ROYAL SOCIETY OF NEW SOUTH WALES

MONOGRAPH No. 1

The Structural Evolution of the Hunter-Manning-Myall Province

New South Wales

by

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SYDNEY
PUBLISHED BY THE SOCIETY, SCIENCE HOUSE
GLOUCESTER AND ESSEX STREETS

1950

Price 15/-

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CONTENTS.

INTRODUCTION AND PREVIOUS RESEARCH.

The present work is a condensed summation of a long series of researches conducted by the author in the Hunter-Manning-Myall region during the last fifteen years. Throughout the period 1920–1928 a detailed examination was made of the Carboniferous, and to some extent of the associated Permian rocks, in a belt about 12 miles wide, extending from Raymond Terrace to Scone along a length of about 60 miles.

The stratigraphy, physiography, petrography and, in particular, the structural evolution of that region were dealt with fairly exhaustively in a series of papers (Osborne, 1920–1929).

In the following decade extensions of these researches were made to the country north and north-east of that already described, and it was soon clear that rather special stress conditions had operated in the Hunter-Manning province during the deformation wrought upon the rocks throughout the late Palæozoic diastrophism. Some attention was drawn to this in a joint paper with S. W. Carey (1937), and further information about the structural problems of the Upper Palæozoic rocks was given in three papers (Osborne, 1938, 1940, 1944).

The special characteristics of the Hunter Overthrust (part of the Hunter-Mooki Thrust System) had been fully described (1926–1929) when dealing with the overthrust block, while adequate description of the Fault-Zone was provided by H. G. Raggatt from the standpoint of the Permian Province south-west of the Thrust Line in the Lower and Middle Hunter Valley.

These special features were investigated experimentally in the geological laboratories of Harvard University. A model was constructed and some experiments conducted with a tectonic revolving device fashioned by D. T. Griggs. Interesting results were obtained (see Osborne, 1944, p. 21).

Since 1935, after reconnaissance work on the Hastings and Manning Valleys had been done, intensive mapping of much of the region shown on Plate I was carried out. Places of very rugged or difficultly accessible character were dealt with in reconnaissance fashiom.

A vision of the importance of the whole area in elucidating the course of the late Palæozoic diastrophism in this part of the State and its relation to earth movements of similar age in other parts of eastern Australia prompted and stimulated the writer to examine systematically the area according to the following plan :

(*a*) To map the boundaries of the main series or formations and thus delineate the broad areal geology and establish large structural features.

(*b*) To make less detailed observations where either (i) the terrain and tectonic conditions were fairly uniform, or (ii) the forest or sand cover prevented detailed examination.

(*c*) To map in full detail (using structural indicators for the purpose) various critical areas or structural elements which, in one way or another, and with varying degrees of importance, give data of a determinative value, contributing to an understanding of the evolution of the whole region.

(*d*) To interpret by detailed observation and analysis the changing tectonic environment from place to place.

Altogether about 7,000 square miles have now been examined, and the maps (Plates I and III) show the extent of this work. It is necessary to say, that of the area shown, geological details of two small areas have been taken from papers respectively by W. R. Browne (1926) and Beryl Scott (1947). These areas, however, have been studied fairly fully by me.

In the course of this project the author has had some assistance from senior students of the Department of Geology, and to these gentlemen he is very grateful. Some of these associates have carried out specified field work under his direction in certain sectors of the area now under review. This work was sometimes in the nature of field studies required for honours degrees. Thus such activities were in the Timor District (A. V. Jopling and F. W. Lancaster), the Gloucester District (P. B. Andrews), the Stroud District (M. R. Banks), the Bullahdelah District (B. P. Webb), and in the Scone-Murrurundi Sector (P. Macleod, A. F. S. Nettleton, W. J. Goodman, the late A. A. Northey, J. C. Webb, W. K. Sneddon and T. D. Hughes). With some of these associates the writer, as senior author, has contributed descriptive papers, and these have been considered in the present monograph, the areas concerned now being treated from the genetic standpoint.

Over the long period of research I have profited greatly by the encouragement and unfailing sympathetic interest of Professor L. A. Cotton, and have had many helpful discussions with Dr. W. R. Browne. Residents in all parts of the region (too numerous to mention by name) have made the field researches a very great pleasure, and have in various ways facilitated travelling and accommodation arrangements. To all these people my cordial thanks are tendered.

The work has been made possible, very largely, by reason of substantial grants from the Commonwealth Research Fund over several years, and the author is anxious to express his gratitude for this vital financial assistance.

RELATION OF MONOGRAPH TO OTHER UPPER PALÆOZOIC RESEARCHES.

The present work may be said to find its place as one unit in a scheme of several large-scale contributions to the stratigraphical and structural geology of the Upper Palæozoic rocks of New South Wales that have been made by various authors since 1920. These may be listed thus:

(a) Research upon the Permian rocks of the Lower and Middle Hunter Valley by H. G. Raggatt (1922 to 1940).

(b) Research upon the Lower and Middle North Coast Districts of N.S.W. by A. H. Voisey (1937 to 1945).

(c) Research upon the Werrie Basin by S. W. Carey (1934 to 1937).

(d) Research upon the North-west Coalfield of N.S.W. by F. N. Hanlon (1947 to 1949).

The first of these projects (H.G.R.) was conducted more or less concurrently with the first main investigation by the author (mentioned above), and the remainder have been carried out subsequent to that investigation providing much data of correlative interest and contributing considerably to our knowledge of N.S.W. geology.

The plan in the present work is to describe concisely the many structural elements in the large area under treatment and then to develop an evolutionary discussion indicating the tectonic progress in late Palæozoic time.

GENERAL GEOGRAPHY AND PHYSIOGRAPHY.

The region embraces the following sectors which constitute parts of the Counties of Brisbane, Durham, Hawes and Gloucester:

(a) The widely drained Upper Hunter Valley and the northern and north-eastern side of the Middle and Lower Hunter. Here great diversity of physiographic development is present.

(b) The Barrington Tops or Barrington Tableland and associated Mt. Royal Range, a "leg and boot"-like projection from the Liverpool Ranges.

(c) The Upper and Middle Manning River and its tributaries.

(d) The Karuah and Avon River Basins.

(e) The Myall River System and north therefrom, the minor Wollamba and Wang Wauk Rivers.

(f) The Myall Lakes and Wallis Lake areas, and the associated coastal lowlands.

(g) The lowland between Raymond Terrace and the drowned valley system of Port Stephens.

There are very marked contrasts in the topographic features and physiographic expression throughout the area.

The north-western boundary of the area described consists of the eastern Liverpool Ranges, which rise with broken profiles to a maximum of 4,850 feet above sea-level in Wombramurra Peak. From the western end of this section of the Liverpool Range (where the Gap or Pass near Murrurundi is situated) the western and south-western boundaries of the area run approximately along the margin of the Carboniferous belt, more or less adjacent to the Great Northern Railway and the New England Highway. In the Lower Hunter region the Lochinvar Dome has been included because the author has undertaken a detailed study of this, the most important structural element in the Permian of the Lower Hunter Province and a unit indispensable in any evolutionary treatise dealing with the interrelations of the Carboniferous and Permian areas on opposite sides of the Hunter Thrust.

The northern boundary is approximately the Manning River except for its lower section, and then the bounding line runs south-eastward towards the coast at Forster. Thence south the eastern coast of N.S.W. marks the limit of the area traversed.

It will be seen from the map (Plate I) that a remarkable radial drainage pattern characterizes the incidence and geographic distribution of the streams of the area. These radially disposed rivers and creeks were thus largely consequent in the initial stages of their evolution, but a complex superimposition of subsequent and other stream facies has taken place since the early part of the physiographic cycle. The coign or hub of high ground from which the streams radiate is called the Barrington Tops, and associated with it in this geomorphic design is the rather ill-defined Mt. Royal Range, of which the "Tops" form a kind of offshoot. The abrupt fall of the country immediately south of the Barrington Tableland, where a great southward-facing scarp is present, and the less abrupt but very rugged facets on the south-east and east of this tableland, contain the headwaters of many streams, large and small, which make their way ultimately to the Lower Hunter or to the Middle Manning.

Some of these streams (the Paterson, Allyn, Williams, Chichester and the Wangat) flow on the west side of a notable physiographic and structural complex known as the Stroud-Gloucester Trough, while others swing to the north of this great structure, by-passing it as it were, and make entry into the Manning system.

Within the Stroud-Gloucester Structure, proceeding northward, is the Avon system (a small river), while draining the Trough to the south is the Karuah River, which empties into Port Stephens.

A fairly noticeable division of the eastern part of the Province into three physiographic regions is brought about by the existence of the Stroud-Gloucester Trough. These regions are the Dungog-Clarencetown sector on the west, the Trough itself, and the Myall-Wallis Lake labyrinth on the east.

The first-named is largely influenced in its physiographic development by many powerful faults; the second is a splendid example of a complex geological structure providing pronounced physiographic control; and the third region is distinctive by reason of the abundance of lakes, occupying the partly drowned and partly silted areas of a late Pleistocene and Recent drainage system, totally unlike the present systems that remain in the youthful and mature stage in the country to the west.

Over the whole area, as might be expected, there is a complete range of geomorphic features to be met with in a complexly evolved series of rivers which, first being consequent, have been modified by subsequent characteristics—rivers developed in an uplifted block where the highest point reaches 5,000 feet above sea-level and where within 70 miles of the coign or hub at the Barrington Tops the base-level of the sea or intermittent tidal lake is to be found.

A study of the valleys shows every type from completely indiscriminant-youthful through modified-youthful to subsequent-mature, and senile and antecedent types. Evidence of geological control of the morphological features by units of varying lithology and structure is prolific and there are many contrasts in physiographical environment related to the varying incidence and amount of rainfall.

The vegetational distribution presents many interesting problems of ecology, and vivid manifestations of control of vegetation by a combination of various geological, pedological and climatic factors are presented in many districts. There are such contrasts as the snow-gum and tussock areas of the Barrington Tops, and the tea-tree, *Casuarina* and mangrove swamps adjacent to the lake-lands, while a third facies is that of sparsely vegetated sandhill country yielding a zerophytic flora.

GENERAL GEOLOGY.

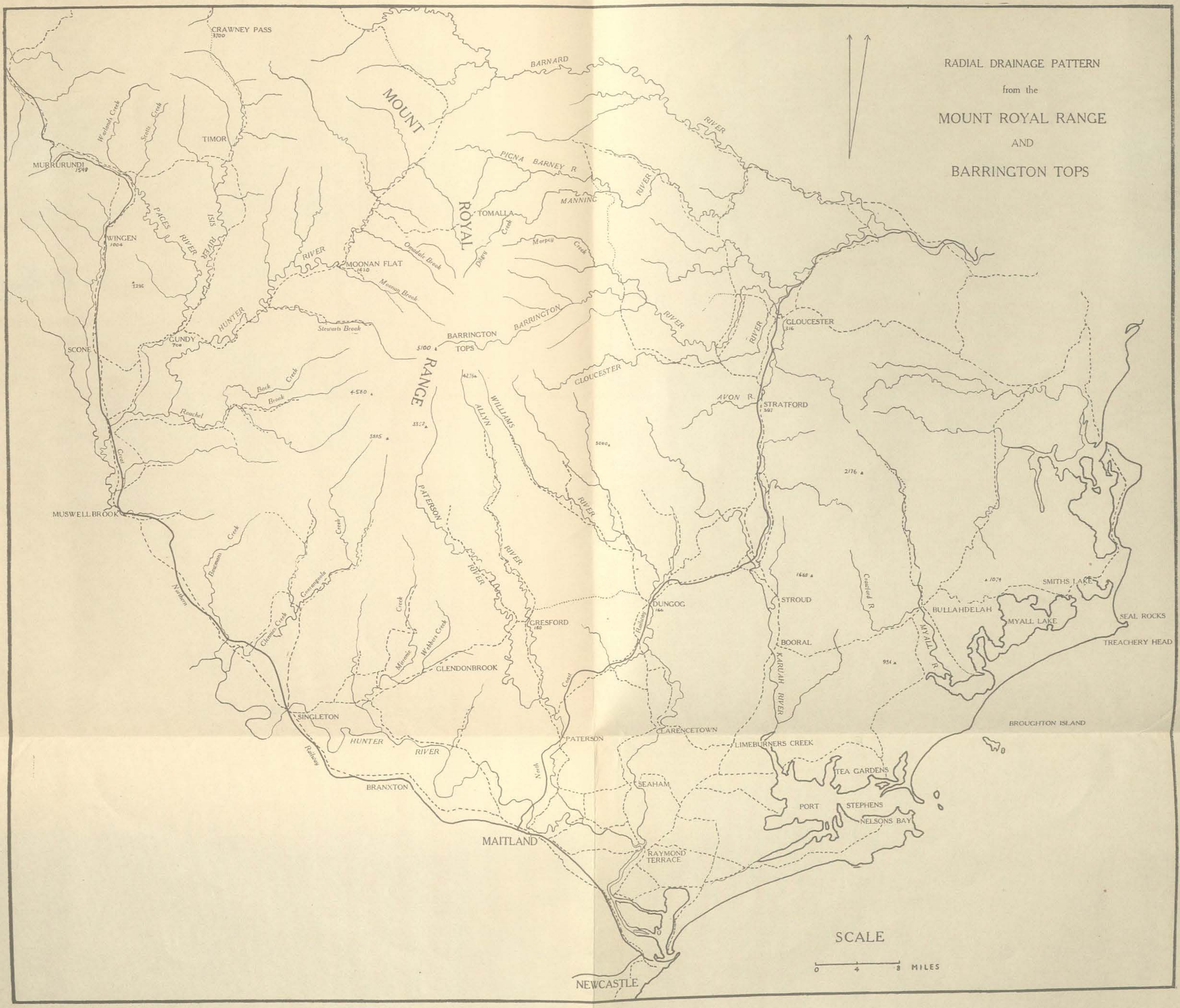
Over the greater part of the region sedimentary and associated volcanic rocks constitute the outcrops. These comprise representatives of the Devonian, Carboniferous and Permian systems, while various loosely cemented Tertiary, Pleistocene and Recent detrital deposits are present in many places.

An extensive region of Tertiary basic lavas and associated basic sills occurs in the north-western part of the region, and a great development of the same rocks characterizes the Mt. Royal and Barrington highlands. In many places small volcanic necks may be seen. Some of these are of normal dolerite; some are of quartz dolerite, while some have teschenitic affinities.

Apart from the basic sills just mentioned, the only intrusive rocks to be recorded are certain granitic inliers which occur near Gundy, east of Scone (probably of late Middle Devonian age) and larger granite areas of probably Kanimbla (late Lower Carboniferous) age, which occur in the upper parts of Moonan Brook and Omadale Brook and between these localities and the head of Stewart's Brook.

On the Barrington Tableland are outcrops of quartz monzonite and granodiorite. These rocks sometimes rise above the level of the basalt flows

Royal Society of N.S.W., Monograph No. 1, 1950, Plate I



RADIAL DRAINAGE PATTERN
from the
MOUNT ROYAL RANGE
AND
BARRINGTON TOPS

which are so strongly developed in that region. It appears that the basic lava has flowed around many residuals which must have risen conspicuously out of the well-developed early Tertiary peneplain. This peneplain is indicated in many places by the nature of the pre-basaltic surface, which can be deciphered by a study of the physiography. (On the geological map small basic necks and small granitic and monzonitic inliers are not shown, as it would be impracticable to do so.)

It is not proposed in this monograph to discuss the intrusion tectonics or petrology of the many acid and basic intrusive rocks, nor to deal with the petrology of the basic lavas. In so far as it is necessary to refer to any of these rocks in discussing the evolution of the tectonics of the region, some mention will be made.

Thus we pass on to present a summarized account of the stratigraphy on which to build much of the structural interpretation, since the main tectonic provinces have been delineated by mapping structural indicators. Further, the influence of overlaps in the present distribution of smaller structural elements has been important.

DEVONIAN.

The oldest rocks known in the region are of the Devonian System. Representatives of possibly Lower Devonian and of Middle and Upper Devonian are present.

Tamworth Series (Lower to Middle Devonian).

These rocks are developed strongly in the rugged country of the headwaters of the Hunter and Manning systems, and also in the main Upper Hunter and Middle and Lower Manning valleys. The slopes and foothills of the Barrington and Mt. Royal Ranges expose good sections of these strata.

In the country between Gloucester and the Barrington region, and also to the east and north-east of Gloucester, these rocks form part of the structures which border the Stroud-Gloucester Trough.

The most important structural area within which the Tamworth Series has been examined is the Timor Anticline, where a very important limestone group is found.

The Tamworth Series comprises keratophyric and spilitic tuffs, coarse breccias, cherty claystones, conglomerates, rhythmically banded chert-tuff units, with intraformational breccias and slump-bedded phases, and limestones with a rich and varied fauna.

The approximate, and in some cases the accurately determined, thicknesses of the various units are stated in the sequel when various structural units are being considered.

Altered Tamworth Series (partly the Eastern Series of W. N. Benson).

In the neighbourhood of the serpentine intrusions which occur on the northern fringe of the area, large areas of the Tamworth Series have been altered by deformatory and metasomatic agencies. These rocks are the equivalents of parts of Benson's Eastern Series (see Benson, 1911) but, in this region, do not appear to include the most drastically altered facies of that series. In the present research the writer has always been able to identify sufficient diagnostic evidence to determine the rocks as altered Tamworth units.

The main changes wrought in the rocks are severe folding, shattering, shearing and jasperization. The probable origin of the jaspers will be discussed below.

Baldwin Series.

The strata intervening between the Tamworth and Barraba Series in New England and elsewhere have been described as the Baldwin Agglomerates by Benson (and others following him). The type of facies throughout this member of the Devonian sequence varies greatly, but certain characteristics distinguish the strata so that one is able to refer many clastic units confidently to this group.

In the gorges radiating from the north and north-east sides of the Barrington Plateau these rocks are prominent. They are found also in the country west and north-west of Gloucester. The main types are keratophyric and rhyolitic tuffs, coarse and fine breccias and occasional agglomeratic phases and cherts.

Barraba Series.

These rocks are Upper Devonian in age and appear to be mainly freshwater in origin although some horizons contain *Radiolaria*. Fossil plants are commonly developed throughout the series, being prominent in bands near the top of the group. The remains are practically entirely of the *Lepidodendron* flora, the chief species being *L. australe*.

When fresh, they include claystones, mudstones with tuff-bands, fine breccias and tuffs with occasional conglomerate bands. The colour and texture of the common units are characteristic. Thus the mudstones, when fresh, are blackish-grey, and present an almost coal-black appearance to the weathered crust of the ground where they outcrop.

The tuffs throughout the mudstones are of a whitish colour and stand out in contrast with them. It is by the presence of these tuff-bands at frequent intervals that one can distinguish the Barraba sediments from the succeeding Burindi mudstones.

CARBONIFEROUS.

The four main divisions to be considered in this preliminary stratigraphy are the Lower Burindi, Upper Burindi, Lower Kuttung and Upper Kuttung Series. Of these, two (the Lower Kuttung and Upper Burindi), are approximately equivalent in time, but represent contrasted facies developed in the late Lower Carboniferous (for principles adopted here, see Carey and Browne, 1938).

Lower Burindi Series.

A large portion of the area consists of these strata.

The following units are present:

(i) Mudstones of an olivine-green and brownish-green colour frequently plant-bearing, with *L. veltheimianum* and *L. osbornei* well developed.

(ii) Tuffs of great variety in texture and composition. Some are very quartzose. These are frequently fossiliferous, chiefly with an abundance of brachiopods, pelecypods, gastropods, bryozoa and some trilobites and crinoidal remains. Some distinctive fine tuffs with almost microscopic crinoid stems are common in the Gloucester-Pignabarney district.

(iii) Oolitic and organic limestones, often impure, but occasionally very pure. These embrace crinoidal units in narrow bands. Many of the limestones have fine micaceous and felspar debris that has been showered upon the calcareous sediment.

(iv) Blue and blackish cherts with *Radiolaria* and high siliceous content. Some of these show slip-bedding, and a series of fucoid structures (probably organic) which mark out this unit in the Bullahdelah-Bungwahl region.

(v) Some altered andesitic and keratophyric lavas which suggest submarine extrusion. These are seen particularly well in some of the very rugged country to the north of Dungog and Stroud.

(vi) Conglomerates with pebbles up to a maximum of one foot in diameter.

Upper Burindi Series.

The rocks most prominently developed in this series are as follows:

(i) Tuffs, which weather to a rust-brown colour. These are keratophyric or dacitic with much biotite.

(ii) Calcareous mudstones and shaly-sandstones with a varied fauna, the fossils often being restricted to marked zones.

(iii) Impure organic and also oolitic (chemical) limestones of no great thickness.

(iv) Conglomerates and mechanically formed breccias.

(v) Volcanic breccias of very acid character.

(vi) Soda rhyolite and keratophyre lavas.

(vii) Cherty rocks with *Radiolaria*.

The plant fossils (mostly of drift origin) are again mainly of the *Lepidodendron* flora, and *Cyclostigma* is prominent on some horizons, particularly near the base of the series.

Lower Kuttung Series.

In the areas where Upper Burindi rocks are absent it is usual to find Lower Kuttung Series well developed. These, except for special phases referred to in this section below, constitute a great terrestrial group of clastic, pyroclastic and lava units.

The following are the chief types:

(i) Coarse conglomerates with tuffaceous matrix. Some beds possess a fairly even size of pebble, but others show great variation in size and evidence of rapid accumulation. Many boulders are angular and of such shape and polished appearance as to suggest derivation from glacial outwash gravels. Occasional striated boulders occur in these beds.

(ii) Tuffs and breccias of great variety in texture and constitution. Many are intensely siliceous, others are dacitic, some strongly hæmatitic, and yet others have stilbite as cement.

(iii) A great variety of lavas including up to thirty flows in some sections, which are magnificently exposed in so many parts of the area. The great range of composition is indicated by the following list:

> Glassy and lithoidal mica-hornblende andesites, pyroxenic andesites, dacites, keratophyres, toscanites, dellenites, rhyolites of several kinds, obsidians, trachy-andesites, trachytes and subordinate alkaline basalts. Many of these rocks show such phenomena as albitization, autobrecciation, devitrification, etc., some of which are deuteric in origin.

(iv) Ignimbrites (*cf.* Marshall, 1935). These are commonly present in the Volcanic Stage of the Lower Kuttung and are invariably of alkaline-rhyolitic composition.

The whole of the Lower Kuttung Series is marked by two facies in the tuffs and conglomerates; one earlier group indicating accumulation when the climate was not conducive to the development of hæmatite in the soils and weathered rock-mantle, and a later group characterized by hæmatitic cements (not due to present katamorphic agencies), which are indicative of humid conditions during formation.

Fossil plants are present in the lowermost parts of this series, *L. osbornei* and *Pitys* being most common, along with *L. veltheimianum*, *Cyclostigma* and *Ulodendron*. Higher up, amongst the tuffs and lavas of the Volcanic Stage, the *Rhacopteris* flora makes its first appearance, and the remarkable Zygopterid *Clepsydropsis australis* (Osborne, 1926; Sahni, 1928) is found in this part of the series also, having been discovered in a coarse conglomerate.

Marine Phases of the Lower Kuttung.

The recognition of marine facies in the upper part of the Lower Kuttung by Carey (1934) was an important development in the moulding of opinion about the stratigraphical evolution of the Carboniferous System in eastern New South Wales (see also Carey and Browne, 1938).

As a result of the interpretation of these marine phases, especially when containing well developed fossil assemblages, it is clear that throughout portions of the Carboniferous areas marine and freshwater sedimentation proceeded simultaneously, and in some critical places a paralic or oscillatory condition marked the sequence of deposition.

The areas within the region of present discussion, where such intermediate conditions obtained, comprise a fairly large section of the Rouchel Basin, east of Aberdeen, a small area immediately east of Dungog, and a very small area in the South Temi Basin, east of Murrurundi.

The most important of these is the Rouchel area, where bryozoa are particularly well developed. These have been described by Crockford (1947).

Upper Kuttung Series.

Succeeding the Lower Kuttung, with evidence of some break, come the glacial and associated rocks of the Upper Kuttung. These comprise strata implying a great glaciation of Upper Carboniferous times, marked by several alternating glacial and inter-glacial periods.

In the lower part of this division of the Kuttung Series there is a great abundance of clastic rock, much of which is pyroclastic in character. The remainder is due to the accumulation of sand and gravel, which was probably mostly derived from the outwash of the Carboniferous Ice Sheet as it advanced from the south. This eventually spread over probably the whole of the region now being considered by the end of the Kuttung epoch, since glacial sediments are recorded from country north-west, north and north-east therefrom.

The impact of the Upper Palæozoic glaciation on the region here considered is indicated in the morainic deposits, partly redistributed by fluvial action, and in the many horizons of varved sediments which were accumulated during the temporary and final retreats of the Ice Sheet. Contemporaneous with the glaciation much vulcanism continued and many tuffaceous rocks, and several lavas, mostly toscanitic, but also trachytic and rhyolitic and occasionally basaltic, were poured over the refrigerated landscape; in the case of the dellenites and toscanites really vast areas were covered.

A richly varied and abundantly preserved fossil flora (*Rhacopteris-Calamites* group, etc.) marks two or three shaly and/or cherty horizons near the top of the Upper Kuttung.

Marine Phases of the Upper Kuttung.

Just as in the upper part of the Lower Kuttung, so in the upper part of the Upper Kuttung there was contemporaneity of marine and freshwater deposition in various districts. Thus in the Limeburner's Creek and Booral districts fossiliferous strata occur which were coeval with freshwater glacial silts and tillites. This marine horizon is definitely fixed because of the occurrence of bryozoa (Crockford, 1946). The rocks in question are broadly equivalent to marine strata described recently from the Stanhope-Lamb's Valley area (Scott, 1947) and to those dealt with in various papers by Voisey (1938–1941).

PERMIAN.

The areas within the region which are occupied by Permian strata form a small proportion of the province, but their structural environment of these areas is most important.

They comprise the Lochinvar Dome, the central and northern parts of the Stroud-Gloucester Trough and the Paterson-Dunn's Creek outliers. Areas of Permian in the Wingen-Murrurundi district, and the great Permian Basin of the west and south-west sides of the Hunter Valley, with the exception of the Lochinvar Dome, are not dealt with here, as they are, or have been, the subject of research by other workers. Incidental mention of their structural relations is necessary in some of the following discussion.

The exception is made in the case of the great Lochinvar structural province because the writer has studied the tectonics and stratigraphy in some detail. Further, the northern end of the dome is within the Carboniferous rocks of the overthrust block, and it is necessary to consider critically the evolution of this structure in relation to the whole question of Upper Palæozoic tectonics.

STRUCTURAL RELATIONS BETWEEN THE MAIN SERIES

The oldest sediments of the region being the Tamworth Series, it is necessary first to test the relationships between these and the associated strata. In many places there appears to be a conformable passage into the Barraba Series, or into the Baldwin Series. At least in these cases there is no angular unconformity. Specific localities where this may be studied are the following:

(*a*) On the road to Rawdon Vale from Gloucester (via Cut Rock Road) splendid sections indicate no change in dip or strike between Tamworth and Barraba strata.

(*b*) In the valley of Brush Hill Creek, near Moonan and south of the divide between the Upper Hunter and the Manning, near the southern boundary of Glenrock property, there is conformity between black Barraba shales and rhythmically banded Tamworth tuffs.

However, in the region of the Beltrees structure and along Stewart's Brook the divergence in strike between the Tamworth Series and the Barraba Series, or in some cases between Tamworth Beds and the Burindi Series, is sufficiently large and of geographic extent enough to establish a mild unconformity in the places cited.

The most satisfactory data concerning this relationship are available from a study of the strata in the rugged upper portions of the valley of Rouchel Brook and in the country forming the Divide between that stream and Stewart's Brook. In Rouchel Brook above "Myrtle Vale" the Burindi Series of mudstones and crinoidal limestones shows a dip of S. 60° W. at 20°, but close by the Devonian banded cherts are dipping N. 47° W. at 44°. Regional investigation shows that this divergence in strike and contrast in dip is not brought about by faulting.

That in some places an angular unconformity is present and elsewhere the beds succeeding the Tamworth Series are conformable need not raise a difficulty or appear fallacious. Actually the variable relationships are probably due to warping which has allowed certain planes of contact between two series to be essentially parallel to the stratal surfaces, and in other places has brought about a geometrical situation which amounts to unconformity. The bulk evidence is that no great movement took place in most of the area, but that some movement and erosion proceeded between the completion of the Tamworth sedimentation and the beginning of Barraba time, or of Burindi time.

Another important criterion in this matter of structural relationship is that of relative diagenesis of the two associated series at any locality. Along many parts of the valley of Stewart's Brook (both branches) the Tamworth Beds are in the condition of dense cherts possessing much jointing in patterns and in such development that do not characterize the Barraba or Burindi of the areas examined. It is feasible to conclude that such textural and structural features and lithological evolution as exhibited by the Tamworth Series are the result of some chemical and stress factors which have not affected the overlying beds.

Further, we know that granitic rocks occur in several places (as for example near Gundy), which are pre-Lower Carboniferous in age, since the overlying Burindi mudstones rest on an eroded surface. Such granitic rocks are to be correlated with the late Middle Devonian intrusives of N.S.W., with the implication that a roof of Tamworth Series was eroded away before deposition of Burindi sediments.

The possibility of such granites being of late-Barraba age can be dismissed because everywhere there is perfect conformity, and sometimes transition between the Barraba and Burindi groups.

Finally, the gold and other deposits of the Stewart's Brook area are associated with granites and granodiorites which have been responsible for mineralizing the Tamworth Beds, but not the later sediments. To a late Middle Devonian metallogenetic epoch these ores are referred.

Relations of Barraba and Burindi Series.

It has been stated above that no angular unconformity exists between the Barraba and Burindi terrains. Some further details regarding this relationship are appropriate.

In the region between the road from Blandford to Timor and the country west of Timor Estate, along the ridges lying east of Green Creek, one can see a perfect conformity between the Lower Carboniferous and Upper Devonian beds. True it is that there are some basal conglomerates in the former series, but this is the expression of a physical change that has not produced geometrical disharmony. Osborne and Andrews (1948) have recorded the persistence of a conglomerate near the base of the Burindi Series, in the Gloucester district, but found it very difficult to draw a line demarking either formation thereby.

It would appear from the researches of Benson and from the present investigations that at the close of the Upper Devonian only epeirogenic movements were operative in the areas of northern N.S.W. that had been covered by the Barraba sea.

Structural Relations within the Carboniferous System.

The critical areas of Gloucester, Taree and Rouchel Brook, where the relationship between Lower and Upper Burindi on the one hand and between Lower Burindi and Lower Kuttung on the other, can be studied, reveal very satisfactory data. Some of the salient aspects of these questions have been dealt with by other writers, but in the present investigation new areas have been examined and the facts available are important.

Thus a splendid section on the Scone-Gundy road, about nine miles from Scone, is exposed in the high cliffs adjacent to the Page River. Here is revealed a gradual passage from marine calcareous mudstones of Lower Burindi age through conglomeratic mudstone and sandy tuff into massive conglomerate which soon overshadows the minor bands of Burindi-like material, which constitute a kind of " echo " of the Burindi facies. Altogether there are about 600 feet of typical quartzitic and aplitic conglomerate, directly equivalent to the Basal Stage beds already described by the author for the Lower Hunter region.

An equally decisive section is available on the road sections between Rouchel and Aberdeen, while the same type of passage is shown on the road from Booral to Bullahdelah, about three miles west of Crawford River sawmill, and also on the Weistmantels-Dungog road.

In the areas where the Lower Kuttung facies is replaced by the marine Upper Burindi facies, one finds it very difficult to recognize any distinct break in the sedimentary sequence. It would appear that in these areas the gradual evolution of faunas from typically Tournaisian to typically Visean proceeded during a continuous sedimentary process.

Coming now to the relations of Upper Kuttung to pre-existing strata, we note the clear-cut evidence, structural, climatic and lithologic, of a pronounced break. This has been described by various writers, but the whole matter was reviewed in 1938 by Carey and Browne. In the present communication the writer wishes to emphasize the point that although attention has been drawn to the basal bed of the Upper Kuttung and to the angular unconformity between Lower and Upper Kuttung, no reference has been made to the probable erosive action that must have followed the late Lower Carboniferous movement (i.e. the Kanimbla diastrophism). In the present researches some evidence of this has been diligently sought and some measure of success has resulted. In the following areas the base of the Upper Kuttung (or Glacial Stage) rests unevenly upon the Lower Kuttung volcanic and associated sedimentary rocks, and there is evidence of erosion in the underlying formation by a lack of uniformity of thickness as traced along the junction surface.

(*a*) Tumbledown Creek west of Glen Oak, Martin's Creek district.

(*b*) Along the high ridges on the west side of the Stroud-Gloucester Trough, between Limeburner's Creek and the Seaham-Seven Mile Creek road.

(*c*) In the Upper Bowman's Creek district near portions 267, 268, Parish of Foy, County Durham.

(*d*) On the eastern face of The Brothers Ridge, north of Clarencetown and near Glen William East.

Relationships between the Carboniferous and Permian.

The detailed stratigraphical studies on the Lochinvar Dome (Osborne, 1949) have produced much data concerning this relationship. Every consideration points to a gradual passage as marking the conditions at this rather inauspicious completion of one system and the entry of another. The only departure from transitional conditions are those constituting overlap. Between the North Coast Road, eight or ten miles north of Raymond Terrace and the Gosforth district, an overlap, more or less progressive in character, marks the boundary of the two systems. Elsewhere, especially in the Kimbriki district of the Middle North Coast, described by Voisey (1938), a continuous passage from freshwater Upper Kuttung through marine Upper Kuttung to marine lowermost Permian is exposed.

It is interesting to observe that the evidence concerning this problem now available from the Limeburner's Creek and East Booral districts, gives us more insight into the palæogeographical conditions towards the close of Kuttung time for this particular locality. The discovery, in 1946, by Mr. W. H. McCoy and the author, of an important marine Upper Kuttung phase (equivalent to some portion of the Neerkol Series of Queensland and of the Emu Creek Series of northern N.S.W.) shows that the transgression of the sea associated with the Lochinvar movement had effectively begun, in the district now being cited, distinctly earlier than in the districts that later were to be the site of the Lochinvar Dome.

The author has, for a considerable time, stressed the marine character of the Upper Kuttung tillites at Stoney Creek (one mile north of Limeburner's Creek) and in the Ellenborough Falls and Bulga areas.

PALÆOZOIC STRUCTURAL ELEMENTS OF THE HUNTER–MANNING–MYALL PROVINCE.

INTRODUCTORY.

The accounts of earlier researches upon the tectonics of the Maitland-Scone Carboniferous belt (Osborne, 1922–1929) have embraced descriptions of the main structural units, and a scheme of tectonic evolution, which may be said to have represented the writer's opinions during the period 1929–1936. The extension of the late Palæozoic researches, and a critical analysis of the genetic aspects of the structural history, led to preliminary publication of some further opinions and modification of earlier views in some cases (1938).

It was shown that the Hunter Thrust movement had been responsible for the production of structural complexes, especially where the main N.N.W.–S.S.E. trends produced by that movement impinged upon the more meridional trends which had their origin in the earlier phase of the late Palæozoic diastrophism.

An analysis of the stress and strain patterns (see Carey and Osborne, 1937, and Osborne, 1938) indicated the probable importance of the operation of rotational stresses rather than simple compression and overthrusting.

There is no need to repeat here the information already described and discussed, but it is appropriate to say that the regional mapping of the large province now being considered has provided so much data of correlative value that it is now possible to extend the discussion begun for the Maitland-Scone sectors. A much more complete story is now available concerning the relations of the various elements that have been involved in the structural evolution. In particular the rôle of certain large faults which had not been finally settled has now been more critically examined, and less ambiguity characterizes some parts of the tectonic history.

For the purpose of giving an all-round picture of the late Palæozoic diastrophic activity as it affected the Hunter-Myall Province, both as regards small-scale features and those of large dimensions, it has been deemed advisable to summarize in the section immediately following the tectonic units which are found in the Raymond Terrace-Scone belt. (Full accounts of these features will be found in the literature already cited.)

SUMMARY OF THE STRUCTURAL ELEMENTS IN THE RAYMOND TERRACE CARBONIFEROUS BELT.

Folds.

Beginning at the eastern margin of the region and proceeding westward and north-westward, one has the following structures:

The Williams River Anticline.
The Dunn's Creek Syncline.
The Moonabung Basin.
The Cranky Corner Basin.

The Mirannie Basin.
The Westbrook Anticline.
The Bridgman Basin.
The Greylands Anticline.
The Owens-Mount Wells Basin.
The Grasstree Faulted Complex.
The Bell's Mountain Structure.
The Colonel Mount Structure.
The Segenhoe Basin.

All of these have been fully mapped and are reproduced from earlier publications and shown on the geological map (Plate III).

Faults.

(*a*) Those with N.N.W.-N.W. strike.
  (i) Definitely of thrust character: Hunter Thrust, Welshman's Creek Thrust.
  (ii) Those apparently of gravity (normal) origin: Brushy Hill Fault, Goorangoola Fault.

(*b*) Those with N.N.E.-N.E. strike. (Character discussed in the sequel.)
  Paterson Fault.
  Paterson River Fault.
  Glenoak Fault.
  Butterwick Fault.
  Charlton Fault.

(*c*) Those with approximately E.-W. strike (some showing a disposition towards arcuate plan).
  Webber's Creek Fault (special case).
  Owens Mount Fault.
  Benvenue Fault.
  Manresa Fault.

(*d*) Those with a strike which is either entirely or mostly in the meridional direction. (These are gravity faults.)
  Williams River Fault.
  Tarean Fault.
  Dry Creek Fault.
  Mirannie Faults.
  Westbrook Fault.
  Mt. Olive Fault.

(*e*) Radial groups of faults (related to torsion).
  Grasstree Faults (five in number).
  Gosforth Faults (three).
  Greta Minor Faults.

DESCRIPTIVE STRUCTURAL GEOLOGY OF THE ELEMENTS IN THE HUNTER-MANNING-MYALL PROVINCE.

The following critical areas have been surveyed in full over the last fifteen years, and for each tectonic unit some special problems have generally been encountered.

After listing the structures, they will be treated in the order of naming. Where a structure cannot readily be described by a well-known structural term, such as dome, basin, anticline, etc., the term " structure " will be employed.

Structural Units and Sub-Units.

Stroud-Gloucester Trough.
Medowie Basin (sub-unit).
Ward's River Structure (sub-unit).
Rawdon Vale Anticline.
Myall Syncline.
Bullahdelah Horst.
Girvan Anticline.
Broughton Island Syncline.
Gresford-Wallarobba Anticline.
The Welshman's Creek Dome and Basin.
Dunn's Creek Syncline.
The Mindaribba Basin.
The Seaham-Kenwary Structure (sub-unit).
The Lochinvar Dome.
The Greater Mirrannie Basin.
The Rouchel Basin.
The Scone-Gundy Syncline.
The South Temi Basin.
The Timor Anticline.
The Beltrees Structure.
The Curricabakh-Rookhurst Structure.

Faults and Fault-Systems to be Discussed Below.

(In a general east-to-west enumeration.)

The Bungwahl-Boolambayt Faults.
The Bullahdelah Faults.
The Girvan-Waukivory Faults.
The Stroud-Gloucester System of Meridional Faults.
  (*a*) East Stratford Fault and similar fractures.
  (*b*) The Manchester and Faulklands Faults.
  (*c*) The Stroud Road Fault.
  (*d*) Intra-Graben Meridional Faults.
The Minor Faults of the Stroud-Gloucester Trough.
The Monkerai Faults.
The Dungog-Chichester Fault System.
The Lewinsbrook Fault.
The Gresford Fault.
The Webber's Creek Fault (reconsidered).
The Goorangoola Fault (extended).
The Moonan Fault.
The Pigna Barney Fault.
The Isis Fault.
The Brushy Hill-Murrurundi Fault.
The Hunter Thrust System (further discussion).
The Wingen Fault.
The East Wingen Fault Complex.

Serpentine and Associated Intrusions.

The Curricabakh Complex.
The Pigna Barney Line.
The Glenrock Line.

THE STROUD-GLOUCESTER TROUGH.

This structure, conveniently titled as above, is one of the most striking tectonic features of the province. A recent paper by Osborne and Andrews (1948), which is accompanied by a map, sets out the varied structural data which characterize the northern end of the trough. In that communication a concise and sufficient review is given of the main investigations that have been carried out in the past, and there is no need to repeat those details here except perhaps to emphasize the remarkable geological insight shown by Odenheimer one hundred years ago, when he reported on the geology and mineral resources of the A.A. Co.'s Estate.

The Trough dominates the geology and physiography through most of its course, which is approximately 60 miles from Gloucester to the Pacific coastline between Newcastle and Morna Point.

The Trough can be divided conveniently into four sections:

(*a*) Northern Sector: Gloucester to Dewrang, about 20 miles in length.
(*b*) North Central Sector: Dewrang to Booral, 12 miles.
(*c*) South Central Sector: Booral to Limeburner's Creek, 12 miles.
(*d*) Southern Sector: Limeburner's Creek to coastline.
  (This is best regarded as the Medowie Sub-unit.)

The salient features of the geology and physiography may be summarized thus:

(*a*) The main structure is a marked, narrow syncline which trends mostly meridionally, but possesses a swing in strike from S.S.W.–N.N.E. at the southern end through N.–S. to N. 15° W.–S. 15° E. from Stroud to Weistmantels and then more or less N.–S. to Gloucester, except for a bend on the east side in the country north-east of Craven.

(*b*) A subsidiary narrow basin or trough is faulted against the main structure to the east of Craven and crossing Ward's River. (See map.)

(*c*) The floor of the Trough is warped strongly and pitches variously south or north.

(*d*) The bounding units of the Trough are Carboniferous highlands, mostly of Lower and Upper Kuttung, but also partly of Burindi rocks, flanked by Devonian rocks on the north-west margin of the Trough near Gloucester.

(*e*) The central portions, which are mainly of gentle relief and low-lying, consist of Permian Coal Measures which are developed in the major basin over a length of 20 miles, and in the minor basin approximately eight miles long.

(*f*) While disconformable relationship between Permian and Carboniferous exists in the northern sector, further south steep boundary faults mark the separation of the coal measures from the resistant Carboniferous lavas which form a sheath-like bounding structure to the syncline. These marginal faults are to be regarded as intra-graben structures, for the Trough in its central portion assumes some of the features of a Graben.

(*g*) In certain parts the narrowness of the Trough is remarkable, being only five miles wide between bounding faults near Stroud Road.

(*h*) The physiographic expression is that of parallel ridges, one on each side of the structure, and one or two noticeable subsidiary ridges within the Trough, as for example east of Craven, and between Weistmantels and Stroud Road.

(*i*) Bounding faults separate this narrow Trough from broader fold units on either side.

(*j*) The northern part of the structure is drained by the Avon and the Lower Gloucester Rivers, and the southern part by the Karuah River.

(*k*) A great covering of Pleistocene and Recent sands and leached clayey soils obscures a great deal of the geology of the southernmost part of the Trough.

The Northern Sector.

Summarized Stratigraphy.

The rocks constituting the Trough in this portion have been fully described in several publications, but it was not until in recent years that the relations of the faulted complex of the Gloucester district were satisfactorily determined.

The formations present comprise :

(*a*) Permian Coal Measures, thickness unknown.

(*b*) Upper Kuttung Series, maximum thickness 2,400 feet.

(*c*) Upper Burindi Series, maximum thickness 4,500 feet.

(*d*) Lower Burindi Series, maximum thickness 7,000 feet.

There are many seams in the Coal Measures, and the associated rocks are conglomerates, sandstones, grits and mudstones. Although some of the seams are quite thick (maximum 30 feet) the general consensus of opinion among Sydney geologists is that the Series belong to some part of the Upper Coal Measures, although correlation with the better known areas of the Main Coal Basin is very difficult to achieve. The possibility of a Greta age for the Series must not be overlooked.

The Upper Kuttung Series consists of a thick volcanic series (rhyolites and keratophyres) and much tuff and conglomerate, remains of the *Rhacopteris* flora having been found in shaly layers. The striking physiographic features of the Gloucester Buckets on the west and the Mograni Range on the east are made of the Upper Kuttung flows.

The Upper Burindi Series (which gives way to a terrestrial equivalent as one proceeds south, and there is described as the Lower Kuttung) comprises much mudstone and several quartz-keratophyre flows, some fossiliferous bands being present at fairly constant positions in the sequence. The tuffs make fairly rugged country on the west and south-west of this sector of the Trough, and as the Upper Burindi facies declines in importance and the Lower Kuttung supplants it, toscanitic lavas make their appearance and form pronounced ridges running southward. In the region around Weistmantels and along Lower Mamme Johnson's Creek there is much more variety in the lava types, and some fluvioglacial conglomerates appear.

The Lower Burindi is well developed on the western fall of the Gloucester Buckets, and on the eastern side of the Mograni Range continues unbrokenly along the margin of the Trough. Going southward the rocks lose some of the facies of the northern Lower Burindi and display the typical features of the Lower Burindi of the Clarencetown district.

Structural Features.

The axis of the Trough lies to the west of the median line that would be regarded as the geographic axis dividing the morphological features into approximately similar areas. The floor dips steeply at the northernmost point of the Trough (see map) but this dip is influenced by the presence of the Barrington River Fault. Nevertheless there is reason to assume that a southward pitch carries on for a considerable distance because within the main coal basin there is a thick series of measures, within which are some very thick seams (up to 32 feet), and these features bespeak the fairly deep burial of the base of the synclinal floor.

The southernmost outcrop of the Permian in this sector can be seen on the Mamme Johnson back-road and also to the east thereof at a point about two miles south of a locality called Dewrang (marked by a railway siding and a group of farms). Here the base of the Coal Measures is pitching gently to the north, and lies on an eroded Carboniferous surface.

Further north the same structural relations can be studied on the roadside about one and a half miles north of Weistmantels. A similar northward pitch is beautifully shown at a lower stratigraphic level about two-thirds of a mile south of Stroud Road Railway Station, where, in the paddocks to the west of the Pacific Highway, exposures of an ignimbrite lava of the Upper Kuttung display the scoop-like structure of the plunging unit. This structure gives the key to the rather complicated volcanic succession hereabouts.

The south end of the Coal Basin possesses strongly faulted junctions against the Carboniferous. Thus on the east side a magnificent fault-face outcrops in the country east of the Mamme Johnson's Road, near Dewrang. This revealed surface is of felsite and ignimbrite with good flow-structure, and shows many slickensides. The attitude of the fault is almost vertical, the slight hade being to the west. This feature running northward for some distance has the following position on the one-inch military maps : 499–500/1005–1006 Dungog Sheet to 498–499/1012–1014 Gloucester Sheet.

On the west there is equal evidence of a faulted junction. Thus near the old tunnels and shafts in the neighbourhood of the historic site of discovery of coal in this area the measures are dipping steeply to the east and a 30 feet seam exists close to the western boundary of the basin. Immediately to the west are Carboniferous confining units dipping at only moderate angles to the east. Near Relf's Creek in this locality it is possible to establish that the coal measures lose the steep dip away from the fault and soon flatten out to the east. Unfortunately the most desired information about this southern extremity of the Coal Basin is not available because of the prevalence of alluvium and timber. Further north these intra-graben faults die out.

Structures in the Coal Measures.

Within the Permian areas the outcrops are rather poor except for one or two outstanding exceptions. Artificial excavations, however, always reveal interesting information, and sometimes produce the most important criteria of the type of movement to which the beds have been subjected in their last tectonic experience. Thus, as already described in another paper, there are excellent sections in the railway cuttings south of Craven Station which show miniature " nappe " structures, small thrusts and drag folds associated with larger displacements. These in general indicate compressive stress from the north-east. In quarries in the same neighbourhood, and in the exposures to be found around Ward's River village and south therefrom, excellent data are also available.

The examination of dip in regions that do not appear to be much faulted indicates that the surface of accumulation of the basal Permian strata was irregular. Thus along a zone adjacent to the Carboniferous lavas of the western side of the Trough, wherever sections can be studied, one establishes that the dip varies eastward by becoming less and less steep, and also shows variable direction interpreted as due to irregularities of the floor.

A splendid section showing the effects of overthrusting produced by forces from the N.E. is that in a narrow quarry (known as Timberline Cutting) just to the north of the Glen Road, two miles east of Craven. Here (Figure 1) the coal measures are dipping N. 30° at 40–48° and are intersected by four overthrusts which in general dip to the north-east, and are fairly low in inclination. At the eastern end of the quarry two of the thrusts have been curled upward so as to be partly underthrust by the excessive stress acting. The main joints of the locality dip W. 15° N., while less prominent fractures strike N. 75° E. Both sets of joints are almost vertical in attitude.

On the almost vertical wall of a N. 70° E. joint two sets of complementary joints are present, dipping respectively easterly and westerly at about 25°. The large thrusts in the quarry have developed on one set of fractures set up by the more or less westerly directed compressive component of the shearing stresses that have operated.

Related to the intra-graben faults of the south part of the Northern Sector are certain almost vertical joints of tensional origin which strike meridionally and give rise to striking outcrops of beds of varying erosive resistance. Such joints and associated steeply dipping strata are seen on the Mamme Johnson's Road about two miles south of Ward's River village.

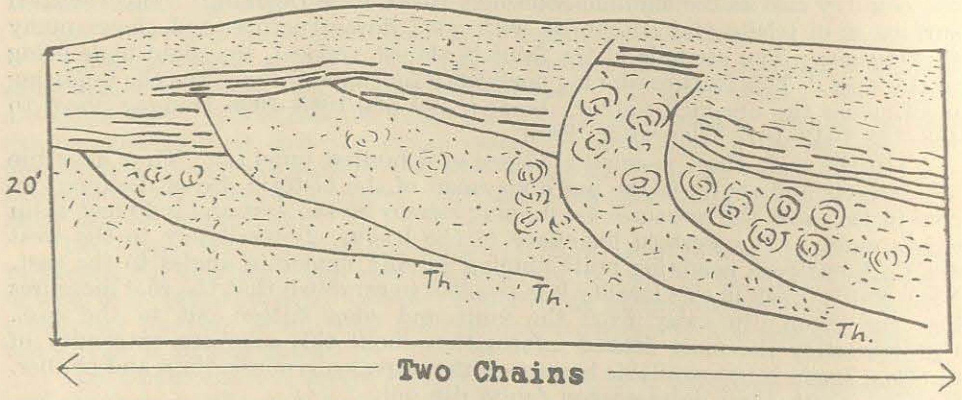


Fig. 1.—Curved thrusts in quarry two miles east of Craven.

The North Central Sector.

Between Dewrang and Booral the Trough is characterized by the disappearance of the Coal Measures because of the upwarping of the strata so as to pitch to the north.

As already mentioned, a splendid section a little to the south of Stroud Road shows the nature of the pitch in this section of the Trough.

The rocks involved in this sector are as follows:

- (*a*) Lower Kuttung Series.
- (*b*) Upper Kuttung Series.
- (*c*) Permian.

(a) Lower Kuttung Series.

On either side of this sector the Lower Kuttung conglomerates, tuffs and lavas make strong outcrops. There is a noticeable asymmetry, however, since the western side of the Trough shows a strong development of rhyolitic tuff and some subordinate rhyolite flows, while on the east the Volcanic Stage is dominated by thick units of toscanite. Further, the tuffs on the east are sometimes completely pyroclastic and may pass into lavas showing autobrecciation.

The striking ridge on the east side of the Trough on which stand the heights of Stroud Trig., Stroud Mountain East and Renwick's Sugarloaf, is composed of the Mt. Gilmore type of toscanite.

(b) Upper Kuttung Series.

The rocks of this group comprise cherty tuffs and glacial sediments with several small impure coal seams and marked horizons of plant-fossils. Altogether about 700 feet of strata are present and the outcrops are good. One belt runs west of the main Pacific Highway and of the Karuah River between Booral and Stroud Road, while the other is found in the foothills which lie to the east of Stroud and trend southerly to Booral. On both sides of the Trough in this sector the rocks of this division are on end due to faults. Several cross faults are prominent near Stroud Road, and these appear to offset the larger meridional fractures.

One puzzling aspect of the stratigraphy of this sector is the occurrence of much shattered basalt which, from the field relationship, may be interpreted as within the Kuttung succession, or alternatively as sills acting as feeders to the Permian basalt flows which are definitely present in three outliers near Stroud. No section has yet yielded satisfactory evidence of intrusive relations between the basalt and associated Kuttung strata, but from the general way in which the basalt units follow the structural lines of the associated volcanic and sedimentary rocks, one is inclined to place the basic rock as contemporaneous. There is great variety among the volcanic rocks, and this is really the chief place in the Karuah province for studying fully the vulcanicity of the Upper Kuttung epoch.

The lavas and tuffs are well exposed in the hills cut by the road from Stroud Road up Mill Creek. This eastern side of the Trough contrasts with the western side, where many of the lavas have cut out and where the dominant flow (excellent for structural mapping) is the well-banded Halls Hill rhyolite.

The plant-bearing cherts are characterized by an abundance of members of the *Rhacopteris* flora and less abundant *Lepidodendron veltheimianum*. The most prominent genera are *Rhacopteris*, *Adiantites* and *Sphenopteridium*. These strata were first brought to light by early investigations of the Australian Agricultural Company. The repeated references in early literature to the fossil locality of Smith's Creek, near Stroud, refer to the area a few miles north-north-east of Stroud, where good material is no longer available.

In the plant-bearing strata several thin seams of poor grade coal occur. These can best be studied in the cuttings at the overbridge on the railway line three-quarters of a mile west of Stroud Road. This development of Carboniferous coal may be correlated with similar occurrences at Tanilba, Port Stephens, Paterson East and Broughton Island.

(c) Permian Rocks.

Although some of the earlier reports dealing with the coal measures of the Stroud-Gloucester region suggested the occurrence of Upper Marine strata of the Permian System, no specific instance of this has been established by the writer. The only rocks which are of post-Kuttung age at Stroud and north and south therefrom are flows and necks of basic type. The flows are of a shattered calcitic basalt, comparable with some of the Permian basalts in the Comerfords district near Maitland. The intrusions are of small size and seem to be less alkaline than the flows, but linked mineralogically with them.

There is a marked unconformity between the basalt and the underlying Kuttung Series, and this has some important implications dealt with below.

The main structural interest of this section of the Trough is the evidence of a northward pitch, and the presence of several faults which trend almost due north and south (magnetic). The faults are steep and are related in origin to the great Williams River Fault which bounds the Trough on the western side. More will be said in the sequel about the fault-systems.

Adjacent to the settled and mature country of this south-central sector there lies, on the eastern side, a wide belt of very rugged and heavily forested country which is part of the western side of the Girvan anticline. The western country contiguous to the sector is a region easily accessible and fairly free from much bushland throughout about 40% of its extent. Here one can study the remarkable effects of the Williams River Fault.

The minor structures of the Upper Kuttung Series at Stroud Road are due to two of the meridional faults. These features comprise much slickensiding, minor thrust-faults and small drag folds, together with intense small-scale jointing. The study of these features leads to the view that original clear-cut gravity faults were affected by later shearing movements.

South Central Sector.

This division is characterized by the following features:

(*a*) Presence of considerable glacial material in the Carboniferous succession.

(*b*) Occurrence of a marine Upper Kuttung succession.

(*c*) Evidence of progressive overlap between the Kuttung Series and the Permian units, and of contemporaneous erosion of a Carboniferous floor prior to outpouring of Permian basalts.

The stratigraphic units in this zone are:

(*a*) Lower Kuttung Series (freshwater).

(*b*) Upper Kuttung Series (partly freshwater, partly marine).

(*c*) Permian (Lower Marine, possibly Greta Coal Measures and Upper Marine Series).

The Lower Kuttung has a much more pronounced physiographic expression on the eastern side of the Trough, where, trending southward from the neighbourhood of the Booral-Bullahdelah Road towards Karuah on Port Stephens, is a series of high hills of coarse toscanite. On the western side the same volcanic horizons are present in the hills which stand a few miles to the west of the Pacific Highway, but which are less continuous than the eastern belt.

Conglomerates of the Basal Stage type (see Osborne, 1922) are prevalent in the country both east and west of the Trough.

Upper Kuttung Series.

This division of the Carboniferous succession is of great stratigraphical interest, but in this work the only need is to refer to the strata in so far as they are helpful in elucidating the structural history of the Trough. Thus we note that the discovery by Mr. W. H. McCoy and the writer in 1946 of marine Upper Kuttung rocks in the quarry about two miles east of Booral, and the tracing of these strata southward, establishes a fairly important development of the Neerkol facies of the Middle Carboniferous in this State. The fossils of most interest in this connection are the *Bryozoa*, which were determined by Mrs. Joan Beattie as identical with species from the Neerkol of Queensland. Along with the *Bryozoa* in these fine cherty shales are representatives of such genera as *Strophalosia*, *Orthotetes* and Upper Carboniferous productids.

Other rocks of the Upper Kuttung Series comprise glacial units of some variety, embracing tillites, fluvioglacial conglomerates and sandstones and rocks akin to varved shales.

Some of the tillites are marine because of the presence of odd micro-fossil debris. The rocks in question are seen very well in the bed of Stoney Creek, a mile or so north of Limeburner's Creek. Similar tillites (greenish in colour when fresh) form a very distinctive type in the marine Upper Kuttung of the Ellenborough and Comboyne areas.

Permian.

The Permian rocks first make their appearance, after having failed to outcrop in the Trough south of Stroud South, in the country between the Highway and the Karuah River at Allworth (Old Booral). It appears that the occurrence here is due to a short steep fault. The rocks have affinities with the Lower Marine Series of the Hunter Valley. A few miles further south the Upper Marine Series outcrops in the bed of Deep Creek, near its confluence with the Lower Karuah River. The belt of Upper Marine then swells out southward, while other Permian units (Lower Marine and possibly Greta Coal Measures) are very subordinate.

Structural Features.

The Trough has now taken on a somewhat different strike in contrast with the more northern sectors. Here the strike is changing from north-south to north-north-east and almost north-east. This swing is associated with the adjacent curving margin of the Lower Williams anticline, described many years ago by the writer.

The Trough also shows in this sector the beginning of the southward plunge which becomes predominant in the South Sector, next to be described.

The main interest of this sector centres around two items of structural significance in the later geological history of the Upper Permian strata. These are (*a*) evidence of overlap, and (*b*) presence of the strong Tarean Fault.

The first of these is established by the finding some years ago of the Upper Marine fossiliferous sandstones of Stoney Creek resting with erosional break upon the *Lepidodendron*-bearing beds of the Upper Kuttung. The stratigraphical break here is of the order of 10,000 feet judged by the standard sections some miles to the west.

The Tarean Fault is a vital piece of evidence in the investigation of the relations between major groups of faults in the province. Some discussion of the rôle of this fault was given in an earlier paper (Osborne, 1938). It is clear from the structural and stratigraphic data to hand that the Tarean Fault is a post-Upper Coal Measure fault, thus contrasting with those which were produced during the late Upper Marine diastrophic episode.

The Southern Sector (*Medowie Sub-Unit*).

This, the southernmost of the four sectors, is characterized by the following distinctive features, geological and otherwise:

(*a*) A considerable proportion of the country is marked by low-lying swampy conditions and one portion is covered with sand ridges and sandhills of the Stockton-Raymond Terrace-Williamtown region.

(*b*) Heavily forested reserves embrace a good deal of the northern area, while on the north-east of this sector the muddy estuaries of Karuah River and Telligerry Creek (where they enter Port Stephens) are covered with mangrove growth.

(c) On the lower west side of the sector hard rock outcrops of the Lower and Upper Kuttung are prevalent in the East Seaham-Raymond Terrace–Irrawang district.

(d) In all areas not given to strong outcrops there is generally a cover of strongly leached soil now largely composed of argillaceous material.

(e) The bounding major fracture of the Williams River Fault comes into this region, and its character and stratigraphical effects are seen to perfection in a quarry about five miles north of Raymond Terrace.

The rocks present here are:

(a) Permian sediments and basalt flows and thin coal seam.

(b) Upper Kuttung Series (mostly glacial).

(c) Lower Kuttung (mostly volcanic).

Lower Kuttung Series.

The lava groups prominently developed in the South Central Sector are continued into this sub-province, but an interesting variation of type and quantity of the lavas on either side of the Trough brings about a contrast with the South Central Sector. Thus in this sector we have abundance of lavas in the neighbourhood of Irrawang and south-east of Seaham, which belong to the Lower Kuttung series.

Upper Kuttung Series.

Stretching along the west side (and less prominently on the eastern margin) from Limeburner's Creek locality for about twelve miles are the Upper Kuttung Glacial Beds. These are freshwater in origin in the south and marine (*cf.* above) further north at Stoney Creek. The passage from one phase to the other is appreciated about six miles south of Limeburner's Creek.

These rocks have been studied by the writer and Mr. M. R. Banks, B.Sc., the latter having made some detailed measurements of the stratigraphy in 1946. A great variety of lava-type is present and many completely pyroclastic rocks are a feature of the area. These rocks show a simple curving structure representing the western side of the Trough in this sector.

Permian.

The Medowie Basin (which is an equivalent term for this southern sector of the Trough) has always given geologists a good deal of difficulty in interpretation, on account of the lack of outcrops and the prevalence of a soil which is a kind of common denominator for the whole district, so thorough has been the leaching by ground waters. The bed rocks of the district are Upper Marine Series and Upper Coal Measures.

Professor David (in 1907) discussed the probable distribution and structural relations of these rocks beneath the cover of soil and sand, and considered very critically the evidence of several deep bores that were put down in the eastern part of the region now under discussion. A good deal of the solution of the problem revolves around the stratigraphical relations of the zeolitic basalts and the impure coal seams which have been struck in the bores, and which in various places in the area outcrop more or less indifferently.

More recent work by the writer, particularly in connection with a hydrological investigation for the Hunter District Water Board, has led to the recognition of certain facts about the rocks, and to a confident interpretation of the structure in the area. It is sufficient to explain that the Tarean Fault (see Osborne, 1938) is clearly proven by the data now available, and that it transects both Upper Marine and Upper Coal Measures.

The sweeping belt of Upper Marine mudstones and tillite shales which is seen at intervals throughout the alluvium of the country between Limeburner's Creek and Raymond Terrace is a continuation in structure of the similar curved area of the Upper Kuttung further to the north-west. No cross faults are present in the Upper Marine outcrops, but it is clear from a study of the few exposures in quarries that concealed faults have caused small displacements of the Permian rocks, quite apart from the matter of the large Tarean Fault. On the eastern side the search for outcrops becomes more difficult, but in many wells and in other artificial exposures it is possible to establish the existence of a mostly concealed, but wide, area of basalt overlain by typical brown mudstones of the Upper Marine.

The Trough thus has gradually widened out at its southern end into this Medowie structure, and the plunge to the south-south-west is quite marked by the inferred-plan of potential outcrop.

Some of the later excavations (made by the Defence Department in connection with World War II) show the presence of pressure striations and small slip-faults in the rocks of the Tomago Stage of the Upper Coal Measures.

Ward's River Structure (Sub-Unit).

About two to two and a half miles to the east of Craven there occurs a subsidiary block-faulted basin of Coal Measures, running north and south, never exceeding half a mile in width of outcrop. The longitudinal extent is about seven miles. This structure is that which has always troubled the investigator because of the ubiquitous soil and vegetation-cover that occurs as soon as one moves any distance into the region of the margins of the main Trough. It is clear from a study of the small-scale structures that faults through this small block place Coal Measures against Upper Kuttung on the west and Burindi rocks on the east.

Not much has been done regarding the nature of the structural condition of the rocks in this small senkungsfeld, but it is clear that strong jointing is universally developed. Some of these joints in the fault-block are complicated by later small thrusts with curving dip.

THE RAWDON VALE ANTICLINE.

General.

Directly adjacent to the marginal western faults of the northern sector of the Gloucester Trough lies the Rawdon Vale anticline, a southward plunging fold that shows an intermediate tectonic position, in that some of its structural features represent response to the forces operating at the time of the deformation of the Stroud-Gloucester belt, while others belong to the north-north-west trend which was implanted on much of the country in a later episode.

The structure cannot be studied fully because of the heavy brush cover and extremely rugged country between Copeland and Berrico and elsewhere in the region of the anticlinal development.

The general relations of the fold can be appreciated by noting the Barraba Series which outcrops between Barrington village and Copeland, and in the country to the north-east of Rawdon Vale and also on the Berrico-Rawdon Vale Road. Such data can be compounded with the evidence of the Tamworth Beds in various places in the Berrico-Cobarkh area.

General Stratigraphy.

The following are the units present in this structure:

Lower Burindi	1,500 feet.
Barraba Series	4,500 feet.
Baldwin Series	300 feet.
Tamworth Beds	Maximum unknown, but at least 2,000 feet.

The Lower Burindi are of the typical mudstone facies and are seen in the faulted blocks just west of Faulklands. The Barraba Series contains in addition to radiolarian chert and carbonaceous mudstones, a series of fine conglomerates and also some thin white tuffs. *Lepidodendron australe* is quite common, as, for example, at Copeland.

The Baldwin Series is mostly tuff with occasional agglomeratic phases, and in all cases there is a proportion of banded cherty rock in the fragments suggestive of derivation from the Tamworth Series. (This is very significant.) The Tamworth Series embraces a wide variety of types. There are always varied tuff-chert banded rocks with evidence of para-depositional brecciation and slump-bedding. In addition there are radiolarian tuffs, cherts and conglomerates with large boulders, the matrix of which weathers to a deep brown colour. Some *Lepidodendron australe* is sparsely present.

Structure.

The core of the fold is given over to Tamworth Beds.

The main outcrops are south of the Barrington River Fault, on towards Copeland. They are also seen in their marginal development at various places on the Berrico-Rawdon Vale Road. Thus on that road several faults bring Tamworth Beds into contact with Barraba and/or Baldwin tuffs.

After the road leaves the course of the Gloucester River one soon finds a succession from Barraba into Lower Burindi. The rocks are fairly steeply inclined to the west and much minor faulting is present, some of which is along bedding planes with no stratigraphical throw.

Then from the " Stockyards ", south of Rawdon Vale settlement, there is a fine section of Lower Burindi mudstones, crinoidal limestones and tuffs, almost identical with rocks of the same age as exposed at Glen William, near Clarencetown, and at Hilldale. These strata strike N. 20° W., and thus the western side of the Rawdon Vale structure has taken up tectonic affinities with the main trend of the Province.

To the north, past the Homestead and on towards Cobarkh, there are splendid sections of the richly fossiliferous Burindi. The various Tournaisian genera, so common at Hilldale and elsewhere, are to be collected here. One rock, which is found in this locality, is very dark, strongly carbonaceous and pyritic shale with many *Orthotetes* present. This is exposed about a mile north of the homestead and will prove a useful fossil datum for any palæontological work in this region.

The greatest structural complexity in the anticline is found on the plunging axial zone. This is best studied on the hills around Berrico Homestead and then onward to the country south of Rawdon Vale. A number of exposures in quarries and in the Gloucester River show that considerable tectonic complexity has marked the adaptation of the anticline to the two contrasted elements of the Gloucester environment and the Gresford-Wallarobba influence.

Thus in one quarry Barraba or Tamworth tuffs (distinction here is difficult) dip S. 2° E. at 50° and on the dip face there are displayed a fine set of joints. Two conjugate sets perpendicular to the stratal face show clockwise pitch respectively of 30° and 120°, while a weaker third series has a pitch of 40°. A set of " back-joints " is present, parallel in strike to that of the rocks.

These fractures are strains of probably two periods set up within the crestal zone by earth movements.

Away from the zone of contusion and severe fracturing on the nose of the fold, tectonic uniformity is reached by the rocks showing a fairly constant dip of about 50° to the W. 30° S.

Perhaps the most spectacular part of the Rawdon Vale Structure is that to be found along the Barrington River, where it flows through the country between Rawdon Vale Homestead and the Cobarkh-Copeland back road.

Along this road, as it passes through the down-like meadows of this beautiful property, one can see much that can be linked with the magnificent section displayed on the right bank of the Barrington River. From the Copeland region the rocks are seen to dip westward and Tamworth Beds give way to Barraba. Then the Barraba can be seen in splendid westward-dipping exposures which steepen as one goes westerly upstream along the Barrington River. Soon a great fault zone is reached, drawing down the rocks to a vertical attitude. This is a true normal fault and has no evidence of any lateral shift. It is absolutely vertical, and away to the north there is a series of vertical fault-face outcrops, the like of which the author has rarely seen in the case of revealed fault surfaces.

Immediately west of the fault the Burindi rocks dip back to the east, and then eventually the axis of a small anticline is crossed and the Lower Burindi resume the south-westward dip of the main western limb of the Rawdon Vale structure. It is clear that the small anticline has been determined by the dragging effect of the large fault reversing the dip in the neighbourhood of maximum displacement.

THE MYALL SYNCLINE.

General.

This feature is marked by considerable structural complexity in the central portion. It stretches from the Pacific coastline north of Port Stephens to the rocky headlands of Seal Rocks, Treachery Head, Charlotte Head and Cape Hawke, and embraces all the country west to the valley of the Myall and Crawford Rivers. In this direction the syncline passes into the Girvan anticline. The total area in question is about 450 square miles, and includes the district of Bullahdelah, where a remarkable ridge known as the Alum Mountain dominates the Lower Myall country. This ridge is the physiographic expression of the Bullahdelah Horst.

Stratigraphy.

The following rocks are present :

Permian : Lower Coal Measures, Upper Marine Series.

Carboniferous : Lower Burindi, Upper Burindi, Lower Kuttung.

The Lower Burindi makes wide areas of outcrop, some partly obscured by alluvium, sand or vegetation. The rocks are uniformly developed, consisting mostly of cherts and quartzose tuffs. There are some crinoidal limestones and fossiliferous tuffs.

The Upper Burindi consists of rocks similar to part of the Gloucester Sequence. Thus the *Productus barringtonensis* bed occurs on the east of the basin, especially in the neighbourhood of Johnson's Hill and Violet Hill at Myall Lake. In places the rocks are dense cherts.

The Lower Kuttung consists of conglomerate and andesite lava, while the Upper Kuttung consists of coarse conglomerate, rhyolites and tuffs.

On the western side of the syncline the Kuttung series has the greater development, and this asymmetry is brought out beautifully on the map. The section on the west embraces a series of dominant toscanites and andesites, while the Upper Kuttung is well developed, including a very great thickness of acid tuff.

The Permian rocks are chiefly Upper Marine sandstones, shales and ironstones, while the Greta Coal Series consists of very coarse conglomerates, white tuffs and poor grade coal.

Structure.

A fairly stable block with constant regional dip is that of the Seal Rocks-Bullahdelah sector. Here the only departures from the regional dip are the locations of the fairly heavy faults, such as F1, F2, F3 and F5.

The asymmetric fold suffers an abrupt truncation by the Myall-Waukivory Fault, which thus expresses influence of the earlier formed Stroud Trough, at its northern end.

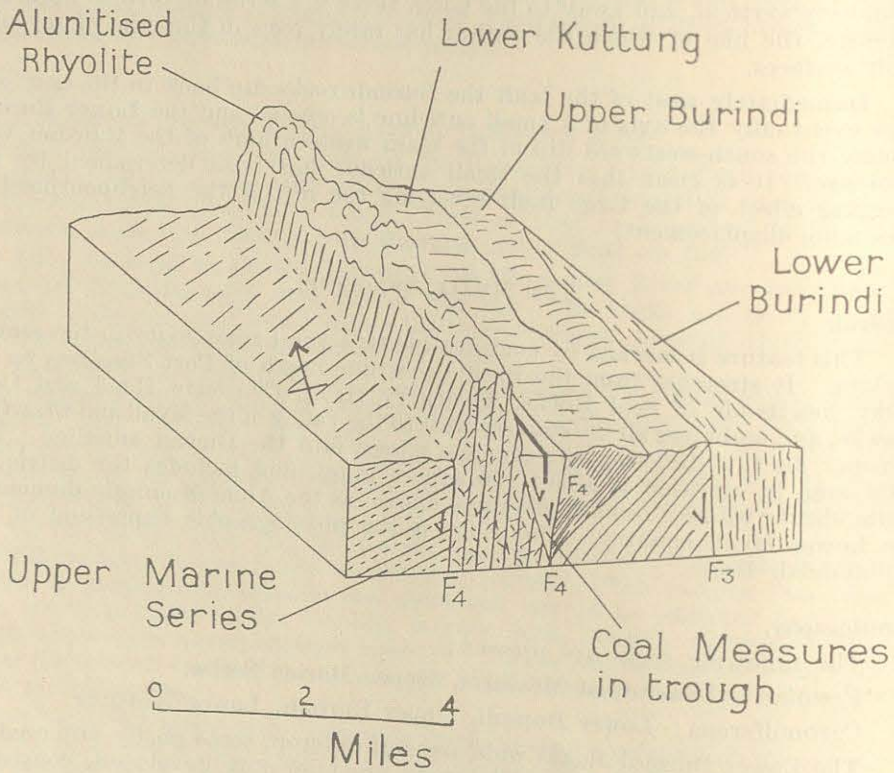


Fig. 2.—Block diagram of the Bullahdelah Horst.

The central part of the fold is given over to Upper Marine fossiliferous sandstones, etc., while a thin development of the Greta Coal Series is present intermittently. The axis of the syncline trends down the line of Myall River and is mostly hidden in alluvium.

Underlying the Permian on the west of the structure is the well developed Kuttung Series, in the lower part of which one finds various indicator beds, while the Nerong toscanite also acts in this way for the Upper Kuttung.

Within the syncline a little to the east of the axis lies one of the most intriguing structures of the whole province. This is the narrow Bullahdelah Horst which is the essential structure of the Alum Mountain (F4 on map).

Full account of this is given elsewhere. We note here that the Alum Mountain rhyolite and associated strata of the Upper Kuttung are bounded on each side by an almost vertical normal fault. In the case of the western side the adjacent rocks are talus-covered Upper Marine sandstones, while to the east the adjacent rocks are certain Upper Kuttung units. The rhyolite is almost vertical in dip, to the west-south-west. The presence of coarse spherulitic structure, arranged in lines parallel to the dip, assisted in determining the tectonics of the Horst.

The evolution of the Horst is interpreted as follows :

In the earlier phases of the Upper Palæozoic orogeny there was produced along the zone of the present Myall syncline an asymmetrical fold consisting of a very steeply dipping eastern side and a less steep western side. After the causal stresses responsible for the compression were removed, no doubt temporarily, pronounced fracturing took place across the fold with the production of three steep surfaces dipping westerly. Along these strong subsidence took place, thus placing the various formations in the geometrical relations shown by the narrow ridge of rhyolite bounded by lowlands of Upper Marine sandstone and Upper Kuttung. Also, the narrow trough of Coal Measures to the south was preserved because of the development of two opposed steeply dipping faults.

Followed south-westward the bounding faults of the Horst open out somewhat, but the eastern fault becomes the bounding wall, *on the west side*, of a narrow strip of Coal Measures (see Figure 2). North from Bullahdelah the whole structure is cross-faulted.

The Myall syncline was formed at the time of the Hunter Thrust System stress episode. In this eastern area the Thrust System is not present, but contemporaneous structures exist.

THE GIRVAN ANTICLINE.

The Girvan Anticline is a simple structure except for the northern end of the fold, where considerable complexity exists. This complexity is difficult to unravel because of the prevalence of forest growth and inaccessibility, but from Forestry Commission tracks and other limited access it has been possible to assess various data and interpret as shown on map.

The anticline is clearly exhibited by the exposures in the region about Girvan village and in the cleared but uninhabited country between the Booral-Bullahdelah and the Karuah-Tea Gardens roads.

There is not much variety in the stratigraphy of the Lower Burindi Series which makes up the bulk of the fold. These comprise mudstones and tuffs, with fossil zones pronounced in several places. Thus at Girvan Brachiopoda and Bryozoa are abundant in olive-green mudstones. Then again, in Bundabah Creek, in the south of the area, beautiful examples of *Spirifer* sp. nov. are common in a tuff exposed where the road crosses the creek.

The axis of the anticline can be fairly satisfactorily placed because of the abundant outcrops on either side of the Booral Road. For example, rocks are horizontal, right on the crest, at a point about 30 chains east of the Nugra Road junction with the Booral Road.

There is a good deal of minor faulting, seen on the Branch Road. Little major faulting has been detected except for the special sector near the head of the Crawford River. The place of the anticline in the structural history of the Stroud Trough is considered below.

SYNCLINAL STRUCTURE ON BROUGHTON ISLAND.

Broughton Island, lying to the north-east of Port Stephens, gives an intriguing section of the Upper Kuttung Series which is cut off by a fault against some Lower Burindi rocks.

The Kuttung development is of interest because of the existence of the following features:

(a) A series of rhyolites with good flow structure which are equivalent to the Bullahdelah-Alum Mountain flows.

(b) An impure coal seam in association with richly fossiliferous cherty shales crowded with the *Rhacopteris* flora.

(c) Minor sections displaying deltaic control of some Upper Kuttung sedimentation.

The chief structural feature is the Syncline which trends N. 22° W. across the island. The axis can be located and the axial plane appears to be inclined steeply to the south-west. The dips on either side are about 40°.

This syncline is the central portion of the continuation of the Myall Syncline, but the presence of a lower tectonic horizon here as compared with the mainland (see map) implies one of two things; either

(a) there has been upwarping of the synclinal floor north of Broughton Island, or

(b) the structure on the Island has been faulted away from the main syncline.

THE GRESFORD-WALLAROBBA ANTICLINE.

General.

This is by far the largest single broad structural entity in the region under consideration, being approximately 900 square miles in area. It covers a large portion of the central zone of the province and spans the region between the Stroud-Gloucester Trough and the zone of basins which lie along the belt from Paterson to the neighbourhood of Aberdeen. The anticline is strongly modified in its most south-easterly sector by a very complicated zone of conflict between the earlier structures (such as the Stroud Trough) and the later trends which find expression in the anticline.

The main direction of the axial zone is north-west–south-east, and there is a fairly constant development of this trend. The anticline may be subdivided into (a) the Main Fold, (b) the Welshman's Creek Dome and Basin, (c) the Paterson Anticline, (d) the Williams River Anticline and the Dunn's Creek Syncline.

Of these the last three have been described in earlier papers, and there is little to add except in the case of the Dunn's Creek syncline, to which some reference will be made below. The other sectors will be taken here in some structural detail.

Stratigraphy.

(a) *The Main Fold.* This section outcrops in the heavily forested country at the head of the Paterson, Allyn and Williams Rivers, as well as in the lower country stretching across north from Mirrannie to the Dungog-Gresford-Hilldale district. The rocks present comprise the following:

Upper Kuttung	(Maximum)	3,400 feet
Lower Kuttung	(Maximum)	2,800 feet.
Lower Burindi	(Maximum)	10,000 feet.

The Lower Burindi include a variety of tuffs, conglomerates, crinoidal and shelly limestones carrying in many places a very varied and prolific fauna. The mudstones and the dacitic tuffs are the most common rocks and very wide areas have nothing but monotonous Burindi mudstones.

There is no Upper Burindi in this sector, because the Lower Kuttung is well developed in sections which have been studied very fully from the standpoint of the volcanic succession and sedimentary oscillations.

The Lower Kuttung comprises conglomerates and a series of lavas and associated tuffs. The volcanic succession constitutes the Volcanic Stage of Osborne (1922). In this area there are many flows and all manner of tuffs, breccias and agglomerates.

The Upper Kuttung Series is well developed in the region between Gresford and East Tyraman, where the Main Clastic Zone is the chief subdivision present.

Structure.

A fairly simple anticlinal structure marks this unit, although it is goffered and buckled badly in the culminating zone in the south-east terminal portion of its axial zone. It is also complicated by the presence of a series of block-faulted masses in the Dungog-Chichester-Salisbury-Underbank areas. These blocks will be referred to under a separate heading.

The pitch of the anticline is not marked in the north-west sector, where the Carboniferous rocks emerge from the wide cover of the Tertiary basalt flows of the Barrington Tableland and its prolongations, but south-eastward the pitch begins to increase and the structure takes on a broader arching, only soon to be merged into the complex basin and dome association which occur near Wallarobba and Welshman's Creek.

Facies changes in the Lower Burindi throughout this large anticlinal sector have brought together various Burindi types in intimate association with varying Kuttung units. Thus mudstones of the former are sometimes overlain by Lower Kuttung conglomerates, while at other times heavy conglomerates, keratophyric flows and sandy tuffaceous rocks are the Burindi types to be found beneath the volcanic sequence.

The Eastern Side.

On the eastern margin the anticline is marked by a strong series of gravity faults which have been responsible for placing all rocks for about two miles in a nearly vertical position. This rather remarkable structural condition can be seen in the country east of Dungog and lying therefrom to the western margin of the Stroud-Gloucester Trough. In the railway cuttings and in countless exposures the rocks are always found to be on end, and to be cut by many small faults which are genetically related to the master faults of the area, such as the Williams River Fault.

From the Dungog-Stroud or Dungog-Weistmantels Road to the south there is a region of much timber where the Lower and Upper Kuttung Series are found. These rocks are separated from Lower Burindi (rich in fossils) by the Williams River Fault, which has dominated every other structure here.

The Lower Kuttung is exposed in the country between Glen William and the Washpool near Stroud. A series of thick lava flows, chiefly toscanite, as well as the Martin's Creek andesite, form rugged hills to the north-east of Glen William. These lavas show erratic variations in thickness. They are cross-faulted in the neighbourhood of The Brothers, and from this locality can be traced through Clarencetown to the country southward.

In the anticline now being considered there appears to be a gradual passage from the Lower Burindi to the Lower Kuttung, especially in the low hills north of Clarencetown.

Fractures through the rocks everywhere testify to the fairly simple tectonic environment of these rocks during their folding, and thus make a strong contrast with Wallarobba structures which give evidence of a very involved tectonic evolution and the operation of rotational stress.

An important fault modifying this structure is the Gresford Fault. This trends north-north-west–south-south-east, and is of very strong character.

It can be appreciated by the study of the dips to the north and north-west of Gresford. From a gentle dip (12–18°) in the village of East Gresford directed to E. 15° N., there is a fairly sudden reversal to south-west at 36–40°. In between the two opposed dips the crestal zone of the anticline has been broken by the Gresford Fault. This fault is of earlier formation than a small transverse fault which may be seen delineated by certain steeply dipping beds trending about north-east a few miles south of Gresford.

(*b*) *The Wallarobba-Welshman's Creek Complex.* The structures described many years ago by the writer when the Paterson-Clarencetown area was being investigated comprised three tectonic entities which were unified into a dome-like feature, centring about a point in the neighbourhood of " Glen Cairn ".

A great deal more information has been obtained by more recent field work, and it is clear that the complexity was brought about by the interaction of trend-lines and by the influence of the Hunter Thrust movement.

The basin in this sector is small, but of some interest in that its component parts show a marked variation among the hornblende andesites and andesitic pitchstones regarding both order of extrusion and thickness.

The Basin is shallow, and may be noted by the south-west dip between Wiragulla and Sandy Creek (Wallarobba) and by the north-east dip seen from the Wallarobba tunnel to the crossing of the North Coast Railway by the Dungog road. Here the andesite-marker lies very flat. This shallow basin is completely closed, and its position on the broad nose of the parent anticline marks it as an elongated dimple caused by the Hunter Thrust movement. It is cognate in origin with the small Welshman's Creek thrust-fault, which is present just near the roadway at Welshman's Creek settlement, where Burindi rocks on Hoffman's Farm are thrust on to Kuttung lavas and tuffs.

The domal structure next to be considered is located about a focal point near Glen Cairn homestead, southward and not far from the headwaters of Wallaroo Creek. A considerable amount of minor shattering has affected the rocks, and the strike of both rocks and fault is approximately N. 30° E. in contrast with the N. 20° W. strike which characterizes the main anticlinal trend. The geological map shows clearly the relations of this domal mass ; thus its tectonic affinities are clearly with the southerly structures of the Seaham-Clarencetown-Paterson block rather than with the main anticline.

The fault which cuts right through the small core-like Burindi outcrop is the continuation of the Charlton Fault (see map), which has been traced a considerable distance in the south. This fault is steep in dip, hading to the east.

To the east of the domal centre the instructive Butterwick Fault is encountered. This fracture is obviously a compromise between two trends of major character. The main part of the fault is in a direction influenced by the tectonics of the western side of the Stroud Trough, while a subsidiary portion of it strikes parallel to the main trend, namely N. 10° W. to N. 20° W.

The east part of this dome is marked by a strong line of shear thrusts dipping very steeply with a strike N. 20° E.

(*c*) *The Dunn's Creek Syncline.* In 1943 a close survey of this feature was made in order to place it more satisfactorily in the tectonics of the East Paterson area than had been possible when the earlier surveys were done in 1925.

The syncline is steeply indented on the broad surface which marks the two gently folded Paterson and Williams River anticlines.

The syncline has a north-north-east trend, and is of the nature of a " scoop " in its main structure, with the plunging base of the " scoop " sharply warped up in the north-east near the head of Dunn's Creek. The front of the " scoop " is closed by a disconformity or local unconformity caused by a covering of Permian (Upper Marine) sandstones which may be seen on the Maitland Road just after it leaves the Dunn's Creek Road intersection. Here, in paddocks to the south-east of the road, occur *Spirifer* beds so characteristic of the Upper Marine here. Tracing these and associated strata over towards the Paterson River near the Duninald Estate, it becomes clear that the syncline is closed by the Permian.

The syncline shows a marked asymmetry in its stratigraphy and also in the value of its dips. The effect of the structure is to isolate a mass of Upper Marine rocks which rest with strong overlap upon Kuttung tillites.

In the recent mapping advantage was taken of new exposures to survey a line of outcrop of *Sporangia*-bearing tuffs which may be seen crossing both the Dunn's Creek Road and the Seaham Road a few chains in each case from their junction.

To summarize, we note that the broad Gresford-Wallarobba anticline possesses a strong trend which allows it to dominate the country lying to the south of the Barrington Tops. The anticline is mainly in Lower Burindi rocks, but when we reach the Kuttung structural levels of the fold we find a very involved arrangement of the various stratigraphical units. These can be mapped with success, and bring out a marked conflict between early Hunter-Bowen trends and the structure lines of a later phase of this movement. The impersistence of some units and the variable nature of the volcanic rocks have brought about a good deal of asymmetry in the various structures. The presence of the Burindi Series at the domal focus indicates a kind of " culmination " where the anticlinal front has been piled up, to a mild extent, against the rigid, tightly folded Stroud-Gloucester Trough in its south-western sector.

The relations of the various fault systems in the large province will be dealt with in a separate section below, but the mention of two important faults is desirable at this stage. These are the Lennoxton and Hilldale Faults. The former can be traced from the neighbourhood of Webber's Creek Falls right through to the Welshman's Creek area. This is a gravity fault separating two structural sub-provinces. The other fault is well indicated by the vertical dipping Burindi Mudstones in the railway cutting just behind the little weatherboard church at Hilldale. The study of the surrounding country has yielded evidence that this fault is not extensive, despite the steep dip and the mechanical alteration of the rocks.

THE MINDARIBBA BASIN.

Reference to this has been made by Browne (1926) and both Dr. Browne and the author have surveyed the Basin and obtained data of the beautiful examples of progressive overlap that marks the relations of the Permian strata.

The full discussion is reserved for another place, but this Basin possesses evidence that assists the investigator who wishes to place the Permian rocks between Eelah, Seaham and East Maitland in their correct tectonic relationships.

The detailed mapping of the Basin was completed by surveying the two *Sporangia* tuff horizons which outcrop right around the area. On the northern (or Paterson) side of the structure a flat minor synclinal unit is developed by a warping of the strata away from the main unit, and erosion by Webber's Creek and Quarry Creek has helped to isolate the minor structure.

THE SEAHAM-KANWARY STRUCTURE (SUB-UNIT).

This has been termed a sub-unit because it may be regarded as intimately related to the front of the plunging surface of the Gresford-Wallarobba anticline in its final development before the folding dies out and merges into one of the simply warped surfaces which dip southward towards the northern margin of the Cumberland Basin.

In fact, the present sub-unit, the Dunn's Creek Syncline and the Mindaribba Basin constitute three sectors lying on the front of the larger anticline that have been caught between the powerful Williams River Fault and the underthrust threshold of the eastern extremity of the Hunter Thrust System.

Reverting to some description of the sub-unit, we note that steep shear thrusts of the Paterson-Seaham region are found here, all intersecting the Upper Marine rocks but not displacing the Coal Measures to the south. This is a fact of cardinal importance. The effect of the faults on strata up to the top of the Upper Marine has been to tip the rocks up steeply and to impose local vertical attitudes with neighbouring steep joints, closely packed.

The Kanwary-Seaham sector possesses some interesting stratigraphical problems involving the question of the extent of the Greta Coal Measures in this area. The overlap that has been stated for the Mindaribba Basin is matched by a similar progressive change in the neighbourhood of "Brandon" property, where many years ago some boring was done for the purposes of checking the underground extension of the Greta Measures.

Another stratigraphical item of interest is the extent and changing lithology of the Muree Beds between the western and eastern zones of the area. The data to hand indicate a certain development throughout the course of the geological history which compares rather interestingly with the data obtained by Raggatt for areas many miles to the westward.

In summary, we may note, therefore, that thin Lower Marine sediments and alkaline basalts are succeeded due to overlap by Branxton and Muree Beds without the appearance of the Mulbring Beds, before all is lost in allivium of the Lower Hunter and Williams Rivers.

THE LOCHINVAR DOME.

The Lochinvar Dome, well known in geological literature on the Hunter Valley and eastern Australia, comes up for study in the present research because of its importance in the evolutionary scheme.

The greatest interest centres around the question of the adaptation of this great structure to the structures north of the Hunter Thrust System in the Lower Hunter areas (see map). Recently the writer has been able to rationalize the various views about the Lochinvar Dome and adopt a conclusion about the area that is in keeping with the evidence of the outcrops and their relations on the northern side of the valley.

Stratigraphy.

The Dome can be conveniently considered within the girdle of outcrops that wrap around the anticlinal portions of the structure south of the Hunter. These outcrops comprise the following:

Upper Marine Series: Mulbring Beds, Muree Beds, Branxton Beds.
Greta Coal Series.

Lower Marine Series (see below).

H. G. Raggatt has discussed the Upper Marine fully (Raggatt, 1940). For the present discussion it is of importance only to discuss the stratigraphy of the Lower Marine because it is by a study of the distribution and interrelations of the component stages in this Lower Marine Series that we can gain a proper perspective regarding the later structural history of the Dome. As pointed out above, the other vital consideration for the present essay of tectonics is that of the northern continuation of the Dome (beyond the Hunter River) particularly in relation to the Carboniferous rocks (which constitute core-rocks of the structure) in the Lamb's Valley and Gosforth districts.

Maximum thicknesses of the Stages in the Lower Marine are as follows:

Farley Stage	985 feet
Rutherford Stage	1,170 ,,
Allandale Stage	1,000 ,,
Lochinvar Stage	2,740 ,,
Total	5,895 ,,

(See Osborne, 1949.)

The detailed examination of the sequences in various parts of the great Lochinvar Province, and the consideration of the palæontological data, especially with regard to facies development, lead one to conclude that within the great southern zone of the Tasman Geosyncline in Lower Permian time there was a marked individualism within the Lochinvar region and its environs. Thus we can picture the early development of a sagging zone which may have lain athwart the more or less meridional trend of the south end of the geosyncline, or may have been orientated in a general north-north-west–south-south-east direction. In either case this zone lay to the west of the area later submerged by the main Permian seas. Whatever the orientation of the early Permian Trough, it is clear that a progressive peripheral sinking marked the conditions attending sedimentation from the Branxton-Singleton district on the west to Raymond Terrace-Bullahdelah on the east.

Structural Elements of the Lochinvar Dome south of the Hunter Thrust System.

We may recognize the following parts of the Lochinvar Dome (south section):

(*a*) The main anticlinal foundation.

(*b*) The subsidiary anticline on the east side of the axis.

(*c*) The Carboniferous core at Gosforth.

(*d*) The Carboniferous inliers near Pokolbin and at Blair Duguid.

(*e*) The Greta Fault (a shear thrust).

(*f*) The Radfordslee Fault (also a thrust).

(*g*) The three associated faults radiating to the south and south-east from "Hillsborough" locality.

(*h*) The minor faults breaking through the Greta Measures between Pelaw Main and Cedar Creek (on the west).

(*i*) The minor radiating or "finger-faults" of the Ravensfield area.

The contributions of the pioneer geologists to an understanding of the structural development of the Dome were those of keen observers, but in more recent years a wealth of information has accumulated and in particular the work of Jones (1939) represents a very close knowledge of the structure in the southern part of its development. Raggatt and others have made some pertinent remarks about the problems. However, hitherto no one has studied in the field the vital aspects which are traced here, viz. the relations of the stratigraphical distribution to the positions of the faults and the tectonic environment in the northern region beyond the Hunter River.

The Greta Fault was discussed by Osborne and Raggatt in an earlier communication (1931), and Raggatt (1940) dealt with some genetic aspects of the matter.

It is clear that the Dome was affected very drastically by the Hunter Thrust movement, and that the minor torsion faults of the Ravensfield-Bishop's Bridge district and the anticline near Pelaw Main were produced at that time.

The minor faults of the southern sector of the Greta outcrop, and in the mines, have been described almost entirely as normal faults. The strike is mostly north-west–south-east, and the direction of downthrow varies from place to place. The faults appear to be due to tensionally controlled movement. Final discussion of this matter is given below.

The three faults (mapped by Browne, 1926) which are seen passing through the central and eastern side of the fold between Jacob's Hill and Eelah are likewise interpreted as evidence of torsion developing prior to rupture. One of these has the distinction of being the last easterly phase of the Hunter Thrust System.

The three or four small faults striking east-west and displacing the Greta Measures are due to cross fracturing and are really tear-faults.

The dominating position and influence of the Lochinvar Dome in the Hunter diastrophic evolution is clearly indicated on the Map. Part of this dominance is also qualitatively apprehended when one meditates upon the problems of structural evolution in this critical area.

Thus the importance of the structural and stratigraphic relations between the Upper Marine Series (at least from Muree time onward) and later sediments make it clear that the Lochinvar Dome had begun to rise at the close of the Muree Stage. (This is well known to N.S.W. geologists, but its place in the present treatise must be made clear.) Thus round the southern flanks of the Dome we gain evidence of the character and magnitude of the early phases of the Late Palæozoic diastrophism. The role of the Carboniferous inliers is of some interest. As discussed by Osborne (1949) and elsewhere, the presence of these masses indicates the distinct physical change that occurred in pre-Allandale time. It is natural, therefore, that we should enquire as to whether these hard foundations within the sedimentary mass imparted a heterogeneity which would lead to differential reaction by the rocks when stressed by the various forces that were impressed upon the region. In answer to this enquiry we find that the Blair Duguid inlier has had no noticeable effect, but in the Pokolbin area it is clear that the hard basements rising through the sedimentary mass of the Lower Marine, to the stratigraphic level of the base of Allandale Stage, have affected the course of deformation resulting from the main Hunter-Bowen orogeny. Thus there are subsidiary warps to the east of the Pokolbin inliers and the marginal faults on the east of the Mt. Bright inlier are fairly powerful in character, yet where the inliers are mantled by Permian sediments the displacement due to the faults is much less than that shown within the inliers. This suggests a view which the author assumes tentatively, that the faults were originally developed in a phase of pre-Permian, and even pre-Kuttung, earth-movement which displaced the Mt. Bright granodiorite and associated intruded rocks, which presumably were of Devonian age. In the Permian diastrophism further movement along the faults must have taken place.

Thus it is seen that the inliers have played an important part in the structural history.

Structural Elements of the Lochinvar Dome North of the Hunter Thrust System.

Practically all investigations connected with the Lochinvar Dome have been concentrated upon the main southern portion of the structure. Browne (1926) discussed some aspects of the northward continuation of the fold and indicated the propriety of calling the feature a dome. He visualized the probable conditions throughout the area of the original Lochinvar Dome and summarized the inferred structural relations north of the Hunter River. Thus the northward pitch of the dome was shown to be that of the broad anticlinal feature which trends northward from the mouth of Lamb's Valley. It was never clear to students of Hunter River geology, however, just how the following associated features

(*a*) the Cranky Corner Basin,
(*b*) the Moonabung Basin,
(*c*) the plunging anticline of Lamb's Valley,

could be structurally reconciled with the non-appearance of Permian beds to the north of Lamb's Valley, assuming a continuance of pitch of the Kuttung Series in that direction.

Recent mapping of the area lying between Gresford, Lamb's Valley and Mt. Tyraman has solved this problem. The author has found that the north end of Lamb's Valley is closed by the Lower Glacial Stage of the Kuttung Series as developed on the flanks of Mt. Tyraman and the northern end of Bell's Plateau. This closure is the result of a south-westward dip which is developed on a broad scale from the pass on the Gresford-Glendonbrook Road towards the area known as Summer Hill on the Paterson River (see Figure 3).

In mid-Lamb's Valley, lying between the bastions of toscanite which surmount the Main Clastic Zone, and which are the margins respectively of the Cranky Corner and Moonabung Basins, there is a shallow basin which links up the west and east dips of the toscanite and associated strata, the northward plunge of the lower Lamb's Valley area, and the south-west dip of the Main Clastic Zone in the eastern foothills of Mt. Tyraman. Thus the long-delayed unravelling of this problem may now be said to have been achieved.

THE GREATER MIRRANNIE BASIN.

The map will display the almost circular nature of the outcrop of the indicator lavas that have been mapped for the Mirrannie Basin. The term " greater " has been applied because in earlier work the inner Mirrannie Basin was discussed (Osborne, 1926) and the central complex with the trough faults was fully considered. In the later work it has been possible to continue the mapping of beds right around the basin and to note some outstanding structural features which give to the large unit certain tectonic individuality, even within the great variety of structural features now under review in this Monograph.

Stratigraphy.

The Mirrannie Basin is almost wholly in Kuttung rocks, and these embrace the following :

Upper Kuttung	1,800 feet
Lower Kuttung	4,350 ,,

The Burindi Series to the north scarcely show the Basin closure, and may be said to be tectonically without the zone of the basin influence.

The Upper Kuttung are conglomerates, tillites, varve-rock and thick toscanites of the Paterson type. These rocks are best exposed in the centre of the Basin, and have been preserved partly because of that position but also because of a trough-fault system right in the heart of Mt. Mirrannie.

The Lower Kuttung includes the Volcanic Stage, but not the Basal Stage. The vulcanicity of the Lower Kuttung in this district was marked by a preponderance of andesites and ignimbrites. Hornblende andesites (which

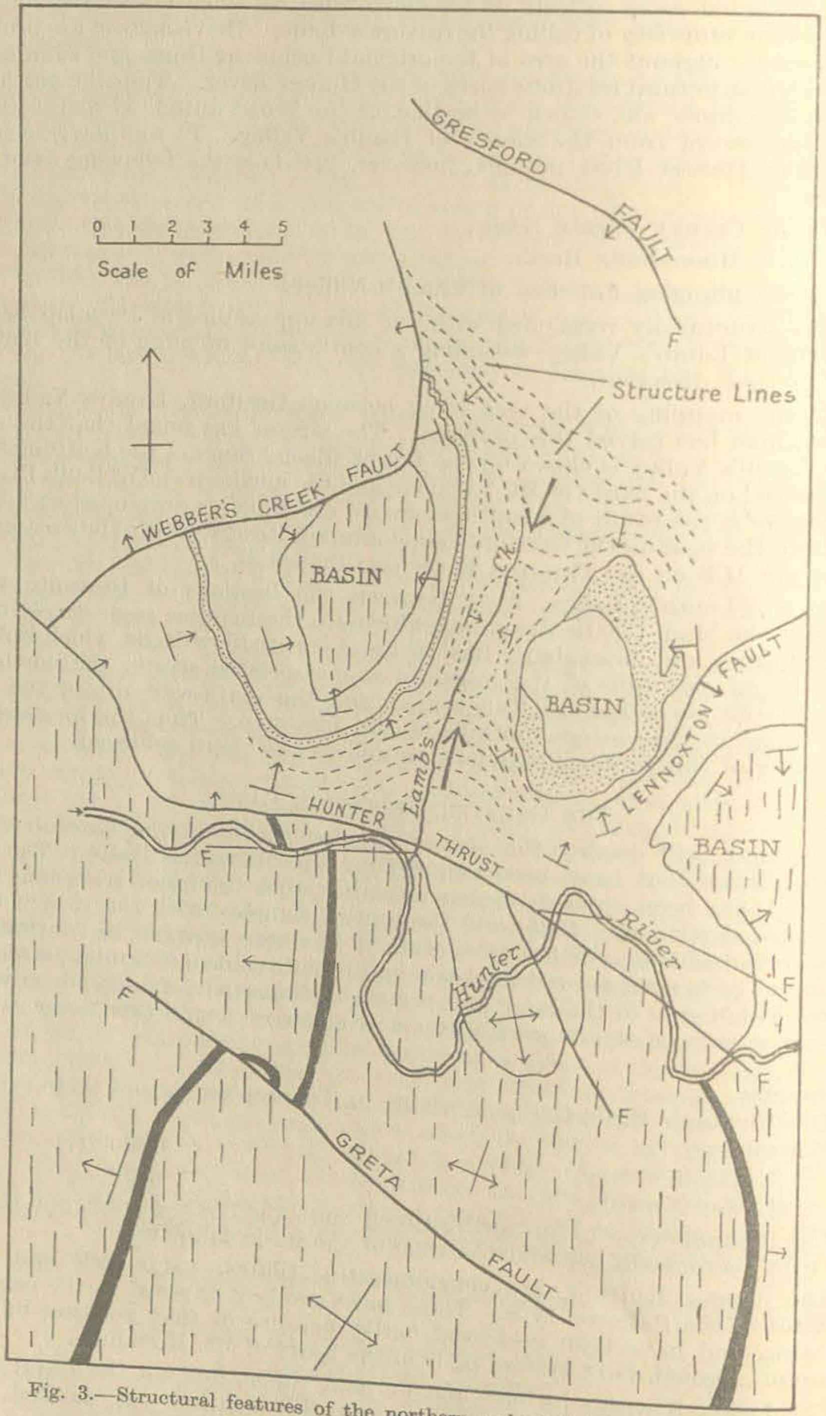


Fig. 3.—Structural features of the northern end of the Lochinvar Dome.

have been followed many miles in structural mapping) occur both at the top and at the base of the Stage. The andesites used as datum levels in this work were the higher group.

Structure.

The Basin has a slight elongation in the meridional direction, and is badly broken on the western side by a series of faults associated with the nose of the Westbrook anticline (see map). The Martin's Creek type of hornblende andesite is developed in a series of flows, and these can be traced as a group, or occasionally for long distances as single flows. No better tectonic datum than the andesite could be had for the structural mapping.

Recent work has led to the recognition of a small anticline within the framework of the Basin along the Upper Myall Creek about eight to nine miles from the Glendonbrook Road. Myall Creek is along the weak zone of this anticline.

Taking now the main delineation of structure by the andesites, we note that andesite outcrops strongly on the western side of The Pass on the Gresford Road, and shows signs of the deformation wrought by the movement connected with the Webber's Creek and Manresa faults. Thus steep joints parallel to the faults make a confused shatter-zone in a quarry near the Pass. From here the andesite runs a little to the west of north and presents a steeply dipping surface to the west and south-west, gradually curving round to cross the creeks in the upper part of Myall Creek, where a south-westward dip is registered near Jupp Trig. Station (see Camberwell Military One-inch Sheet, co-ords. 44–45 N-S, 92–93, E-W).

From here to Upper Mirrannie Creek the andesite flows increase in number and thickness and a series of southerly sloping dip surfaces marks the topography. The Lower Kuttung Series has now lost some of the dominant volcanic character which it possessed elsewhere in the southern part of the Basin, and apart from the andesites only thin ignimbrites and reddish felsites are noticed in amongst a large quantity of tuff and almost pure sandstone.

In the northern part of the structure the dip is very gentle and contrasts with the steep dips associated with faults of the Basin. Eventually the Basin is shut off by the Westbrook anticlinal nose with its fracture-complex.

The faults of the Mirrannie Basin are to some extent the faults of the Cranky Corner Basin. They comprise two main fractures which possess the most baffling features, and several minor fractures, especially in the central part of the unit, near Mt. Mirrannie.

The two major faults are the Webber's Creek Fault and the Manresa Fault. The former has a steep dip to the north and is apparently a shear thrust related to, and truncated by the Hunter Thrust System. The Manresa Fault is evidently of irregular shape and variable dip, turning through a zone of inversion at a locality near Manresa property at Glendonbrook. According to the geometrical details as determined by the author after careful field work, it seems that the fault is to some extent an arcuate one, with a steep partially conical surface directed to the north, but modified by an inversion leading to a nearly vertical alignment across the eastern part of the Mirrannie Basin, in the foothills of Mt. Tyraman.

The relation of the Mirrannie and Cranky Corner Basins is a matter calling for some thought. It would appear that the former is a much lower tectonic level than the Cranky Corner structure, and that the Webber's Creek Fault has isolated zones of a former unified structure, now modified by the thrusting of the Webber's Creek fault so as to steepen the dip of the Carboniferous rocks on the north side of the Fault and also along the zone of the Manresa fracture. If one tries to link up the Stanhope Carboniferous units with those north of the

Webber's Creek Fracture Zone, it is found that the only manner in which this can be done, assuming the fault to be a steep thrust, is by postulating a thickening of the strata in the central part of the Basin and a truncation of the Kuttung lavas along a plane that will allow the present geometrical relations, and will reconcile the great contrast of the thick Volcanic Stage at Stanhope (see Scott, 1948) and the relatively poor development of lavas in the Mirrannie areas.

Away to the north of the Basin in the valleys of Carrow Brook, Glendon Brook and Gorrangoola Creek the Kuttung Series, still dipping south, rest upon the Burindi Series with a notable absence of the Basal Stage and Lower Volcanic Stage. The Burindi outcrops in the headwater tracts leading eventually to the heavily forested slopes of the Tertiary capped basaltic and doleritic mountains, e.g. Mt. Royal, Mt. Losy, Mt. Peerie, etc.

THE ROUCHEL BASIN.

General.

The Rouchel Basin is situated east of Aberdeen lying between the Brushy Hill Fault and the high land of the south-west part of the Mt. Royal and Barrington Plateaux. The main structure covers an area of about 180 square miles, and is drained largely by Rouchel Brook and its tributaries, of which Back Creek, Davis Creek and Stoney Creek are the most important.

The Basin is less complex than the smaller basins of the Mirrannie, Bridgman and Owens Mount districts, but it has a very important place in the evolutionary scheme of the more westerly portion of the thrust-block of Carboniferous rocks, which are bounded to the west by the Hunter Thrust System.

The relations of the Basin to the Beltrees Structure are difficult of exact determination, as the country lying between the two is very heavily dissected, is served with few roads or tracks and possesses in some places much vegetative cover.

Stratigraphy.

Full stratigraphic study of this Basin will eventually be accomplished, since it plays an important part in any understanding of the gradual geological development of the country now occupied by the Kuttung Series of the Hunter Region. The most important discovery made in 1943 by the author in this field of the work was that of the occurrence of a marine phase in the Lower Kuttung Series, different from the phase at the top of the Lower Kuttung which had been discovered by S. W. Carey in 1934. The Rouchelbrook fossil-horizon will help in the gradual elucidation of the problem of the facies changes throughout the Kuttung areas of N.S.W. Mrs. Joan Beattie has described the *Bryozoa* from the Lower Kuttung horizons now being discussed (see Crockford, 1947). The fossils occur in a narrow belt of tuffaceous mudstones which may be traced from Back Creek, in Portion 34, Parish of Doon, through the region of the Cameron Bridge over Rouchel Brook (Portions 1 and 34, Parish of Rouchel) and south-eastward to Fishole Creek, about a mile and a half to the east of Kangaroo Trig. Station (Woolooma Military Sheet, Co-ords. 409–410 N.S. and 1013–1014 E.W.).

The stratigraphic position of this zone can be fairly closely placed, being from 800–1,000 feet above the base of the Lower Kuttung Series.

The summary of the stratigraphy is as follows :

Lower Kuttung Series	4,000 feet
Lower Burindi	7,000 ,,

The Lower Kuttung comprises the typical Basal Stage and Volcanic Stage units of the types areas in the Lower Hunter. The Basal Stage consists of very coarse conglomerates and andesites, but the maximum thickness is only 700 feet.

The Volcanic Stage presents a great display of variety of type and indicates a period of tremendous explosive vulcanicity since more than half of the volcanic succession is pyroclastic, there being no area elsewhere (except perhaps the Myall Syncline) where there is a more magnificent section of tuffs of many kinds.

The Martin's Creek Type of andesite is well represented in the area making a series of narrow dip-ridges which look particularly spectacular from the air. The andesites are the equivalents of those near the top of the Volcanic Stage in the Goorangoola and neighbouring areas. In this Basin, however, there is still a considerable amount of material overlying the andesite. These indicators have been mapped through the central and south-eastern parts of the Basin and they have proved a wonderful guide to the structure. The other common lava types which also assist in unravelling structure are some reddish felsites of dacitic composition which are often strongly hæmatitized. The thin flows of this type may be followed through the Stoney and Davis Creek areas and are associated intimately with the Back Creek-Rouchelbrook fossil zone.

The conglomerates and tuffs of the western part of the Basin are of a general pinkish or salmon colour and can be directly correlated with beds of the same character and climatic significance from Martin's Creek and Bowman's Creek.

The result of the control of topography by structure has been very marked in the areas where these lava units are persistent.

The Lower Burindi Series comprises the important Brushy Hill crinoidal limestone which makes a very dominant marker through the area, many tuffs and shaly mudstones and a variety of felsitic and rhyolitic flows, some of which are marked by an abundance of red orthoclase crystals. This feature is very constant in some flows and can be traced for about twenty miles in the case of a very thin (probably ignimbritic) flow that eventually peters out in the Gundy area.

The tuffs of the Burindi Series vary a great deal in different parts of the Basin and, in the more easterly portion beyond the axial zone of the structure there is a complete contrast in stratigraphic succession with that of the areas nearer Aberdeen. Thus on the north-eastern side of the axis the rocks are similar to the Chichester type of crystal tuff, so prevalent in the Dungog district, but in the south-west part of the Basin limestones and calcareous mudstones are prevalent.

Structure.

The passage from Burindi Series of Lower Kuttung may be seen very well along the Rouchel Road leading eastward from Aberdeen. The Brushy Hill limestone outcrops on the roadside about eight miles from Aberdeen and is succeeded by Burindi sediments and red felsite, and then the Lower Kuttung conglomerates and lavas make their appearance, dipping easterly. This general dip is maintained with an occasional reversal and some rolling in the strata until the Fault, which divides the Basin into rather separate portions, is reached. This trends across the area so as to cut the course of Rouchel Brook about the township of Rouchelbrook. This fault throws the rocks into a south-westward dipping attitude for a short distance but soon the north-easterly dip is resumed. Certain complexities are seen near Upper Rouchel, and it is possible that a small wedge of Burindi Series may have been caught up along a steep fault since some rocks almost certainly of Burindi facies are found here with much shattering.

After the main Fault (which becomes the Goorangoola Fault of the country more eastward) has been passed over, the rocks eventually resume their eastward dip and about four miles from Upper Rouchel village the small Davis Creek Fault is encountered, striking north-west–south-east and trending up the Creek.

Then there is a local rolling in the strata and soon a strong vertical joint-system announces more gravity faulting which can be interpreted near Croften homestead. It is not until one has proceeded about another two miles, near " Brookdale ", that the main synclinal axis is reached.

From here to the east the rocks are of a facies very different from that characterizing the Burindi on the south-west side of the axis. We now have large rolling hills and broad valleys of monotonous geological character. This type of Burindi sediment is prevalent until one approaches " Myrtle Vale " where the well-known Hilldale and Salisbury facies of impure limestone and mudstone with abundant brachiopods, bryozoa and occasional trilobites reappears.

The rocks here are dipping to the south-west and at the head of Rouchel Brook there is evidence of the unconformity between Burindi and Tamworth Series (already discussed on page 13 of this Monograph).

The effect of the main fault, in association with the curvature of the Basin periphery, and the bounding region of the Brushy Hill Fault all combine to bring about the division of the Basin into the following components :

(*a*) A narrow basin on the north-east of the area bounded on the south-west by the Goorangoola Fault.

(*b*) A truncated basin in which the rocks are almost wholly within the south-west portion of the centroclinal structure.

The unit (*a*) actually is the only part of the region in which the axial zone can be studied. The component (*b*) is marked by a peculiar swinging away of the boundary of the structure from the Lower Burindi of the Hunter River sector near Brushy Hill village.

The relations of this Rouchel Basin to the country immediately to the east is obscured by the Goorangoola Fault, but it is clear that closure of the structure occurs by the westward dip of the strata lying in the Upper Glennie's Creek valleys.

THE SCONE-GUNDY SYNCLINE.

General.

This is a fairly large composite feature occupying about 250 square miles and making most of the country between the line of the Wingen Fault on the west and the course of the Lower Isis River on the east. The northern and southern boundaries are respectively the Brushy Hill Fault near Waylands Gap, and the Hunter River. Part of the area is very rugged and inaccessible.

A considerable range of geological features are associated in this syncline, and the whole region is of great interest because the Brushy Hill Fault (about which there is some difference of opinion) runs right through the central part of the area.

Stratigraphy.

The rocks included within the great synclinal feature are as follows :

(*a*) Permian	Thicknesses not determined (see below)
(*b*) Upper Kuttung Series	4,000 feet
(*c*) Lower Kuttung Series	2,840 ,,
(*d*) Lower Burindi Series	3,000 ,,

The present author has made observations in the Permian areas and has mapped certain horizons, but in the present work it was not necessary to measure thicknesses, especially as F. N. Hanlon has been examining these strata for some time (see Hanlon, 1947).

The Kuttung Series reaches one of its greatest developments for any part of N.S.W. It is exposed in a broad belt twelve miles wide, trending more or less north-south. Much of the country is hard to deal with because of its rugged character and also because of its uninhabited nature and the absence of water in the summer.

The Kuttung Succession is as follows :

Upper Kuttung : Glacial beds (varves and tillites) in strong development, many thin lavas of acid composition, and cherty shales with the *Rhacopteris* flora.

Lower Kuttung : A great series of felsites, andesites, rhyolites, ignimbrites and many varieties of tuff. Very coarse conglomerates, interbedded with banded tuff, and some plant-bearing grits and sandstones.

These rocks can be examined in a traverse running east-west when the whole sequence is obtainable. From the western boundary of the almost vertical Wingen Fault one finds the strata pulled down to the west by that fault, and then the sequence goes eastward with an easterly dip except where the East Wingen Fault intervenes and where heavy jointing and local faulting make the tracing of the sequence difficult.

On the east side of the area the Kuttung Series is underlain by a great thickness of Lower Burindi mudstones and tuffs and oolitic limestones. The Kuttung rocks surmount the lower masses of Burindi which are exposed in the valley of the Isis where excellent complete sections can be examined. One magnificent sequence through the Kuttung lavas and conglomerates and tuffs into the glacial beds with beautifully developed varve-structure is exposed on the striking mountain with peak-like top known as Waverley Pinnacle.

Important stratigraphical and petrological problems are presented by the data given by these Kuttung rocks, but this Monograph cannot encompass them. The Burindi rocks are of Lower Burindi facies and have many fossiliferous localities. There is no special interest about this unit. The Barraba Series lying to the east is not very productive of fossil remains, but some radiolaria and *Lepidodendron australe* characterize this terrain.

Structure.

It will be convenient, for the purpose of description, to divide the treatment of the syncline according to three sectors, as adopted below.

(*a*) *The North-West Sector.* This embraces the country north and east of Wingen and is composed partly of Permian strata and partly of Carboniferous. The great fracture of the Wingen Fault marks the boundary between the two Systems from near Wingen to the south. The boundary north-east from Wingen Station is either a continuation of the fault or else a steep junction plane without displacement. The Carboniferous beds certainly dip steeply to the west, and the dip of the Permian, while steep at first, soon flattens out considerably.

The author takes the view, often expressed by Dr. Raggatt, that the Wingen Fault, after reaching the latitude of Wingen Station, passes away from its meridional strike and bears to the north-west, leaving the Permian rocks to trend, without faulted junction, alongside the Kuttung Series which strike about north-north-east here. The Wingen Fault comes up for consideration below, but it must be pointed out here that in this sector the evidence is in favour of it being a steep gravity fault with dip to the west, except for one place where a slight reversal to the east is seen. This is not incompatible with being a steep normal fault hading west. From the site of the Burning Mountain to the north and north-east, the Permian rocks trace out a small anticline and associated syncline (see Hanlon, 1947) and this is adjacent to a simple steep westerly dip in the Lower Marine basalts, and presumably Lower Marine Coal Seams which are found east of Sandy Creek and up against the Kuttung ridges along the course of the Brushy Hill Fault, just a little south of Wayland's Gap. The section here is most instructive and should resolve any doubt about the type of fault that exists. Thus the Permian Coal Measures (which it must be remembered underlie the basalts, described by Hanlon as Lower Marine in age) are seen dipping at angles from 65° to 80° to the west, and are pasted down the steeply inclined face of the Kuttung units of Glacial Stage. The relations of outcrop to contour will not permit of any arrangement except a westward dip of high value.

The Kuttung rocks of this sector are noted for their acidity and reddish colour in many places, due to the conditions of weathering and the presence of original magnetite. There are some glacial beds in small development in the country lying east of the Page River.

The Kuttung lavas and tuffs show a succession not characteristic of the Lower Hunter areas.

The dip is locally to the west, as explained, but this is due to the influence of the Wingen **Fault** in its downward pull of the marginal rocks east of the fracture. The regional dip is to the east at about 35°, and this constitutes the western side of the syncline. The axis of the syncline is very much affected by the Brushy Hill Fault, and it is difficult to show it upon a map at this stage.

(*b*) *The Eastern Sector*. Stretching from the Murrurundi-Timor Road for twenty miles to the south down the valley of the Isis River we have the Eastern Sector of this syncline, as exposed between Gundy on the south and Timor village on the north. This sector shows the passage of the Barraba into the Burindi, and from these into the Kuttung. The lowlands are in Barraba Mudstones with *Lepidodendron australe*, the foothills in Burindi with *L. osbornei* and the unbroken high ridge from Snowden Hall to Wayland's Gap, in the Kuttung. This is a region for excellent stratigraphical sections. For example the whole of the Kuttung Series is exposed up the sides of the imposing Waverley Pinnacle.

The rocks along this sector dip almost constantly over the whole area thus: 28° to 30° in direction W. 20° S. This is the dominant strike of so much of the Upper Palæozoic strata in N.S.W.

The Brushy Hill Fault at its northern end bounds the sector, and from the fault to the east there is an impressive section in the Kuttung Volcanic and Basal Stage rocks which stand almost vertical for about a mile and a half, laterally. This is a very significant piece of evidence, because it is the author's view that the Murrurundi Thrust of Hanlon (which is the same fracture as the Brushy Hill Fault) is in no sense a thrust, but a normal fault. The structural data seen along the course of the structure supports this.

Lower down the eastern sector the valley closes in somewhat, and an interesting adjustment of streams to structure is a feature of the Isis Valley in the interval between Gundy and a point about eight miles north.

At the south end of the syncline there is a wonderful section of the Basal Stage of the Kuttung, exposed in two large cuttings (and also in the nearby country). Thick conglomerates with very coarse boulders and occasional reversion to Burindi tuff-facies occur here.

A noted bulging in the outcrop of the base of the syncline takes place and a very irregular boundary exists between Kuttung and Burindi in the area east of Gundy.

(*c*) *The South-Western Sector*. This is a fairly large unit and is bounded by the Wingen Fault on the west and the Brushy Hill-Murrurundi Fault on the east. The rocks of the Kuttung Series are drawn down and this has been

accomplished by the Wingen Fault. As soon as the influence of the Wingen Fault is lost there is a turning over of dip to the east, and this continues right to the edge of the syncline and even beyond.

The Wingen Fault is responsible for placing glacial beds against fairly low beds of the Volcanic Stage. It is in the extreme south-eastern corner of this sector that a critical zone exists, for here the Brushy Hill Fault breaks through Burindi strata on the east and Kuttung on the west and where Glen Creek enters the Page River there is a small patch of Burindi east of the fault, but this soon wedges out and the fault places Kuttung against Kuttung for many miles to the northward.

Now the evidence here again favours an opinion for normal faulting. In fact it is impossible in most of the zone to interpret it other than a steep, westerly directed, dipping fracture.

The effect of the fault on the rocks immediately east of it is to draw them down and make a temporary anticlinal bulge against the fracture.

South Temi Basin.

General.

Rising in a pronounced ridge out of the relatively low land of the Murrurundi-Blandford district are the highlands immediately north and north-east of the alluvium-skirted upper Page's River. These hills rise to heights well over 3,000 feet in the Liverpool Range, which is capped by basalt, and indeed Mount Temi is approximately 4,000 feet high, but the bulk of the ridge standing east of Murrurundi and possessing no basalt cap is composed of hard Carboniferous rocks, and reaches not more than 2,800 feet above sea-level.

The high land is soon succeeded to the east by the lower country of the valleys of Warland's Creek and Scott's Creek. In these lower portions are the outcrops of an interesting series of Permian strata which have a disconformable relationship with the underlying Kuttung.

The rocks constitute a partly closed synclinal fold which has been termed the Temi Basin by F. N. Hanlon (1947). The author surveyed this area in 1941 and has decided to call the structure at present under description the South Temi Basin, as the Liverpool Range shuts off this feature, and the north Temi Basin is found on the other side of the range.

The boundaries between Kuttung and Permian are shown on both Hanlon's map and on the author's. They are substantially the same. The boundary on the west is a little to the east of Lower Warland's Creek, but to the west of Upper Warland's Creek. The eastern boundary is partly to the east of Scott's Creek and later swings away to the north-west (see map).

The main structural feature which separates this Carboniferous upland from the plain is the Brushy Hill-Murrurundi Fault. This title has been employed because the writer has now shown that the two faults are identical, the earlier name having been given in 1928 (see Osborne, 1928) and the latter having been given recently by Hanlon.

Stratigraphy.

The rocks of the area which are dealt with in the present research belong to the Kuttung Series only. There are representatives of both Volcanic Stage (Lower Kuttung) and Glacial Stage (Upper Kuttung). A splendid section that embraces both Stages may be obtained by ascending the ridge at any point east of the western boundary of the Parish of Murulla. By doing this the complication of the subsidiary fault (see below) is avoided.

Along such a section line the volcanic succession is found to be dipping towards the south or south-west. This is interpreted as due to the fault, and not to primary folding. Soon the easterly dip is in evidence, and this becomes stable as one goes down into the valley of Warland's Creek. The succession is straightforward, and a variety of lavas, tuffs, breccias and conglomerates is

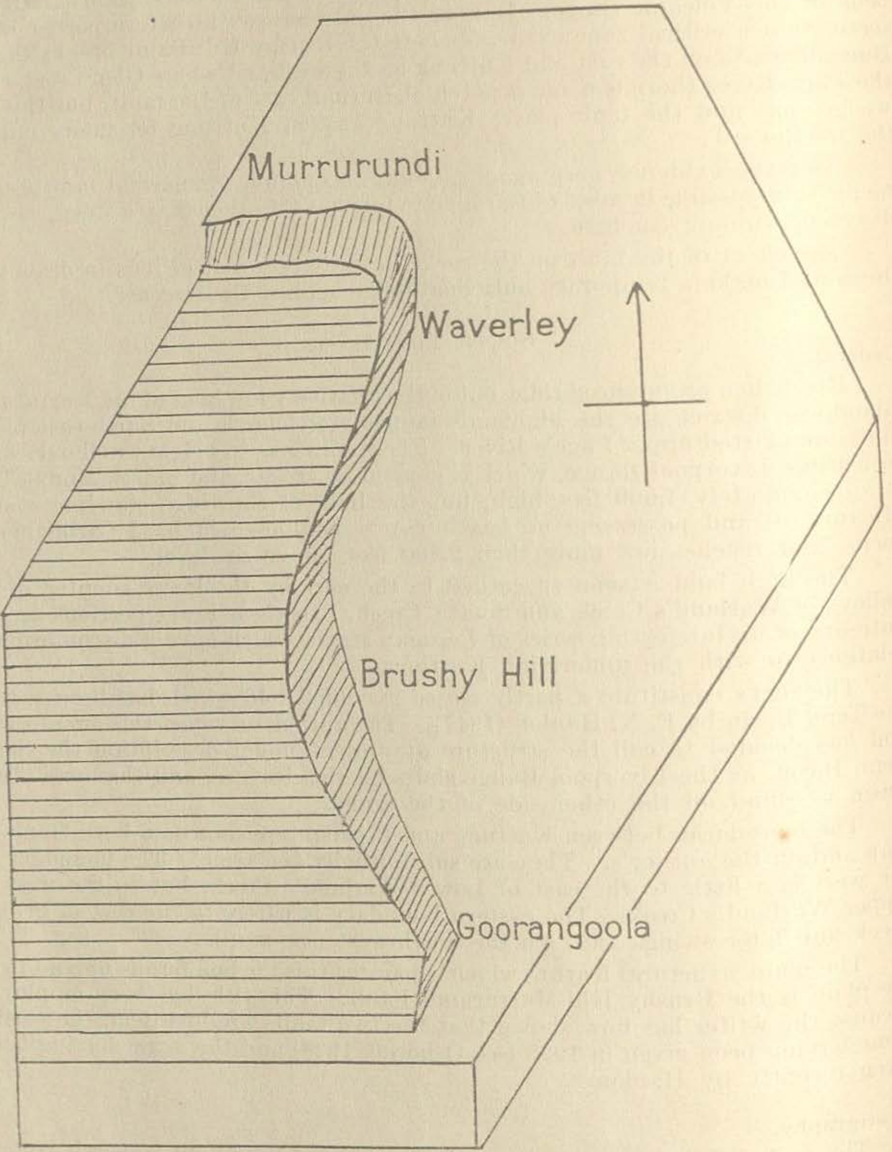
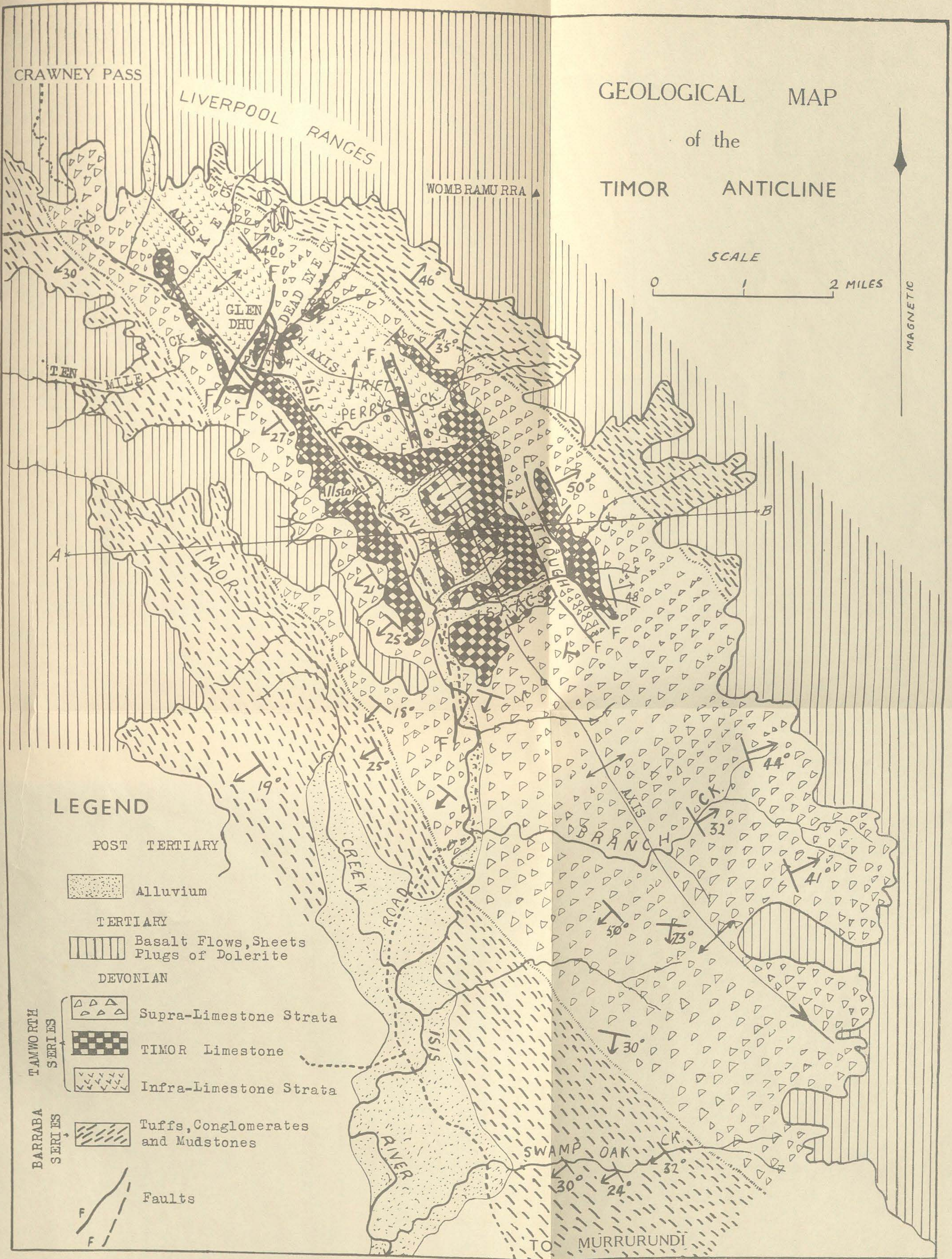


Fig. 4.—Diagram showing the Brushy Hill-Murrurundi Fault as due to isostatic sag.

seen before the Glacial Stage makes its appearance with a succession of varves, tillites, felsites and trachytes. In the Volcanic Stage a noteworthy unit is the hypersthene andesite, probably on the same horizon as that developed at the south-east end of the Werrie Basin near the road from Wallabadah to Nundle.

Royal Society of N.S.W., Monograph No. 1, 1950, Plate 2



Many of the varves and tillites are jointed by cross fractures, and these make erosion easy, giving rise to small cross gullies.

On the east side of the Basin, as seen to the east of Scott's Creek, there is a totally different section.

The Kuttung Series of the eastern side is found in country west of Green Creek Valley, from about the longitude of a point a mile and a half east of Wayland's Gap on the Timor Road. From this line to Scott's Creek there is a section of the eastern Kuttung component of the South Temi Basin. This component is composed largely of tuffs and conglomerates with *Lepidodendron veltheimianum*, *L. osbornei* and *Aneimites*, the last being in the upper levels.

Structure.

The basin has a simple curvature, and the axis is plunging gently to the south-east. The asymmetry shown by the Kuttung distribution is rather suddenly achieved in a short lateral space. It points to a very abrupt limitation of the volcanic rocks of the Kuttung succession. It almost suggests that some movement or faulting may have occurred between Kuttung and Permian time, but such a suggestion would not receive any supporting data from the area. There is a slight disconformity between Kuttung and Lower Marine, but it is not in line with the facts of asymmetry to postulate pre-Permian movement.

The paramount structure is the Murrurundi-Brushy Hill Fault (see Figure 4). This fracture has now been traced and mapped by the author for a distance along the outcrop of about 50 miles, and the geological data throughout the greater part of that interval leave no doubt in his mind as to the character of the fault. At Murrurundi there are features which might suggest a thrust, and this view has been adopted by Hanlon, but the information given elsewhere in this Monograph about the relations of the fault, especially in the Scone-Gundy Syncline, must override the interpretation of the fault as a thrust. It is possible that movement has occurred more than once on the fault, and complications may have developed leading to local structures suggestive of thrusting.

As this is a subject of cardinal importance, the author wishes to emphasize the following facts about the fault and its relations at Murrurundi:

(*a*) The Carboniferous strata exposed at the base of the highlands all along the fault zone from west side of Portion 68 (Murulla) almost to Warland's Creek are of the Glacial Stage, generally including varves. These rocks are always dipping steeply to the south or south-west, and their small-scale fractures, etc., indicate tensional conditions during displacement.

(*b*) The glacial rocks just mentioned form a shoulder flanking the main ridge on its south-western side, and the dip throughout the whole of the "shoulder" is towards the fault.

(*c*) In the road cuttings at the Gap on the New England Highway, west of Murrurundi, and in the exposures down the Highway towards Ardglen, the Carboniferous *glacial* strata are either vertical or steeply dipping to south-west, and the structures are those associated with gravity-controlled (not compression-controlled) movement.

(*d*) The only way to relate the Glacial Stage rocks of the south "shoulder" belt to the unmoved Glacial Stage in Warland's Creek is by a strong fault throwing south-westward. This is an associate of the main fault.

The final opinion of the author about this fault is made clear below (see page 77.

The Timor Anticline.

This key unit of the central anticlinal belt of the Province has been dealt with in a preliminary way in an earlier paper (Osborne *et al.*, 1949), where the general structure and stratigraphy have been outlined without the genetic aspects being considered in full. See map (Plate II).

We now proceed to consider aspects complementary to the scope of the earlier communication.

Stratigraphy and Structure.

This fold occupies an important median position in the zone between the Temi Basin on the west and the country to the east, where a large block of Barraba and Tamworth rocks lies west of the Serpentine Line. The main anticlinal structure is characterized by a south-south-east pitch, and this is continued for 15 miles until its unity of form is complicated by a group of structures which lie athwart the main direction of plunge.

Covering an area of about 70 square miles, the anticline possesses a domal core, the origin of which is treated below. In the earlier paper it was emphasized that the Middle Devonian limestone had provided a splendid unit for structural mapping, since throughout its mass there are several fossiliferous zones or horizons marked by the preponderance of one or two key species. The writer, in his original survey of the Anticline (1937), recognized eight horizons, all of which have helped in delineating the tectonic features. Dr. Ida Browne has kindly confirmed the existence of the zones and has identified certain fossils of importance.

The Limestone Core is succeeded on both sides by Tamworth Beds and then by a limited development of the Baldwin Series on the western side. Next succeeding are typical Barraba mudstones and tuffs in strong development, showing many occurrences of fossil plants (*Lepidodendron australe*).

On the nose of the anticline the amount of supra-limestone strata is distinctly greater than that on the sides of the fold. This is not due to deformation, but indicates the probability of some erosion having taken place between the periods of Tamworth and Barraba sedimentation.

However, apart from anything already communicated it is now necessary to point out that because of the existence of several very interesting (including one rather rare) minor features the Timor Anticline becomes fascinating to the geologist. These minor features, which will now be described, are as follows:

(*a*) The Glen Dhu Complex and adjacent boundary of the domal core.
(*b*) The Crestal Rift near Perry's Creek.
(*c*) The Eastern Trough and associated faults.
(*d*) The warped and jointed strata in the creek east of the Isis Road, in Portion 62, Parish of Crawney.

(a) The Glen Dhu Complex. (Figure 5.)

Near Glen Dhu homestead a very pronounced departure from the simple anticlinal structure is seen in the closure which takes place at the northern end of the main limestone mass (Portions 20 and 21, Parish of Crawney). Here some warping and crumpling extend along an axis trending north-east–south-west.

The limestone has been overthrust after deformation into a minor closed fold. The final movement was expressed in the development of two branches of an overthrust fault dipping steeply to the north-west and enclosing a block of Tamworth Series consisting mainly of a coralline limestone which (by the evidence of the palæontological zones) is high up in the sequence.

This limestone dips steeply to the north-north-west and is associated with small quantities of tuff and conglomerate.

Near by, an outcrop of limestone on the right bank of the Isis River just upstream from its junction with Deadeye Creek, in Portion 75, Parish of Lincoln, shows a wonderful section of closely packed minor overthrust faults in small imbricate blocks, the whole section comprising only about five chains, horizontally. A thin bed of rhythmically banded shaly limestone acts as a datum in delineating the minor structures.

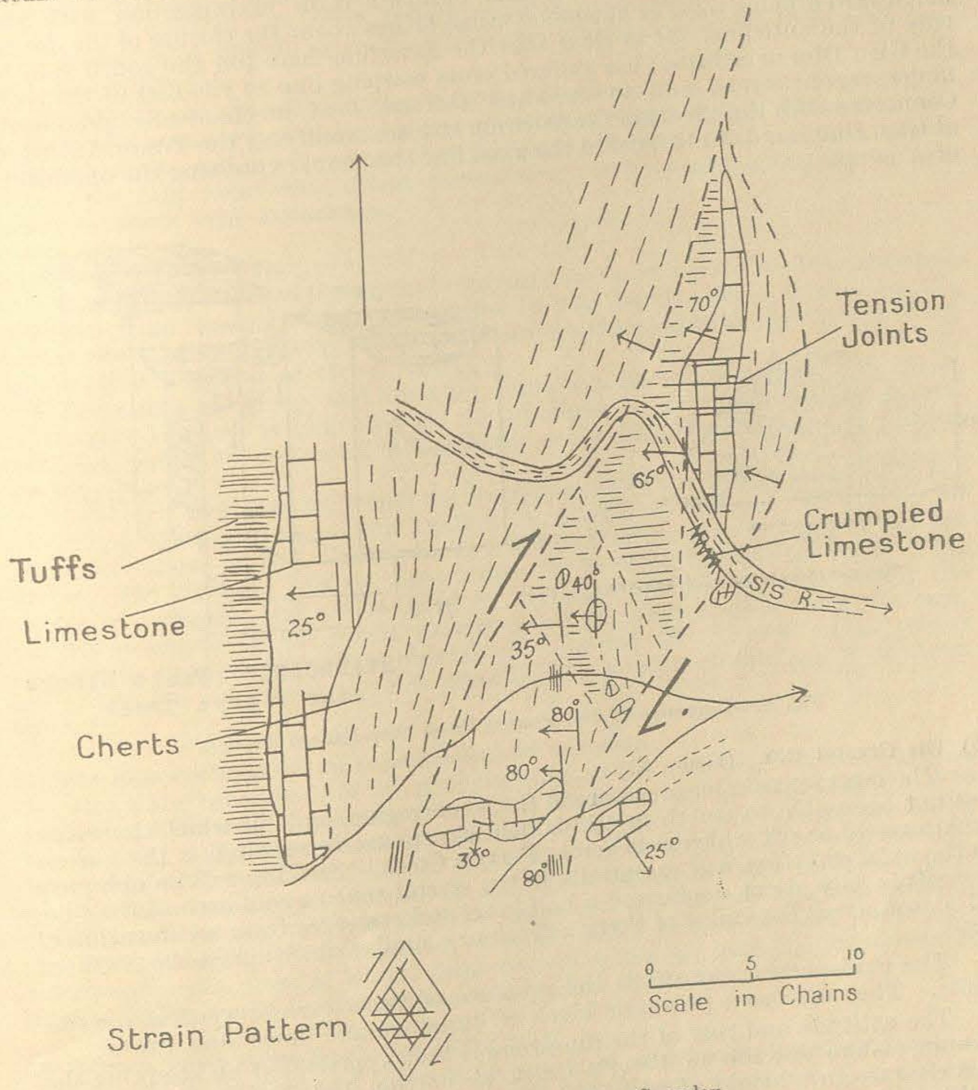


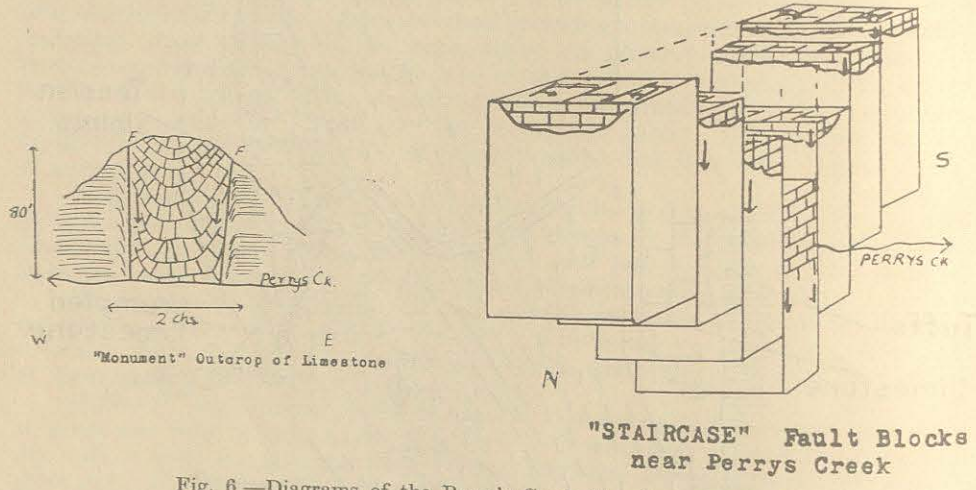
Fig. 5.—Map of the Glen Dhu Complex.

Cutting through the zones of minor thrusts are the larger faults bounding the wedge of Tamworth Beds. These indicate overthrusting from the north-west.

The nature of the stresses that have acted are fairly satisfactorily indicated by the strain pattern shown in the many exposures. Thus, particularly in the small creek joining the Isis River from the west at this locality, one can see rhombs of chert and tuff cut by complementary shear joints which intersect at an average angle of 65°. The directions of these are respectively N. 20° W.

and north-east. One set is more pronounced than the other, and this is parallel to the direction of the major thrust. A further structural feature of interest and correlative value is a group of wedge-like masses of limestone enclosed by steep cross faults within the main block.

The south side of the Glen Dhu Complex is in juxtaposition with the northward dipping mass of limestone which brings about the closure of the domal core of the anticline. It is clear that the limestone here (on the south side of the Glen Dhu overthrust) has suffered cross warping due to yielding of the rock under severe stress, and to weakness through heat mechanically produced. Connected with the effects of the shearing stresses modifying the Timor Anticline at Glen Dhu is a distinct bend in the axial line (see map) expressing the operation of a couple.



"Monument" Outcrop of Limestone

"STAIRCASE" Fault Blocks near Perrys Creek

Fig. 6.—Diagrams of the Perry's Creek Step-faulted Trough.

(b) The Crestal Rift. (Figure 6.)

The most remarkable structure in the whole region, and one which the writer has not been able to match in all his field experience or reading, is the narrow senkungsfeld or rift which cuts across Perry's Creek. Striking a little obliquely to the axial direction, but essentially in the crestal zone or roof-arch of the fold, this rift is only about a mile and a half long, and stretches from an elevation of 2,700 feet across the valley of Perry's Creek to a similar elevation on the southern side.

The evidence for the rift is the presence of two clear-cut vertical gravity faults. They enclose a prismatic block of limestone and associated strata.

The attitude and role of the limestone is best appreciated by studying the monument-like outcrop in Perry's Creek in Portion 168, Parish of Crawney. This rises up to a height of 80 feet above the bed of the creek. Close scrutiny of this reveals that the sides of the limestone block are curved due to frictional drag which operated when the limestone subsided between the boundary walls. An excellent clue to the detailed structure is the presence of a mass of rhythmically banded limestone which is from the basal part of the limestone sequence (so well developed throughout the Timor region). This, as a datum, can be traced in its successive positions, stepping down from the high ground at the north end of the rift to the base of the sturcture in Perry's Creek, and rising upward to the south side.

Thus within the sunken block there are

(*a*) Curved sides due to local steep synclinal development, caused or accentuated by drag,

(*b*) Cross faults which displace the limestone in an orderly manner from the ends of the little trough towards the centre. This structure is that of a double staircase with steps arranged in opposed fashion (see Figure 6).

No doubt can attend the examination of this area by a competent geologist, because the peculiar association of this rift with upturned edges and cross step-faulting is discernible after careful investigation and the reading given above can be the only valid one. These geometrical relations of faulting are unique in the writer's field experience.

(c) The Eastern Trough.

A small well-marked trough is encountered on the eastern side of the anticline trending from Isaacs' Creek two miles to the north. This is due to the development of two gravity faults which were associated with the early folding, probably in a period of stress relief.

The faults are steep, and show no noticeable lateral movement. A throw of at least 150 feet is indicated by the relations of the limestone hereabouts. Heat generated by deformation has marmorized the limestone into a pinkish marble.

Collateral evidence regarding the development of the trough is found in the occurrence through the soil (in Portion 57, Parish of Crawney) of a series of fractured masses of tuff which possess a distinctive fracture pattern of lozenge shape. The lozenges (up to three inches in length) characterize fairly large masses of bed-rock, and are bounded by vertical shear joints which occupy the correct directions in the strain pattern assuming compression from the east. The angle between the joint directions is about 70°. These strain effects are due to the compression which preceded the tensional fault period of stress relief.

(d) The minor folding on the nose-front of the anticline.

Down the broad zone of the plunging front of the anticline very complicated crumpling exists. This indicates the low resistance of the carbonate rock to deformation. The best place to study the folds is on the southward facing valley wall of lower Isaacs' Creek. Here the convolutions can be examined.

At the most curved sections of the minor anticlinal folds there are small overthrust fractures which replace the tensional fractures of the less strongly puckered material. This indicates that the early crestal tension joints of a unit become the place of lateral displacement when the anticline leans over to be modified in shape by the continued operation of compressive stress.

(e) Warped Zones at the South End of the Fold.

A very interesting and informative group of minor structures which are of value in sizing up the tectonic environment may be seen in certain places in and near Portion 62, Parish of Crawney. Thus in a small creek near the tip of the anticline a broad outcrop of tuff gives evidence of uneven warping near the axial zone. The minor features present are almost like text-book examples. They include

(i) Steep joints intersecting at 85° and bisected by the direction of compressive stress component.

(ii) Anticlinal bulge perpendicular to the direction of compressive component.

(iii) Cross fractures perpendicular to the direction of tension.

(iv) Small thrust faults with minimal displacement almost parallel to the trend of the anticlinal bulge.

(f) Small-scale Imbricate Structure in the Tamworth Beds of Branch Creek.

In several places in the creeks to the south of the disappearance of the limestone the overlying Tamworth Beds show interesting small-scale structures, some of which are post-depositional, and therefore of use in unravelling tectonic development. Others are quasi-para-depositional, such as the beautifully developed cases in the creek bed within Portion 82, Parish of Crawney. In a large block of Tamworth Beds 18 tiny overthrust faults cut an 18 inch bed of cherty-claystones and produce a perfect set of imbricate schuppen recalling (on small scale) the classic imbricate zones of the Scottish North-western Highland thrusts. Evidence of the almost para-depositional character is given by the undisturbed strata above and below the fractured bed, and the absence of any shattering of lateral displacement of the enclosing strata.

THE BELTREES STRUCTURE.

The title "Structure" has been applied here rather than any more definite term because the expression of the geological architecture in this area is really ill defined. Briefly, the Beltrees Structure lies in a region mostly of Devonian and Burindi rocks, but chiefly of the former, which fits in between the various more definitely developed basins and domes, etc., that are described and considered.

Thus the area is a kind of "no-man's land" between the following: (*a*) Moonan Syncline, (*b*) end of the Timor Anticline, (*c*) margin of the Scone-Gundy Syncline, and (*d*) the north-western part of the Rouchel Basin.

It would appear that if the Beltrees Structure deserves any fairly definite tectonic title then the term Dome would be the least inappropriate.

Thus the rocks of the Structure are found to dip somewhat in an irregular manner, south-westward towards the Scone-Gundy Basin, north-eastward and northward towards the Moonan Syncline, and so on for other surrounding folds.

A large development of Barraba mudstones is seen between Beltrees, Moonan and Brush Hill Creek and in the valley of Page's Creek. These rest on the sides of the Timor Anticline, or pass under the edges of the Moonan Basin.

The dips throughout this mass of Barraba rocks are quite low, and this feature contrasts with the rather general higher dip of the Tamworth Beds which underlie the Barraba with a slight unconformity.

There are few faults in the Beltrees Dome, and the general tectonic character may be described as that of rolling strata mainly centring about a domal focus.

Careful study of strike and dip in the Rouchel Basin suggests that a narrow anticlinal corridor is necessary to link the Scone-Gundy Syncline and the Rouchel Basin. This would be down the course of the Hunter River between Beltrees and South Brushy Hill. The influence of such a narrow anticlinal connecting structure on the development of the river has been examined, and it is concluded that the only method of reconciling the various structural entities and their features of strike and dip is to postulate that the Beltrees Structure does occupy the rôle defined above.

THE MOONAN SYNCLINE.

For many years the existence of synclinal structure about the region of Moonan Flat, Moonan Brook and Omadale Brook has been known (see Morrison, 1918). Investigations in connection with the gold and other ore deposits of that area led to the recognition of this structure.

The author has examined the area carefully and mapped certain horizons and has found that the structure is fairly simple, as shown on the map.

The rocks of this tectonic unit are entirely Burindi Series for the central, closed outcrop, and Barraba mudstones for the sheath surrounding the centroclinal portion. Breaking through these rocks are granitic intrusions of probably two ages, viz. Tabberabberan (epi-Middle Devonian) and possibly Kanimblan or just possibly Late Permian. These rocks have little interest for us in the present communication.

The trend of the syncline is west-north-west, and therefore more or less at variance with the trends of the other important structures in the region and also oblique to the main trend line of the Upper Palæozoic territory throughout eastern N.S.W. In particular the lack of parallelism in axial trends of the Moonan Syncline and the Timor Anticline is most marked and raises a distinct problem. Some remarks on this are made below, in another section.

The strata of the Burindi Series embrace many kinds of tuffs and impure limestones, and also a great development of richly fossiliferous crinoidal beds. These remind one of the Glen William Beds. It is probable that only Lower Burindi rocks are present, but some Upper Burindi are not yet ruled out of consideration. Cuesta-like dip ridges are found where the hard bars of the Series have resisted differentially and where the curvature of the structure has produced a changing direction of the ridge or spine-like trend.

The only large-scale feature to modify the otherwise simple structure of the syncline is the Moonan Fault, which breaks through on the southern side and can be very satisfactorily studied along the road and in the adjacent creeks a few miles south of Moonan Flat.

The south-western side of the syncline makes a slight unconformable junction with the Tamworth Beds, and this heightens the interest of this broad fold.

STRUCTURE OF ROOKHURST-CURRICABAKH SECTOR.

General.

Westward and north-westward from Gloucester a large section of country in the Middle Manning drainage leads to the foothills of the Barrington Tableland and the southern spurs of the New England Plateau. In this country, a good deal of which is very rugged, unsettled and unserved by roads, there is a great development of Devonian rocks with intrusive masses of acid, basic and ultra-basic rocks. The chief interest of part of this country in the present study is the occurrence of structures which have been adjacent to the northern sector of the Stroud-Gloucester Trough and yet have featured conspicuously in the adjustments of the north-west and west-north-west folded tracts to the meridionally-stamped early structure of the Trough.

For the purposes of completing the study of the tectonic evolution in this area and gaining some idea of its relations to the Manning-Macleay Province described by Voisey (1938–1941), the author carried out a number of trips, in some of which only reconnaissance work could be done and in others more detailed observations were possible. In the rough country near the head of the Manning and Pigna Barney Rivers, and on some sections of the Barrington Tableland I have had considerable help in the organization of expeditions from local settlers, and their unstinted service is gratefully remembered.

The great properties of Curricabakh, Cobakh, Myra, Rawdon Vale, Boonara and many others have been visited in the task of unravelling the structural relations in these wide areas of Devonian rocks.

Summarized Stratigraphy.

Rookhurst, 14 miles from Gloucester, is in a region where the easterly dipping Burindi Series is succeeded by the Barraba Series in strong and typical development. These then pass downward stratigraphically into tuffs, bluish cherts and keratophyric breccias of the Baldwin Series. These may be seen particularly well-exposed along the Nowendoc Road, north-west from Rookhurst. In the hills to the north and east of the Rookhurst-Curricabakh Road (which follows upstream the valley of the Little Manning and later traverses the upper part of the Dewitt River), one can see the striking cliffs of the high range of jasper which trends in an east-south-east–west-north-west direction from the neighbourhood of Mt. Myra (3,700 feet) to Vinegar Hill (1,100 feet).

Between the confluence of the Dewitt and Manning Rivers and Curricabakh Station there are excellent sections which expose Baldwin and Tamworth Series, and the relations are fairly clear (see below). Further west in the neighbourhood of the station one meets the first of the ultrabasic complex which makes a considerable outcrop here and extends to the Pigna Barney River and eventually falls into line with the narrow serpentine belt running north-westward towards Barry and the Barnard River.

A summary of the stratigraphy of this sector is as follows :

Barraba Series	2,300 feet
Baldwin Series	6,000 ,,
Tamworth Series	5,500 ,,

(All thicknesses are approximate.)

Structure.

The constant observations of dip and strike in the many cuttings available and in the creek beds make it clear that the tectonic conditions of this sector may be summarized as follows :

(*a*) There is a slight unconformity between the Tamworth Beds, on the one hand, and either the Barraba or Baldwin Series on the other.

(*b*) The Devonian rocks are thrown into a syncline and anticline with axes approximately north-west–south-east, but in one place indicating a swing to the west-north-west.

(*c*) Powerful vertical (and apparently tensional) faults cut across the Barraba and Baldwin Series and cause very steep dips in the neighbourhood of the fractures.

(*d*) On the whole the dips of the strata are distinctly higher than in other areas already discussed.

(*e*) The diagenetic state of the rocks varies somewhat, but all types show a stronger development of hard cherty facies, possibly connected with a more drastic tectonic experience than had been the case with rocks in other structural sectors.

(*f*) Many minor puckerings, tear faults and other attendant features suggest that the folding has been severe. Large faults, with the exception of that connected with the serpentine intrusion, showed invariably the association of steep well-cut tensional joints.

Some data to substantiate the above conclusions may now be stated briefly.

(*a*) Over a good deal of the district the Baldwin and Barraba strike in the interval N. 25° W. to N. 40° W., while the Tamworth Beds show dips in the direction E. 10° S.-E.S.E. The values for dip are generally greater in the Tamworth (omitting the effects of faults).

(*b*) The road climbing out of the Dewitt River and leading over into the beautiful " Myra " Estate gives clear evidence that although the regional dip is to the west there are folds bringing repetition of Barraba, Baldwin and Tamworth Beds.

(*c*) One of the most satisfactory fault-exposures to be seen anywhere in the province is that along the Little Manning River about four miles from its junction with the Dewitt River. Here intense shattering and strong jointing are associated with a vertical fault bringing Baldwin and jasperized Tamworth Series together.

(*d*) The steep dip of the strata in general reminds one of the similar condition seen in the Lower and Upper Burindi rocks of the Bullahdelah-O'Sullivan's Gap-Mayer's Flat sector.

In both cases the folding is in a zone where much strong crustal shortening is associated with steep gravity faulting and later overthrusting.

Readings of dip along the Dewitt and Little Manning Rivers and also near Tibbuc and Bretti (north of Rookhurst) invariably give evidence of strong compression.

(*e*) A corollary of the severe tectonic experience that the rocks have undergone is the production of a compact texture and strong lithifaction. Thus many of the sediments have been affected by silicification due to regional cementation by ground waters giving a texture partly determined by relative antiquity of the rocks and partly by the intensity of stress that has operated. Greater development is invariably seen with Tamworth Beds rather than with the somewhat newer rocks.

(*f*) A number of detailed structural analyses made with minor tear faults cutting through intensely shattered and drag-folded cherts confirmed the suggestion that strong faults had affected the region on at least two occasions, and that the earlier movement followed a period of strong folding.

FAULTS.

Classification According to Association with Various Structural Elements.

In the descriptions of the many structural entities given above it has been necessary to refer to various faults in a preliminary way, and a certain amount of genetic discussion has been inevitable. It is now appropriate to classify the faults according to the fold or major structure with which they are associated, beginning in the east and proceeding west and northward.

Altogether, apart from relatively minor fractures, seventy-one faults have been mapped, and are shown on the map (Figure 7). A geographico-tectonic summary of the faults follows.

A. *Faults of the Myall Syncline.*

F1–F5. Booloombayt Fault, Mayer's Flat Fault, Bombah Fault, Bullahdelah Horst Faults, Waukivory-Myall Fault.

B. *Faults of the Girvan Anticline.*

F6, F7. Crawford River Fault No. 1 (probable), Crawford River Fault No. 2.

C. *Faults of the Stroud-Gloucester Trough.*

(*a*) *Marginal Faults.*

F8, F10, F11, F16, F23. Stroud Mountain Fault, East Stratford Fault, The Glen Fault, Williams River-Manchester Fault, Washpool Fault.

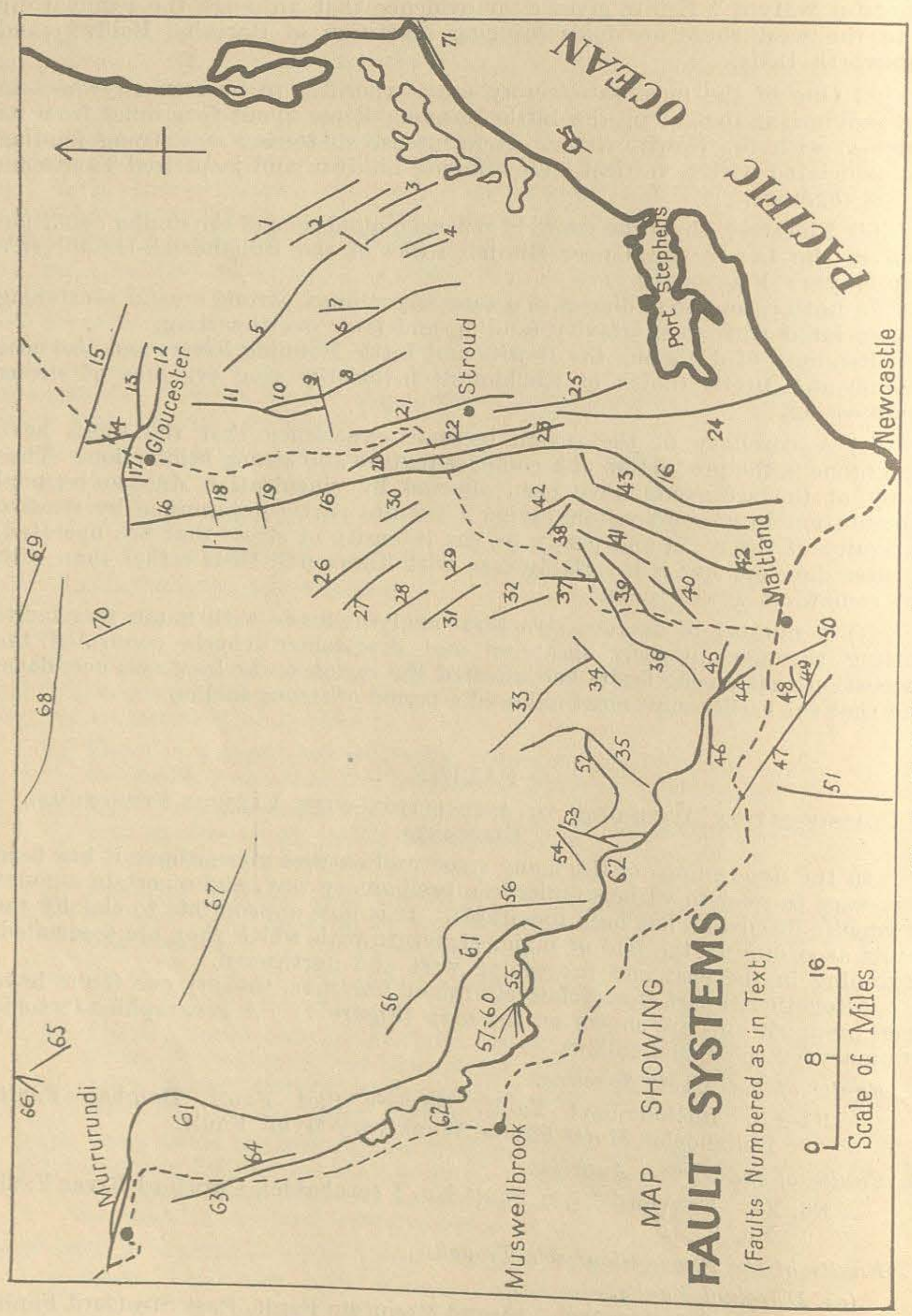


Fig. 7.—Fault Patterns of the Province.

(*b*) *Intra-graben Faults.*
F20, F21, F22, F24, F25. Dewrang Faults, Stroud Road Fault, Tarean Fault, Allworth Fault.

(*c*) *Cross Faults.*
F9, F12, F13, F18, F19. Johnson's Creek Fault, Mograni Fault, Barrington River Fault, Cut Rock Fault, Upper Avon Fault.

(*d*) *Faults Geographically Associated with Trough.*
F14, F15. Tugrabakh Fault, Pitlochry Fault.

D. *Faults of the Dungog-Chichester Group.* F26–30.

E. *Faults of the Wallarobba-Gresford Anticline.*
F31, F32, F33, F34, F37, F38. Bingleburra Fault, Lewinsbrook Fault, Gresford Fault, Trevallyn Fault, Wallarobba Thrust, Hilldale Fault.

F. *Faults of the Paterson-Williams River Structure.*
F39, F40, F41, F42, F36. Paterson River Fault, Hungry Hill Fault, Charlton Fault, Butterwick Fault, Lennoxton Fault.

G. *Faults of the Lochinvar Dome.*
F46, F47, F48, F49, F50, F51. Radfordslee Fault, Greta Fault, Greta Minor Faults, Ravensfield Fault, Mathews Gap Fault, other Minor Faults.

H. *Faults of the Mirrannie Basin.*
F52, F35. Manresa Fault, Webber's Creek Fault, Central Faults.

I. *Faults of the Westbrook Anticline.*
F53, F54 and F56. Westbrook, Benvenue Fault, Goorangoola Fault.

J. *Faults of Grasstree-Owens Mt. Structure.*
F55, F57–60. Owens Mt. Fault, Grasstree Faults.

Numerical List of Significant Faults.

1. Booloombayt Fault.
2. Mayer's Flat Fault.
3. Bombah Fault.
4. Bullahdelah Horst Faults.
5. Waukivory-Myall Fault.
6. Crawford River Fault No. 1.
7. Crawford River Fault No. 2.
8. Stroud Mountain Fault.
9. Johnson's Creek Fault.
10. The Glen Fault.
11. East Stratford Fault.
12. Mograni Fault.
13. Barrington River Fault.
14. Tugrabakh Fault.
15. Pitlochry Fault.
16. Williams River (=Manchester) Fault.
17. Bowman Road Fault.
18. Cut Rock Fault.
19. Upper Avon Fault.

20–21. Dewrang Faults.

22. Stroud Road Fault.
23. Washpool Fault.
24. Tarean Fault.

25. Allworth Fault.
26–30. Dungog-Chichester Faults.
31. Bingleburra Fault.
32. Lewinsbrook Fault.
33. Gresford Fault.
34. Trevallyn Fault.
35. Webber's Creek Fault.
36. Lennoxton Fault.
37. Hilldale Fault.
38. Welshman's Creek Fault.
39. Paterson Fault.
40. Hungry Hill Faults.
41. Charlton Fault.
42. Butterwick Fault.
43. Glenoak Fault.
44. Gosforth Fault.
45. Eelah Creek Fault.
46. Radfordslee Fault.
47. Greta Fault.
48–49. Greta Minor Faults.
50. Ravensfield Fault.
51. Matthews Gap Fault.
52. Manresa Fault.
53. Westbrook Fault.
54. Benvenue Fault.
55. Owens Mount Fault.
56. Goorangoola Fault.
57–60. Grasstree Faults.
61. Brushy Hill (=Murrurundi) Fault.
62. Hunter Thrust System.
63. Wingen Fault.
64. Wingen East Fault.
65. Isis River Fault.
66. Glen Dhu Thrusts.
67. Moonan Fault.
68. Pigna Barney Fault.
69. Myra Fault.
70. Rawdon Vale Fault.
71. Treachery Head Fault.

Character of the Main Faults.

There is considerable variety in the character of the faults. A large number of the faults are gravity or normal faults, and appear to be mainly the result of adjustment in folded terrains in the stress-relief period connected with an episode of the folding. Other faults are true overthrusts dipping towards the direction from which the causal stresses came. Yet other thrusts appear to be shear-thrusts and to form components in a great scheme based on the operation of rotational stress.

In a former paper (Carey and Osborne, 1938) attention is drawn to the very complicated plan of fracturing in the Carboniferous overthrust block of the Hunter River district. A preliminary analysis of the faulting and its relation to the folding indicated that a considerable variability of tectonic environment existed in the Hunter sector from time to time, in the course of the Late Palæozoic diastrophism. Later work has confirmed the general thesis put forward in the earlier paper. It can now be pointed out that through the large region we are considering there were variable stress environments, and in some places successive movements were characterized by changing tectonic relations, due to variability in the direction and kind of stress operating.

The overall plan for a good deal of the area in the main episode of the Late Palæozoic orogeny was as follows:

Direct compressive stress produced overthrusts and rarely underthrusts. After cessation of thrusting, gravity adjustments initiated normal faults, some of which were of considerable magnitude. An important later episode was marked by rotational stresses operating so as to accentuate certain preexisting gentle folds and to produce conjugate sets of shear-thrusts with genetically associated tensional gashes and tear faults of a dip-slip character. In some cases interesting faults possessing a noteworthy bend or kink (often presenting an angular change of 50° or 130°) have been formed by the functioning of fractures in two directions, the displacement being adjusted along two planes meeting to form a "corner" which in some cases was smoothed out into what appears to be a continuous fracture. The Brushy Hill Fault has this characteristic in two places.

Reference to the earlier paper (1939) will give the data for the fault-pattern of the main belt of Kuttung rocks running adjacent to the Hunter Thrust System from the Lower Hunter to Scone. These fault-patterns may now be extended to include other faults which appear to fit into the scheme originally postulated by Osborne and Carey. (Of course, there are some anomalies and cases where it is hard to fit faults into a rational scheme, but the region is a large one and we must expect variable tectonic environments from place to place).

To summarize, we may note that, in addition to the faults already described in earlier works, the following groups can be established by genetic consideration:

Overthrusts.

F26–F30, F7, F38.

Shear Thrusts (frequently constituting cross faults).

F13, F12, F15, F34, F9, F18, F19, F71.

Tear Faults (perpendicular to the tensional direction).

F35, F36.

Steep Gravity (Normal) Faults.

F1, F2, F3, F4, F5, F6, F8, F10, F11, F16, F20, F21, F22, F23, F24, F25, F31, F32, F33, F35, F65.

Special Cases.

Certain large faults which have, in past years, been the subject of a good deal of discussion among those who have worked in the Hunter areas still present problems, although our knowledge about them has increased.

The Hunter Thrust System.

A great deal of evidence is available regarding this fault zone (see Osborne, 1926, 1929, and Raggatt, 1929 and 1941). The undersurface of the fault-block is considered by the author to have been rather irregular, consequent upon the movement of the Thrust being controlled by some preexisting plunging anticlinal and synclinal structures. The probable time of development for this fault is dealt with below. The great contrast between this Thrust and the steep fault-zones in which serpentine and associated intrusions have been emplaced is apparent when one takes note of the analysis of the Wood's Reef (near Barraba) area. As described below, I am of the opinion that the culminating event of the diastrophism was related to this notable contrast in fracturing.

The Brushy-Hill Murrurundi Fault.

Originally described by Osborne as a steep normal fault under the title "Brushy Hill", this fracture has proved one of the most controversial items in discussions of Late Palæozoic tectonics. Hanlon (1947) described the powerful fault at Murrurundi as the Murrurundi Thrust, but full study of the fault in its course through the Scone-Gundy syncline confirms the writer's original thesis (see description of South Temi Basin, above). The fault is on a grand scale, and its progress from near Singleton to Murrurundi is marked by successive characteristics and successive associations with truncated strata. On account of the good outcrops invariably available in the Carboniferous terrain, one is able to interpret the geometrical relations of this fault with satisfaction.

As the fault cuts across marked trends developed in the Late Palæozoic thrusting, it is to be marked off as different from the other normal faults which are integrated into the parent folds with which they are genetically associated, and with whose axes they are generally parallel. This great fault, therefore, is later in date than many other normal faults. (See below for further discussion.)

The Wingen Fault.

This is another fault with a first-rate importance and a dominant rôle in the evolution of structures in the Scone-Murrurundi province. The author has consistently adhered to the view of Browne (1924) and to his (the author's) confirmatory opinion that this is a very steep gravity fault.

Raggatt's view has been accepted that the Wingen Fault strikes away north-west from its dominant meridional trend after reaching Wingen township, in its progress from Segenhoe, where it was mapped in 1928 (Osborne, p. 588) and interpreted as the truncating fracture that wiped out the Hunter Thrust.

Mapping of this fault along the edge of the high country between Scone and Wingen shows that only in about one-fiftieth of its course does it depart from a steep westerly or a vertical dip. The limited exception shows the fault steeply inclined to the east. It is considered that such a small reversal is consistent with normal character elsewhere.

The Williams River Fault (Manchester Fault).

First suggested by Professor David and mapped and described by Osborne (1922), this magnificent fault possesses a very clear-cut character exhibiting faithful parallelism with the Stroud-Gloucester Trough (see map). No more striking evidence of genetic associations could be wished for. The effect of this great gravity fault has been to place so much of the neighbouring strata on end and to cause such severe shattering that one is forced to assume that successive periods of movement have occurred.

In the north of the western zone, adjacent to the Trough, a strong fault (called the Manchester Fault by Andrews) was recently shown to be the continuation of the Williams River Fracture.

The Treachery Head Fault (F71).

The few exposures that are available along the wide sandhill coastal strip between Myall Lakes and Forster give much structural data and reward the investigator who has to endure certain hardships to get to these "islands" in the sea of sand. At Treachery Head and the rugged headlands of Seal Rocks, excellent exposures of Burindi rocks are to be seen. These dip very consistently to the west at an angle of 40°, and at the former locality are cut by an overthrust (or possibly underthrust) fault dipping northward and striking east-north-east. This fault-exposure is probably the remnant of a very powerful and extensive structure, since the degree of mechanical alteration and crumpling of the rocks are very intense. One would be justified in concluding that high temperature existed in the rocks at the time of faulting, since excessively deformed and flat, overturned strata are to be seen. Some of the folds are miniature "nappes", piled one upon the other.

The position of this fault in the Late Palæozoic orogen suggests the possibility of its being one of a series of thrusts developed on the front of the great plunging geanticline which is built of the Middle and Upper Palæozoic terrains mantling the older sedimentary core and associated intrusives of New England.

The Rôle of Faults in the Stroud-Gloucester Trough.

Four sets of faults are present. These may be reviewed again for the purpose of noting the remarkable degree of fracturing that this narrow structure has endured. The four groups are:

(*a*) Marginal Faults (north-south).

(*b*) Intra-Graben Faults (north-south).

(*c*) Cross Faults (east-west).

(*d*) Minor thrusts in the Crumpled Coal Measures.

The last-mentioned are the result of the main south-westward movement at the close of the diastrophism. The cross faults have relieved the strain sustained by the Trough when adjustments had to be made in the already strongly-compressed meridional zones.

SERPENTINE AND ASSOCIATED INTRUSIONS.

General.

Three areas have been examined with reference to the occurrence of Serpentine and associated basic and ultrabasic intrusions. These are (*a*) the Curricabakh-Boonara District, (*b*) the Valley of the Pigna Barney River, and (*c*) the Glenrock-Barry District.

In the latter two areas the Serpentine occurs in the more or less normal manner so common in this State, and especially in the northern areas of the State, namely as narrow, linear intrusions associated with a fault zone. The trend of the belts is W. 15–20° N. In the first of the three localities there is, compared with the other two, a greater variety of intrusion, greater lateral development, due to several tongues of serpentine and basic intrusives, and more complicated tectonic environment.

Serpentines of western New England have been studied by Benson (1911–1918, 1919, 1924), but little has been attempted regarding an analysis of the stress relations of the intrusions. Quite recently the author has investigated serpentine intrusions near Barraba, N.S.W., and in New Zealand. For correlative purposes detailed remarks about the Barraba occurrence will be made subsequently, in order to bring into focus some of the problems of serpentines as the author sees them.

Field Relations and Evidence.

The Serpentines on the Barnard River near Barry Station behave in much the same way as those of western New England, i.e. to say the ultrabasic rocks are in definite fault zones of some magnitude, and intimately associated with large bars of jasper.

The invariable relationship is that the jaspers and altered Tamworth Series are east or north-east of the Serpentine Line. These features are well displayed along the route from Glenrock to Barry Station on the Barnard River.

At Curricabakh, however, the igneous rocks have a much more irregular structure and appear to have invaded a shattered terrain where many narrow intrusions have been made possible.

The following field data were obtained by a recent study:

(*a*) The main trend of the longer intrusions is W. 25–30° N., and occasionally E. 10° N.

(*b*) In addition to much harzburgite there are masses of dunite, hypersthenite and many minor intrusions of dolerite.

(*c*) The serpentine is intrusive mainly in a terrain of Tamworth Beds, although Baldwin rocks have sometimes been invaded. There has been a good deal of shattering prior to intrusion.

(*d*) The dolerite and fine gabbro which have invaded and wrought certain hybrid effects upon the serpentine are massive, and give every evidence of intrusion when stresses were tensional rather than compressional.

Between Curricabakh Homestead and the Pinga Barney River the following section was obtained, figures for width of outcrop being only approximate. (Direction of traverse, north to south.)

Ultrabasic and basic complex	4,500	feet
Jaspers	200	,,
Alternations of gabbro injections and altered Baldwin agglomerates	2,000	,,
Serpentine and spilite breccia	800	,,
Dolerite	4,000	,,
Serpentine with sedimentary inclusions ..	200	,,
Jaspers and quartzites	400	,,
Serpentines amid Tamworth Beds in many lenses	3,000	,,

The petrogenetic relationships of the many basic rocks have not yet been examined, but in the Barraba (Wood's Reef) district of western New England a full investigation has recently been made upon the serpentine, in association with Mr. John S. Proud, B.E. Since the results of that work appear to be of general applicability to serpentine belts in northern N.S.W., a full account of Wood's Reef will be given for correlative purposes.

(I am indebted to Mr. Proud for his approval of the incorporation of my Wood's Reef research results in this Monograph.)

TECTONIC AND PETROGENETIC EVOLUTION OF THE WOODS REEF SERPENTINE.*

The Woods Reef serpentine (using this term collectively for all the ultrabasic intrusives and genetically associated rocks) forms part of the Great Serpentine Belt, made famous by the researches of Professor W. N. Benson.

The Serpentine occurs in a broad belt one to one and a half miles wide, trending approximately N. 20° W. in the main outcrop. One marked virgation trending N. 25° E. is present in the district. In addition, one or two subsidiary intrusions occur, east of the main mass. The western margin of the serpentine is a well-marked crush zone. This zone appears to be more or less vertical, although in odd places the dip is steep to the west or to the east. The general trend of the western margin is N. 20–25° W.

The eastern boundary is less regular and presents a zigzag and at times sinuous pattern, especially in the region where the virgation begins, and within the virgation itself. The pattern is frequently marked out by alternations in direction thus: N. 20–25° W. and N. 25° E. Also cutting across these directions are faulted boundaries trending east and slightly *south of east*.

Another noticeable direction contributing to the pattern of the eastern margin and the virgation focus is that of south-east–north-west. It is seen then that the directional controls are very much in contrast when one considers the east and west boundaries of the serpentine belt. The detailed pattern of the eastern side is very instructive, and some further discussion is given below.

The serpentine complex, of multi-intrusion character, has invaded Middle Palæozoic rocks, partly Devonian, and partly Carboniferous.

Present in the area are the following:

(i) *Burindi Series* (Lower Carboniferous).

Basal conglomerate, cherts, mudstones, tuffs and claystones with occasional fossils.

(ii) *Barraba Series* (Upper Devonian).

Carbonaceous mudstones and tuffs with odd pieces of *Lepidodendron australe*.

(iii) *Tamworth Series.*

Cherts (often Radiolarian), tuffs, odd spilite lavas, banded claystones and conglomerates, sometimes sheared with "augen" structure; also jaspers in prominent bars or dyke-like development.

The Tamworth Beds do not occur west of the Serpentine Belt, and this fact sets forth the cardinal feature of the ultrabasic complex, namely that it intrudes a strong zone of discordance between Barraba and Burindi Series on the west and Tamworth Series on the east. All three series have a constant regional strike of N. 20–22° W.

(iv) (*a*) *The Jasper Bars.*

Throughout the Tamworth Series (east of the Serpentine) a prominent feature is the occurrence of dyke-like masses of jasper, frequently veined with quartz of more than one period of crystallization.

The jasper units are mostly vertical in their attitude, and vary from about four feet wide to as much as 70 feet, as seen in one or two places along Ironbark Creek. Mostly the bars are 10 to 15 feet wide, with fairly sharp boundaries.

The jaspers are invariably strongly and irregularly jointed but devoid of much determinative structure-pattern which could be used to elucidate their detailed tectonic evolution. In spite of this, however, the writer is of the opinion that they represent, largely, the replacement or reconstitution of country rock by solutions of silica and iron compounds. Actually one good example was obtained between Woods Reef and Bundarra, where it could be demonstrated that the jasper had replaced and retained the stratified structure of the Tamworth rocks.

The strike of the bars is almost always north and south ±5°, but two or three notable departures from this general direction were observed. Thus the following strikes were recorded: N. 10° W., N. 20° E., N. 25° E.

The tectonic implications of the jaspers will be taken later on.

1. THE EASTERN ENVIRONMENT.

In order to appraise the relative importance of the stress episodes in the emplacement and subsequent alteration of the igneous complex, the writer

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* The problems of serpentine-emplacement, made more urgent by the recent epochal paper by Bowen and Tuttle (1949), are not finally considered here, but are the subject of a communication now in preparation by the author.

would draw attention to the contrast in tectonic environment of the areas respectively east and west of the serpentine belt.

On the eastern margin we have the serpentine strongly sheared and the presence of the virgation, trending about 45° to the main strike of the belt.

The general plan of the *Eastern Zone*, using this term for the country rocks east of the serpentine, is that of a strongly folded terrain in which drag folding indicates fairly broad pitching of irregular anticlines and synclines. The regional strike of the zone is N. 20–35° W., and the direction of pitch is variable. Joint systems and faults are somewhat confused, especially as one approaches the serpentine boundary, but they can be sorted out and analysed more or less satisfactorily with recognition of the following groups :

(*a*) (i) A series of "back-joints" developed during the tilting and/or folding of the strata. These are best developed in strata with easterly or north-easterly dip.

(ii) A series of almost vertical dip joints (i.e. those striking in the direction of dip).

(i) and (ii) indicate pressure from the east-north-east, i.e. perpendicular to the regional strike.

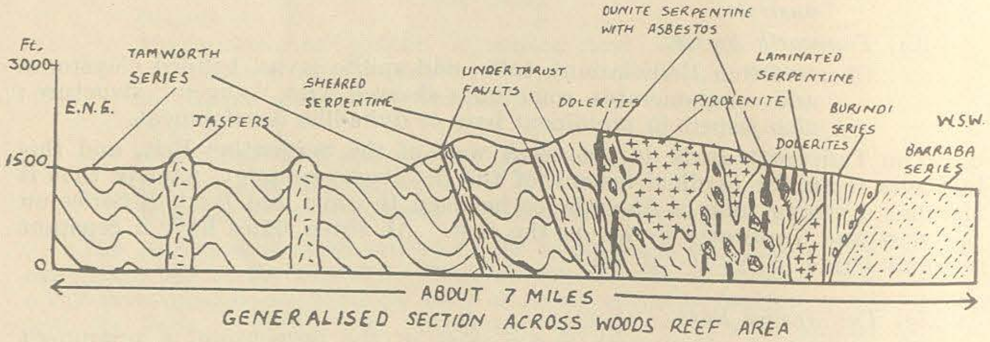


Fig. 8.

(*b*) Several crush-zones parallel to the subsidiary serpentine belts and to the main virgation, N. 30° E. These are connected with later movements in the area (see below).

(*c*) Almost vertical cognate fault-systems trending 165° and 95° which were connected with later phases of the diastrophic cycle.

(*d*) Fault-systems of steep character marked by the absence of shear-phenomena. These are due to stress-relief developed during periods of release from the main compression which produced the folds (Figure 8).

The Probable Origin and Tectonic Significance of the Jaspers.

The jasper bars are due to the activity of medium to high temperature (hydrothermal) solutions containing silica and iron, which have invaded and partly replaced the Tamworth Beds along parallel faults, mostly meridionally orientated. The genetic relationships of the jaspers are not *absolutely* clear.

It is suggested that the jaspers are intimately connected with the serpentines, because there is no part of the serpentine belts known to the writer where jasper is found without the presence of the ultrabasic rock. One observation made by the writer in the Barnard River Valley suggests that serpentine has invaded rocks previously jasperized, but whether this is to be regarded as unusual in our serpentine belt areas is not yet known.

It is the writer's opinion that the jaspers are in north-south fractures of the eastern zone associated with an early phase of the diastrophism. The invasion of silica may have been connected with the early intrusion of pyroxenite (see below). One is inclined to the view that a mass of residual silica (with considerable iron) may have existed as a "light" fraction of the ultrabasic magma, and that this quartzose material may have been tapped by the earliest of the earth-movements, thus rising up and carrying out hydrothermal activity (an action so commonly performed by siliceous and ferruginous solutions at medium temperatures).

It is significant that the jaspers are not in the western zone of the Burindi and Barraba rocks. This is due, I think, to two factors :

(i) There was little fracturing in the western block beyond the margin of the serpentine belt.

(ii) The rocks, dominantly argillaceous and notably carbonaceous, were not suitable for replacement or "activation" by hydrothermal solutions.

Concerning (ii) it is interesting to note that the jaspers are only developed in rocks of the Tamworth Series facies (cherts, siliceous tuffs, etc.), where there is abundant silica for reconstitution of the sediments. This is a valid conception whether the hydrothermal action were early or late in the igneous sequence.

The tectonic implications, therefore, are that jaspers in this region are the result of hydrothermal activity along fractures in the block on the *active* side of the fractured region, and that the clear-cut distribution and geometrical details of the bars indicate fracturing in a period unmarked by torsion or shearing, i.e. in the early part of the earth-movement cycle.

The Eastern Edge of the Serpentine.

The serpentine in almost every case is sheared along its eastern margin, and this is due to the result of rotational stresses associated with its injection (see below) and by later (posthumous) slippings, perhaps of Mesozoic or Tertiary age. Naturally, serpentine will become laminated and "paste-sheeted "near its margin, especially if that margin is sensibly linear.

In summary, we may note that the eastern tectonic environment points to complexity of structural development, produced in more than one tectonic episode. There has been direct compression giving rise to folding and fracturing and associated stress-relief faults. There has also been the local operation of horizontal shearing stress giving a typical fracture-pattern producing strong lamination in the serpentines and a development of shear-joints in the country rocks. The jaspers are to be relegated either to early tensional fracturing or slightly later stress-relief faults.

The Eastern Zone shows that it has taken the brunt of the diastrophic forces which assailed the area in Late Palæozoic times. After the development of a master fault line which is now the western boundary of the serpentine belt, and which allowed the country west of it to be protected from later deformation, successive stresses affected the eastern block and "schuppen" structure was gradually brought into existence. These "schuppen" are bounded by steep faults.

The Lozenge-Pattern in Xenoliths in the Serpentine.

Throughout the serpentine belt there is plenty of evidence that rotational stresses have operated about the time of the injection of the serpentine, and also slightly afterwards. Thus several masses of country rock and also of jasper are embedded in the serpentine near its margins. The geometry of these and their relation to the alignment of fractures is most instructive.

2. The Western Environment.

The main western boundary of the serpentine is a pronounced crush with scaly serpentine well developed at contact with country rock, and extending into the igneous belt for varying distances up to 30 chains. The country rocks on the western side of the igneous mass comprise the Burindi and Barraba terrains. The former are found in a very narrow belt against the igneous rock and lying between it and the main Barraba outcrops. The dip of the Burindi is mostly steep to the west, but occasionally it is very steep to the east, or often vertical. The behaviour of the rocks and their geometrical features of fracturing, etc., indicate that steep normal faulting with pronounced downthrow to the west has operated.

3. The Igneous Rocks.

The igneous rocks of the area comprise:

(*a*) A strongly pyroxenic harzburgite, grading in places into pyroxenite.
(*b*) A more olivinic peridotite (sometimes almost a dunite).
(*c*) Dolerite and quartz-dolerite dykes in great numbers.
(*d*) Altered gabbro in restricted outcrops.

The order of intrusion is:

(i) Harzburgite (pyroxenite).
(ii) Dunitic rock.
(iii) Gabbro.
(iv) Dolerite.

Descriptive.

Harzburgites.

Variations can be traced where the typical harzburgite becomes almost a pyroxenite. Jointing is not marked but several major joints have produced parallelepipeda of harzburgite, especially where this rock is invaded by dunitic types. The freshest material is obtainable from two places:

(i) From the scarp and ridge which occur some distance north-north-east of the main western edge of the serpentine, up above the course of Ironbark Creek.
(ii) In Broadback Creek, at a place a mile and a half north-east of "Anglesey", where a magnificent exposure shows the relations of the harzburgite and dunitic rock and the serpentine derivatives (Figure 9).

Dunitic Types.

The less pyroxenic rocks are not true dunites, but have considerable olivine, while enstatite is not so prominent as in the harzburgites. They vary somewhat and sometimes could perhaps be called a dunite, but mostly are a transition between dunite and harzburgite.

They have intruded the harzburgites and then have suffered considerable changes, chemical and physical. The areas of development are not as extensive as in the case of the harzburgites, but within the limits of their occurrence considerable range of autometamorphic and other changes have taken place.

Gabbros.

The mode of occurrence is in small intrusions of speckled rock, often schistose. They are invariably deuterically altered with the development of features and decomposition products which, in an earlier generation, were referred to as saussuritization. These alterations can be better described as

(i) Late Magmatic,
(ii) Dynamical.

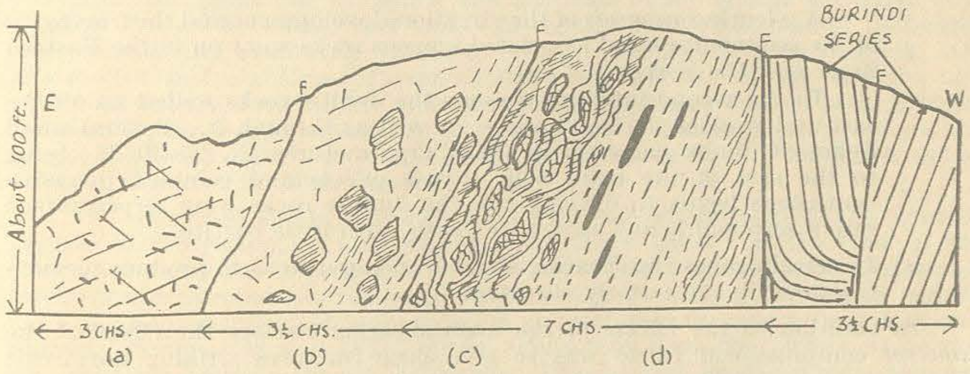
Dolerites.

The tectonic pattern of the dolerites in association with the lozenge-shaped pyroxenite masses is an outstanding geometrical feature of the Woods Reef occurrence, and indicates an obvious genetic relationship. It appears that the contributing tectonic circumstances were such as to facilitate the intrusion of dolerite magma at a time when the significant fracture patterns in the dunitic-serpentine were being developed.

4. Intrusion History.

The foregoing account of the igneous rocks partly states the data on which we build the discussion of the Intrusion History. This may now be summarized.

(i) Injection of harzburgite along the main quasi-vertical fault between the *Barraba-Burindi province* and the *Tamworth province*. Limited autometamorphic change.



SECTION OF INTRUSION-ZONE AT BROADBECK CK.

Fig. 9.

(ii) Injection of dunitic rocks into the pyroxenic types and attack thereon by solutions to give further serpentinization.
Strong autometamorphic activity upon the dunitic rocks, with selective development of antigoritic and serpophitic material from olivine, and very limited amount of bastite from enstatite.
(iii) Injection of gabbros through minor tensional fractures and deuteric action immediately upon these basic rocks—these events occurring not long after (ii).
(iv) Injection of dolerites which, although occurring after (ii) and (iii), are still to be regarded as within the main magmatic cycle.

5. Tectonic Evolution.

The following tectonic events have already been described or mentioned above in some way, and their coordination is now undertaken.

(*a*) Compression from the east-north-east during the Late Palæozoic diastrophism folding the Middle Palæozoic rocks of the district.

(*b*) Stress-relief and strong gravity (isostatic) faulting to produce, especially, the master fault line (formerly called the Peel Thrust) along which the earliest intrusions came. Separation of the west block from the main orogen to the east. A little overfolding took place along the master fault. Shear fractures along N. 20° W. and N. 25° E. were incipiently developed.

(*c*) Opening of magmatic episodes . . . Invasion of pyroxenic peridotite during static conditions in the upper crust producing unstressed intrusion. A little autometamorphic alteration of olivine, but none of enstatite.

(*d*) Invasion of dunitic rocks at a time when the tectonic conditions were changing from alternation of compression and tension (due to simple sub-crustal and isostatic controls) to conditions of *Horizontal Shearing Stress*, due to the operation of a great couple associated with complex sub-crustal drag. This, with the incipient fractures (see above), caused the beginning of the lozenge pattern in country rock margins and the production of the virgation.

(All of these features and the details described above have been arrived at by applying the theory of stress and strain ellipsoids to the area.)

A relentless progress of the virgation-development and the fracturing of the sedimentary and associated igneous rocks went on in the Eastern Zone and the Serpentine Belt.

In the second intrusion episode the dunitic rocks welled up on the east and west of the harzburgite, as well as through it. Several small dykes of dunite came up in subsidiary fractures (N. 25–30° E.) lying to the east of the main belt. Crush effects and complex intrusive contusions began to develop and the dunitic rocks were serpentinized into a serpophitic and antigoritic mesh, with little bastite.

(*e*) In certain zones the shearing stresses operated so as to produce tension-fractures in an easterly direction.

In addition to the effects of the main shearing stresses the effect of the *inherent* compressional forces was to give shear-fractures striking north-east and south-east, and these were due to the direction of easiest relief being vertical at the time.

STRUCTURAL HISTORY OF THE HUNTER-MANNING-MYALL PROVINCE.

Introductory.

The geological map (Plate III) displays the great concourse of structural entities that are ranged throughout the province. These have been examined in detail and discussion, partly descriptive, partly genetic, has been contributed above. The course of the Late Palæozoic diastrophism is now to be considered, and the structural history presented from the results of the extensive researches epitomized in this Monograph.

Previous contributions by the writer and correlative and noteworthy work by Raggatt and Voisey, as well as the background of the cumulative data from earlier work, often by pioneers, have led to the moulding of views about the Upper Palæozoic earth movements in the Hunter River and Manning River districts.

Various workers agree on certain basic principles, but some difference of opinion exists about several, mostly minor, matters.

Movement Prior to the Hunter-Bowen Orogeny.

In order to give a tectonic setting for the appreciation of the detailed structural evolution during Late Permian and post-Permian times, it will be desirable to summarize the pre-Hunter-Bowen movements, of which there is a considerable body of evidence. It is not possible within the scope of this Monograph to trace the full story nor to give an account of the palæogeographical history for the region.

We note the evidence from Rouchel Brook and elsewhere (given above) for movement between the end of Tamworth sedimentation and the beginning of Barraba and/or Burindi developments. This implies epi-Middle Devonian activity. The next item, connected with the same period of crustal activity, is the question of the significance of the granitic inliers of the Pokolbin, Gosforth and Upper Hunter areas. These are covered by post-granitic sediments ranging from Lower Burindi to Upper Kuttung. Thus these rocks indicate an age of at least pre-Lower Carboniferous. Considerations of palæogeography and magmatic relationships of the batholiths of eastern Australia lead to the conclusion that these inliers were intrusive into a now-eroded Devonian (excluding Upper Devonian) terrain. This injection would be attendant on the Tabberabberan orogeny.

After the uplift due to folding and intrusion of the Middle Devonian (and possible Lower Devonian) roof and wall rocks, the Tabberabberan batholiths were eroded and eventually subsided. These were isostatic movements. On the eroded surfaces Upper Devonian sediments (mostly of the Barraba and partly of the Baldwin facies) were accumulated. There was no serious break between Upper Devonian and Lower Carboniferous, although in two places the writer has found a slight erosional hiatus, as at Woods Reef in the north and at Green Creek east of Murrurundi.

The continued sinking through Lower Burindi was related to the isostatic control of the region, at least during Tournaisian time. At the close of the Tournaisian changes in geography, climate and to some extent in physiographic environment affected the region to varying degrees. Thus the Visean reflects the varied environment of sedimentation and habitats for organisms, plant and animal. Some areas were fully marine, others fully terrestrial, while others saw an oscillation between the two extremes. The detailed stratigraphical data are not to be repeated here.

At the close of Visean time the present Province, in common with a large region of eastern Australia, was affected by the Kanimblan orogeny. The effects in this area were slight compared with the large-scale folding and igneous injections in other parts of the State and Australia. The mild unconformity between Visean (upper part of the Lower Carboniferous) strata and Lower Kuttung (or Upper Burindi), which has been noted by Browne and Osborne in various places is the expression of the Kanimbla influence. The best area to see this structure in the present province is throughout the belt of country lying north of Clarencetown towards Alison and East Dungog. Here Lower Kuttung toscanites are dipping east at 45°, while the overlying Glacial Stage rocks are dipping in a slightly different direction at 23–25°.

Slow sinking of the areas covered by Upper Kuttung Series went on, so that over most of the Kuttung areas the subsidence did not overtake the effects of the sedimentation, glacial, fluvioglacial and otherwise. In some areas, however, the sea was able to make incursions giving a marine stamp to sediments which are the probable equivalent of the marine Neerkol Series of Queensland.

In some places the marine inundations were sustained and led eventually to the first phases of the Lower Marine (Permian) sedimentary period. Thereafter events of tectonic significance were again controlled by isostatic forces. We now have arrived at the stage when a summarized account of the Hunter-Bowen orogeny would be appropriate.

HUNTER–BOWEN OROGENY.

The latest views of the writer about the Hunter-Bowen Orogeny derived from the personal mapping of the Province (including the Lochinvar Dome) are summarized as follows:

(*a*) *First Episode.*

Movement about the end of Muree Stage time producing broad folds in the Lochinvar and other areas, and initiating the synclinal feature known as the Stroud-Gloucester Trough. Causal stresses operated approximately in a westerly direction.

(*b*) *Second Episode.*

Renewal of stress about the end of Upper Marine time emphasizing the previous folding and producing several large and many small gravity faults, mostly meridional in strike.

(*c*) *Third Episode* (at close of Permian).

Impress of severe earth movement, the cardinal feature of which was the operation of strong thrusting (maximum compressive stress) from the north-east. This produced a new grain on the country and erected large and small folds and many overthrusts and upthrusts. Injection of the peridotites of this province and of the New England-Hastings area in general began early during this episode.

(*d*) *Fourth Episode.*

Modification of the earlier stress conditions (episode (3)) by the development of a strong rotational stress influence, due essentially to the culmination of action by a regional couple affecting most of the province, and some country beyond it.

This episode was responsible for a very marked modification of pre-existing structure and for the development of strain-patterns quite different from those obtaining previously. The Hunter Thrust movement occurred at this stage.

This was the culmination of the Late Palæozoic Orogeny.

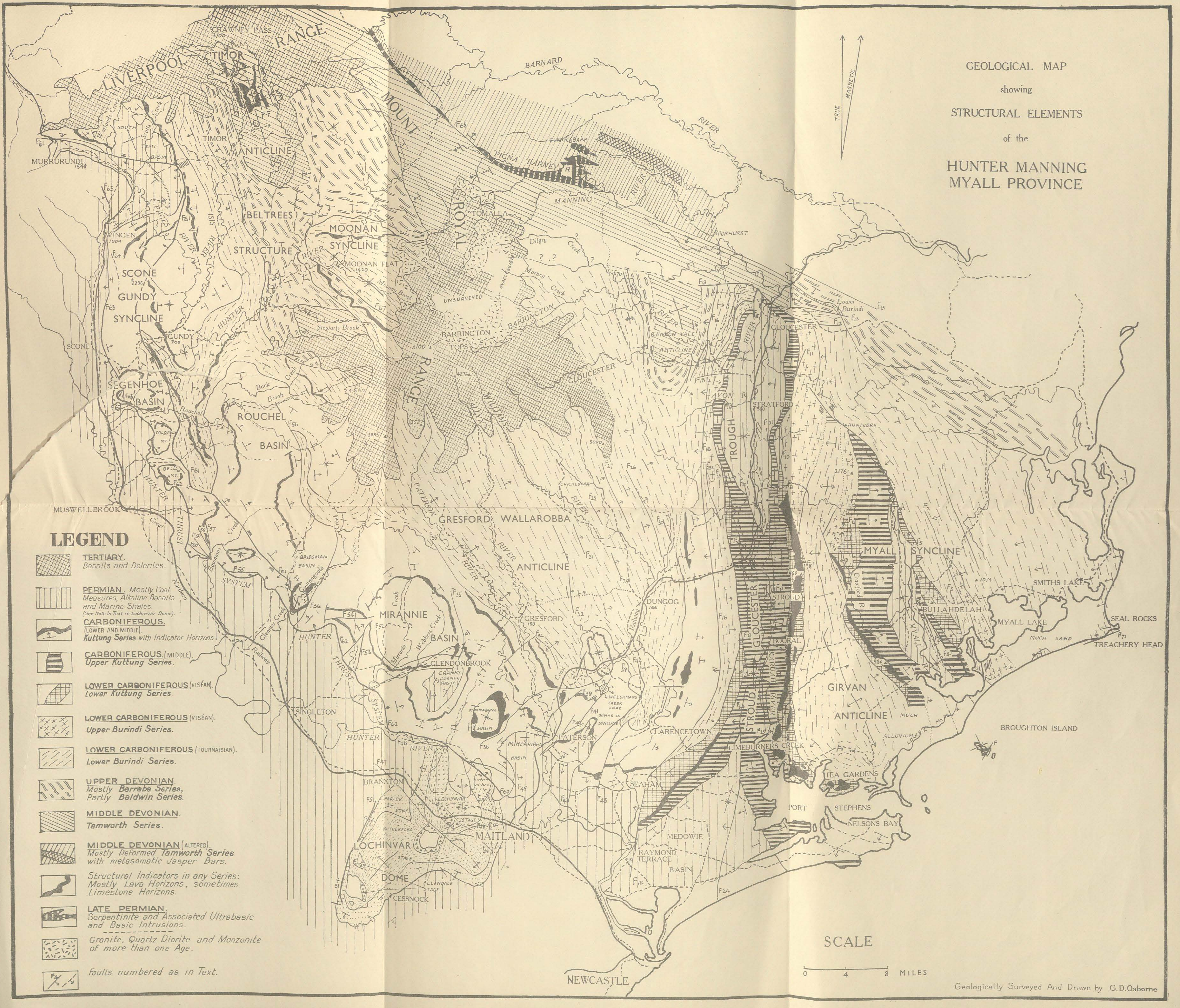
We now examine the diastrophism in more detail.

The main trends imposed by episode (1) were essentially meridional with some variations towards the north-north-east. Folds cognate with the Lochinvar Dome in the Permian terrain were produced, as were also the Stroud-Gloucester Trough and the many basins and anticlines of the Carboniferous Belt. Thus we can cite the following structures as illustrations of that movement: Stroud-Gloucester Trough, northern sector of Lochinvar Dome, Moonabung Basin, Cranky Corner Basin.

Development of Stroud-Gloucester Trough.

The evolution of the Stroud Trough enters into our discussion here, for this was the greatest of the early folds.

The early condition was that of a simple syncline, possessing a variable cross-section. Thus in the north the base was flat, while near Stroud Road there was a distinct " V " cross-section. Whether the plunging of the base of the fold, partly southward and partly northward, was completed by the early movement is not clear. We know that the pitch was accentuated at the north end by the development of cross-faulting, but it is probable that early warping of the floor took place.



GEOLOGICAL MAP
showing
STRUCTURAL ELEMENTS
of the
HUNTER MANNING
MYALL PROVINCE

Geologically Surveyed And Drawn by G.D.Osborne

The evidence of the chief marginal faults is that they were genetically associated with the early epi-Upper Marine movements, because the paramount fault of all, the Williams River Fault, does not transect the Upper Coal Measures. Some of these faults appear to have undergone successive movements, as shown by the evidence of smaller structures.

Marginal faults such as the Glen Fault intersect the Upper Coal Measures, but their place in an environment of isostatic faults connected with the early movements suggest they too were then developed, and experienced later movement also.

Intra-Graben Faults.

There may be some criticism of the use of the term " graben " as an alternative appellation for the Trough, but there is much in the present nature of the southern end of the Structure to justify such a term if the usage be defined as describing a narrow fold that has suffered considerable normal strike faulting, subsequent to the compression which made the syncline.

It would not seem appropriate to call the entity a " syncline ", since in more than half of its length the margin and the central tract are bounded by steep isostatic faults. It must be repeated, however, that the structure does not show the full range of tectonic evolution peculiar to " grabens " or " rifts " such as those of the Rhine, of East Africa and elsewhere.

The age of the Coal Measures in the Trough is a question full of complexity. Most workers take the view that probably they belong to the Upper Coal Measures, whether of the Tomago or Newcastle Stage, or both. The presence of very thick seams against the interior faults and in juxtaposition with the Carboniferous bounding walls can be explained only by assuming that the Coal Measures were developed beyond the boundaries of the present Trough.

Pertinent to the present discussion are the following points :

(*a*) The wide development of Upper Coal Measures at Medowie, to the south, and continuously into the Newcastle Coalfield, indicates the improbability of the Stroud Basin having limited, geographically, the deposition of the coal strata.

(*b*) The absence of the Measures between Dewrang and the Limeburner's Creek district and the data regarding the pitch of the floor of the Trough show that a considerable amount of deformation of the Trough was during epi-Newcastle time, probably episode (3) in the Late Palæozoic diastrophism.

(*c*) The disconformity and slight angular discordance between the Coal Measures and the Upper Kuttung indicates that movement had occurred before the former were laid down.

Evidence of Trend Lines and Relation of the Trough to Neighbouring Structures.

The critical mapping of three structural entities adjacent to the Trough has revealed the manner in which the Trough was adjusted to the later episodes of the Hunter-Bowen Orogeny, especially the climax of that movement.

It is now clear that the north-west–north-north-west trend which characterizes so much of the Upper Palæozoic rocks of eastern Australia was implanted upon the Myall Syncline, the Girvan Anticline and the Rawdon Vale Anticline. The elements may have had some embryo development, which helped to orientate their later tectonic evolution, but they were confronted with a strong steeply downfolded Trough at the time of the renewal of stress which constituted the Hunter Thrust Episode. The meridional trend was sufficiently well implanted on the region to withstand any noticeable mega-deformation, and thus the folds produced by the Hunter Thrust episode began to adapt themselves against the sides of the Stroud Structure. The manner in which the Girvan Anticline and Myall Syncline come together in a very complicated territory at the head of the Myall and Waukivory Valleys is clearly displayed by the map. Several faults with *strike-slip* character have developed in this critical area, and some of the Myall Syncline is thrust over the attenuated apex of the anticline. Further, the anticline has been able to spread outward in the region of least confinement to the south, thus contributing a broad nose which dominates the Port Stephens area.

The Rawdon Vale Anticline has been kept in bounds by the Williams River (Manchester) Fault, and the dominant trend of the country north of the Gloucester Trough has been maintained by the development of great thrust faults which have some of the features of overthrusts and partly of shear thrusts. A considerable amount of slip has marked the evolution of the faulting here. Voisey has called this group of fractures the Manning Fault System. Of genesis cognate with this system are the Barrington River and Mograni Faults, F12 and F13 (see Osborne and Andrews).

Thus the much-perplexing problem of the structural relations and tectonic environments at the region of abrupt change of strike and strain-pattern seen near the north of the Trough has been more or less satisfactorily solved.

The effects of the Hunter Thrust Movement were taken up by the already existing faults in the Trough due to further development of steep jointing with strike-slip. Other faults were developed, one of which is in a shear thrust direction, and some of these meridional faults brought about truncation of coal measures (*cf.* Tarean Fault and Dewrang Faults). Others became cross-faults and displaced the trough bodily along east-west fractures.

The weak coal measures responded to the stress by the development of many minor folds and thrust-complexes seen so well near Craven and already described (1948).

In concluding our discussion upon the Trough, we can feel confident that, from the large amount of data available, the following conclusions are likely to be valid. Thus the successive stress episodes within which the Trough was assailed wrought the following effects:

(*a*) Mild meridional folding initiating the syncline.

(*b*) Further synclinal development with warped floor along the axial zone.

(*c*) Strong marginal faulting in period of stress-relief.

(*d*) Renewal of compressive stress to intensify the existing curvature of the syncline, followed by a relaxation of the compression and the production of intra-graben faults. These were related to a variable longitudinal sagging of sections of the Trough.

(*e*) Impress of Episode 3 of Upper Palæozoic Diastrophism, with cross fracturing of the Structure, and strike-slip movements along marginal faults. At this time the associated anticlines were jammed against the sides of the Trough, and their north-north-west trend-lines were deflected along the sides of the Trough, and the coal measures crumpled.

(*f*) It is not clear whether the rotational stresses of Episode 4 of the Diastrophism affected the Trough. Probably not, since the tectonic environment of this district is in contrast with that of the country westward where the great couple was effective.

Evolutionary Relations of the Three Great Sub-Provinces of the West and North Sectors.

The broadest pattern of mega-features which we discern on taking a bird's eye view of the whole area is that of a series of three great zones in north-west–south-east alignment, and a fourth entity (the Stroud-Gloucester Structure) which breaks the continuity of the main trends in the greater portion of the area (see Plate III and Figure 10).

As the Trough has been exhaustively treated, we proceed, in summary form, to review the broad architecture of the other three zones.

(*a*) The first is the zone of fourteen synclinal and centroclinal units in the great Kuttung Belt from the Liverpool Ranges to the coast at Port Stephens. This range of basins is punctuated by alternating domal structures which sometimes are absolutely complementary (tectonically and geometrically). The modification of the zone from its early structural plan was brought about mainly by the Hunter Thrust episode and the closely following period of strong rotational stress-action which gave to the whole Province its characteristic patterns. This zone, which is dominated by synclinal characteristics, is the southern continuation of the Werrie Basin of Carey, the Werrie structure itself being a southern extension of the large synclinal conditions known to mark the Carboniferous belts away to the north.

The basins in the present province have maintained the original impress of compression from the north-east. The western and south-western line of this zone is the Hunter Thrust System, which has had a vital measure of control of the evolution of the edge of this centroclinal belt.

(*b*) The second zone is geanticlinal, and plunges to the south-east. It stretches from the Liverpool Ranges to the longitude of the western side of the Stroud Trough. The map displays clearly the core-like position of the Timor Anticline, which itself has been locally domed, due, I think, either to a local stress environment that closed the anticline or to the existence of some foundational irregularity that has affected the folding.

Succeeding the Timor Anticline in the south-eastward progress of this zone comes the Beltrees Structure, which is a modified domal unit. The irregularity hereabouts and the structural exoticism of the Moonan Syncline are problems not yet properly solved, but the two possibilities of local cross-warping or of "floor-influence" (see descriptive section above) are worthy of consideration.

After passing the anomalous Beltrees area, we pass into the grand feature of the Gresford-Wallarobba Anticline. This has marked contrast of relatively simple trend and freedom from fracturing in the north and central parts, and very complicated tectonic pattern and stress environment in the south, where the broad nose of the anticline has been jammed against the preexisting, well-established, steep Stroud Trough. The greatest complexity on the lower Hunter occurs here, and part of this complexity is shared by the Lochinvar Dome, which was drastically modified in structure, and particularly in the truncation and offsetting of its axial zone. The trend of the geanticlinal zone was such that its effects could not be operative any further to the south-east.

This geanticlinal zone is the continuation of the broad zone adjacent, on the east, to the Werrie Basin and its more northerly relatives. The anticlinal influence has been maintained by the persistent plunging of the Timor-Gresford components, despite the intervention of the Moonan synclinal influence.

(*c*) The third zone embraces the country which structurally is closely linked up with the Manning areas, described by Voisey. Thus the trend lines of this third zone have changed from the dominant north-north-west–south-south-east direction to north-west–south-east, and the master fractures are west-north-west–east-south-east. In this alignment comes the serpentine intrusion of Curricabakh, a continuation of the Peel line of intrusions described by Benson.

The great break in structure at the north end of the Gloucester Trough is vitally dependent on the strength of the major fractures of this third zone. By considerable lateral displacement the zone to the north has broken away from the region that was confined to the west of the Trough and has become tectonically integrated into the Lower Manning structural plan.

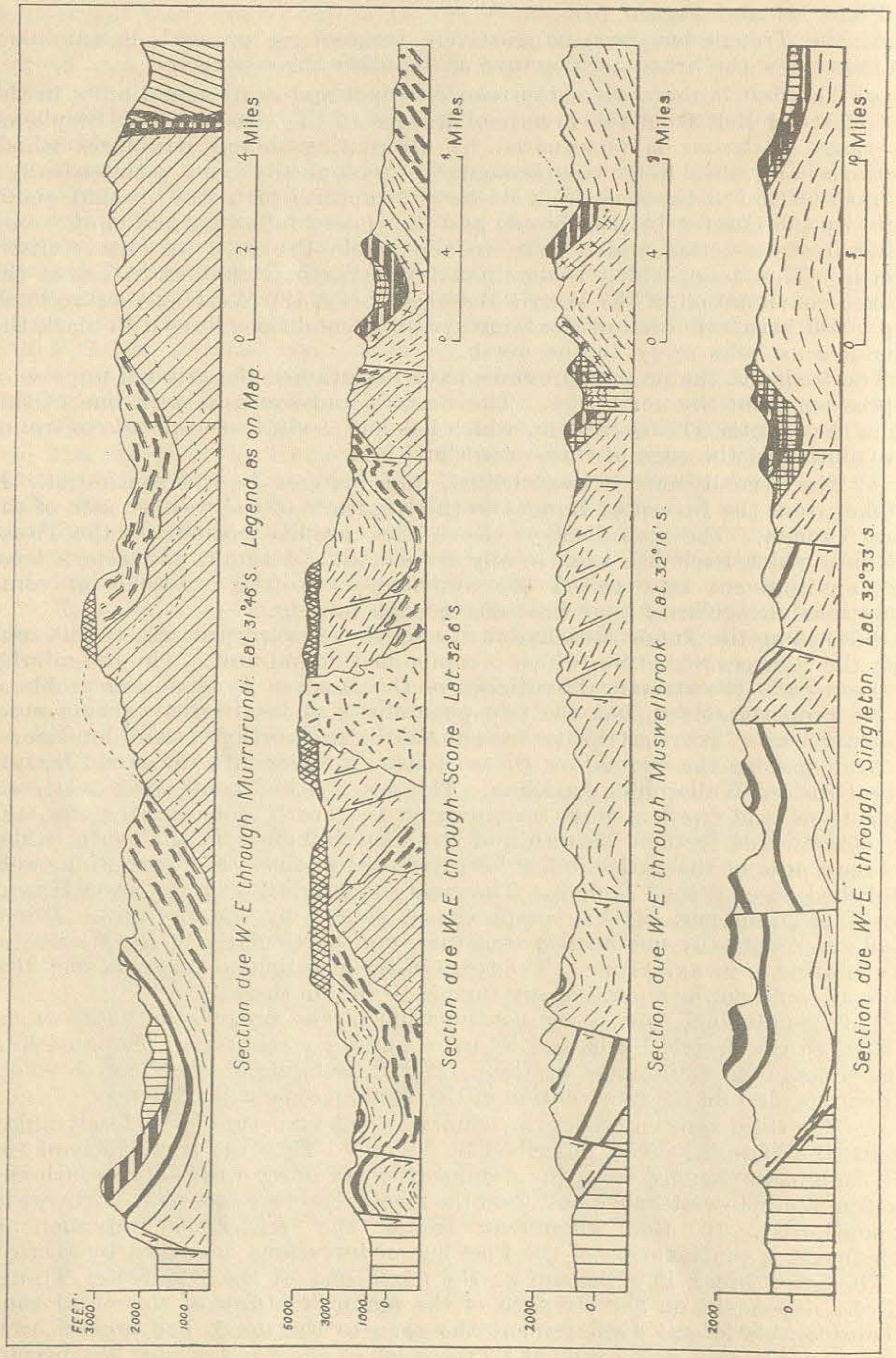


Fig. 10.—East-west Structure Sections.

POST-PALÆOZOIC MOVEMENTS IN RELATION TO STRUCTURAL EVOLUTION: POSITION OF THE BRUSHY HILL–MURRURUNDI FAULT.

This Monograph aims at a full treatment of the Late Palæozoic Diastrophism, but certain post-Palæozoic structures and movements are vital in the evolutionary discussion.

The Brushy Hill Fault has been discussed to some extent above, and to save space it must now be simply affirmed that its relationships with other faults and its physiographical influence do, in the opinion of the writer, establish it as a great normal or gravity fault, but with certain special features. One such feature is that three main directions have contributed to facilitate its operation. This operation has been essentially a downward movement of a great block bounded by three large fractures, and one smaller, with directions thus: (*a*) almost due east-west near Murrurundi, (*b*) more or less meridional from Brushy Hill to east of Blandford, (*c*) N. 40° W. from Brushy Hill to Goorangoola Creek, and (*d*) a small zone running north-south. Of these the first, (*a*), is totally unrelated to any of the other directions in the Province.

My final view is that this great fault is to be regarded as the margin of a block which has subsided during an epeirogenic period, the rocks on either side of the edge of the block having been thrown into attitudes to give the present features, namely, steep dips parallel to the fault surface.

The whole fracture edge may be regarded as a composite Isostatic Fault. The age of the Fault is post-Triassic (even if we consider possibilities of more than one movement along it), but its relations to the Tertiary basalts is obscured by the fact that the pre-basaltic surface was not everywhere a level surface that can be taken as a physiographic and tectonic marker.

There is no doubt of the Hunter Thrust being of pre-basalt age, and genetically its age is bound up with so many other structures which we know to be closing-Palæozoic. Thus the Brushy Hill-Murrurundi Fault is different in age from the Hunter Thrust. The Wingen Fault is also post-Hunter Thrust and may be of the same age as the Brushy Hill fracture, or may even be a post-basalt fault. The author inclines to the view that both the Brushy Hill-Murrurundi Fault and the Wingen Fault are to be placed at the time of the Maryburian Diastrophism of Queensland, as this was the only post-Palæozoic movement of magnitude sufficient to make it feasible for us to refer to it the faults now being discussed.

COMPARATIVE DISCUSSION.

The main purpose of this work has been to record and interpret the multitudinous structural data assembled throughout a long period of field work, and to critically assess these data in the integration of all the observations into the production of the Geological Map and Sections. In this manner a contribution to the Late Palæozoic tectonics of Australia has been forthcoming.

Comparative studies with parts of Australia other than in N.S.W., and with extra-Australian areas have been made by the author at intervals in his research, but obviously there is not sufficient room in this work to do justice to such a grand theme. A full account of the comparative aspects can be considered in a separate communication.

However, some brief pertinent remarks may be given in the few paragraphs that follow.

The Place of the Hunter-Myall Province in the Upper Palæozoic Tectonics of Eastern Australia.

The Late Palæozoic movements affected a broad strip of country stretching from the Lower Hunter Valley to the neighbourhood of Townsville, in

Queensland. This strip was part of the Hunter Bowen Orogen, developed by a series of tectonic episodes.

The genetic consideration of the marginal thrusts of the orogen, and the increasing tectonic complexity shown as one proceeds eastward and north-eastward from the Lower Hunter area suggest that in the N.S.W. section of the orogen (to say nothing of the Queensland section) we are dealing with the west side of a mobile belt which arose in a broad central zone out of the Tasman Geosyncline in Carboniferous and Permian times. The eastern side of that belt lay in the east of the Australia of that time.

In N.S.W. the core of the belt is the ancient New England massif with its Silurian horst-like structures, stiffened by epi-Silurian and later (epi-Permian) granites. Considerable mobility in the crust must have attended the intrusion of the large late-Permian batholiths.

Tracing the folds and fault systems from the Hunter-Manning region northward beyond the Liverpool Ranges, one finds that although the Werrie Basin possesses some complexity there is not the same grand display of fractures produced by rotational stresses which dominated the fourth phase of the Hunter-Bowen movement in the more southern province. On northward into Queensland the tectonic environment is less complicated and the broad folding and strong faulting present suggest the repeated operation of simple compression from the east-north-east and north-east.

The western thrust lines prominent in N.S.W. are continued into Queensland, but change from a marginal position to a more central location.

The broad picture therefore is of a strong deformation in Late Palæozoic time throughout a length of 1,000 miles in eastern Australia; the most complicated stress environments of that diastrophism are revealed in the Province at present under discussion. The relation of these facts to the ultimate genesis of the earth stresses is outside the scope of this thesis.

Comparison with Extra-Australian Areas.

In some geological circles it has been customary to regard the diastrophic events of the Middle and Late Devonian as final phases (or echoes) of the Caledonian Revolution (*cf.* Umbgrove, 1947, p. 28). In the present discussion we can place the Tabberabberan movements in such a chronological position, even if not referring it specifically to a place in the title Caledonian. However, it is clear that the Kanimbla and later movements are marked off from the Tabberraberan and are to be correlated definitely with movements in Europe and elsewhere that come under the general term Hercynian or Variscan.

Just how far we can carry our correlation between Australia and other continents will not be determinable until we have more information from other parts of eastern Australia about the Late Palæozoic diastrophism.

The four possible diastrophic epochs with which correlation could be conducted are:

Pfalzian.
Saalian (Appalachian).
Asturian.
Sudetic.

The most pronounced movement in the Australian Variscan would be the Kanimblan, and this can be confidently correlated with the Sudetic. The fourfold character of the Hunter-Bowen Orogeny in N.S.W. prompts a correlation with some of the remaining three epochs given above, but in the light of present knowledge one would counsel caution in this matter. It might be reasonable to suggest, with some reservation, that the strong epi-Newcastle phase of deformation was coeval with the Saalian, although there is just the possibility (not yet disposed of) that the correlation should be with the Pfalzian.

EPILOGUE.

This long account of the many structures in the Province and of their varied roles and experiences in the great architectural plan of the region must now be concluded. The vicissitudes through which the rocks passed from time to time varied in intensity and direction, being sometimes orogenically, sometimes isostatically (epeirogenically) controlled. In between the episodes of Hunter-Bowen movements there was no doubt some erosion, but it was between the final phases of that diastrophism and the later Wingen and Brushy Hill fracturing that much erosion and sedimentation proceeded elsewhere. Another great period of erosion marked the middle Tertiary, and gigantic basaltic lava fields with associated sheets and sills of dolerite (mostly alkaline) had been developed prior to that erosion. The final structural experiences of the Province were of the nature of pulsatory uplifts which eventually raised it to a maximum elevation of 5,000 feet in the fascinating Barrington Tops region. This pronounced positive event was thus indirectly responsible for making available to the investigator an unrivalled display of structures built out of a wide series of terrains by successive stress episodes in post-Devonian times.

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WHOLLY SET UP AND PRINTED IN AUSTRALIA
BY AUSTRALASIAN MEDICAL PUBLISHING
COMPANY, LIMITED, SEAMER STREET, GLEBE
NEW SOUTH WALES.