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THE GEOLOGY OF THE ESK RIFT VALLEY

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By K. L. McDONNELL, B.Sc.

The fresh-water Triassic Esk Beds outcropping in the Esk Rift Valley between Harlin and Linville are about 10,000 feet thick, and consist chiefly of rapidly alternating quartz pebble conglomerates, dark green sandstones, and shales; the sandstones are mainly fresh-water greywackes. The Linville Tuff which occurs halfway through the sequence is a white lithic tuff of trachytic composition. Before being folded the sediments were intruded by the Balfour Trachytes—a suite of quartz- and augite-trachytes; after the folding, the Nurinda porphyritic olivine microgabbro and the Brisbane Valley Porphyrites (now known to be dacites) were emplaced. The north-north-westerly trending structural pattern of the Esk Beds is dominated by the Colinton Complex Anticline, an elongated structure with a maximum structural uplift of 10,000 feet. One of its major components, the Nurinda Anticline, is overfolded towards the west along most of its length. This is thought to be due to thrusting in the basement consequent on compression from the east, the forces being applied after rift formation and subsidence, and being followed by the period of tensional faulting and intrusion.

CONTENTS

INTRODUCTION AND ACKNOWLEDGEMENTS

Since the investigations made by D. Hill in 1930 between Esk and Linville, no study of the structure of the Esk Beds has been undertaken. In the present work a further study of the structural and stratigraphic features of the Esk rocks between Harlin and Linville has been made in an attempt to reconstruct their tectonic and sedimentary history. The area under consideration is situated in the upper part of the Brisbane Valley, and takes in the townships of Harlin, Colinton, Moore and Linville, covering approximately 100 square miles.

My thanks are due to Professor W. H. Bryan and the staff of the Geology Department of the University of Queensland for help and encouragement throughout the work; to Dr. Jones for help in identifying the plant fossils, to Dr. Gradwell for assistance with petrological problems, to Mr. Robinson for advice in structural matters, and in particular to Dr. Hill for her unfailing interest and enthusiasm; also to G. W. Tweedale for helping to identify some of the microslides; to J. B. Jones for much help and advice; to C. B. Edwards, J. M. Pulley, V. G. Swindon, and Miss N. Ould for assistance in the field; to Miss N. Ould for reading the manuscript; and to my colleagues and B. V. McDonnell for help in preparing the figures.

I wish also to thank Mr and Mrs. F. J. Biggs of "Sarner Alps," Colinton, Mr. and Mrs. J. Sharpe of "Glendon," Colinton, Mr. and Mrs. A. C. Boneham of "Glen Haven," Harlin, Mrs. M. M. Masters of Moore, the many other residents of the district and the members of my family, who made the field work such a pleasure.

PREVIOUS WORK

A comprehensive summary of early work in the Brisbane Valley has been given by D. Hill (1930 (b)).

In 1930 D. Hill redefined the Esk Series of J. H. Reid and C. C. Morton (1923), and suggested the following division:

Esk Series {
Esk Shales = Bellevue Conglomerates = Basal Ipswich Conglomerates.
Acid Tuff Stage = Brisbane Tuff.
Andesitic Boulder Beds.

In a later paper in 1930 D. Hill examined the development of the Esk Series between Esk and Linville. Here she used a division into the Lower Esk Series (Andesitic Stage or Andesitic Boulder Beds) and the conformable Upper Esk Series (which included the northern representatives of the Acid Tuff Stage and the Esk Shales). These rocks were "trough-faulted along the north-westerly grain of the country into the Palaeozoic (including folded Permo-Carboniferous) formations." Internal structures took the form of sharp fractured anticlines along the Ottaba, Stone House, Colinton and Neara Creek, and probably also the Toogoolawah Mountains axes of disturbance. The facturing was accompanied by the intrusion of the Brisbane Valley Porphyrites.

Accurate observations on the lithology and structure along the Linville-Benarkin railway link and the main road (now disused) over the range were made by E. C. Tommerup, in 1930.

Other workers in the Brisbane Valley have been R. A. Dunlop (1951) and K. S. W. Campbell (1952). From their work on the eastern and western margins of the Brisbane Valley trough a provisional historical summary of its evolution can now be drawn up.

PHYSIOGRAPHY

The topography of the area shows the effect of a major control, viz., the regional distribution of rock masses of different weathering characteristics and of several minor controls, such as structural attitude of the beds, differenial hardness within the Mesozoic sediments and presence of intrusives.

Three physiographic units are discernible:

(a) Bordering highland of Palaeozoic rocks on the west;
(b) Moderately high ridgy country of the Neara Beds on the east; and
(c) Dissected ridges of the Esk Beds between the two.

In the Glen Howden-Boat Mountain area the boundary between the Mesozoic sediments and the metamorphics of the Neranleigh-Fernvale Group is well expressed topographically, the metamorphics forming the high rugged block to the west. The scarp is a resequent fault line scarp (Plate 1, Fig. 1).

In the Esk Beds country three areas of different relief can be distinguished, the first being north of Wallaby Creek, where many of the hills are more than 1,000 feet in height. South of this creek the average level of the tops of the hills is about 850 feet. Here a certain amount of structural control becomes evident. From Emu Creek north to Sandy Creek the country, although crossed by undulating ridges, is not as steep and hilly as the two mile wide belt of high land from Mt. Williams through Harlin and Colinton to Moore. The first contains the moderately dipping sediments of the broad Wallaby Syncline, the second the steeply dipping, much disturbed strata of the complex Colinton Anticline.

Lack of accord between the drainage system and the geological structure is expressed by the entrenchment of meanders, both in the area and further to the south (Marks, 1933) ; it is also seen in the manner in which the tributary streams run directly across the strike of the Esk Beds and cut through the belt of hills marking the Colinton Anticline, and through such obstacles as the Nurinda intrusion. The evidence agrees with that seen elsewhere in south-east Queensland for the origin of the present drainage system on a pre-existing surface.

THE NERANLEIGH — FERNVALE GROUP

Rocks of this group form the highlands bordering the area to the west. They include quartzites, greywackes, slates, hornfels and andesites.

The quartzites are fine grained and well jointed, and are restricted to the region south of Ironside Creek. The rocks in this area are continuous with, and lithologically similar to, those described by Campbell to the north-west of the Permo-Carboniferous fault block near Cressbrook.

From Ironside Creek north to Wallaby Creek no quartzites are found, slate and hornfels dominating the lithology. These rocks dip steeply and are much contorted and veined with quartz. Wherever they are seen along the contact with the Mesozoic sediments they show the effects of large scale movements and shearing. They are here included tentatively in the Neranleigh-Fernvale Group on the basis of lithology and structural deformation.

THE NEARA BEDS

The name applied to this volcanic and sedimentary sequence follows the suggestion of Bryan and Jones (1946) that it be termed the "Neara Series," and is in accordance with the Australian Code of Stratigraphic Nomenclature published in 1950.

In addition to the andestic boulder beds which are important further south, normal lacustrine sediments—conglomerates, sandstones and shales—are abundant. A typical boulder bed outcrop is to be seen at 449629* where the road crosses a tributary of Arribaby Creek. Large rounded boulders of a very dark grey andesite are set in a matrix of porphyritic andesite with well-developed flow structure. The dark felspathic sandstones at Gregor Creek are megascopically very similar to the Esk Sandstones further west, but in the conglomerates a striking difference is to be seen. Practically all the pebbles are of blue, grey, or light green porphyritic andesite, a very small percentage only being of quartz or chert. On weathering, the pebbles are removed from the matrix, giving the rock a pitted appearance, whereas in the quartz pebble conglomerates of the Esk Beds the matrix is removed more easily, leaving the siliceous pebbles protruding.

The validity of the boundary which has been provisionally mapped on the presence of the andesites and andesitic pebble conglomerates will be in question until a detailed examination of the Neara Beds in this part of the Brisbane Valley has been made.

THE ESK BEDS

Approximately 10,000 feet of sediments are exposed in the area, although it is suspected that thickness calculations may be affected by faulting of unknown magnitude, as evidence of faulting is to be found in the Linville-Benarkin railway cuttings. Any movement which has taken place, however, has not been sufficiently severe to cause dislocation or repetition of the Linville Tuff in the sections which have been measured.

The sequence is a rapidly alternating one of fresh water conglomerates, sandstones and shales, with some interbedded trachytes in the Ironside Creek area. There is one trachytic tuff, which has been used as a marker bed, approximately 5,500 feet above the lowest exposed horizon. Nowhere in the area is

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* Grid references to the Blackbutt 1-Mile Military Sheet.

the true base or top of the sequence to be seen. Conglomerates dominate the lithology above the tuff, sandstones and shales below.

The sediments have a characteristic dark green appearance, and the sandstones at least are highly felspathic. The conglomerates are largely quartz pebble conglomerates. Some of the shales are carbonaceous but most are olive-green; many contain plant fossils. Bedding is well developed in the conglomerates and in the shales, but the sandstones are for the most part massive. The conglomerates average 30 feet in thicknss, but some are as thick as 100 feet. The shale beds range from a few inches to 10 feet or more.

Conglomerates.—A typical conglomerate is that outcropping at 360601 on Wallaby Creek, and illustrated in Plate 1, Fig. 2.

Most of the conglomerates have a pebble : matrix ratio of about 2 : 1, and the pebbles vary in length from one-quarter of an inch to four inches, two-and-one-half inches being the most usual. They are commonly well rounded, though many of the smaller ones are sub-angular. Most of the pebbles are siliceous, a characteristic assemblage including quartz, quartzite, chert and red jasper. Other types do occur, but in subordinate amounts.

Sandstones.—The sandstones are dark grey, green or mustard coloured, indurated, poorly sorted, and often without any traces of bedding. Calcite veining is common. A well jointed outcrop in a road cutting near the "Stone House" is shown in Plate 1, Fig. 3.

Examination of thin sections has revealed the presence of greywackes, sub-greywackes, and felspathic sandstones. Typical of the greywackes is 4750* from Dry Creek. It is on the whole medium grained, but grain sizes range from 0.2 to 3.0 mm. Some of the grains, especially the softer rock fragments, are moderately well rounded, but most are angular or sub-angular. The sphericity of many of the grains is high, but fragments of shale and some of the quartz grains are elongated. Quartz constitutes 10% of the rock. Angular quartz slivers show strain extinction and are much cracked. Weathered plagioclase laths make up about 10% of the rock. Rock fragments (70%) are of five types: fine quartz sandstone, metamorphic quartzite, a volcanic with fine needle-like felspars, phyllite and shale. The matrix (10%) between the larger grains consists of small broken felspar fragments and much chlorite.

The interpretation placed on the term "greywacke" varies with different workers. Pettijohn regards felspar as an essential constituent, but is quoted by Condon (1952) as requiring "15 to 50 per cent. more felspar." This statement considered in its context, however (see Pettijohn, 1949, p. 255), refers to "typical greywackes" in contrast to subgreywackes. Elsewhere (p. 245), Pettijohn states, "In some greywackes the felspar content is very small." To such rocks

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* Rock and Microslide numbers quoted refer to collections in the Department of Geology and Mineralogy, University of Queensland.

the term "greywacke" can be applied if it is warranted by other properties such as angularity of grains, lack of sorting, abundance of rock fragments and of primary argillaceous, chloritic and/or micaceous matrix.

Many of the rocks here termed "greywacke" have a moderately low felspar content but all have an argillaceous or chloritic matrix and a high percentage of rock fragments, most of which are of sedimentary or volcanic origin.

Fresh water greywackes are not a common rock type, but some from the Late Tertiary Siwalik Series of Northwest India have been described by Krynine (1937). The rock fragments are mostly of schist and phyllite and in this respect they differ from the greywackes of the Brisbane Valley.

Fresh water sediments from the Upper Permian Tomago Coal Measures of the Singleton-Muswellbrook Coalfield of New South Wales have been provisionally classed as greywackes by Booker, Bursill and McElroy (1953), using Condon's definition. The authors suggest, however, that a new name be erected to cover such rocks which do not fulfill the generally accepted requirements of induration and dark colour, the name being used in the meantime to indicate that they have the mineral composition of greywackes.

Shales.—The shales of the area are characteristically olive-green, but may be red, brown, or even black, and many are limonitic. Differential Thermal Analysis of some typical Esk shales tentatively indicates that the clay minerals present are montmorillonitic rather than kaolinitic in type.

Many of the shales are rich in fossil plants and the following forms have been identified from among the many present:

Neocalamites , sp.

Cladophlebis sp.

Cladophlebis johnstoni Walkom.

Pecopteris (Asterotheca) hillae Walkom.

Thinnfeldia odontopteroides (Morris).

Sphenopteris superba Shirley.

Taeniopteris crassinervis (Fiestmantel).

Trachytes.—The trachytes outcropping in the Ironside Creek area are lithologically distinct from the Balfour Trachytes described later, and are provisionally included here as part of the Esk sequence. R 16070 from the outcrop at 354562 is a light brown, fine grained rock showing flow structure and possesses minute prisms of clear glassy felspar and a small number of needle-like hornblende phenocrysts. The groundmass is trachytic in texture. The thickness of the body, which is conformable with the sediments, is approximately 100 feet.

The Linville Tuff.—In its characteristic development the Linville Tuff is a white, pink or grey fine to medium grained trachytic tuff consisting of broken subhedral felspar grains and angular trachytic fragments in a fine felspathic groundmass. It is not a completely homogeneous body, and various modifications occur, including some lapilli tuffs of very striking appearance. The thickness varies from place to place, but averages 50 feet.

The best exposure is that at 384672, in and near the railway cutting opposite the Linville sawmill, a few hundred yards north of the Linville Railway Station. The tuff here is well bedded and is in part a crystal tuff, the concentration of dark and light fragments into layers giving the rock a finely banded appearance which it does not elsewhere possess. Thin section 4781 reveals the presence of phenoclasts of felspar and quartz up to 0.5 mm. in diameter. Thin section 4769 is somewhat coarser and consists mainly of roughly aligned volcanic fragments in a kaolinized groundmass of fine felspars.

The grey varieties of the tuff are typified by 4773, which is medium grained, the grains being angular or subrounded. Most of the kaolinized felspar seems to have been potash felspar. A few plagioclase grains with lamellar twinning are in the albite-oligoclase range. Some fragments are of a fine felspathic (probably volcanic) rock, and there are a few of dark, almost opaque, foreign material, probably shale or sandy shale incorporated with the volcanic debris as it exploded from the vent. The groundmass is fine, dark, and extensively altered.

The Linville Tuff is in the main a lithic tuff and the presence of small grains of quartz suggests that the parent lava was of the composition of quartz trachyte. That the tuff was, in part at least, laid down in water, is demonstrated by the presence of plant fragments at 366580, and of well preserved plant fossils and intermixed argillaceous material at 434523.

Notes on the Sedimentation.—Several features of the sediments point to the conclusion that they have been deposited in a rapidly subsiding fresh water basin, under conditions of high relief and rapid erosion. One of these is the abundance, thickness and lateral extent of the conglomerates. Rapid alternations of conglomerate, sandstones and shale take place, often without any gradation between the beds. The presence of calcareous cementing material in some of the greywackes, and the montmorillonitic nature of the clay minerals were used by Whitehouse (1952) in assessing the Esk basin as "an intermontane basin of internal drainage, rapidly subsiding."

IGNEOUS ACTIVITY

The Brisbane Valley Porphyrites

These related intrusions take the form of elongated, parallel-sided bodies up to 1,000 feet in width and one-and-one-half miles in length.

Examination of thin sections has shown them to be dacites. 4785 from the tunnel area is a holocrystalline porphyritic rock with euhedral and subhedral zoned plagioclase phenocrysts up to 4 mm. long. The plagioclase is in the andesine-labradorite range. It is extensively sericitized, and constitutes more than two-thirds of the rock. Little of the original euhedral pyroxene remains, its place having been taken by pseudomorphous uralite. Secondary calcite and chlorite are also abundant. The groundmass is very fine and granular. Interstitial quartz is present as small angular grains, iron ore is plentiful, and sphene is present as an accessory.

Absence of augite and abundance of hornblende characterize the hornblende dacite (4786) from Mt. Williams. This is a porphyritic rock with zoned plagioclase phenocrysts 3 mm. in diameter, the composition in this case being closer to oligoclase. Kaolinite and sericite are abundant. Hornblende is present as brown, euhedral grains of medium size, and green biotite is plentiful. Together the dark minerals make up 15% of the rock. Free quartz is present as a few isolated grains, and sphene occurs as an accessory.

The instrusions are believed to be sills emplaced after the post-Esk folding and faulting. Observations at Ottaba by D. Hill show that the Ottaba augite andesite, thought to form part of the Brisbane Valley Porphyrites, is pre-Tertiary, and at Paddy Gully that an intrusive felspar-hornblende rock is post-Bundamba. Consanguinity of all these intrusives, however, has not yet been demonstrated.

The Nurinda Microgabbro

This is the "core-like intrusion at Nurinda and Colinton" described by D. Hill (1930 (b)). It is a large tabular mass, 3 miles long and up to 800 feet thick, tapering at both ends, and with a rough north-westerly alignment.

The rock is a porphyritic olivine microgabbro in the sense of Hatch, Wells and Wells (1949, p. 294) and thin section 4787 shows that it is a holocrystalline rock with approximately equal proportions of phenocrysts and groundmass. The phenocrysts are of much kaolinized plagioclase, 5 mm. long and 2 mm. wide, with equidimensional cross sections and random orientation. Light coloured augite is present and olivine occurs as euhedral grains and irregular, roughly equidimensional masses about 1 mm. across. It is much cracked and is associated with light brown iddingsite. The matrix is medium grained and consists of lath shaped felspars, much kaolinized and sericitized. Opaque iron ore is plentiful.

Some accordance between the position of the Nurinda intrusion and the geologic structure is apparent. The intrusion is aligned approximately along the axis of the Colinton Anticline and is transgressive in the vicinity of Stradbroke Creek, where overfolding does not occur.

The Balfour Trachytes

Representatives of this suite of trachytes occur throughout the area, but are most numerous north of Sandy Creek. They occur as dykes in both the sediments and the Taromeo Tonalite, as a large lens-shaped mass near the "Stone House," and as conformable sheets up to 4 feet in width, some of which are exposed in the Balfour Range road cuttings.

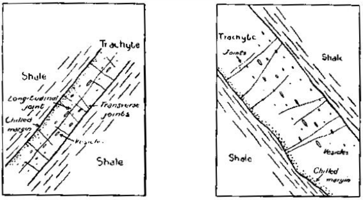
Most of the Balfour Trachytes in the hand specimen are tough and fine grained, and range in colour from green to dark grey. Both porphyritic and non-porphyritic varieties occur.

Typical of the porphyritic trachytes is that occurring in the railway cutting at 298635. Thin section 4796 shows euhedral phenocrysts of zoned plagioclase up to 4 mm. across, set in a fine groundmass of clouded felspar laths. The phenocrysts are extensively kaolinized and sericitized. Small angular quartz grains are present in the groundmass. Some euhedral hornblende is present, and accessory minerals include euhedral apatite and opaque ore.

The characteristic feature of 4801 is the presence of augite, much of which is poikilitically enclosed by the felspar phenocrysts, being included as small, rounded, irregular, and occasionally subhedral masses.

The light coloured porphyritic rock occurring at 427592 (4802), has the mineral composition of trachyte but possesses several distinctive features. It differs from the trachytes previously described in that a large number of the phenocrysts are of oligoclase. Together, however, they constitute less than one-third of the rock. The groundmass is fine grained and granular, the average diameter of the grains exceeding 0.05 mm. With the presence of acid plagioclase phenocrysts and a granular orthoclase groundmass this rock agrees well with Johannsen's description of "syenite-porphyry." It is a porphyritic microsyenite in the terminoloy of Hatch, Wells and Wells.

Of the thin conformable trachyte sheets two can be regarded definitely as sills; the evidence in the case of the others is inconclusive. One is shown in Text Fig. 1 (a). It is cut by both longitudinal and transverse joints, and the upper margin is chilled. Drawn-out vesicles occur throughout but are most numerous in the upper half of the sheet. The largest vesicles are in the centre. Its intrusive nature is indicated by slight discordance in one part, the otherwise conformable margins being displaced about three inches from one horizon to another.



(a) (b)

Text Fig. 1

The other conformable trachytes are typified by that at 291633 (Text Fig. 1 (b)). This sheet is three feet wide and is crossed by transverse joints. The lower margin is not conformable, though the upper is. A chilled margin occurs at the base, where small fragments of shale have been incorporated in the trachyte. A four-inch zone without vesicles lies immediately over the chilled margin. As in the case described above, the vesicles are aligned parallel to the edges of the mass and the largest are in the centre.

The constant association of these conformable tracytes with weak shale beds is a notable feature which suggests an intrusive origin. The most important features favouring the view that some are extrusive are the presence of shale inclusions on the lower edge and not on the upper, and the transgression of the bedding by the lower margin and not by the upper. The trachytes are too thin for joint patterns to give any indication of their mode of formation. The vesiculation is not that which would be expected in a flow, and the absence of associated pyroclastics and the extreme thinness of some of the beds are features suggesting that they are sills.

None of these criteria enables a definite decision to be made, but the weight of evidence seems to be in favour of intrusion, especially as similar trachytes in the same area are known to be intrusive.

The relation between the trachyte intrusions and the regional structure is not readily apparent. They occur in both the steeply dipping strata of the Colinton Anticline and the relatively gently dipping beds of the Wallaby Syncline and its associated structures, but are far more numerous in the latter. The structural line of weakness represented by the Western Border Fault has determined the position of many trachytes in the western area.

All the trachytes in the Esk Beds, with the exception of the large masses west of Linville (the nature of which is a matter of some doubt), have been intruded into strata below the Linville Tuff. Most of those in the Colinton anticlinal belt outcrop to the south of Nurinda, where longitudinal arching of the Nurinda Anticline brings up beds as far down in the sequence as those on the Balfour Range. Almost constant restriction to the lower part of the sequence suggests that the trachytes were intruded prior to the folding of the Esk Beds, their present distribution being dependent on the depth to which the folded strata have been eroded.

STRUCTURAL GEOLOGY

Both the structures associated with the western edge of the trough and the sharp folding of the Esk sediments reflect the sub-meridional trends characteristic of the Lower Palaeozoic geosynclinal rocks of Queensland. The Esk rift valley is particularly interesting in that a record of the tectonic activity affecting the trough after the time of deposition has been preserved in the structures assumed by the Mesozoic sediments.

Marginal Faulting

The Western Border Fault System comprises a number of intersecting faults marking the western edge of the rift valley and separating, in this area, Triassic basin sediments from the metamorphic and granite rocks of the Yarraman Block. In the vicinity of Ironside Creek the main fault is dislocated by the north-north-easterly trending Ironside Fault, which has here displaced the western edge of the trough about one-and-three-quarter miles to the west. The southern part of the main fault is to be called the Glen Howden Fault, the northern part the Blackbutt Fault.

Along the main fault the downthrow is to the east. It has not been possible to demonstrate conclusively the attitude of the fault plane, but it is nearly vertical, and from the deflections of its outcrop caused by the spurs of Glen Howden, is thought to dip at a high angle (80 to 85 deg.) to the east. This means that the fault is probably a normal fault of very great throw (10,000 feet or more).

The trace of the Ironside Fault across the ridges between Ironside and Misery Creeks indicates that the dip of the fault plane is about 60 deg. to the north; as the downthrow is to the north this is a normal fault.

Consideration of the relations between the Ironside Fault and the main fault admits three possibilities (See Text Fig. 2).

(a) The Glen Howden and Blackbutt Faults were originally continuous and the Ironside Fault is a dip-slip fault, the present displacement being caused by slip of the northern block down the dip of the fault plane.

(b) The above two faults were originally continuous and the Ironside Fault is a strike-slip, or an oblique-slip fault, with movement of the northern block towards the west.

(c) The two north-north-westerly faults are separate and distinct, and the Ironside Fault is essentially a dip-slip fault, the stepping-back of the trough boundary being due to slippage of the basement rocks down both the Ironside and Blackbutt Faults.

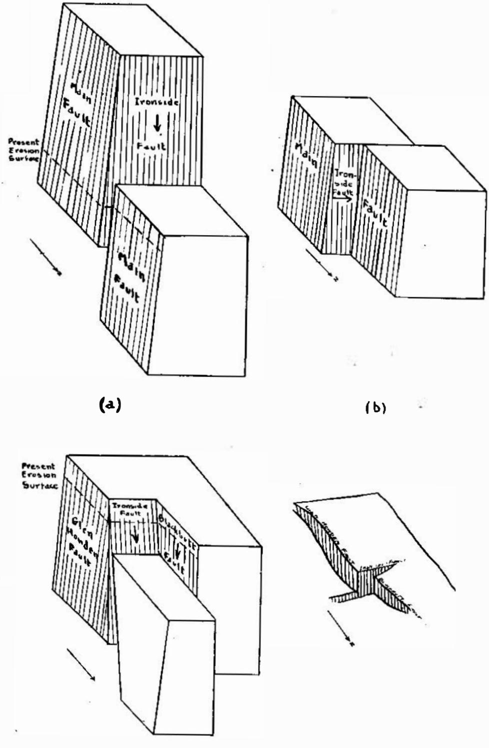
The first possibility is of theoretical interest only as a horizontal displacement of the two parts of the original fault of nearly two miles would require an impossibly great throw (of the order of 15 miles), with the dips of the fault planes as quoted above.

Suggestion (b) is within the realm of possibility, but there is at present no geological evidence in support of it. Observations previously made with regard to the distribution of rock types of the Neranleigh-Fernvale Group along the Western Border Fault, viz., quartzites being dominant to the south of the Ironside Fault and hornfels to the north, are not in favour of this mechanism, because if a simple lateral shift of one or both blocks along a dip fault is all that is involved the same rock types would be expected to occur along the two displaced segments of the original fault. Also, post-Esk movement along the Ironside Fault has not been of the transverse type.

The third suggestion seems to explain the observed facts most satisfactorily. If the northern and southern sectors of the main fault be regarded as two separate, parallel faults, depression of the basement rocks bounded by the Blackbutt Fault on the west and the Ironside Fault on the south would produce the present arrangement. Whether or not a continuation of the Glen Howden Fault extends northward beneath the cover rocks, forming a fault slice in this part of the basement, is unknown.

With possibilities (b) and (c) definite evidence one way or the other should result from a study of the distribution of the various lithological types within the Neranleigh-Fernvale Group in this part of the Yarraman Block.

The swathing of the sediments about the node formed by the junction of the Glen Howden and Ironside Faults, and the absence of any major disturbance or dislocation within the sediments which would be consequent on the



(a)

(b)

(c)

Text Fig. 2 (See Text)

formation of a fault of the dimensions of the Ironside Fault after deposition, indicate that the margins of the original basin followed the course of the border faulting.

That subsequent movement along the old fault lines has taken place, however, is indicated by the steepness with which the conglomerates at the margin dip away from the fault (some approaching verticality), the shattered nature of the sediments near Boat Mountain, and the close jointing and fracturing of the sandstone at 359561, which is on a line with the Glen Howden Fault. Minor faulting is to be seen in the conglomerate near the Blackbutt Fault on Cutting Creek.

The Ironside Fault was thought by D. Hill to have a different throw from the Maronghi Creek-Happy Creek section of the main fault because ". . . trachytes are not visible in the steeply tilted strata of the latter, while they are very obvious in the moderately dipping strata of the former."

A very striking fault breccia (R 16056) has been formed at 297586, near the junction of the sediments and the Taromeo Tonalite. Irregular, angular and subrounded fragments of light coloured, much weathered, probably volcanic material are set in a matrix of clear crystalline drusy quartz. Several small cavities contain well-formed prismatic quartz crystals. Some fracturing and small scale faulting has occurred, the factures now being occupied by quartz veins.

Campbell concluded from work in the Cressbrook area that subsequent movement occurred in both post-Esk-pre-Bundamba, and post-Bundamba times.

Internal Folding and Faulting

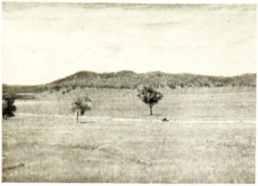
The sharp folding of the Esk Beds along sub-meridional axes parallel to the western edge of the trough, first detected by D. Hill in 1930, has been elucidated by mapping the outcrop of the Linville Tuff. D. Hill described the structure as being dominated by "axes of disturbance" (of which in this area the Colinton axis is the chief), separated from one another, and from the margins of the trough, by "gentle synclinal structures." The Colinton disturbance was thought to be a very sharp fractured anticline, accompanied by intrusions along the line of disturbance. In the present analysis the structural names applied by D. Hill will be retained where possible, but in some cases it has been thought advisable to discard the old terms and adopt new ones to avoid confusion.

The various structural units will be dealt with in order of importance, viz.:

(a) The Colinton Complex Anticline.
(b) The Wallaby Syncline and related structures.
(c) Folds in the north-western part of the area.

(*a*) *The Colinton Complex Anticline*.—This structure has been mapped as a broad belt from near Mt. Williams where it is four miles wide, to the north of Linville where it narrows to about half that width. It is an anticline,

PLATE 1



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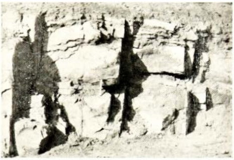

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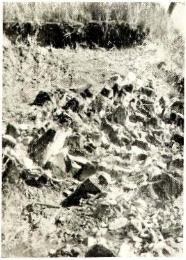

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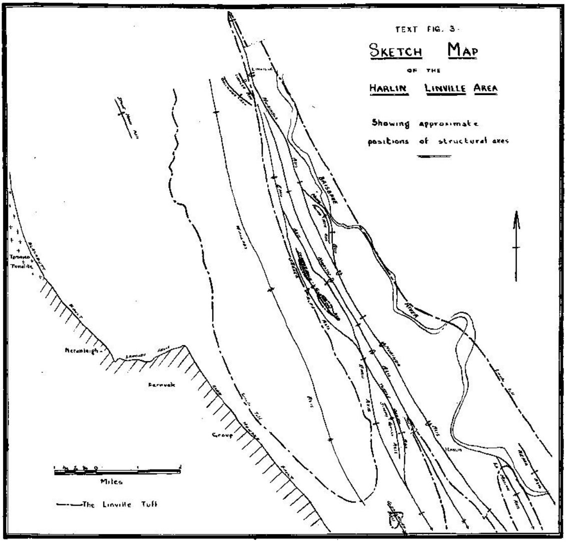


TEXT FIG. 3.

SKETCH MAP OF THE HARLIN LINVILLE AREA

Showing approximate positions of structural axes

overfolded towards the west along most of its length, and complicated by subsidiary structures on both flanks. South of Harlin these subsidiary folds attain major proportions. The main structure plunges at both ends—at a maximum of about 25 deg. to north and south, but flattening to about 5 deg. away from the main culmination which accurs to the south of Nurinda. Another culmination occurs at Moore. The maximum structural uplift from syncline to anticlinal crest is about 10,000 feet.

The broadly sinuous axes of the component folds have been plotted on the accompanying map, and Text Fig. 4 is an "exploded" perspective view of the Linville Tuff as it has been affected by the folding, with the restoration of eroded parts. The numbered edges of the blocks correspond to the grid lines on the Blackbutt 1-mile Military sheet.

The structures become less complex towards the north. In the south the quite distinct Nurinda and Emu Anticlines are separated by the Harlin Syncline. The anticlinal axes converge on being traced northwards, the syncline becomes less well defined, and near Greenhide Creek the Emu Anticline and the Harlin Syncline die out on the western flank of the Nurinda Anticline.

The "backbone" of the structure is then the Nurinda Anticline. The dip of the eastern flank is highest in the north, where it is approximately 65 deg.; dip readings further south average 45 deg. The Nurinda Anticline is strongly asymetrical and at various points along its length it is overfolded towards the west. It is in this that the particular interest of the structure of the area lies.

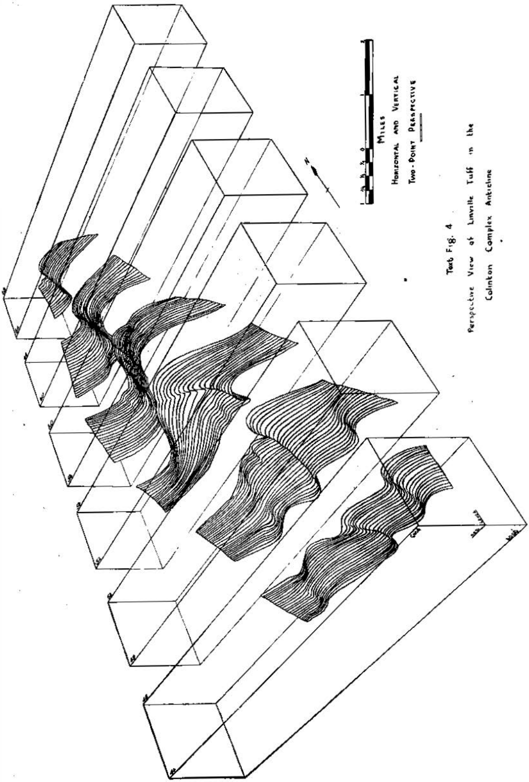
Overfolding has been detected in the extreme south near Mt. Williams, from Maronghi Creek north to Emu Creek, from Stradbroke Creek to Sandy Creek, and in the vicinity of Linville. The perspective drawing (Text Fig. 4) does not illustrate the overfolding near Nurinda, as with parallel folding (which can be safely assumed for sediments as competent as the Esk Beds), the intensity of folding decreases with distance from a certain horizon, at which it is a maximum. Cross section D illustrates this. Both Text Fig. 4 and the cross sections have been constructed by Busk's method for drawing parallel folds from surface dip readings, with the outcrop of the Linville Tuff providing a fairly close control.

The tuff on the underlimb of the overfold south of Harlin is exposed in the railway cutting at 493472, where it dips at 60 deg. to the east. On the other limb it outcrops on Mt. Williams at 500474, dipping east at 20 deg. The conglomerates between these two outcrops dip at moderately high angles to the east.

North of here the anticline reverts to the normal asymetrical type, the western limb maintaining dips in excess of 65 deg. The best exposure of overfolding in the area is to be seen in the next overfolded section, near Jimmy Gully. Here the southerly plunge of the Harlin Syncline has brought the tuff to the surface, forming a "nose," both limbs of which dip at about 55 deg. to the east. On the top of the east-west ridge at 452521 are three outcrops about 50 yards apart, and separated by sediments. The most easterly outcrop is on the underlimb of the overfold and is inverted; the other two are on the western limb of the Harlin Syncline, repetition probably being the result of thrusting. Jointing in the tuff here is strongly developed.

Observations on the grain size distribution within the sandy bands and lenticles in the conglomerates, both here and at the previous locality, indicate that in many cases the larger grains are on the bottom and the smaller grains on top, but results were not sufficiently consistent to allow use of this feature as a top-and-bottom criterion. In any case, regular grading would not be expected in a sequence so obviously the product of torrential and rapidly changing conditions of sedimentation.

Northwards from Jimmy Gully the overfolding becomes less severe as the underlimb becomes steeper and then vertical. Then at 429572 the dip is 85 deg. W. and the Harlin Syncline is again easily recognizable. It is in this area that the Nurinda Microgabbro becomes transgressive and crosses the axis of the Nurinda Anticline. On Point Danger overfolding is re-established for a short distance, the easterly dips of the upper and lower limbs being 40 deg. and 65 deg. respectively.



Text Fig. 4

Perspective View of Linville Tuff in the Colinton Complex Anticline

It is on the steeply dipping (80 deg. W.) limb of the Nurinda Anticline near Greenhide Creek that the Emu Anticline and Harlin Syncline come suddenly to an end. Here an *en echelon* arrangement of fold axes exists. The Greenhide Anticline arises lower down on the flank of the Wallaby Syncline, so the western limb of the Nurinda Anticline becomes the eastern limb of the Linville Syncline.

Discontinuous outcrops between here and Linville indicate that the beds become vertical and then tilt over until the tuff in the Linville railway cutting is overturned and dipping at 75 deg. to the east. North from here the beds again become upright, and at 376693 where the northerly plunge of the anticline brings together the outcrops of tuff on both limbs of the fold, the dip on the western limb is 45 deg. W.

Two groups of subsidiary folds are developed on the eastern limb of the Nurinda Anticline. One comprises the short, but very sharp, Round Mountain Syncline and the corresponding Moore Anticline. The beds dipping 60 deg. E. on the limb of the Nurinda Anticline suddenly dip 70 deg. W. in this structure.

A larger feature is the Neara Anticline which arises between Neara and Gregor Creek. The complementary La Maison Syncline separates it from the Nurinda Anticline. These folds plunge to the south with the main structure and the tuff outcrop apparently follows around the nose of each, although much is obscured by alluvium and the mapping has not been taken into the "Moorabool" area. The dip on the limb common to the Neara Anticilne and the La Maison Syncline is moderate (about 45 deg.).

The other major component of the Colinton Anticline is the Emu Anticline. Dips away from the axis in the southern part of the area are relatively low (ranging from 10 deg. to 30 deg.), but they increase towards the north. The Emu Anticline at 444517 involves a cliff-forming conglomerate and so is easily made out from the Turtle Creek Road, although the conglomerate at the crest has been removed by erosion. Changes of plunge and slight bending of the main axis have resulted in the apparently anomalous attitudes of the conglomerates in the upper parts of Stradbroke Creek. Here the conglomerates can be traced around the nose of each plunging section of the anticline.

Virgation of the axis occurs near Jimmy Gully and in the Happy Creek-Wallaby Creek area, around sharp central depressions. The first of these is the Jimmy Gully Syncline, separated from the Harlin Syncline by the Turtle Creek Anticline. This anticline is asymetrical, with the steepest limb (dipping at 40 deg.) towards the west.

The other central depressions are the Glendon and Stradbroke Synclines, separated from the Wallaby Syncline by the Sarner Alps Anticline. Rapid changes of plunge of the synclinal axis have resulted in the formation of these two narrow, elongate structures, both of which close on the Linville Tuff. The beds on the limbs dip at a high angle (about 60 deg.) and the angles of plunge reach a maximum of 25 deg.

(*b*) *The Wallaby Syncline and Related Structures*—The Wallaby Syncline is a large, relatively simple structure over 11 miles long and nearly 3 miles wide. The southern part of it separates the Colinton Anticline from the Palaeozoic highland, but north of the Ironside Fault the western limb passes into a series of small folds which are treated under the next heading.

The syncline is outlined by the Linville Tuff and the average dip on the limbs is 30 deg. Steeper dips occur, however, on the limb common to both the syncline and the Emu Anticline north of Moore, and against the Glen Howden Fault where the effects of post-Esk movement along the fault are well shown.

Central arching occurs to the west of Moore where the Dry Creek Anticline arises with high dips. Further north a small anticline interrupts the western limb of the syncline. From Greenhide Creek the Wallaby Syncline becomes shallower and less important as its role as bounding syncline for the Colinton Anticline is taken over by the Linville Syncline, a structure formed by the up-arching of the Greenhide Anticline.

Changes of plunge near Maronghi Creek have produced the small, closed Glen Haven Basin, a structure on the same synclinal axis. In contrast to the Glendon and Stradbroke Synclines this basin is equidimensional and, as delineated by the tuff, roughly triangular in shape. It is well expressed topographically. On the east the Glen Haven Basin is bounded by the Emu Anticline, but on the west only an anticlinal bends marks it off from the easterly dipping strata of the Wallaby Syncline.

South of the Glen Haven Basin another change in plunge occurs, and the tuff outcrops around the nose of another syncline, plunging south with the Emu Anticline.

(c) *Folds in the North-Western Part of the Area*—The moderately dipping beds between the Wallaby Syncline and the Blackbutt Fault are folded in a series of comparatively shallow folds which have not been mapped in detail. The Stone House Anticline has dips of 30 deg. and 25 deg. on the east and west flanks respectively. Two other anticlines and adjacent synclines between here and the Blackbutt Fault are revealed in the railway cuttings, with dips of comparable magnitude. High dips and irregular strikes along the western margin are due to the influence of the Blackbutt Fault.

Jointing in the sediments is best developed in the sandstones. Usually two, and sometimes three sets are present; cubical jointing is very well shown in the railway cuttings on The Round Mountain.

One notable feature of the fold structures of the Esk Beds is their sharpness. Flat-lying or gently tilted beds are not found along the crests or troughs except in a few cases, as on the Emu Anticline at 441517, and in the Wallaby Syncline. The folds in the north-west also are fairly gentle, but elsewhere the change in dip from one limb of a structure to the other is very abrupt. D. Hill described the structures as "fractured anticlines." Slickensiding has been found near the crest of the Nurinda Anticline at 388663, and at 458523 near Jimmy Gully. It also occurs along the line of the Emu Anticline at 434548 and the Sarner Alps Anticline at 416563. It has not been possible to determine whether the movements represented by the slickensides have been of a compressional nature associated by the overfolding, tensional associated with stretching over the anticlinal crests, or of an independent origin and unrelated to the folding. The presence of the Nurinda intrusion along the axis of the Nurinda Anticline suggests localization along a zone of weakness, if not along an actual fracture.

Faulting—Repetition of the Linville Tuff on the eastern limb of the Turtle Creek Anticline at 452521 is probably the result of thrusting, as suggested by Cross section C, but the actual direction of movement along the fault is unknown. A number of faults can be seen in the Linville-Benarkin railway cuttings, but it has not been possible to determine their nature or throw. All are steep and most are marked by bands of gouge and rock flour up to 30 inches in width. A fault is visible in the Linville Tuff in the railway cutting at 384672. It transects the bedding, dipping at about 45 deg. to the west, and is probably a reverse fault as "drag" of the bedding below the fault is in an upward direction.

Discontinuity of the Linville Tuff between 384681 and 389683 suggests the presence of a dip fault trending approximately E.N.E. Exposures in critical areas are, however, lacking. The abruptness with which the ridge running north-north-west from 395675 ceases at 389683, and the steepness of the scarp rising from Sandy Creek suggest that some factor other than erosion has been operative. Strong vertical joints in the conglomerates on the face of this scarp cut cleanly through both pebbles and matrix. They trend 30 deg. E.—roughly in the direction of the supposed fault.

Similar relations exist in the tunnel area south of Harlin, where faulting across the strike is believed to have displaced the tuff by about 100 yards. The nearby Brisbane Valley Porphyrite intrusion has not been similarly affected.

Some minor faulting is visible in the sediments against the Blackbutt Fault. On Cutting Creek conglomerate pebbles have been cut through and displacements of a few inches can be measured.

Mechanics of Folding

The folding of sediments as competent as the Esk Beds could be accomplished either by buckling or by bending, as defined by Hills (1953). The numerous thick, massive conglomerates have probably controlled the extent of response of the beds to the deforming forces, the interbedded shales and sandstones accommodating themselves to the structures so formed. If buckling has been the dominant mechanism the conglomerates would probably adjust themselves by inter-pebble movement and slip along the contacts with adjacent beds. Slickensiding developed in various parts of the structures may attest to this bedding plane slip.

On the other hand, bending involves either stretching, with flowage from the anticlinal crests towards the limbs (supratenuous folding), which does not appear to have taken place, or normal faulting. That fairly extensive faulting has taken place is shown by the Linville-Benarkin railway sections, and the slickensiding and shattering elsewhere may be the expression of strike faulting consequent on bending.

Conclusive evidence one way or the other is at present lacking.

Tectonic Interpretation

The Western Border Fault System in the area studied separates Mesozoic sediments from the rocks of the Yarraman Block, so no deductions as to its original nature can be drawn. That subsequent movement in post-Esk times has been tensional is indicated by the up-tilting of the sediments against the fault, and by the attitude of the Ironside Fault plane.

The presence of overfolding in the Esk Beds and the asymetrical nature of the normal anticlines are indicative of deformation by compressional forces acting from the east. For the most part the overfolding is not unduly severe, though in places it is almost isoclinal. The distribution of tectonic elements and their parallelism to the margins of the trough and the regional strike of the basement rocks are features worthy of note.

Steep folding and overturning is confined to the narrow zone of the Colinton disturbance, and immediately to the west the complex anticline is bordered by the broad, relatively simple Wallaby Syncine. This complete restriction of strong deformation to a particular belt, and the north-north-westerly alignment of that belt, suggest that folding is the result, not of regional compression, but of localized stresses set up by movement in the basement.

Intensification of tectonic processes seems to have taken place in the vicinity of Nurinda and near Moore, where longitudinal arching has formed culminations on the Colinton Anticline. It is along the first of these that the Nurinda Microgabbro has been intruded. Cross faulting and transverse jointing have developed as a result of this longitudinal arching, being at right angles to the direction of stretching or the greatest axis of strain.

Deformation of the basement may take the form of folding as well as of fracturing, as indicated by Lees (1952): ". . . the basement is not nearly so rigid as is commonly thought, even under conditions of relatively light cover." He describes numerous examples of strong flexuring of crystalline basement rocks in different parts of the world. One of these is in the Arbuckle Mountains, Oklahoma, U.S.A., where unmetamorphosed Cambrian and Ordovician strata, ". . . mostly strong limestones, are infolded in a pinched syncline between two folds of basement rocks." It seems likely that the observed deformation of the Esk Beds could result from flexuring and thrusting in the basement.

Tabular intrusions indicate a direction of minimum pressure (sometimes of active tension) across the plane of the intrusion at the time of emplacement. The Balfour Trachytes indicate merely that the direction of least stress before the compressional epoch was vertical, as most of them are conformable.

The intrusion of the Nurinda Microgabbro and the Brisbane Valley Porphyrites is believed to have occurred after the folding. Relief of pressure in an east-west direction was accompanied by the emplacement of conformable sheets in the steeply dipping sediments, particularly in the southern part of the area.

The tectonic history of this part of the trough, therefore, is dominated by alternations of tension and compression acting from east to west. That such alternations take place is indicated by Evans (1925) in the statement: "Tension may also occur as a reaction against compression when the forces causing the latter have ceased to operate."

REGIONAL RELATIONS AND TECTONICS

The relation between the tectonics of the area just discussed and those of the Esk Rift Valley, as far as they are known, and the extent to which previous ideas will be modified by the present findings, will be considered under this heading.

The relation between the Neara Beds and the Esk Beds in this part of the Brisbane Valley is by no means clear. All along the boundary as mapped the dip of the Esk Beds is to the east, and at Gregor Creek they can be seen in the creek bed dipping underneath the andesite and andesitic pebble conglomerate previously described under the heading "Neara Beds," which outcrop 750 feet above the stream.

If the Neara Beds are stratigraphically above the Esk Beds they would be expected to outcrop in the Wallaby Syncline, but they have not been found east of the Brisbane River except in the Cressbrook area (Campbell, 1952, p. 14).

Also, Upper Esk rocks in the Paddy's Gully area south of Esk are overlain by Bundamba Sandstone. Had the Neara Beds overlain the Esk sediments a tremendous volume of material must have been eroded from one part of the basin but not from another in post-Esk-pre-Bundamba times. This difficulty does not exist if restricted distribution of the Neara Beds (to the eastern portion of the trough) be invoked, at least in certain areas.

As insufficient field work in this part of the area has been done to do more than hint at the nature of the problems, the traditional view established near Esk by Reid and Morton (1923) and D. Hill (1930) is maintained, viz., that the Neara Beds conformably underlie the Esk Beds.

The Esk Rift Valley is a parallel sided depression over 120 miles long and averaging 15 miles in width. It is thus comparable in dimensions with the rift valleys of Europe and Africa. At its southern end it opens out into the younger Ipswich Coal Measures basin; at its northern end it is closed in by Lower Palaeozoic rocks of the South Coastal High.

The West Moreton Fault, which borders the trough on the east, was developed as a thrust probably in the Upper Devonian (Dunlop, 1951, p. 89). Nothing has been seen along the Western Border Fault System to suggest that it is a compressional feature; all the evidence so far obtained indicates that it is a system of intersecting vertical and normal faults.

Dunlop has attempted a reconstruction of the evolution of the trough from observations in the Northbrook area, and from the findings of Campbell in the west. He suggests that rift valley formation began with thrusting along the West Moreton Fault in the Upper Devonian, or with later movement, of either a tensional or a compressional nature, probably in the Upper Carboniferous. In this he disagrees with Campbell, who suggested that rifting began in late Permo-Carboniferous or early Triassic times.

Shallow marine seas invaded the trough in the Permo-Carboniferous, after which block-faulting and rifting of a tensional nature occurred, with renewed movement along the West Moreton Fault. That the faulting is tensional is indicated by the lack of strong folding within the fault blocks, although Campbell has suggested that folding in the Cressbrook-Buaraba block may indicate the onset of mild compression prior to the action of disrupting tensional stresses.

Subsidence following this rifting was accompanied by the deposition of the Mesozoic sedimentary and volcanic sequence. A third period of rifting (under tensional stresses) then occurred, in regard to which Dunlop states: "That the post-Esk rifting was tensional is suggested by the Dundas dyke swarms and possibly also by the internal folding and intrusion in the Esk Series."

No further evidence as to the time of initiation of the Western Border Fault System, or the original nature of the component faults, has been obtained in the present investigation, but subsequent movement along them, in post-Esk times, has been of a tensional character.

The previously unsuspected compressional nature of the post-Esk folding shows that a period of compression succeeded the period of tension during which the Triassic rift valley was formed. The forces were directed from the east, as were the compressional forces of the Tasman Geosyncline. Probably this post-Esk compression was relieved by flexuring and thrusting in the basement, with consequent deformation of the overlying sediments. This basement thrusting was possibly the result of interaction between three stable blocks—the D'Aguilar Block, the Yarraman Block and the intermediate depressed block forming the floor of the rift valley. A deep-seated vice-like action with pressure from the east could result in failure in the valley basement along one or more sub-meridional lines of weakness. This movement is seen as an echo of the compressional deformation which finally brought to an end the Tasman Geosyncline at the close of the Palaeozoic.

That the post-Palaeozoic history of the whole of Queensland be considered in the light of Saxonian tectonics was advocated by Fairbridge in 1948: "During the Mesozoic and Tertiary, the history has been basically one of epeirogeny, expressed by orogeny of a low order, in the "jostling" movements of longitudinal, more or less rigid blocks, with faulting and folding mainly restricted to their margins." The type of movement here described differs from that visualized by Fairbridge in its strongly compressional nature, for typical Saxonian structures take the form of monoclines, *Kofferfalten*, and *decollement* structures.

The release of the compressional stresses is expressd by such features as the intrusion of the Brisbane Valley Porphyrites and the Nurinda Microgabbro, and further tensional rifting movements along the Western Border

Fault. This is the third (post-Esk) rifting period of Dunlop, during which probably the Dundas dyke set was emplaced, and normal faulting took place along some of the old fault lines.

That another, less severe, period of tensional faulting occurred in post-Bundamba times is indicated by Campbell's work in the Buaraba area.

The part played by vulcanism in the development of rift valleys has been emphasized by Escher (1952). He is of the opinion that the volcanic activity associated with rift valley structures is "a consequence of tensional forces in a horizontal direction." Multiplicity of rock types is attributed to assimilation of pre-existing rocks in the graben, not to magmatic differentiation. Probably the extrusion of the material of the andestitic boulder beds was an important occurrence in the history of the basin, but as Dunlop observes, "It is doubtful if any of the major rifting movements can be ascribed solely to this process."

It is not yet possible to give a full and satisfactory explanation of the tectonics of the Esk Rift Valley, but it is now apparent that both tension and compression have been involved—tension in the block faulting along the margins which has preserved some of the Permo-Carboniferous marine beds, in the intrusion of numerous dyke and sill swarms, and in at least the subsequent movement along the Western Border Fault, and compression in the overfolding of the Esk Beds and probably also in the originally compressional nature of the West Moreton Fault.

COMPARATIVE DISCUSSION

The distinctive features of some of the rift valley regions in other parts of the world, together with some of the suggestions that have been put forward to explain their origin, are outlined below. Some striking similarities, and equally striking differences, are apparent.

The classical rift valley of Europe, the Rhine Valley, has been closely studied and the nature of the border faults is well understood. They are normal faults dipping in towards the graben, and represented by well-defined shear zones. Similar structures, with similarly disposed antithetic and synthetic subsidiary faults, have been obtained by Cloos (1939) on subjecting blocks of clay to tensional and bending stresses. As with other rift valleys the Rhine Graben traverses a stable block—in this case the Rhenish Shield.

The Musinia Graben of Utah, U.S.A., has been described by Spieker and Baker (1928). It is a smaller feature than the Esk trough, the displacements on the border faults reaching a maximum of 2,500 feet; the beds between these are divided into blocks by a series of parallel faults. It is interesting in that practically all the faults are vertical. Movement has taken the form of down-dropping along these faults, accompanied by the tilting of individual blocks.

The Newark troughs of Connecticut and New Jersey are described by Dunbar, Eardley, King and others as having been formed by normal faulting on either side of a great low arch. The troughs are "one-sided" and do not necessarily connect across the arch. The Connecticut trough is regarded as typical. It is 100 miles long and up to 25 miles wide, and contains Triassic "conglomerates, sandstones, and shales, with interbedded flows of dark (basic) lava." The sediments, which are between 10,000 and 13,000 feet thick, dip eastwards against a fault with a maximum throw of 3 miles.

These basins fit the description of the "half-graben" basins of Weeks (1952). They resemble the Esk trough in dimensions and in thickness of contained sediments, but differ in having bounding faults on one side only. The sediments are poorly sorted and irregularly bedded, but are arkosic in nature, and many are red. They have not been disturbed by later folding movements. The period of trough formation followed the release of the compressive stresses of the Upper Palaeozoic Appalachian Orogeny.

The nature of the rift valleys of Africa has long been a matter of debate, but in recent years the balance of opinion seems to have moved in favour of tension. Goguel (1949) and Vening Meinesz (1950) have shown that it is possible to reconcile the negative gravity anomalies found over rift valleys with formation under tensional stresses (Escher, 1952, p. 750).

Cloos (1939) pictures the Eastern and Western Rifts of Africa as the result of tensional collapse consequent on regional updoming, one rift forming on each side of the original arch. Sagging at the top of the dome has produced the Lake Victoria depression.

That the Gulf of Suez is a tensional feature is maintained by Busk (1945). He describes the border faults as a series of clean cut faults of great throw, either vertical or dipping steeply away from the upthrow side; they have a marked *en echelon* arrangement. Evidence of lateral compression is absent. Busk's interpretation of the Gregory Rift follows similar lines, though the evidence in this case is not so well defined.

Some who admit a tensional origin for the Gregory Rift and the Eastern Rift System of Africa hold that the Western Rift was formed under compression, but in a recent paper (1951) Davies has summarized the evidence obtained by geological work and drilling in Uganda. Evidence of compression and thrusting of an early age is found in the basement rocks, but rifting seems to have taken place entirely under the influence of tension.

A study of the Kavirondo Rift Valley of Kenya by Kent (1944) revealed the presence of "normal and reversed faulting, and of strong disturbances, including isoclinal folding and shearing" in the Miocene beds of Rusinga, unlike and previously described in the Tertiary rocks of the East African rifts. Kent considered that these features supported the compressional hypothesis for the formation of rift valleys. This interpretation was criticized by Busk in 1945 when he pointed out the small size of the structures (displacements being measured in terms of a few feet or tens of feet), and the probability that minor compressional structures would form as the downthrow block of a tensional rift valley accommodated itself to its new position.

Following the work of the 1947 British-Kenya Expedition, Shackleton has put forward another explanation of the "low-angle thrusts, isoclinal folding, imbrication and other complexities" described by Kent. Some of the supposed thrusts are now known to be unconformities, and he interprets most of the other structures in terms of gravitational tectonics and slumping. It is concluded that "in the Miocene beds of Kavirondo evidence of crustal compression is entirely lacking."

The Red Sea Graben is not attributed by Tromp (1950) solely to tension or compression, but to "a complicated interaction of different fold and fault mechanisms." He suggests that updoming of a rigid area may have been accompanied by shearing and the development of stretch faults along which differential movement took place, with the formation of horsts and graben.

Dixey (1946) likewise rejects both simple tensional and compressional explanations for the East African Rift System. He considers that it originated "in two main series of fractures following the same lines but separated by a prolonged period of intermittent continental uplift and regional planation." The dominant stresses under his hypothesis are, however, of a tensional nature.

The compressional theory for the formation of rift valleys has been recently restated, with minor modifications, by McConnell (1951). He visualizes the formation of ramp faults which rise steeply to the surface, where they appear as vertical or even steeply inclined normal faults. Compression and tension are often related to each other, and under this arrangement lateral compression at depth will be expressed by tension at the surface. Compressional effects in the cover rocks, therefore, as in the Brisbane Valley, do not mean that the rift valley has been originally formed under compression, and in fact with this arrangement they could not in any way be directly related to such initial movements. The answer to the question of the origin of rift valleys lies in a complete understanding of the nature of the border faults.

A different approach to the study of rift valley tectonics has been made by Lees (1952), in the development of his thesis that "the crystalline basement can be plastically deformed by crustal contraction." He concludes that in the development of the African Rifts both tensional and compressional forces have been operative. "The valleys may have been downwarps in their early stages of development, and the boundary faults, spectacular though they may be, are only an accentuation of the broad flexure. The effects of later compressive movements are seen within the valleys in a number of cases . . ."

The Dead Sea-Jordan Valley rift is quoted as an example of rifting at an angle to a previous fold pattern. The tensional border faults trend obliquely across the folds, though some are diverted along the flanks of the anticlines, become reversed on the steep fold limbs and eventually die out.

In the Jordan Valley-Dead Sea-Wadi Araba valley flexuring and thrusting in the crystalline basement has deformed the overlying 10,000 feet of sediments in a complicated pattern of folds and faults. Some of the border faults are normal faults, some are thrusts. The causal effect is considered to be dominantly crustal contraction, with "tensional effects playing, at most, a minor role." Resemblance to the Esk trough is seen in the compressional deformation of the basin sediments. As to the relative importance of tension and compression in the history of the Brisbane Valley, however, little is known; at the present state of our knowledge it seems that tension has been the more important.

HISTORICAL SUMMARY AND CONCLUSIONS

The geological history of the Harlin-Linville area may be summarized as follows:

(1) The Lower Palaeozoic sediments in this part of the Tasman Geosyncline were folded, overthrust, intruded by granites and uplifted in the Upper Devonian.

(2) Basin subsidence, and probably initiation of rifting, began, according to Dunlop, either in the Upper Devonian under compressional stresses, or in the Upper Carboniferous with either tension or compression. Under Campbell's view rifting did not take place until epi-Permian times.

(3) Rapid subsidence of the trough in the Triassic was accompanied by the outpouring of a large amount of andesitic material, deposited mainly as "boulder beds." Normal lacustrine sedimentation also took place at this time.

(4) Continued downsinking led to the accumulation of a thick sequence of rapidly alternating conglomerates, sandstones and shales under conditions of high relief, heavy rainfall and poor drainage. Localized volcanic activity with the extrusion of trachytes occurred in the western area. Normal sedimentation over the whole area was interrupted once by a short period of intense explosive vulcanicity during which a widespread blanket of trachytic tuff, about 50 feet thick, was deposited.

(5) Numerous thin trachyte sills and dykes were then injected into the Taromeo Tonalite, along the Western Border Fault and into the lower part of the sequence.

(6) This was followed by the application of strong compressional forces which deformed the basement and were thus transmitted to the overlying sediments, resulting in the anticlinal uparching and overfolding of the Colinton Complex Anticline, with doming near Nurinda. This longitudinal arching was accompanied by the formation of a dominant transverse joint set and the onset of minor transverse faulting.

(7) Subsequent relief of pressure in an east-west direction was accompanied by the intrusion of the large sill-like masses of the Nurinda Microgabbro and the Brisbane Valley Porphyrites, the latter in the southern part where the folding was not so intense. The relief of pressure was also accompanied by renewed movement along the Western Border Fault System, with uptilting, shattering and brecciation of the sediments. This movement is thought to be mainly pre-Bundamba in age.

(8) Basalts were later extruded along the Western Border Fault, probably in Tertiary times.

The observations made above, and a consideration of some of the many published descriptions of rift valleys in other parts of the world, suggest that the Esk Rift Valley is probably unique in the degree to which the contained sediments have been deformed by later movements. Much remains to be done, however, before we will arrive at a full undrstanding of the regional significance of the trough, and of the extent to which its history will throw light on the origin of rift valleys in general.

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EXPLANATION TO PLATE I

Fig. 1—Boat Mountain, showing resequent fault line scarp marking western edge of Esk Rift Valley. Mesozoic sediments form low country in foreground; Palaeozoic metamorphics form hills.

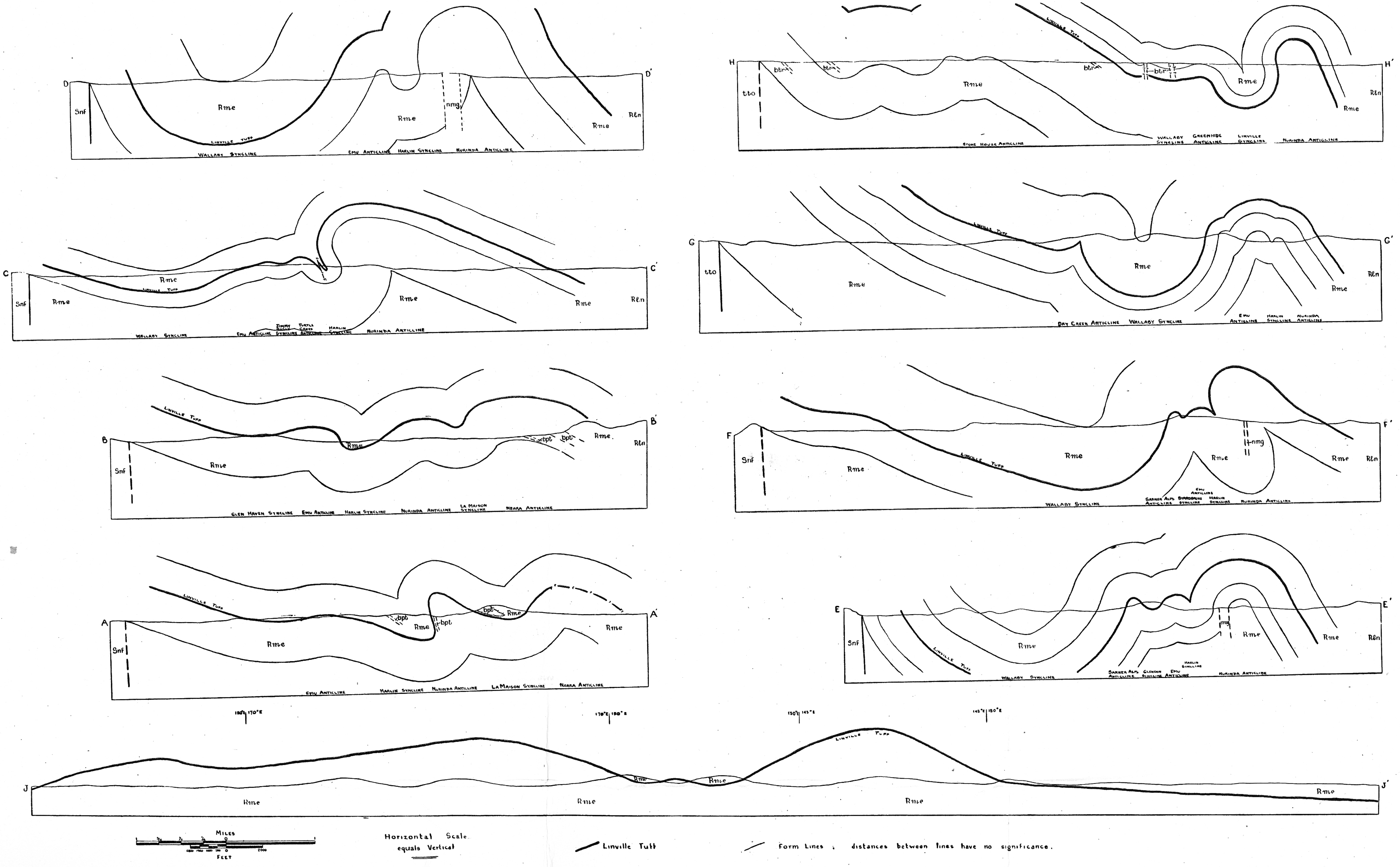
Fig. 2—Typical quartz pebble conglomerate of Esk Beds. Wallaby Creek*(360601).

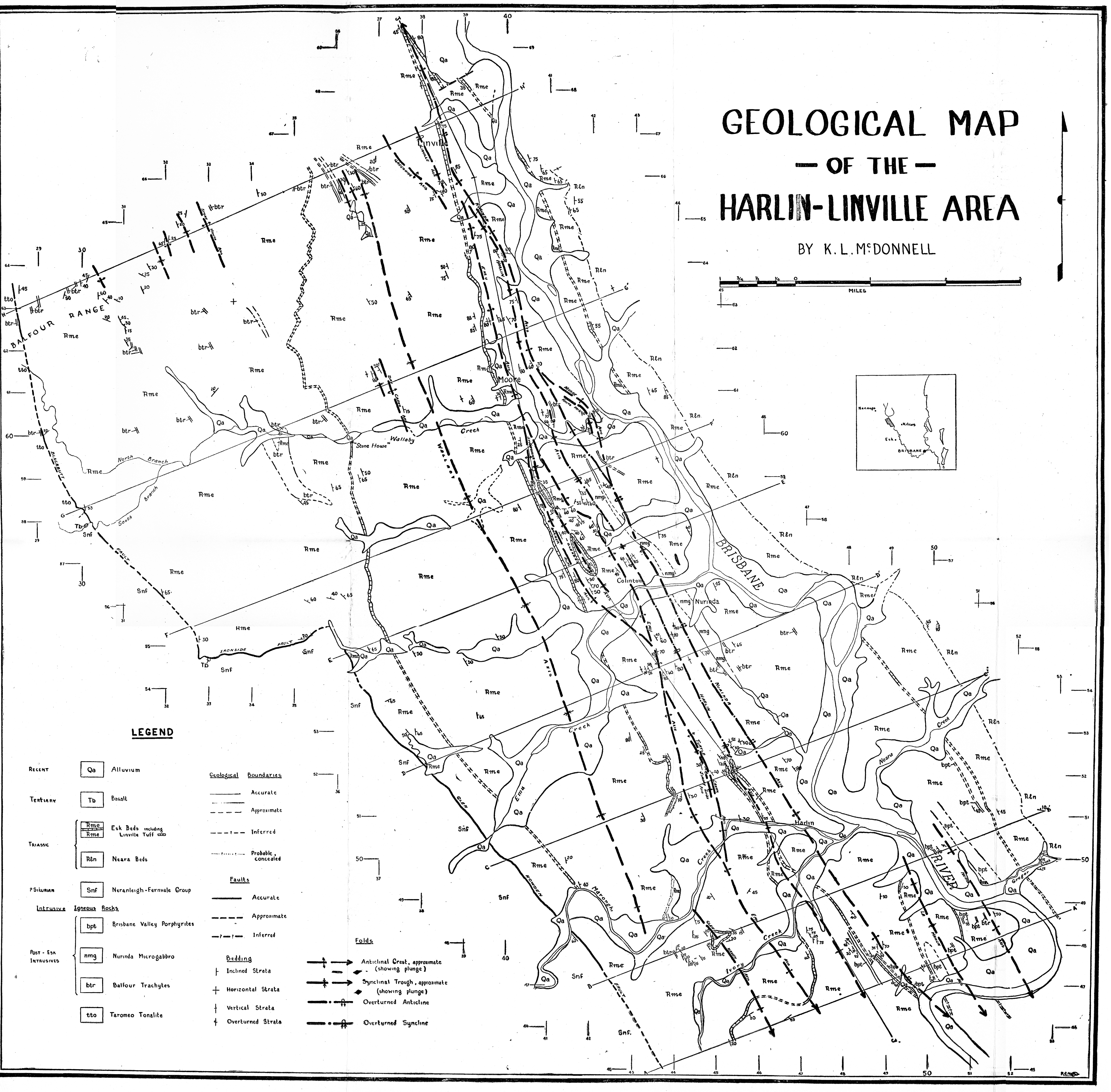
Fig. 3—Well jointed sandstone of Esk Beds in road cutting near the "Stone House".

Fig. 4—Block outcrop of Brisbane Valley Porphyrite on Neara Creek, looking north. Hammer is on shale dipping east under intrusion.

Fig. 5—Balfour Trachyte dyke in railway cutting at 493474. Intruded shales dip towards observer.

— CROSS SECTIONS : HARLIN-LINVILLE AREA —





GEOLOGICAL MAP
— OF THE —
HARLIN-LINVILLE AREA

BY K. L. McDONNELL