A review of current research into the timing and evolution of the northern Sydney Plain and the Lapstone Structural Complex.

By Richard Miller for the Amateur Geological Society of the Hunter Valley 2020

Abstract

In the last two decades significant advances have been made in explaining the geomorphology of the Sydney Basin and, in particular, the Blue Mountains and Sydney Plain. This paper outlines these discoveries and is largely based on the work of Lewis Carter (2011) and P.J. Hatherly (2020).

The formation of the landform block containing the Blue Mountains Plateau, the Lapstone Structural Complex (LSC) on its eastern side, the Hornsby Plateau to the North/East of the latter, and the alluvial terraces associated with the Hawkesbury River, have been the subject of much debate. Most research has focused on the formation of the dominant feature, the LSC, but as Carter has indicated, the most significant feature in an explanation of the geomorphology is the formation and timing of the Hornsby Warp.

At the end of the Triassic (Ca 200 Ma) a basin that had been formed between the high lands of the Lachlan Orogen (LO) in the West and the New England Orogen (NEO) in the East, was undergoing extension. This was the result of retreat in the subduction zone associated with the NEO. The basin was subsequently covered with layers of Hawkesbury Sandstone and they were topped by the rocks of the Wianamatta Group.

In the area north west of Sydney, four events appear to have re-shaped the Basin. The first was a widespread uplift that occurred about 130-80 Ma and helped form much of the Great Dividing Range (Mueller 2016). The area uplifted would have been at some, but an undetermined distance, from the LSC. It was probably the result of the Australian plate moving North over mantle hot spots.

Carter believes that the uplift of the Hornsby Plateau began sometime around 55 and 45 Ma and was a result of under-plating associated with the break-up of the Tasman Sea. The lack of deformation in the structure of the Plateau, apart from the slight southerly dip, supports this.

Hatherly suggests that, following this event, a more localised uplift began in the eastern highlands. He says this process was widespread along the East Coast and that it was progressively younger towards the South. In the Blue Mountains it occurred at about 30 Ma and was probably also the result of passage over a hot spot. This event led to the development of large knick points on the Wollondilly, Coxs and Kowmung Rivers that drain the area. These are similar to those on the Shoalhaven River and other rivers that flow from the eastern highlands. Since then these knick points have retreated a considerable distance into the raised area.

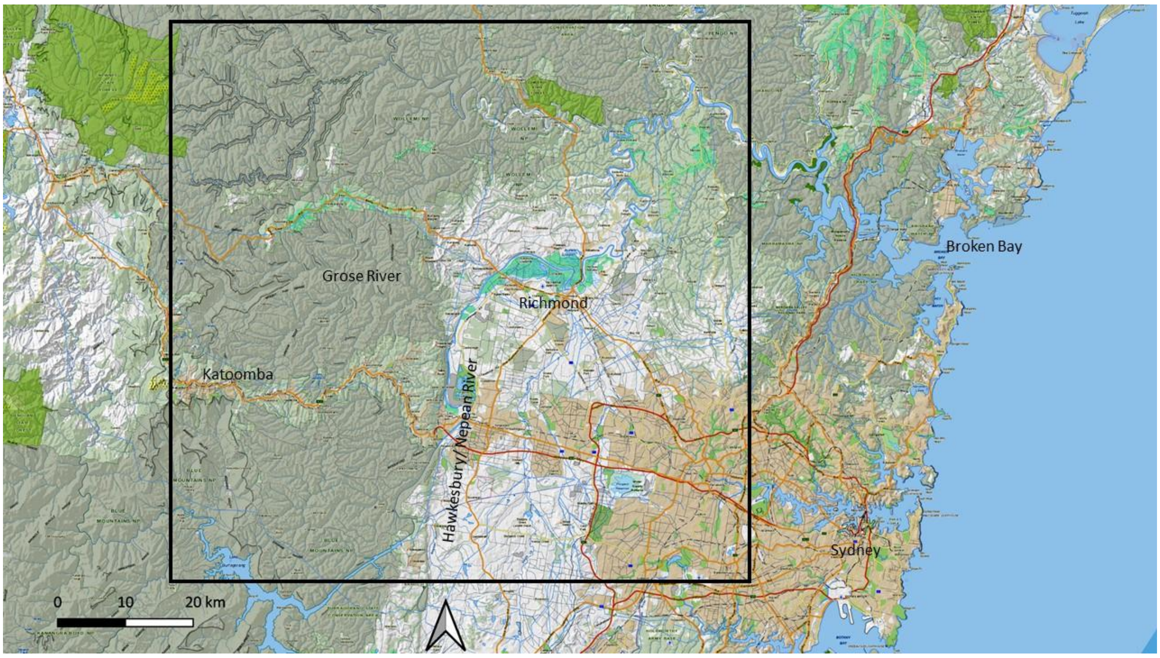
At approximately 10-5 Ma a further uplift produced the Lapstone Structural Complex (LSC).

Prior to uplift of the LSC the paleo Hawkesbury/Nepean River was dammed by the uplift of the Hornsby Warp, creating a large lake. It was able to overtop this and continue to the sea. Since then it has deposited and reworked its sediments to create a series of alluvial terraces and form the landforms of the current northern Sydney Plain.

Within the last 40000 years there have been movements on the faults associated with the LSC.

Introduction

The Sydney Basin is part of a larger landform unit, the Sydney-Bowen Basin, which extends for over 1,500 km from Bowen in Queensland, through Gunnedah, to the area around Sydney in NSW. It was formed by extension in the Early Permian. Initially half grabens were developed and they were then infilled with sediment from the New England Orogen in the East and The Lachlan Orogen in the West.



Map 1. The rectangle in Map 1 shows the area involved in this review. It lies to the North West of Sydney, NSW and includes the northern section of the Sydney Plain, sections of the Blue Mountains and the Hornsby Plateau

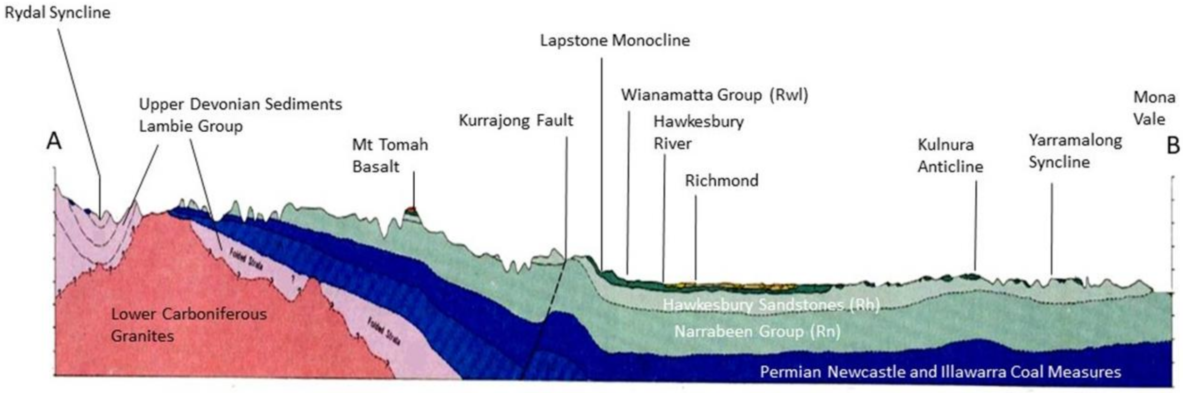
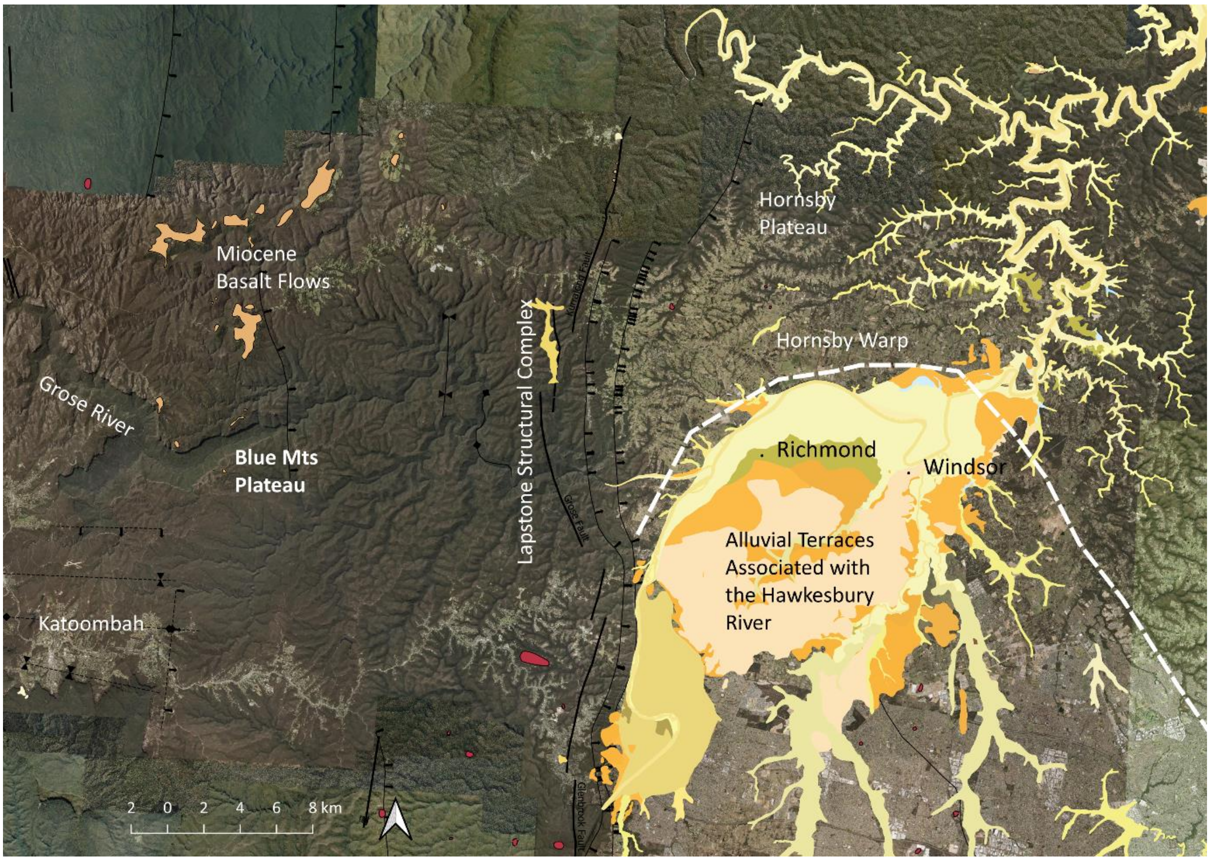


Figure 1. A West – East cross-section through Lapstone Structural Complex and the northern Sydney Plain. VE approx. 8.5.

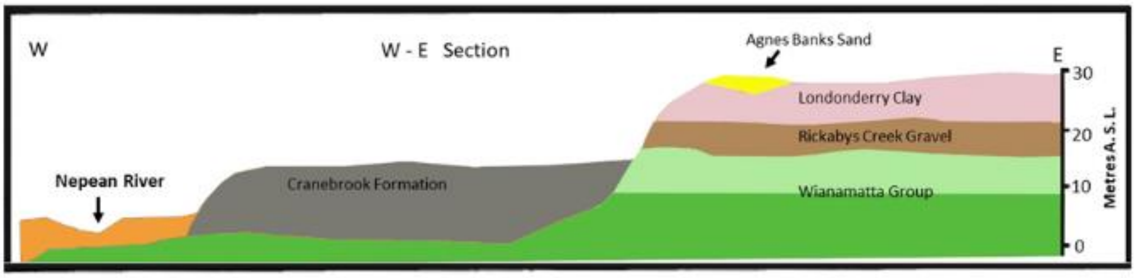
The Lapstone Structural Complex involves a series of westward dipping faults and a monoclinal fold (the Lapstone Monocline); these are shown in Figure 1 and Map 2. In the North and East the land has been raised to form the Hornsby Plateau, leaving between them, a basin occupied by the Hawkesbury River. It is this basin that I have termed the Northern Sydney Plain (NSP).



Map 2. An overview of the main landform units in the study area

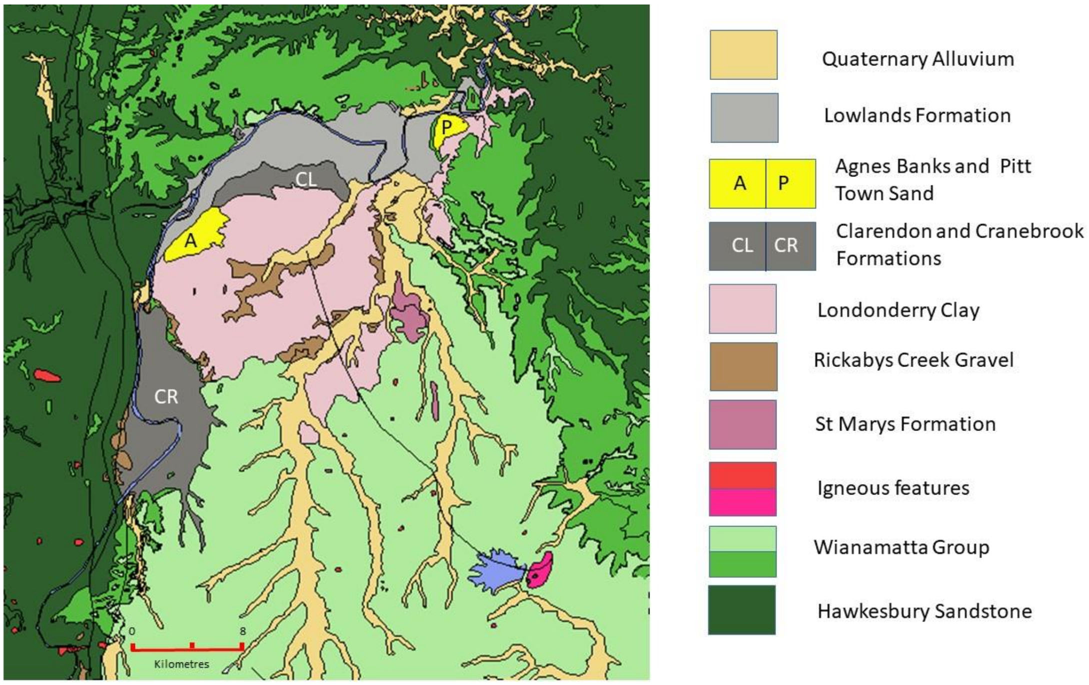
There are six major geological units in the area, the Hawkesbury Sandstone, the Wianamatta Group, the Rickabys Creek Gravel, the Londonderry Clay, Quaternary sediments and the Miocene Basalt Flows (Map 3). An explanation of the current geomorphology requires knowledge of the timing and mode of formation of each unit.

Figure 2 shows a stylised cross-section in the NSP. The Wianamatta Group and Hawkesbury Sandstone are the underlying strata. These are covered by the Rickabys Creek Gravels and they are then overlayed by Londonderry Clay. Since their deposition, the last two units have been reworked in many places by the Hawkesbury River and this has formed a current floodplain and two terraces. The latter are the Cranebrook and Clarendon terraces; probably formed synchronously.



Based on the nomenclature and classification by the Geological Survey of NSW in Quarterly Survey Notes 32

Figure 2. A stylised cross-section of the alluvial terraces in the NSP. The Cranebrook Formation, in the area near Penrith, is coeval with the Clarendon Formation near Richmond. Beside the channel of the Hawkesbury/Nepean River is the current floodplain (Lowlands Formation).



Map 3. Compiled from the Penrith 1:100,000 Sheet this map shows the distribution of the major geological units in the NSP.

The Agnes Banks and Pitt Town Sand beds are Aeolian and associated with the Rickabys Creek Gravels. The river that deposited the gravels had a braided form and was the source of the sand.

Geomorphology

Four events appear to have shaped the geomorphology of the NSP and its surrounds. The first was a widespread uplift that occurred about 130-80 Ma and helped form much of the Great Dividing Range (Mueller 2016). The area uplifted would have been at some, but an undetermined distance, from the LSC and it was probably the result of northward movement of the Australian plate over mantle hot spots.

The second was the uplift of the Hornsby Plateau. This today forms a semi-circular area of high land across the direction of flow in the present Hawkesbury/Nepean River and its location can be seen in Map 2. This uplift dammed the river and formed a large lake. During periods of heavy rain this lake is partly recreated. The biggest flood in European memory was that of 1867 (Map 6).

Carter (2011) suggests that, as there is no evidence of significant deformation in the strata of the Hornsby Plateau and that it has a slight slope down to its edge on the Hornsby Warp, it was formed by uplift rather than compression. He attributes this uplift to passage over another hot spot.

Photo 1. From Grose Vale Rd, Nth Richmond and looking across part of the Hornsby Plateau to the LSC and Kurrajong Heights. The land in the foreground was the original site for the demonstration of the world renowned "Keyline Farming" technique.

For his timing of the uplift of the Plateau relative to the LSC, Carter relies on his study of boreholes that have been drilled extensively throughout the area and stored by NSW Government Agencies. The distribution of both the Londonderry Clay and Rickabys Creek Gravel are pivotal for him in understanding the development time line of the current landforms.

There is general consensus that the Rickabys Creek Gravels (Photo 2) were deposited by a paleo Hawkesbury-Nepean River flowing out of the Lachlan Orogen and towards the North East and the sea. The river was braided in form and its load of gravels were deposited over a wide area. Present deposits are found over a width of approximately 16km.

It flowed over a surface with a slight slope downwards towards the North East and in a similar course to the present Hawkesbury-Nepean. By examining borehole data Carter found that the deposits of gravel declined in thickness towards the Hornsby Warp and both Carter and Hatherly found deposits of the gravels on and near the edge of the LSC. Neither, however, found deposits that were more than two kilometres to the West of its present edge.

The gravel deposits are overlain by Londonderry Clay (Photo 3). Carter found that these deposits began on the edge of the Hornsby Warp and decreased in thickness away from it, to the South.

Photo 2. A deposit of the Rickabys Creek Gravels near Londonderry.

Photo 3. A deposit of the Londonderry Clay at Windsor. Laterisation has produced the lower indurated horizon.

Carter concluded that the deposition of the Londonderry Clay had been initiated by the uplift at the Hornsby Warp. The paleo Hawkesbury River was dammed by the uplift and a large lake formed against the Warp. The river was no longer able to carry its load of gravels and the clays were then deposited in the slack water of the lake. The process is shown in Figure 3.

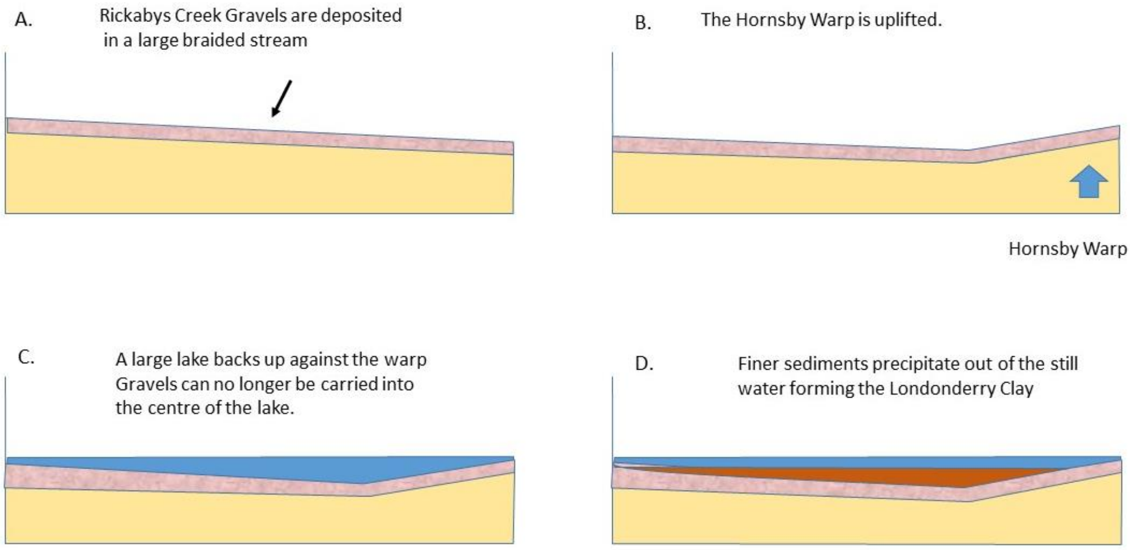
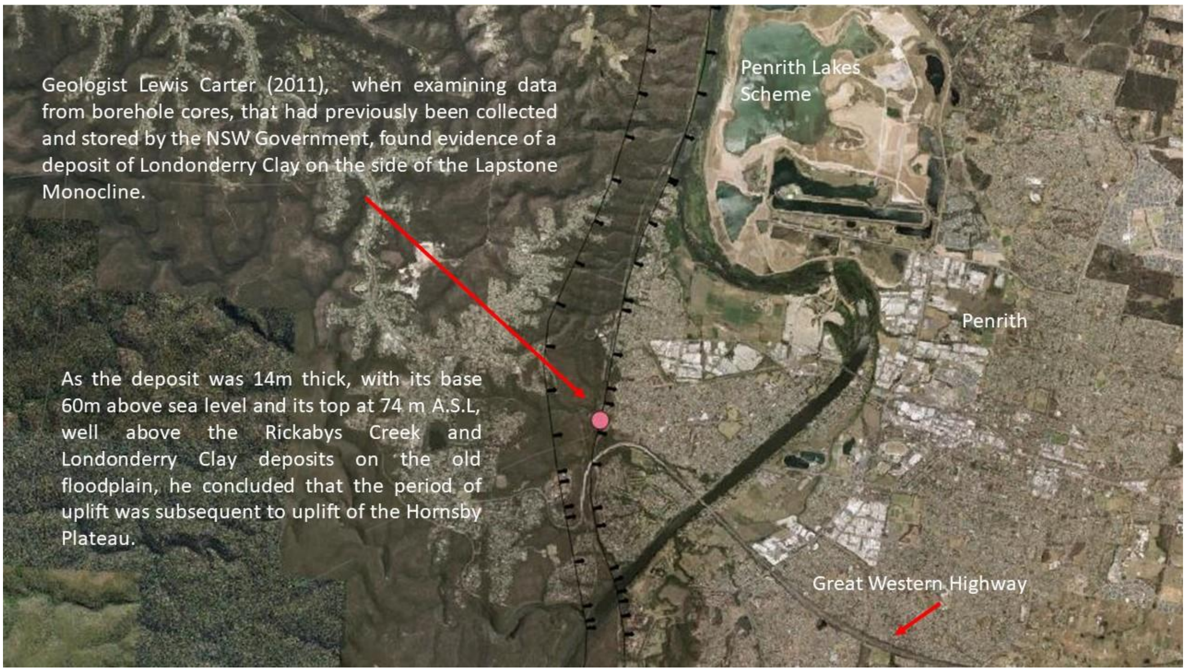


Figure 3. Stages in the formation of the Londonderry Clays.

While no deposits of the Londonderry Clays have been found on the Hornsby Plateau, Carter found deposits of both gravels and clay on the edge of the Lapstone Structural Complex. This was significant as previous geologists had not found the Londonderry Clay on any part of the LSC.



Geologist Lewis Carter (2011), when examining data from borehole cores, that had previously been collected and stored by the NSW Government, found evidence of a deposit of Londonderry Clay on the side of the Lapstone Monocline.

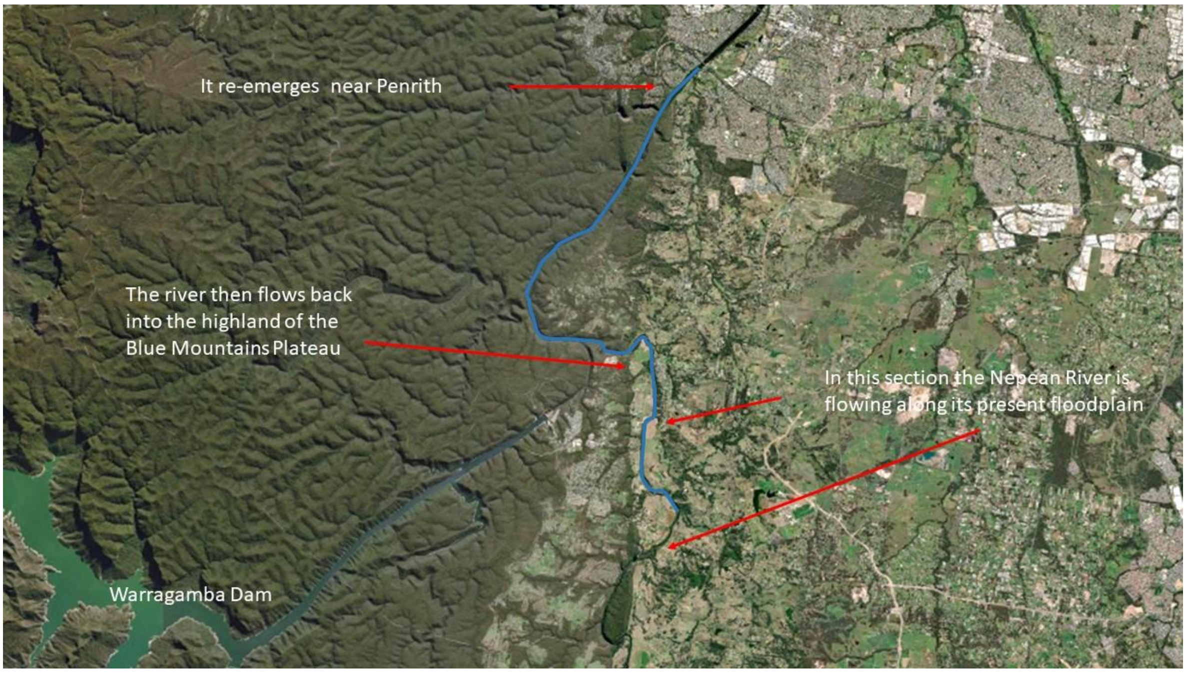
As the deposit was 14m thick, with its base 60m above sea level and its top at 74 m A.S.L, well above the Rickabys Creek and Londonderry Clay deposits on the old floodplain, he concluded that the period of uplift was subsequent to uplift of the Hornsby Plateau.

Map 3. Location of deposit of Londonderry Clay in the Lapstone Structural Complex

Carter's conclusion is that the formation of the LSC post-dated the deposition of both the Rickabys Creek Gravels and the Londonderry Clay.

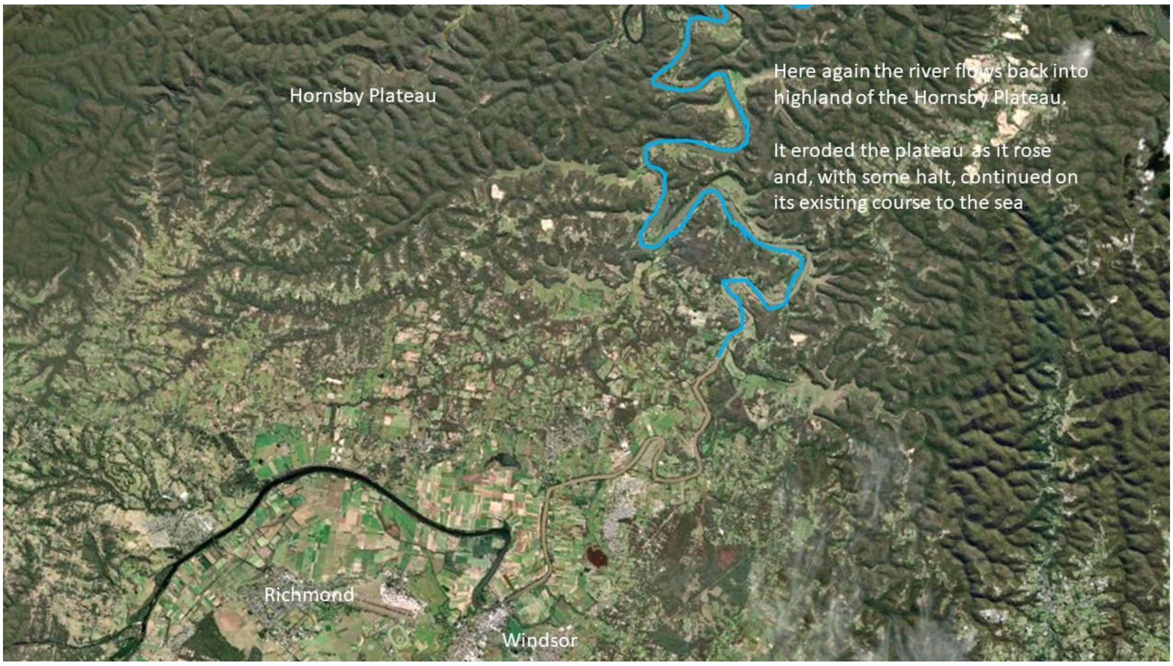
The uplift of the LSC appears to have been very slow. Evidence for this is found on the LSC near Penrith (see Map 3). The river flows from its floodplain back into the LSC, through what is called the Fairlight Gorge and then back onto the plain near Penrith (Map 4). This process is repeated in the Gulguer Gorge near Bents Basin.

The Hawkesbury Nepean also flows back into and through the higher land of the Hornsby Plateau (Map 5). The steep gorges it has eroded through the Hornsby Plateau suggest that the river was able to overtop the uplift and then continue its course to the sea; eventually draining the dammed area.



Map 4. The Nepean River flows on the eastern side of the LSC before turning back into it and flowing through the Fairlight Gorge. It re-enters the plain near Penrith.

In the present, however, this is not always the case and after periods of heavy rain, part of the basin is still flooded. It often takes weeks to fully drain and a layer of silt covers the turf farms and fields on the Lowlands. Map 6 shows the extent of the 1867 flood.

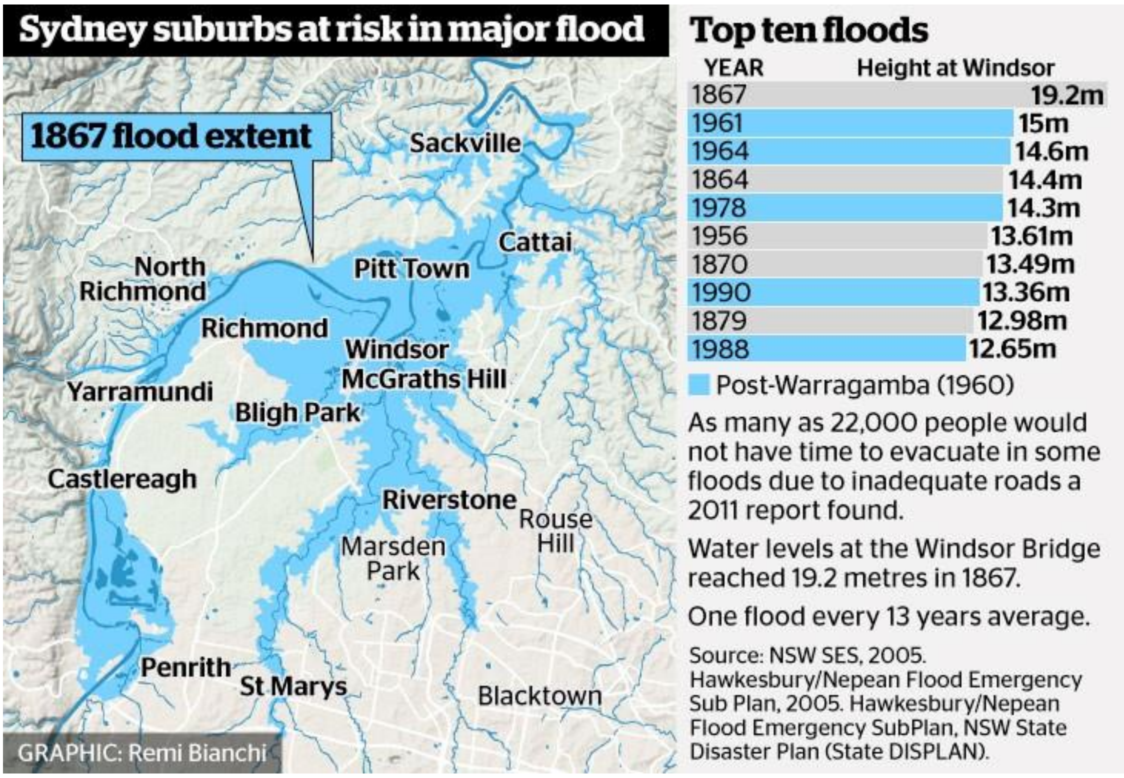


Here again the river flows back into highland of the Hornsby Plateau.

It eroded the plateau as it rose and, with some halt, continued on its existing course to the sea

Map 5. The Hawkesbury River continues into the highland to the North of Windsor.

Carter was unable to give a firm date for the uplift of the Hornsby Warp and in comparison to the more prominent LSC, very little effort has been made by geologists in studying it. He did, however, give a minimum date based on research by (Graham et al. 2010).



Top ten floods

YEAR	Height at Windsor
1867	19.2m
1961	15m
1964	14.6m
1864	14.4m
1978	14.3m
1956	13.61m
1870	13.49m
1990	13.36m
1879	12.98m
1988	12.65m

🟦 Post-Warragamba (1960)

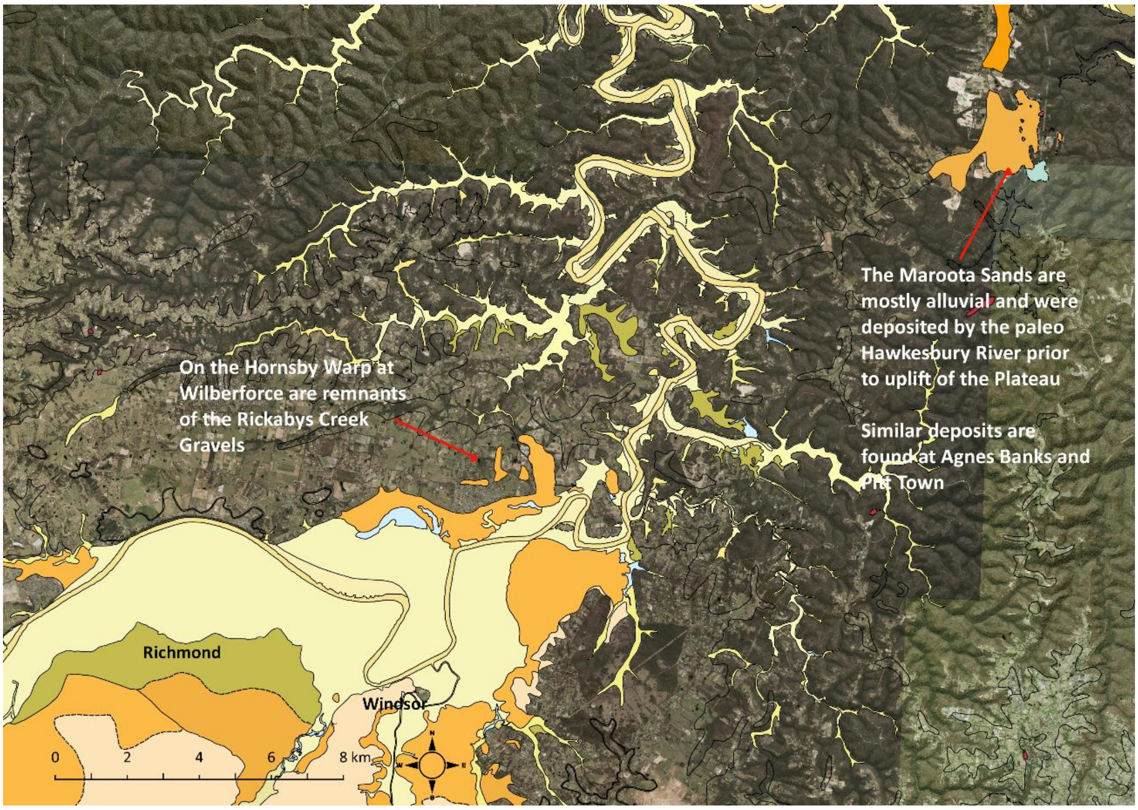
As many as 22,000 people would not have time to evacuate in some floods due to inadequate roads a 2011 report found.

Water levels at the Windsor Bridge reached 19.2 metres in 1867.

One flood every 13 years average.

Source: NSW SES, 2005. Hawkesbury/Nepean Flood Emergency Sub Plan, 2005. Hawkesbury/Nepean Flood Emergency SubPlan, NSW State Disaster Plan (State DISPLAN).

Map 6. Flood Map for 1867

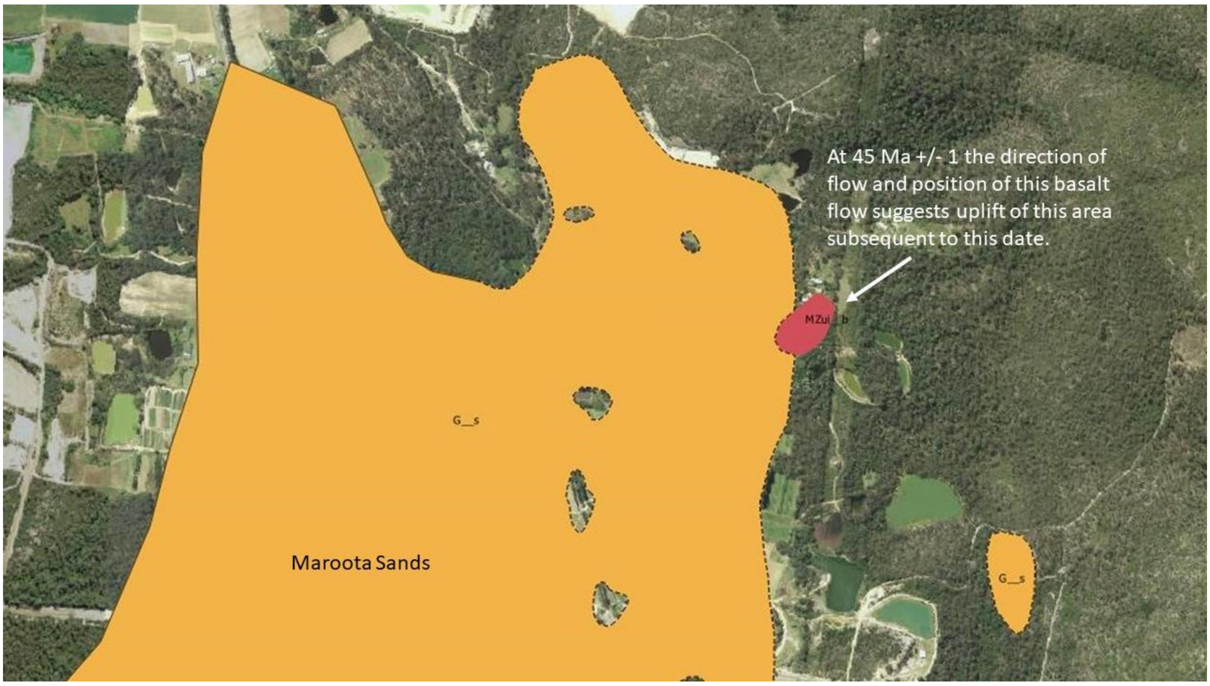


Map 7. The location of deposits of Rickabys Creek Gravels near the village of Wilberforce are shown here. The Maroota Sand Beds are shown on the Hornsby Plateau.

On the uplifted Hornsby Plateau is an aeolian deposit of sand (the Maroota Sands) that is associated with reworking of deposition by the braided paleo-Hawkesbury River. Similar deposits are also found in the terraces of the present basin near Agnes Banks and Pitt Town. Graham found a small area of basalt had flowed onto the Maroota Sands in an orientation prior to uplift. It was dated at 45 Ma +- 1 and this suggests that the uplift of the Warp is after this time or was beginning.

Based on this Carter believes that the uplift of the Hornsby Plateau began sometime between 55 and 45 Ma and was a result of under-plating associated with the break-up of the Tasman Sea. As stated before, apart from the slight southerly dip, the lack of deformation in the structure of the Plateau supports this and it is also supported by Och et al (2009) whose research on fault gouges in the Plateau supports widespread igneous intrusions at this time.

The form and altitude of the land to the West of the LSC, prior to and during this uplift, is not clear. It must have had low relief and been relatively level with the plain as the Paleo Hawkesbury Nepean was able to deposit both gravels and clay in the area within 2km of its eastern edge.



At 45 Ma +/- 1 the direction of flow and position of this basalt flow suggests uplift of this area subsequent to this date.

Map 8. A small basalt flow has overlain part of the sand beds. Its orientation is consistent with the flow occurring after the uplift of the warp.

Recent research by PJ Hatherly (2020) helps to explain the subsequent development of the LSC and Blue Mountains Plateau. His research involved the study of longitudinal river profiles (thalwegs) of the rivers and streams in the Blue Mountains and also of the widespread basalt flows in the area.

Overtime geomorphologists have found that streams with dendritic drainage, such as those in the Blue Mountains, will wear their beds down to base level and produce a concave longitudinal profile (thalweg). Continued erosion will move this profile back into the land of the headwaters. Concave profiles are termed as being Mature.

An instantaneous uplift of land in the stream course, such as that shown in Figure 4a, will cause the stream’s velocity to increase at the change of slope (known as a Knick point). It will then erode its bed until it resumes a concave profile. At this time its capacity to do work is even throughout its profile. Capacity to erode is provided by a combination of slope and discharge.

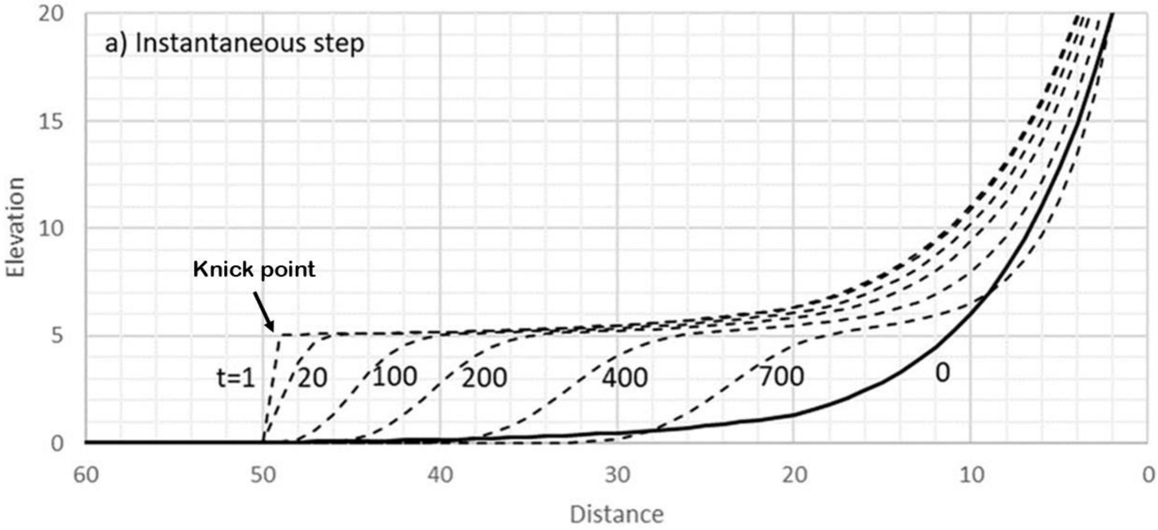


Figure 4a. Hatherly produces this diagram and figures 3b and 3c to explain the effect of uplift on the thalweg of a stream.

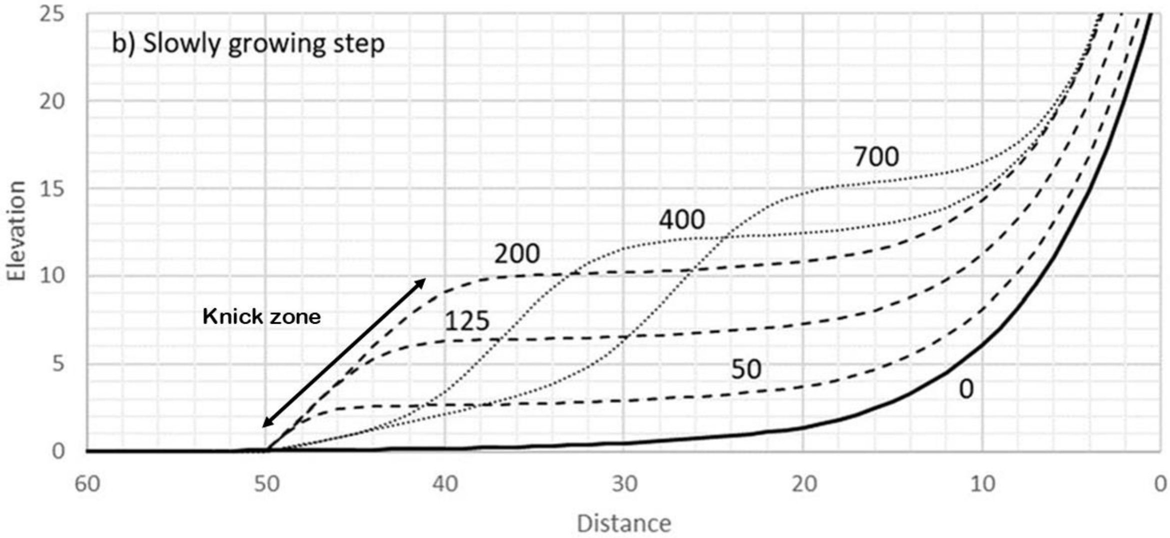


Figure 4b. With a slowly rising block the thalweg will not be able to free itself from the edge of the rising block

If the uplift is slow and occurs over a significant period, the stream profile will be locked onto the boundary of the rising block and erosion will produce a long knick zone, as seen in Figure 4b. If the uplift ceases, then over time the stream will return to a concave profile over its length.

In Figure 4c Hatherly simulates the progressive rise of an asymmetrical Horst block. At first the water from the stream will pool behind the Horst until it is able to overtop it and then erode a channel. This process is that proposed by Carter for the Warp.

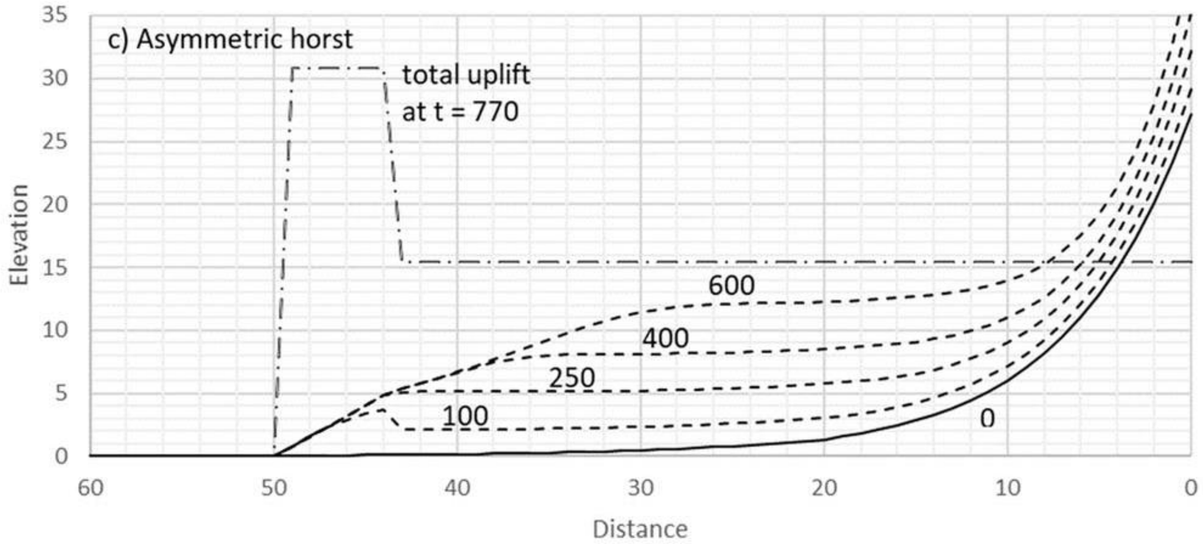


Figure 4c. A simulation of a slowly rising asymmetric horst block

Hatherly has examined the thalwegs of the rivers that appear to be antecedent to the uplift of the LSC. Both Hatherly and van der Beek (2016) suggest that the profiles of many of the antecedent streams in the Blue Mountains Plateau have remnants of a concave profile in their upper reaches but that in their lower sections the profiles are convex and pinned to the LSC. Van der Beek suggests that these concave sections are consistent with a relief, prior to the uplift of the LSC, of about 200m above the level of the paleo Hawkesbury River. Importantly Hatherly provides evidence that excludes variations in lithology as causes of these long term knick points.

Hatherly produced Figure 5 to show the profiles of the streams in the Blue Mountains

He says that the characteristics of these profiles can be explained by the following eight scenarios and that the scenarios are all related to a process where the LSC forms on the edge of an area with existing relief.

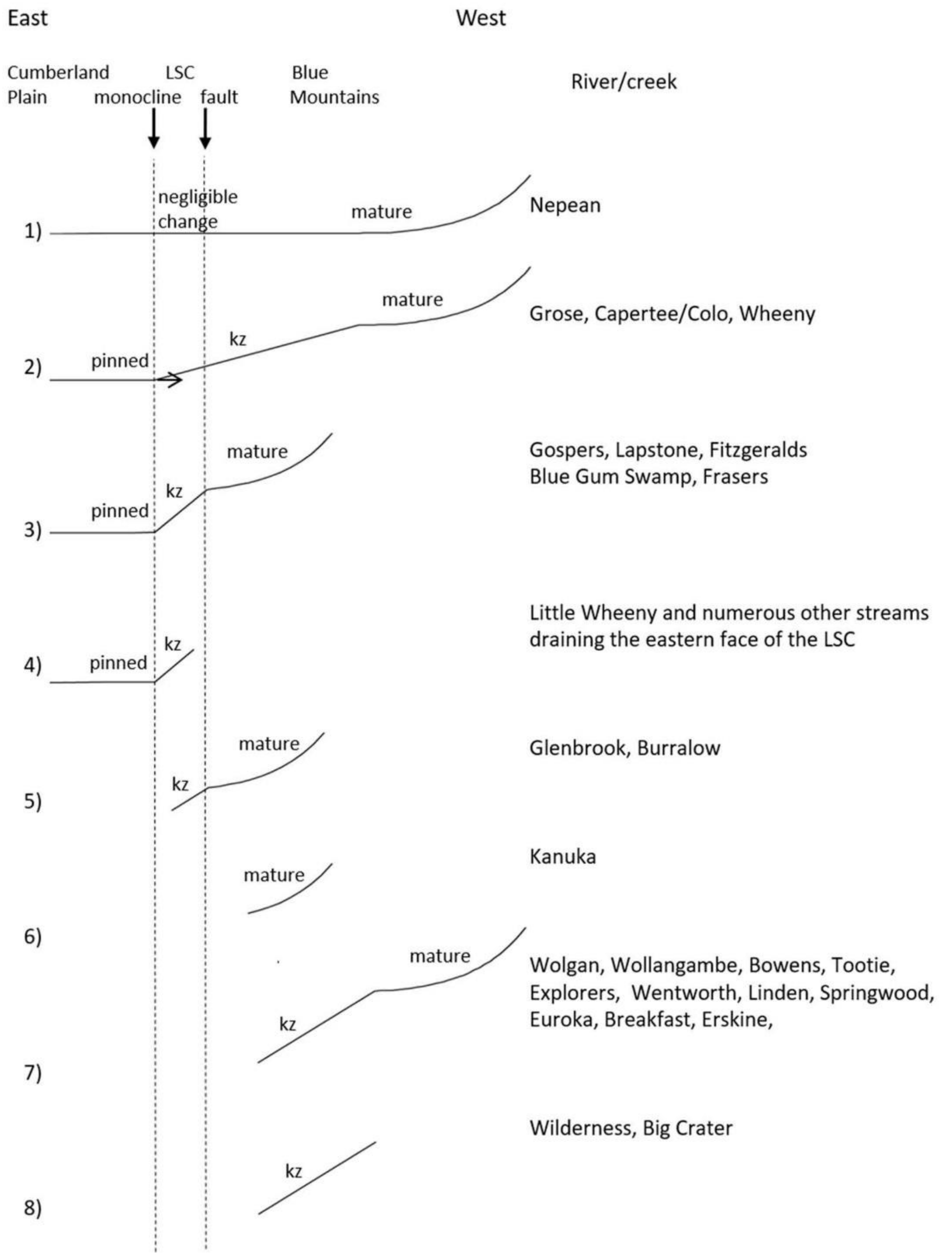


Figure 5. (From Hatherly 2020). Stream profiles from the Blue Mountains. Those that cross the LSC and appear to be antecedent to its formation have profiles pinned to it. The exception is the Nepean which originally flowed outside and to the East of the LSC.

The numbering of the eight scenarios below refers to the profiles in Figure 5.

1. The Nepean River in the area of the Fairlight gorge was able to cut into, through and out of the LSC at much the same pace as the uplift. This is confirmation of a slow uplift for the LSC.

2. These larger streams and rivers have knick zones commencing at or near the edge of the LSC and include the Capertee/Colo River, the Grose River and Wheeny Creek. Their large knick zone reflects the size of the river and their headwaters are many kilometres into the Blue Mountains Plateau, with the Grose River extending for 205km. In their upper reaches the

thalwegs of these streams are concave consistent with the existence of local relief at the time of uplift.

3. These streams also have knick zones pinned at the eastern edge of the LSC and extend to the western margin of it. Erosion in these streams has been matched by the rate of uplift. Again the thalwegs are concave beyond the LSC, suggesting existing local relief.

4. In this category are streams such as Little Wheeny Creek that only drain the edge of the LSC and were formed subsequent to uplift.

5. These profiles are of tributaries of major streams such as the Nepean and Grose. Again the existence of mature concave thalwegs suggests local relief prior to the uplift of the LSC.

6. These profiles are of tributaries that join the main streams in their headwaters. The streams into which they flow have upper stages with concave profiles.

7. In this group are tributary streams, located west of the LSC, in which are found knick zones that have progressed upstream from their junctions with main streams.

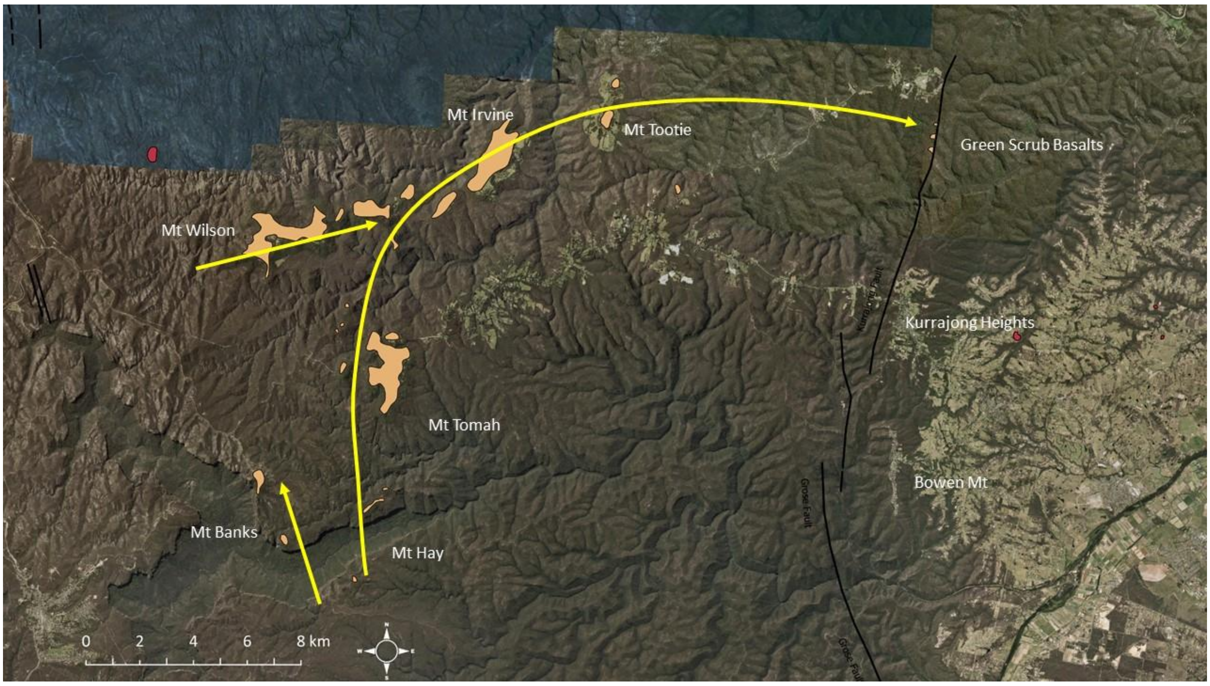
8. Short tributary streams in which the knick zones have reached their headwaters.

Hatherly's observations of basalt flows in the Blue Mountains also confirm the existence of local relief prior to the LSC uplift.

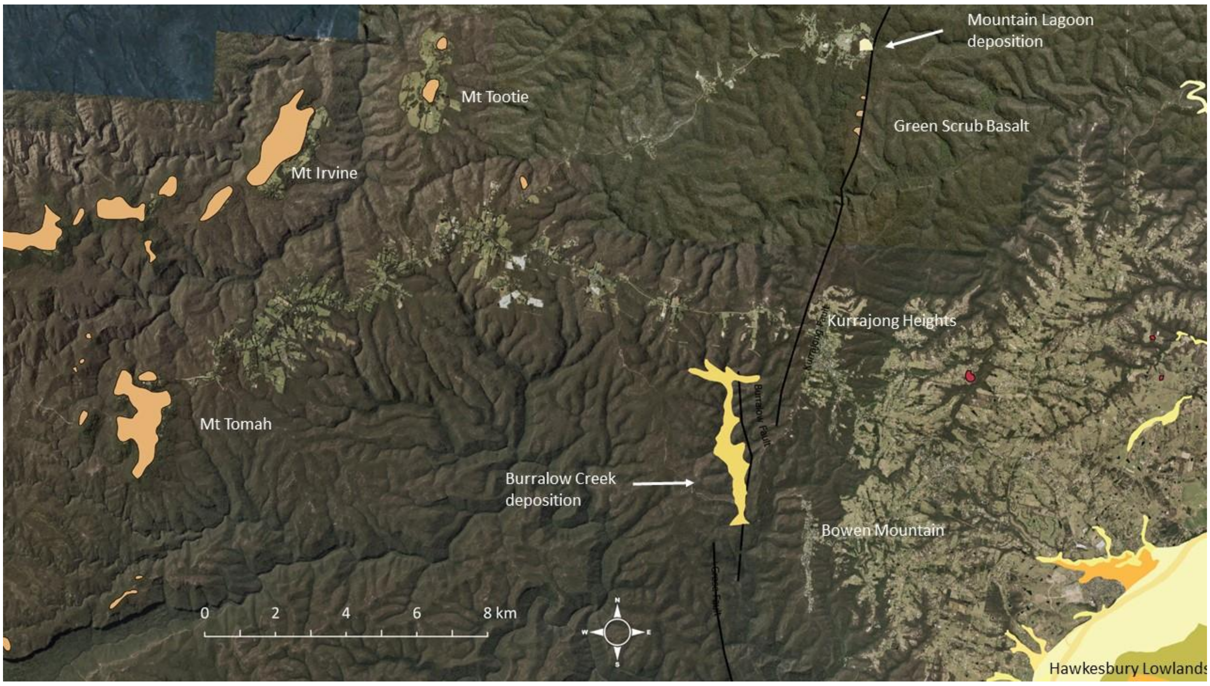
These basalt flows, aged Ca 20.1-14.5 Ma, are on the Blue Mountains Plateau and extend for approximately 20 km to the West of Kurrajong Heights. They finish with the Green Scrub Basalts (GSB) at the edge of the LSC near Mountain Lagoon. The GSB are situated on the edge of the LSC and appear to have been disturbed during uplift; they may have originally extended further.

Hatherly says that the presence of river gravels directly under some of these flows and a generalised slope in them to the North East of 0.85 degrees, suggests that the basalts flowed down a paleo river channel towards the LSC in the East (Map 10). In many of the area's major streams, the parts of their thalwegs with concave profiles occur west of these basalts and the low slope in the flows suggests the existence of a low relief prior to uplift and also at the time of the flows.

The timing of uplift in the LSC is uncertain but Hatherly believes that it is likely to be the result of compressive stress from the North beginning at about 10-5 Ma. The view that compressive stress developed in the area at this time is widely accepted by geologists (van der Beek 2001).

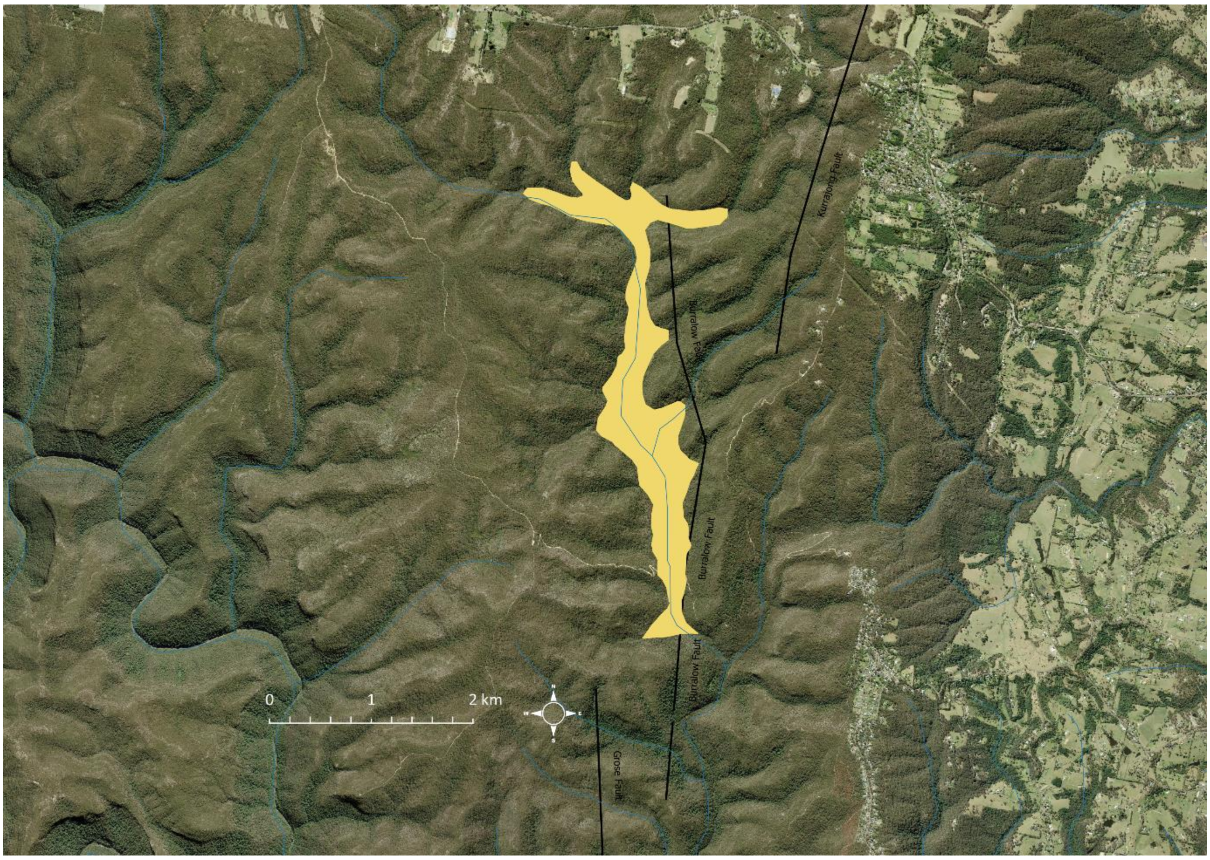


Map 9. Miocene Basalt flows in the northern Blue Mountains Plateau. The yellow arrows shows the approximate direction of flow determined by Hatherly.



Map 10. Location of the lacustrine deposits at Burralow Creek and Mt Lagoon that are associated with recent movement on the LSC.

Geoscience Australia organised a workshop in 2005 on Potential geologic sources of seismic hazard in the Sydney Basin. This was informed of evidence of recent movement on the LSC using discoveries of lacustrine deposits built against the edge of the Kurrajong and Burralow faults as a result of uplift in them. Maps 10-12 shows the locations of these deposits.



Map 11. Lacustrine deposits at Burralow Creek; formed against the Burralow Fault.

Map 12. Lacustrine deposit from Seamless Geology of NSW overlayed on current surface. The thin black line is the geological boundary of the unit and is a more accurate measure of the deposit.

Precise dates for the deposits at Burralow Creek and Mountain Lagoon have been difficult to achieve. Clark et al who researched the deposit at Mountain Lagoon suggest that the 15 m thick deposit there reflects displacement across the Kurrajong Fault in the last few million years. Recently, however, Robbie & Martin (2007) have found a sedimentary record there spanning 23,000 years. At Burralow Creek a date was obtained in the lacustrine deposit, 12m below the surface and this gave a date of about 30,000 years BP.

Conclusion

In summary, about 100 Ma ago, a large braided river flowed into the Sydney Basin, towards the North East, and out of the area of highlands that were associated with the Lachlan Orogen. It was carrying and depositing a large load of gravels and it flowed to the sea in a course similar to that followed by the present Hawkesbury/Nepean River.

The land to the West of the river had been previously raised by uplift and this constituted a paleo Blue Mountains. This occurred about 130 -80 Ma and was probably the result of passage over a hot spot of medium wave length. At approximately 55-45 Ma passage over another hot spot caused uplift of the Hornsby Plateau to begin; this dammed the river and the clay and finer sediments it carried were then deposited in the slowly moving water of the lake. The slow rate of uplift allowed the river to over top the rising plateau and erode a course to the sea. Eventually the lake was drained and the deposits of Londonderry Clay exposed.

At about 30 Ma there is evidence of further igneous activity and Hatherly says this produced uplift in the area west of the LSC. This established a land surface that sloped gently towards the basin, with a relief of about 200m. Streams developing in this surface flowed eastwards to the paleo Hawkesbury and overtime they developed concave thalwegs.

The uplift of the LSC began about 10-5 Ma and probably resulted from the compressive stress caused by the northwards movement of the Australian Continent. It was slow enough that the Hawkesbury River was able to maintain its course over part of the uplifted land. This created the steep sided gorges in the lower section of the present Hawkesbury River. Deposits of both the Londonderry Clay and the Rickabys gravel were then lifted with the LSC.

Since this time the river has continued to erode the plain and re-sort the clay and gravel deposits. It has formed a number of alluvial terraces and its channel has generally moved towards the edge of the LSC and Hornsby Warp. There also appears to have been some more recent uplift on the LSC. This has resulted in significant lacustrine deposits in the valleys of two streams, Burralow and Gospers Creeks.

References

Carter, Lewis, Tectonic Control of Cenozoic Deposition in the Cumberland Basin, Penrith/Hawkesbury Region, New South Wales, Bachelor of Science (Honours), School of Earth & Environmental Sciences, University of Wollongong, 2011. =

Dan Clark1, Andrew McPherson1 & Kerrie Tomkins2 RE-EVALUATING THE SEISMIC HAZARD POTENTIAL OF THE NORTHERN LAPSTONE STRUCTURAL COMPLEX
1. Georisk Project, Geoscience Australia, GPO Box 378, Canberra ACT 2601
2. Department of Physical Geography, Macquarie University, North Ryde NSW 2019

C. L. Fergusson, A. Bray & P. Hatherly (2011) Cenozoic Development of The Lapstone Structural Complex, Sydney Basin, New South Wales, Australian Journal of Earth Sciences, 58:1, 49-59, DOI: 10.1080/08120099.2011.534505

Graham I., Hatzopoulos Z., Sutherland L., Zwingmann H., Byrnes J. and Corkhill T. 2010, The age, geochemical affinity and significance of the Maroota Basalt, Hawkesbury Region, NSW, Proceedings of the 37th Symposium on the Geology of the Sydney Basin, Hunter Valley, May 6-7 2010

P. J. Hatherly (2020) Landscape evolution of the Blue Mountains revealed by longitudinal river profiles and Cenozoic basalts and gravels, Australian Journal of Earth Sciences, 67:2, 243-263, DOI: 10.1080/08120099.2019.1658639

Muller, R Dietmar; Flament, Nicolas; Matthews, Kara J.; Williams, Simon E.; and Gurnis, Michael, "Formation of Australian continental margin highlands driven by plate-mantle interaction" (2016). Faculty of Science, Medicine and Health - Papers: part A. 4195.
https://ro.uow.edu.au/smhpapers/4195

D. J. Och , R. Offler , H. Zwingmann , J. Braybrooke & I. T. Graham (2009) Timing of brittle faulting and thermal events, Sydney region: association with the early stages of extension of East Gondwana, Australian Journal of Earth Sciences, 56:7, 873-887, DOI: 10.1080/08120090903005345

D. J. Och, R. Offler & H. Zwingmann (2014) Constraining timing of brittle deformation and fault gouge formation in the Sydney Basin, Australian Journal of Earth Sciences, 61:3, 337-350, DOI: 10.1080/08120099.2014.906503

Andrew Rawson [1] & Dan Clark [2]. Geomorphological evidence for neotectonic activity on the northern Lapstone Structural Complex. Potential geologic sources of seismic hazard in the Sydney Basin GeoCat # 65991 Proceedings volume of a one day workshop 2005

1. NSW DEPT. OF NATURAL RESOURCES, C/O FACULTY OF SCIENCE AND AGRICULTURE, CHARLES STURT UNIVERSITY, LEEDS PDE, ORANGE PO BOX 883 NSW 2800 2. GEOSCIENCE AUSTRALIA, GPO BOX 378, CANBERRA ACT 2601

A Robbie & H A Martin The history of the vegetation from the last glacial maximum at Mountain Lagoon, Blue Mountains, New South Wales 2007 Proceedings- Linnean Society of New South Wales 128:57-80

Peter van der Beek,1 Anna Pulford,2 and Jean Braun Cenozoic Landscape Development in the Blue Mountains (SE Australia): Lithological and Tectonic Controls on Rifted Margin Morphology
Research School of Earth Sciences, Australian National University, Canberra ACT 0200, Australia
(e-mail: pvdbeek@ujf-grenoble.fr) The Journal of Geology Vol. 109, No. 1 (January 2001), pp. 35-56 (22 pages)
Published By: The University of Chicago Press DOI: 10.1086/317963
https://www.jstor.org/stable/10.1086/317963