



Discussion and Reply

Paleogene basalts prove early uplift of Victoria's Eastern Uplands

DISCUSSION

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We thank VandenBerg (2010) for continuing to add to the debate about the Eastern Highlands. There is much to commend about his paper, but we differ on the following points.

He has described a series of Paleogene age basalt infilled paleovalleys on the southern side of the Eastern Highlands. Through his detailed descriptions of these paleovalleys, he disagrees with Holdgate *et al.* (2008a) as to the existence of substantial post-basaltic uplift and shifting of the position of the drainage divide. His model is claimed to explain mostly pre-existing Paleogene highland relief, allocating most of this relief to the mid-Cretaceous. In his model, the paleovalleys have remained to this day as set by mid-Cretaceous altitudes and gradients. However, he ignores any paleovalleys other than the south-heading ones nearer to Gippsland (which in all but one case we would agree with as regards their paleodrainage directions). He does not consider the major issues raised by Holdgate *et al.* (2008a) on all the other Eastern Highlands paleovalleys such as the evidence for reversals of drainage directions, paleocurrent directions that are contradictory to their present disposition, and their low-energy sedimentary facies. It is also not clear whether available borehole data were included in his interpretation of the Toorijil–Aberthomson paleorivers. We also question the interpretation of aeromagnetic data concerning the paleodrainage direction for the Nunniong Plateau. Our findings on these two areas are detailed below.

Toorijil–Aberthomson paleorivers

VandenBerg (2010; figures 2, 3, 6) shows mapped and aeromagnetic views of two main basalt filled Eocene paleorivers heading south to Gippsland (the Toorijil

and Aberthomson). Both originate near the Eocene divide, due south of the present divide interpreted by Holdgate *et al.* (2008a). His Toorijil paleoriver flowed south to the Moe Swamp Basin and his Aberthomson flowed south to the Gippsland Basin. In cross-sections along the two flows, VandenBerg (2010) interprets pre-existing relief up to 600 m at Mt Toorong and the Baw Baw Dome, which are granitic/hornfels-based monadnocks outboard of the present divide, and therefore also likely to also be pre-existing Eocene relief and probably remnants of earlier (mid-Cretaceous?) highlands. However, he shows most pre-existing relief on cross-sections (his figure 7) to be less than 200 m, which agrees with Holdgate *et al.* (2008a), who demonstrated a similar 200 m average pre-existing relief for most of the Eocene paleovalleys of the Eastern Highlands. Holdgate *et al.* (2008a) emphasised (p. 228) that this paleorelief estimate increases to >450 m in the south flowing paleovalleys close to the Eocene divide such in the Aberthomson, Gelantipy–Buchan region—areas included in the VandenBerg (2010) interpretation. Therefore, both papers appear to be in general agreement on position and degree of pre-existing relief, but we would question that this proves pre-Eocene uplift of more than 600 m.

Two major issues arise from the use VandenBerg (2010) makes of base-of-flow downriver paleoprofiles and their comparison to modern lateral stream profiles. These are:

a. The base-of-basalt profiles determined by VandenBerg (2010) were derived from overlays of mapped and aeromagnetically defined basalts on 1:25 000 topographic base maps. These take no account of the actual paleovalley base where sub-basaltic sediments are in contact with basement, since this is generally hidden underneath the thickest areas of basalt paleovalley infill. Infills can often be readily determined from borehole data. The sediments are rarely exposed along lateral valley sides because the modern rivers preferentially erode the softer pre-existing paleovalley sides, and not the deeper paleovalley bases (Holdgate *et al.* 2008b). Consequently, it is rare to see the sub-basalt sediments exposed. The maximum paleovalley bases (demonstrated

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by such sediments) are only shown in one case for the Aberthomson on the profiles at Aberfeldy (VandenBerg 2010, figure 7).

We also show in our Figure 2 what happens if drilling data from Hunter (1909) are used to determine the true paleoriver depths. At Erica, detailed drilling for sub-basalt deep lead gold investigated the true base of the Aberthomson paleoriver—a site shown in VandenBerg (2010, figure 7b), where base-of-basalt is placed at ~420 m ASL and about 230 m above the adjacent lateral-Thomson River (Figure 1). The drilled transverse cross-section (Figure 2) shows that the actual lowest base-of-basalt-sediment from drilling at Erica can be up to 170 m lower than presented by VandenBerg (2010), or approximately 50 m above the base of the adjacent Thomson River. Also, two parallel paleorivers were

defined with very different river base levels, suggesting significant complications in local detail not shown on the VandenBerg (2010, figure 7) profiles (Holdgate *et al.* 2009). We show on Figure 1 interpreted faulting and steps on channel bases recording post-depositional tectonics that disrupt the simple pattern shown on the VandenBerg (2010, figure 7) profiles, and this also helps explain the sudden step-downs on the profiles, such as between Fingerboard Spur and Parkers Corner.

b. If the VandenBerg (2010) sections are extended into the basins using drilling data (Figure 1), the modern stream profiles (the lateral streams) do not emulate the profiles for Toorojil and Aberthomson paleovalleys as shown by VandenBerg (2010). For example, borehole data show that the Toorojil paleovalley extends to -396 m (below present sea-level) (Fraser 1982; Holdgate

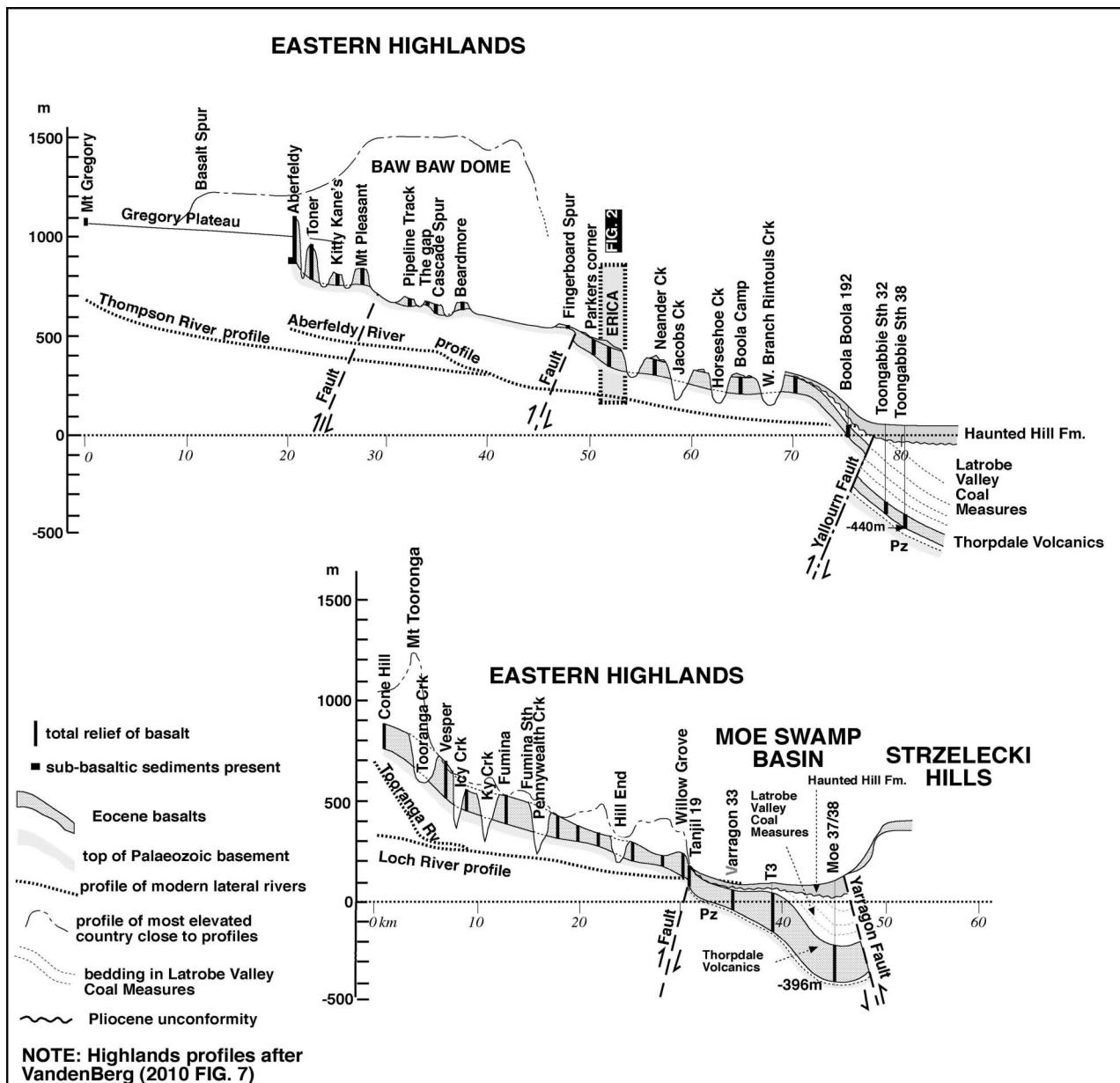
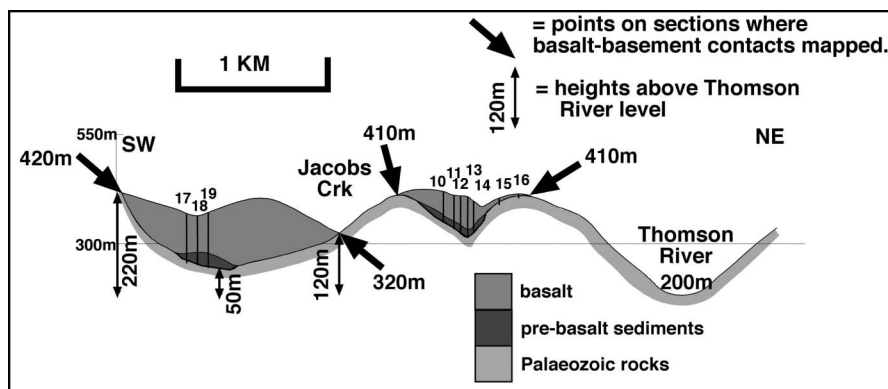


Figure 1 Cross-sections modified from VandenBerg (2010, figure 7) showing extensions of profiles into the adjacent basins from borehole data, and the location of the sub-basalt profile highlighted in the Erica area in Figure 2.

Figure 2 Borehole cross-section across basalts at the Erica location shown in Figure 1 (modified from Hunter 1909; Holdgate *et al.* 2009). Heavy arrows show key base-of-basalt points available to outcrop studies alone. Borehole measurements show depths of the true paleovalley bases relative to the Thomson River valley along the section line.



1985) and the Aberthomson paleovalley extends to –440 m (below present sea-level) into the Gippsland Basin (GeoScience Victoria bore database) diverging from modern stream profiles. This takes them into the basin sedimentary sequence considerably below the present sea-level and in the process crosses, then diverges from, the modern stream profiles. This divergence commences around significant basin margin reverse faults such as the Yallourn Monocline/Fault (Dickinson *et al.* 2002), where at least 100 m of offset is present in post-Eocene basalt and coal seams. This suggests that the basins have subsided at least 400 m since the Eocene. It is also likely that the reverse fault movements have elevated the highlands at the same time, because the Eocene paleovalleys could not have extended below Eocene sea-levels.

The angular unconformity between the Latrobe Valley Coal Measures and the Haunted Hill Formation (Figure 1) indicates considerable uplift and stripping of the pre-Pliocene section on the upthrown side of the Yallourn Fault, as substantiated by the existence of perched Oligocene coal measures on the Moondarra Platform (Gloe 1960) and the angular unconformity between Latrobe Coal Measures and Haunted Hill Formation. Gloe (1960) documents extensions of the Latrobe Valley Coal Measures as far north as the Thomson dam, i.e. a position on our Figure 1 between Parkers Corner and Fingerboard Spur at present elevations of up to 550 m—a height unlikely to be their original altitude considering the same coal seam in the Latrobe Valley extends to over 400 m below present sea-level.

Nunniong Plains

VandenBerg (2010, figure 11) shows basalt outcrops at Bald Hills, The Springs and several other localities along strike to the north and south. However, he did not include the basalt outcrops of the Nunniong Plateau in the southwest corner of his figure 11. All of these localities can be seen on a magnetic image (Figure 3) to show in greater detail in Holdgate *et al.* (2008a, figure 5a). Holdgate *et al.* (2008a, b) used the aeromagnetic patterns shown on Figure 3 for basalts across the Nunniong Plains to interpret a NNW flowing paleodrainage. On the Nunniong Plains, there are two main areas

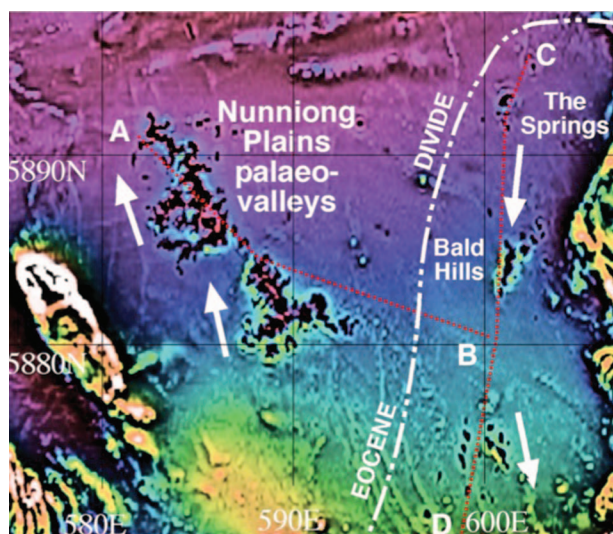


Figure 3 Aeromagnetic imagery of part figure 5a (Holdgate *et al.* 2008a). Proposed directions in paleovalley flows by Holdgate *et al.* (2008a) are shown by broad white arrows, and the approximate position for the Eocene divide is indicated. The VandenBerg (2010; figure 12a) cross-sections are indicated as dotted red lines (A–B; C–D). Making the Nunniong Plateau paleovalleys (A–B) tributaries to the Bald Hills (C–D) paleovalley (as shown by VandenBerg (2010; figures 9, 10, 12) is at odds to the paleoflow directions proposed on this figure.

of strong magnetic responses above a less magnetic basement. These two areas coincide with the two main areas of basalt outcrop centred around the more northerly Nunniong Plains and the more southerly Nunnett Plains (also shown on VandenBerg's 2010, figure 10). The aeromagnetic image shows a bifurcation to the south that we interpret to represent two NNW-trending paleovalley tributaries that merge downstream. Therefore, in the absence of sub-basaltic evidence (we found no outcrop of sediments here), we concluded that the main valley had a NNW trend consistent with tributaries and trends of the paleovalley under the Nunniong Plateau.

It is important to note that in the present landscape the two plateaus are separated by a deep valley carved by the Timbarra River and are now tilted south. The northerly trend of this paleovalley is suggested to reflect

a divide to the southeast before 33.9 Ma and 37.6 Ma, using the uncorrected K/Ar age of the basalt that infills this paleovalley (Wellman 1974). Holdgate *et al.* (2008a, b) placed a paleodivide between these outcrops and the basalts at Bald Hills and The Springs (although this locality was not included in summary figure 9 of Holdgate *et al.* (2008a).

Holdgate *et al.* (2008a, 2009) show the Bald Hills and other aligned N–S basalts to be part of a southerly paleodrainage direction and so agree with VandenBerg (2010) on the Bald Hills paleodrainage direction. However, we disagree with the linking of the Bald Hills to the Nunniong Plateau as shown by VandenBerg (2010) in outcrop (his figure 10) and cross-section (his figure 12a). We interpret the two paleodrainages as two distinctly different river systems on the basis of paleodrainage directions, paleogradients, paleolevels and positions on different sides of the Eocene divide. This can be seen on the profiles shown in VandenBerg's (2010) figure 12a, where very different gradients and levels occur between the measured Nunniong sites and the Bald Hills tributary. As argued by Holdgate *et al.* (2008a, b), the divide has moved northwards some 15 km from an Eocene location southeast of the Nunniong Plateau to where it is today. This has left the Nunniong Plateau south of the present divide. A similar use of aeromagnetic imagery of basalt filled paleovalleys resulted in Nelson *et al.* (2010) describing a similar phenomenon in North Queensland, where he interpreted the divide to have moved westerly some 10 km in the last 1.79 Ma. In conclusion, we believe the Nunniong Plateau and Bald Hills paleodrainages cannot be joined as shown in VandenBerg (2010, figure 12).

OTHER COMMENTS ON VANDENBERG (2010)

The connection between the Basalt Hill–Mt Gregory and Aberthomson VandenBerg (2010, figures 2, 3, 6) requires a right-angled bend, which appears to contradict the SSE aeromagnetic trends from Basalt Hill shown on his figure 6. If his interpretation is correct, why is no connection made to the large areas of basalt and subbasaltic gravels to the northeast at Mt Useful and Connors Plain? The statement by VandenBerg (2010, p. 297) of the 'presumably Oligocene fluvial plain south of Willow Grove' is incorrect. Holdgate (1985) demonstrated from drilling that the Moe Swamp Basin immediately south of Willow Grove is underlain by Pliocene Haunted Hill Formation unconformably overlying Middle Miocene coal seams and 19–26 Ma basalts (Fraser 1982) of the Thorpdale Volcanics to a depth of over 400 m (as shown on Figure 1, lower profile). It is not clear how VandenBerg (2010, figure 14) produced the base-of-basalt contours south from Gelantipy using two isolated sub-basalt outcrops, and showed the detailed subsurface geometry of this Paleocene valley constructed without using bore hole data.

It is also not clear how VandenBerg (2010, p. 311) obtained a Miocene age for the high-level gravels between Bruthen and Buchan. VandenBerg (2010, figure 15) uses sedimentation rates from the Bernecker & Partridge (2001) model to prove mid-Cretaceous highlands

as a source of sediment supply to the Gippsland Basin. However, we argue that the diminished sedimentation rates during the Eocene–Oligocene reflect the total denudation of these mid-Cretaceous highlands by this time, yielding mid-Cretaceous apatite fission track cooling ages, and the preferential sediment supply was directed to the Murray Basin (Holdgate *et al.* 2008a). We note that the post-Eocene renewal of highlands uplift, and consequently of sediment supply, produced the increase in sedimentation into Gippsland in the Miocene and Pliocene. As explained by Holdgate *et al.* (2008a, p. 229) a northwards shift in the divide provides a means for the south-directed modern rivers (such as the Macalister, Wonnangatta and Tambo) to extend their catchments northwards. In many examples they have cut gorges through the old divide position and captured north-flowing rivers at boathook bends. Such a situation also occurs with the upper Yarra catchment and its northward projections being blocked by a rising present-day divide.

We conclude that, contrary to a newly 'proven' position, VandenBerg (2010) has carefully documented some features of the southern margin Eastern Highlands paleovalleys where his positions and paleoflow directions broadly agree with our previously published paleoflow directions. However, he has not addressed the whole story of the Eastern Highlands paleovalleys as documented by Holdgate *et al.* (2008a).

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