NEOTECTONIC DISRUPTION OF CAINOZOIC BASALT AT KRAWAREE WEST, NSW: IMPLICATIONS FOR LANDSCAPE EVOLUTION?

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CAINOZOIC BASALT AND NEOTECTONISM

Theories of landscape antiquity and relative tectonic stability have dominated Australian long-term landscape evolution models. The regional significance of tectonically disrupted Cainozoic basaltic volcanics to landscape evolution has been largely overlooked, despite the fact that these data have been applied to various landscape studies. Radiometric dating allows relatively reliable ages to be placed on basalt remnants and, from this, a maximum age for tectonic disruption can be constrained. Modern analogues of tectonic disruption of basaltic lava flows from, for example, Hawaii can be used to aid the recognition of these and other similar features in the older, more weathered southeastern Australian landscape. Combined with evidence of neotectonic disruption from other facets of the inland and coastal Australian landscape, this is a tool to further constrain neotectonic contributions to landscape evolution.

The area of Krawaree West in the headwaters of the Shoalhaven Catchment provides an ideal detailed case study for this research (Lewis 2000) (Figure 1). Previously, basalt remnants in the middle and lower Shoalhaven catchment have been used to determine long-term rates of river incision, headward gorge extension and scarp retreat, or were identified as the parent material of ancient weathering profiles (see references later). Miocene (19.1 ± 0.4 Ma) basalt in the upper catchment at Krawaree West is reported as being displaced by the Shoalhaven Fault (Wyborn & Owen 1986). However, previous studies in the lower Shoalhaven Catchment, e.g. Ruxton & Taylor (1980), Young (1983), Taylor & Ruxton (1987) and Nott *et al.* (1996) have not reported neotectonism associated with the basalts.

A range of techniques were used at Krawaree West to determine the nature of the relationship between the Shoalhaven Fault and the basalt (Figure 2). Extensive post-eruption weathering, erosion and stream incision makes it difficult to accurately gauge the former extent and volume of the lava flows however these can be reconstructed by using the divergence in the course of Jerrabattgulla Creek and the position of the remnant basalts in the landscape. Maximum rates of river incision and surface lowering since the Miocene were calculated assuming that these were valley-filling lavas that were longitudinally extensive but laterally confined in a valley less than 1.5 km wide. Whole-rock geochemistry was used to determine the stratigraphy of the lava pile and to aid in the interpretation of any possible neotectonic disruption. The trace of the Shoalhaven Fault was impossible to see through the basaltic colluvium that covered the steep slopes of the lava pile however flow bases were well exposed.

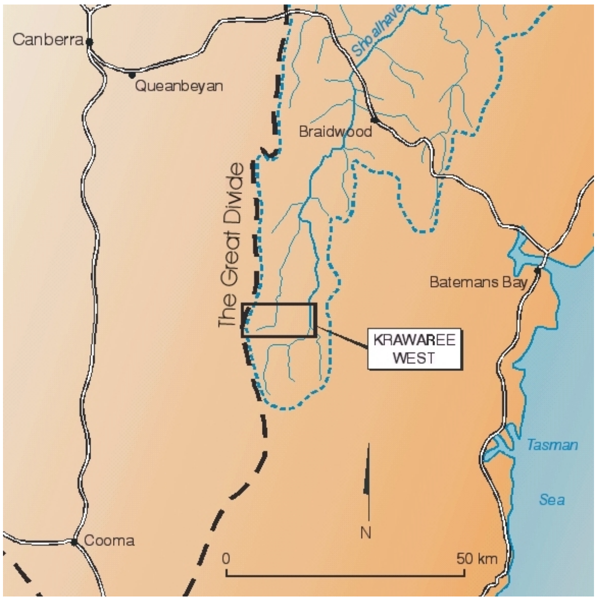

Figure 1: Location of the Krawaree-West area.

LANDSCAPE EVOLUTION AT KRAWAREE WEST

The Shoalhaven Catchment has been the focus of many landscape evolution studies. Basalt remnants from within the catchment have been used to demonstrate the antiquity and stability of the landscape (e.g. Young 1977, Nott *et al.* 1996). The basalt in the Jerrabattgulla Creek valley offers an opportunity to study in detail the relationship between it and a major fault line, and to assess possible neotectonic contributions to regolith and landscape evolution in the catchment.

There is evidence of a long history of weathering at

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Krawaree West. The partially silcreted sub-basaltic sediments define a palaeochannel beneath the basalts. These sediments consist mostly of quartz and kaolinite, suggesting that the landscape was intensely weathered before these sediments were transported and deposited, reflecting pre-Miocene weathering. Silcrete formed in the sediments, however, could be pre- or post-basaltic. Silcrete was previously found on the Shoalhaven Plain within the pre-Eocene Badgerys Sub-Group Sediments (Nott 1992) and Taylor & Ruxton (1987) postulated an Early Mid Tertiary to Latest Tertiary age for these and others. No certain age correlations can be made between these and the Krawaree West silcretes.

There has been considerable erosion of the Krawaree West landscape since the Miocene and the basalt flows in the upper Jerrabattgulla Creek valley now have inverted relief. Since their extrusion into a valley during the Miocene, substantial weathering and erosion have left the flows situated at high elevations in the landscape. The sub-basaltic sediments are also elevated above the present valley bottom by less than 70 m, indicating erosion, at a rate of ca. 3.7 m/My, of the surrounding bedrock as well. The estimated volume of basalt at the time of eruption was at least 0.65 km^3. Present volume now is no more than 0.1 km^3.

Sediment deposition at Krawaree West is predominantly colluvial with alluvium confined to the axes of valley systems. Alluvial sedimentation within the valley systems has been both pre- and post-basaltic. The east-west distance between sediment exposures indicates that Jerrabattgulla Creek, prior to basalt extrusion, was depositing sediments in a valley system over 500 m wide before it was pushed to the east by the lava flows. Colluvial deposition that is associated with the erosion of basalt flows incorporates basalt cobbles into landslide deposits that are very extensive on the eastern side of the basalt pile. These landslides are largely associated with the discharge of sub-basaltic and inter-basaltic aquifers (see Figure 2).

Bedrock lithology, combined with structural features, has had significant controls on the landscape evolution at Krawaree West. The local landscape is predominantly fault-controlled in this region, the Jerrabattgulla Creek area sits in a graben defined on the west by the Shoalhaven Fault and on the east by the Gundillion Fault. The north-south trending Gundillion Fault has facilitated some of the weathering of the undulating granite terrain around the Shoalhaven River in the east of the Krawarree area. There has been differential weathering of granite to form ridges and hills and other resistant lithologies form prominent ridges (e.g. the Gundillion Conglomerate). In the west of the Krawarree area granitoid intrusives and relatively weathering-resistant regionally- and contact-metamorphosed Ordovician sediments, combined with uplift on the Shoalhaven Fault has, formed the Gourock Range (part of the Great Dividing Range).

At Krawaree West, evidence for recent tectonic movement is uncertain, however, the offsets on granitoid rocks (noted by Wyborn & Owen 1982) suggest that the Shoalhaven Fault was active during or since at least the Devonian. Movement has not visibly affected the basalt flows but displacement could conceivably be at most less than the thickness of one flow unit. At Sweetwater South, subdued river terraces are associated with the Jerrabattgulla Creek, however, it is unclear whether they are associated with periodic incision of the stream following extrusion of the lava flows or movement of the Shoalhaven Fault. Knick points on both the Shoalhaven River and the Jerrabattgulla Creek appear to be predominantly associated with bedrock changes rather than fault movement. To the north of Krawaree West (Kain 1:25,000 sheet) there are raised terraces and alluvial fans associated with the Shoalhaven Fault that are suggestive of neotectonic activity in part of the Shoalhaven catchment.

IMPLICATIONS FOR NEOTECTONISM AT KRAWAREE WEST

Previous studies have used basalt flows to reconstruct landscapes at the time of extrusion (e.g. Bishop *et al.* 1985, Jones & Veevers 1982, Webb *et al.* 1991, Taylor *et al* 1985). Taylor *et al.* (1985) and Ollier & Pain (1994) suggested that lava flows originating from small volcanoes on the Great Divide can be used to constrain the relief of the landsurface at the time of emplacement. Although basalt has been used in the lower Shoalhaven catchment to determine rates of river incision, scarp retreat and gorge extension (e.g. Nott *et al.* 1996, Young & McDougall 1985) this application to basalt at Krawaree West for landscape reconstruction is not as straight-forward.

The reported methods used to reconstruct lava levels in a landscape (that assume lava acts much like water) would suggest that the interfluve on the eastern side of the Jerrabattgulla Creek valley should be the level to which basalt filled the valley. The remnant lava pile reaches a maximum thickness of eight flows at Sweetwater North (average flow thickness is 10 m) and a minimum of one flow thickness at Sweetwater South (see Figure 2). The top flow of the lava pile at Sweetwater North (that extends up into the Tallaganda State Forest) is at an elevation of 1088 m (Table 1). The elevation of the ridge on the eastern side of the valley is 1060 m. Assuming the basalt once filled the valley up to the maximum elevation of its field settings

(1088 m) and, using these elevations to re-construct a perceived cross section of the extent of lava infilling the valley, it can be estimated that there has been approximately 30 m of surface lowering on the eastern valley interfluve and 100 m of incision by Jerrabattgulla Creek down to 890 m elevation since the Miocene (Figure 3). In this case there is no evidence of the former course of Jerrabattgulla Creek on the hill slope of the eastern valley interfluve. The creek has remained in its present position since being displaced and has incised in-place about 70 m vertically. If the whole valley was filled the creek would have diverted through the range to the Shoalhaven River valley, or, at the very least, there would be evidence as elevated river gravels. Given that the basalt only occurs on the western side of the valley and that no remnants have been found on the eastern side, it is thought that the basalt only partially filled the valley and formed a wedge-shaped outcrop. This was thickest in the west along the Shoalhaven Fault scarp and extending northwards down the valley, bounded on the east by Jerrabattgulla Creek.

Initial observations of the thickest part of the lava pile (top at 1088 m elevation) could at first be used to suggest that the flows have been faulted and tectonically thickened to account for their present elevation. Furthermore, it seems unlikely that the lava has simply flowed over the fault scarp and filled the valley to a lower level because the flows have sub-horizontal attitudes. Using this argument, the mapped position of the Shoalhaven Fault (Wyborn & Owen 1982) coincides with the fourth flow terrace of the thickest remnant pile at approximately 1027 m elevation. Given that the elevation of the top flow of this pile is at 1088 m, this equates to approximately 61 m displacement of the flows, assuming they have been faulted, which contradicts Wyborn & Owen’s estimate of 30 m.

If this faulting scenario has occurred, repetition of the flows would be expected across the faultline. The geochemical analysis of the lava pile that is situated on the fault line, however, reveals that individual terraces can be correlated between outcrops parallel to the line of the Shoalhaven Fault, but not across it (Figure 2 and Table 1). That is to say, there is no geochemical basis to support repetition of rock types across the fault line that may be used to indicate vertical movement. Analysis of basalt immediately on either side of the proposed position of the Shoalhaven Fault reveal geochemical differences in the flows. The lava on the on the supposed upthrown side of the fault (Sample no. TSF 4) has significantly higher Mg and SiO_2 than the flow on the supposed downthrown side (Sample no. TSF 5) (Table 1). Indeed, none of the rocks samples show any exact geochemical similarities. The absence of repetition across the faultline suggests at most minimal movement (at least less than the thickness of one lava flow ~10 m), and probably no movement, since the time of volcanism (19.1 ± 0.4 Ma; Wyborn & Owen 1986) on this segment of the fault.

Table 1: Major element (XRF) contents of basalts sampled across the Shoalhaven Fault.

Sample No.	TSF1	TSF2	TSF3	TSF4	TSF5	TSF6	SWN2	SWN1
Elevation (mASL)	1088	1076	1063	1043	1027	971	964	959
TAS Name*	Ne-Hawaiite	Hy-trachybasalt	Ne-Basanite	Ne-Tephrite	Ne-Tephrite	Ne-Tephrite	Ne-Tephrite	Ol-nephelinite
$100(Mg/Mg+Fe^{2+})$	59.72	60.00	60.93	61.09	57.00	59.76	58.23	59.63
SiO_2	47.37	47.76	43.05	42.42	41.91	41.20	42.74	40.59
TiO_2	2.11	2.09	2.16	2.23	2.31	2.24	2.28	2.22
Al_2O_3	15.92	15.95	13.85	13.60	13.75	13.56	13.71	13.41
FeO	8.80	8.86	10.12	10.36	10.57	10.27	10.70	10.14
Fe_2O_3	1.76	1.77	2.02	2.07	2.11	2.05	2.14	2.03
MnO	0.15	0.15	0.19	0.20	0.2	0.19	0.21	0.21
MgO	7.32	7.46	8.86	9.13	7.86	8.56	8.37	8.40
CaO	8.45	8.54	10.14	10.43	10.59	11.14	10.38	11.08
Na_2O	3.66	3.51	3.45	4.26	5.01	3.7	4.95	3.58
K_2O	1.64	1.61	1.66	1.75	1.29	1.51	1.50	1.34
P_2O_5	0.77	0.76	1.61	1.79	2.07	2.06	1.89	2.04
Total	97.99	98.49	97.13	98.26	97.69	96.52	98.90	95.07

*TAS Name: Name derived using the Total Alkali-Silica diagram of Le Maitre (1989). Ne: nepheline; Hy: hypersthene; Ol: olivine.

A more probable explanation for the elevated position of the flows in the landscape, given that the faulting scenario does not appear to be correct, is that the vent was most probably situated in the vicinity of the Tallaganda State Forest flows in the southwest of the area. The greater thickness of the lava pile at this location is consistent with this idea. Furthermore, the top flow elevations of remnant piles to the north decrease uniformly, suggesting that the thickness of the lava pile was reduced as lava flowed down the valley away from the vent. The small remnant pile to the south possibly represents a flow that backed up the valley, that has been isolated from the larger flows and the vent by incision of the Jerrabattgulla Creek (Figure 2).

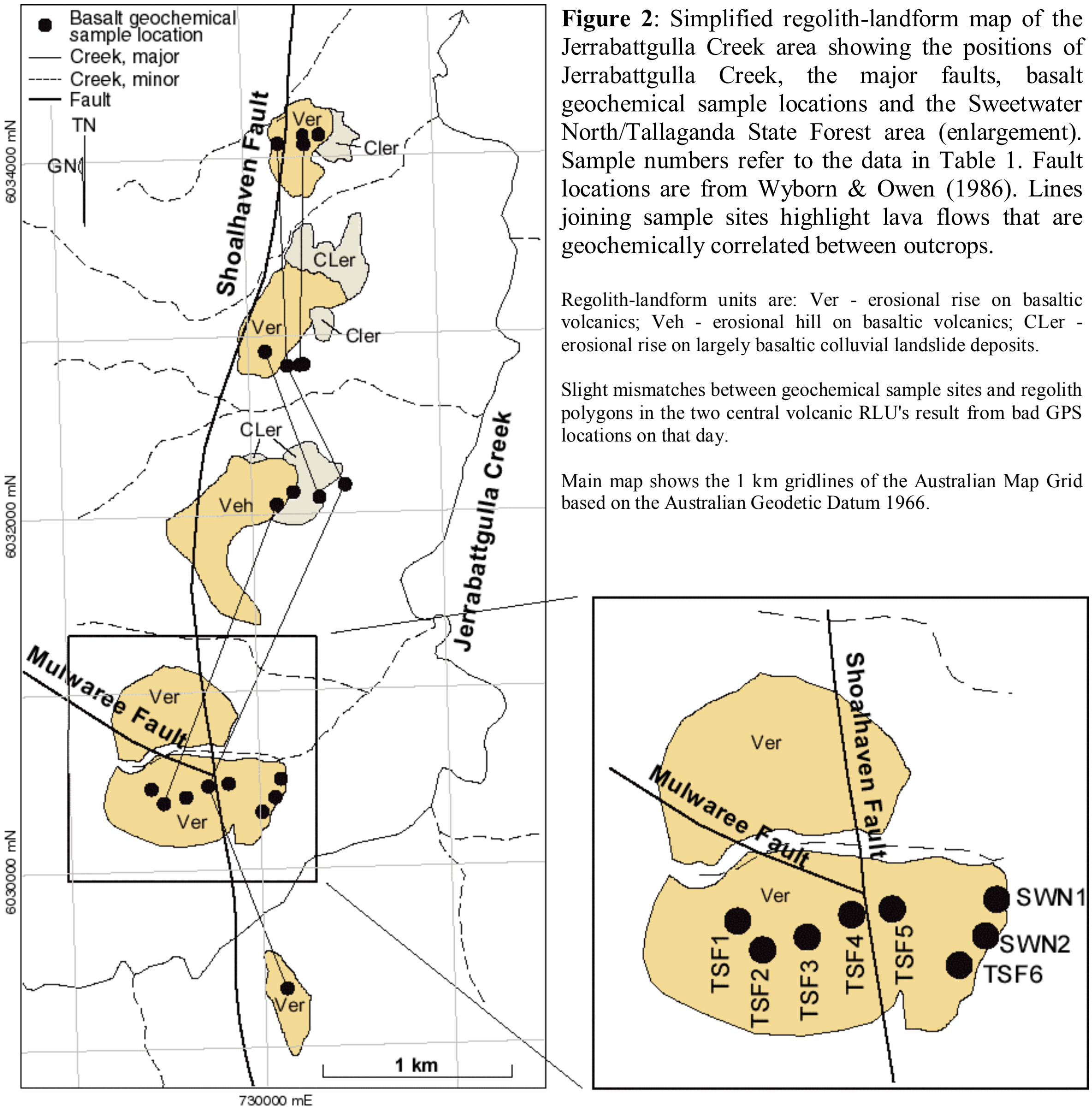

Figure 2: Simplified regolith-landform map of the Jerrabattgulla Creek area showing the positions of Jerrabattgulla Creek, the major faults, basalt geochemical sample locations and the Sweetwater North/Tallaganda State Forest area (enlargement). Sample numbers refer to the data in Table 1. Fault locations are from Wyborn & Owen (1986). Lines joining sample sites highlight lava flows that are geochemically correlated between outcrops.

Regolith-landform units are: Ver - erosional rise on basaltic volcanics; Veh - erosional hill on basaltic volcanics; CLer - erosional rise on largely basaltic colluvial landslide deposits.

Slight mismatches between geochemical sample sites and regolith polygons in the two central volcanic RLU's result from bad GPS locations on that day.

Main map shows the 1 km gridlines of the Australian Map Grid based on the Australian Geodetic Datum 1966.

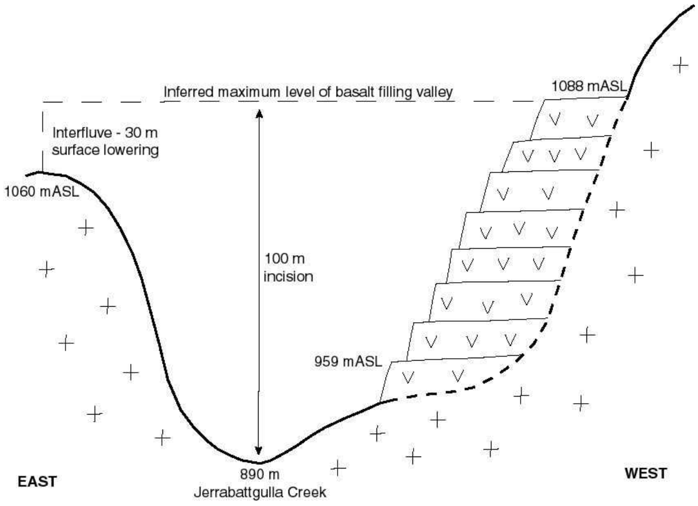

Figure 3: Diagramatic cross-section of the lava flows located over the intersection of the Shoalhaven and Mulwaree Faults at Krawaree West (see Figure 2). Diagram shows the sub-horizontal attitudes of the flows, the estimated amount of incision by the Jerrabattgulla Creek and the estimated amount of surface lowering, assuming that the lava filled the valley to the maximum level (1088m ASL) of its present day field settings.

The proposed position of the vent, where the basalt pile is at its thickest, coincides with the mapped position of the junction between the Shoalhaven Fault and the Mulwaree Fault. Roach *et al.* (1994) and Roach (1999) demonstrated that the intersections of similar faults have been shown to be associated with eruption points in southeastern Australia, particularly in the Monaro Volcanic Province, to the southwest of Krawaree West. This suggests that perhaps the volcanism at Krawaree West was characterised by a localised eruption, that may or may not have been synchronous with localised movement along either the Mulwaree or Shoalhaven Faults.

Further study to the north of Krawaree West is needed to assess evidence of more recent movement on the Shoalhaven Fault (e.g. elevated stream terraces and alluvial fans associated with the Shoalhaven Fault). The Cainozoic basalt in the Jerrabattgulla Creek area however does not support previous interpretations of neotectonic displacement of 30 m (Wyborn & Owen 1986) on this segment of the Shoalhaven Fault since the Early Miocene.

REFERENCES

BISHOP P., YOUNG R.W. & MCDOUGALL I. 1985. Stream profile change and long term landscape evolution: Early Miocene and modern rivers of the east Australian highland crest, central New South Wales, Australia. *Journal of Geology* **93**, 455-474.

JONES J.G. & VEEVERS J.J. 1982. A Cainozoic history of Australia's Southeast Highlands. *Journal of the Geological Society of Australia* **29**, 1-12.

LE MAITRE R.W. 1989. *A Classification of Igneous Rocks and Glossary of Terms.* Blackwell Scientific Publications, Oxford.

LEWIS A.C. 2000. *Neotectonic disruption of Cainozoic volcanics in southeastern Australia: implications for landscape evolution*. University of Canberra Honours thesis, unpublished.

NOTT J.F. 1992. Long-term drainage evolution in the Shoalhaven catchment, southeast highlands, Australia. *Earth Surface Processes and Landforms* **17**, 361-374.

NOTT J., YOUNG R. & MCDOUGALL I. 1996. Wearing down, wearing back, and gorge extension in the long-term denudation of a highland mass: quantitative evidence from the Shoalhaven Catchment, southeast Australia. *The Journal of Geology* **104**, 224-232.

OLLIER C.D. & PAIN C.F. 1994. Landscape evolution and tectonics in southeastern Australia. *AGSO Journal of Australian Geology and Geophysics* **15(3)**, 335-345.

ROACH I.C. 1999. *The setting, structural control, geochemistry and mantle source of the Monaro Volcanic Province, southeastern New South Wales, Australia.* PhD Thesis. School of Resource, Heritage and Environmental Sciences, Division of Science and Design, University of Canberra, 272 pp.

ROACH I.C., MCQUEEN K.G. & BROWN M.C. 1994. Physical and Petrological Characteristics of Basaltic Eruption Sites in the Monaro Volcanic Province, Southeastern New South Wales, Australia. *AGSO Journal of Australian Geology and Geophysics* **15(3)**, 381-394.

RUXTON B.P. & TAYLOR G. 1982. The Cainozoic geology of the Middle Shoalhaven Plain. *Journal of the Geological Society of Australia* **29(2)**, 239-246.

TAYLOR G. & RUXTON B.P. 1987. A duricrust catena in South-east Australia. *Zeitschrift fur Geomorphologie N. F.* **34(1)**, 385-410.

TAYLOR G., TAYLOR G.R., BINK M., FOUDOULIS C., GORDON I., HEDSTROM J., MINELLO J. & WHIPPY F. 1985. Pre-basaltic topography of the northern Monaro and its implications. *Australian Journal of Earth Sciences* **32**, 65-71.

WEBB J.A., FINLAYSON B.L., FABEL D. & ELLAWAY M. 1991. The geomorphology of the Buchan Karst – Implications for the landscape history of the Southeastern Highlands of Australia. *In:* WILLIAMS M.A.J., DE DECKKER P. & KERSHAW A.P. eds. *The Cainozoic in Australia: A Re-appraisal of the Evidence.* Geological Society of Australia **Special Publication 18**, 210-234.

WYBORN D. & OWEN M. 1986. *ARALUEN 1:100,000 Geological Map.* Bureau of Mineral Resources, Geology & Geophysics, Canberra.

YOUNG R.W. 1977. Landscape development in the Shoalhaven River catchment of southern New South Wales. *Zeitschrift fur Geomorphologie* **21**, 262-283.

YOUNG R.W. 1983. The tempo of geomorphological change: evidence from southeastern Australia. *Journal of Geology* **91**, 221-230.

YOUNG R.W. & MCDOUGALL I. 1985. The age, extent and geomorphological significance of the Sassafras basalt, South-eastern New South Wales. *Australian Journal of Earth Sciences* **32**, 323-331.

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