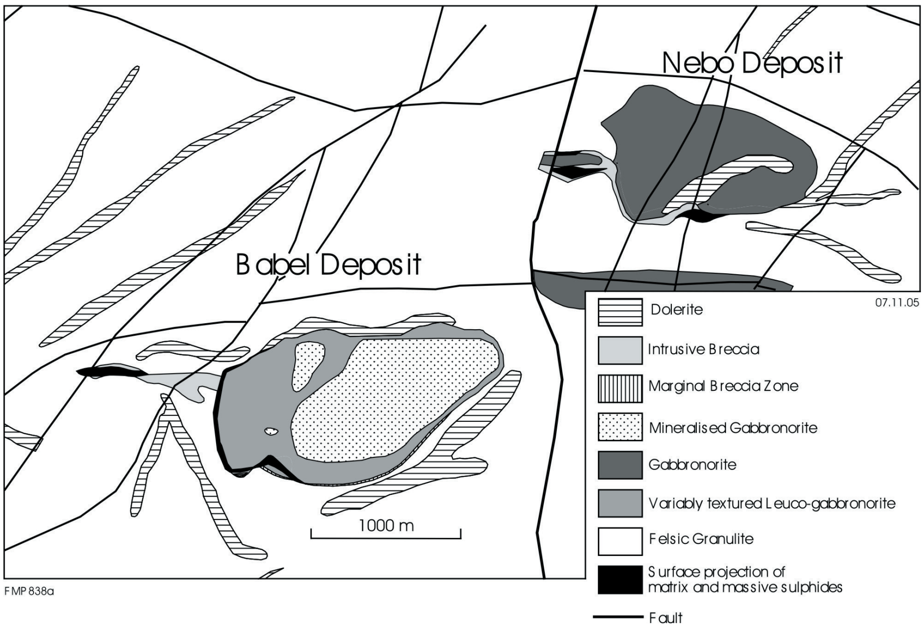

Figure 5: Plan view and simplified geological map of the Nebo and Babel Ni-Cu sulphide deposits. After Baker and Waugh (2004).

The Nebo sector consist of three lithostratigraphic units, which from bottom to top include: variably textured leucogabbronorite, barren gabbronorite and oxide-apatite gabbronorite. The latter unit is a plagioclase-pyroxene cumulate with 10-20% ilmenite and magnetite and about 5% apatite. Most of the massive sulphide mineralisation is by the Nebo gabbronorites.

Vanadiferous titano-magnetite

In the Jameson Range, Blackstone Range and Bell Rock troctolite-gabbro intrusions there are layers and lenses of V-bearing titano-magnetite and ilmenite. Of these, only the Jameson Range occurrences may be of economic importance. In the other two intrusions (Blackstone and Bell Rock), the titano-magnetite only forms thin, discontinuous units or lenses no more than 30 cm thick. In other parts of the Giles intrusions magnetite forms small pods in shear zones (Daniels, 1974).

The Jameson Range magnetite bands are present in Zones 2 and 4 of the intrusion (Daniels, 1974). Zone 2 in the northeast of the Range contains from 20 to 50 vol. % of opaques (probably all titano-magnetite) in the ultramafic layers, with the V2O5 tenor estimated at about 1.4 wt% (Daniels, 1974). Zone 4, located in the southwest, has at its base a band of titaniferous magnetite, which has been traced along strike for about 19 km (Daniels, 1974). At one locality this band reaches a thickeness of 15 m. Analyses of samples from this band yield an average of 0.9 wt% V2O5 and 23.4 wt% TiO2 (table 35, in Daniels, 1974). Zone 4 has more titaniferous magnetite layers towards the upper parts of the sequence, where one of these bands can be traced intermittently for 37 km, with thicknesses of up to 61 m at an average of 0.79 wt% V2O5. Daniels (1974) also noted compositional variations of V, Ti, Fe, Cr and P with stratigraphic height. The higher magnetite bands have lower V, Ti and higher Fe, Cr and P, which he attributed to the more advanced fractionation of the liquids.

Exploration potential and discussion

The economic potential of the Musgrave Complex can be considered in terms of primary magmatic ores in mafic-ultramafic layered intrusions, sill complexes (Noril'sk type and/or Voisey's Bay), anorogenic complexes and hydrothermal deposits. The Giles intrusions are associated in space and time with bimodal volcanic rocks of the Bentley Supergroup and various types of 1090-1060 Ma granitic rocks, such as Angatja Granite, the 1070 Ga Hull Granite Suite and a ~1070 Ma rapakivi granite (Scrimgeour et al., 1999; Close et al., 2003). This lithological association is important because it may reflect a genetic relationship similar to that between the mafic to ultramafic Layered Suite of the Bushveld Complex and the spatially and temporally associated Lebowa Granite Suite and the felsic volcanic rocks of the Rooiberg Group, in South Africa (see Pirajno, 2000 for an overview and references therein). The felsic rocks associated with the Bushveld Complex are well endowed with a wide range of hydrothermal ore deposits, ranging from greisen style deposits, breccia pipes with Sn-W to epithermal and mesothermal lode Au and iron oxide-copper-gold style deposits (Pirajno, 2000). The Musgrave Complex in Australia has a similar potential, as this is highlighted by the recent discovery of Cu-Au vein style mineralisation in the felsic volcanic rocks of the Tollu Group in the Cavenagh Range (Abeysinghe, 2003).

Insofar as Ni-Cu and PGE mineralisation is concerned, it is important to distinguish deposits that contain Ni and Cu as principal ores, with PGE and Au as by-products, from deposits containing PGE as principal ores, with Ni and Cu sulfides as by-products (Maier, 2005). Examples of the first kind are Noril'sk and Voisey's Bay, whereas the Merensky reefs of the Bushveld Complex and the JM reef of the Stillwater Complex are examples of the latter.

Magmatic sulphide ore deposits are typically hosted by mafic-ultramafic layered in-

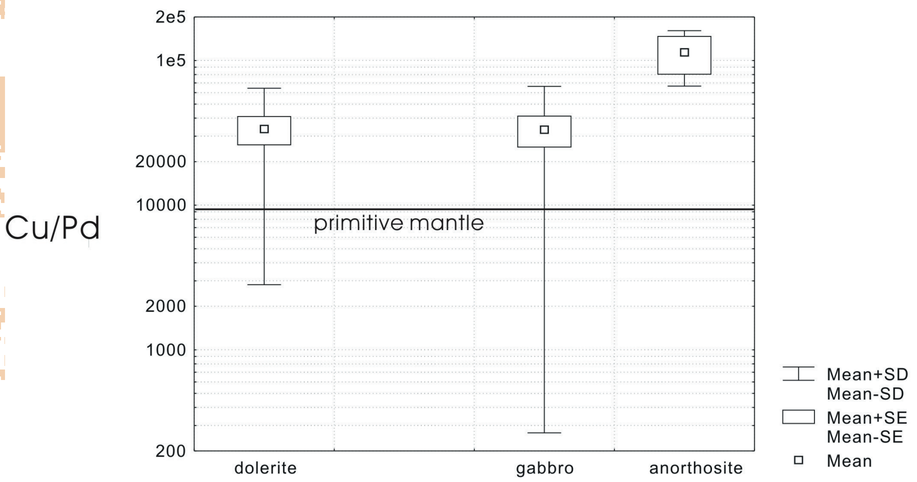

Figure 6: Plot of Cu/Pd ratios for dolerite dykes, gabbroic rocks (including gabbro, norite, gabbronorite) and anorthosite of the Giles intrusions in Western Australia. Primitive mantle line after Maier (2005).

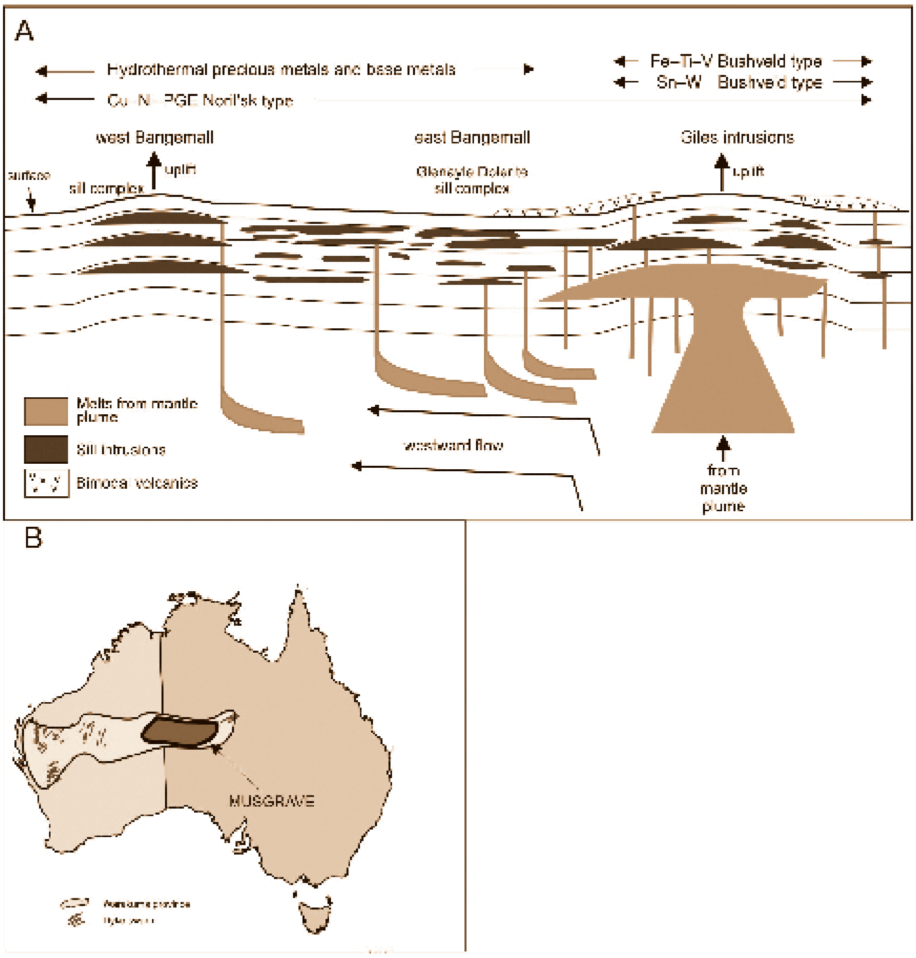

Figure 7: A) Schematic longitudinal section (not to scale) depicting the interpreted regional architecture of the Warakurna LIP that is characterised by a series of sill complexes (west and east Bangemall) and the layered Giles mafic-ultramafic intrusions. It is assumed that the Giles intrusions were derived from a mantle plume that impinged onto the lithosphere at about 1076 Ma. In places, the plume manifested itself with the eruption of bimodal volcanics in the Musgrave region, whereas westward flow of mantle melts resulted in the emplacement of the Bangemall sill complexes. The model also shows the distribution of potential magmatic and hydrothermal mineral deposits across the Warakurna LIP. After Morris and Pirajno (2005). B) Extent of the Warakurna LIP and position of the Musgrave Complex.

trusions, dykes and sill complexes. Sulphides, both massive and disseminated, tend to form near the base of layered intrusions or in embayments of feeder systems. Sulphide veins and disseminations commonly penetrate the footwall rocks. Most of the Giles intrusions consist of ultramafic to mafic successions (e. g. Fig. 4) and recent geological mapping has revealed that these successions are by no means confined to the northern sectors of the intrusions but are also found, albeit apparently in lesser amounts, at Mt West, Latitude Hills, Bell Rock and Hinckley Ranges (Fig. 3). The potential for magmatic Ni-Cu sulphide ores in these intrusions remains untested.

There is, as yet, no record of primary PGE occurrences in the Giles intrusions, but the potential for PGE rich zones in the ultramafic cumulates (e. g. peridotite, pyroxenite) in the basal layers of mafic-ultramafic intrusions has not been tested. Maier et al. (2003) found anomalous PGE abundances in the more evolved magnetitite layers of the Stella layered intrusion, South Africa. This style of mineralisation, according to Maier et al. (2003), is found in those layered intrusions that lack chromitites, as is the case for the Giles intrusions. Indeed, PGE mineralisation has recently been found associated with magnetitite-bearing Jamieson intrusions at a number of prospects (Canaan, Zen; Fig. 2) (AXG Mining Ltd, 2004).

The exploration potential for PGE deposits could be enhanced by systematic studies of Cu/Pd ratios. Maier (2005) pointed out that if Cu/Pd ratios are higher than mantle values, then the potential is low because PGE would have been retained in the mantle source during partial melting. However, if the Cu/Pd ratios are below mantle values, a PGE-bearing layer (or reef) could have developed where the change from high to low Cu/Pd ratios takes place (Maier, 2005).

In Table 1 we present ranges of values and averages of Pd, Pt, Cu, Pt/Pd and Cu/Pd ratios for gabbro, dolerite and anorthosite rocks from a limited dataset (n= 37), based on low-level analyses (detection limits: Pd 0.16 ppb; Pt 0.07 ppb; Cu 1 ppm).

Figure 6 shows the range and mean values of the Cu/Pd ratios for gabbro, dolerite dykes and anorthosite of some of the Giles intrusions in Western Australia. While Cu/Pd ratios are predominantly above the mantle values, four gabbros and three dolerites plot below the mantle value, suggesting that these intrusions may have potential for PGE mineralisation.

The Ni-Cu and PGE potential of the Giles intrusions is likely to be considerable because these bodies are speculated to form sill-like intrusions at various levels of emplacement in the crust (Glikson et al., 1996), thereby enhancing the chances of sulphur saturation in either staging magma chambers or conduits that feed the sill-like bodies above them. A conceptual model showing the possible relationship of the Giles intrusions with the rest of the Warakurna mafic-ultramafic rocks and the distribution of possible mineral systems is given in Fig. 7.

Acknowledgments

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