CHARACTERISATION OF REGOLITH MATERIALS IN THE GIRILAMBONE REGION, NORTH-WESTERN LACHLAN FOLD BELT, NSW

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INTRODUCTION

Regolith in the Girilambone Region of NSW is thought to contain significant quantities of aeolian materials that can adversely affect mineral exploration techniques and complicate regolith landform mapping (Chan *et al.* 2002). A detailed study was made of the characteristics of the regolith materials found at selected sites in this region, with emphasis on determining how much of the near-surface regolith is residual and how much has been transported, in particular by aeolian processes. Characterisation of the aeolian materials will assist in developing a set of procedures to identify and estimate proportions of aeolian contributions in the field. This will improve the accuracy of interpretation of exploration data when using soil as a sampling medium for mineral exploration.

Aeolian materials have contributed to soil formation processes in many regions of the world. However, except for some desert regions in Australia, the deposition, characterisation, and influences of these materials on soil-landscape development are poorly understood (Cattle *et al.* 2002). Of particular interest are the very stable composite clay microaggregates found in Australian aeolian material. Butler (1956) used the term “parna” to describe the aeolian materials in Australia that contain these stable microaggregates. These clay microaggregates are reported to be significantly more stable than similar microaggregates that occur in aeolian loess deposits in the USA (Mays *et al.* 2003). As such they can have profound effects on landscape processes and pedogenesis, and hence significant consequences for land management (Chan *et al.* 2001).

RESEARCH DESIGN

Study sites

Study sites were selected to: include a range of potential parent materials, highlight areas of mineralogical and/or geochemical anomalies, and incorporate a variety of regolith landform units, which may contain significant aeolian contributions (Figure 1). The study site details are:

1. *Girilambone Region sites.* Ten sites were chosen to examine trends across different mapped regolith landform units, and to contribute detailed studies to the CRC LEME drilling programs: Hermidale (2001) and Byrock (2003). Sites discussed in this paper are a colluvial depositional site CBAC153 and an alluvial erosional site CBAC186.
2. *Leucitite lava outcrops in the Girilambone Region: El Capitan Knob, Mountain Tank, and Bye Hill.* Three leucitite lava outcrops ranging in height from 15 to 25 metres were chosen to represent “natural dust traps” (NDT). These young tertiary basaltic outcrops were formed by lava flow inflation and have been positive landscape features since the Miocene. They now exist as detached hills in a generally flat landscape and provide potential traps for wind blown material. They are lithologically distinct from the surrounding bedrock and wind blown material. Only skeletal soils, to a maximum depth of approximately 0.1 m, exist on the leucitite basalts. Sampling sites were chosen towards the top of these topographic highs to avoid any alluvial or colluvial contamination, thus leaving the only options available for the derivation of the soils to be residual or aeolian. Similar parameters were used by Walker *et al.* (1988), Gatehouse *et al.* (2001), and Cattle *et al.* (2002) in their study site selections involving comparable “natural dust traps” for aeolian deposits.
3. *Windara: Dune-Swale land-system.* A longitudinal dune (in a dune-swale land system) approximately 100 km west of Cobar was chosen to incorporate a site suspected of containing material from local and distant sources, to compare the characteristics of the NDT aeolian deposits with that of a wind blown landform evident in the landscape, and to test the applicability of the procedures developed in identifying aeolian material.
4. *Corop: Lunette/Source-bordering dune:* This northern Victorian site has been extensively studied by Butler (1956), and allows for the sampling of both aeolian transported material, as well as material from the suspected source area. It also allows the inclusion of a site with a different source to the main

Girilambone study area and can thus be used to test the transferability of the procedures developed in identifying aeolian materials to other areas of aeolian activity.

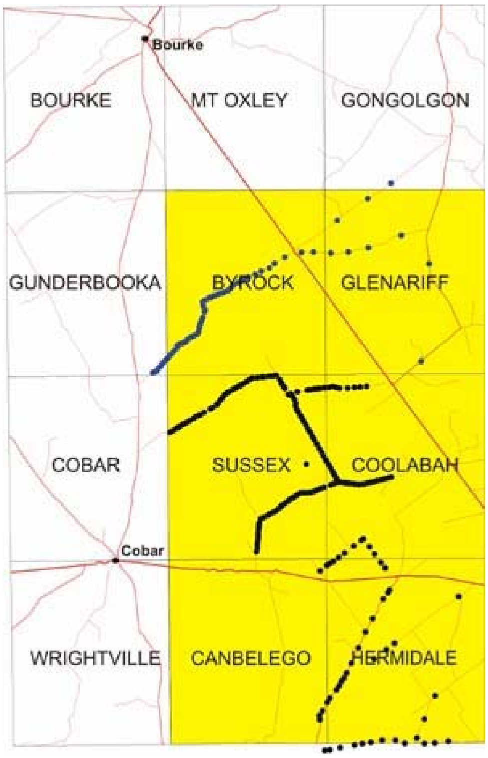


Figure 1: Locality of study area, from Fleming & Hicks (2003).

Analysis and techniques

Uniform characteristics of a common soil material across varying topographies and lithologies has been used as a major criterion to indicate aeolian processes (Butler 1956, Summerell *et al.* 2000, Chen 2001). Therefore, if a contrast exists in characteristics between this soil material and, for example, the underlying leucitite basalt of the "natural dust traps" (NDT), then the characteristics of the soils can be assumed to indicate aeolian material that would have been deposited across other landforms in the Girilambone Region (Figure 2).

Previous work has shown that uniformly distributed aeolian materials display little regional variation in texture and geochemistry (Qi-zhong *et al.* 1980). Hence it is expected that across all three NDT the aeolian component will be physically and geochemically similar. Furthermore, as aeolian material is deposited across all landscape features, it is expected that aeolian material with the same suite of geochemical characteristics to that on the NDT will be found at the other Girilambone Region sites. However, due to the different depositional sites- for example leucitite basalt compared with Girilambone Regional sediments, it is expected that the soils of the region would contain a mixture of *in situ* characteristics. For soils located on the NDT influences of the basalt dissimilar to the aeolian material will result in geochemical differences, indicating that they also contain an *in situ* component.

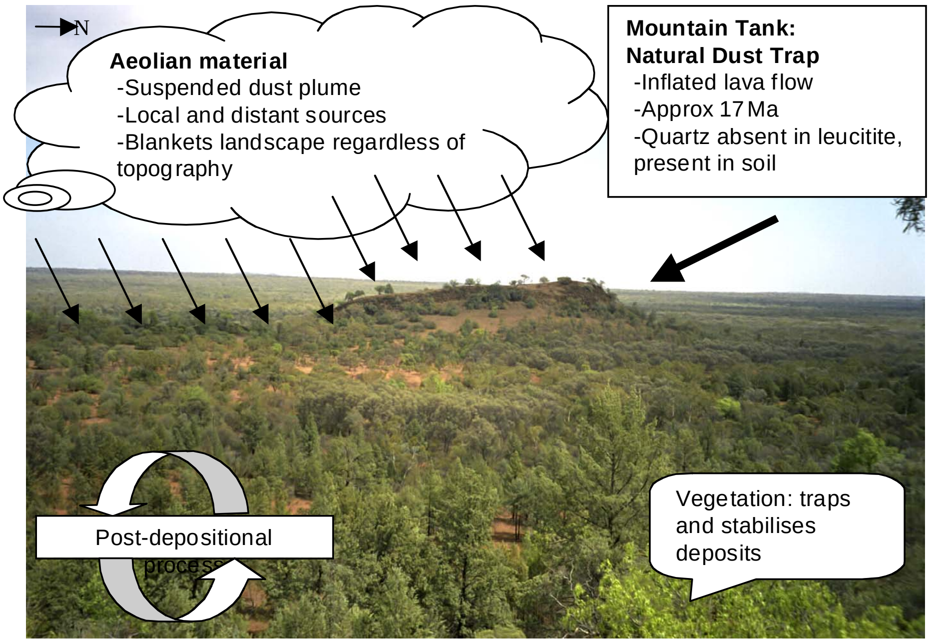


Figure 2: Photograph of Mountain Tank natural dust trap (04/2003) with notes.

Several techniques were employed to investigate the solum at the study sites, and to identify any significant aeolian contributions. These techniques included: particle-size analysis (PSA); X-ray diffraction (XRD); X-ray fluorescence (XRF); scanning electron microscopy (SEM); thin-section micromorphology; radiometrics; digital elevation models (DEMs); and Landsat imagery. A variety of geochemical procedures: pH; electrical conductivity (EC); exchangeable cations; and exchangeable sodium percentage (ESP) were also measured.

RESULTS

The particle size distributions (PSD) of all NDT display a well-sorted pattern with a dominant size fraction peak at 70 µm (Figure 3). Major mineral composition and micromorphology reveals this fraction is represented by spherical quartz particles and therefore is taken to be indicative of aeolian material. The distribution curve also shows smaller peaks at the 520 µm and 4 µm particle sizes. The Girilambone Region sites display similar PSD plots to that of the NDT (Figures 4 and 5). For example, at the colluvial CBAC153 site (Figure 4), throughout the upper 0.7 m of solum, a bimodal distribution is evident, with two dominant peaks initially 70 µm at the surface (varying with depth to 30 µm) and at 500 µm. A decrease in particle size with depth within this profile is evident through the 30-70 µm and 4 µm fractions indicating a transported component. The increase in coarse 500 µm material in the near surface samples could reflect the concentration of lag within this colluvial depositional plain. However, at the alluvial CBAC186 site, the coarse 500 µm fraction has a constant abundance from the surface to 1 m depth . The 70 µm fraction decreases with depth, moving towards a more prominent 30 µm fraction, reflecting either a more abundant *in situ* or alluvial component.

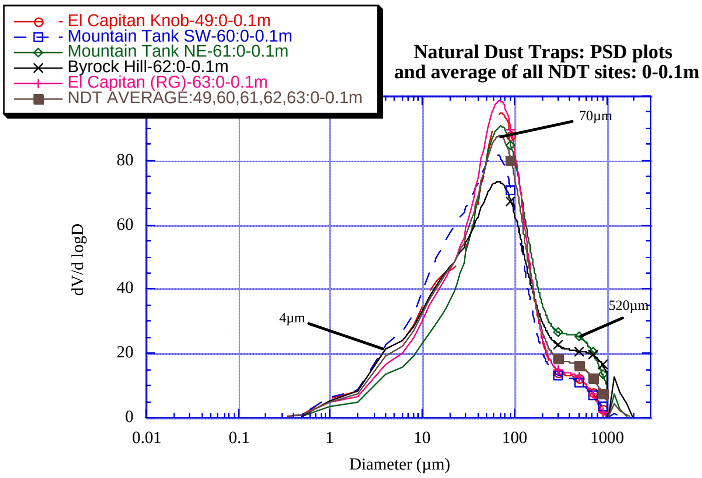


Figure 3: PSD plots of all NDT, including the average pattern of all NDT sites.

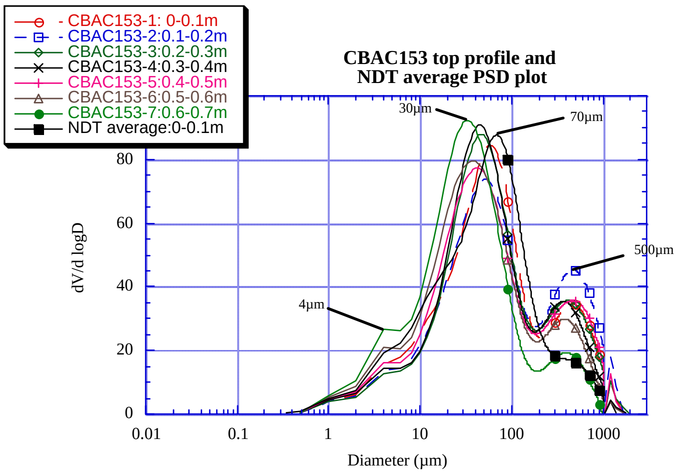


Figure 4: PSD plots of the colluvial CBAC153 site surface 0.7 m profile samples, plotted with the average NDT PSD plot.

Micromorphological analysis of thin-sections and SEM images from surface (0.1 m) samples of the NDT soils and Girilambone Region sites notably display: a) 70 µm pitted spherical quartz particles consistent with aeolian transport quartz component, and b) only a minor presence of clay aggregates (Figures 6, 7, and 8). These clay aggregates are thought to be typical of aeolian material formed in hot, dry areas through deflationary processes, however are obviously not dominant in these Girilambone Region aeolian sediments. Furthermore, SEM and micromorphological observations interestingly display clay materials distributed between different sizes, for example as shown in SEM's: clay coats on quartz grains, clay coats on silt grains, clay aggregates, and as free clay.

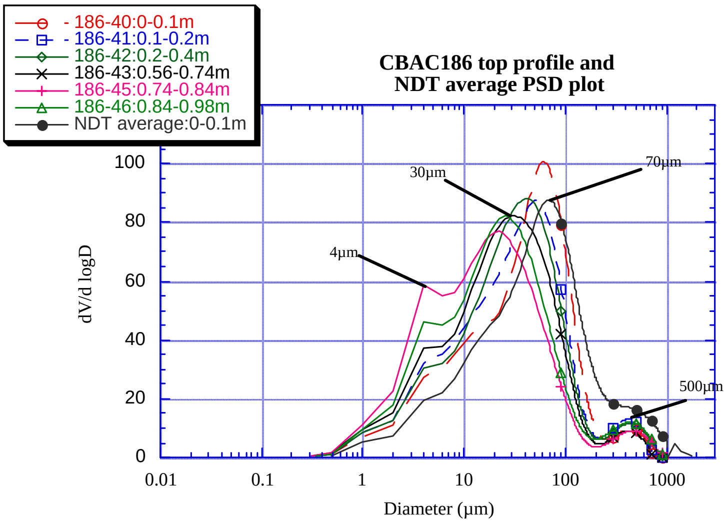


Figure 5: PSD plots of the alluvial CBAC186 site surface 1 m profile samples, plotted with the average NDT PSD plot.

Figure 6: SEM image of El Capitan NDT soil surface 0-0.1 m sample.

Figure 7: SEM image of the colluvial CBAC153 surface 0-0.1 m sample.

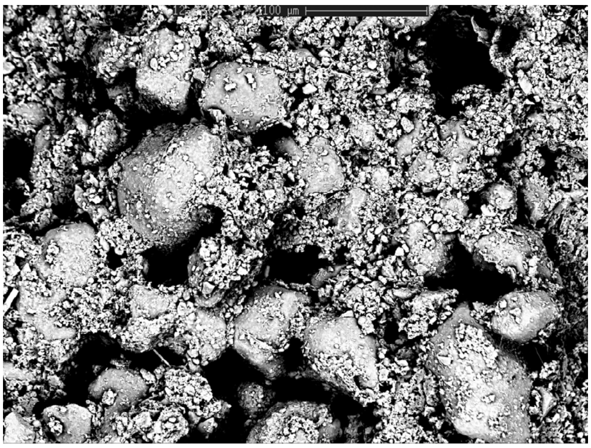
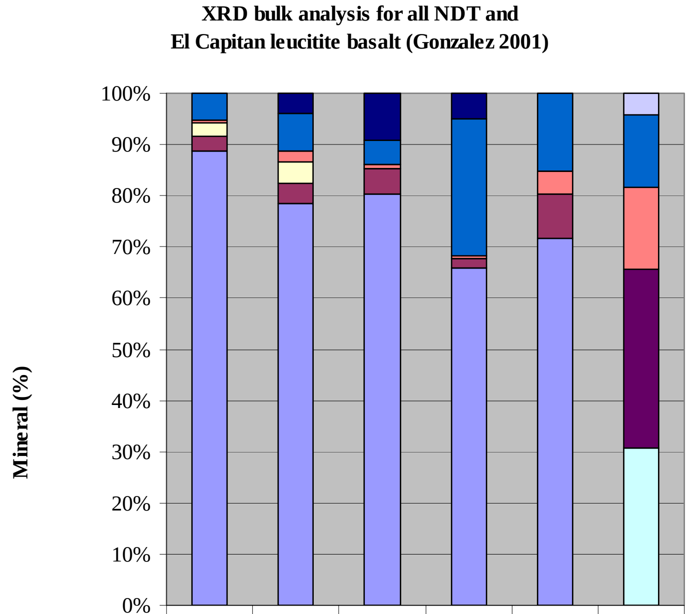


Figure 8: SEM image of the alluvial CBAC186 surface 0-0.1 m sample.

As mentioned above, major mineralogical analysis of bulk samples confirms the dominance of quartz in the soils covering the NDT (e.g. Figure 9). The most common clay minerals across all NDT and Girilambone sites are kaolin and muscovite. Major elemental analysis indicated that the Girilambone Region soils are dominated by: Si, Al, Fe, and K. Variations in the abundance of these elements correlate with mineralogy For example, high clay contents corresponded with elevated Al, high Fe results associated with the occurrence of hematite, and compounds of silicon elevated relative to the abundance of fine sand/quartz grains. Soils on the NDT displayed significantly different geochemistry to the surrounding Girilambone Region sites, proving that despite aeolian additions, they remain heavily influenced by the leucitite bedrock. Ti/Zr ratios (Figure 10) display similarities between the non-quartz fraction of the soil on the NDT and the underlying leucitite basalts. The subsequent dissimilarity of these NDT Ti/Zr ratios with the other Girilambone Region sites is also evident in Figure 10 and indicates that the non-quartz fraction (i.e., < 70 µm) of the NDT and Girilambone Region soils is not aeolian.



	El Capitan Knob: 0-	Mountain Tank SW: 0-	Mountain Tank NE: 0-0.1m	Byrock Hill: 0-0.1m	El Capitan (2001): 0-	Leucitite basalt: El Capitan
Other Minor Phases (Wt%)	0	4	9	5	0	0
Amphibole	0	0	0	0	0	4
Mica + (including muscovite, biotite)	5	7	5	27	15	14
Fe, Ti Oxides (including hematite, rutile)	1	2	1	0	5	16
Clinopyroxene	0	0	0	0	0	35
Leucite	0	0	0	0	0	31
Augite (Wt%)	3	4	0	0	0	0
Kaolin (Wt%)	3	4	5	2	9	0
Quartz (Wt%)	88	79	80	66	71	0

Figure 9: Major mineral composition of NDT surface (0-0.1m) samples determined by quantitative XRD (SIROQUANT).

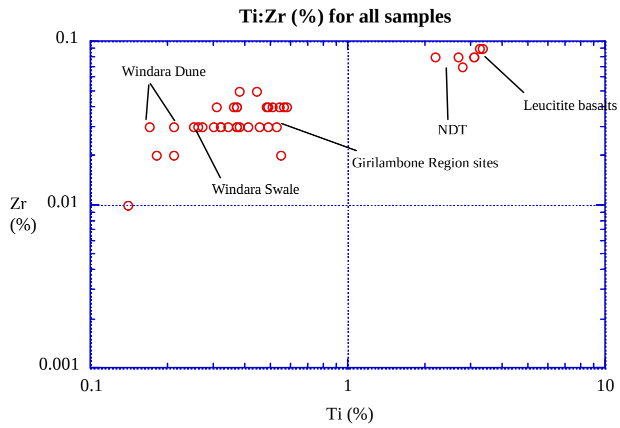


Figure 10: Fe:Al (%) for all sites sampled: NDT soils, leucitite basalt (Gonzalez 2001), Girilambone Region sites, Windara dune-swale land system, and Lake Corop.

DISCUSSION

The PSD of soils over all the NDT revealed a distinct 70 µm peak. SEM and XRD analysis indicate that this material is composed of fine-grained, spherical quartz consistent with aeolian transport. The presence of quartz on the NDT confirms an introduced component, as the parent leucitite does not contain quartz. The elevated locality of the sampled sites on the inflated lava flows precludes alluvial and colluvial additions of material. Therefore a significant proportion of the material on the NDT can be confirmed as aeolian, and consequently may be used to aid characterisation of aeolian additions in the surrounding Girilambone Region landscape.

At the Girilambone Region sites, a peak of approximately 70 µm is also dominant. However, the intensity of this size fraction decreases with depth, suggesting that the source of this particle size fraction is not *in situ* weathering.

Therefore the 70 µm fine sand fraction has been introduced to the profile by transportation processes, probably the most important of which is aeolian processes. Confirming this, the 70 µm fraction consists of spherical quartz particles consistent with aeolian transport. The coarser fraction of material throughout the Girilambone Region sites ranges from 400-600 µm. Considering this coarse fraction cannot be entrained in aeolian transportation, it can be assumed that it has come from other alluvial, colluvial, or *in situ* processes. Such a mixture of sediments is compounded by additional fine fractions from sources other than aeolian, both of which dilute aeolian deposits complicating the determination of the characteristics of aeolian material. Thus, the absence of a discrete aeolian mantle and the deposition of aeolian sediments on other transported materials in the Girilambone Region demands the use of shape and geochemistry to validate the aeolian nature of sediments.

Clay is distributed between different particle size modes for all of the NDT soils and Girilambone Region sites. The SEM and micromorphological analysis of thin sections revealed that a considerable fraction of clay exists as clay coatings on silt and quartz grains, clay as free particles, and to a lesser extent, as clay microaggregates. It is possible that a greater proportion of aeolian material was transported as clay aggregates, typical of Australian aeolian deposits. However, bioturbation and dispersion of aggregates in the surface of soil profiles, encouraged by a low overall deposition rate and length of time at the surface, would have changed this aggregate distribution and transformed original characteristics (Mays *et al.* 2003). Additionally, it is probable that the Malvern Mastersizer 2000 used to perform the particle size analysis is underestimating the clay fraction. Unfortunately this is a characteristic of the laser diffraction technique, and seems to be worst when the clay is mixed with silt and sand fractions (Hesse *pers. comm.* 2003).

CONCLUSIONS

This study has shown that it is important to use a range of techniques to identify aeolian deposits in the landscape. Identification should involve studies of morphological and geochemical characteristics, study sites should incorporate aeolian material that has been sourced from different locations—local and distant—and ideally that sites should be chosen where aeolian deposits have been preserved and/or contrast with the geology of the area to establish the characteristics of the aeolian material in the particular area. Due to the variability of aeolian sediments dependant on source areas, it is essential that more than one diagnostic tool be employed to insure the correct characterisation of aeolian deposits.

IMPLICATIONS FOR MINERAL EXPLORATION AND LANDSCAPE PROCESSES

Contrasts between *in situ* and transported material can be used to indicate an aeolian origin especially when the source is dissimilar to the deposition area. Contrasting aeolian sediments with leucitite bedrock provides the aeolian sediments with a unique suite of characteristics. Variations in element abundance with depth can be tracked, and whole rock XRF analysis provides the potential to use titanium/zircon and titanium/chromium ratios where a strong contrast is present between the geology and overlying transported material. This technique proved extremely valuable in proving aeolian origins for the solum present on the NDT.

Post-depositional processes such as pedogenesis, bioturbation, alluvial, and colluvial affect the preservation, dilution, and implications of aeolian additions in the landscape. It is important to note that:

1. Aeolian deposits vary with location, climate, landscape position, and source areas; and,
2. Aeolian deposits are most effectively recognised through contrasts with *in situ* material, uniform distributions across varying topographies and lithologies, and where a signature for the area of interest can be defined through definitive indicators, for example: mineralogical and/or geochemical composition.

Therefore, it is recommended that researchers always start from first principles to detect aeolian sediments.

Once it has been established that the soil contains significant aeolian additions, the appropriate caution can be taken when interpreting exploration data. Chemical or mechanical mixing as a result of aeolian additions may potentially dilute the geochemical anomalies. Aeolian additions may also mask primary geological features in radiometric analysis of an area presenting characteristics dissimilar to the regional geology.

This research revealed the necessity to note the fine, dominant size fractions in predominately aeolian deposits in the Girilambone Region (70 µm) as these may cause problems if it is decided to incorporate soil sampling into the exploration program. Excluding this size fraction from sampling would help to avoid introduced aeolian materials, and may reduce exploration expenses and increase exploration accuracy through sampling local, *in situ* materials. Therefore, this research recommends that a coarser fraction of material than the 70 µm fine sand size be sampled to avoid any aeolian contamination.

REFERENCES

BUTLER B. 1956. Parna, an aeolian clay. *Australian Journal of Science* **18**, 145-151.

BUTLER B. & HUTTON J. 1956. Parna in the Riverine Plain of south-eastern Australia and the soils thereon. *Australian Journal of Agricultural Research* **7**, 536-553.

CATTLE S. 2002. Aeolian dust contributions to soil of the Namoi Valley, northern NSW, Australia. *Catena* **47**, 245-264.

CHAN R., GREENE R., DE SOUZA KOVACS N., MALY B., MCQUEEN K. & SCOTT K. 2001. *Regolith, geomorphology, geochemistry and mineralisation of the Sussex-Coolabah area in the Cobar-Girilambone Region, North-Western Lachlan Foldbelt, NSW*. CRC LEME **Report 166**.

CHAN R., GREENE R., HICKS M., MALY B., MCQUEEN K. & SCOTT K. 2002. *Regolith architecture and geochemistry of the Hermidale area of the Girilambone Region, North-Western Lachlan Foldbelt, NSW*. CRC LEME **Report 179**.

CHEN X. 2001. The red clay mantle in the Wagga Wagga region, New South Wales: evaluation of an aeolian dust deposit (Yarabee Parna) using methods of soil landscape mapping. *Australian Journal of Soil Research* **39**, 61-80.

FLEMING G. & HICKS M. 2003. *Preparations for third programme of shallow aircore drilling, Byrock area, Cobar NSW*. Cobar Project **GS2003/065**, NSW DMR and CRC LEME.

GATEHOUSE R., WILLIAMS I. & PILLANS B. 2001. Fingerprinting windblown dust in south-eastern Australian soils by uranium-lead dating of detrital zircon. *Australian Journal of Soil Research* **39**, 7-12.

GONZALEZ OR. 2001. *The geology and landscape history of the El Capitan area, Cobar, NSW*. B App. Sc. Honours Thesis, University of Canberra, unpublished.

GREENE R., GATEHOUSE R., SCOTT K. & CHEN X. 2001. Symposium report: Aeolian dust-implications for Australian mineral exploration and environmental management. *Australian Journal of Soil Research* **39**, 1-6.

GREENE R. & NETTLETON W. 1995. Soil genesis in a longitudinal dune-swale landscape, NSW, Australia. *AGSO Journal of Australian Geology and Geography* **16**, 277-287.

MAYS M., NETTLETON W., GREENE R. & MASON J. 2003. Dispersability of glacial loess in particle size analysis, USA. *Australian Journal of Soil Research* **41**, 1-16.

QU-ZHONG W., GUI-YI D., SU-HUA Y., FU-QING S., XIONG-FEI G., QING-MU C. & YU-LAN L. 1980. Some problems of loess geochemistry in China. *In:* WASSON R. ed. *Quaternary Dust Mantles of China, New Zealand and Australia*. Australian National University, pp. 69-85

SUMMERELL G., DOWLING T., RICHARDSON D., WALKER J. & LEES B. 2000. Modelling current parna distribution in local area. *Australian Journal of Soil Research* **38**, 867-878.

WALKER P., CHARTRES C. & HUTKA J. 1988. The effect of aeolian accession on soil development on granitic rocks in South-Eastern Australia. I. Soil morphology and particle-size distributions. *Australian Journal of Soil Research* **26**, 1-16.

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