# GEOCHEMICAL DISCRIMINATION OF WEATHERED BEDROCK IN THE HERMIDALE-BYROCK REGION OF WESTERN NSW

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## INTRODUCTION

Recognising primary lithologies is difficult in deeply weathered terrain where the mineralogical and chemical composition of the bedrock has been strongly altered by intense weathering and later cementation and induration. In saprolite and saprock the original rock fabric and texture may be preserved to give clues to the original parent rock. However, in many cases, particularly in the upper part of the weathering profile, these features may be destroyed. This study has investigated some geochemical criteria that may help discriminate different parent bedrock types from deeply weathered regolith in the Hermidale-Byrock region of central-western New South Wales. Samples for the study were collected from the base of 226 air core holes drilled along road traverses across the Hermidale, Sussex, Coolabah, Byrock and Glenariff 1:100,000 sheet areas (Figure 1). This sampling was part of the Girilambone Project, a joint regional study carried out by CRC LEME and the New South Wales Department of Mineral Resources (now Department of Primary Industries) between 2001 and 2004.

## METHODS

Four kilograms samples were collected from the bottom 1 m interval of the air core holes. The depth of sampling varied from 3 m to 87.5 m, depending on the thickness of the weathering profile and the depth of drill refusal. Samples were pulverised in a tungsten carbide mill and analysed for major elements by X-Fay Fluorescence spectrometry (XRF) and trace elements by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) at Geoscience Australia.

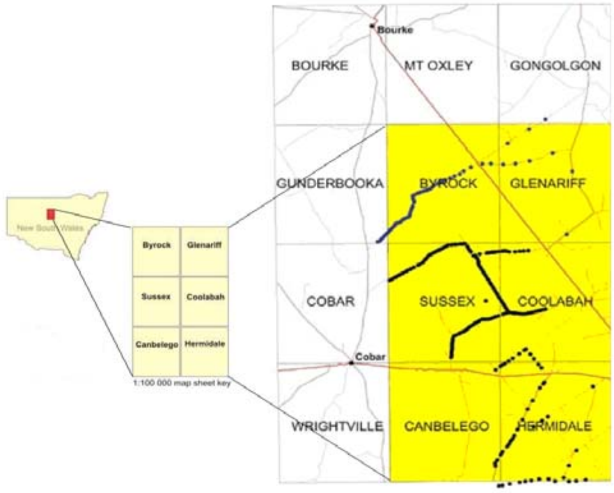


**Figure 1**: Location of the Hermidale-Byrock study area in western New South Wales. Large map shows the position of the drill holes sampled in relation to the 1:100 000 sheet areas.

## BEDROCK STRATIGRAPHIC UNITS

The known bedrock in the Hermidale-Byrock region has been subdivided into a number of stratigraphic units and intrusive rock types (e.g., Byrnes 1993, Suppel & Gilligan 1993, Gilligan & Byrnes 1995). These units are described as follows.

### Girilambone Group (Cambro-Ordovician)

The Girilambone Group consists of rhythmically bedded, poorly sorted, fine- to coarse-grained quartzose sandstones with subordinate quartzo-feldspathic sandstones, siltstones and chert together with minor intercalated basic volcanic rocks and minor conglomerate, marl and serpentinite bodies. In zones where metamorphic grades are higher, clastic rocks are psammitic and pelitic schists while basic-intermediate igneous rocks become amphibolitic at the highest metamorphic grades (Suppel & Gilligan 1993). Felsic volcanic rocks associated with quartz sandstones and cherts are known from Harts Tank, but the relationship of these rocks to those of the Girilambone Group is uncertain.

### Kopyje Group (Early Devonian)

The Kopyje Group consists of accumulated lenses of coarse-grained quartz-lithic sandstone and conglomerate deposited in high-energy fluviatile to shallow marine environments (Gilligan & Byrnes 1995). This clastic sequence is intercalated with several felsic volcanic units. These volcanic units are mainly rhyolites with minor rhyodacite, dacite and rare andesite components (Supple & Gilligan 1993).

### Granite

There are several granites exposed in the area. These can be grouped according to their composition into: magnetic; poorly to non-magnetic biotite-dominant; high silica; weakly magnetic pink feldspar; and,

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peraluminous granites (Blevin & Jones 2004).

**RESULTS**

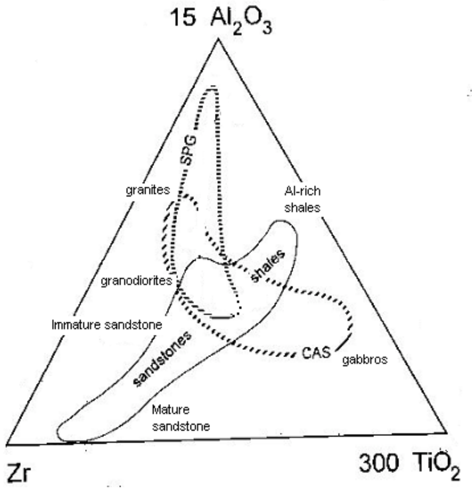
A series of key geochemical parameters were investigated for their potential use in discriminating the variably weathered bedrocks in the study area. A three-step approach was taken:

1. The first step examined the use of relatively immobile elements including Zr, Ti and Al to broadly classify the major rock types;
2. The second step tested several methods for determining the degree of weathering-related alteration of the rocks; and,
3. The third step was to determine whether major and minor element variables could be used to indicate possible differences in sediment provenance for the least altered rocks. It was thought that such differences might help distinguish rocks from different stratigraphic units.

**1. Al-Ti-Zr Diagram**

Of the major and minor elements Al, Ti and Zr are generally considered the least mobile during chemical weathering. Significant amounts of Ti and Zr are typically fixed in resistate minerals such as zircon, rutile and ilmenite. Variations in these elements are conveniently expressed in a ternary Al-Ti-Zr plot (Garcia *et al*. 1991). Interpretation of compositional variation on this diagram is based on the premise that sedimentation involves weathering, transport, mixing from different sources and sorting (Sawyer 1986). In the first three processes, the contents of insoluble elements such as Al, Ti and Zr may vary in response to the degree of leaching of the soluble elements. However, their relative proportions are transferred from the source area into the bulk sediment or regolith with little, or without, modification. This material is then sorted according to the hydraulic properties of its mineral components and the chemical fractionations between complementary shales and sandstone are generated (Garcia *et al*. 1994, Figure 2). Other rock types such as felsic and mafic igneous rocks or immature volcanic-derived sediments will also plot in specific fields on this diagram.

Figure 2 shows a plot of the bedrock samples from the study area together with siltstones and shales from the CSA Siltstone unit of the Cobar Supergroup and known granites from the Byrock area. Most of the bedrock samples plot on the sandstone-shale fractionation line with a wide range of $TiO_2$/Zr variation. Some samples plot in the granite compositional field and some in the mafic igneous rock field.



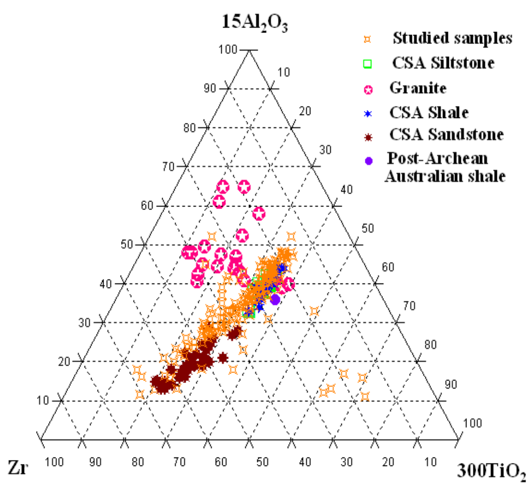




**Figure 2 (left):** The Al-Ti-Zr diagram (wt. %) after Garcia *et al.* (1994), where SPG is strongly peraluminous granite and CAS is calc-alkaline suites. **(Right):** Plot of bottom of hole samples from Hermidale-Byrock region together with unweathered samples from CSA Siltstone (Binns & Appleyard 1986), CSA shale and sandstone (Whitbread 2004), granites of the area (Blevin *pers. comm.*) and post-Archean Australian shale (Taylor & McLennan 1985).

More detailed investigation of Ti/Zr ratios can provide additional discrimination between rock types, particularly igneous rocks or sediments with different proportions of contained zircon, rutile or anatase or micas. Hallberg (1984) showed that the major groups of igneous rocks could be distinguished, even in the moderately weathered state, by the Ti/Zr ratio. This method of distinction was also used (e.g., Robertson *et al*. 1997) to discriminate moderate to severely weathered saprolite units.

A plot of the saprolith samples from this study (Figure 3) shows a distribution of compositions similar to the compositional range from dacite to andesite. In the case of the sedimentary and metasedimentary rocks this may partly reflect the composition of the source rocks for the sediments, modified to some extent by sedimentary processes. Samples of weathered granitic rocks fall in the dacitic compositional field. A small number of samples plot in the field of mafic compositions and probably reflect mafic dykes intersected in the drilling program.

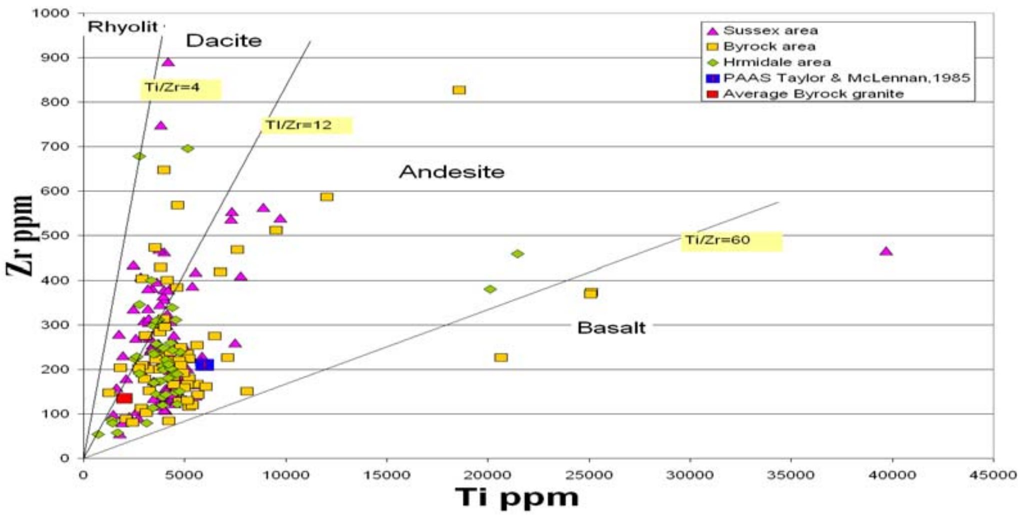



**Figure 3:** Ratios of wt. % Ti/Zr for samples from the Hermidale-Byrock region with Post-Archean Australian Shale (PAAS, from Taylor & McLennan 1985) and average Byrock granite (Blevin *pers. comm.*).

## 2. Chemical Index of Alteration

The Chemical Index of Alteration (CIA) provides a measure of the total weathering alteration of source material for sediments and the subsequent weathering of the sedimentary rocks. The CIA ratio and the Al-Ca+Na-K diagram (Figure 4) show clear discrimination of slightly, moderately and deeply weathered materials. Unweathered sedimentary rocks from the CSA Siltstone plot on a linear trend towards the muscovite composition. Slightly to moderately weathered (CIA < 70) compositions from the Hermidale-Byrock region generally show a low spread and are similar to unweathered sandstones from the CSA Siltstone. These less altered samples are mostly from the southern Hermidale region and cluster close to the igneous evolution line between dacite and rhyolite. Igneous rocks of this composition occur in the southwestern portion of the Hermidale sheet area. With greater weathering these compositions show a trend towards the illite composition. Such linearity is also typical of more quartzose suites derived from mature continental margin arc systems (Roser & Korsch 1999). The trend towards illite diverges from the ideal feldspar weathering line (IWL), which parallels the Al-Ca+Na (Nesbitt & Young 1984), due to syn- or post-depositional K-enrichment in clay fraction (Fedo *et al.* 1995) suggests significant K-metasomatism of clay minerals (Fedo *et al.* 1997, Roser *et al.* 2002). High Ca+Na values with low Al and K are possibly an additional input of Ca and Na due to metasomatism.

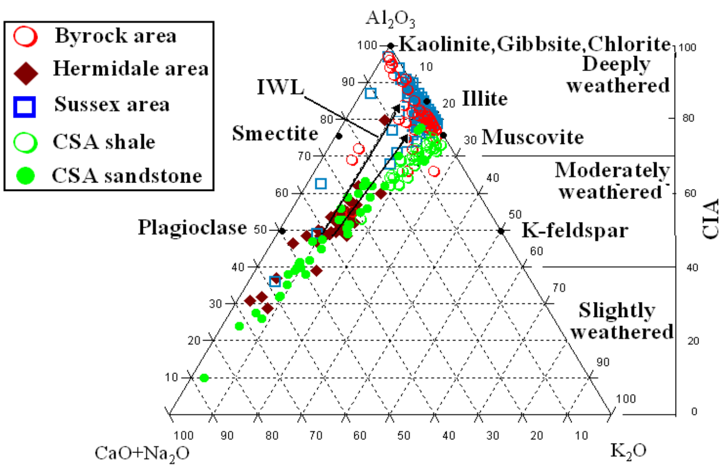



**Figure 4:** A-CN-K diagram (Nesbitt & Young 1984) showing compositions for bottom of the hole samples from the Hermidale-Byrock area. A=$Al_2O_3$; CN=$CaO+Na_2O$; K=$K_2O$ (Molar proportions). Average values for basalt, andesite, dacite and rhyolite are from Roser *et al.* (2002). CSA shale and sandstone data are from Whitbread (2004).

Samples with compositions showing strong weathering alteration are mainly from the Byrock and Sussex areas. These samples plot along the muscovite-illite trend on the Al-K axis, with high Al content. It has been observed that high Al concentration in marine sediments relates to fine-grained aluminosilicate detrital fractions (Calverts 1976). Potassium is mostly associated with potassium feldspar ($K[AlSi_3AlO_8]$) (Shimmield & Mowbray 1991, Martinez *et al.* 1999), and illite ($(K, H_3O)Al_2[(OH)_2Si_3AlO_{10}]$) (Yarincik *et al.* 2000). Al-rich samples with high CIA (> 75) indicate a significant amount of K-rich clay, mostly produced by advanced weathering processes.

**3. Major-element provenance discrimination**

Major-element variations were examined using the discriminant functions of Roser & Korsch (1988). The majority of the slightly weathered (CIA < 40) and the moderately weathered (40 > CIA < 70) saprolith samples plot in the intermediate igneous provenance and quartzose sedimentary provenance compositional ranges and a few samples plot in the felsic and mafic fields (Figure 5).

The manner in which data points tend to cluster in the sedimentary quartzose the intermediate provenances reflects the average composition of rocks exposed to erosion at the time of deposition. Plotting fresh granite and CSA Siltstone (shale and sand) data on Figure 5 showed identical occurrences of granite in the Byrock region and the majority of the Hermidale saprolith that are plotted in the quartz rich provenance are mostly matching with CSA sand.

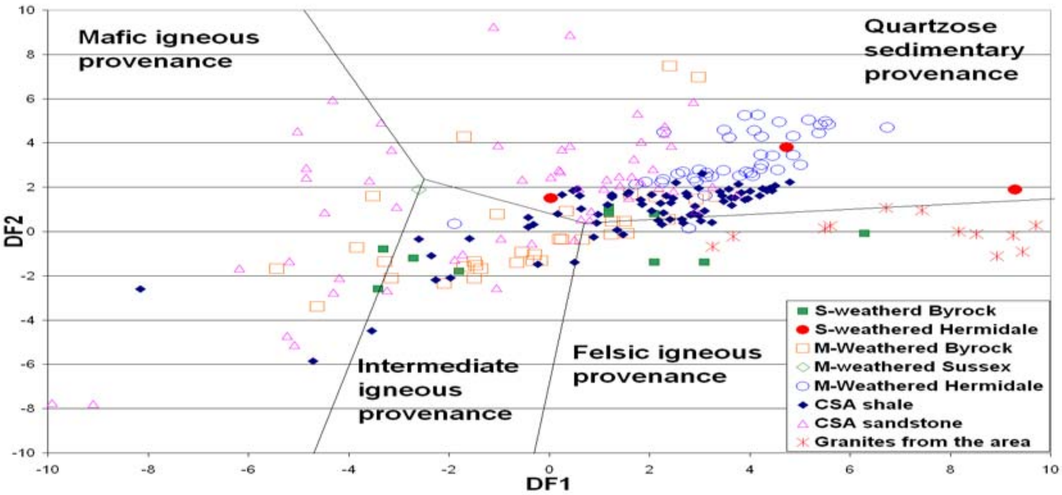



**Figure 5:** Major element provenance discriminant diagram shows the slightly (S) weathered and moderately (M) weathered saprolith samples of the Byrock, Hermidale and Sussex areas. Discriminants and fields are after Roser & Korsch (1988). $DF1=30.6038TiO_2/Al_2O_3–12.541Fe_2O_{3(total)}/Al_2O_3+7.329MgO/Al_2O_3+12.031Na_2O/Al_2O_3+35.42K_2O/Al_2O_3-6.382$. $DF2=56.500TiO_2/Al_2O_3-10.879Fe_2O_{3(total)}/Al_2O_3+30.875MgO/Al_2O_3–5.404Na_2O/Al_2O_3+11.112K_2O/Al_2O_3-3.89$. Granite data are from Blevin (*pers. comm.*), CSA shale and sandstone data are from Whitbread (2004).

The relative abundance of trace elements such as Th and La (indicative of a felsic igneous source) and Sc and Cr (indicate of mafic source) and ratio plots such as Th/Sc-Sc, Cr/Th-Sc/Th and Th/Sc-Zr/Sc were used to differentiate the source of sediments (e.g., McLennan & Taylor 1991, Roser *et al.* 2002). These ratios allow assessment of aspects of bulk source composition because they are resistant to alteration process, and a part from the effects of heavy- mineral concentration may be only slightly modified during transport (Roser *et al.* 2002).

The Th-Sc diagram (Figure 6) and the Ti/Zr-Sc/Th diagram (Figure 7) show apparent discrimination of the saprolith samples to mafic, intermediate and felsic provenance. Several sets of fresh rock data of basalt, granite, CSA Siltstone (sand and shale) as well as the post-Archaean Australian shale and the present upper continental crust that plotted on the diagram are support this geochemical discrimination. Some samples from the intermediate provenance are closely correlated and overlapped with the sand or the shale of the CSA unit (Figure 7), which indicates that these saprolith samples were derived from similar source bedrocks.

**CONCLUSIONS**

A wide variation of geochemical parameters in the Hermidale-Byrock region make the identification of bedrock units more difficult except for a few sites of strong mafic and felsic signatures.

Wide compositional differences were noticed on the Al-Ti-Zr and A-CN-K diagrams where most of the

Hermidale samples displayed the early weathering stages of rhyodacitic-rhyolitic igneous and/or quartzose sources. The Byrock and Sussex samples show advanced weathering stages and/or less felsic compositions with intermediate-mafic interferences. These interferences most probably are related to local mafic intrusives that have been observed in the region (all but Hermidale) (Chan *et al.* 2001, 2002).

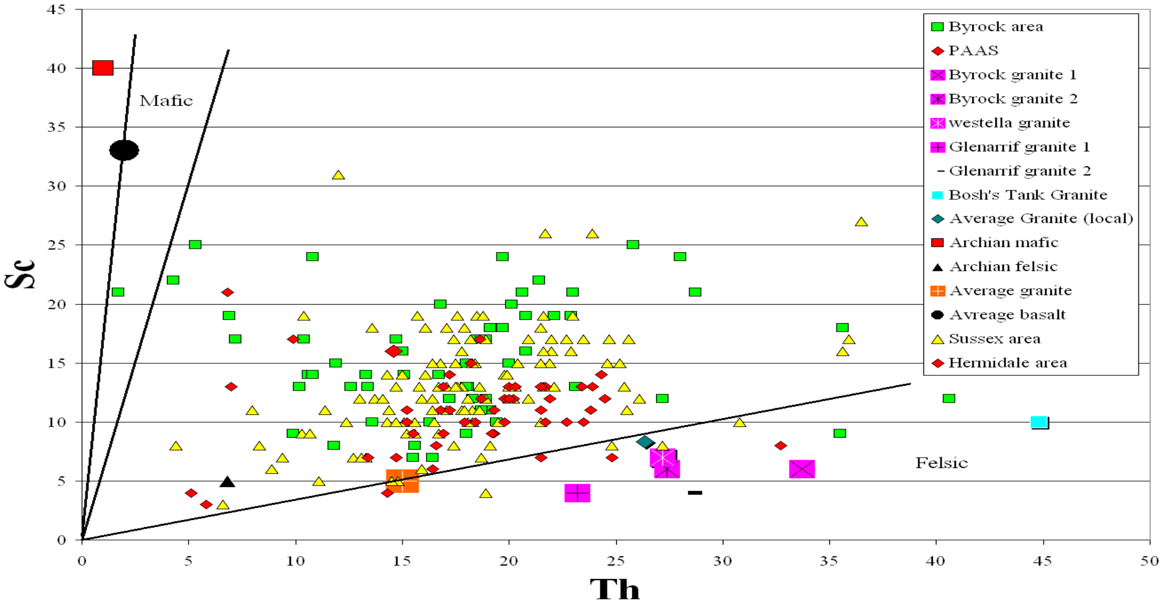



**Figure 6:** Th-Sc diagram shows discrimination of the saprolith samples in the Hermidale-Byrock region. Granite and PAAS data indicated in Figure (3).

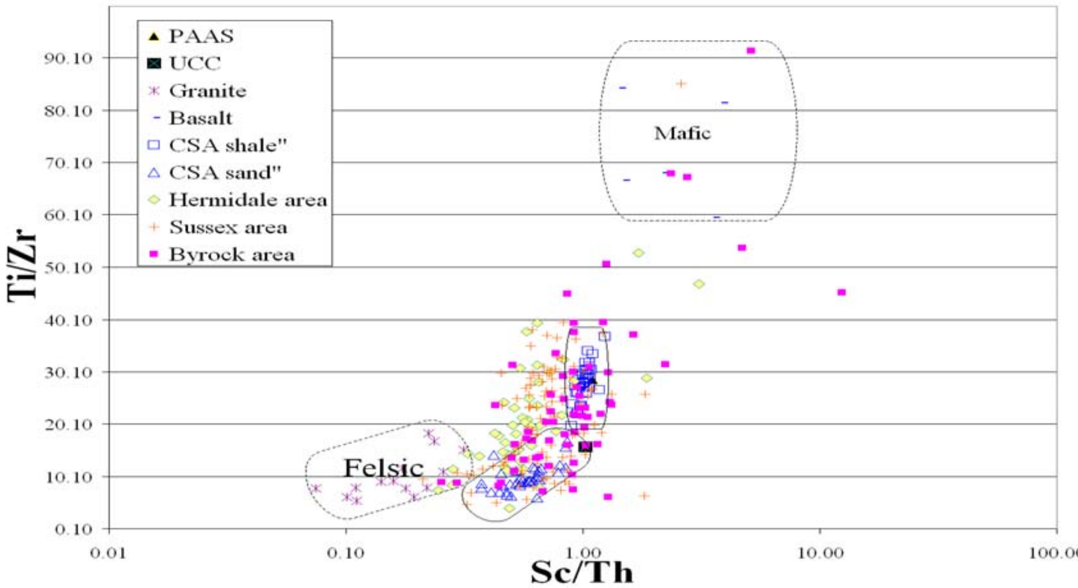



**Figure 7**: Ti/Zr-Sc/Th diagram of the Byrock, Hermidale and Sussex bottom of the hole samples. Upper Continental Crust (UCC) and Post-Archian Australian Shale (PAAS) data are from Taylor & McLennan (1985). Granite data are from Blevin (*pers. comm.*) and CSA data are from Whitbread (2004).

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