REGOLITH MAPPING AT BENDIGO, AND ITS RELATIONSHIP TO GOLD IN CENTRAL VICTORIA, AUSTRALIA.

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INTRODUCTION

Regolith-landform mapping of the Bendigo 1:100,000 sheet area, published by the Geological Survey of Victoria (Kotsonis & Joyce 2003), discusses the relationship between weathering, landscape evolution and secondary Au. The regolith in the Bendigo sheet area can be divided into the following regolith-landform units (RLUs): Palaeozoic bedrock units with predominantly *in situ* regolith; Cainozoic units of transported regolith including transported mining residue from the 1850s and later; and, Neogene volcanic lava flows. There is evidence for Cainozoic movement along major bedrock structures (e.g., Leichardt-Muckleford, Sebastian and Whitelaw Faults), affecting weathering profiles and soils preserved on bedrock units, displacing buried leads, and affecting modern drainage. For a full reference list, see Kotsonis & Joyce (2003).

GEOLOGICAL STRUCTURE AND NEOTECTONICS

The geology of the Bendigo 1:100,000 sheet area is described in Cherry & Wilkinson (1994). Sediments of the Ordovician Castlemaine Supergroup were deformed during the Silurian Benambran Deformation into north-south trending regional folds and faults, and intruded by the post-orogenic Upper Devonian Harcourt Batholith (Figure 1). Post-Palaeozoic (predominantly Cainozoic) movement occurred along some of the bedrock faults, including:

- Sebastian: A run of alluvial Au traced for over a quarter of a mile west of Frederick the Great Company's main shaft to Myers Creek, where *"a sudden drop of 70 feet,"* (21m) *"from 30 feet"* (9m) *"to 100 feet,"* (30m) *"was encountered"* (Whitelaw 1899) coincides with the northern extension of the Sebastian Fault.
- Guildford (south of the Bendigo 1:100,000 sheet area): Sub-basaltic gravels have been displaced by 50 m on the Muckleford Fault, an east-west trending lead has been displaced by 20 m vertically, and the overlying basalts by 15 m, indicating at least two periods of movement.
- Marong (Wilson's Hill): The deep leads near Bald Hill have been displaced by movement on the Leichardt Fault, where the outlet to the leads occurs on the upthrown block of the Leichardt Fault, which has been upthrown by about 45 m.
- White Hills: A drop from 8 m to 22 m occurs across the Whitelaw Fault at White Hills where the Huntly deep lead was downthrown to the east. The Whitelaw Fault now forms a prominent fault scarp.

REGOLITH MAPPING

The Bendigo 1:100,000 sheet area is dominated by thick regolith, both transported and *in situ*, which overlies fresh bedrock (Figure 2). The *in situ* regolith is developed on bedrock units (Palaeozoic bedrock, the Harcourt Batholith and associated contact metamorphosed aureole) and consists predominantly of deep saprolite overlying fresh bedrock. Transported regolith consists predominantly of weathered Cainozoic sediments.

The regolith preserved on the bedrock units, Palaeozoic metasediments ($SMel_1$, $SHel_1$, $SVer_1$) and metamorphosed aureole ($SSeh_1$) surrounding the Harcourt Batholith ($BUeh_2$, $BHel_2$) are largely controlled by Tertiary erosion and landscape evolution. Palaeozoic metasediments are the oldest rock in the Bendigo 1:100,000 sheet area and form subdued ranges that are deeply weathered. Radiometric imagery has revealed that variations in the character of the regolith are generally related to boundaries along major bedrock faults, suggesting that the composition of the regolith may be influenced by neotectonism (Figure 1). The Harcourt Batholith has a well-defined contact metamorphosed aureole, and itself forms subdued rolling hills, with fresh granite outcrop with tors widespread in higher relief areas ($BUeh_2$), whereas in topographically lower areas fresh granite or saprolite is typically covered with thin soil and colluvium ($BHel_2$). Several intrusive phases have been recognized (Cherry & Wilkinson 1994), but the regolith does not clearly reflect these variations. The metamorphosed Palaeozoic metasediments surrounding the Harcourt Batholith consists of deep *in situ* regolith with poorly developed soils. The aureole has a high K radiometric signature and has a relatively uniform width and the outer limit of contact metamorphism is well defined.

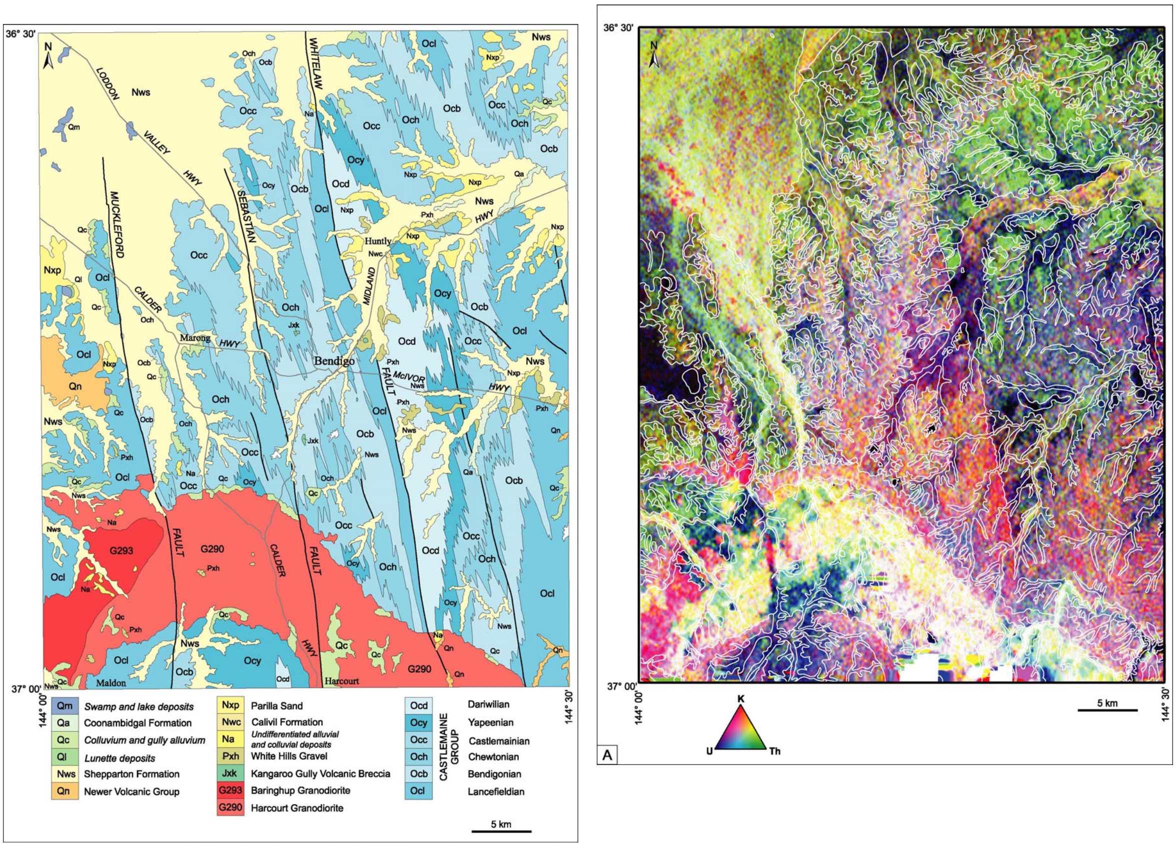

Figure 1: Geological structure and tectonic elements of the Bendigo 1:100,000 sheet area (modified after Edwards & Slater 1991) and a radiometric ternary ratio image (red = K, green = Th, blue = U) with regolith-landform boundaries in white.

Units of transported regolith on Tertiary consist of thin and discontinuous fluvial and marine sediments in the Highlands, and thick composite fluvio-lacustrine deposits on the Riverine Plain. Remnants of early Tertiary drainage (White Hills Gravel, ACer) made up of well-rounded quartz sand, coarse to very coarse gravel and conglomerate are preserved on hill tops and the upper slopes of bedrock ridges. These deposits were formed by the earliest known drainage systems in the region, are elevated in the landscape, overlie deeply weathered Palaeozoic bedrock, and are moderately to strongly indurated with silcrete, clay argillans, and minor ferricrete several metres thick.

The Au-rich deep lead deposits (Aep) are predominantly subsurface and include the Huntly and Telegraph deep lead (and the minor leads of Forest deep lead and Ironstone Hill deep lead), the leads at Marong and Raywood and the Elysian deep lead at Neilborough (Calivil Formation and equivalents). Possible exposure of this unit occurs at Fosterville and at Axedale, both of which have gradational soil profiles with weak mottling of the underlying saprolite.

The Loxton-Parilla Sands (OMep) are Late Neogene (Late Miocene to Plio-Pleistocene) marine quartz sands deposited during a short-lived marine transgression-regression in the western Murray Basin between 6.6 Ma and 3.5 Ma (Kotsonis, 1999). The surface of these sands is capped with a ‘lateritic-type’ weathering profile consisting of pisolitic ferricrete, named the Karoonda Surface.

The Riverine Plain consists of flat-lying fluvio-lacustrine and aeolian sediments, and much of the surface consists of Pliocene to Recent, Shepparton Formation (Aap), and the younger incised ancestral rivers of the Coonambidgal Formation (Aam). Pisolitic ferruginous soils identified within the older parts of the Shepparton Formation are equivalent to the Karoonda Surface. The younger ancestral river systems form the present drainage of the Bendigo region.

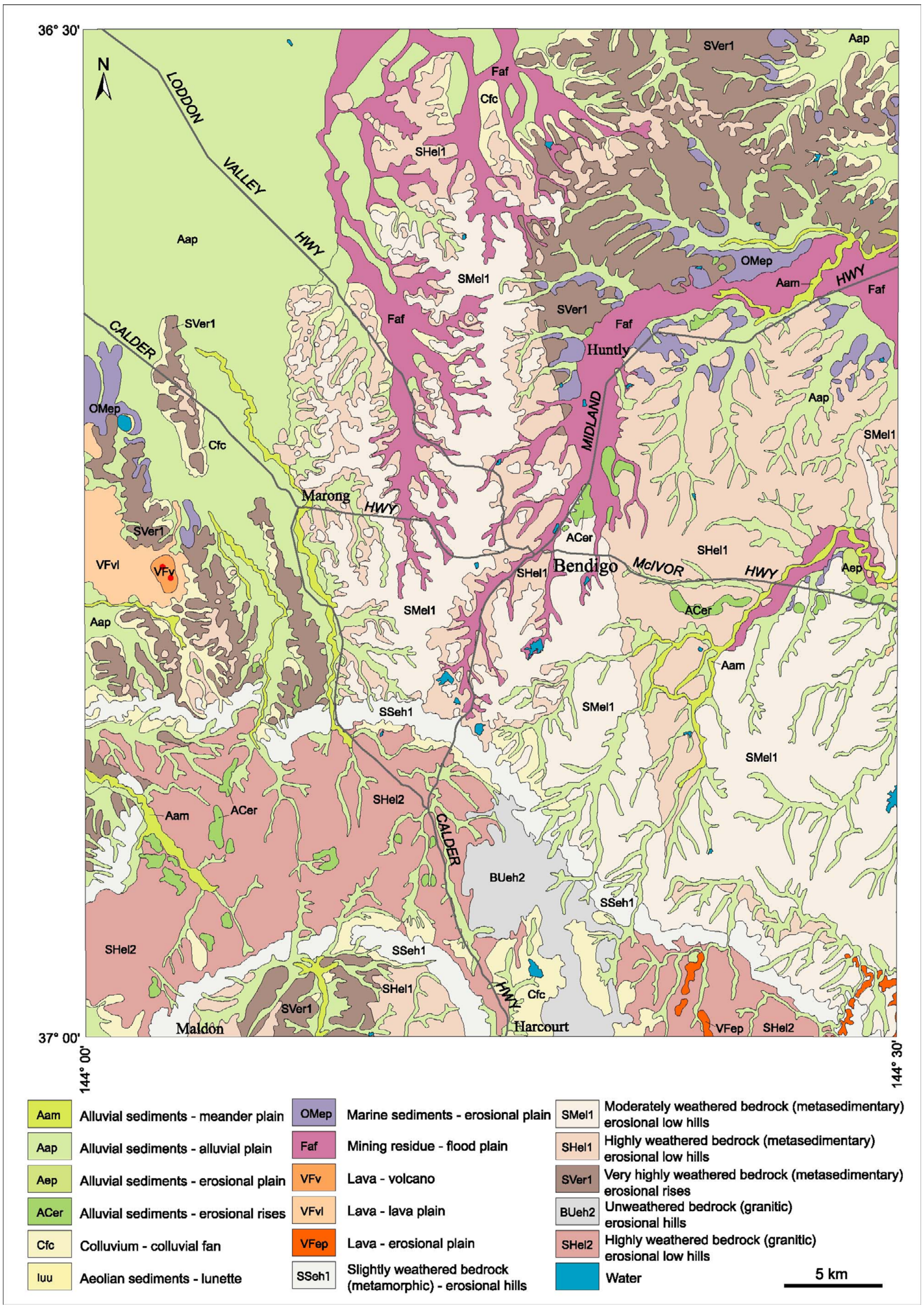

Figure 2: Regolith-landform map of the Bendigo 1:100,000 sheet area.

Many bedrock hill slopes flanking the Riverine Plain are mantled with colluvial material (Cfc), which is poorly exposed, and merges with fluvio-lacustrine sediments of the Riverine Plain. In some places the colluvium has a pisolitic weathering profile equivalent to the Karoonda Surface, suggesting that the older parts of this unit are from the Pliocene.

Late Neogene lava flows (VFv, VFvl, VFep) show regolith development largely dependent on the time since their eruption, and occur at Bald Hill (1.64 Ma) and along the Coliban River (4.49-5.57 Ma). Both lavas have stony rises with minor red-brown soils and spheroidal weathering.

Mining residue (Faf) from the 1850s onwards ('sludge'), is common in the study area and is a significant regolith unit that has been identified at Myers, Bendigo and Axe creeks. This consists of hard setting and weakly laminated clay and silt. Areas identified with mining residue in the radiometric imagery have a bright and patchy radiometric signature.

GOLD

The only documented occurrence of secondary Au in the Bendigo 1:100,000 sheet area is at Fosterville, and is poorly understood (McKnight *et al.* 2001). It occurs within with oxidised quartz-Au-stibnite veins at Robbins Hill pit where primary crystalline nuggetty Au has undergone refinement, with precipitation of colloform and small cauliflower encrustations of extreme fineness. The remobilised Au occurs within colloform iron oxides precipitated within the oxidised veins and is not found in the surrounding host rock, and is typically extremely fine (< 0.1 wt. % Ag). The timing and extent of secondary Au formation is not well known.

LANDSCAPE EVOLUTION

The evolution of the landscape in the Bendigo 1:100,000 sheet area is summarized below (Figure 3):

- SILURIAN: Palaeozoic metasediments of the Castlemaine Supergroup were deformed during the Silurian Benambran Deformation with Au emplacement believed to have occurred during, or just after, the final stages of regional deformation.
- DEVONIAN: Intrusion of post-orogenic Upper Devonian granites (Harcourt Batholith) and contact metamorphism of Palaeozoic metasediments.
- JURASSIC: lamprophyre dykes intruded both the Palaeozoic metasediments and the Harcourt Batholith.
- PERMIAN: Glaciation stripped the landscape, leaving behind gravel deposits (till), of which only minor occurrences are found within the Bendigo 1:100,000 sheet area.
- MESOZOIC: Mesozoic deep weathering, planation and erosion during a period of tectonic stability, resulting in the formation of a deeply weathered Mesozoic palaeosurface, which is not preserved in the Bendigo 1:100,000 sheet area. The Bendigo 1:100,000 sheet area lies several hundreds of metres below the projected Mesozoic landsurface for central Victoria, which lies at nearly 1,000 m a.s.l. (e.g., Mount Cole, Mount Lonarch and Mount Avoca, near Ballarat).
- CRETACEOUS TO PALAEOGENE: In the Late Mesozoic, Gondwana began to break up, and by the Cretaceous, an east-west trending ridge, the Victoria Divide, had developed. Erosion occurred throughout this time, with the development of the earliest coordinated drainage system and the deposition of quartz gravels (White Hills Gravel). Weathering of these gravels resulted in ferricrete, silcrete and clay argillan profiles. Sometime around the Late Cretaceous-early Tertiary boundary, the Murray Basin began to subside, and was infilled with fluvio-lacustrine sediments derived from the erosion of Palaeozoic bedrock.
- EOCENE TO MIOCENE: Au bearing deep leads resulting from the erosion of both Palaeozoic bedrock and earlier fluvial deposits were deposited along pre-existing valleys, often after incision.
- PLIOCENE TO PLEISTOCENE: Fluvio-lacustrine deposition continued throughout the Late Tertiary, within highland valleys and in the Murray Basin (Shepparton Formation). In the Pliocene, a marine incursion into the Murray Basin deposited marginal and near-shore marine quartz sands (Loxton-Parilla Sands). Weathering formed the Karoonda Surface; a ferricrete+/-silcrete profile on the marine sands and on the Shepparton Formation. Within the highland valleys Au was eroded from the Palaeozoic bedrock and fluvial deposits concentrated alluvial Au within gully deposits and shallow leads exiting highland valleys. Erosion of Palaeozoic bedrock also resulted in the deposition of colluvium flanking bedrock rises and within gullies. Volcanic activity (Newer Volcanics) occurred at and around Bald Hill volcano and along the Coliban River. Fluvio-lacustrine deposition occurred throughout the Quaternary. Fluvial sediments of the Coonambidgal Formation were deposited in valleys incised into older fluvial deposits of the Shepparton Formation, forming narrow floodplain terraces. These valleys and terraces make up the present drainage system. Minor aeolian and swamp deposits also formed at this time.

REFERENCES

CHERRY D.P. & WILKINSON H.E. 1994. Bendigo, and part of Mitiamo 1:100,000 map geological report. *Geological Survey of Victoria Report* **99,** 80 pp.

EDWARDS J. & SLATER K.R. (compilers) 2001. Bendigo 1:250,000 geological map. *Geological Survey of Victoria*.

KOTSONIS, A 1999. Tertiary shorelines of the western Murray Basin: weathering, sedimentology and exploration potential. *In:* Murray Basin Mineral Sands Conference, 21-23 April, 1999, Mildura, Victoria, Australia, *Australian Institute of Geoscientists Bulletin* **No. 26, Extended Abstracts**, 57-63.

KOTSONIS A. & JOYCE B. 2002. Regolith mapping of the Bendigo region of Victoria. *In:* PHILLIPS G.N. & ELY K.S. eds. *Victoria Undercover, Benalla 2002,* Conference proceedings and field guide: collaborative geoscience in northern Victoria, pp.137-145.

KOTSONIS A. & JOYC, E.B. 2003. The regolith of the Bendigo 1:100,000 map area. *Victorian Initiative for Minerals and Petroleum* **Report 77**, Department of Primary Industries, 62pp.+ map.

MCKNIGHT S., DOWLING K. & KOTSONIS A. 2001. High grade Au-Sb vein-type mineralisation at Fosterville. *In:* VICMIN2001: The Third Conference on Developments in Victorian Geology and Mineralisation, 26-27th April 2001, *AIG Bulletin* **34**, 29-36.

WHITELAW H.S. 1899. Report on the Sebastian Goldfield. *Geological Survey of Victoria, Monthly Progress Reports*, **6 and 7**, 3-6.

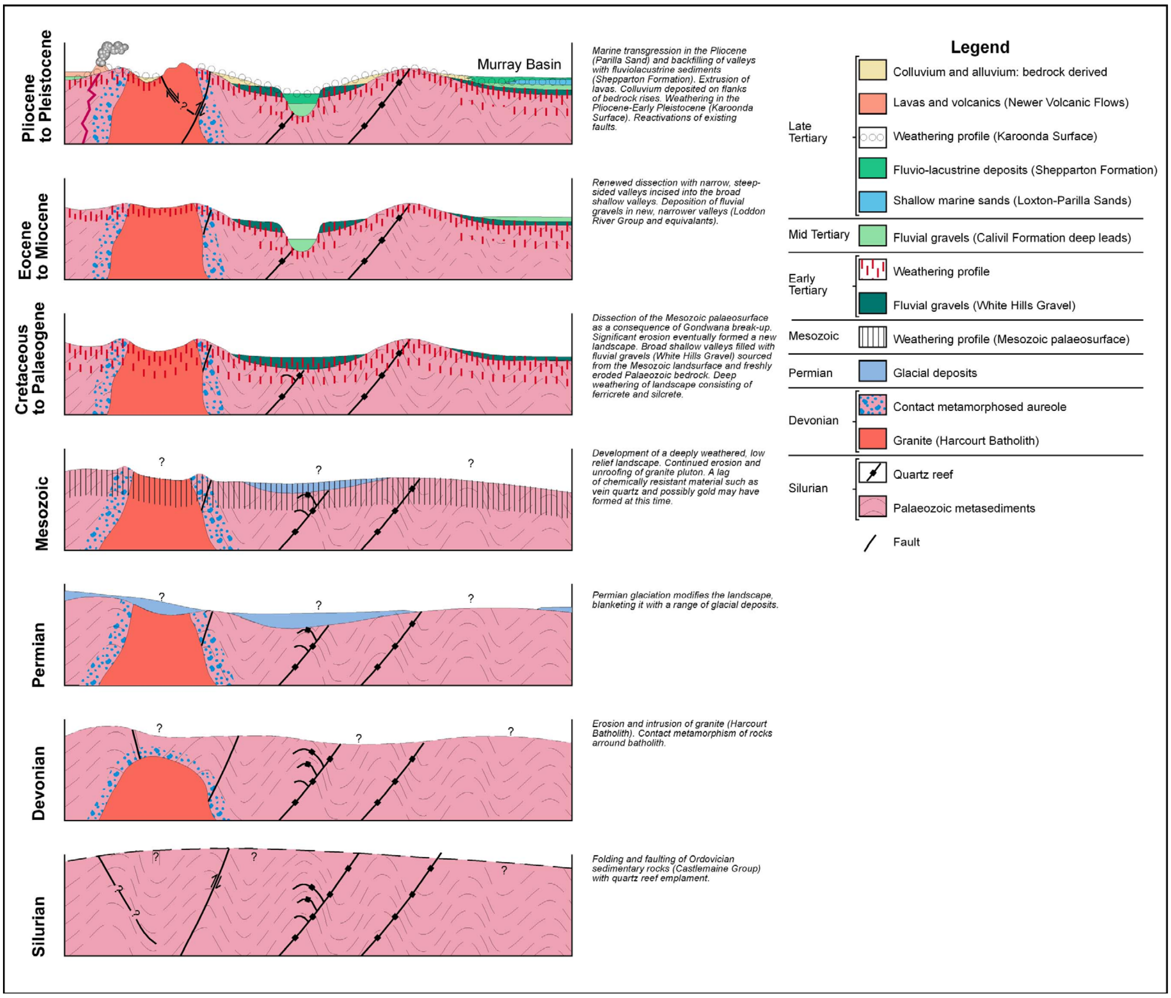

Figure 3: Landscape evolution diagram for Bendigo 1:100,000 map sheet.

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