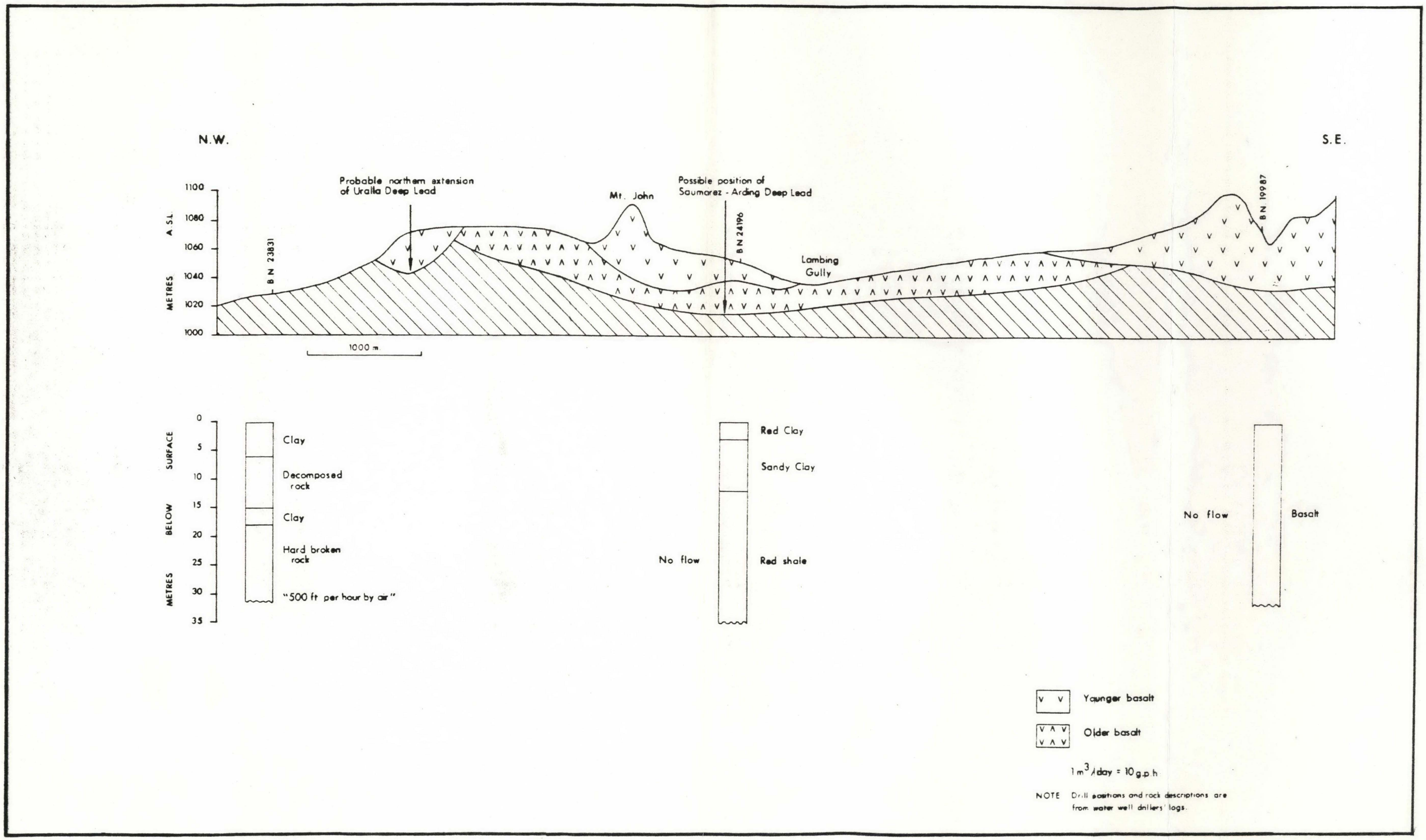
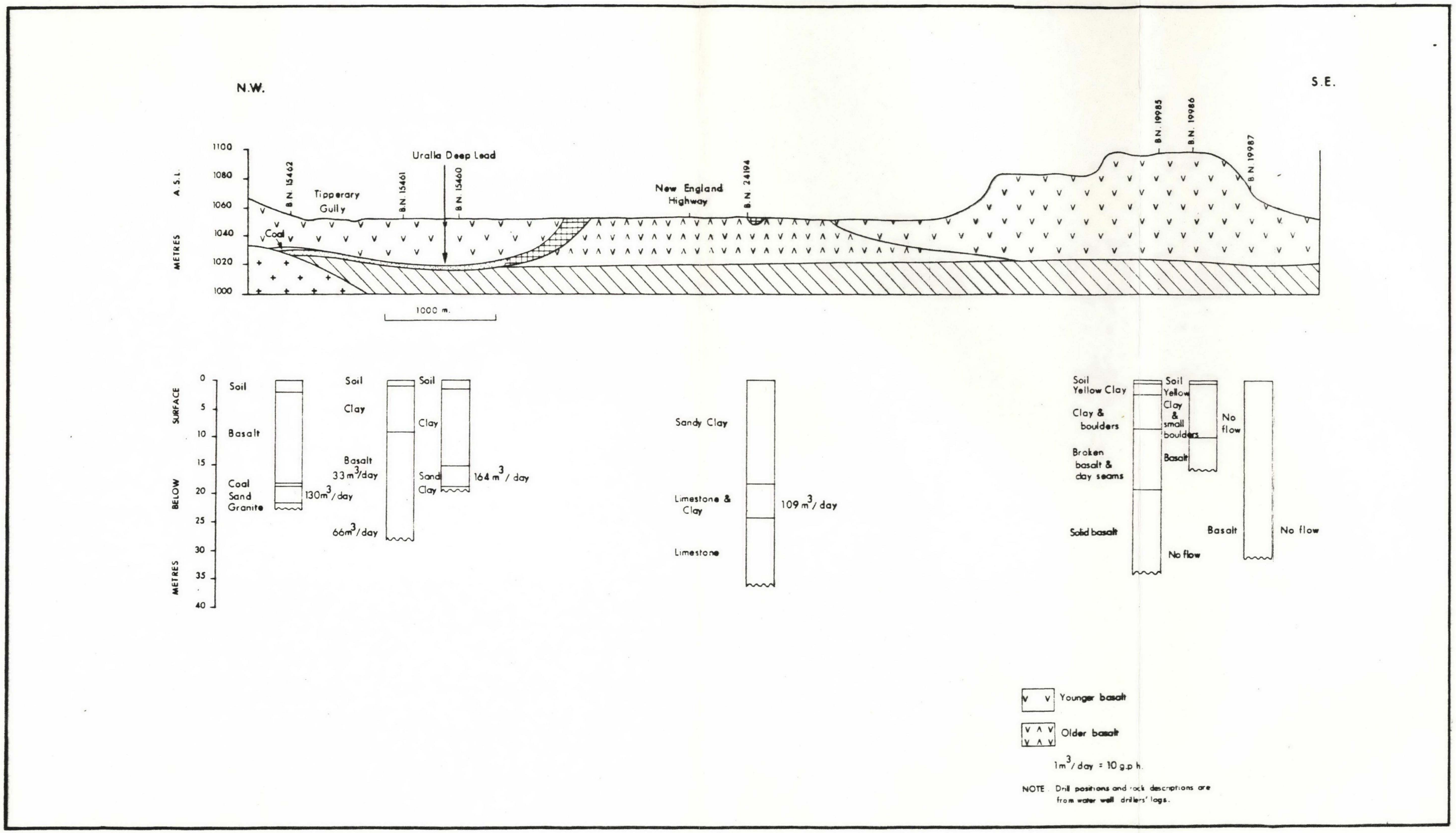


Figure 30. Cross-section 3. The location is shown in Map 1. The contacts shown between younger and older basalts are approximate. Bore logs along this cross-section were of limited assistance in construction of the section. Detailed traverses across the line of the cross-section showed that basalt was ubiquitous east of the Main Divide. The 'red shale' recorded at bore no. 24196 is either weathered basalt or Sandon Beds basement.



NOTE. Drill positions and rock descriptions are from water well drillers' logs.

Figure 31. Cross-section 4. The location is given in Map 1. The contacts between older and younger basalts are approximate. The 'limestone' recorded at bore no. 24194 is interpreted as Sandon Beds basement rock. The coal recorded at bore no. 15462 is probably similar to Tertiary lignite I found at an un-numbered bore at Armidale sheet GR 532110 in the same area. This lignite was mixed in with fluvial sediments also extracted from the bore hole, and was evidently formed from vegetation deposited in swampy depressions in the pre-basalt environment.

the suggested position of the pre-basalt divide (Figure 18).

Considering the first problem, the form lines suggesting a broad valley in Figure 17 are drawn on the basis of fairly sparse spot height data, for the base of basalts with an age span of at least 11 my (Section 6.3.4). There is a suggestion of a topographic high at the western end of the valley, which may in reality have linked the north and south sides of the apparent east-west valley. However establishing the existence of this link would require more complete spot height data than is available in the area. Despite this the simplest explanation consistent with the available evidence is that there was sufficient high ground in the western parts of this apparent east-west valley, to confine most of the basalt to the valleys flanking the Saumarez-Arding basalt.

Considering the second problem, from the form line map (Figure 17) it appears that the valleys in the pre-Oligocene basalt landscape were fairly shallow features, that in at least some places ran very close to the pre-basalt drainage divides. As the pre-basalt form line map is based on spot heights at the basalt margins, it cannot show the pre-basalt topography in areas still covered by basalt. the landscape along the modern Main Divide is one such area. In such cases the pre-basalt topography can only be revealed, as shown in Figures 28-31, by drilling or other sub-surface techniques. Figures 28 and 30 show the younger basalts of the Uralla deep lead forming the Modern Main Divide. These younger basalts lie right alongside the probable older basalts and Sandon Beds that appear to have formed the pre-Oligocene basalt Main Divide. Thus the likelihood, suggested by Figures 17 and 18, that in places valleys and divides were close to one another, appears sustainable on the basis of the field evidence presented in Figures 28 and 30.

Several points about landscape evolution in the Armidale-Uralla region arise from the above two explanations of landscape development. First, both assume that the Saumarez-Arding ferricrete area is underlain by basalt. This is in fact the case, as is shown by bore logs (Figures 28, 29), and excavations for poles carrying high-voltage power lines (for example at Armidale sheet GR 593173).

Secondly, the Saumarez-Arding basalts are likely to be older than the oldest basalts so far dated in the Armidale-Uralla region, because the dated basalts in the Armidale-Uralla region are upper slope and interfluve basalts that originally filled the lateral streams along the east and west flanks of the Saumarez-Arding basalt.

Thirdly, some of the ferricrete in the Saumarez-Arding area may by older than the basalts so far dated in the region, because the Saumarez-Arding basalt on which these ferricretes have formed, probably pre-dates the dated basalts. Fourthly, some of the silcrete in the Saumarez-Arding area may be older than the dated Tertiary basalts in the Armidale-Uralla region. This is so because these silcretes are silicified sediments that originally occupied river terraces in the valley that was filled by the Saumarez-Arding basalt.

Finally, the Main Divide appears to have been moved slightly by the Tertiary basalt extrusions and the resulting incisions of lateral valleys. Prior to the extrusion of the Saumarez-Arding basalt, the Main Divide was probably located along the western interfluve of the old north-trending valley. Following the extrusion of the Saumarez-Arding basalt and the development of a lateral stream in the approximate location of the pre-basalt Main Divide, the Main Divide moved to the east. This is more likely than the Main Divide having moved to the west, as the Palaeozoic Sandon Beds that would have formed the Main Divide prior to the extrusion of the dated basalts are now higher to the east of the western lateral stream than they are to the west of it (Figures 28, 30). The lack of evidence of faulting or tilting suggests this was also the case in the pre-basalt landscape.

When the lateral streams were themselves filled with basalt, and the drainage was diverted from the western side of the Saumarez-Arding area to form the ancestral Saumarez Creek, the Main Divide moved west again, onto the top of the valley-fill basalt in the western lateral stream (Figures 28, 30, 31).

In summary, it seems likely that there were relatively minor shifts in the position of the Main Divide as a result of the Tertiary basalt extrusions. This conclusion is in agreement with that of Jones and Veevers (1983a), who on the basis of the pattern of basalt ages in eastern Australia, suggested that late Cainozoic migration of the Main Divide has been minimal.

There is what Taylor (1978b) calls a remarkable synchroneity in phases of deposition throughout major Cainozoic basins in eastern Australia. Taylor's research was centred on the upper Darling basin. This catchment includes the Gwydir River that drains the western side of the Main Divide in the Armidale-Uralla region. Taylor (1978b) compared his own findings with the results of sedimentary studies in other east Australian Cainozoic basins, and found similar histories in the other basins, including

1. an absence of major phases of deposition in eastern Australia from Eocene to Miocene times;
2. extensive deposition of thin sheets of conglomerate and sands during the Miocene and late Miocene;
3. widespread weathering from the early to mid-Pliocene;
4. widespread and continuing fluvial deposition from the mid-Pliocene to Recent times.

Taylor (1978b) suggested that the synchroneity of these events indicates 'extensive uniformity of climate and/or tectonism during the late Cainozoic in eastern Australia'.

The relevance of Taylor's (1978b) work for the Armidale-Uralla region is that the eastern highlands are the principal sediment source for the east Australian Cainozoic basins. Phases of deposition in the Cainozoic basins must correspond with phases of erosion in the eastern highlands. On the basis of Taylor's (1978b) work, the following sequence of erosion and deposition is likely to have taken place during the Tertiary in the Armidale-Uralla region.

1. A period of slow erosion from Eocene to Miocene times. This phase corresponds with the time span of Tertiary volcanism in the eastern highlands; a period during which weathered bedrock was being covered by flows of lava on which erosion rates were probably initially low due to the lack of weathering.
2. Marked erosion during the mid-Miocene and late Miocene. This phase corresponds with the post-volcanic period in the Armidale-Uralla region; a time when erosion rates were probably higher than in 1, above, as streams re-established their courses on and around basalt flows, and incised to new base levels.
3. A period of lower erosion from the early Pliocene. One cause of this could have been a slowing of post-basaltic drainage adjustment, as stream gradients and relative relief decreased

This sequence of events may have some application to other parts of the eastern highlands, but the applicability is likely to be limited by differences in factors such as the timing of volcanism, the volume of basalts extruded, and the timing and extent of tectonism.

If increased erosion is equated with uplift, studies of sedimentation in east Australian Cainozoic basins (Macumber, 1978; Taylor, 1978b; Woolley, 1978; Grimes, 1980; Jones and Veevers, 1982), would suggest that there were uplifts of the eastern highlands in the Armidale-Uralla region during and after the late Cretaceous; during Miocene to late Miocene times; and after the mid-Pliocene. However the exact timing and extent of these uplifts is uncertain. Brown's (pers. comm.) evidence that sedimentation in the Murray Basin can be explained by eustatics without invoking tectonism, is an added and major difficulty for theories that attempt to explain sediment records in terms of highland uplift and/or subsidence. It also means that caution should be used in correlating the depositional record in Cainozoic basins with events (such as volcanism) in the eastern highlands.

9.6 LAGOON DEVELOPMENT

The Saumarez-Arding basalt and the more recent dated basalts that filled the lateral streams on the eastern and western sides of the Saumarez-Arding area, contain the lagoons of the Armidale-Uralla region. This means that at some time after the dated phases of basalt extrusion, there was a period or periods of lagoon development. In all there are over 40 lagoons either on or very near major drainage divides in the New England region. Lagoons are not a feature unique to the New England region. They are found along the length of the east Australian highlands (Ollier, 1979).

Many of the lagoons in the New England region are filled only during unusually wet seasons and none of the 10 lagoons in the Armidale-Uralla region are situated along active streams. They are all located within 1.7 km of either the Main Divide or the Saumarez-Dumaresq divide, and at least part of each of their margins are on ferricrete. The floors of the lagoons are composed of silt and clay, with the exception of the floor of Green Wattle Farm Lagoon which is mainly ferricrete. All the lagoons form shallow depressions in the landscape; the deepest depression being that of Farm Lagoon which has a maximum potential water depth of about 2.5 m.

In the Armidale-Uralla region the Main Divide is a poorly drained, low relief feature, with slopes near the spine of the divide often less than 2°. Where lagoons have developed on the Saumarez-Arding divide, this divide too is of low relief with slopes of 0-2°. Low relief and poor drainage may have been features of the Main Divide since the Tertiary basalt extrusions, and in these areas would have meant that during wet periods water would have been ponded in any minor topographic depressions. The lagoons are all wholly on basalt bedrock, with the exception of Primrose Lagoon which is partly on rocks of the Sandon Beds, and Barley Field Lagoon, which is on ferricrete, but is within 100 m of granite outcrop. Thus, leaching of iron as ponded water infiltrated, would have reduced the volume of the basalt underlying the lagoons, causing subsidence and deepening of the initial surface depression. The clay dunes (lunettes) associated with several of the lagoons in New England, such as Dangars Lagoon, 4 km south of Uralla at Gostwyck sheet GR 530020, and Mother of Ducks Lagoon at Guyra (Guyra sheet GR 710540; Walker, 1979), suggest that seasonal deflation has also been a contributing factor in their development.

Walker (1979) suggested that the New England lagoons began as swamps, formed following exhumation of ferricrete or silcrete that acted as a barrier to drainage. He argued that the lagoon basins developed from these swamps as a result of late Pleistocene aeolian deflation, and have persisted because of their proximity to topographic divides that has resulted in very low rates of sedimentation of the basins. Walker (1979) thought that the clay dunes associated with some of the New England lagoons have developed by similar aeolian processes to those described by Bowler (1973, 1975) for clay dunes in southeastern Australia. He also thought that the numerous lagoons on the Monaro plateau in southern New South Wales may have had a similar origin to the New England lagoons.

Some of the lagoons in the Armidale-Uralla region were drained 50-60 years ago, by digging a hole through the lagoon floor. A long-time resident of the Saumarez-Arding area has told me that once the silt floor of the lagoons was penetrated, the water drained away like water from a bath. This suggests that the vesicular ferricrete that borders most of the lagoons in the Armidale-Uralla region (as discussed in Section 5.6) also extends beneath them, enabling the lagoon water to drain through it if the impermeable silt floor of the lagoon is perforated. Not all lagoons are underlain by porous ferricrete. Walker (1979) reported that wells sunk on the floors of some New England lagoons during drought, passed through '6-8 m of sticky buff-coloured clays, apparently well-weathered bedrock rather than lacustrine sediments'.

An alternative to Walker's (1979) suggestion that the New England lagoons were initiated by drainage ponding following erosional exhumation of ferricrete and silcrete, is the idea that regional backtilting along the New

England tablelands caused drainage ponding in the headwaters of some streams. East of Armidale nearer to the eastern scarp, the valleys draining the Ebor Volcano to the west have swampy stretches which Ollier (1982b) noted are consistent with them having been back-tilted. There are no such swamps in east-draining valleys in the area. If tilting caused the swamps to form in the headwaters of the Ebor volcanics, it was downwards to the east. Lagoons in the Armidale-Uralla region occur on both the eastern and western sides of the main topographic divides. Regional tilting, except on the most localised and intricate scale, cannot explain lagoon development on both sides of a topographic divide. It would only be a possible explanation if all the lagoons were on the same side of the topographic divides.

The main problem in explaining the origin of the lagoons in the Armidale-Uralla region, is to account for the initial development of swampy depressions in the landscape. Once there is such a depression, lagoon development can be adequately explained by the poor drainage, restricted catchment and resulting low rate of sedimentation, deflation during dry periods, and possibly subsidence of the lagoon floor due to leaching as water percolates downward from the lagoon. But the problem of explaining the initial topographic depression remains. Walker's (1979) suggestion was that 'the fortuitous exhumation of laterite or silcrete across post-basalt drainage lines close to present topographic divides produced long-lived structural barriers'. This appears initially to be a reasonable explanation, but several aspects of the lagoons in the Armidale-Uralla region do not fit this explanation. First, four of the ten lagoons have no evident outflow zone across an exhumed ferricrete or silcrete margin. Secondly, while all the lagoons have ferricrete around at least part of their margin, this does not always correspond with the outflow zone, and is sometimes the highest part of the lagoon margin. Tanglewood lagoon is one example. Thirdly, though the lagoons in the Armidale-Uralla region are small compared to some other New England lagoons, their catchment area usually extends through an arc of at least 180o. There is no indication that any of the lagoons were fed by a stream or streams that may have been defeated by an exhumed sill of ferricrete or silcrete. The catchments of the lagoons are usually very gently sloping (0.5-2.0o), without defined drainage lines, so that water movement downslope to the lagoons is mainly by throughflow and possibly overland flow, rather than by flow in channels. These three aspects of lagoons in the Armidale-Uralla region make it difficult to completely accept Walker's (1979) explanation of lagoon development.

Despite the problem of fully accounting for the initial development of the topographic depressions from which lagoons formed in the Armidale-Uralla region, silcrete and/or ferricrete now form erosion resistant margins around at least part of the basins of all the lagoons in the region. This strongly suggests that lagoon development has been enhanced by the presence of duricrusts on the lagoon margins. Lagoon development in the Armidale-Uralla region may have followed the following sequence.

1. Development of the broad, almost level topography of the Main Divide and the Saumarez-Arding divide, on basaltic rocks underlain by ferricrete, silcrete and Palaeozoic basement rocks.
2. Seasonal ponding of water in minor depressions on and near the topographic divides, where the catchments were too small and slopes too gentle for competent drainage away from the divides.
3. Seasonal deflation of the weathered floors of these depressions, and probably minor subsidence of the depression floors as a result of leaching by ponded water.

Lagoons near the topographic divides in the Armidale-Uralla region have persisted because of the very low rates of sediment inflow to the lagoon basins (Walker, 1979). There are several reasons why lagoons developed on or near topographic divides. First, as Walker (1979) noted, catchment areas are restricted, and as a result the rate of sediment infilling of minor depressions or lagoon basins will be minimal. This has meant that lagoons near topographic divides have persisted, while lagoons that may have developed further from the topographic divides would have been filled with sediment. Slatherum Swamp, 11 km southwest of Armidale (Armidale sheet GR 592163; Plate 61), may be a lagoon in the last stages of complete infilling by sediments. The swamp covers an almost level area several hundred metres across, marshy in wet periods, with a slight slope down to the north. Slatherum Swamp has a catchment area of about 4 km^2, bigger than any of the existing lagoons in the Armidale-Uralla area,and sufficient to provide sediment to completely fill a lagoon. Secondly, because of the very gentle slopes on the topographic divides in the Armidale-Uralla region, and the small size of catchments, water entering minor depressions in the landscape will have very low capacity to erode the down-gradient margins of the depression margin.

The origin and persistence of the lagoons in the Armidale-Uralla region and elsewhere in New England cannot be fully explained on the existing evidence, and full explanation must await more detailed and extensive study.

9.7 RATES OF DENUDATION AND VALLEY INCISION

Geomorphologists, hydrologists and geologists have calculated average rates of denudation (lowering of the land surface by erosion) and valley incision in many areas of the world. Two main methods have been used. Process geomorphologists and hydrologists have calculated the average rate of denudation in (usually) small catchments by measuring the solute and sediment load of the stream draining the catchment. The period of measurement is often 1-2 years. Geologists and geomorphologists studying long-term landscape evolution have calculated rates of denudation and/or valley incision in landscapes containing dated basalts, and elsewhere, by reconstructing the pre-basalt landscape and estimating the amount of basalt originally extruded. Similar inductive methods have been used in other areas containing other materials for which a date of arrival in the landscape is known (Table 2).

Plate 62. *Slatherum Swamp, 11 km southwest of Armidale, looking to the southeast. The swamp may be a lagoon in the final stages of infilling by sediment. The swamp has a larger catchment than the persisting lagoons in the Armidale - Uralla region, and this may have resulted in increased sedimentation into the depression that now remains only as a swamp (Armidale sheet GR 592163).*

TABLE 2. RATES OF DENUDATION AND VALLEY INCISION CALCULATED FOR NEW ENGLAND AND OTHER AREAS

LOCATION	LITHOLOGY	STUDY TYPE	RATE mm/1000yr	SOURCE
Armidale-Point Lookout area (three catchments)	basalt, adamellite, granite	A	60-90	Loughran, 1969
Dumaresq Ck, W.trib.	adamellite	A	7.71	Bevan, 1970
Dumaresq Ck, W.trib.	adamellite	A	3.22	Bevan, 1970
Mount Duval	adamellite	B	12.5-23	Warner, 1975
Sandy Creek	adamellite	A	1.4	Zakaria, 1977
Pipeclay Creek	greywacke	A	8.2	Zakaria, 1977
Boorolong Creek	basalt	A	4.0	Zakaria, 1977
Upper Sandy Creek	adamellite	A	9.1	Lam, 1979
New England,N.S.W.	Palaeozoics	B	0.23-0.31 (valley incision)	Francis *et al.*, 1979
Hunter valley,N.S.W.	basalt cover	B	5-10	Galloway, 1967
SE Australian highlands	varied	B	1.1 (valley incision)	Wellman, 1979a
SW Western Australia	cratonic (varied)	B	0.1-0.2	Finkl and Fairbridge, 1979
SW Western Australia	cratonic (varied)	B	4.5-5.0	Van De Graaff 1981
North America (4000 km^2 basins)	mainly sedimentary	A	18-225(H) 75-900(S)	Schumm, 1963

(A=small catchment process study; B=inductive study; H=humid area; S=semi arid area)

Although rates of denudation and valley incision are not necessarily the same, they are likely to be of the same order of magnitude. There are 2 orders of magnitude difference between the highest and lowest rates calculated for denudation in the New England area, and 3 orders of magnitude difference between Schumm's (1963) denudation rates for North America and the valley incision rate Francis *et al.* (1979) calculated for New England. The vast range in estimates of rates of denudation in the New England area suggests that the difference in these estimates lies in the calculations rather than in the landscape.

The denudation rates calculated by Loughran (1969), Bevan (1970), Zakaria (1977) and Lam (1979) (Table 2), were based on catchment process studies of 1-2 years duration. Loughran studied three catchments between Armidale and Point Lookout, and the catchments of Bevan, Zakaria and Lam were all situated between Armidale and Mount Duval. The total amount of material removed from each catchment during the study period was measured by monitoring the stream sediment load and solute concentration. This total figure of suspended load plus dissolved load, was used to calculate an average amount of surface lowering in the catchment above the sampling point during the study period. This figure is commonly expressed as a rate in mm/1,000 yr, the units used in this thesis. There are several major problems with long term rates of denudation calculated in this way. First, in calculating the amount of denudation from solute concentrations and sediment loads, it is assumed denudation is uniform throughout the catchment. At best this assumption is unproven, at worst it is false, for the rate of denudation in catchments has been shown to vary greatly both between different parts of the catchment, and over time (Douglas, 1964; Lam, 1979). Secondly, when the average amount of surface lowering in the catchment during the study period is transformed into an average rate of denudation, the extrapolation of this rate to give average long-term denudation rates, shows a faith in uniformitarianism that our present knowledge suggests is misplaced. Human activities, particularly agricultural activities, have greatly increased sedimentation from catchments (Douglas, 1967, 1970; Meade, 1969; Seymour, 1980). Long term climatic change and resulting vegetation changes are also likely to have had major effects on rates of denudation. Thirdly, seasonal and other short term fluctuations in climate mean that denudation rates based on one or two years records of sediment and solute concentrations, may be very atypical, even of modern denudation rates.

The denudation rate of 5-10 mm/1,000 yr calculated by Galloway (1967) (Table 2) for post-basaltic times in the Hunter valley to the south of the New England region, was based on an estimated basalt age of 35 my, and an estimated original average basalt thickness of 150 m over 15,500 km2 of the Hunter valley. Galloway (1967) claimed that up to twice this amount of basalt may have been extruded. The age of basalt in the Hunter valley is now known to range between 53.3 my for the Barrington Volcano in the northeast of the valley (Wellman and McDougall, 1974a), 42.1 my in the Airlie Province in the southwest of the valley (Dulhunty, 1972; Wellman and McDougall, 1974a) and 40.0 my for the eastern section of the Liverpool Volcano in the north and northwest of the Hunter valley (Wellman and McDougall, 1974a). These ages are older than the 35 my suggested by Galloway (1967), and are one possible source of inaccuracy in his calculation of denudation rates.

Galloway (1967) assumed an original basalt volume of 23,000-46,000 km3. This was based on the assumption that the modern scattered basalt occurrences in the Hunter valley are 'survivals of a former continuous sheet'; an assumption that Galloway (1967) accepted was unproven. By comparing the present topographic contours with sub-basalt form lines, Galloway (1967) calculated that another 2,700 km3 have been eroded from the older sub-basaltic rocks. Isotopic dating has shown that there is a difference of at least 13 my in the ages of major basalt extrusions in the Hunter valley. The resulting diachronous basalt landscape makes the interpretation of sub-basalt form lines difficult, and this figure of 2,700 km3, though carefully calculated may be unreliable.

For these reasons Galloway's (1967) calculation of an average denudation rate 'over the whole catchment of 5 to 10 m in a million years' (5-10 mm/1,000 yr) is of limited practical use. In an area the size of the Hunter valley (21,000 km2), the concept of an average rate of denudation must be used with caution. There are now, and have been in the past, great differences in erosion rates in different parts of the Hunter valley: alluvial plains that have rates of deposition rather than rates of erosion; mid-slopes that can have high rates of erosion; and gently sloping basalt-capped interfluves that can have very low rates of erosion. In all of these areas the rate of erosion or deposition will vary greatly over time, because of non-uniform process types and intensities.

Warner's (1975) calculation of the rate of denudation in the Mount Duval area (Table 2) was based on his estimate of the depth of emplacement of the Mount Duval Adamellite. He suggested these granitic rocks were intruded at depths of 2,000-3,000 m, and that 2500-3500 m of erosion has taken place to result in Mount Duval being 500 m above the Eocene plain. This model of deep emplacement was challenged by Korsch (1977, 1982a, 1982b), with his alternative model of shallow, diapiric emplacement, discussed in Chapter 5. If Korsch's interpretation is correct, Warner's (1975) calculation of 12.5-23 mm/1,000 yr average denudation is far too high.

The relative relief of the exposed granitic intrusions (such as Mount Duval) in the New England region enable a conclusion to be drawn regarding the relative rates of erosion on and off the granite. The streams draining Mount Duval have accumulated substantial sandy deposits for several kilometres downstream from Mount Duval. This is evidence of erosion on the granitic rocks. There is also a marked decrease in stream gradient as streams flow off the Mount Duval Adamellite onto other rocks. This suggests that erosion is lower off the granitic rocks than on them, and raises the question of how can Mount Duval have come to be a topographic high if it is eroding faster than the surrounding country? Korsch (1982a, 1982b) suggested that the Mount Duval diapir may have domed the land surface so that the top of Mount Duval was well above the level of the surrounding landscape, even when still covered by its thin overburden of country rock and pyroclastics. Korsch (1982b) also suggested that Mount Duval had about the same elevation above the surrounding landscape when it was first exposed, as it does now. If Korsch's (1982a, 1982b) explanation was correct, the rate of erosion on Mount Duval must have always been comparable to the rates of erosion on the surrounding country, for Mount Duval to have maintained its position as a topographic high in the Armidale-Uralla landscape since the Permian.

Francis _et al._ (1979) suggested there had been 15-20 m of valley incision in southern New England since the beginning of the Tertiary (Table 2). This estimate was based on three assumptions. First, that silcrete in southern New England formed subaerially before the basalt was extruded; secondly, that at sites where silcrete now extends part of the way down valley sides, the valley below the silcrete has been incised since the silcrete formed; and thirdly, that the basalt extrusions in southern New England were scattered and so patchy that in many areas they did not even flow to the valley floors. I have presented evidence that suggests that all these assumptions are false, and that much of the basalt in the Armidale-Uralla region of southern New England was originally valley-fill basalt, covering sediments that in some areas have since been silicified. Because of the long time period during which silcrete was developing in the Armidale-Uralla region, the modern topographic position of silcrete on valley sides cannot necessarily be used with any accuracy as a basis for calculating rates of valley incision. However at sites where silcrete consists of silica-cemented fluvial sediments, the second assumption (above) of Francis _et al._ (1979) seems valid.

Rates of denudation that have been calculated for areas outside New England appear to have many difficulties also. For example Wellman's (1979a) calculated rate of 1.1 mm/1,000 yr for valley incision in the southeast Australian highlands over the last 90 my (Table 2), is based on the fact that modern river valleys in the southeast highlands are about 50 m below basalt flows 30-50 my old. The calculation is also based on the assumption that the rate of valley incision has been constant back to the suggested initiation of uplift 90 my ago. This assumption was unsupported, and the weaknesses of Wellman's (1979a) conclusions were discussed in Section 9.2 of this Chapter.

Finkl and Fairbridge (1979) argued that the cratonic surface in southwest Western Australia may not have been effectively lowered by erosion for as long as 1.5x10^9 years, the age they assigned to the initial peneplanation of the Western Australian craton. Finkl and Fairbridge (1979) interpreted the sediments of the Kirup Conglomerate about 50 km southwest of Bunbury in Western Australia, as relief-inverted remnants of the original Permian glacial surface. On this basis they postulated a mean post-Permian denudation rate of 10-20 cm/my (0.1-0.2 mm/1,000 yr) on the West Australian craton (Table 2). The validity of this extremely low rate of denudation has been strongly challenged by Van De Graaff (1981) on two main grounds. First he claimed that there is no evidence that the Kirup Conglomerate is glacial, and that Finkl and Fairbridge (1979) had postulated a fluvial origin for similar sediments in other areas. Secondly Van De Graaff noted that there were about 120,000 km^3 of siliciclastic sediments deposited in the Perth Basin during the Jurassic to early Cretaceous. These sediments were eroded from an area of approximately 340,000 km^2 on the Yilgarn Block. This represents a mean surface lowering of 350 m during the Jurassic to early Cretaceous, a rate of 4.5-5 m/my (4.5-5 mm/1,000 yr) (Table 2). Van De Graaff (1981) suggested that on the eastern part of the Yilgarn Block at least, denudation rates during the late Cretaceous to early Tertiary were still as high as 1.5-2 m/my.

On Van De Graaff's (1981) reckoning, denudation rates during the whole of the Mesozoic were 10-50 times as high as those postulated by Finkl and Fairbridge (1977, 1979). Despite the uncertainty about actual rates of denudation before the Tertiary, both Van De Graaff (1981) and Finkl and Fairbridge (1979) agreed that erosion rates in the later Cainozoic were probably no more than several tens of centimetres per million years. This is attributable to aridity and stability, and is indicated by the widespread remnants of duricrusted Eocene to Miocene landsurface in the interior of Australia.

The rates of denudation calculated by Schumm (1963) (Table 2) were based on studies of solute and sediment yield from North American drainage basins averaging 4,000 km2. Schumm's rates of 18-225 mm/1,000 yr for humid areas, and 75-900 mm/1,000 yr in semi-arid areas, were calculated in similar fashion to the rates derived in smaller catchments in New England, cited in Table 2. Schumm's (1963) results had an added disadvantage in comparison to the New England studies, in that having being calculated for large catchments, the average rate of denudation calculated for each catchment was quite unrepresentative of the actual erosion rate for most of the time in any specific part of the catchment. For example in a 4,000 km2 catchment there will probably be at least several areas, such as floodplains or scree slopes, where deposition rather than erosion is taking place. Also, sediment and solute concentrations in streams in the catchments may have represented reworked material from valley floors and floodplains, that was originally eroded from slopes under different climatic conditions (Francis *et al.*, 1979).

Besides these difficulties, such calculations are also based on numerous explicit and implicit assumptions, discussed below, the net effect of which is to make the calculations of dubious validity

The rate of valley incision and the rate of denudation in the Armidale-Uralla region since the Tertiary basalt extrusions, can in theory at least, be calculated using the following equations.

$$\begin{array}{l}\text{Average rate of}\\ \text{valley incision}\\ \text{(mm/1000 yr}\\ \text{or m/my)}\end{array} = \frac{\text{original thickness of basalt (m)} + \text{vertical distance valley has incised below base of basalt (m)}}{\text{age of basalt in area (my)}}$$

The average rate of denudation on the basalt is given by:

$$\begin{array}{l}\text{Average rate of}\\ \text{denudation on}\\ \text{basalt (mm/1000}\\ \text{yr or m/my)}\end{array} = \frac{\text{original thickness of basalt (m)} - \text{present thickness of basalt (m)}}{\text{age of basalt in area (my)}}$$

In the above equations the age of the basalt, the present thickness of basalt and the vertical distance of valley incision below the base of the basalt can all be measured. The original basalt thickness can only be estimated, and the estimate will depend on what assumptions and conclusions are made concerning Tertiary volcanism in the Armidale-Uralla region. At least three assumptions are necessary. First, I have argued that Tertiary basalts in the Armidale-Uralla region were mainly valley fill basalts. Secondly, is is assumed that the pre-basalt landscape in the Armidale-Uralla region had similar relative relief to the present landscape, and thus pre-basalt valleys were of similar depth to modern valleys in the same location. This assumption is based on form line reconstructions of the sub-basalt surface, which are in turn based on an assumption that the sub-basalt surface approximates to the pre-basalt surface. That is, it is assumed there have been no differential earth movements since the basalts were extruded. Thirdly, it is assumed that pre-basalt valleys now preserved as relief-inverted landforms capped with basalt, were filled only once with basalt, rather than being filled or semi-filled and eroded several times.

On these assumptions, the original basalt thickness in any part of the Armidale-Uralla region is equal to no more than the depth of the pre-basalt valleys that this basalt once filled. The depth of these pre-basalt valleys is in turn equal to the depth of modern valleys in the same area. None of the assumptions on which this conclusion is based, can be verified on present evidence. Any assumption based on form line reconstructions is dubious, as the form lines are themselves based on the false but necessary assumption that basalts in the Armidale-Uralla region were extruded over a single, short time period. The assumption that valleys were filled only once with basalt is of dubious validity, given the long history of basalt extrusions in the region. If any one of the above three assumptions, or the premises on which they are based, is false, the estimate of original basalt thickness will be wrong, as will be the calculation of average rates of denudation or valley incision based on this estimate.

If the estimate of original basalt thickness is correct (though there is no way of knowing if it is), the rate of denudation or valley incision calculated from it will be an average rate; that is, a rate averaged over time and averaged over the landscape. Such an average needs to be interpreted with caution. For example it is quite possible that much of the post-basaltic erosion in the Armidale-Uralla region has been confined to relatively short periods of increased erosion as a result of climatic variations and/or periods of adjustment to changes in base levels. Therefore when discussing long term rates of denudation, it should be remembered that the average rate may be composed of both very high and very low denudation rates.

For these reasons, the calculation of average rates of denudation or valley incision is unlikely to be a valuable result of landscape interpretation. Such calculations may in fact confuse, by introducing figures for original basalt thickness that are actually no more than guesses. Despite these problems it is possible to make some informed comments about post-basalt erosion and valley incision in the Armidale-Uralla region. Much of the basalt now present in the Armidale-Uralla region has been shown by gold mining operations and bore logs, to be valley-fill basalt overlying deep leads. Thus the depth of modern valleys adjacent to remnants of these basalts gives a reliable minimum figure for valley incision since the overlying basalts were extruded. For example near Armidale Airport, Martins Gully at Armidale sheet GR 668214, is 75 m below the top of the 33 my basalts at Armidale Airport. From this it can be concluded that there has been a minimum of 75 m of valley incision in the area in the 33 my since the valley-fill basalts at Armidale Airport were extruded. There is no doubt that this basalt was a valley-fill basalt. A mineshaft near the western end of Armidale Airport (at Armidale sheet GR 640210), encountered gold in a deep lead beneath the basalt (Harrington et al., 1971; Figure 28). Only 2 km northwest of this area on the same basalt, a bore sunk near 'Micklegate' in late 1982 (at Armidale sheet GR 627221), entered rounded to sub-rounded quartz and chert sediments at a depth of 33 m, after passing through 20 m of basalt and 13 m of variably coloured clays (H. Eames, boring contractor, pers. comm.; I have inspected the sediments).

At Bald Knobs, the 22 my basalts are 105 m above Powers Creek at Armidale sheet GR 715129 (Figure 2). If these basalts are flow remnants, there has been a minimun of 105 m of valley incision in this area in the last 22 my. Unfortunately no deep leads have been found in this area to confirm that the basalts are actually flow remnants. In the absence of conclusive evidence there must remain a possibility that parts of the Bald Knobs basalt were always above the level of the streams in the area. If this was the case there may have been less than 105 m of valley incision in the area in the last 22 my.

The 25 my basalts 25 km northwest of Armidale are up to 100 m above the level of Saumarez Creek, flowing 1.5 km to the west. These basalts form the divide between Saumarez and Dumaresq Creeks, and have been interpreted by me as relief-inverted valley-fill basalts. If this interpretation is correct there has been a minimum of 100 m of valley incision in this area in the last 25 my.

Of these three figures for minimum valley incision in the Armidale-Uralla region since the Tertiary basalt extrusions, the Armidale Airport figure of 75 m in 33 my (2.2 mm/1,000 yr) is the most reliable, having been calculated in an area where the basalts have been shown conclusively to be valley-fill basalts, meaning that the post-basalt surface was initially at the same level as immediate post-basalt drainage lines. Basalts in the other two areas are almost certainly flow basalts, but this conclusion is based on extrapolation from the characteristics of known deep leads, rather than specific sub-surface data, and is therefore less firm than the conclusion that the Armidale Airport basalts are valley-fill remnants.

The present maximum thickness of basalt in the Armidale-Uralla region may be as much as 60 m (Figure 7). The overall rate of surface lowering since the basalt extrusions is likely to have been much less than the rate of valley incision in the rejuvenated, post-basaltic landscape. As Crickmay (1974) has argued, the rate of general surface lowering is usually only a small fraction of the rate of valley incision. Thus, estimates of valley incision and basalt thickness in the Armidale-Uralla region cannot legitimately be added to give an estimate of original basalt thickness.

9.8 EVOLUTION OF THE ARMIDALE-URALLA LANDSCAPE

The landform evolution of the Armidale-Uralla region and adjacent areas probably involved the following stages.

1. Deformation and welding of the marine New England region onto the Australian craton. At this stage parts of New England became terrestrial, and continental landform evolution began.
2. Erosion of higher parts of the landscape and deposition in sedimentary basins. These sedimentary basins were outside the Armidale-Uralla region, to the east and west of the ancestral eastern highlands.
3. Intrusion of the New England Batholith 250-245 my ago. Parts of the Batholith (such as Mount Duval) rose sufficiently close to the surface to cause doming of the surface rocks, and subsequent accelerated erosion of the dome. In the case of the Mount Duval diapir there was localised deposition of erosion products from the dome, to form the Dummy Creek Conglomerate in depressions around the emerging Mount Duval.
4. An extended phase of erosion during which Mount Duval and other parts of the New England Batholith were exposed.
5. Possible volcanism during the Jurassic, which could have supplied the volcanic rocks that now form highly weathered ferricrete deposits in parts of the Armidale-Uralla region, such as at the Sugarloaf, at the base of Arthurs Seat and near Mount Butler.
6. Development of a main drainage divide running north-south, in the same region as the present Main Divide. The initial up-warping of the east-west divide may have been associated with the opening of the Tasman Sea

80-60 my ago.

7. Possible accelerated erosion near the east Australian coast in response to the formation of the new continental edge. This will have been the case if continental splitting resulted in increased gradients near the new coastline.

8. Development of a landscape of low to moderate local relief in the Armidale-Uralla region, and deposition of the Armidale Beds, prior to the first of the dated phases of basalt extrusions 33 my ago. By this time the Main Divide was probably close to its present position.

9. Partial covering of the Armidale-Uralla region by a series of basalt extrusions that may have emanated from the Glen Innes region to the north of Armidale. The extrusions began at least 33 my ago and continued sporadically for at least 11 my. These extrusions may have been accompanied by episodes of uplift, as discussed in Section 9.2, but the stratigraphic evidence for uplift is ambiguous, and can be explained more simply be eustatic changes.

10. Drainage modification and possibly drainage reversal as a result of basalt flows filling existing valleys. The Armidale-Uralla region cannot have been inundated by lava flows, as the post-basalt drainage formed as lateral streams on the margins of the basalt flows. These lateral streams persist today as Dumaresq Creek and Saumarez Creek.

11. Silicification of fluvial sand and gravel, and some weathered bedrock, to form silcrete. Some sub-basaltic deep lead sediments remained unsilicified. Silcrete development may have been at its maximum during the early to mid-Miocene.

12. Extensive development of ferricrete by the mobilisation and concentration of iron in basaltic soil profiles. This may have taken place during most of the Miocene.

13. Erosion of the Tertiary basalt, exposing silcrete, ferricrete, Eocene sediments and basement rocks.

14. A modern rate of erosion in the Armidale-Uralla region that is many times less than the erosion rate on the eastern scarp.

This sequence of events is neither exhaustive nor definitive. For example there is still great uncertainty about the extent, variability and timing of uplift(s) in the eastern highlands of Australia of which the Armidale-Uralla region is a part. There is also uncertainty about the relationship between uplift(s), continental splitting and the initiation and retreat of the eastern scarp. Despite such problems, the detailed investigation on which this sequence of landscape evolution is based, has enabled some suggestions to be made about landscape evolution in the Armidale-Uralla region and some adjacent areas.

CHAPTER 10

CONCLUSION

10.1 RELEVANCE OF FINDINGS TO ADJOINING AREAS

Landscape development results from the complex interaction of many factors, including lithology, drainage pattern, climate, and local, regional and ultimate base level. The intensity or rate of landscape development can change rapidly over a short distance, and in the east Australian highlands, the plateau zone has a very low rate of landscape development, while the scarp and gorge zone has a high rate of landscape development.

These differences in the intensity of landforming processes are mainly the result of the development of the east Australian highlands and scarp, and the ensuing changes in base level. The intensity of landforming processes in the Armidale-Uralla region was probably little affected by the development of the eastern highlands and scarp. Relative relief and stream gradients have mostly remained low, and local base levels still govern the rate of incision of streams. Thus the modern landscape in the Armidale-Uralla region may bear some resemblance to the pre-uplifted, pre-scarp landscape, in terms of relative relief and intensity of erosion, and can be used as a point of reference and source of evidence in considering the landscape history of adjoining areas.

10.1.1 THE SCARP AND GORGES

The modern eastern scarp has developed in response to uplifts of the eastern highlands. As the line of the scarp has eroded progressively westward, a diachronous landscape has developed in the area between the present east Australian coast and the scarp. The youngest parts of this landscape are immediately east of the scarp, and the landscape increases in age from the scarp to the coast.

Gorges have developed where rivers flowing as waterfalls over the scarp have progressively undercut the foot of the waterfall. Periodic rock falls resulting from this undercutting erode the base of the scarp, forming a gorge that retreats upstream. In the view of Ollier (1982b) the eastern scarp in the New England region is now retreating very slowly in comparison to past rates. He argued that the eastern scarp now approximately follows the contact between two distinct Permian beds. The beds to the east of the scarp are composed of slate, phyllite, schistose sandstone, schistose conglomerate and basic volcanics, while the beds underlying the scarp are composed of greywacke, slate, siliceous argillite and pebbley mudstone. Ollier (1982b) has claimed that these latter beds are much harder and more resistant to erosion than the beds to the east of the scarp, and that the concordance of the scarp with the contact between the rocks, results in the scarp now retreating very slowly. The relative erodibilities of the rocks east of and underlying the scarp would need to be closely examined before this conclusion could be confirmed.

In the Barrington Tops area 170 km south of Armidale, Pain (1983) has estimated that the eastern scarp has retreated a minimum of 80 km in the last 50 my. The basalt-capped Barrington Tops region is located east of the eastern scarp, but is connected to it by a series of ridges. It is a part of the eastern highlands that has been all but isolated from the main highlands by scarp retreat. Pain's (1983) estimate of the rate of scarp retreat in the Barrington Tops area is based on a reconstruction of the possible original areal extent of the 53-52 my Barrington volcano, and an assumption that at the time of volcanism the eastern scarp had not reached the area covered by the volcanic pile. Using data from Ollier (1982b), Pain calculated that the rate of scarp retreat in the Dorrigo area is the same (1,600 mm/1,000 yr) as his calculated rate for the Barrington Tops region.

The possibility must be considered that volcanism took place after the scarp had developed, but before it had retreated to its present position. If this were the case however, remnant valley floor basalts could be expected to have survived east of the scarp. None have been reported.

If development of the scarp was related to the continental splitting of eastern Australia, the oldest possible age for the initiation of the scarp is probably 80-60 my, the time of continental splitting. The scarp is now 40-120 km from the modern coast, although the modern continental edge in New South Wales, as delineated by the 200 m ocean depth contour, is 20-40 km east of the coastline (Bureau of Mineral Resources, 1979). Assuming the distance between the coastline and the continental edge to have been fairly stable except for eustatic changes, since the opening of the Tasman Sea, the minimum rate of scarp retreat is about 40 km in 80 my, or 500 mm/1,000 years. This is less than one-third of the rates calculated by Pain (1983) from both his own data, and from that of Ollier (1982b).

On the other hand, the highest rate of scarp retreat possible if the scarp was initiated by continental splitting, is about 120 km in 60 my (2,000 mm/1,000 years), slightly more than the rates calculated by Pain (1983). These two rates differ by a factor of four. This is probably an indication of the lack of reliability and usefulness of such calculations, which can only be made on the basis of many variables and assumptions. Despite this lack of accuracy, the rate of scarp retreat can be seen to be many times the rates of erosion calculated for the plateau regions of New England (Section 9.7, Table 2).

10.1.2 THE NEW ENGLAND TABLELANDS

The landscape of the New England tablelands has evolved largely unaffected by the formation 80-60 my ago of a new east Australian continental edge. Tectonic events such as regional uplifts have provided the impetus for continued, though slow erosion of the gorges back into the tablelands, but the dominant influence on landform evolution in New England during the Tertiary Period has been the basalt extrusions between 33 and 22 my.

As in the Armidale-Uralla region, basalt extrusions elsewhere in New England disrupted drainage patterns and formed new local base levels for post-basalt streams. The present distribution of basalt in New England suggests that the Glen Innes, Walcha and Ebor areas had more basalt to begin with than the Armidale-Uralla region. In parts of the New England tablelands where basalt inundated the landscape, new drainage networks formed, with little or no relationship to the pre-basalt drainage. This probably was the case in the Walcha and Glen Innes regions as well as some areas around Ebor and Point Lookout. All these areas still contain basalts several hundred metres thick. In areas that were only partly covered by basalts, new base levels formed where lava flowed onto existing valley floors. These new, higher base levels caused streams to aggrade upstream of the valley-fill basalt. Downstream of these new raised base levels, there was probably valley incision due to the increased gradient away from the basalt margin. This sequence of events is not based on field evidence in the Armidale-Uralla region or elsewhere in New England, as any such evidence has long been eroded, but can be seen in areas of more recent volcanism, such as the Newer Volcanic Province in southwestern Victoria (Figure 3), where valley-fill basalts have been the main determinant of drainage development and landscape evolution.

10.2 ANTIQUITY OF THE ARMIDALE-URALLA LANDSCAPE

The Armidale-Uralla landscape is extremely old. Some of the higher landforms, such as Mount Duval and Little Duval have probably been recognisable since well before the Tertiary basalt extrusions. The Main Divide may have moved no more than several kilometres since early in the Cainozoic. Less prominent landforms, such as Saumarez Creek and Dumaresq Creek, and their basalt-capped drainage divide have been evolving to their present form since the end of the basalt extrusions some 20 my ago.

The rate of geomorphic development in the Armidale-Uralla landscape is much lower than the rate in the gorge country to the east of Armidale. In this area rivers such as the upper Macleay have carved out landscapes with local relief of up to 500 m in the 18 my since the basalts were extruded in the Ebor area. In the same period creeks in the Armidale-Uralla region have probably incised no more than one-quarter of this amount.

Much of Australia has been tectonically stable for hundreds of millions of years and has been unaffected by glaciation since the Permian-Carboniferous glaciation (Fairbridge and Finkl, 1980). Remnants of this glaciation in the form of moraines and glacio-fluvial channels are claimed to be still visible in the landscape of southwest Western Australia (Fairbridge and Finkl, 1978; Finkl and Fairbridge, 1979). Parts of this post-glacial land surface may have been constantly exposed over large parts of the Western Australian craton since the end of the Permian-Carboniferous glaciation 250 my ago.

Even though the landforms of the New England plateau, and the east Australian highlands generally, do not have the antiquity of the cratonic surfaces of southwest Western Australia, they are still immensely old in comparison to the landforms of the Northern Hemisphere, many of which date from the end of the Pleistocene glaciations. Recognising this vast age difference is only a start. To understand landform evolution in an old landscape such as the New England region it is necessary to question and discard or modify many of the assumptions in traditional accepted models of landscape evolution. These traditional models, based on landform studies in very young Northern Hemisphere landscapes, cannot adequately explain the development of landforms in such geomorphically ancient areas as the New England region.

10.3 DIRECTIONS FOR FURTHER RESEARCH

The main aim of this thesis was to explain the geomorphic history of the Armidale-Uralla region. It became increasingly evident as the study progressed that this aim could only be achieved through extremely detailed investigation of the many individual components that comprise the Armidale-Uralla landscape. As a result there are a number of areas where further research could make a valuable contribution to fully achieving the aim stated above.

10.3.1 BASALT

Detailed petrographic analysis of basalts from throughout the Armidale-Uralla region would give valuable information about the extent of individual flows, the number of flow phases, and likely flow directions. Investigation of thicker basalt sequences (such as that shown in Plate 6), is likely to be particularly useful.

Radiometric dating of basalt at sites characteristic of each apparent flow phase would aid the identification of individual flows, and would enable absolute ages to be incorporated into a detailed explanation of the basaltic history of the Armidale-Uralla region.

Comparison of the petrography of basalts in the study area, with basalts from possible source areas in the Guyra, Walcha and Ebor areas, would help firmer conclusions to be drawn about the sources of basalts in the Armidale-Uralla region. At the same time, the possibility that some basalts were extruded within the study area, should be continually considered.

I have suggested that the basalts underlying the Saumarez-Area are older than those so far dated in the region. Radiometric dating, if sufficiently unaltered basalts can be obtained, would establish if this is the case.

10.3.2 FERRICRETE

Detailed study of ferricrete profiles throughout the Armidale-Uralla region is likely to give valuable information about formative processes. Further study should involve microscopic examination of oriented thin-sections from each horizon within the profile. This further detailed study would also enable thorough testing of the adequacy of the ferricrete classification scheme proposed in this thesis. Ideally, at each site, profiles would be studied at several points down the slope, so that the effect of slope position on ferricrete development could be considered.

Profiles could be exposed at several sites along an east-west traverse from the Main Divide, across the Saumarez-Arding area to the divide between Saumarez and Dumaresq Creeks. Study of these sites would enable comparison of ferricrete formed on the dated Oligocene basalts, with ferricrete on the as-yet-undated basalts underlying the Saumarez-Arding area. Backhoe excavation of ferricrete profiles might expose samples of this basalt suitable for radiometric dating (Section 10.3.1).

10.3.3 SILCRETE

This thesis did not consider in detail the topographic and stratigraphic relationships of silcrete profiles. Close study of these relationships at field sites and through oriented thin sections, would enhance understanding of the formative processes and landscape significance of silcrete. The results of this further study could be used to examine whether the silcrete classification scheme proposed in this thesis enables meaningful distinctions to be made between silcretes from different sites in the Armidale-Uralla region.

As in the case of ferricrete, there is great scope for further investigation of quartz grain provenance. This would involve the comparison of quartz grains in silcrete with those in possible quartz sources in the Sandon

Beds and granitic rocks. By direct comparison, a minimum reliance is placed on generalisations about quartz grain provenance on the basis of grain characteristics.

I have argued that silcrete in the Armidale-Uralla region is post-basaltic; a conclusion I feel is warranted on the basis of the available field evidence. Detailed stratigraphic study of silcrete-basalt contacts may provide further evidence on this crucial point. The best area to begin such a study is probably the silcrete-basalt contacts that straddle the Main Divide, down the eastern side of Map 1. Ultimately excavation may be necessary to expose the stratigraphic relationships.

10.3.4 PRE-BASALT DRAINAGE

Estimations of the position and flow directions of pre-basalt streams could be much improved by the systematic investigation of the roundness, imbrication patterns and lithology of sub-basaltic fluvial sediments. Such a study would result in a better understanding of pre-basalt drainage trends than that shown in Figure 18.

The pre-basalt drainage may have been considerably modified throughout the 11 my period of basalt extrusions. It is possible that the successive changes to the drainage system could be isolated, and put in dated sequence, by radiometric dating of basalts overlying sediment sites where the flow direction and regime appear clear. The basalt ages obtained at these sites could be also used in elucidating basalt flow history (Section 10.3.1).

The above suggestions are not exhaustive. Rather they relate to areas where further work is most likely to increase our understanding of landscape evolution in the Armidale-Uralla region, and the place of this region in the east Australian geomorphic setting.
