Geochemical dispersion processes in deep cover and neotectonics in Coompana, Nullarbor Plain, South Australia

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SUMMARY

Mineral exploration in regions under thick cover is challenging. This study looked into vertical geochemical dispersion processes through ~550 m of cover in the Coompana Province, South Australia. We collected new data from CDP008 drill hole (~680 m), which contains the most complete record of the cover sequence in this region including: (1) mafic volcanic basement; (2) ~140 m of undifferentiated fluvial sediments (Phanerozoic); (3) overlain by ~230 m of fluvio-lacustrine to marine Mesozoic deposits; and (4) followed by ~200 m of Cenozoic carbonates. Our study revealed that REE patterns in the basalts and the overlying sandstone package show similarities. Yet, no geochemical similarities existed with the Mesozoic units and the upper stratigraphic units. Regolith mapping of this area revealed intricate landscape patterns. These include numerous linear scarps, which trend NW-SE to N-S to NE-SW and experienced <10 m of displacement. When coupled with magnetic data, this scarp trend correlates with basement structural trends at depth and hence these scarps are interpreted as neotectonic features. Based on the geochemistry we concluded that: (1) the lower sandstone package contains a geochemical footprint of the basement rocks produced by vertical and lateral geochemical dispersion; (2) the Mesozoic sediments do not record vertical dispersion related to the underlying basement; (3) the top limestone units are a chemical barrier for vertical geochemical dispersion due to lack of permeability. They are an efficient stratigraphic boundary to produce redox gradients and therefore differential geochemical horizons; and (4) basement features identified from magnetic data are mimicked by linear surface landscape features. We pose that neotectonic surface features may record vertical geochemical dispersion from lower stratigraphic units. The relation between neotectonic structures and landscape geochemistry could have critical implications in mineral exploration under cover in Australia and in other similar landscape settings in the world.

Key words: Coompana, mineral exploration, Nullarbor, geochemical dispersion, neotectonics.

INTRODUCTION

The Coompana Landscape

The Coompana region comprises a small eastern portion of the large-scale Nullarbor Plain in southern Australia (Figures 1 and 2). The Nullarbor Plain is the surface expression of the Cenozoic Eucla Group carbonates and marginal clastic equivalents, which were deposited on a vast subtropical epeiric marine platform, and represents one of the largest limestone outcrops on Earth (>300,000 km²; O’Connell, 2012). The Nullarbor Plain exhibits minimal topographic variation (Figure 1) and currently experiences semi-arid climatic conditions (annual precipitation and evaporation of ~150-400 mm and ~2,000-3,000 mm respectively). In the Nullarbor Limestone numerous large caves, karst pocket valleys, and thousands of metric-scale blowholes have formed under Neogene-Pleistocene palaeoclimatic conditions, which were different than todays (Lipar and Ferk, 2015). The topography in the Coompana region displays a northwest-southeast elevation trend, increasing in elevation by ~100 m over the ~90 x ~50 km study area.

Figure 1. Example of a very gently undulating limestone and regolith plain in the Coompana area.

Despite being Australia’s largest karst region and one of the world’s great karst areas the Nullarbor Plain has a poorly developed surface karst landscape containing only ~100 caves with significant passage lengths and ~150 collapse dolines mostly along the coast (Burnett et al., 2013).

The Nullarbor Plain as a whole comprises a flat surface tilted towards the southeast, which slopes gently towards the sea, from 240 m above sea-level (masl) in the northwest to 40-90 masl at the coast in the southeast. The topography in the Coompana region displays a northwest-southeast elevation trend increasing to the northwest, increasing in elevation by ~100 m over the ~90 x ~50 km study area (Figures 1 and 2). The coastline is characterised by vertical cliffs that extend continuously for hundreds of kilometres. Only along the Roe and Israelite plains do these cliffs reach inland, and have eroded to bluffs.

The landscape surface above the underlying sedimentary basin formations comprises a thin cover of shallow, red-brown, calcareous, loamy to sandy soil with limestone sub- and outcrops occasionally covered by a variably thick, hard calcrite layer. The Nullarbor Plain formed through solution, concretisation and deflation by wind resulting in its regular uniformity across the plain (Figure 2).
Method and Results

Drill hole CDP008 is located approximately 105 km east-northeast of Border Village and approximately 15 km northeast of Koomalda Homestead (Dutch et al., 2017). CDP008 intersected mafic volcanic basement rocks at a depth of ~550 m. Out of the eight drill holes of the Coompana drilling project reported by Dutch et al. (2018) only CDP008 acquired core for the cover in order to characterise the sedimentary sequence (Figure 3). In CDP008, basalts are covered by a ~150 m-thick succession of upward-coarsening fluviatile red beds associated with the Officer Basin, that display a wide variety of detrital zircon age clusters spanning from 1,700 Ma, ~1,580-1,555, ~1170-1130 Ma, and 1,080-415 Ma (Jagodzinski and Bodorkos, 2018). The overlying sedimentary packages correspond to the Bight Basin that developed during the rifting of Australia from Antarctica (Barham et al., 2018 and references therein). In the onshore stratigraphy, the Early Cretaceous Loongana and Madura formations (characterised by sandstones, carbonaceous sandstones, glauconitic sandstones, siltstones, claystones and shales, commonly pyritic; Geoscience Australia, 2017; Figure 3) display detrital zircon spectra similar to their Western Australian counterparts (Barham et al., 2018). The Loongana Formation presents primary zircon cluster ages at ~1,560 Ma, ~1,140 Ma, ~570 Ma, and ~350 Ma, and several minor age clusters that span back to Archean ages. The Madura Formation records a primary zircon age cluster at 1,150 Ma, with a minor age cluster at ~1,560 Ma (Jagodzinski and Bodorkos, 2018). The Loongana Formation was deposited in a terrestrial low-sinuosity fluvial environment within isolated grabens in a developing rift valley (Hill, 1995), whereas the Madura Formation is interpreted as the result of sedimentation in a marine environment with limited circulation, under low-energy conditions (Hill, 1995).

In the offshore stratigraphy, the Ceduna Sub-basin was the main depocentre of the Bight Basin, which accumulated up to 15 km of siliciclastic non-marine, marine and deltaic sediments (Geoscience Australia, 2017). This large depositional thickness was the result of the Ceduna transcontinental river system draining detritus from northeastern Australia due to rapid exhumation in that part of the continent at c. 80 Ma (Lloyd et al., 2016).

The top stratigraphic sequence of CDP008 corresponds to the Cenozoic Eucla Basin carbonates that were deposited on a shallow marine platform with low siliciclastic input (James and Bone, 1991).

Stratigraphic Geochemistry

Throughout ~650 m of core from CDP008, 46 samples were collected for whole-rock geochemistry: nine samples from basement rocks and 37 from the overlying sedimentary sequence. No drilling samples were available between ~20 and 180 m depth, due to the presence of a karstic system, and attempting to core such rocks poses the risk of losing drilling rods (Figure 3).

REE patterns in the basalts and the overlying sandstone package show similarities (Figure 4 and Table 1), which could be interpreted as the result of basement reworking during the sandstone unit deposition and/or post-depositional vertical and lateral geochemical dispersion processes.
The sedimentary sequence of the Bight Basin contains abundant K-feldspar with a glauconitic-rich matrix, and kaolinite present as a minor component. This is consistent with low chemical weathering intensity in the catchment area (e.g. Nesbitt and Young, 1982) and a marine continental shelf depositional environment experiencing a low sedimentation rate and anoxic conditions (e.g. Hiscott, 1982; Figure 3).

Table 1. Summary of REE mean values in CDP008 in the different geological units compared to the Upper Continental Crust (UCC; Rudnick and Gao, 2003).

<table>
<thead>
<tr>
<th>Ratio</th>
<th>UCC (ppm)</th>
<th>Basalt</th>
<th>Sandstone</th>
<th>Bight Units</th>
<th>Nullarbor Limestone</th>
</tr>
</thead>
<tbody>
<tr>
<td>TREE</td>
<td>~150</td>
<td>~105</td>
<td>~120</td>
<td>~220</td>
<td>~10</td>
</tr>
<tr>
<td>(La/Pr)</td>
<td>1.3</td>
<td>1.1</td>
<td>1.1</td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td>LREE/HREE</td>
<td>~35</td>
<td>~37</td>
<td>~36</td>
<td>~35</td>
<td>~35</td>
</tr>
<tr>
<td>En/Eu*</td>
<td>25</td>
<td>27</td>
<td>28</td>
<td>27</td>
<td>40</td>
</tr>
</tbody>
</table>

Figure 4. Geochemical ratios. Different elemental ratios are employed to describe main HFSE and REE fractionations and fingerprint the different stratigraphic units identified in drill hole CDP008.

At the top of the cover sequence a semi- to continuous 10-20 cm thick layer of calcareous soil blankets the outcrops of the Nullarbor Limestone throughout the Coompana region. This soil comprises clay (mixed kaolinite/illite-smectite, being predominantly kaolinite at ~75%), quartz (~18%), K-feldspar (~5%), and apatite, magnetite and ilmenite (latter three total at ~2%). The majority of the quartz and K-feldspar grains show relatively little variation in terms of grain size, but they vary considerably in grain shape from well-rounded (relatively rare) with high-sphericity to sub-angular with low-sphericity. Noble et al. (2018) interpreted this soil as residual, with a small aeolian component. The geochemistry of the soil and plants growing in it is very uniform and do not display any major recognisable trace element patterns (e.g. REE, Zr, Hf, Th, U; Dunn and Waldron, 2014; Noble et al., 2018).

DISCUSSION AND CONCLUSIONS

Insights on landscape evolution and potential geochemical dispersion through cover

The verified buried topography of the top of the basement rocks at Coompana varies by ~200 m throughout the ~90 x ~50 km study area (from ~230 m to ~550 m depth; e.g. Dutch et al., 2017). This buried basement ‘landscape’ surface has a strikingly low topographic gradient. This is coupled with a maximum overburden thickness of ~550 m that records a time span of ~900 Ma (basement mafic volcanics at ~1,076 Ma; Jagodzinski and Bodorkos, 2018).

Figure 5. Panels displaying features of: (A) Interpreted regolith. ERP = erosional residual plain and (B) DEM and interpreted linear surface features.

The rifting of Antarctica, and the temperature gradient produced in the region associated with the generation of oceanic crust, may have been the driving forces needed to activate basal fluid circulation, comprising brines or hydrothermal fluids within the basin and basement rocks in the Coompana region. This, in combination with the presence of the Eucla Basin limestone deposited in the last c. 45 Ma, could have played a role in altering the redox conditions of potential fluids, with direct implications on geochemical metal accumulation and dispersion processes within the sedimentary sequences, and between the basement rocks and overburden at redox stratigraphic boundaries. All of the ingredients needed for large-scale geochemical dispersion within the sedimentary packages were present.

The uppermost stratigraphic unit at Coompana resembles the carbonate units of the Eucla Basin. The uppermost Nullarbor Limestone comprises ~95 wt% carbonate. This lithological unit and its rheological properties represent a restriction to vertical geochemical dispersion, which limits the possibility of geochemical footprints reaching the modern surface. However, stratigraphically deep geochemical signals could have reached the landscape surface by direct fluid migration through pathways facilitated by neotectonism. The neotectonic effects in this region may be the result of stress-transfer from plate margin reorganization during Cenozoic deformation (<66 My; Summerfield, 1987 and references therein). Large-scale tectonic events directly impact small-scale morphological features and build the framework in which they develop (e.g. changes in sea-level, Tibet orogenic uplifting, the developing of the East African Rift). Sea-level changes can result in distinct large stratigraphic hiatus. In the Coompana region there were very pronounced sea-level changes within
The most significant plate-wide neotectonic deformation in Australia occurred during the Late Miocene (c. 10–5 Ma). There is evidence for deformation and reactivation at the scale of 100s km over the last several million years (Clark et al., 2012). In the neotectonic domain of the Nullarbor Plain post c. 10 Ma, displacement along faults are generally <10 m and rarely reach ~30 m, with displacements after c. 10 Ma likely to be 5–10 m (Clark et al., 2012). Krapf and Irvine (2018) compiled a regolith map for the Coompana region that contained interpreted surface features, interpreted as surficial structural features. These are mainly orientated northwest-southeast (Krapf and Irvine, 2018; Figure 5A and B). Foss et al. (in preparation) recognized the magnetic basement anomalies in the region when describing the characteristically large negative Coompana anomaly , and the northwest-southeast magnetic trends to the west mirror DEM surface trends and interpreted surface feature alignments (Figures 5A and B).

Available datasets show no evidence to support present day geochemical links between the basement rocks and the modern-day landscape surface. However, within this landscape framework geochemical vertical dispersion processes may have been active and efficient through the ~500 m of cover in the Coompana region. The possible link between neotectonics and geochemical dispersion processes should be carefully considered when studying landscape geochemistry in areas with thick overburden. The relative significance of vertical and lateral geochemical dispersion processes related to neotectonics and landscape evolution in the Coompana remains uncertain.

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**REFERENCES**


Geochemical dispersion processes in Coompana


