ILLUSTRATIVE SECTIONS DEPICTING LANDSLIDE SUSCEPTIBILITY OF THE ILLAWARRA ESCARPMENT

Andrew Leventhal[1] and Phil Flentje[2]
[1] *Senior Principal Geotechnical Engineer, GHD Geotechnics, Locked Bag 2727, St Leonards, NSW 1590, Australia*
[2] *Senior Research Fellow, Faculty of Engineering, University of Wollongong, 2522, NSW, Australia*

1 INTRODUCTION

The challenge that landslides pose to infrastructure and to domestic and commercial development in the Illawarra region has been recognised in land-use planning for decades. The seminal regional mapping undertaken by Bowman (1974) and, before him, the work reported by Shellshear (1890), set the technical benchmarks for others to follow. The challenges presented to development and road and rail infrastructure were recognised by both Wollongong City Council and major infrastructure providers in the NSW Roads and Maritime Services (previously NSW Roads and Traffic Authority) and NSW Rail Corp (previously State Rail Authority). Continuing support from this group has permitted research and work in the field throughout the Illawarra by Flentje since 1993, which has brought together the collectively faced issues into a composite landslide inventory.

The landslide issues are well recognised by those who are familiar with the Illawarra area – in particular, the typically steep terrain of the 45 km long Illawarra Escarpment, the presence of a colluvial mantle draped over the steep terrain, the presence of many sub-horizontal coal seams throughout the stratigraphy, past and present underground coal mining throughout the region and intense rainfall events generated by virtue of its location and also as a consequence of the escarpment's influence upon local meteorology with the orographic rainfall.

One of the challenges of the application of Bowman *(ibid)* is the mapping base available at that time. Bowman reported mapping at 8 chains to the inch (1:6,336) but appears to have used a basemap enlarged from a much earlier base (possibly enlarged from 2 inch to the mile, viz: 1:31,680, or 1 inch to the mile, *viz:* 1:63,360). Bowman also noted the poor edge matching of his basemaps in his work. The NSW Central Mapping Authority 1:4,000 scale 2 m contours generated in the late 1970's provided a significant enhancement to the mapping base, though draping of the Bowman mapping over this improved basemap faced obvious challenges. Recently, the availability of the contours in electronic format and the rise of both Geographic Information System (GIS) capability and expertise, have greatly facilitated mapping in the Illawarra. Subsequent Airborne Laser Scan (ALS) digital terrain mapping at high resolution has also recently become available, which together with Flentje's detailed mapping (Flentje, 1998) and access to landslide records of Wollongong City Council (through council's Geotechnical Engineer, Peter Tobin) has permitted enhanced understanding of the specific conditions and characteristics that influence the Illawarra landscape. This area is also the scene of the Engineering Geology course run biennially on behalf of the Australian Geomechanics Society (2010).

As no doubt is often the case, a simple question triggers a line of action, and the *raison d'etre* for this paper fits that pattern. In this case, the question asked of themselves by the authors was "Is there a type-section of landslide issues within the Illawarra?" This paper, and the development of the illustrative sections herein, is a response to that somewhat rhetorical question.

Keywords: Slope stability

2 LANDSLIDE SETTING

The regional geological setting of the Illawarra Escarpment is the southern limb of the Sydney Basin, with its gently north-westerly dipping strata (dipping towards the basin centre beneath Sydney at 1 to 2 degrees). The geology extends up from the basal Shoalhaven Group, through the Illawarra Coal Measures, Narrabeen Group, Hawkesbury Sandstone and lower members of the Wianamatta Group, as shown in Figures 1A & 1B.

There are significant accumulations of colluvium on the escarpment. The colluvium comprises a mix of rocky debris, with some extremely large boulders, and smaller fragments derived from the sandstone and siltstone units. The coarse material is supported in a matrix of sands and clays derived from not only the claystone units but also from the finer materials through the stratigraphy. The colluvium is widely associated with past and active contemporary landslide activity on the escarpment. This slope instability is a significant hazard for urban development and associated infrastructure that is on, and which crosses, the escarpment slopes.

Processes and mechanisms of slope failure are controlled in the Wollongong region by factors that include the local geology and its stratigraphy, the geotechnical strength parameters of the bedrock material and their derivatives of alluvium and colluvium, the discontinuities in the bedrock mass (including faults, dykes and joints etc), hydrogeology, geomorphology, slope inclination, rainfall, pore water pressure and the actions of man.

The escarpment consists of slopes with moderate to steep inclinations with several intermediate benches and cliff lines. The geological sequence encountered on the escarpment comprises an essentially flat-lying sequence of interlayered sandstone, claystone and coal of the Illawarra Coal Measures, overlain by interbedded sandstones and claystones of the Narrabeen Group. Spectacular cliffs of Hawkesbury Sandstone (of Middle Triassic age) cap the escarpment. Where residential development is yet to occur, there is dense vegetation over most of the escarpment length below these cliffs.

An appraisal of the evolution of the Illawarra Escarpment terrain is presented by Flentje (2012). Specific issues relating to the mechanics of instability of the 25 km transit of the Escarpment by the South Coast Railway which were a consequence of the 1988-1990 El Nino event are addressed by Stone (2012).

Extensive underground coal mining of the Bulli Seam in the north and the Wongawilli Seam to the south has occurred throughout the Illawarra. The impacts of extraction and mine dewatering (and groundwater recovery) are to be recognised. The state-of-the-art in mine subsidence effects is presented in MSTS (2011), with more specific reference to the management of mine subsidence in the Illawarra region in Kay (2012).

Four detailed Illawarra Escarpment illustrative cross sections have been developed. These sections are included as Figures IIS-1A to IIS-2A. The location plan and the Illustrative Section figures are:

Figure LP 1:	Plan depicting location of illustrative sections relative to the Illawarra Escarpment
Figure IIS-1A:	Illustrative Section - Mt Mitchell / Coalcliff
Figure IIS-2A:	Illustrative Section - Bulli Tops to Austinmer
Figure IIS-3A:	Illustrative Section - Mount Ousley
Figure IIS-4A:	Illustrative Section - Avon / Huntley area

The Landslide Inventory developed by Flentje (2012) for the Illawarra region identifies ‘affected areas’ and contains three main types of landslides: falls, flows and slides (Cruden and Varnes, 1996). The Landslide Inventory currently contains 615 locations with a total of 985 events (including first time occurrences and multiple recurrences at some sites). The 615 landslide locations comprise 49 ‘Fall’, 43 ‘Flow’ and 481 ‘Slide’ category landslides, together with several scour related sites and a few sites that have not been classified. Within the total inventory, 426 Slide category landslides cover 2.4% of the 188 km^2 study area.

3 LANDSLIDE SUSCEPTIBILTY

Landslide susceptibility is developed from and in recognition of the landslide inventory, geology, geomorphology and slope-forming processes.

The companion figures depicting landslide susceptibility are:

Figure IIS-1B:	Illustrative Section depicting landslide susceptibility - Mt Mitchell / Coalcliff
Figure IIS-2B:	Illustrative Section depicting landslide susceptibility - Bulli Tops to Austinmer
Figure IIS-3B:	Illustrative Section depicting landslide susceptibility - Mount Ousley
Figure IIS-4B:	Illustrative Section depicting landslide susceptibility - Avon / Huntley area

With reference to these, the key features of landslide susceptibility in the Illawarra are:

- Rockfalls from the escarpment are common where the near vertical escarpment in the Hawkesbury sandstone has developed. A toppling mechanism may apply.
- Debris flows with extensive run-out travel are prevalent, and particularly so in the Narrabeen Group Bulgo Sandstone Formation terrain.
- Deep-seated landslides are frequently associated with the geomorphologically controlled benches or terraces within the terrain. The benches themselves have developed as a direct result of the underlying low shear strength claystone units within the stratigraphy – eg: the type-example being the Coalcliff landslide SC15 (with a volume of approximately 600,000 m^3) within the geomorphically identifiable “landform bench” upon the Stanwell Park Claystone and the Wombarra Claystone stratigraphic units observable in the Mt Mitchell / Coalcliff Illustrative Section on Figure IIS-1A. Another illustrative deep landslide is the Mount Ousley Road Site 141 landslide (with a volume of approximately 720,000 m^3) as seen in the Mount Ousley Illustrative Section on Figure IIS-3A.
- Landslide volumes, determined for 378 of the 426 sites within the landslide inventory, range from 1m^3 up to 720,000 m^3, with an average volume (arithmetic mean) of 21,800 m^3.

- Shallow colluvial landslides are ubiquitous.

The Landslide Susceptibility that has been developed, thus far, for Wollongong relates to 'Slide' category landslides only - leaving aside "Flow" and "Fall" categories. Developed using data-mining techniques, Landslide Susceptibility zones have been identified as:

(a) **high** susceptibility with 8% of this area subject to landslides and containing 60% of the known landslide population,

(b) **moderate** susceptibility with 4% of this area subject to landslides (contains 32% of known landslides),

(c) **low** susceptibility with 1% of area subject to landslides (contains 3% of known landslides) and

(d) **very low** susceptibility with 0.1% of the area subject to landsliding (contains 4% of known landslides) and yet representing 71% of the study area.

The **high** susceptibility zone identifies over 2,300 hectares of land, in addition to the known landslides, as being highly susceptible to landsliding. Furthermore, the model also identifies over 13,000 hectares of land as having a **very low** susceptibility to landsliding.

The knowledge-based data-mining technique used to develop the susceptibility classification is derived from the fundamental base dataset (i.e. the Landslide Inventory) and has been completed within a GIS data management system (Flentje *et al.*, 2011).

4 EMPOWERMENT

The figures provided herein in Australian Geomechanics V47N1 are reproduced at a scale to suit printing of the journal. **Interested readers are, however, encouraged to download copies of the figures from the AGS website** (viz: www.australiangeomechanics.org).

The Society actively encourages dissemination and use of its material, as do the authors in regard to these Illustrative Sections. Should the sections be used in other publications, the source (this paper and this journal) should be prominently acknowledged and duly referenced. Copyright of the sections rests, and will continue to rest irrevocably, with the Australian Geomechanics Society (AGS).

5 ACKNOWLEDGEMENTS

The illustrative sections have been developed through collaboration between the University of Wollongong and GHD Geotechnics, and the contribution of both entities is acknowledged.

6 REFERENCES

AGS (2007) Suite of papers AGS (2007a) to AGS (2007e) – see Bibliography

Australian Geomechanics Society (2010) "Engineering Geology Field Course", developed and presented by Phil Flentje, Fred Baynes and Mark Eggers, on behalf of the Society.

Bowman HN (1972a) "Natural slope stability in the City of Greater Wollongong", Records of the Geological Survey of New South Wales, Volume 14, Part 2, 29/9.

Bowman HN (1972b) "The geology and natural slope stability of the City of Greater Wollongong", Master of Science Thesis, unpublished, the University of Sydney, March 1972.

Bowman HN (1974) "Geology of the Wollongong, Kiama and Robertson" 1:50,000 Sheets 9029-II 9028-I&IV Sheets, Department of Mines, Geological Survey of New South Wales.

Cruden DM and Varnes DJ (1996) "Landslide Types and Processes" in Turner AK and Schuster RL (editors) 1996. *Landslides, Investigation and Mitigation*. Special Report 247, Transportation Research Board, National Research Council, National Academy Press Washington DC.

Flentje P, Stirling D. and Chowdhury RN (2011) 'Landslide inventory, susceptibility, frequency and hazard zoning in the Wollongong and wider Sydney Basin area". Landslide Risk Management Roadshow 2011 National Seminar Series, *Australian Geomechanics*, Vol 46, No 2, June 2011, pp 41 – 49.

Flentje P (2012) "Evolution of the Illawarra Escarpment terrain" *Australian Geomechanics* V47N1, March 2012 *(companion paper in this edition)*.

Kay D (2012) "Managing mine subsidence in the Southern Coalfield", *Australian Geomechanics* V47N1, March 2012 *(companion paper in this edition)*

MSTS (2011) "Management of subsidence – state of the art", Mine Subsidence Technological Society, Proceedings of the 8th triennial conference, Hunter Valley, NSW, 15 to 17 May, 2011.

NSW Department of Mineral Resources (2000) "A compilation of the geology of the Southern Coalfield", Notes to accompany the 1:100 000 Southern Coalfield Geological Map, geological Survey Report No GS1998/277, edited by RS Moffitt.

Shellshear W (1890) "On treatment of slips on the Illawarra railway at Stanwell Park", J. Proc. Royal Soc. NSW, Vol 24 No 1, pp58-62.

Stone PC (2012) "Landslide impacts on the South Coast Railway during the 1988-90 El Nino event", *Australian Geomechanics* V47N1, March 2012 *(companion paper in this edition)*.

7 BIBLIOGRAPHY

AGS (2000) "Landslide risk management concepts and guidelines". Australian Geomechanics Society, *Australian Geomechanics*, Vol 35 No 1, March 2000, reprinted in Vol 37 No 2, May 2002.

AGS (2007a) "Guideline for landslide susceptibility, hazard and risk zoning for land use planning". Australian Geomechanics Society, *Australian Geomechanics*, Vol 42 No 1, March 2007.

AGS (2007b) "Commentary on guideline for landslide susceptibility, hazard and risk zoning for land use planning". Australian Geomechanics Society, *Australian Geomechanics*, Vol 42 No 1, March 2007.

AGS (2007c) "Practice note guidelines for landslide risk management". Australian Geomechanics Society, *Australian Geomechanics*, Vol 42 No 1, March 2007.

AGS (2007d) "Commentary on practice note guidelines for landslide risk management". Australian Geomechanics Society, *Australian Geomechanics*, Vol 42 No 1, March 2007.

AGS (2007e) "Australian GeoGuides for slope management and maintenance". Australian Geomechanics Society, *Australian Geomechanics*, Vol 42 No 1, March 2007.

<u>Mt Mitchell Section</u>

Leventhal A, Stone P & Christie D (2000) "Landsliding of the South Coast Railway – The Coalcliff slide", Proc GeoEng2000, Int Conf on Geotechnical & Geological Engineering, Melbourne, 19-24 Nov 2000, Technomic.

Moon AT, Wilson RA and Flentje PN (2005) "Developing and using landslide size frequency models", Joint Technical Committee on Landslides and Engineered Slopes, JTC-1, in association with Vancouver Geotechnical Society, Proceedings of the International Conference on Landslide Risk Management / 18th Annual Vancouver Geotechnical Society Symposium, Vancouver, May 31 to June 4, pp 681 - 690.

Pitsis SE (1992) "Slope Instability along the Illawarra Escarpment", Master of Engineering Science thesis, University of New South Wales (unpublished).

Wilson R, Moon A., Hendrickx M. & Stewart I (2005) "Application of quantitative risk assessment to the Lawrence Hargrave Drive Project, New South Wales, Australia". Joint Technical Committee on Landslides and Engineered Slopes, JTC-1, in association with Vancouver Geotechnical Society, Proceedings of the International Conference on Landslide Risk Management / 18th Annual Vancouver Geotechnical Society Symposium, Vancouver, May 31 to June 4, pp 589 – 598.

<u>Austinmer Section</u>

LongMac Associates (1991) "Preliminary Report of Geotechnical Investigation Morrison Avenue Landslide, Coledale" report prepared for Wollongong City Council (unpublished), LongMac project ref BGT5180.

<u>Mount Ousley Road Section</u>

Hawkins B (1990) "Slope Instability in the Mount Ousley Road area, Wollongong". Master of Engineering Science (Geotechnical Engineering) thesis (unpublished), University of New South Wales.

RTA (1989) "Monitoring of slips. Main Road 95 - Mount Ousley Road. One kilometre north of the Mount Pleasant bridge", Roads and Traffic Authority of New South Wales, Materials Services Branch, Illawarra Division.. Report No G1767, 10 February 1989.

<u>General</u>

Flentje P (1998) "Computer Based Landslide Hazard and Risk Assessment". PhD Thesis, Faculty of Engineering, University of Wollongong, Australia, 550 + pages. Available to download at - http://www.uow.edu.au/eng/research/landslide/flentjephdthesis/index.html

McMahon Associates and SRA NSW (1982), "SCR Illawarra Electrification Project Catalogue of Geotechnical problem areas, Seabank to Scarborough area".

==

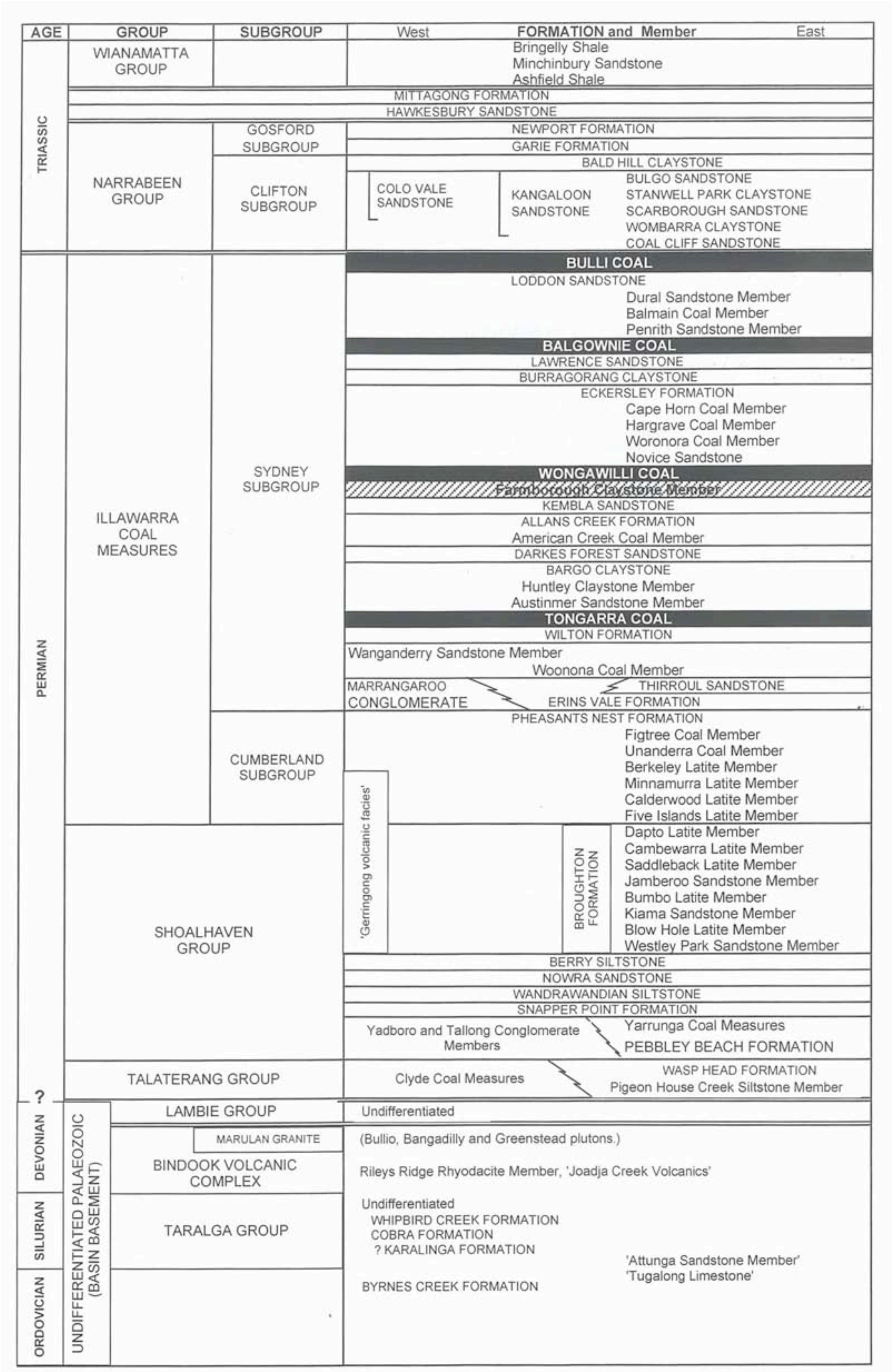

Figure 1A: Stratigraphic column for the Southern Coalfield (NSW DMR, 2000)

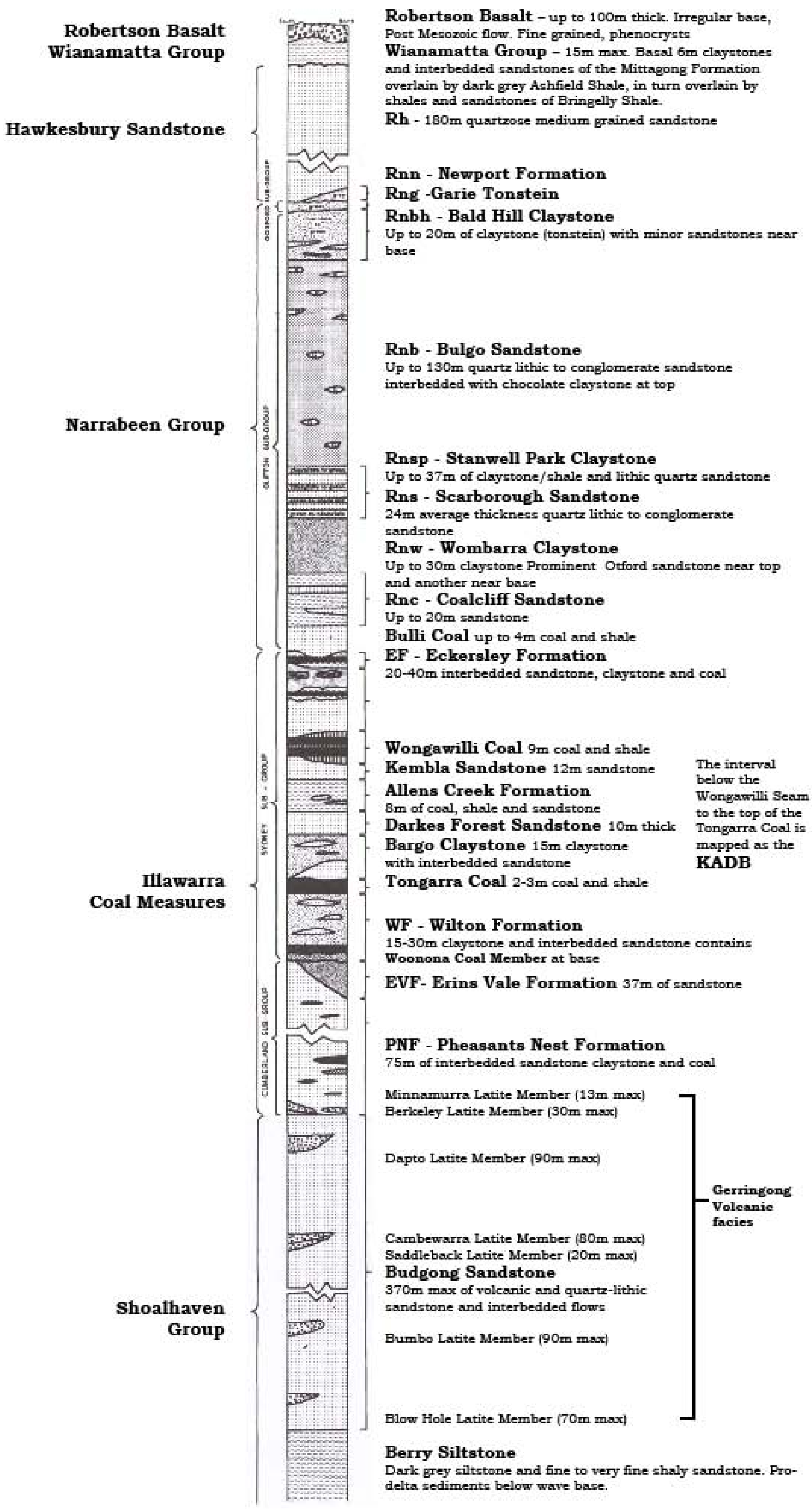

Figure 1B: Stratigraphic column for the Southern Coalfield (after Bowman, 1974)

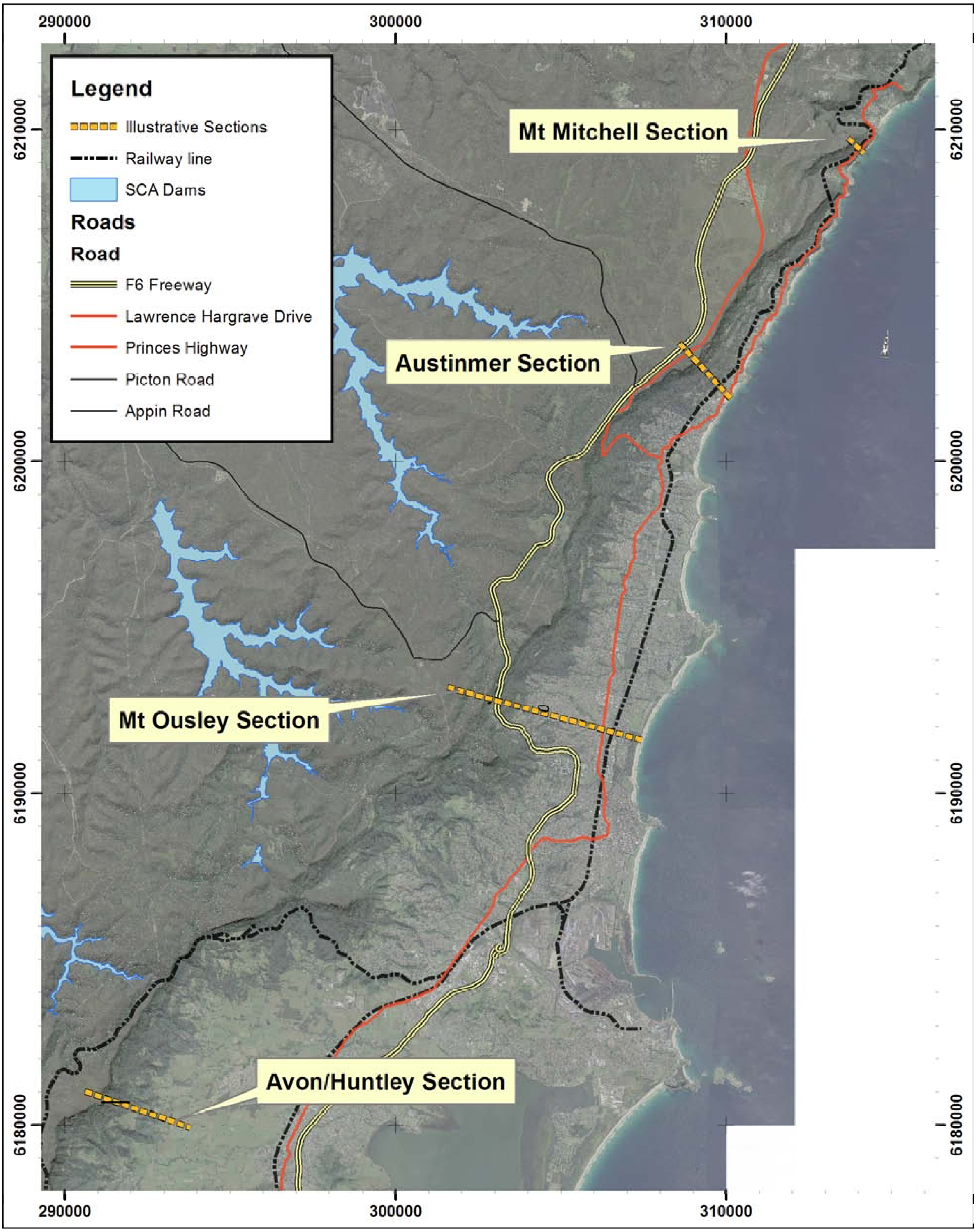

Figure LP 1: Plan depicting location of Illustrative Sections relative to the Illawarra Escarpment