# CHAPTER 8

# PALAEOCLIMATIC INTERPRETATION OF PERMIAN SEQUENCES

## 8.1 INTRODUCTION

The aim of this study has been to reassess the glacial designation of sediments in the northeastern district of Victoria. Chapter 1 indicates the extent of prior knowledge of the sediments and further shows that a major part of this knowledge has been subsequently overlooked since the late 1930s because of the preoccupation with summary accounts. Detailed geological mapping ( Ch. 3 and maps 1 to 6 - map pocket) now shows more accurately the distribution of these sediments and attempts to correct the recent summary accounts.

Chapter 2 shows how difficult it is to reliably identify glacial deposits and that there is no single absolute discriminator for glacial deposits. Instead as many discriminators as possible should be employed in the hope of eliminating other possible interpretations.

In the case of the designated glacials in the northeastern district there are added difficulties resulting from their widely scattered and isolated nature. The gathering of detailed information has been severely hampered by very poor exposure and lack of stratigraphic control. Therefore, an assessment of these deposits has been reduced largely to a dependance on lithology. The only two lithologies

available are diamictites and associated interstratified traction current (?fluvioglacials) deposits. Sediments of the latter environment have no clearly diagnostic characteristics and are identified only by their association with diamictites.

## 8.2 DIAMICTITES

Assessment of the diamictites (see descriptions Ch.3, pp.63 to 117) is based on petrography, provenance and glacio-geomorphic evidence using discriminators evaluated in chapter 2 (pp.28 to 62).

### 8.2.1 PETROGRAPHY

The diamictites contain clasts which are clearly and well striated by either uni- or multidirectional striae. Striae do not extend into the supporting matrix. These features point clearly to the glacial origin of striated clasts (see Ch.2, pp.34 to 37). In addition, the diamictites contain well striated diagnostic clasts shapes (wedges and bullets) corresponding to those shapes believed to be characteristic of glacial environments (Ch.2, pp.36 and Ch.7, pp.173 to 177).

### 8.2.2 GLACIO-GEOMORPHOLOGY

The seven pavement surfaces are associated with some of the diamictites. Erosional features on these surfaces demonstrate their glacial origin (Ch.2, p.32, Ch.5, p.163) and also indicate ice-movement from south to north. One of the glacial pavements is in the form of a miniature roche moutonnée and because of its orientation further confirms ice-movement to the north (Craig and Brown, in press).

### 8.2.3 PROVENANCE

The diamictites contain a variety of clast lithologies (Ch. 1, p.3 to 12 and Ch. 3 ) most of which are not sufficiently distinctive to reliably determine source terrains. Some erratics are, however, distinctive (pl.23, p.105) and indicate likely southern sources between 20 km and 150 km (p.161) beyond the Wangaratta district. The most distinctive erratics are fossiliferous (p.122) and were earlier thought to be derived from Heathcote (p.161) but this now is not the case. Instead, the source terrains are beyond the present southern margin of the Australian craton (p.160 to 161).

## 8.3 SUMMARY

The evidence available from clast petrography, provenance and associated glacio-geomorphology points clearly to the glacial derivation of the diamictites of northeastern Victoria. The interstratified traction deposits are therefore very probably fluvioglacials. This is further supported by evidence (p.182) showing that traction deposit clasts are derived from the diamictites.

Other lines of investigation not in themselves definitive but which do not detract from the present interpretation are:

1. Quartz sand grain surface textures (p.203)

2. Heavy minerals (p.209 to 211)

3. Fabrics (p.167)

The degree of weathering of the deposits prevented any successful granulometry of the finer than gravel fraction and therefore this line

of investigation was not persued beyond the preliminary attempts. Neither has it been possible from this study to confidently discriminate between lodgement, ablation or flow tills (see glossary, p.279).

# CHAPTER 9

## A SUMMARY OF PERMIAN GLACIAL SEDIMENTATION IN NE VICTORIA

Isolated and widely scattered Permian glacial deposits crop out over an area of about 15.5 x$10^3$ km in Northeastern Victoria. For the Wangaratta sheet, the total outcrop covers less than about 75 $km^2$ and represents less than 0.5% of the sheet. Outcrop is restricted to the following six major areas:

1. Wilby (pp.93-94, map 5)
2. Taminick (pp.93-94, map 4)
3. Nillahcootie (pp.94-99)
4. Moyhu-Whitlands (pp.81-93, 99-120, maps 3 & 6)
5. Ovens-King Rv. Valley (pp.77-81, maps 2 & 3)
6. Wooragee Valley (pp.63-77, 120, map 1)

The two original localities of Dunn (1871) have now been mapped in detail (pp.63-76) and their distribution extended by the recognition of about ten new localities (see map 1,). In the Moyhu-Whitlands area about 30 new Permian outcrops (see Ch.3 & 4, tab 1 & maps 3 &6) now bring the total number known to 114. The Permian sequences are thin, ranging from 1 m to 30 m thick; most are less than 5 m. The precise

stratigraphic relationship between scattered outcrop is not known. All rest unconformably on either Ordovician or Carboniferous basement rocks.

The sequences comprise conglomerates (including diamictites) and sandstones, with lesser amounts of laminated siltstone and mudstone. At localities where one or more rock-types are present (pp.81-92) lack of suitable exposure prevents stratigraphic relationships being determined. On a regional scale, the only discernable facies trend is the relative abundance of laminated siltstones and mudstones at some localities just north of the amphitheatre-like depression (p.87), just south of the Moyhu glacial pavement. Neither conglomerates nor sandstones show apparent regional coarsening or fining. All deposits are assumed to be terrestrial. Marine glacigene sediments and deltaic facies occur about 80 km north of the study area in the Oaklands Basin (Powell and Driver, 1971). The possibility of marine influence in the subsurface Ovens Graben has been raised by Lawrence (1975) - (p.21).

Because lack of exposure prevents the determination of stratigraphic relationships, it is not possible at this stage to interpret detailed glacial history with any clear degree of confidence. However, the interbedding of conglomerates and diamictites and fluvioglacial sediments in the best exposures (Wooragee, p.64 & Whitfield-Whitlands, p.100-119), and the increasing occurrence northwards of laminated siltstones and mudstones, together with marine and deltaic sediments in the Oaklands Basin all point to an ice margin to the south. There is no evidence of more than one glacial event being recorded. Neither is there any evidence in the best exposed sections of relative advance or retreat of an ice front.

Siluro-Devonian faunal assemblages (p.132) from Permian glacial clasts in the study area are now known to be similar but not identical with Siluro-Devonian assemblages at Heathcote (p.158-161), Zeehan - Tasmania (p.159), Antarctica (p159) and Cobar: the Amphitheatre Group -N.S.W.( Talent, pers. comm.). However the recognition of Australocoelia only in Permian glacial clasts of Northeastern Victoria suggests Heathcote is unlikely as a source (p.160). Australocoelia is known from the Bohemian province of the Zeehan area in Tasmania but the species is different (p.159). Furthermore, Cobar can be discounted because of ice flow data (p.163). Looking to the much wider distribution, Australocoelia is known in the Malvinocaffric provinces in South America, South Africa, Falkland Islands, Antarctica. Although the accompanying faunal assemblages do not correspond closely to those of the Northeastern district clasts (p.159), some southerly source for the fossiliferous erratics is therefore still contemplated. However, from the palaeontological evidence available all that can be deduced is that the source of the fossiliferous clasts is a presently unknown sequence either in Tasmania or the Horlick Mountains region of Antarctica. Such a source would be involve much shorter transport distances and be more consistent with known transport distances than any contemplated in South America, Africa or the Faulkland Islands, and is more in accord with known ice flow directions (Hamilton and Krinsley, 1967 p.795).

Clasts comprise many varieties of igneous, sedimentary and metamorphic rocks as well as quartz, agate and gossanous residues (chapter 3, pp.63-121). Radiolarian cherts (p.24) and corundum pebbles (p.13) are most probably derived from the Mt. Wellington axis about 150 km S of the study area (p.161). Rhodacites, rhyolites and acid porphyries closely resemble rocks from the Tolmie igneous complex ( Dr.

M.C. Brown, pers. comm.) about 20 km south of the study area. Sandstone clasts indicative of the Carboniferous red beds of the Mansfield Basin between 20 to 50 km south of the study area have been recognised (p.17,74). One large (approx. 2 m) erratic at the Lower Road cutting (plate 23, p.105) resembles quartzite from the Cambrian inlier (Dr. M.C. Brown, pers. comm.) about 30 km SSW of the study area. Many of the other lithologies listed (Ch. 3) are not sufficiently distinctive to indicate any particular source areas without very exhaustive studies. The earlier mentioned gneiss and pisolitic limestone clasts (p.83) cannot be sourced with any terrain south of the study area and at this stage remain enigmatic.

Petrographic evidence further confirming such a southern source is the radiolarlian cherts (Ch. 4, p.161) probably derived from the Mt. Wellington axis. Other circumstantial petrographic evidence includes the rhyolites, rhyodacites and acid porphyries presumably from the Tolmie igneous complex (p.88) and the sandstone clasts similar to the Carboniferous of the Mansfield basin (p.74). However, most of the 2 - 3 thousand clasts examined are not sufficiently distinctive petrographically to be attributed to any particular source. Medium grained indurated sandstone is dominant and comprises more than 70% of the clasts. Some sandstone and siltstone clasts are richly fossiliferous (p.86).

Morphological examination of clasts shows the most common shape is a spheroid (see Ch. 3, pp.63-119& Ch. 6, pp.178-186). Two areas examined (Wooragee, p.68 and in more detail, Whitfield-Whitlands Road Cutting deposits, p.181) show proportions as high as 80% at Wooragee and 50% in the Road Cutting samples. Roller and Disc shapes (p.181) are less abundant with blade shapes comprising the remainder.

The proportion of clasts with striae vary from < 5% at Wooragee to 10% in the Road Cutting samples. Only sedimentary clasts exhibit striae and 95% of these striated clasts show multidirectional scoring. Unidirectionally striated clasts (p.179) have been recovered from only two localities (unit 1 diamictite in the Lower Road Cutting, p.108 and at Nillahcootie, p.98). Fossiliferous clasts are often multidirectionally striated. Multistriations are restricted to less indurated sandstones and siltstones, unidirectional striae are only visible on the tougher resistant sandstones.

The rare but diagnostically most important non-fossiliferous wedge and bullet shaped clasts with well preserved unidirectional striae indicate subglacial environments (Von Engeln, 1930; Wentworth, 1936; Drake, 1972 and Boulton, 1978 :see Ch. 6) and because their shape is so unlike the spheroid or ovoid shapes developing after prolonged transport (Holmes, 1960 and Drake, 1972: see pp.175-182) imply relatively short transport and hence local derivation. I believe the survival of the striations indicates little reworking. Some minor reworking (perhaps Tertiary) is possible at Nillahcootie. Dominant ovoid shapes present in all diamictites and conglomerates (sometimes multidirectionally striated and/or fossiliferous), point to englacial transport (p.175-182) from distant sources (Ch. 4, p.122& Ch. 6, p.173). Detailed study of clast suites from the Upper and Lower Road Cutting sections (pp.99-120) show dominant sandstone clasts with spheroid and disc shapes (p.181). Statistical comparison of these shape populations with Hooker Valley (p.183), Taylor Valley (p.183) and Breidamerkurjoekull glacial clasts shows similarity with the latter but differences with the former two (p.188). These differences have been attributed (p.185) to presence of supraglacial detritus in the Hooker and Taylor Valley samples and shows

the diamictite clasts as having been shaped in a sub- or englacial transport environment. In addition, at the Whitfield -Whitlands road cuttings the similarity of clast shapes in both the diamictites and the interbedded conglomerates shows there has been no shape modification in the latter environment and strongly suggests:

1. Derivation of traction current deposits from interbedded diamictites

2. This in turn points to the very likely fluvioglacial origin of the similar glacial deposits exposed nearby, in the Upper Whitfield - Whitlands road cutting (pp. 99 - 120).

That some of the material is of local derivation or has only undergone a relatively short transport distance is indicated by the presence of uni-directionally striated wedge or bullet shaped clasts. These are unlikely to have survive great distances in a subglacial environment (see chapter 6, p.173). Furthermore, the fact that non-fossiliferous rocks petrographically similar to many of the clasts crop out south of the study area, supports this view.

Heavy mineral studied provided little useful data to this study. The dominance of opaques (p.246) in heavy mineral suites from Upper and Lower Road Cutting strata (p.208) and Wooragee (p.209) indicated some chemical weathering. The suites are lacking in garnets and contain varied amounts of metastable minerals (p.246) and because of this are different from the heavy mineral assemblages in Bacchus Marsh deposits (p.211 ). Differences in heavy mineral species between the fluvioglacials and the diamictites although statistically significant cannot be given a satisfactory geological explanation.

The seven glacial pavements and miniature roche moutonnée (p.216) all demonstrate ice motion towards N. Furthermore, this is in part supported by the ENE ice-flow direction indicated by the pebble imbrication data a Wooragee.

# CHAPTER 10

# PHYSIOGRAPHY AND LANDSCAPE EVOLUTION

## 10.1 INTRODUCTION

For much of the twentieth century landscape evolution has been interpreted in terms of cycles of erosion where erosion dominates, together with depositional landforms where aggradation dominates. A more recent approach has been to determine present day geomorphic processes and from the assumption that the landscape was in a state of "dynamic equilibrium" explain the landscape in terms of observed present geomorphic processes. In Australia landscapes have evolved over geologic time measured in Periods instead of epochs or some smaller period of geologic time. Neither process studies, "dynamic equilibrium" nor cycles of erosion can provide meaningful explanations for landscape evolution over such vast time scales as those evident in Australia (Ollier, 1979).

For this reason I shall attempt to describe the development of the landscape in the northeastern district of Victoria from Permian times to the present in terms of "evolutionary geomorphology" (Ollier, 1979). Conventional geological data, including tectonics have an important role when dealing with landscape evolution over such a long time scale but as the area has remained landsurface since about the Middle Palaeozoic and has been dominated by erosion for much of this time, the erosional

landscape features are of prime importance. Even though the geomorphic explanation is presented in evolutionary terms it still will shown to be consistent with the physiography of the study area. This chapter begins by outlining regional landscape units and their ages in parts of the Eastern Victorian Highlands, including Northeastern Victoria. Relief, drainage and watershed patterns, and the distribution of Tertiary basalts are described in detail for the study area because they provide final constraints on possible landscape histories. Because any account of landscape evolution in the study area must take into account the distribution of Permian glacial deposits; the geology, geomorphology and history of Glenrowan Gap; and the validity of the Ovens Graben, they are also discussed in detail. The chapter ends by suggesting a model of landscape evolution (in part necessarily somewhat speculative) followed by an overall chapter summary.

## 10.2 PHYSIOGRAPHIC UNITS AND THEIR AGE

The major physiographic divisions of Victoria (Hills, 1946) have been recently revised and modified by Hills (1975). The rearrangement of the divisions has led to a simpler, more consistent set of physiographic divisions. Northeastern Victoria is described by two major divisions:

1. The Central Highlands
    - [a] The Eastern Highlands
    - [b] The Northern Uplands
2. The Murray Basin.

The highland areas east of a line between Melbourne and Echuca contain a number of relatively flat surfaces or "high plains" for example:

* Bogong High plains;
* Dargo High plains;
* Snowy High plains;
* Connor's Plains;
* Bennison Plains;
* Howitt Plains;
* Cobbler Plateau;
* Nuniong Plateau;
* Baw Baw Plateau;
* Hotham Tablelands.

(from Hills, 1975)

These are now called "oldlands", "palaeoplains" or "palaeosurfaces". Hills (1946,253;1975,302) shows the evolution of these palaeoplains by a series of generalized east-west cross-sections. Many of these surfaces are now covered by remnants of Older Volcanics (Abel et al 1976, 180). The palaeoplains owe their preservation to a variety of circumstances.The main modes of preservation are:

1. Preservation because of a very resistant bed rock

   for example: Mt. Baw Baw¦
   and ¦both granite
   Mt. Buffalo¦

Warburton range¦
and ¦both Devonian lavas
Mt. St.Leonard ¦

2. Preservation due to divide proximity

for example: Bogong High Plains

3. Preservation as a result of down-faulting

for example: Omeo and Benambra Regions

(from Hills, 1975)

Hills (1975, 302) suggests the age of the first palaeoplain of the evolutionary sequence is older than Cretaceous, perhaps either Jurassic or Triassic; the sequence developing after Permian ice retreat and therefore containing local relics of Permian landsurfaces. He adds that the identification of these relic Permian surfaces is as yet only speculative.

The Triassic-Jurassic age of the Mesozoic palaeoplain (Hills, 1975) is in part based on the occurrence of terrestrial Cretaceous sedimentary rocks in southern Victoria. The palaeoplain is therefore Cretaceous or older. The most direct evidence of the age of the oldest palaeosurface is from dated trachytic lavas, tuffs and intrusions. These events show a K-Ar age of 200 my.(Hills, 1975). Revision of palaeontological data has led to the general acceptance of an Early Cretaceous age for those outcrops for many years regarded as Jurassic (Douglas and Ferguson, 1976).

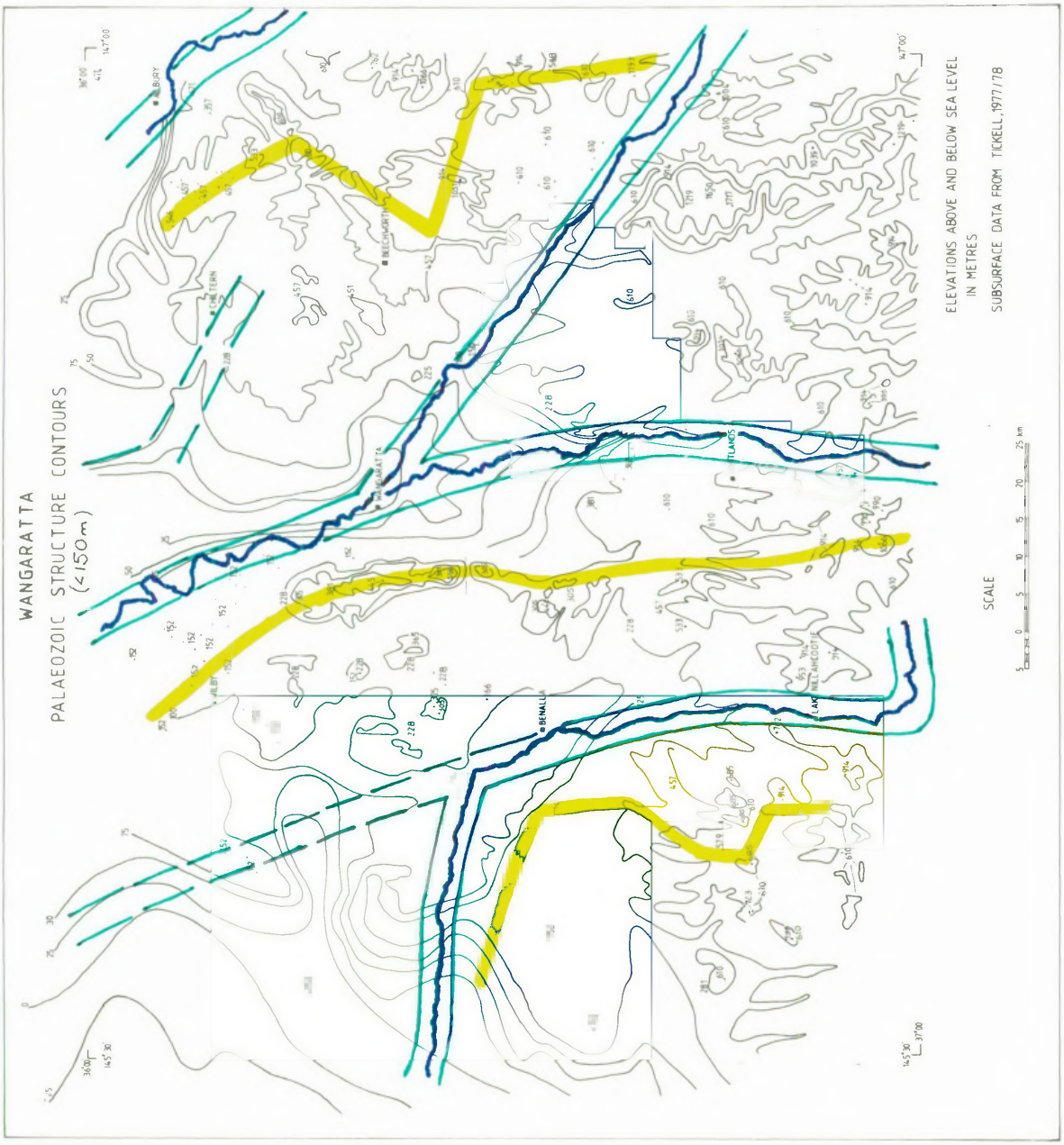
Jenkins, 1976 (in-Douglas and Ferguson eds., 1976) believes the oldest recognisable geomorphic elements in Victorian landscapes to be erosional relicts from Late Palaeozoic or Early Mesozoic times and cites the extensive erosional surfaces in the eastern part of the Central Highlands as examples. His scenario includes uplift along an east-west axis in the vicinity of the Central Highlands as long ago as Permian followed by renewed activity along pre-existing Palaeozoic meridional structures. Amongst these he shows the Ovens "Graben" as a structure with a single western fault boundary: a fault angle depression rather than a graben.

## 10.3 DRAINAGE AND WATERSHED PATTERNS

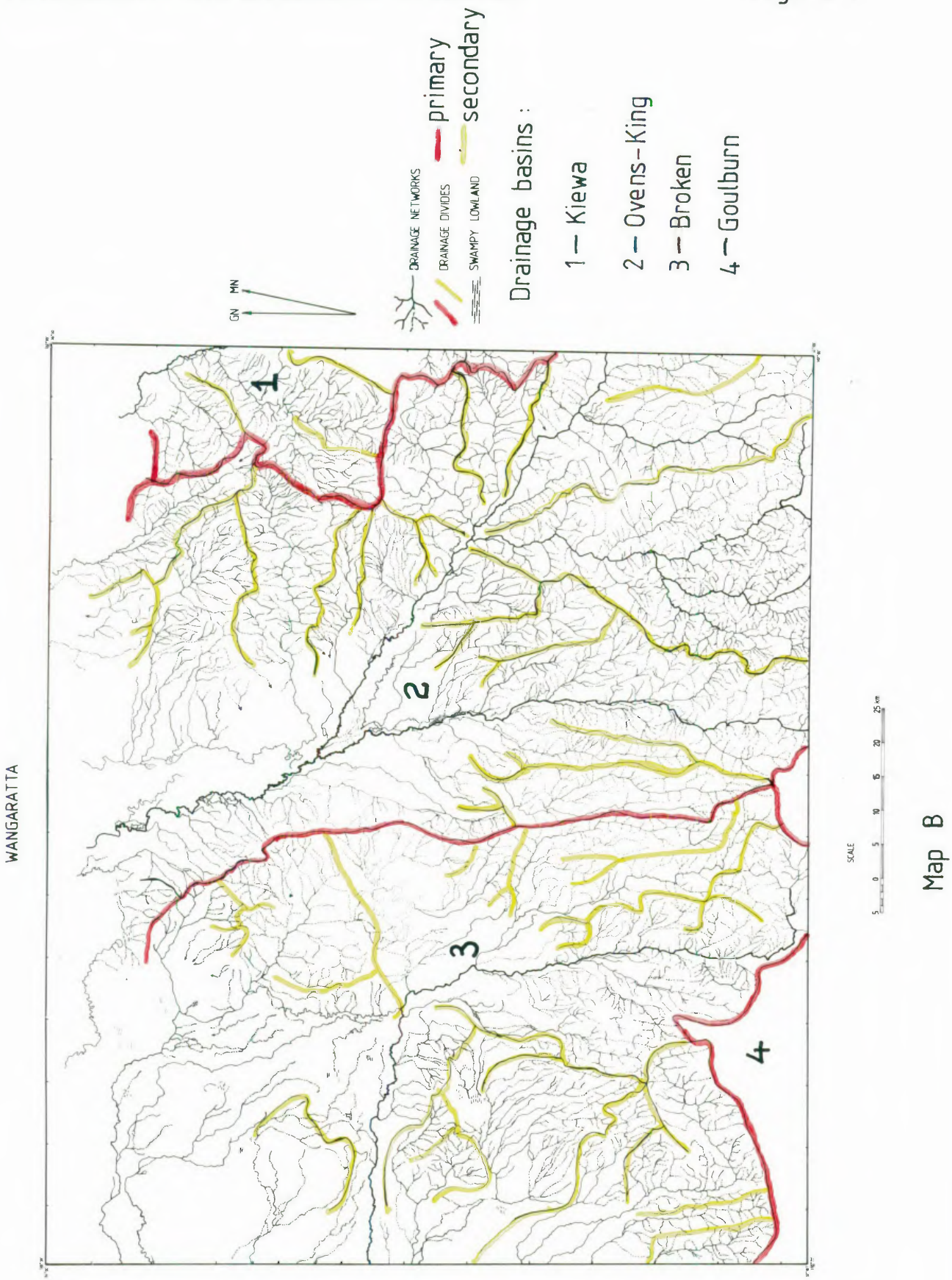
### 10.3.1 INTRODUCTION

There is a variety of drainage patterns with varying drainage densities but all indicate a strong structural influence. The major rivers, the Ovens King and Broken Rivers coincide with major basement lows (see map A, p.231). The trend directions of the basement lows seem to be related to gross fault geometry across Victoria (see Abele, 1976). The detailed drainage patterns (map B, p.232) shown on the Wangaratta sheet are in part influenced by the Palaeozoic basement structure.The divides can be clearly grouped and outline basement structure patterns which suggest likely complex fault blocks rather than simple graben structures.

The Wangaratta 1:250 000 topographic map (sheet SJ55-2, ed.1, 1972 as ammended) shows three major divides. The most significant exception is the central divide which trends almost north-south until it reaches a point about 5 km NW of Wangaratta. From there it swings NW to NNW




Map A Palaeozoic subsurface structure contours (<150 m) and Palaeozoic surface contours (>150 m), and the positions of major rivers and divides.




Map B Major drainage divides, lines and basins

toward the town of Cobram, forming a continuation of a lineament along the course of the Murray River.

The second major divide winds from Porepunkah via Mt. Stanley toward Yackandandah and continues to an area just south of Wodonga. The divide separates drainage that flows N and NE from drainage that flows N and NW toward the central major divide. On the west of the central divide, drainage is both W and NW.

The third major divide is located in the Strathbogie Range, south of Benalla. This divide separates drainage of the Goulburn River catchment from the north flowing Broken River and its tributaries. The divides and major drainage lines are shown on map B, page 232. The network of divides outlines four major drainage basins:

1. The Kiewa Basin

   Drainage NE and N

2. The Ovens-King Basin

   Drainage NW, W and NNW

3. The Broken River Basin

   Drainage NNW and W

4. The Goulburn Basin

   Drainage S and W

A number of secondary divides continue beneath Mesozoic and Cainozoic sedimentary cover and can be followed as ridges in pre-Permian basement (see map A, p.231). In the Kiewa Basin, secondary divides show a NE alignment; in the Ovens-King Basin, divides south of the Ovens

River point N but on the N side, predominantly W. No clear single pattern is present in the Broken River Basin, which has a mixture of N, NW and W pointing divides. The area between the major central divide and the Broken River but south of Lake Makoan, has divides that point N but some NW divides can be seen. In contrast, SW of Lake Makoan, an area SW of the Broken River has divides which point mostly N, NE and NW. Just NW of Lake Makoan divides west of the major central divide point NW with minor ones pointing SW. Map A, p.231 shows detailed drainage networks together with the three major divides as well as other secondary divides.

The pattern shown by drainage and divides suggest evolution from NW drainage controlled by initial structures, then by N-S structures except for a major anomaly: Glenrowan Gap. This Gap was part of an ancestral westerly drainage system which flowed through the N-S Warby Range divide. The nature of this feature will be discussed in more detail in the course of this chapter.

### 10.3.2 RELIEF

Relief in the northeastern district of Victoria varies from about 150 m to around 1400 m. The Uplands falls between these two relief categories and is located between the Murray Basin plains and the rugged higher dissected topography of the adjacent Eastern Highlands.

The northeastern district, a geographic region rather than a physiographic entity, involves all relief categories of the major physiographic divisions. Relief varies from:

1. The Central Highlands

   The Eastern Highlands portion:from 1000 m in the Tolmie Highlands to 1600 m at Mt. Baffalo.

2. The Central Highlands

   The Northern Uplands portion:From 600 m in the hills around Beechworth to about 150 m on the floor of the Ovens-King River Valley to around 500 m in the Warby Range to the west of the Valley. West of the Warby Range there is a gradual slope toward Dookie.

3. The Murray Basin Plains

   to about 150 m around the flat expanses between Yarrawonga and Rutherglen.

The area south of the Ovens Valley is rugged and intensely dissected but from appropriate vantage points (Power's Lookout, Mt. Samaria or in the Strathbogie Range) remnants of the Cretaceous and subsequent Tertiary erosion surfaces can be seen. Most rivers north of the east-west divide are strongly influenced by basement structure and tend to flow generally north or northwest to eventually meet the Murray.

The Eastern Highlands rise gradually from WSW to ENE, a trend that is approximately at a right angle to the NNW basement structural trend. The eastern part of the Central Highlands is separated from the western part by a relatively low area (335 m) referred to as a Geocol (Taylor, 1911) near Kilmore (Hills, 1946, 1975; Ollier, 1978). Relief in the Eastern Highlands ranges from about 1350 m at Connor's Plains to about 2000 m at Mt. Bogong. The Central Highlands, both east and west show a distinct asymmetry: slopes on the southern side of the Highlands are steeper than those on the northern side. This is readily seen in relief models of southeastern Australia (see photos in Hills-1975, 277).

### 10.3.3 THE SIGNIFICANCE OF TERTIARY BASALT

The most valuable clues to tectonic activity besides major structural discontinuities are the planation surfaces and the distribution of the Older Volcanics.

In central and eastern Victoria vast quantities of basaltic lavas were extruded onto erosion surfaces. The volcanic centres have been shown (Wellman and McDougall, 1974; Hills, 1975; Ollier, 1978; 1979; 1981) to become progressively younger toward the SW.

The basaltic lavas of the Eastern Highlands range from about 18 my to about 42 my old. Many are about 35 my old. Near the Northern Uplands only one basalt had been dated (the Seven Creeks flow) and gave a radiometric age of 7 my. Further to the north in the Murray Basin Plains, near Dookie, another basalt gave a radiometric age of 6 my. Basalt on the eastern side of Glenrowan Gap gave a radiometric age of about 36 my.

Dated basalts can be used to indicate minimum or maximum ages for a variety of geomorphic, geologic and tectonic events in the surrounding landscape thereby adding to the total story of landscape evolution. This technique has already been successfully applied in parts of the Eastern Highlands. Uplift in the vicinity of Gelantipy appears to have been about 600 m since Late Eocene; to the WSW, at Aberfeldy, uplift is about 650 m since Oligocene (Ollier, 1978; 1979). In contrast, there has been little or no uplift at Seven Creeks for at least the last 7 my because dated basalt is presently at river level (Wellman and McDougall, 1974).

Older Volcanics of about the same age in the Northern Uplands show a difference in elevation of about 750 m and are associated with Tertiary erosion surfaces. This amount of uplift compares favourably with estimates of uplift of the Central Victorian Highlands by Ollier (1978; 1979).

### 10.3.3.1 THE GLENROWAN GAP

#### 10.3.3.1.1 PHYSIOGRAPHY -

A major divide trends along the Warby Range and contains a number of gap-like features but the Glenrowan Gap is the only one of any significance. The others are merely saddles where east and west headward erosion are now lowering the divide. The Glenrowan Gap is a distinct topographic feature about 200 m to 300 m below the general level of the Warby Range and is about 60 m above the floor of the Ovens-King River Valley. It extends through the Warby Range for a length of about 4 km maintaining a width of about 1 km and a general altitude of about 210 m. The Gap is similar in setting to Geary's Gap

on the western scarp of Lake George N.S.W. (see Ollier, 1979) where, sometime during the Tertiary, faulting resulted in the defeat of the west flowing Taylor's Creek. The physiography and following detailed geology of Glenrowan Gap are critical to an understanding of its development which is discussed further in section 10.5 of this chapter.

10.3.3.1.2 GEOLOGY OF GLENROWAN GAP -

Sediments within the Gap are well bedded, dip about $5^{o}$ W and are derived from weathered Silurian granites of the surrounding Warby Range. The age of the sediments is probably Tertiary with perhaps some Quaternary sediments overlying them.

Basalt is present in the eastern end of the Gap near the intersection of the Hume Highway and the Greta Road. The radiometric age of the basalt is 35.6 + - 0.5 $x10^{6}$ yrs (see Amdel report appendix 1 ). The basalt suggests that the Gap existed at that time and lava flowed through it. Basalt remnants are also present near the northeastern end of Lake Makoan where they unconformably overlie Permian glacial deposits. The elevation of the Lake Makoan basalt is only a few metres below that of the Glenrowan Gap basalt. Similar basalts overlie Permian glacials and Lower Palaeozoic basement beyond the southern end of the Ovens-King River Valley in the vicinity of Hansonville. The elevation of the base of the basalt beyond Hansonville gradually increases south toward the Tolmie Highlands.

The Glenrowan Gap occurs at the boundary between Ordovician basement and Silurian granite. The Gap does not follow the contact perfectly because on the eastern side of the divide, it begins wholly within the granite, but toward the west it appears to be closely aligned

with the contact. The contact metamorphosed Ordovician rocks at the boundary doubtless would be far too tough to provide an easily erodible pathway. It would seem more likely that the path of least resistance would occur just beyond the contact zone within the more erodible granite. The metamorphic rock bounding the Warby Granite at the Gap is not shown on the Wangaratta geological map but it is definitely present, and is quarried within the Gap.

## 10.4 TECTONICS AND THE DISTRIBUTION OF PERMIAN DEPOSITS

### 10.4.1 TECTONICS

The present distribution of Permian in the northeastern district of Victoria has long been associated with faulting. Summers in (Skeats 1935, 122) suggested trough faulting is responsible for preservation of glacial deposits in the Ovens-King River Valley. He offered no evidence for trough faulting, and his view was based on analogy with similar situations elsewhere in Victoria where glacial deposits were thought to be associated with trough faulting. Summers' "trough faulted" Ovens-King River appears to be the first reference to the area now known as the "Ovens Graben".

Mahony (1937, 515) stated that most Permian glacial deposits in Victoria have been preserved by faulting or by the presence of a protective covering of younger rock.

Hills (1946, 37) presented a model for the evolution of the Futter's Range (now better known as the Warby Range: shown on geological maps as the uplifted block west of the Ovens Graben). Hills used a series of diagrams to show the development of a fault-line scarp, facing east in the same direction as the proposed fault. No direct

evidence was offered for the existence of the fault and so Hills' evolutionary model remained speculative. The proposals of Summers and Hills are similar but both lack direct evidence.

Harris and Thomas (1948, 51) showed a suggested western fault boundary in the northeastern district, but for an area much larger than the Ovens-King River Valley. The suggested fault is near Dookie, just west of Devenish and Baddaginnie. The fault was suggested because of the juxtaposition of areas of Ordovician shales and Cambrian "diabases" and "the widespread metamorphics" to the east. Three areas of glacial deposits were shown on their map to be associated with possible meridional faults. In addition to proposing the major north-south faults that preserved the Permian glacials they also stated that the eastern edge of the Warby Range and the western edge of the Beechworth granite complex both marked a minor basin [the Ovens-King River Valley] and that the Coorabin-Oaklands coalfield, in N.S.W. (Palese, 1974), is in line with its northerly extension.

Scheibner (1974), Bembrick (1974), Palese (1974), Lawrence (1975;1976) , Abele (1976), Bowen and Thomas (1976), McIntyre (1976) and Tickell (1977/78) all treat the Ovens Graben as a well established and proven structure. Palese suggested the possibility of the Oaklands Basin (80 km N of the Ovens-King River Valley) being fault bounded and suggested that the faults extend to the south to link with the Ovens Graben. McIntyre was not convinced of the reliability of the interpreted fault boundaries of the Oaklands basin but expressed no similar doubt about the nature of the supposed Ovens Graben.

From these models and proposals, the Ovens-King River Valley has been gradually transformed in the literature from a possible fault bounded depression into the fully fledged Ovens Graben. No evidence supporting this transformation is presented in the literature. The first reference to the Graben as such is on a map by Spencer-Jones (1969, 48). It has remained unquestioned since then. Since any account of the geology and palaeogeography of the northeastern district involves the Ovens-King River Valley, the validity of the Ovens Graben is very important and will be considered in greater detail.

### 10.4.1.1 THE OVENS GRABEN

The graben concept probably owes its birth to those (Summers,1935; Mohony, 1937; Hills, 1946 and Harris and Thomas, 1948) who had a speculative eye for landform evolution.

The structure as we now know it is shown on the Wangaratta geological map (edit. 1, 1974, sheet SJ55-2) as an approximate north-south feature with a near linear western edge bounding the Warby Range granite, a central plain approximately 25 km wide consisting of Permian and Tertiary sediments overlain by Quaternary alluvium resting on Ordovician basement and a somewhat irregular eastern edge bounded by Devonian granites of the Beechworth district. The alluvial plain and the eastern and western boundaries extend N for about 60 km.

The highlands rise about 450 m on both sides of the plain but the slope gradients are quite different. The gradient of the eastern slopes to the highlands is about $2^{o}$ but on the western side the slopes have gradients of about $5^{o}$. On the geological map the Graben is bounded to the south by a structure line interpreted from ERTS satellite

photography. The eastern boundary consists of three areas:

1. The southern part by an inferred fault;

2. The central part consists of intact (not faulted) Devonian granite;

3. The northern part is shown by a line interpreted from satellite photography

This northern boundary curves toward NNW just as the central major divide does (see map B, p.232). The western limit of the Graben is shown by similar structural boundaries to those in the east:

1. A northern inferred fault swinging to the NNW.

2. A central intact section

3. A southern inferred fault

The geological map depicts the Ovens-King River Valley as a bilateral graben structure with a central east west hinge. These boundary structures are reproduced in fig. 8, p.247, north of the Moyhu pavement. Seismic activity recorded in the northeastern district by officers of the State Rivers and Water Conservation Commission (D. Currey, pers. comm.) shows activity both east and west of the Ovens-King River Valley, but this does not coincide with any of the inferred graben boundary faults. Instead, epicentres plot near Myrtleford. These relate strongly to a lineament inferred from satellite photography, which cuts across the Ovens Graben along a NW--SE direction. Other epicentres show minor seismic activity in the vicinity of Benalla and appear to relate to a lineament inferred from satellite

imagery in the Lake Makoan-Benalla district. This lineament is a NE-SW trending feature.

It is also instructive to examine how the alleged Ovens Graben fits the wider tectonic pattern of Victoria. An inspection of the general fault patterns across Victoria reveals two important observations:

1. The faults belong to either a NW-SE : NE-SW conjugate set, or to a N-S bisectrix set which seem to be associated only with tilt blocks, not Grabens. Examples of these faults are:

   [a] Cadell;

   [b] Leahur;

   [c] Mt. Ida;

   [d] Hindmarsh;

   [e] Murrayville

   [f] and Danyo,

   so in this respect the Ovens Graben is an atypical structure.

2. The major faults (listed in 1) all displace basement rocks. The boundary faults which supposedly limit the Ovens Graben (see Abele et al. 1976, 190 and Tickell, 1977/78, 9) do not. This suggests that some or all of the faults do not exist.

In view of the general pattern of faults, the pattern of seismicity and the lack of basement disturbance the Ovens Graben concept cannot be supported. The model which best fits the available evidence is a tilt block.

### 10.4.2 DISTRIBUTION OF THE PERMIAN DEPOSITS

Early reports of the northeastern district showed Permian deposits confined to present valleys. However, the Permian glacials in the northeastern district are not restricted to the valley floors; they occur at all levels south of the Ovens-King River Valley toward the Tolmie Highlands. In some places the base of Permian is wavy and can be best explained as initial variations in the pre-Permian surface. There is no evidence for major displacement of the Permian or older Palaeozoic basement to the south of the Ovens-King River Valley. The distribution of Permian glacials at the supposed southern boundary of the Ovens Graben indicates nothing more than gentle northward sloping Permian sediments unconformably overlying Ordovician and probably unconformably overlying Carboniferous basement.

One curious anomaly in the distribution of the Permian glacials within the southern end of the Ovens-King River Valley is that the major outcrops have an approximate NW alignment towards Glenrowan Gap. The first Permian deposit west of the Warby Range at Taminick is capped by a thin veneer of Older Volcanics that is at the same elevation as the Gap. Other Permian deposits in the Taminick area also have a NW alignment and are quite close (5km) to the Gap.

## 10.5 DEVELOPMENT OF THE GLENROWAN GAP

To explain the long term evolution of the Glenrowan Gap and associated glacial deposits we must look to Permian times.

The divide near Glenrowan was quite possibly low even in Early Permian times due to differential erosion along the contact between the more erodible Warby Range granite and the tougher bounding Ordovician metamorphic rocks.

The pattern of glacial deposits just west of the Gap could be explained by a process of ice over-spill during a major advance from the south but this does not help explain the pattern of NW aligned deposits preserved SE of the Gap on the eastern side of the Warby Range.

One possible explanation of the pattern of Permian deposits which accounts for all present data is that perhaps small glaciers developed from isolated ice caps in the south and then extended north into the southern portion of the Ovens-King River Valley where they may have been slightly realigned by the penetrative NW basement structure. The formation of isolated ice caps could have been during a retreating phase. A glacier moving toward the Warby range divide could have spilled through the divide at the lowest point which would have been at the

differentially eroded contact between the granite and the metamorphics, ie. a precursor of Glenrowan Gap.

Present elevations of the floor of the Glenrowan Gap, the top of the Permian glacials and the base of Tertiary basalt (which at some localities unconformably overlies Permian sediments) are all within about 20 m of a mean altitude of 200 m. This suggests there has been little differential movement around this area since the extrusion of the Tertiary lavas. This data contradicts movement inferred from the faults shown on the Wangaratta geological map (sheet SJ55-2, 1:250 000, ed.1, 1974) and also contradicts movement implied by the Graben structure which many believe exists in the Ovens-King River Valley.

The Moyhu pavement is only a few metres below the mean level of the Gap. In the same general area, Permian deposits (either capped by basalt or not) are still very close to the level of the Gap. The pre-Tertiary drainage probably modified the Gap and Tertiary valley-fill basalts later flowed over Permian deposits through the Gap and over Permian deposits at Taminick west of the divide. Figure 8, p.247 shows the elevations of the Gap, basalts and top of the Permian near the Warby Range divide.

The presence of the basalt in the Glenrowan Gap suggests that it was functioning as a westerly drainage line at least 36 Ma. ago. How long it existed before then is uncertain. The Glenrowan Gap is now about 60 m above the general level of the floor of the Ovens-King River Valley. From this an average erosion rate of 1.7 B (B= Bubnoff= 1 mm per 1000yrs) is calculated. This rate is rather low when compared with a rate of 10 B. reported for the Burdekin River area (Wyatt and Webb, 1970) and even lower when compared with a world average rate for plains

of 50B (Ollier, 1982). The westerly flowing drainage that once passed through the Gap was defeated sometime since 36 Ma. ago.

The simplest explanation is that the defeat was caused by normal faulting along the eastern side of the Warby Range but this explanation does not take into account the lack of observable displacement on a Warby Range fault and Tertiary basalts.

Faulting (or reactivated faulting) on the eastern side of the Warby Range could not have been the sole cause of the modification (ie. defeat) of the westerly drainage system through Glenrowan Gap. If faulting were involved, then it must have preceded the extrusion of the basalts, and not have downthrown the eastern block (ie. the Ovens - King River Valley) below the level of Glenrowan Gap. This constraint to faulting exists because with a greater downthrow, basalts would not have flowed through the Gap (see discussion p.238). Basalts in the Gap, west of the Gap at Taminick and southeast of the Gap near the Moyhu pavement indicate a gradual (1 in 500) NW slope rather than fault displacement. Differential erosion of softer Permian and Tertiary sediments by headward erosion east of the Warby Range, in the Ovens - King River Valley, has subsequently led to the defeat of the westerly drainage system through Glenrowan Gap. An idea similar to this was suggested by Hills (1946).

The only westerly drainage which could account for the Gap would be from an ancestral King and Ovens Rivers which would have flowed west through the Glenrowan Gap and not N to meet the present Murray between Yarrawonga and Corowa as they do now. Drainage flowing through the Gap would have met an ancestral Broken River and continued on to an ancestral Murray system elsewhere. The most obvious course for the

present Broken River is directly NNW rather than the WNW course that it now follows just NW of Benalla. Such a NNW course would be more consistent with the pattern of divides shown on map B, p.232. The map shows the NNW trend of the major divide between the Kiewa Basin and the Ovens-King Basin, the NNW trend of the major central divide of the Warby Range, and the major NNW trend of drainage lines. The Broken River and the divide just to its west appear to be the exception to this pattern. The Broken River, a likely tributary of the west flowing ancestral Ovens-King River, retained its westerly path after defeat of the ancestral river. The former drainage line connecting the Gap and the Broken River is now occupied by a swampy area ( the Winton Swamp - now man-modified to be Lake Makoan).

The western divide alongside which the Broken River would have flowed could well be a feature as linear as the central divide shown in maps 1 and 2 (along the Warby Range), and owe its origin to fault activity. The fault could well be a continuation of the Barjarg Fault already mapped along the course of the Broken River near the Strathbogie Range. In addition there is an observed ERTS lineament that continues north from the Blue Range Fault also along the course of the Broken River in the vicinity of the Strathbogie Range. This area is possibly a second tilt block like the Ovens-King River Valley but movement along the fault was not rapid enough to defeat the westerly flowing ancestral Ovens-King river and its ancestral Broken River tributary.

A suggested evolutionary sequence based on differential erosion is shown in figure 9, p.250 to account for the palaeodrainage, Glenrowan Gap and present drainage patterns. The sequence is based on superimposition of a westerly flowing ancestral drainage system over buried ancient NNW trending ridge-like features, and N-S structures

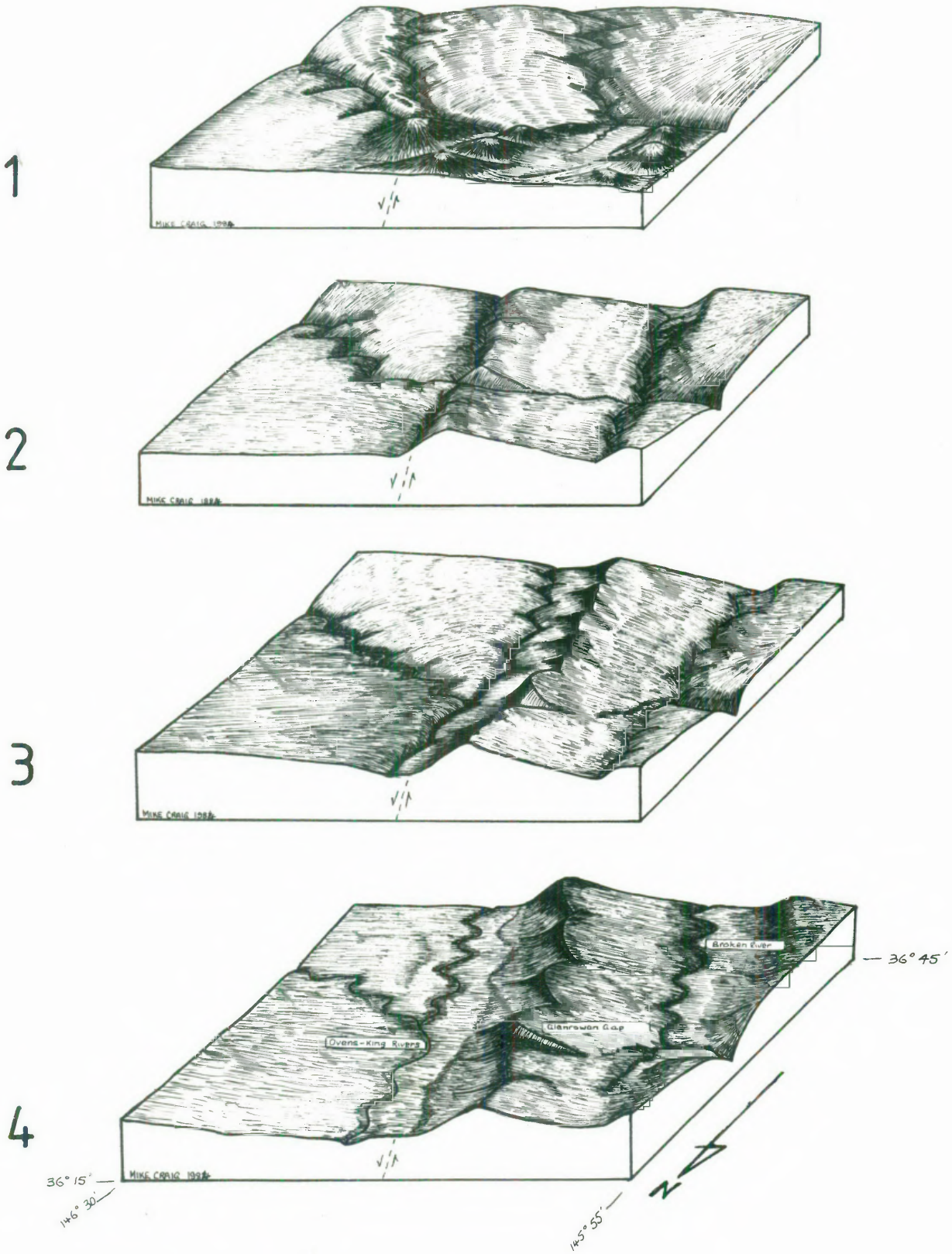



FIGURE 9

EVOLUTIONARY MODEL OF THE OVENS-KING AND BROKEN RIVERS AND THE DEVELOPMENT OF THE GLENROWAN GAP

which were probably upthrown sides of fault-angle depressions formed as long ago as Permian.

Drainage was probably influenced by basement structural discontinuities even at that time. There seems to be little change in the landscape over millions of years. Even the major divides are still relatively straight and little relief inversion appears to have occurred since the Gap-filling flows of Early Oligocene times.

The relict nature of parts of the present landscape is an important aspect of the landscape history of the region, for much of the present landscape may have survived with only minor changes since Permian times. The Glenrowan Gap is at least an Early Tertiary landform surviving virtually unchanged to the present day.

## 10.6 THE LANDFORM EVOLUTIONARY MODEL

The following landform evolutionary model is a synthesis and discussion of the material contained in the preceding 25 pages. The Ovens-King River Valley and the Broken River Valley at Lake Nillahcootie are considered to have been in existence even prior to Permian times, as minor fault angle depressions adjacent to tilt blocks (see p.230, 244-245 and 249). During Permian times the Ovens-King River Valley and the Lake Nillahcootie areas were scoured by Permian ice. These areas provided paths of least resistance to ice for at least two reasons. The first is that they were tectonic depressions, and secondly the capping of Carboniferous sediments within them would have been more erodible than the surrounding granites, volcanics and Lower Palaeozoic sediments.

Permian glaciation deepened these depressions and modified them into glacial valleys (Craig and Brown, 1984 : copy in pocket). Development may have been in part modified by basement structure, so NNW to N as well as NW trending valleys were formed. Remnants of Permian deposits on these valley floors are still present today. Tributary valleys followed structural trends of the basement strata or faults. At the time of glaciation a precursor to Glenrowan Gap may well have been in existence and utilized possibly as an ice overflow channel. Since Permian times the major drainage was by E-W rivers which were very likely the ancestral Murray and Ovens-King-Broken River systems.

Permian glaciers deposited tillites (possibly lodgement tillites), englacial debris, outwash deposits, and siltstones and mudstones. The details of these deposits have been discussed in chapter 3. Overall it seems that the Permian landsurface was not greatly different from that of today. With the exception of post-Oligocene differential erosion along the eastern Warby Range fault, the topography which is based on surface contours of Palaeozoic rocks and subsurface structure contours of Palaeozoic rocks as shown on figure 10, p.254 could well represent the Permian topography.

There is no evidence of Triassic, Jurassic or Cretaceous sedimentation. During the Tertiary, there was some landscape erosion and deposition of fluvial sediments. The major drainage network drained the south and eastern hinterlands, flowing in a westerly direction and possibly controlled, in part, by the same structural grain thought to have had some influence the development of the Permian landscape (p.230 and 245). The reason for this change and its timing is not known. Oligocene basalt flowed from east to west through the Gap. However, subsequent differential erosion along the Warby Range fault led to the

eventual defeat of the ancestral west-flowing Ovens-King River system. Glenrowan Gap thereby records a substancial modification of the landscape.

The landscape of the Ovens-King River area of the northeastern district of Victoria has been traced in this model to an origin as early as Permian times. Since that time little landscape change has taken place, except for the post 36 Ma. rearrangement of the drainage sometime during the Tertiary as a result of the differential erosion. If there were any post-Permian tectonic movements they have not significantly modified the landscape.

## 10.7 SUMMARY

Landscapes in Victoria contain elements of at least Permian age. Eastern Highland palaeoplains developed following Permian ice retreat and probably contain relict Permian surfaces (Hills, 1975). Jenkins (in Douglas and Ferguson, eds. 1976) attributes a Permian age, or possibly an Early Mesozoic age to erosional surfaces in the Central Victorian Highlands (see p.229).

Across the north of Victoria, landscapes reflect tectonic control in the form of tilt blocks (p.243) except for the Ovens-King River area which has come to be regarded as a graben (p.239-244). In addition, the distribution of glacial deposits in the Wangaratta area (see maps 1 to 6, in pocket) previously has been attributed entirely to tectonics.

Drainage and divide analysis for the Wangaratta area (p.230 to 234 and Maps A & B) reveals strong NW quadrant structural control. A four-fold division of drainage is recognised and comprises:

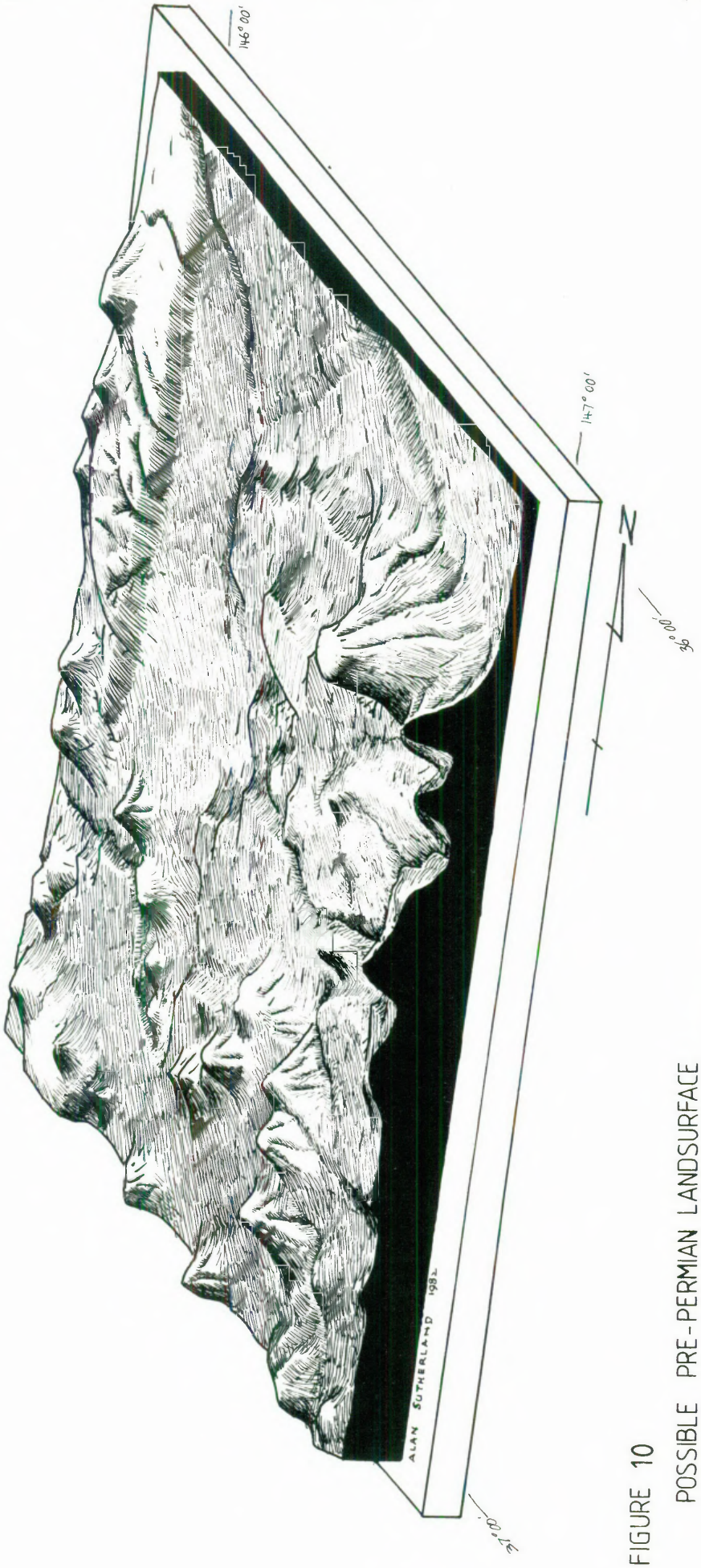



FIGURE 10

POSSIBLE PRE-PERMIAN LANDSURFACE

FOR THE WANGARATTA 1:250.000 SHEET AREA

1. The Kiewa Basin

   Drainage NE and N

2. The Ovens-King Basin

   Drainage NW, W and NNW

3. The Broken River Basin

   Drainage NNW and W

4. The Goulburn Basin

   Drainage S and W

On balance, these patterns are more consistent with a tilt block topography, not a graben and horst topography.

Major rivers and divides have NNW or NW trends (see maps A & B, p.231-232) and respectively coincide with lows and highs when superimposed on the map of combined Permian subsurface structure contours and contours of the exposed palaeozoic rocks (see map A p.231) of the Wangaratta area. Present major drainage lines and major divides are probably relicts of a Permian landsurface.

The Wangaratta landscape and the associated distribution and preservation of Permian glacials have long been associated with a graben structure. Detailed geological mapping in the region (see maps 1-6 -pocket) shows, contrary to earlier views, that not all the deposits are in the lowland areas (supposedly downfaulted). Instead in the Wangaratta-Moyhu-Whitlands area, glacials are preserved from valley floors to highland plateaux. In some areas (west of Boggy Creek, see map 3) glacials area partly concealed beneath basalt flows. The variation in altitude of these glacials demonstrates the survival of

Permian landsurfaces ( see p.244 and also Craig and Brown, 1984 : in press). Of all the inferred faults which delinitate the supposed Ovens Graben only the fault which lies just east of the Warby Range (see map 2) seems to have any justification (see p.246: I have used the term Warby Range Fault to identify this feature). Hills (1946) recognised the Warby Range Fault as a fault-line scarp. No other inferred fault boundary of the supposed Ovens Graben can be substantiated by geomorphic, geologic or geophysical observations. Available seismic data (p.242) support the possible existance of a NW-SE active fault, along the present course of the Ovens River. However, this fault is not part of the Ovens Graben boundary system. The graben concept has not evolved with the usual need for detailed evidence. Instead, its evolution can simply be followed as a process of popular acceptance. Subtly but surely the Ovens-King River lowland area has been transformed from a lowland area with a possible single western fault into a fully fledged Ovens Graben. At present a tilt-block (with development beginning before Permian times -p.230) with a western boundary fault is the only model supported by the evidence.

Glenrowan Gap (fig 8-247; p. 237) is the major geomorphic feature of the Warby Range, and contains 36 Ma. basalt (p.273) on the floor at its eastern end (p.238). The age of this basalt is comparable with the general SW younging of Eastern Highland basalts (p.236). The defeat of the Gap points to its formation and development by differential erosion rather than local major faulting. Changes of slope on sub-basaltic surfaces (fig. 8, p.247) associated with the Gap basalt and the Warby Range Fault indicate regional palaeoslope rather than fault displacement. Glenrowan Gap is an inherited feature which is now known to be >36 Ma. (p.236). Exactly how long it was functioning as a major

westward drainage feature before 36 Ma. cannot be clearly determined.