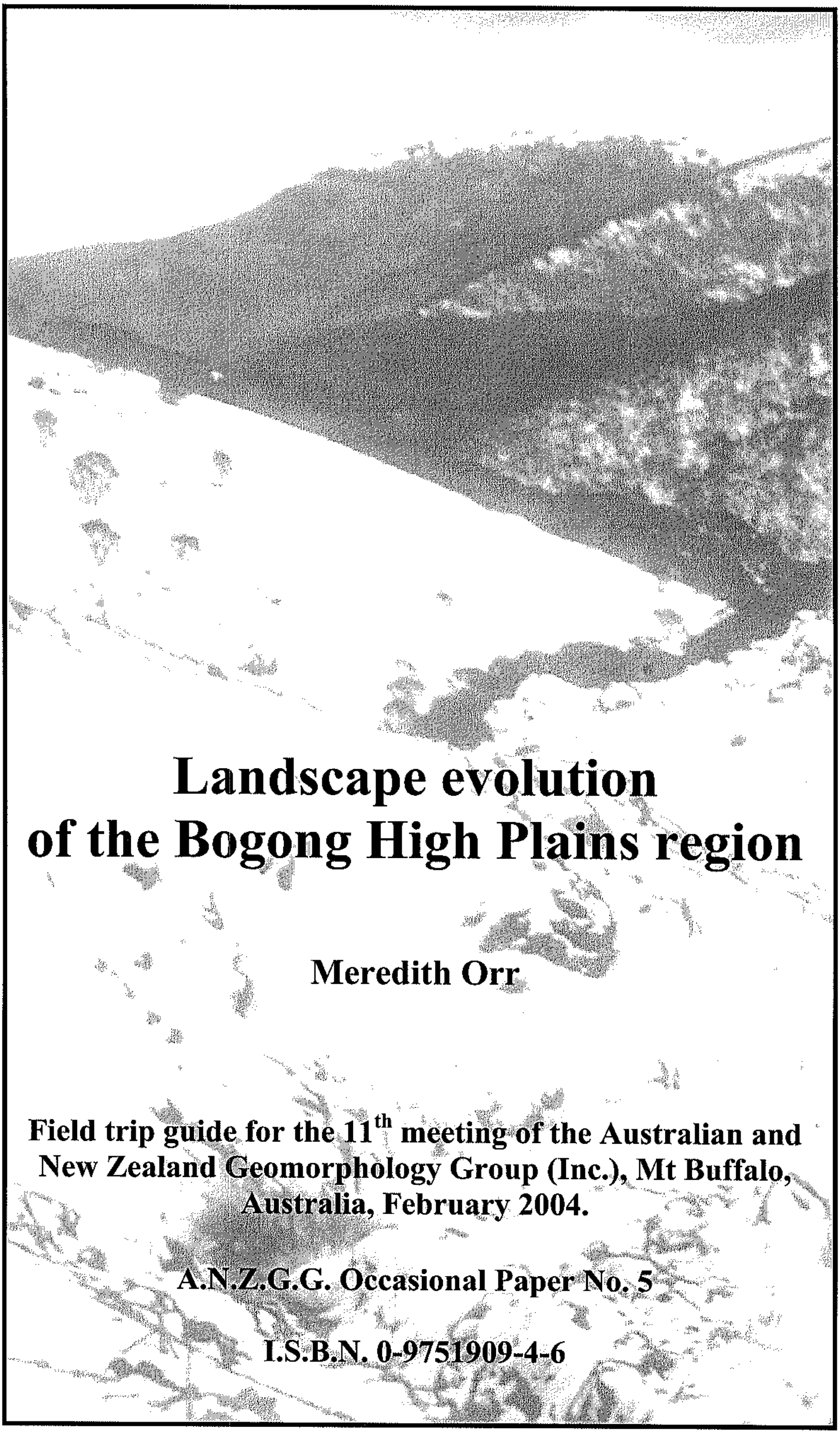

Landscape evolution of the Bogong High Plains region

Meredith Orr

Field trip guide for the 11th meeting of the Australian and New Zealand Geomorphology Group (Inc.), Mt Buffalo, Australia, February 2004.

A.N.Z.G.G. Occasional Paper No. 5

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“[H]ow do we address the methodological issue that erosional development of landscapes involves the removal (denudation) of that landscape (that is, destruction of substantial parts of the evidence)?”

- Bishop (1996).

ITINERARY

8.00 **Depart Mt Buffalo Chalet**
The trip to stop 1, after descending Mt Buffalo, is to the south and then eastward along the Great Alpine Road and Bright-Tawonga Road. The route crosses the foothills of the Australian Alps, following the Ovens River valley for a short distance before crossing the divide to the Kiewa River valley. The main part of the Australian Alps is not reached until after stop 1.

9.15 **Arrive at stop 1: Tawonga Gap lookout**

10.00 **Depart Tawonga Gap lookout**

10.20 **Morning tea at Mt Beauty**

10.40 **Depart Mt Beauty**
After Mt Beauty the road ascends the Kiewa River East Branch valley to the level of the high plains and alpine peaks. Note the periodic views of benched slopes, some of which are interpreted as valley-in-valley features (the narrow road does not permit the bus to stop). The road leads to Falls Creek, which is on the edge of the Bogong High Plains.

11.40 **Arrive at stop 2: Windy Gap, Falls Creek**

12.00 **Depart Windy Gap**

12.15 **Lunch at Rocky Valley Storage picnic area, Bogong High Plains**

1.0 **Depart Rocky Valley Storage**
Cainozoic volcanic rocks are visible at Ruined Castle, shortly before stop 3.

1.15 **Arrive at stop 3: Mt McKay**
Participants have the choice of walking up the 750m-long (steepish) track to Mt McKay or getting a lift in the Landcruiser.

2.30 **Depart Mt McKay**

2.40 **Arrive at stop 4: Pretty Valley, Bogong High Plains**

3.30 **Depart Pretty Valley and Bogong High Plains**

4.30 **Arrive at stop 5 (time permitting): Tawonga rest area, Kiewa River valley**

4.50 **Depart Tawonga**
The return trip is northward along the Kiewa Valley Highway, westward over the divide to the Ovens River valley along Running Creek Road, and southward back to Mt Buffalo Chalet via the Great Alpine Road. High-level alluvial terraces of the Kiewa River valley are encountered along the Kiewa Valley Highway, with road cuttings revealing the coarse nature of the sediments.

6.15 **Arrive Mt Buffalo Chalet**

INTRODUCTION

This field trip will introduce you to the Australian Alps, a region unusual in Australia as steep rugged topography has developed during the Cainozoic period. It contains almost all of the alpine and subalpine environments, and the highest land elevations, of the Australian mainland.

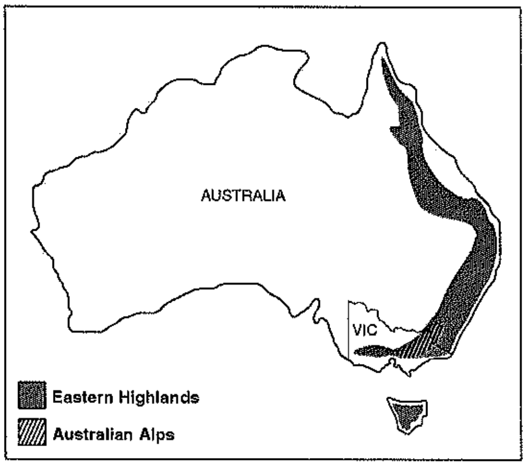


Figure 1. Broad distribution of the Australian Alps and Eastern Highlands, from Orr (1999).

In eastern Victoria the Alps are higher than the general level of the Eastern Highlands and are more deeply dissected. High relief occurs both at the highland margins and at the continental divide. Some valleys are over one kilometre in depth, including here at the Kiewa River East Branch valley, which is over 1500m deep near Mt Bogong.

In addition to the steep dissected terrains, low-relief, high-elevation "high plains" surfaces exist. The high plains in this area are the Bogong, Cobungra and Dargo High Plains. They occur at elevations of between 1300m and 1880m a.s.l., and have the appearance of a dissected plateau. Local high plains relief is generally below 200m. The topography is flat to undulating, with some isolated hill tops.

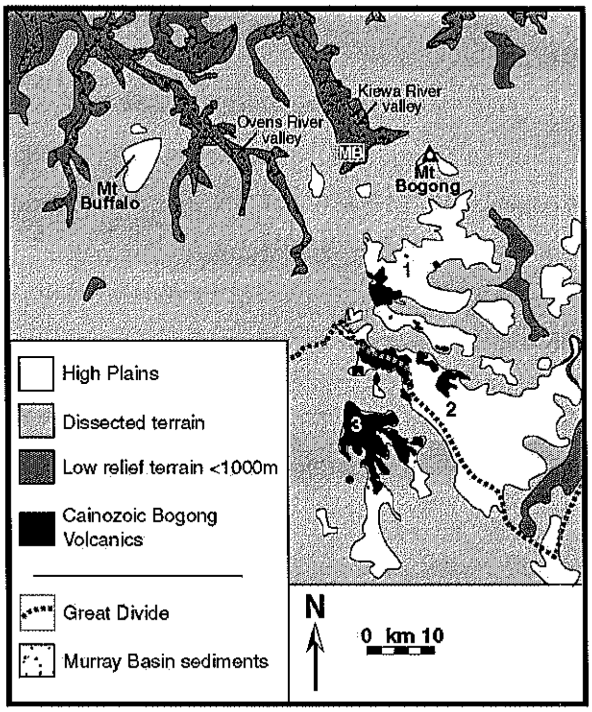


Figure 2. Land surface types in the Mt Buffalo and Bogong High Plains region. Adapted from Orr(1999).

1 = Bogong High Plains
2 =Cobungra High Plains
3 = Dargo High Plains
MB = Mount Beauty.

Remnants of Cainozoic lavas, known as the Bogong Volcanics, overlie the high plains in part. These lavas have been dated by K-Ar methods as around 36 Ma to 30 Ma (Wellman 1974).

STOP 1: TAWONGA GAP LOOKOUT

Tawonga Gap overlooks the Kiewa River valley, at the boundary between Quaternary alluvium and the high country of the Australian Alps. The Tawonga Fault is located at this boundary, and it separates the low peaks of the highland foothills from the high peaks of the Australian Alps. The fault is known to have thrust gneissic bedrock over unconsolidated sediments at the boundary (Beavis 1960), and it may also be responsible for an elevated block of land to the south (see Figure 6 ahead).

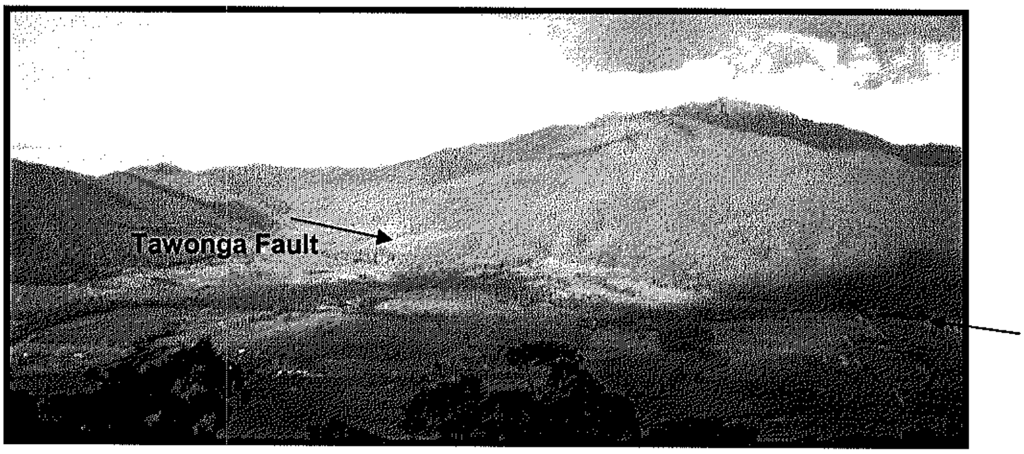
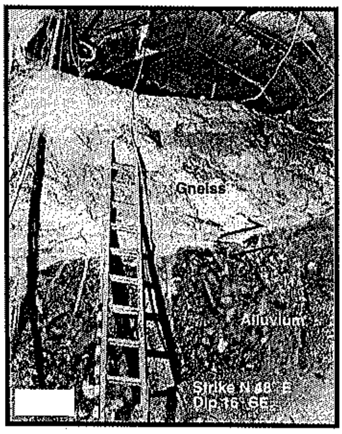


Figure 3 (above). *View of the upper Kiewa River valley with the position of the Tawonga Fault indicated. Mt Bogong (1986m a.s.l.) is the highest peak visible. Photo by Meredith Orr.*

Figure 4 (right). *Exposure of gneiss thrust over alluvium in the No. 4 Tail Race Tunnel, near the Kiewa River West Branch. From Beavis (1960).*



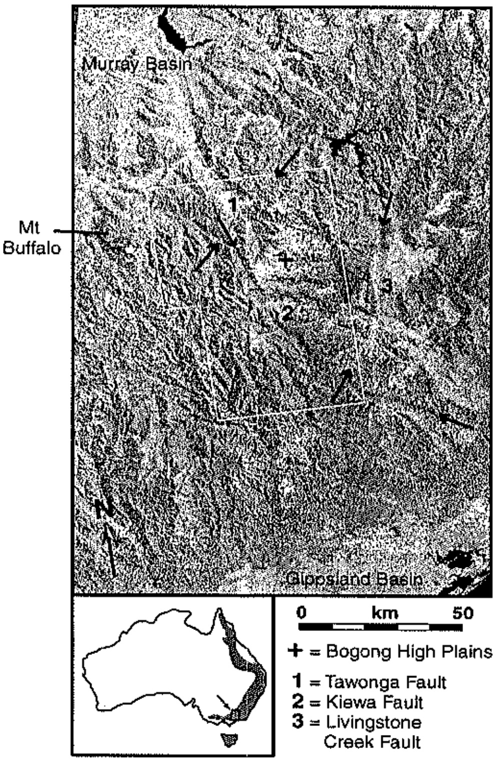
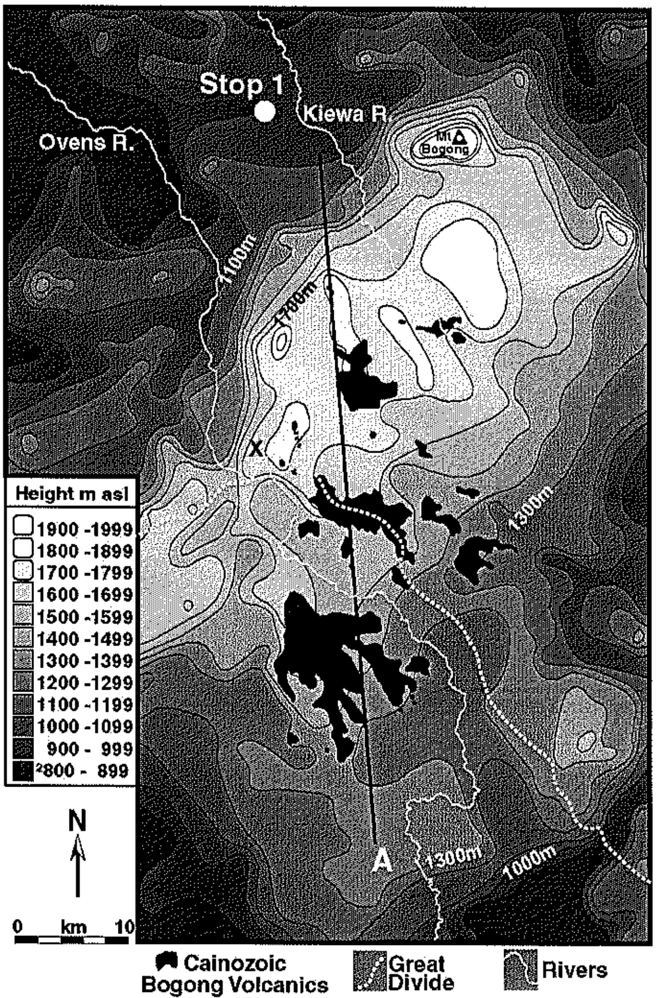
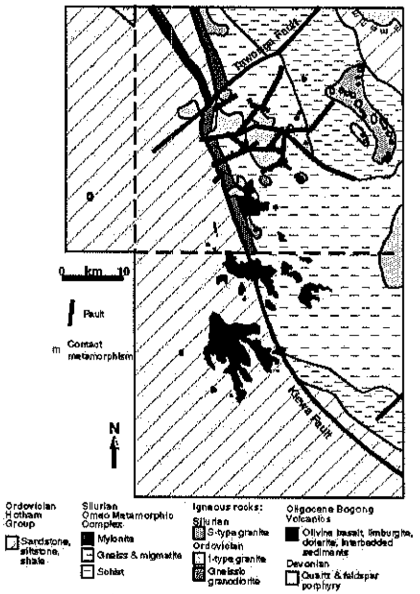


Figure 5. *Central east Victorian highlands Landsat Thematic Mapper band 4)near-infrared image, with major faults in the vicinity of the Bogong High Plains indicated. Adapted from Orr (1999). Inset area is that of Figure 6.*

Though the thrust fault is evident in a tunnel cutting (Figure 4), Morand and Gray (1991, 1992) argue that the Tawonga Fault was reactivated after the Palaeozoic as possibly a high angle reverse fault. According to their interpretations, the thrust fault recorded by Beavis (1960) is the result of localised surficial gravity gliding (mountain front creep) over the base of the Kiewa River valley.

Major faults are visible in satellite imagery across this region, and some of these are proximal to the high plains (Figure 5). The possibility of topographic displacements occurring in association with the faults is indicated by contouring peak heights in this dissected terrain (Figure 6).





High plains study area basement geology, as mapped by the following sources, aozoic Bogong Volcanics, as mapped by Orr (1999). Quaternary basin sediments are not included. Basement geology sources: A = Easton et al 1974; B = Bolger & King 1976, with modifications from Morand & Gray 1991; C= Vandenberg 1977.

***Figure 6.** High plains region peak height contour map (left), from Orr (1999). The area of the map is indicated in Figure 5. The transect line corresponds to the section in Figure 9. 'X' marks the location at which the photo below was taken. Basement geology of the area is shown above for comparison.*

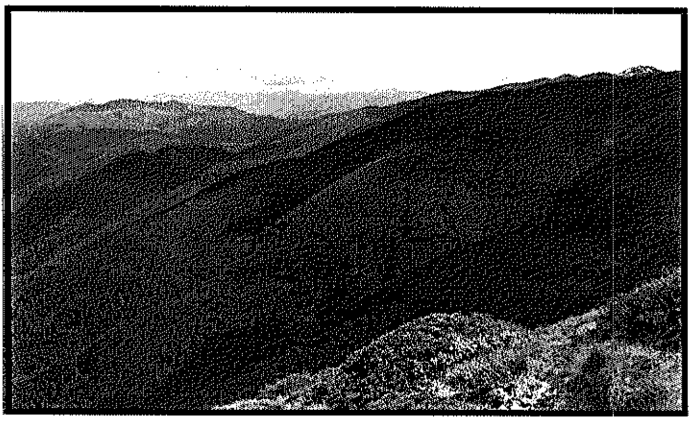


***Figure 7.** View north from the position marked 'X' on Figure 6, along the topographic displacement associated with the Tawonga Fault.*

A total of 548 watershed peak heights were plotted for the area shown in Figure 6. These heights were contoured at 100m intervals to produce the peak height contour map. The contours define a large northeasterly-oriented zone above 1100m a.s.l., bounded by abrupt linear changes in height on the northwestern and southeastern sides. These correspond to the positions of the Tawonga and Livingstone Creek Faults respectively. Basement geology (Figure 6), though it exerts a strong control on the distribution of dissected terrain (Figure 5), does not exert strong control on the peak height contours. The map is interpreted as indicating a broad northeasterly-oriented fault bound block, with major boundaries along the Tawonga and Livingstone Creek Faults.

These faults have apparently controlled the nature, rate and timing of about two-thirds of the Cainozoic (post-volcanic) stream incision of the areas upstream (Orr 1999). About one-third of the stream incision comes from sources downstream of the faults. The degree of Cainozoic tectonic disruption and erosion in this landscape is unusual compared to the rest of the Australian Eastern Highlands.

Part of the evidence (as far as the term "evidence" can be used!) for this conclusion comes from apparent valley-in-valley forms that exist in many valleys of the highlands here. Some of these can be seen in the Kiewa River East Branch valley from the Tawonga Gap lookout (Figure 8).

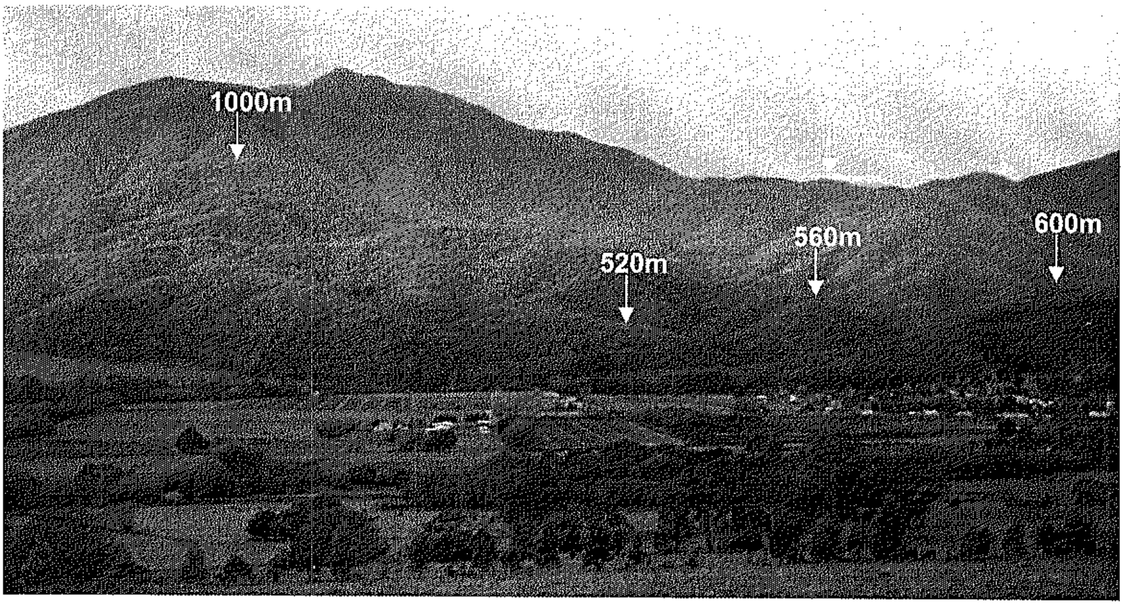


Figure 8. Benched slopes in the Kiewa River East Branch valley interpreted by Orr (1999) as valley-in-valley forms. Heights of the benches are given in metres above present sea level.

Valley-in-valley forms can be remnants of former valley floor levels cut into bedrock. Stream incision into the valley base may leave a benched slope profile at the site of the former slope change to the valley floor. The levels may be correlatable upstream or downstream in valley long profiles.

Valley-in-valley forms can indicate any periodicity of stream incision and long profiles can indicate any deformation of the original profiles by tectonics. But before these interpretations can be made, the challenging task of separating possible valley-in-valley forms from benched slopes caused by differential erosion in gently dipping strata, differential erosion at a boundary between two lithologies, erosion along the site of a structural weakness (such as a fault or lineament), and nivation and periglacial erosion to form nivation hollows and cryoplanation terraces needs to be undertaken. This process is discussed in more detail at the next stop.

Assuming for the moment that interpretations of valley-in-valley forms in the Kiewa River East Branch valley by Orr (1999) are correct, there have been three periods of stream incision since the time of the syn-volcanic sediments, separated by two periods of relative stream stability at the terrace levels before the present stream bed formed (Figure 9).

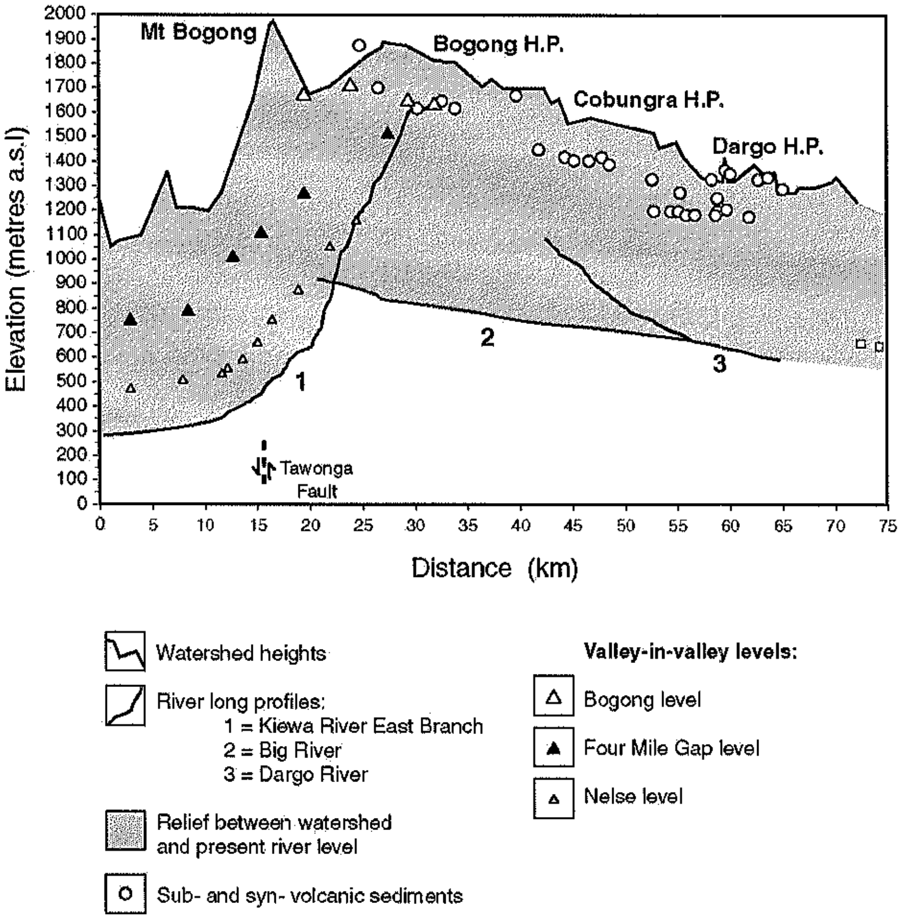


Figure 9. *Major features of the fault block across the Tawonga Fault, along transect A (location shown in Figure 6). From Orr (1999).*

The transect is taken in a direction which does not display the true peak height gradients, but the relationships between the highland block, Cainozoic sediments and valley-in-valley levels are revealed.

Interpretations:

The Bogong terrace level and the volcanics may have formed part of a low relief terrain before uplift along the Tawonga Fault. A period of stream incision increased relief and stream gradients between that time and the Four Mile Gap level formation. The original river long profile appears to have been uplifted along the fault, with major displacement occurring between the times of the Bogong and Four Mile Gap stream levels.

The stream stabilised at the Four Mile Gap level, after which there was minor deformation across the Tawonga Fault. Stream incision of between 250m and 400m depth occurred below the Four Mile Gap level, before the stream stabilised at the Nelse level. Stream incision of around 200m continues in the present landscape below the Nelse level. The Four Mile Gap and Nelse levels have been slightly deformed (bowed) across the fault since their formation.

STOP 2: WINDY GAP, FALLS CREEK

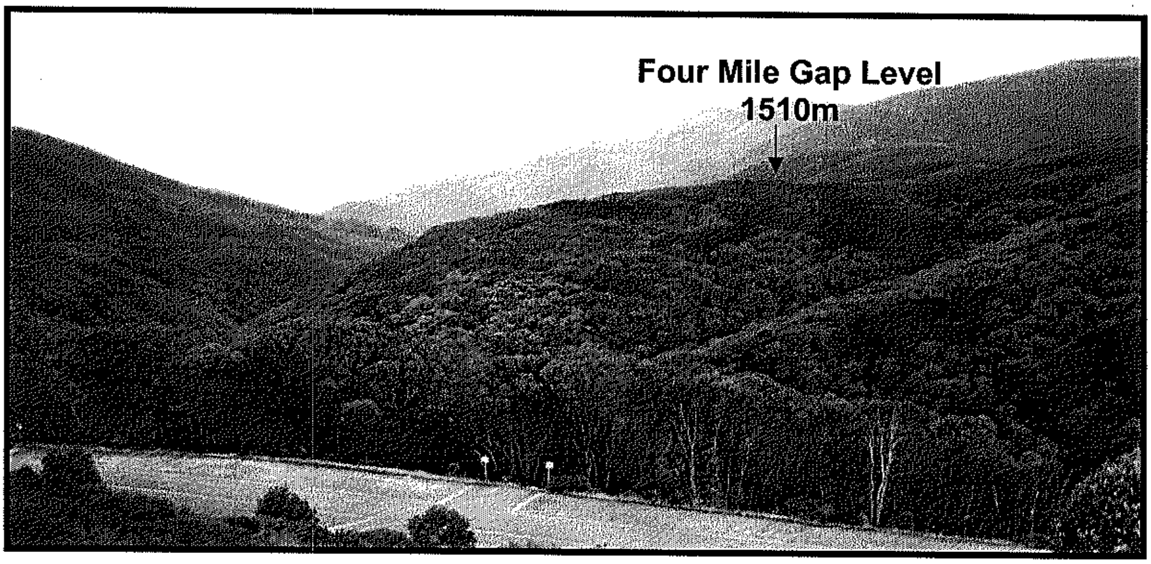


Figure 10. View from stop 2, to a benched slope interpreted by Orr (1999) to be a valley-in-valley form. Photo by Meredith Orr.

This stop has a view to a benched surface interpreted by Orr (1999) to be part of the Four Mile Gap valley-in-valley level, near the point where it intersects the Bogong level (Figure 9).

Notes on identification of valley-in-valley levels (Orr 1999):
Benched slopes were identified from topographic maps, aerial photographs and field observation. Benched slopes were interpreted as valley-in-valley levels if they fulfilled the following criteria:

- they do not occur on lithological boundaries* or structural weaknesses such as faults or lineaments, as determined by geological maps, aerial photographs, satellite imagery and field checking;
- they do not have nivation hollow or cryoplanation terrace morphology, as indicated by topographic maps and field observation;
- they do not occur as laterally continuous steps on gently dipping strata, as determined by geological maps and mapping of Bogong Volcanics (by Orr 1999);
- they have dimensions longer than they are wide, and usually occur on spur ridges;
- the bench surface is more level than convex; and
- the lower bench end is marked by bedrock outcrop, and may have an abrupt change to a steeper slope.

*It was found from both map analysis and field observation that the most common product of lithological variation is changes in slope gradient, but not benches.

The presence of rounded gravels on some of the checked bench surfaces was considered to be verification of valley-in-valley form origin.

STOP 3: MT MCKAY, BOGONG HIGH PLAINS

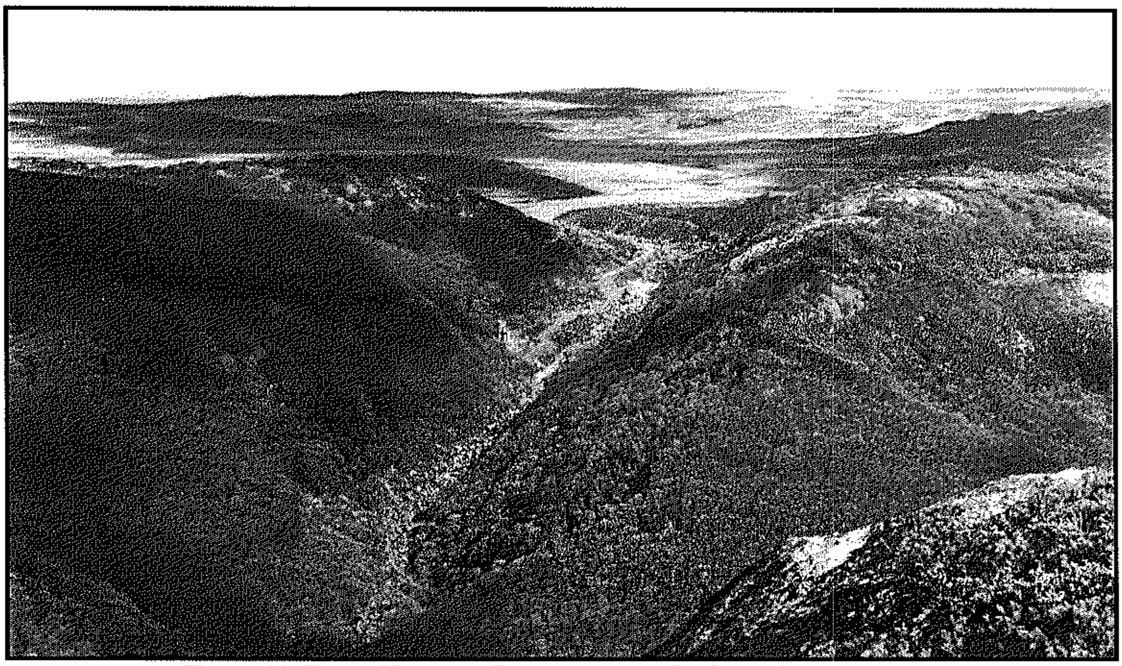


Figure 11. View of Pretty Valley, Bogong High Plains, from Mt McKay.

An explanation of the view at this stop, and the position here in the apparent Cainozoic fault block, will be provided, along with a discussion on the degree of post-volcanic stream erosion below the level of the high plains. Results of fission track analysis of Mt McKay will then be presented.

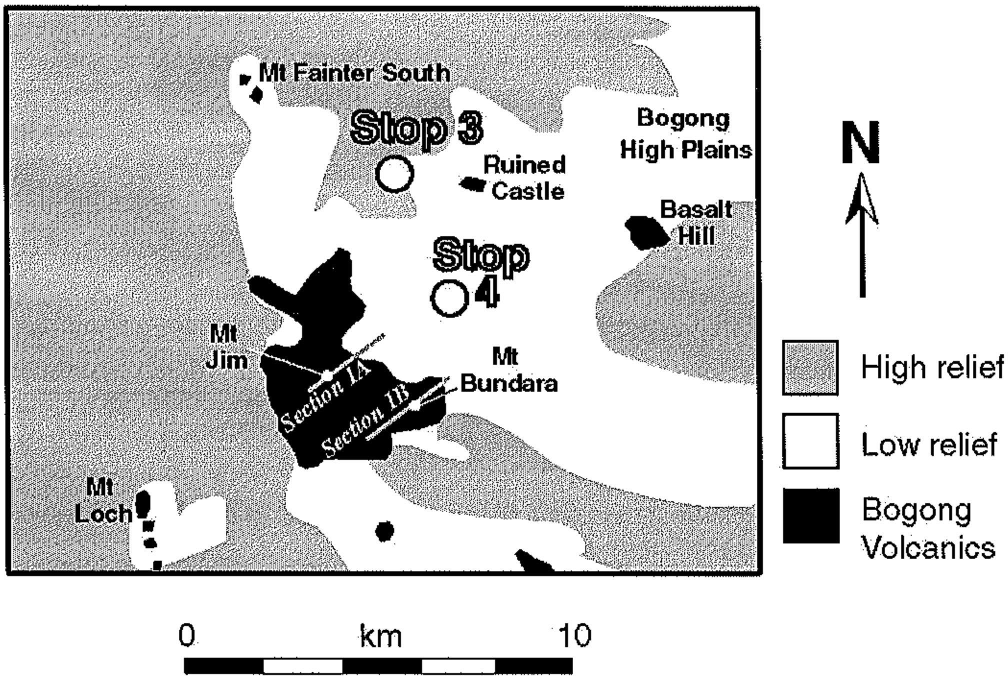


Figure 12. Cainozoic lava distribution on the Bogong High Plains, as mapped by Orr (1999), and locations of sections shown in Figure 15.

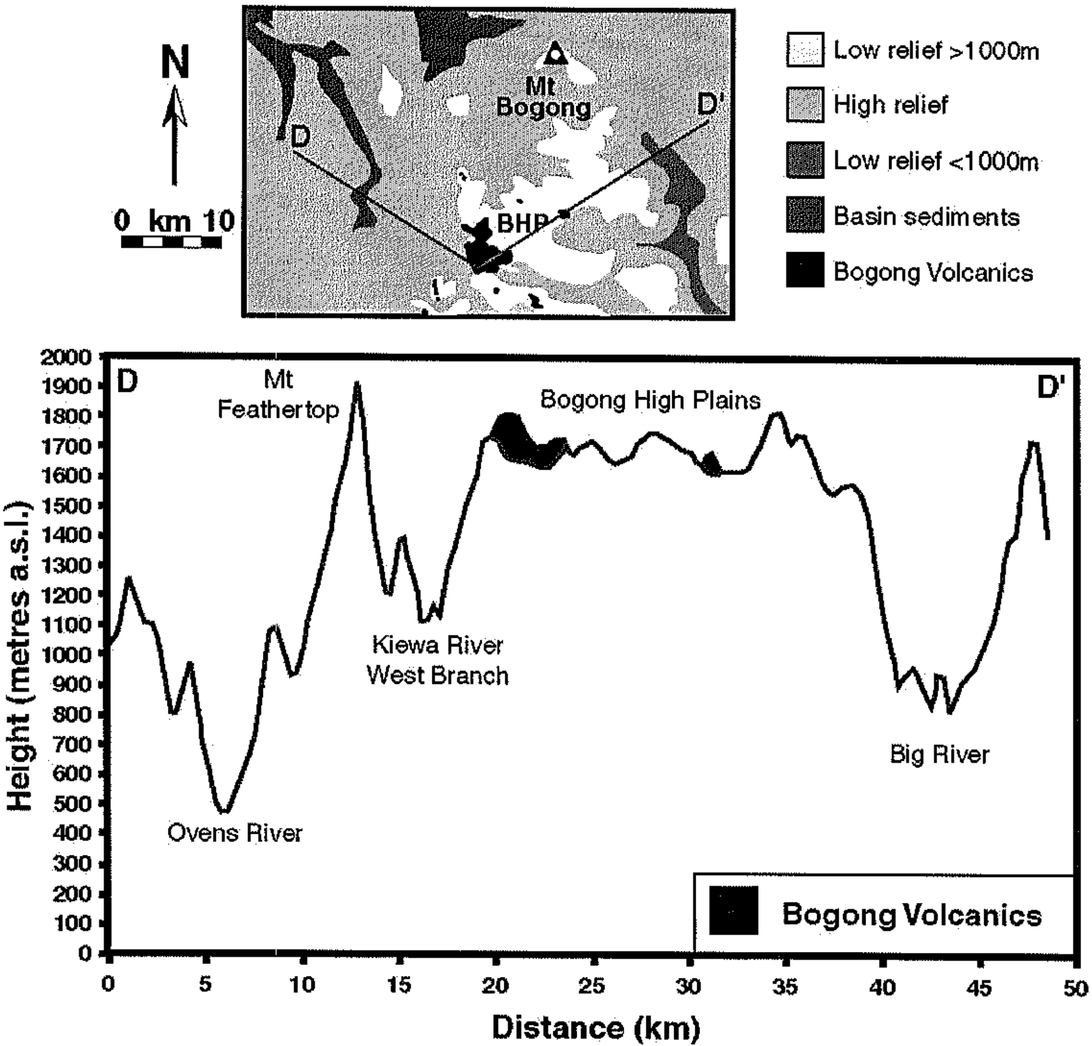
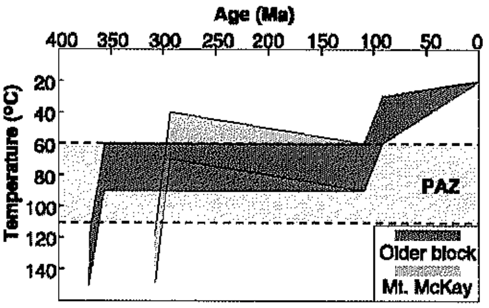


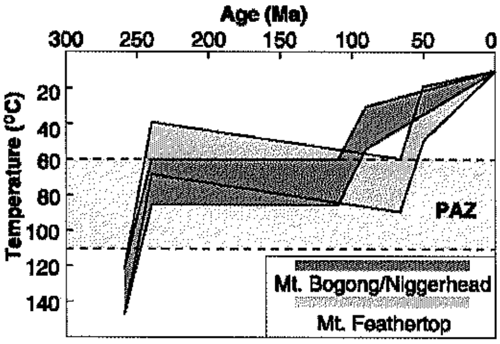
Figure 13. *Cross-section of present relief in the vicinity of the Bogong High Plains, and position of Cainozoic Bogong Volcanics. Adapted from Orr (1999).*

Post- middle Oligocene stream incision was not apparently transmitted from the Murray Basin to the highlands. Highland incision across the northern margin of the east Victorian highlands generally appears to have a near margin origin and the magnitude increases in an upstream direction. The upstream-increasing incision is suggestive of highland warping, with major increases along reactivated faults such as the Tawonga Fault.

FISSION TRACK ANALYSIS (O'Sullivan et al. 1999)



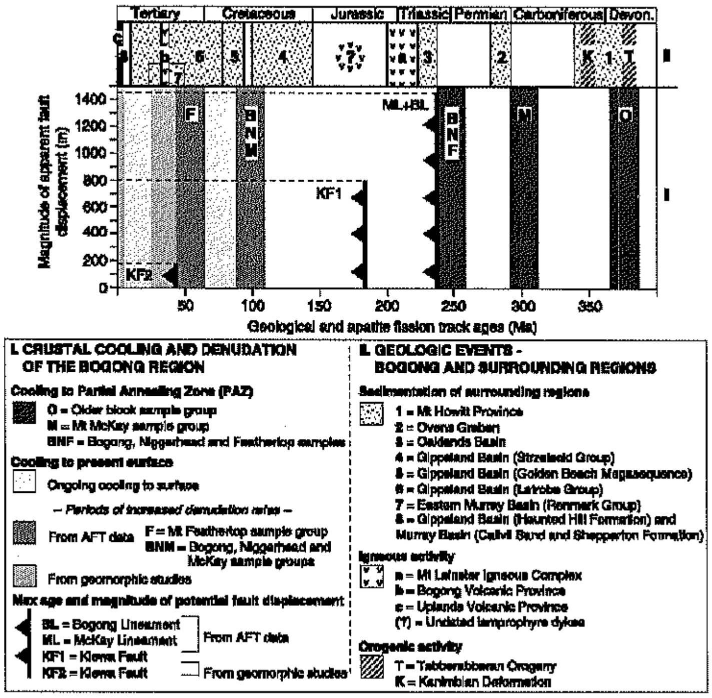
Schematic proposed time-temperature history for the Mt McKay region of the Bogong High Plains inferred from apatite fission track data presented in this paper. To fit the apatite data, samples from the main section experienced two major rapid cooling episodes: (i) during the Late Permian from greater than ~110°C; and (ii) during the middle Cretaceous. All cooling is interpreted to have occurred in response to denudation. PAZ refers to the apatite partial annealing zone described in Figure 4. Further



Schematic proposed time-temperature histories for the Mt Feathertop, Mt Bogong, and Mt Niggerhead regions of the Bogong High Plains inferred from apatite fission track data presented in this paper. To fit the apatite data, all samples experienced two major rapid cooling episodes: (i) during the Late Permian to Early Triassic from greater than ~110°C; and (ii) during the middle Cretaceous. More recently, samples from Mt Feathertop on the western side of the Kiewa Fault experienced rapid cooling during the Early to middle Tertiary. PAZ refers to the apatite partial annealing zone described in Figure 4. Further details discussed in the text.

The diagrams presented here are all from O'Sullivan et al. (1999), and are used as the basis of discussion at this stop. The cooling history of rocks now exposed at the surface can be determined for the time that the sampled column of rocks passed through the apatite partial annealing zone (PAZ), and the cooling could be related to denudation at the surface at those times. Once the rocks have passed through the PAZ, the resolution of cooling history is lost.

O'Sullivan et al. (1999) used these results to conclude that from the late Paleozoic onwards, parts of the region experienced rapid cooling during the Late Permian to Early Triassic, and fault reactivation and rapid cooling during the middle Cretaceous (110-90 Ma) and Early to mid-Tertiary. The mid- to late Tertiary history is not well defined by the data.



STOP 4: PRETTY VALLEY, BOGONG HIGH PLAINS

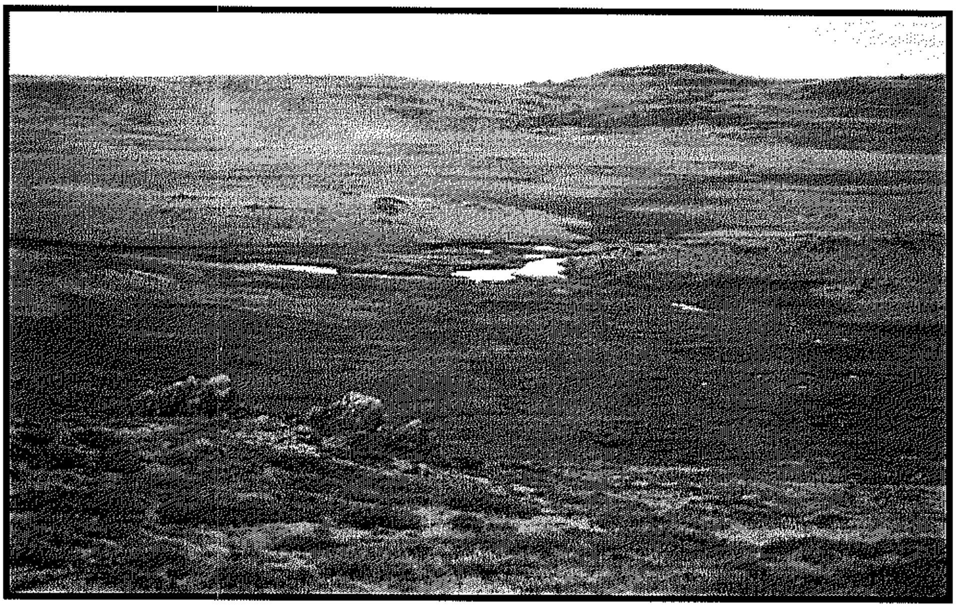


Figure 14. Pretty Valley, Bogong High Plains. Photo by Meredith Orr.

Present relief is much higher in the high plains vicinity than in the (Eocene to) Oligocene when the volcanics erupted. Regionally, the relief preserved under the lavas is generally less than 200m.

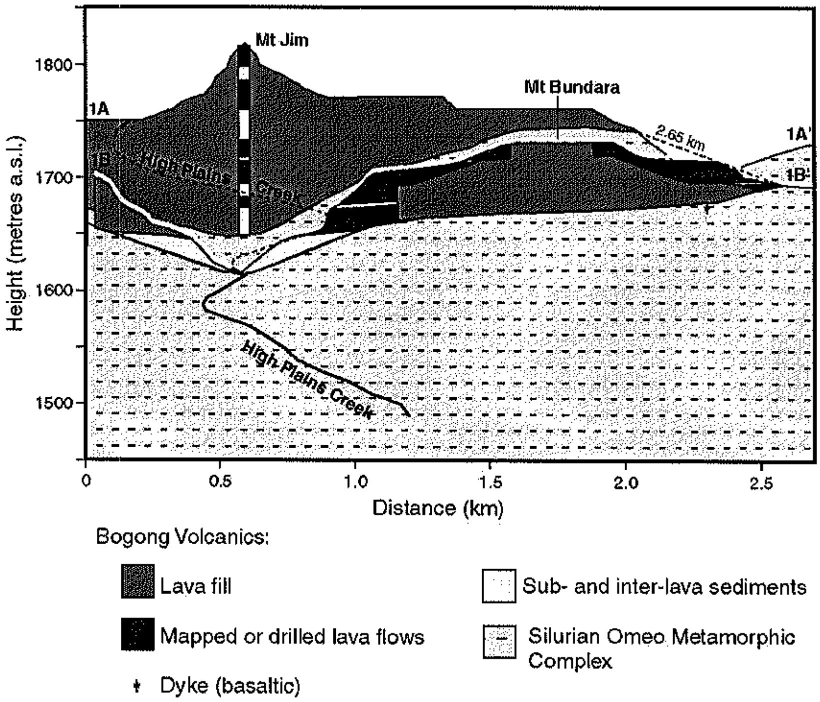


Figure 15. Bogong High Plains lava fill, based on the mapping of Orr (1999) and results of drilling at Mt Jim (Beavis 1962). Locations of sections 1A and 1B are shown in Figure 12. Section 1B is displayed in front of section 1A.

The maximum depth of the lava and sediment cover on the Bogong High Plains is around 200m. Minimum pre-volcanic relief might be derived from the height difference between the bedrock peaks and the lowest sub-volcanic sediment contact, giving a result of nearly 180m. The presence of remnant lavas adjacent to these peaks, however, suggests that 180m may be a reasonable local relief estimate.

HIGHLAND PALAEOELEVATIONS (Greenwood et al in prep.)

PALEOELEVATION OF THE VICTORIAN HIGH PLAINS, AUSTRALIA, CONSTRAINED BY PALEOBOTANICAL DATA.

David R. Greenwood, Meredith Orr, Anthony J. Vadala, Meredith A. Banks, and John A. Webb

ABSTRACT

There is equivocal evidence for substantive uplift of the Australian Alps before or after eruption of mid Cenozoic basalts throughout these highlands. Geological reconstruction of the Mt Hotham area suggests an Eocene paleoelevation of 800m, implying that additonal uplift occurred after the Eocene. Paleobotanical data from a diverse megaflora from early Eocene sediments at Hotham Heights, near the Bogong High Plains, Victoria, is used to estimate paleoelevation for a site in these highlands. The paleobotanical evidence is consistent with geological reconstruction, and suggests Hotham Heights was likely an upland area (paleoelevation 800m ±430m) but at a lower elevation in the early Eocene than it is now (1723m).

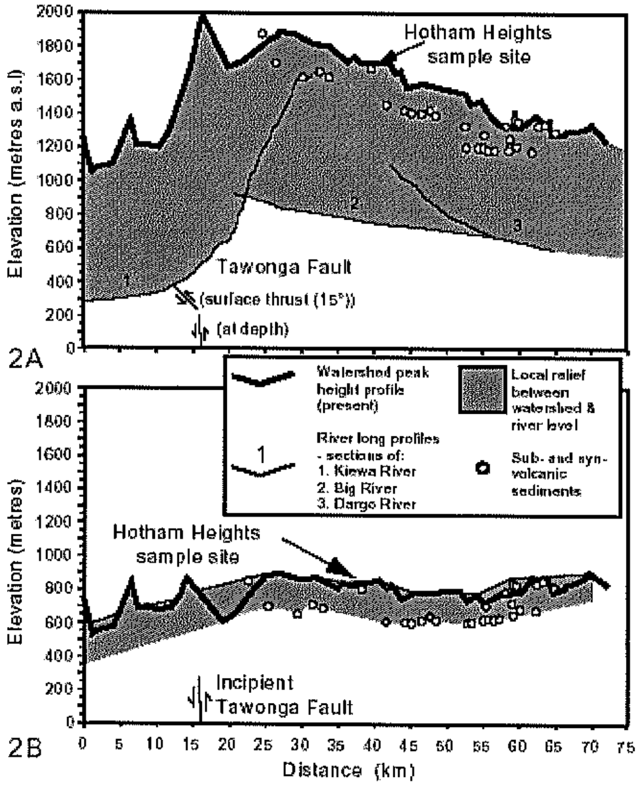


Fig. 16. Cross sections of: (A) present elevations across the Tawonga Fault in the High Plains; and (B) reconstructed Eocene elevations. Elevations are displayed in the form of peak height profiles and relief. Sub- and syn- volcanic sediments associated with the Paleogene Bogong Volcanics are shown. River distances in (A) are adjusted to correspond to transect distances. Surface thrust interpretation of the Tawonga Fault is based on Beavis (1960). Adapted from Orr (1999); from Greenwood et al. (in prep.).

case	RP MAT (°C)	ΔT°C / 1° latitude	RP MAT adjusted to HH latitude (°C)	MAT difference (RP - HH)	ΔT°C / 100 m	Z (m) – rounded to nearest 50m
1	16.3	0.47	18.7	0.7	0.58	150
2	20	0.47	22.1	4.1	0.58	800

***Table 1.** Calculations of the early Eocene palaeoelevation (Z) of Hotham Heights. Bioclimatic analysis and leaf physiognomy of sub-basaltic fossil plant material was used to determine mean annual temperature (MAT) of the two sites. Palaeoelevation was calculated, assuming a lapse rate of 0.58 °C / 100m, by the equation:* Paleoelevation = $(MAT_{SL} - MAT_{flora})$ / lapse rate + SL . *Regatta Point is 5.3 °S of Hotham Heights. From Greenwood et al. (in prep.).*

DUST ACCESSION TO ALPINE SOILS (Dickinson 2003)

In 2002 a series of dust storms deposited dust over snow in the Australian alpine area, including here at the Bogong High Plains. Two previous studies in the Australian Alps, by Walker and Costin (1971) and Johnston (2001), had collected dust samples from snow for comparison with local soil properties. Dickinson (2003) undertook an Honours project using similar methods to Johnston (2001). Dust was collected from snowpatches on the Bogong High Plains and nearby at Mt Loch (Figure 18) and the properties compared to those of soil profiles developed on basalt and organic matter-rich alluvium, and of alpine humus soils, on the Bogong High Plains (Dickinson 2003).

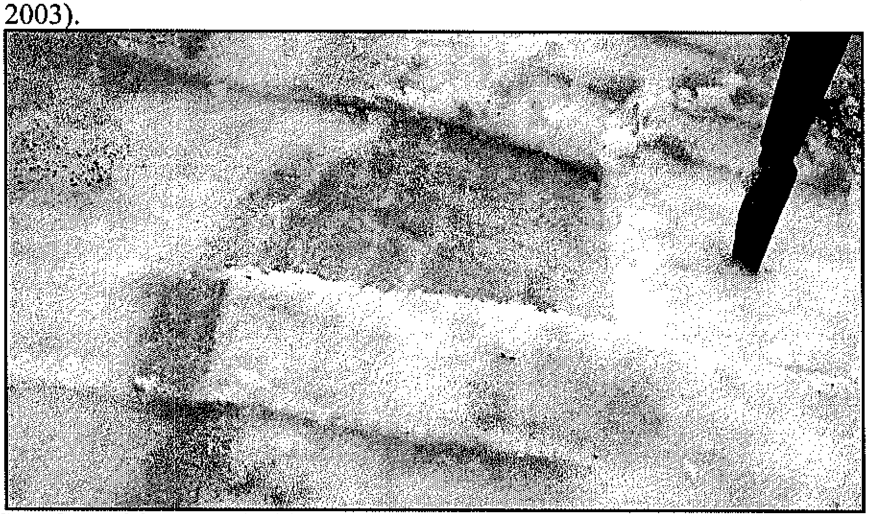
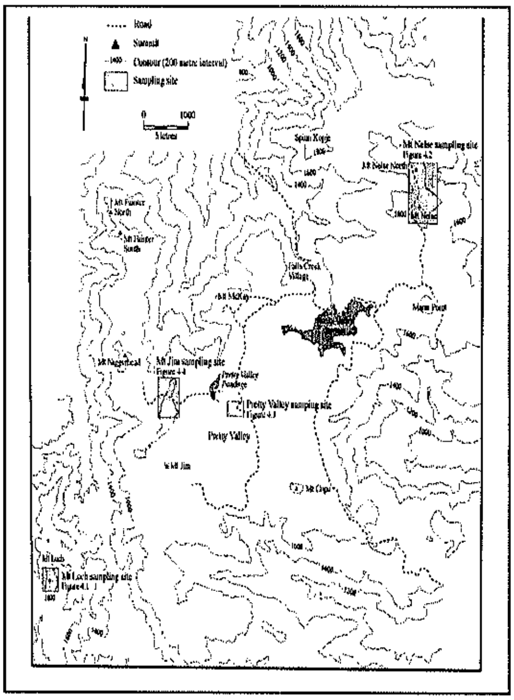


Figure 17. *Sampling of dust-enriched layers of snow from a snow patch at Mt Nelse North, Bogong High Plains, in November 2002 after a series of dust storm events. Photo by Meredith Orr.*

Composite samples were created from sampling of snow from dust-enriched layers collected at multiple points in snow patches from each of the Mt Nelse (Bogong High Plains) and Mt Loch sites. Snow was placed in clean plastic crates for melting and placed in cool storage. The melted snow was filtered to retain the dust component.

Particle size analysis of the dust samples by laser diffraction methods indicated bimodal diameters of around 13μm and 38μm. Exchangeable cation results are shown in Table 2.



Cation	Mt Nelse snow dust	Mt Loch snow dust
Al mg/kg	295.0	91.9
Ca mg/kg	662.6	571.4
Mn mg/kg	29.1	73.3
Fe mg/kg	22.9	12.8
Mg mg/kg	246.0	437.6
Na mg/kg	BDL	272.6
K mg/kg	329.8	246.0
Total mg/kg	1585.4	1705.5
OM %	13.3	10.9

Table 2. *Exchangeable cation contents of composite snow dust samples from Mt Nelse and Mt Loch, from Dickinson (2003).*

Figure 18 (left). *Study sites of Dickinson (2003). Stop 4 is at the Pretty Valley study sites.*

Soils were sampled here at Pretty Valley (Figure 19), Mt Jim and in the vicinity of the sampled snow patches. All but one of the profiles indicated clearly higher levels of exchangeable Ca and Mg in the surface soil relative to the subsurface (for an example profile see Figure 20). The possible contribution of dust towards those higher levels will be discussed at the site.

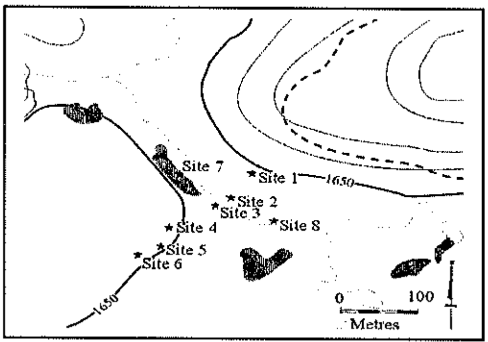


Figure 19. Location of soil sampling sites at Pretty Valley (Dickinson 2003).

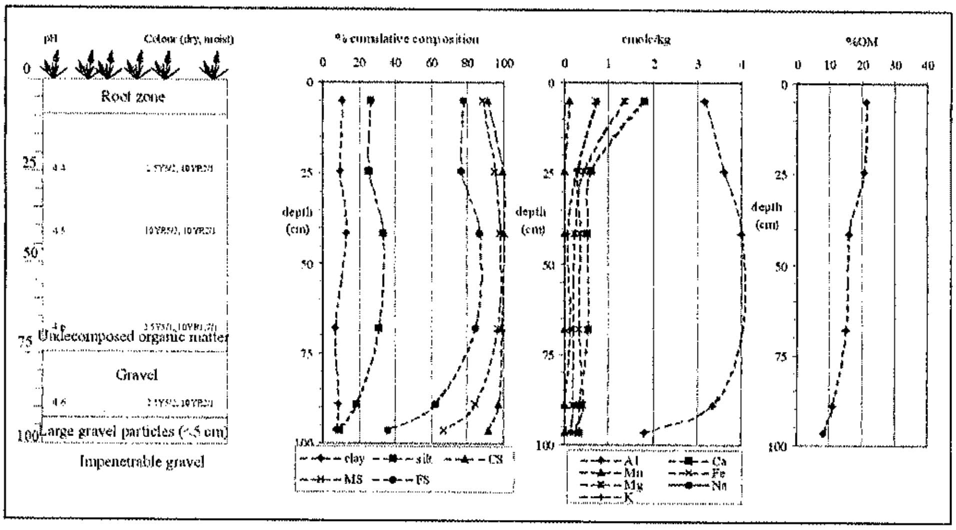


Figure 20. Results of analyses from an example soil profile (site 3) from Pretty Valley, Bogong High Plains. From Dickinson (2003).

Paper		OM (%)	Ca (cmol$_c$/kg)	Mg (cmol$_c$/kg)	K (cmol$_c$/kg)	Na (cmol$_c$/kg)	CEC (cmol$_c$/kg)
Costin *et al.* 1952	Surface		0.57	1.28	0.12	0.00	9.00
	Sub-surface		0.49	1.86	0.05	0.00	4.64
Costin *et al.* 1952	Surface		12.87	3.08	1.89	0.00	27.87
	Sub-surface		0.91	0.82	Trace	0.00	10.69
Johnston 2001 (alpine humus)	Surface	25.4	0.12	0.18	0.20	0.07	
	Sub-surface	2.2	0.04	0.15	0.03	0.09	
Johnston 2001 (snow patch meadow)	Surface	14.4	1.03	0.79	0.32	0.05	
	Sub-surface	3.2	0.05	0.30	0.05	0.04	
This paper (Pretty Valley alpine humus soil	Surface	21	1.91	1.24	0.77	*BDL	
	Sub-surface	14	0.38	0.24	0.14	BDL	
This paper (Pretty Valley alluvium, site 3)	Surface	21	1.80	1.35	0.73	BDL	
	Sub-surface	15	0.52	0.19	0.13	BDL	

Blank space indicates parameter not measured
*BDL indicates below detection limit

Table 3. Organic matter content and exchangeable cations of soils at Pretty Valley, Bogong High Plains, and other Australian alpine soils. From Dickinson (2003).

	No. quartz-like grains/mg soil	
Site	**Surface**	**Sub-surface**
10	153	10
11	219	29

***Table 4.** Amount of quartz-like grains in the <212 μm fraction of soil from Mt Jim, Bogong High Plains. From Dickinson (2003)*

STOP 5: TAWONGA REST AREA, KIEWA R. VALLEY

Murray Basin sediments occur at the base of the Kiewa River valley to the position of the Tawonga Fault (Beavis 1962, Lawrence 1988). Valley fill of the Kiewa River includes the Pliocene to Quaternary Shepparton and Coonambidgal Formations, which overlie Miocene Calivil Sands further downstream (Lawrence 1975).

Broad alluviated valleys have developed along both the Ovens and Kiewa Rivers. The alluvial surfaces are mostly between 320m and 480m a.s.l. Valley interfluves are 500m to 600m above the alluviated surfaces.

Quaternary stream incision into the alluvium produced a 4-fill 3-terrace system (Lawrence 1975, 1988) but did not cut below the base of the alluvial fill. The Ovens River valley at the Murray Basin margin has also a 4-fill 3-terrace alluvial base that has mostly not been incised below the alluvium.

Stream incision in the highlands generally continued through the Quaternary at the Gippsland Basin margin, on the other side of the continental divide, but here at the Murray Basin margin relief development was largely completed by the Pliocene. Highland valleys near the Murray Basin margin are as a result alluviated with Pliocene to Quaternary sediments from upstream, whereas highland valleys in the Gippsland Basin catchment lack significant alluvial fills.

The most likely explanation for this difference is that the Gippsland Basin transmitted more potential erosional events to the highlands than the Murray Basin. There are few identified stream incision causes in the Murray Basin, as fault magnitudes (such as from the Hindmarsh, Leaghur and Cadell Faults) are low and have favoured aggradation rather than incision. If late Cainozoic sea level changes did cause stream incision in the basin, its effects were not transmitted to the highlands, as no marginal stream incision occurred after the Pliocene.

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