THE UNIVERSITY OF NEWCASTLE

DEPARTMENT OF GEOLOGY

EIGHTEENTH NEWCASTLE SYMPOSIUM

EXCURSION SYNOPSIS FOR

Monday, 30th April

EXCURSION Number. 1.

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COMPILED BY

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INTRODUCTION

Part 1

The aim of the excursion is to study the lower, middle and upper portions of the Newcastle Coal Measures in three outcrops at Shepherds Hill, Catherine Hill Bay and Swansea Heads. Emphasis will be on stratigraphic, lithologic and petrographic features of the exposed sections, as well as some palaeoenvironmental interpretation, particularly the stratigraphically upward change from alluvial plain to piedmont deposits and the influence of explosive volcanism on coal seam characteristics.

The discussion of the sections is preceded by a general discussion of the Newcastle Coalfield which relies heavily on material presented in "A Guide to the Sydney Basin", edited by Chris HERBERT, and Robin HELBY (Geological Survey of N.S.W. Bulletin 26, 1980). Other works referred to are T.W.E. DAVID"s "The Geology of the Hunter River Coal Measures, New South Wales" (Mem. Geol. Surv. N.S.W., 1907), Peter WARBROOKE's "Depositional Environments of the Upper Tomago and Lower Newcastle Coal Measures, New South Wales" (Ph.D. Thesis, Newcastle, N.S.W., 1981) and C.F.K. DIESSEL's paper to the 10th International Congress on Carboniferous Stratigraphy and Geology entitled "Tuffs and Tonsteins in the Coal Measures of New South Wales, Australia".

Part 2

The second part of the excursion which for technical reasons will be run first, is a visit to Aberdare North Colliery, operated by Coal & Allied Industries Limited. In the colliery the Greta Seam displays highly unusual sedimentary features related to mass movement (viscous flow), in the form of clastic intrusions into the coal and soft sediment deformation structures in its roof. These features will be examined and possible origins will be discussed.

The Newcastle Coal Measures

In the Lower Hunter Valley the upper portion of the Permian System is formed by some 1,200 m of predominantly terrestrial sediments which have been subdivided into two groups, the Newcastle and Tomago Coal Measures. This division has economic rather than geological reasons, the main consideration being that a very important marker bed in the form of 10-30 m thick Waratah Sandstone separates an upper highly productive sequence, the Newcastle Coal Measures, from a lower group of coal bearing sediments containing fewer economic coal seams (Tomago Coal Measures).

Distribution and Stratigraphy

The Newcastle Coal Measures outcrop in the coastal portion of the Hunter Valley. The largest continuous area of exposure occurs around the northern closure of the Lake Macquarie Syncline. As the axis of this structure plunges to the south, younger sediments of the Mesozoic Narrabeen Group tend to conceal the coal measures in this direction, while to the north of Newcastle up to 100 m thick alluvial and aeolian Holocene deposits do the same. To the east the outcrop is restricted by the sea whereas the western boundary is erosive against the Lochinvar Anticline which is one of several large structures that developed in the Hunter Valley towards the end of the Permian Period. West of the Lochinvar Anticline time equivalent coal measures of similar combined thickness occur throughout the Hunter Valley.

The age of the coal measures is Kazanian and possibly Tartarian for the upper portion. Apart from some worm burrows and insect remains, the Newcastle Coal Measures contain abundant representatives of the Gondwana Flora. No detailed systematic inventory has as yet been made but common genera are *Annularia*, *Phyllotheca*, *Glossopteris*, *Gangamopteris*, *Vertebraria*, *Cordaites*, *Noeggeratiopsis* and the fossil wood *Dadoxylon*.

Geotectonic Setting

The Hunter Valley which forms the north-eastern margin of the Sydney Basin was the depositional centre of Permian Sedimentation. It thus acted as a fore-deep (retroarc basin) to the New England Fold Belt from which it received a large proportion of clastic wedge deposits that occasionally overlapped onto the older and then largely peneplained Southern and Central Fold Belt to the south-west. Palaeocurrent directions derived from cross-bedding measurements in the Upper Permian coal measures of the Hunter Valley show, therefore, a strong centripetal tendency while in other parts of the Sydney Basin palaeocurrents have often a tangential or parallel arrangement with respect to the basin margin.

Throughout the Tomago Coal Measures marine, or at least brackish, influence is apparent and is exemplified by many intercalations of shale, siltstone and fine sandstone full of worm burrows and other forms of bioturbation.The frequently laminated nature of the sediments displaying worm burrows, their association with delicate flaser bedding and micro-crosslamination of bimodal azimuths indicate deposition on tidal mud flats. In contrast to this transitional environment the overlying Newcastle Coal

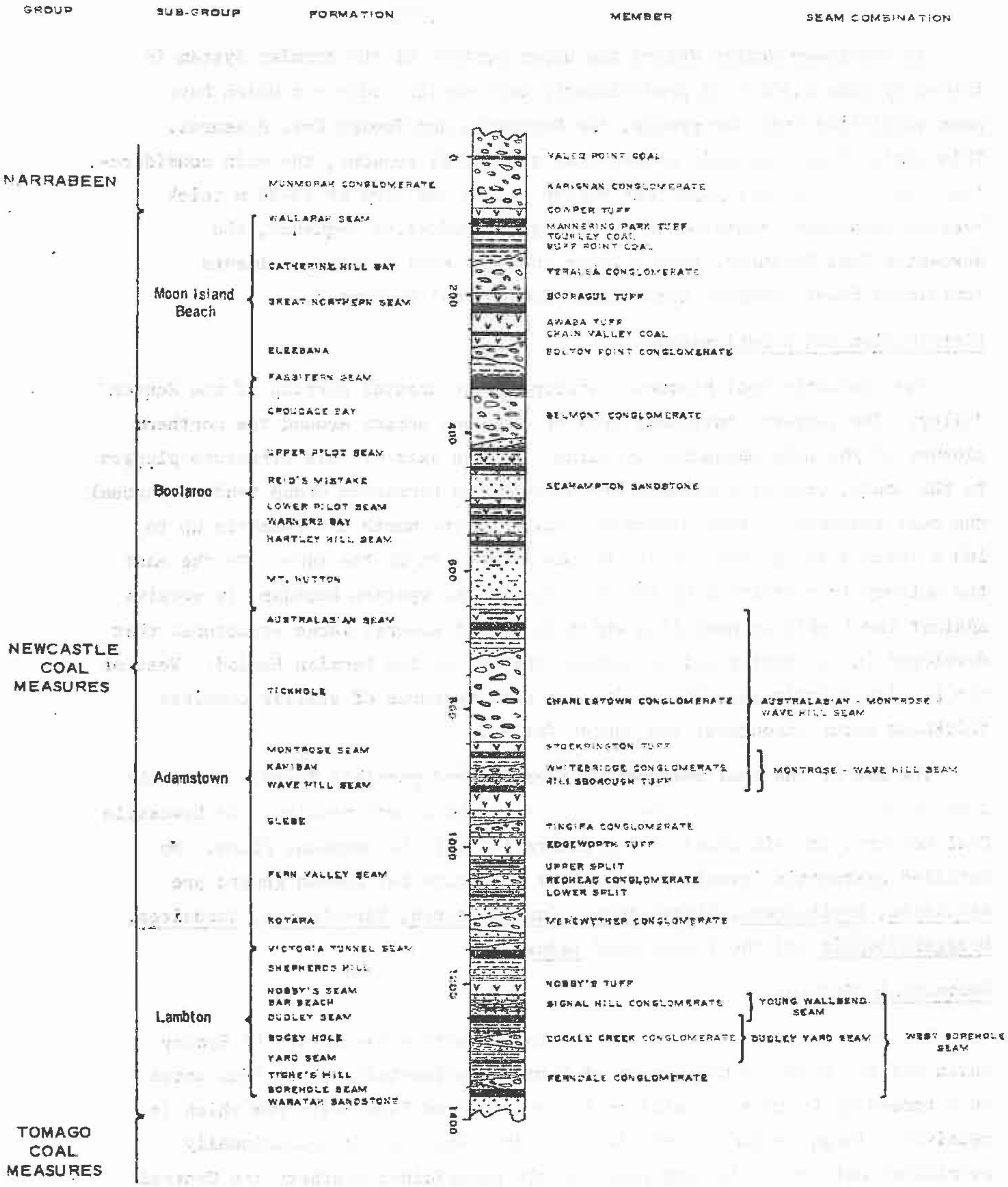

Figure 1 DIAGRAMMATIC VERTICAL SECTION AND STRATIGRAPHIC SUBDIVISION OF

NEWCASTLE COAL MEASURES

P. MCKENZIE
B.H.P. COAL GEOLOGY SECTION

Measures contain worm burrows in their lower portion only. They were formed in a more terrestrial setting characterized by high energy release. The result is a substantial increase in coarse sediments as shown in Table 1.

Table 1. Lithologic comparison between Newcastle and Tomago Coal Measures.

	Tomago C.M.	Newcastle C.M.
conglomerate	1%	29%
sandstone	59%	23%
shale	34%	17%
tuff and claystone	insignificant	19%
coal	6%	12%
	(15 seams)	(21 seams)

The high proportion of conglomerate and a substantial influx into the Newcastle Coal Measures of pyroclastic material seem to indicate an accelerating tectonic activity in the adjacent orogen to the north and north-east. The conglomerates are distinctly fan-shaped and show large scale heterogeneous cross-bedding. Down palaeoslope, mainly to the south-west, they grade into finer grained clastics of smaller thickness. Because of their geological setting close to the northern basin margin and their external and internal geometry these rudites are regarded as the south-western extensions of piedmont deposits (alluvial cones) which intermittently were pushed down from the northern and possibly eastern uplands over the valley flats of the Newcastle Coal Basin. This means that much of the clastic detritus initially dumped above base-level on piedmont and alluvial plains was later redeposited so that diastems and erosion contacts between rock units are common. Depositional cycles which have received so much attention in other coal fields in the world are therefore poorly developed.

Sedimentary Facies

In both Newcastle and Tomago Coal Measures the conglomerates and sandstones represent fluvial deposits. Usually they have basal erosion contacts, and washouts are common. Cross-bedding is prolific and of varied character. The large scale types alpha, beta, gamma, all related to migrating sand waves, are frequent (terms after Allen) and supplemented by common types such as epsilon (often on point bars), xi (probably wind drift), theta (scour and fill) and others.

Laterally the sandstones grade either into siltstone and clay-shale or they are replaced by laminated arenite/lutite transitions. Small scale cross-lamination related to asymmetric ripples (kappa-, lambda- and mu-types after Allen) are common and it seems that such sediments have been deposited on flooded alluvial plains, e.g. back-swamps, outside established stream channels.

Lacustrine deposits are represented in the form of "wants", i.e. irregularly shaped areas within coal seams in which the coal has graded into mudstone, carbonaceous shale, or chert and clay ironstone. Varvoid laminites of siltstone and claystone (laminated shale) are likewise assumed to be of lacustrine origin. Invariably they contain many horizons with abundant plant remains and symmetrical ripple marks.

Paludal facies is indicated by carbonaceous shale and coal. The rank of the latter does not vary much with stratigraphic position and near the surface ranges in both Newcastle and Tomago Coal Measures from 0.8 to 0.9% mean max. vitrinite reflectance. Macroscopically the seams appear thinly bedded with bright lithotypes predominating in the lower portion of the Newcastle Coal Measures. This is backed up by their microscopic composition. High vitrite and clarite contents occur up to the level of the Australasian Seam whereas dull coals with high durite and inertite dominate in the upper part of the Newcastle Coal Measures. It is interesting to note that this trend is parallelled by an increasing proportion and coarseness of conglomerates in the interseam sediments. (Figure 1)

The rather simple separation into predominantly bright and dull coals, respectively, has a strong bearing on their utilisation. The durite-rich coals of the upper part of the Newcastle Coal Measures, mainly the Great Northern and Wallarah Seams are extensively used as fuel in three large pit-top power stations near Newcastle. While some of the brighter coals are exported, the bulk of the output coming from the coal seams in the lower portion of the Newcastle Coal Measures is used in local steel works for the production of metallurgical coke. Commonly the coke oven charge is a blend of washed coal from the Borehole, Dudley, Young Wallsend and Victoria Tunnel Seams.

Most raw coals are high in ash with values up to 25% for some seams. A large portion of this ash is contained in numerous thin claystone bands. The claystones vary in composition, some are pure kaolin-tonsteins while in others illite and montmorillonite predominate. Carbonates are frequent on cleat and joint planes except for siderite which is a common constituent of clay-ironstone concretions, particularly in the Victoria Tunnel Seam. Pyrite nodules occur mainly in the Borehole Seam. Among other components of coal ash, chlorite, biotite, muscovite, feldspar, apatite, garnet and pyrophyllite have been recorded.

Pyroclastic Facies

The Newcastle Coal Measures contain a large number of tuffaceous intercalations which range in particle size from coarse crystal-vitric tuff with occasional lapilli to dense ashstones, the latter often appearing now as bentonitic claystone. Quartz, biotite, plagioclase, orthoclase, volcanic rock fragments and unwelded glass shards occur in varying proportions in the tuff layers which often display normal grading from coarse crystal tuff at the bottom through vitric tuff to fine ashstone within a thickness of only a few centimetres. The various particle assemblages responsible for the grading are listed in Table 1 which is a general guide only and not completely represented in each stratum of a pyroclastic sequence. Indeed, many tuff beds begin with layer 2 or 3 in Table 1 or miss out on layer 5. Some tuff beds consist of one layer only and others display multiple and reverse grading.

On the basis of their composition a rhyolitic to rhyodacitic source is suggested for most tuffs of the Newcastle Coal Measures but post-depositional alterations have often obliterated their genetic association. The fine grained tuffs are generally more altered than the coarse ones which results from a combination of both the general instability of small particles and the high concentration of volcanic glass in them.

According to Ziolkowski (1978) many of the devitrified fine grained tuffs display a microcrystalline intergrowth of authigenic chalcedony and analcime in irregular, almost cloudy concentrations, or they occur as metasomatic replacements of glass shards. Angular quartz grains show marginal resorption and precipitation of chalcedony around the rims. Biotite which occurs in very high concentrations in some tuffs, usually shows some alteration to montmorillonite/illite random mixed layers (Loughnan, 1966).

The coarse grained tuffs may also be rich in secondary chalcedony and analcime. Quartz is often the dominant pyroclast, sometimes displaying a weak undulatory extinction. Plagioclase is usually fresh in specimens obtained from borecores or underground samples but shows sericitization in outcrop samples. As in the above example, biotite is at least partly altered to clay whereby maghemite concentrates around the margins of the pseudomorphs. Glass shards are surrounded by montmorillonite which also rims the inner walls of unbroken degassing vesicles. It is radiofibroblastic and passes into chalcedony towards the centre of the vesicles. Following Ziolkowski (1978) this relationship suggests that montmorillonite is the earliest authigenic phase resulting from the hydrolysis of fine grained volcanic glass as rain water filters through the tuff layer after it has settled on the ground. The same process leaches alkalis, silica and iron from the glass which increase the pH of the descending fluids. Zeolites form as an intermediate metastable phase which break down as the sodium concentration increases and, together with montmorillonite, transforms into analcime and silica (opal and chalcedony) near the bottom of the pyroclastic pile (Hay and Sheppard, 1977, and Hay, 1977).

A common characteristic of all pyroclastic deposits in the Newcastle Coal Measures is their considerable lateral persistence although considerable thickness variations occur between inter- and intraseam tuffs. Usually, the latter consist of one individual stratum in each case which retains its thickness over a large area. Interseam tuffs commonly consist of stacks of strata which differ from each other in grain size (coarse pyroclasts to fine ash), colour (white, pink, green, cream), fabric (massive, crossbedded), different grades of secondary silicification and other forms of authigenesis resulting in contrasting weathering patterns. These piles of pyroclastic lithosomes, whilst also covering many hundreds and in some cases probably over one thousand square kilometres, vary considerably in their composite thickness.

Tectonic Structures

Outcrop pattern, thickness variation and spacial attitudes of both coal measures are dominated by two shallow but wide fold structures, the south plunging Lake Macquarie Syncline in the centre of the Newcastle Coalfield, and the Lochinvar Anticline against which the coal measures are terminated to the west. This boundary is not merely due to erosion but there has been likewise a substantial reduction in sediment thickness due to at least one local angular unconformity in the Tomago Coal Measures whilst the Newcastle Coal Measures show considerable wedging towards the anticlinal flank. This and other evidence indicate that the Lochinvar Anticline is an old barrier which as early as in late Permian time separated the Newcastle Coalfield from the remainder of the Hunter Valley. In an easterly direction the Newcastle Coal Measures continue to thicken past the synclinal axis and up to the eastern limb right to the coast. This is taken as evidence not only for the slightly younger age of the Lake Macquarie Syncline compared with the Lochinvar Anticline, but it seems also to be proof of a substantial off-shore extension of the original coalfield.

Apart from the two major structures mentioned there are some minor folds, such as the Delta Syncline at the mouth of the Hunter River and the Shepherd's Hill Anticline further south. Both are situated on the eastern flank of the Lake Macquarie Syncline and act as cross-folds.

One of the most striking features in many parts of Eastern Australia is the magnitude of joint planes trending about N 40°W and N 20°E, respectively. In the Newcastle area these are not the only joint directions present but they are important ones. Particularly the NW-direction is followed by several faults usually of small displacement as well as by a large number of dolerite dykes. Whenever the latter have penetrated coal seams they have caused the coal to be converted into natural coke near the contacts.

TABLE 1. COMMON TYPES OF NORMAL GRADING DUE TO DETRITAL PARTICLE SEGREGATION IN THE TUFFS OF THE NEWCASTLE COAL MEASURES.

5. FINE ASH

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4A. FINE ASH PLUS GLASS SHARDS — 4B. FINE ASH PLUS BIOTITE — 4C. FINE ASH PLUS ACCRETIONARY LAPILLI

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3. GLASS SHARDS, BIOTITE, PLUS FINE ASH

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2. GLASS SHARDS, BIOTITE, QUARTZ, PLUS FELDSPAR

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1. QUARTZ, FELDSPAR, BIOTITE, PLUS ROCK FRAGMENTS

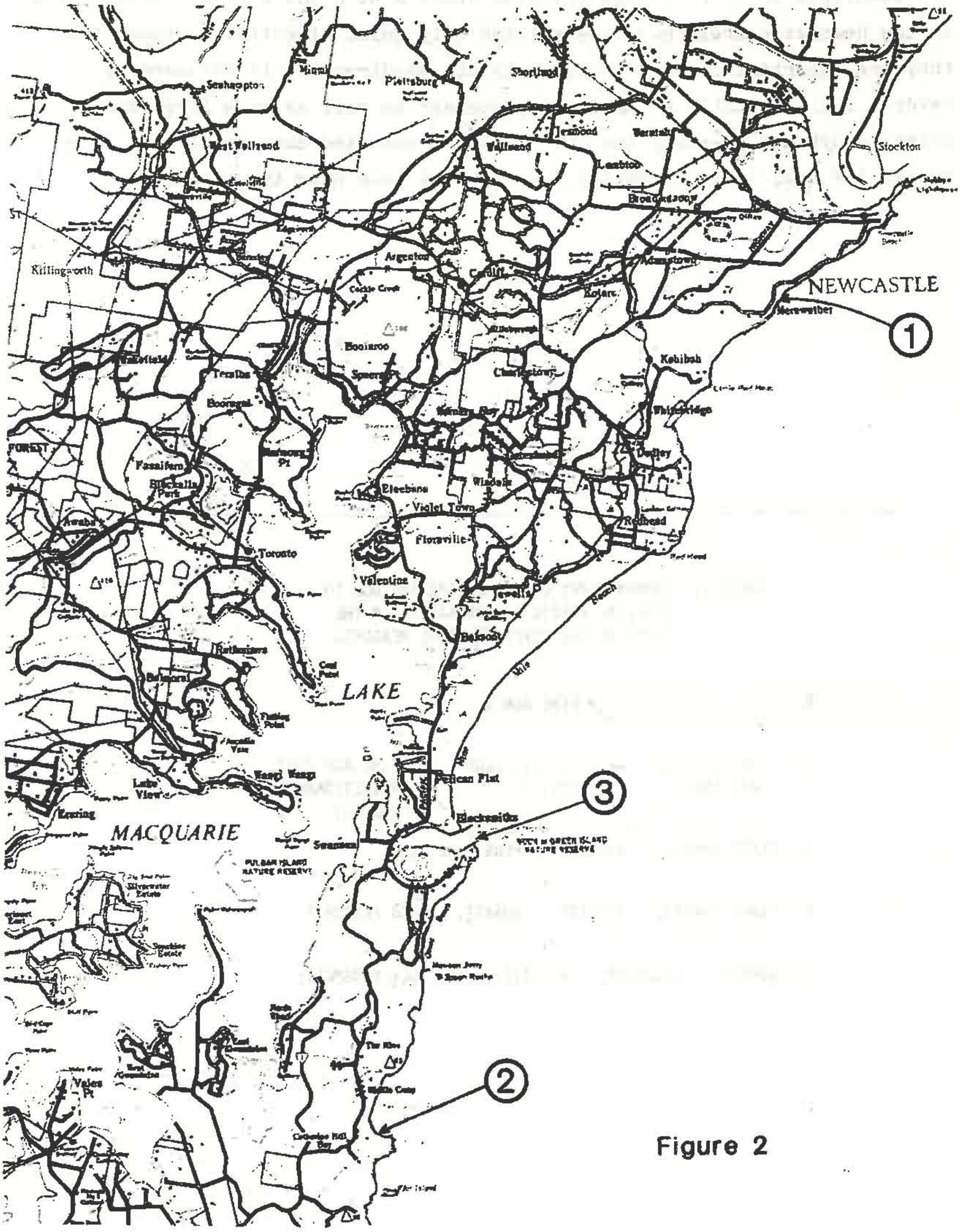


Figure 2

Locality map indicating the three scheduled stops.

1 Bar Beach

2 Catherine Hill Bay

3 Swansea Head

Stop 1 (Figure 2)

SHEPHERDS HILL, BAR BEACH AND SUSAN GILMORE BEACH

The coastline is characterised by a physiographic high dominated by Shepherds Hill which is the topographic expression of an anticline (Shepherds Hill Anticline) on the north-eastern limb of the Lake Macquarie Syncline. On the seaward side steep cliffs provide excellent outcrops of the lower portion of the Newcastle Coal Measures ranging from below the Yard Seam to the top of the Merewether Conglomerate. The sequence contains some prominent sandstones of fluvial origin alternating with laminated shales and siltstones of floodplain origin and coal seams. Each sandstone unit begins with coarse arenites above a sharp erosion contact followed by cross bedded medium arenite. In the upper portions the sandstones become flat-bedded and laminated. Striking examples of climbing ripples can be observed near the top of the sandstone overlying the Yard Seam at the northern end of Bar Beach. Structure and geometry of the sandstone bodies suggest that they have been formed in meandering rivers by lateral migration of channels and accretion on point bars which combined to form continuous sand sheets.

Between Bar Beach and Susan Gilmore Beach a large sandstone filled washout occurs in the sandstone overlying the Yard Seam at beach level. The thickness of the channel fall equals that of the host sandstone but both base and top of the former are situated slightly above the equivalent limits of the latter. Nevertheless, it is suggested that the washout was formed by the same river channel which produced the partially underlying sandstone sheet. This could have happened during a flood when the channel was temporarily deflected across its former point bar system which, at that stage, was already covered by approximately one metre of overbank silts and clays.

All three point-bar sandstone banks exposed in the cliff section at Shepherds Hill are overlain by several metres of overbank deposits which consist of alternating and frequently laminated siltstones, shales and claystones. In their lower portions fine and medium grained sandstone layers and prisms are common. They represent crevasse splay deposits resulting from breaches of levee banks during floods at a time when the main channel was still close-by. Higher up in the sequence the sediments become finer because the channel has meandered away such that only the finest outwash can reach this part of the flood plain. When that happens the continuing high rate of subsidence is not any more balanced by a commensurate rate of sediment supply which results in the formation of swamps and peat deposits. The Yard, Dudley, Nobby's and Victoria Tunnel Seams, all bear testimony of this development in the Shepherds Hill area. In the case of the Yard and Dudley seams peat accretion continued as long as the plants could cope with the rate of subsidence. Eventually, insufficient supply of vegetable matter caused flooding of the peat resulting in the deposition of lacustrine clays and muds on top of the seams. In an upward direction the lutites give way to laminites with an increasing sand content. They herald the re-approachment of a river channel whose basal erosion contact usually is encountered not far above the Yard and Dudley Seam, respectively.

The Nobby's Seam follows a different pattern as far as its roof sediments are concerned. They consist of several metres of tuff which choked the swamp vegetation and caused termination of peat accretion, probably by a series of intermittent volcanic ash falls (Nobby's Tuff).

The uppermost coal seam exposed at Shepherds Hill is the Victoria Tunnel Seam. It is capped by the widespread Merewether Conglomerate which represents one of the many alluvial fan deposits that dominate the middle and upper section of the Newcastle Coal Measures.

Victoria Tunnel Seam is of great economic importance in the northeastern portion of the coalfield but it thins to the south and west. Where mined the coal is up to 4m thick but the actual working section is commonly in the order of 2m or a little less. The seam is divided into high and low ash sub-sections by a number of claystone bands some of which are rich in siderite and quite montmorillonitic while others contain more kaolinite, usually in pellet form. The highest unit visible in the outcrop is the Merewether Conglomerate overlying the Victoria Tunnel Seam. It is a pebble conglomerate that has its maximum development in the northeast corner of the coalfields. To the southwest it thins and grades into sandstone.

The relationship between the Victoria Tunnel Seam and the Merewether Conglomerate is well exposed at the Memorial Drive near the top of Shepherds Hill where the conglomerate forms the seam roof with only an insignificant thickness of tuffaceous siltstone occurring between the coal and the basal erosion contact of the conglomerate. At this locality tectonic tilting of the strata is practically zero because of their position in the centre of the Shepherds Hill Anticline. This suggests that the 10° southerly dip of the strata indicates the slope angle of successive accretion surfaces at the front of a prograding alluvial fan.

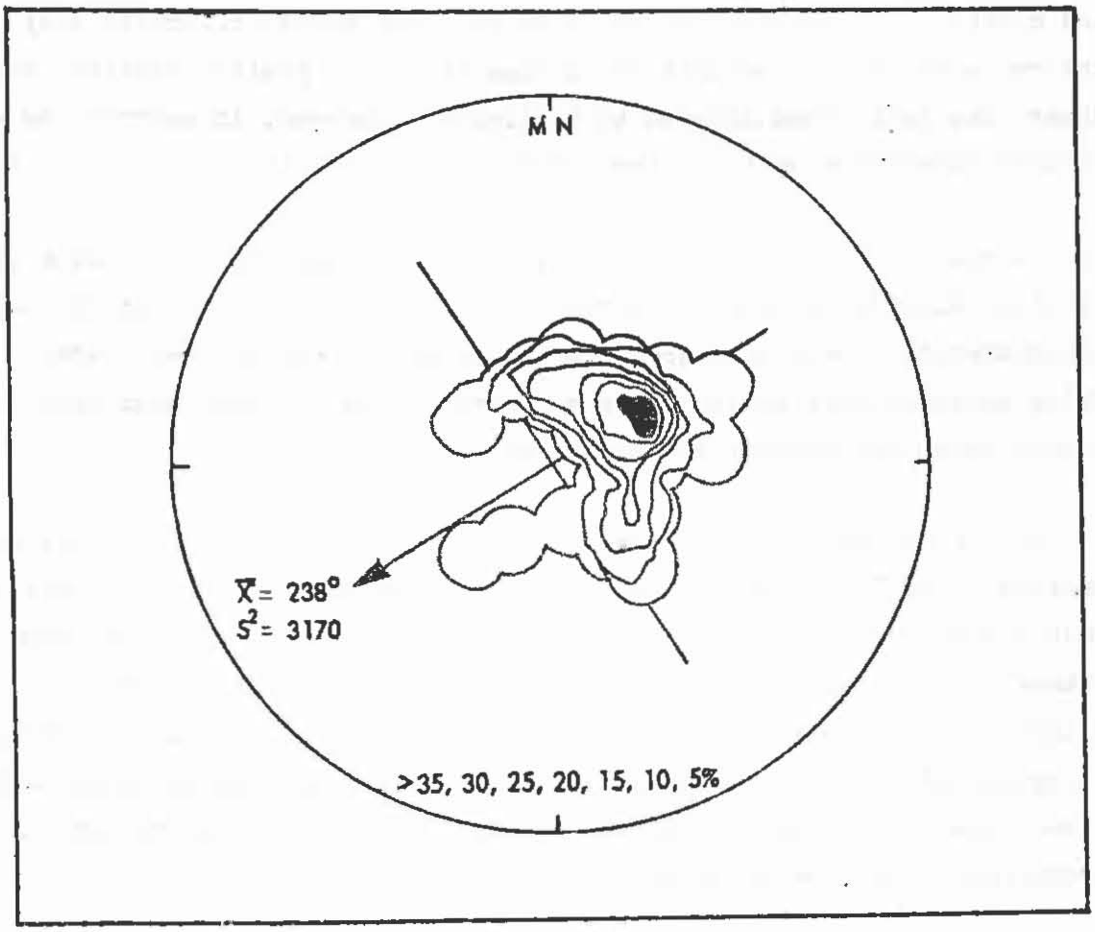
STOP 2: CATHERINE HILL BAY

After a short walk along the beach to the south, underneath the coal loader, the Great Northern Coal can be inspected in outcrop. This coal seam is separated from the overlying Wallarah Coal by up to 50m of the Teralba Conglomerate Member which is the main member of the Catherine Hill Bay Formation in the upper part of the Moon Island Beach Sub-Group. A large portion of the conglomerate can be seen above the Great Northern Coal. The coal seam occurs almost at beach level, and the exposure shows quite well the predominantly dull nature of the coal. Unlike many other coal seams in the Newcastle Coal Measures, the Great Northern Coal is not subject to slitting. It contains a number of thin claystone bands that are persistent over a large area. The maximum thickness of the seam is a little over 7m.

Over much of the eastern and central portion of the Lake Macquarie Syncline a wedge of tuffaceous sediment occurs in the roof of the Great Northern Coal. This rock is commonly responsible for bad roof conditions during mining. It consists of up to 90 per cent montmorillonitic clay intermixed with varying amounts of subangular quartz grains, biotite, and feldspar, the last often altered to kaolinite. However, in outcrop, as well as in many subsurface parts of the coalfield, the Teralba Conglomerate Member is in direct contact with the seam. Some northeast-southwest oriented shallow washouts (roof rolls) are developed in the uppermost coal with pebble imbrication dipping towards the northeast. Driftwood horizons at the base of the conglomerate show a similar orientation, with roots of tree trunks pointing northeasterly whilst stems projecting from the coal seam into the roof have been bent towards the southwest.

The Teralba Conglomerate Member is very widespread. It consists mainly of rounded to well-rounded pebbles set in a sandy matrix. Clastic particles include a wide range of rock types such as chert, jasper, rhyolite, andesite, and other acid and intermediate volcanics, silicified shale, hornfels, sandstone, rare granodiorite, some vein quartz, as well as clay ironstone. The conglomerate is quite massive; however, graded bedding is occasionally observed, and so are small sandstone lenses. Pebble imbrication indicates a palaeocurrent flow from NE to SW.

The Eleebana Formation occurs below the Great Northern Coal. The Awaba Tuff Member and the Bolton Point Conglomerate Member are usually the most conspicuous members. At Catherine Hill Bay the Bolton Point Conglomerate Member is very well exposed on the wave-cut platform on the headland to the south of the beach. This conglomerate is of the same polymictic composition as the Teralba Conglomerate Member above, although usually more lenticular, less extensive, and of wider particle size range (maximum diameter 0.2m). Many pebbles are strongly imbricated. Point bar type crossbedding (epsilon after Allen 1963) with foreset beds varying greatly in particle size is very common. Other cross-beds are trough and scoop shaped, and are probably related to the many washouts that can be observed in the cliff faces of the headland south of Catherine Hill Bay. The vector mean of dip azimuths of fifty foreset beds measured in the Bolton Point Conglomerate Member at Catherine Hill Bay indicates a palaeocurrent direction from the northeast (Figure 2a). This is in agreement with crossbedding and particle imbrication measurements taken elsewhere in the Newcastle Coal Measures east of the Lake Macquarie Syncline. These measurements indicate that in addition to the New England Fold Belt source to the north there was, at that time, an easterly sediment source.



Polar stereogram of fifty foreset beds in the Bolton Point Conglomerate Member at Catherine Hill Bay.

Figure 2a

Another geological feature of interest at Catherine Hill Bay is the occurrence of dolerite dykes on the wave-cut platform. Unlike the northwesterly trend of most other dykes in the Newcastle Coal Measures, they strike about N30°E and form a dyke swarm with individual intrusions ranging in width from several centimetres to about 1.5m. Cooling joints normal and parallel to the dyke walls are very pronounced, and good examples of differential weathering can be observed along the chilled margins.

STOP 3: SWANSEA HEADS

At Swansea Heads parts of the Boolaroo Sub-Group are exposed, particularly the Lower and Upper Pilot Seams with the intervening Reids Mistake Formation. Both Pilot Seams occur as a series of thin coal and coaly shale bands which cannot be individually defined. The beds dip here at 8^{o} to the west, and one of the most interesting features of the area is the occurrence of remnants of numerous tree trunks, many of them in growth position on top of the Lower Pilot Seam. The seam is overlain by the Reids Mistake formation. This is a pyroclastic sequence which forms prominent outcrops along the coastline south of Newcastle. Within its thickness of 7m it is possible to distinguish four major units (Figure 3).

Unit 1: The Lower Pilot Seam at the base of the Reids Mistake Formation is overlain by parallel bedded vitric to crystal tuffs which consist of 2 to 20 cm thick strata. They are crosslaminated and show surface undulations, such as ripple marks and minor cut-and-fill structures indicating some lateral movement from the northeast.

Unit 2: The second unit above the Lower Pilot Seam (Figure 4) displays extensive dune and antidune development which has been accentuated in many places by the ramping-up of subsequent deposits against earlier bedforms. On the wave cut platforms along the coast this unit shows a distinct hummock-like surface pattern. Pinch-and-swell structures and cross-bedding are common.

Unit 3: A 0.5 to 1.5m thick massive and coarse crystal to vitric tuff (Figure 5) which seems to correlate with the Seahampton Sandstone further west. It has irregular upper and lower bounding surfaces and the coarsest portion including pebbles of aphanitic volcanic material occurs near the top of this unit (Figure 4).

Unit 4: Similar to Unit 2 with wavy to contorted bedding, hummock-like surfaces, dunes, antidunes, ripples, climbing megaripples, cross-bedding and pinch-and-swell structures. Thin beds which internally show pronounced grain size separation are draped over bed forms (Figure 4).

The contorted Units 2 and 4 display lateral changes in the intensity of dune development. In some areas the standing waves forming the basal portion of the antiform structures have a ripple height of 30-40cm and a wave length of 2-3m. Their morphology has often been propagated into overlying tuff sheets under which the dunes were buried, such that the composite ripple height

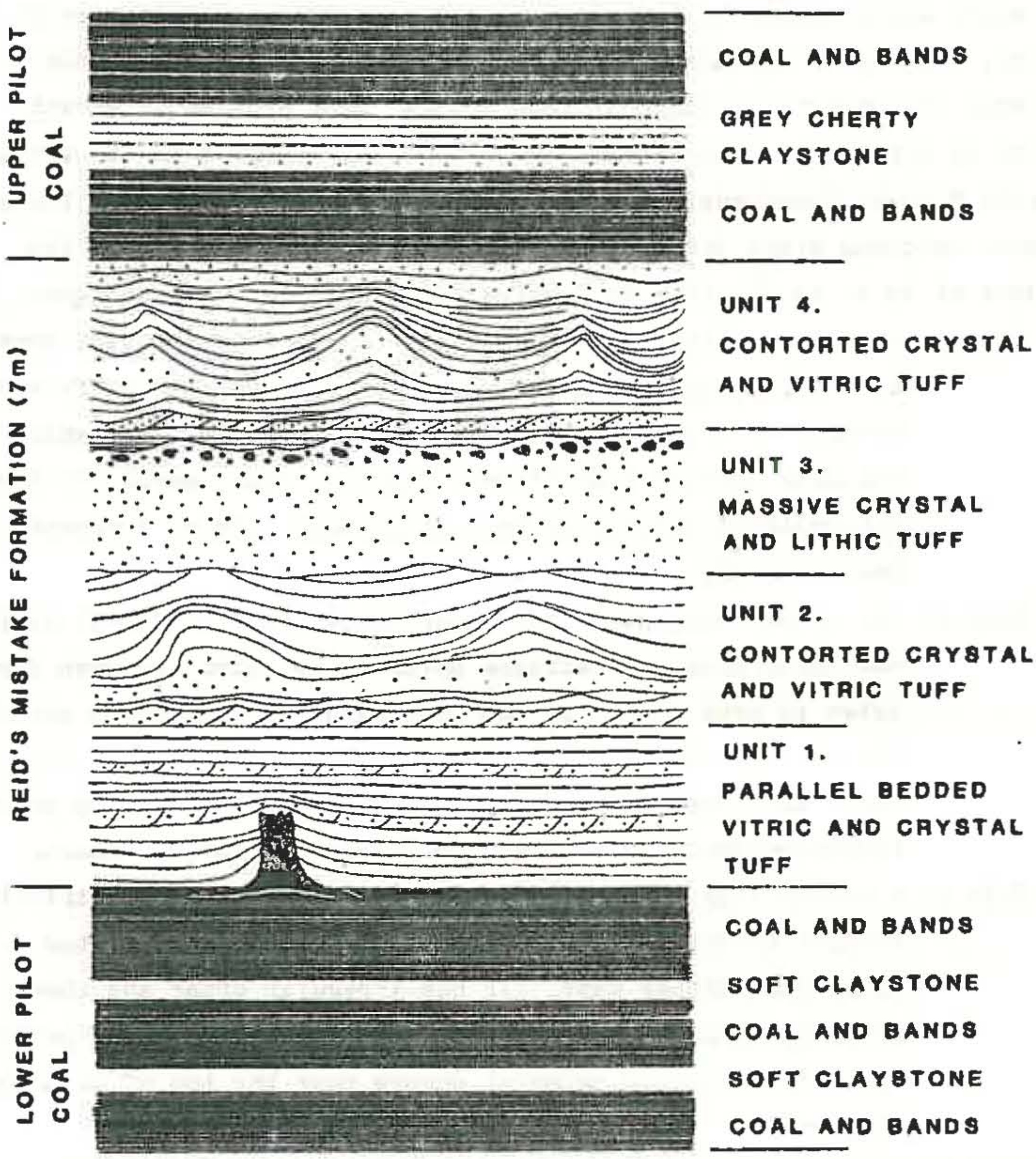


Figure.3. Generalized sketch of the Reids Mistake Formation south of Newcastle showing its major subdivisions. After DIESSEL (1984).

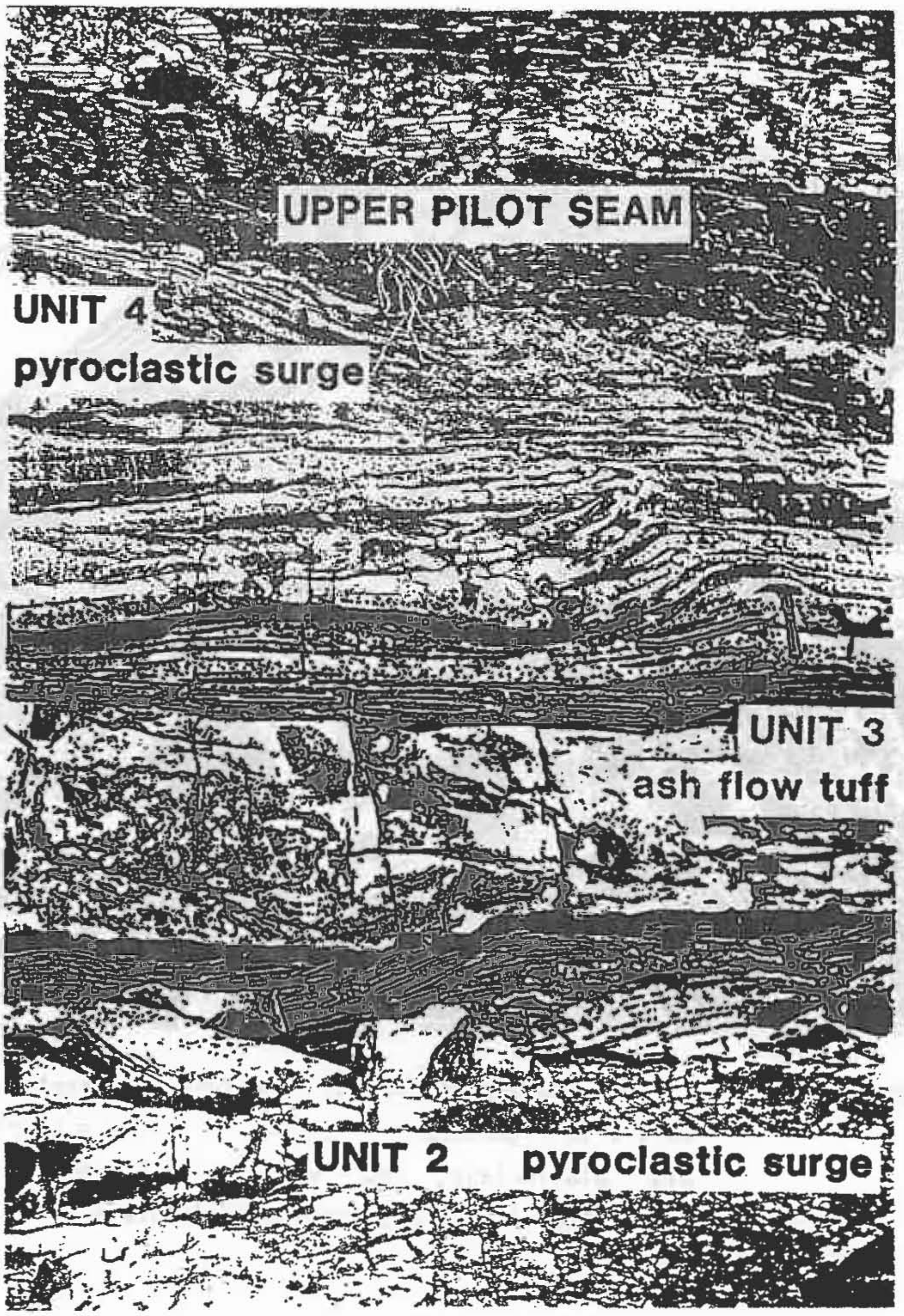


Figure.4. Illustration of the pyroclastic sequence in the Reids Mistake Formation south of Swansea Heads near Newcastle, N.S.W. A scale is given by the hammer above Unit 3 at the climbing megaripple.

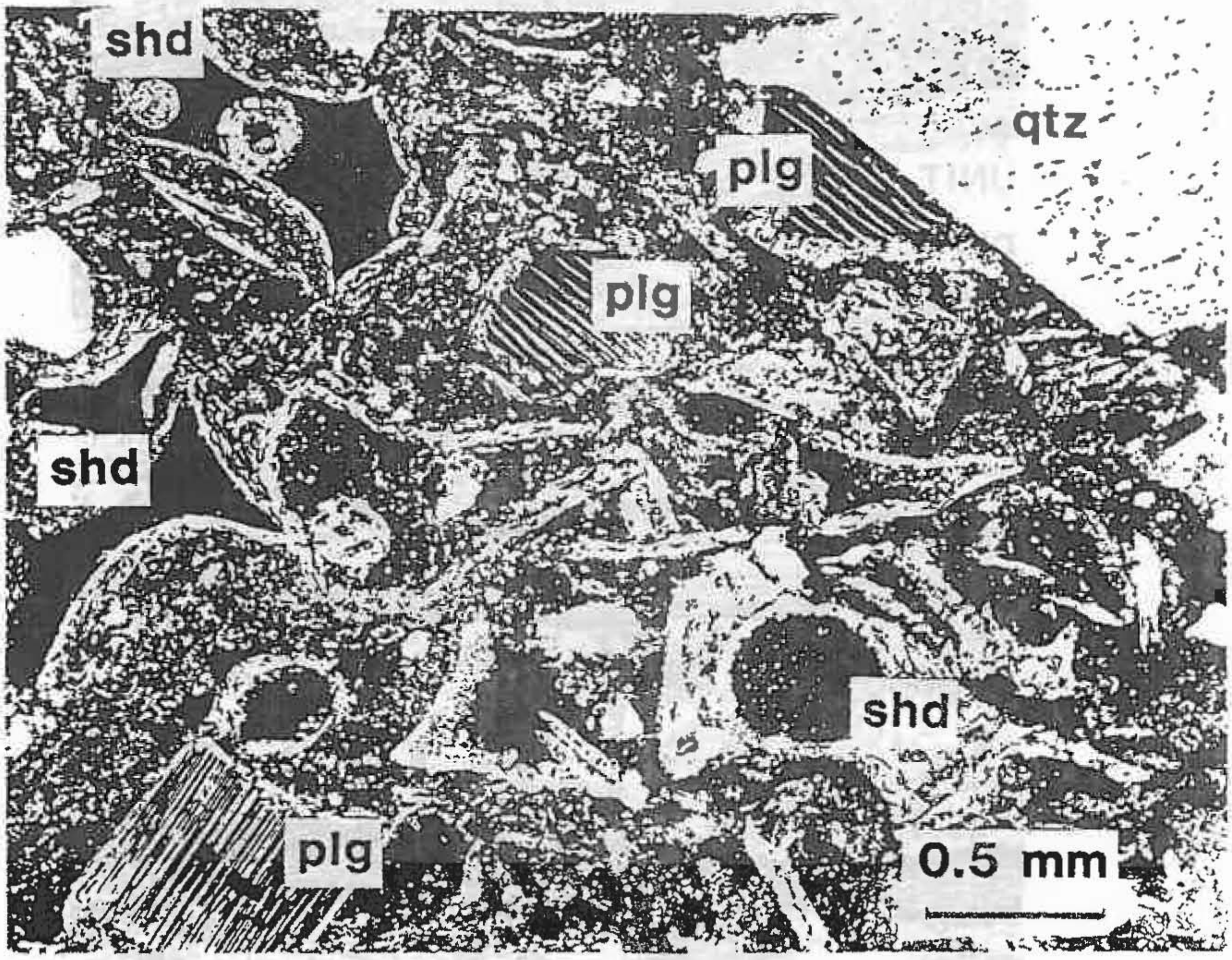


Figure.5. Photomicrograph of the ash flow tuff represented by Unit 3 in Figures 3 and 4. Qtz = quartz, plg - plagioclase, shd - volcanic glass shards. Transmitted light, half crossed polarizers.

appears larger than it really is. Laterally, dune sizes can decrease and disappear altogether such that parallel bedding prevails. Likewise, the basal Unit 1 can undergo lateral changes by becoming more wavy.

All pyroclastic units overlying coal seams contain a variety of coal inclusions of which the most conspicuous ones are tree trunks in growth position. At Swansea Head the trees are rooted in the Lower Pilot Coal and most of them penetrate only for 1/2 to 1m into the overlying vitric tuff. At that level many of the trunks snapped off and became embedded in the volcanic ash. The mean thickness of the trunks above the root system is 27.3cm ($S=13.4$, $n=36$) and mean spacing is 2.90m ($S=1.40$, $n=30$). Most of the downed trees point into a southwesterly direction (mean azimuth=260°, $n=65$) and some are still attached to the stumps on the ground. Figure 6 is a sketch map of part of the distribution of both stumps and downed trunks at Swansea Head. Also included is a rose diagram of the measured azimuths supplemented by directions given by David (1907).

The wood of the fossil trees is commonly both coalified and petrified, the latter mainly by silica and iron carbonate. In the interior of the stems the coal consists of vitrinite and has a maximum reflectance of 0.75% ($S=0.019$, $n=50$) which is normal for this stratigraphic level. However, close to the surface the wood is often charred and the bark is partly torn off the trunk.

Apart from the trees which broke off a short distance above their base some stems extend for several metres into the overlying tuff. Many of these trees are markedly tilted to the southwest (Figure 6 and 7). At Swansea Heads the mean plunge angle of 11 stems is 52° in a direction of 30° whilst 4km further south mean plunge of 18 trees is 68° at an azimuth of 54°. In addition to the tilt several trees show signs of abrasion on their north-eastern sides in the form of flattening and missing portions of annual growth rings.

Other coal inclusions consist of fragments of fusinite and semi-fusinite, fusinitised fragments of peat, resinite and pitch-like or tarry distillation products resulting from the pyrolysis of wood enclosed in hot ash.

The Origin of the Reids Mistake Formation

The various modes of emplacement of pyroclastic deposits are schematically illustrated in Figure 8. In accordance with current under-

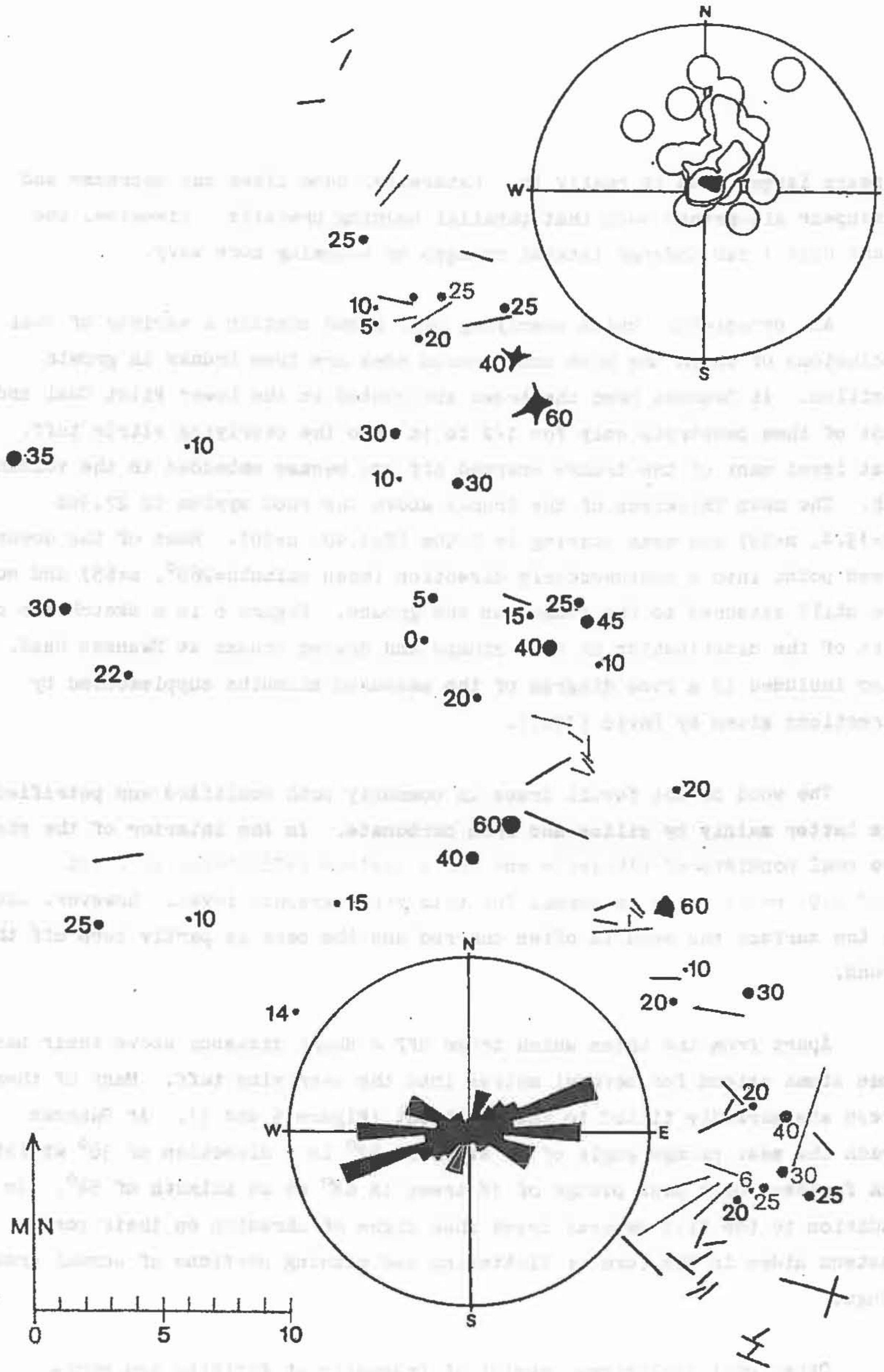


Figure.6. Sketch map showing the distribution of tree stumps and fallen trunks above the Lower Pilot Seam at Swansea Heads. The rose diagram and grand mean have been supplemented by measurements reported by DAVID (1907). The stereogram indicates the tilt of tree stumps, the digits next to them gives their diameters in centimetres.

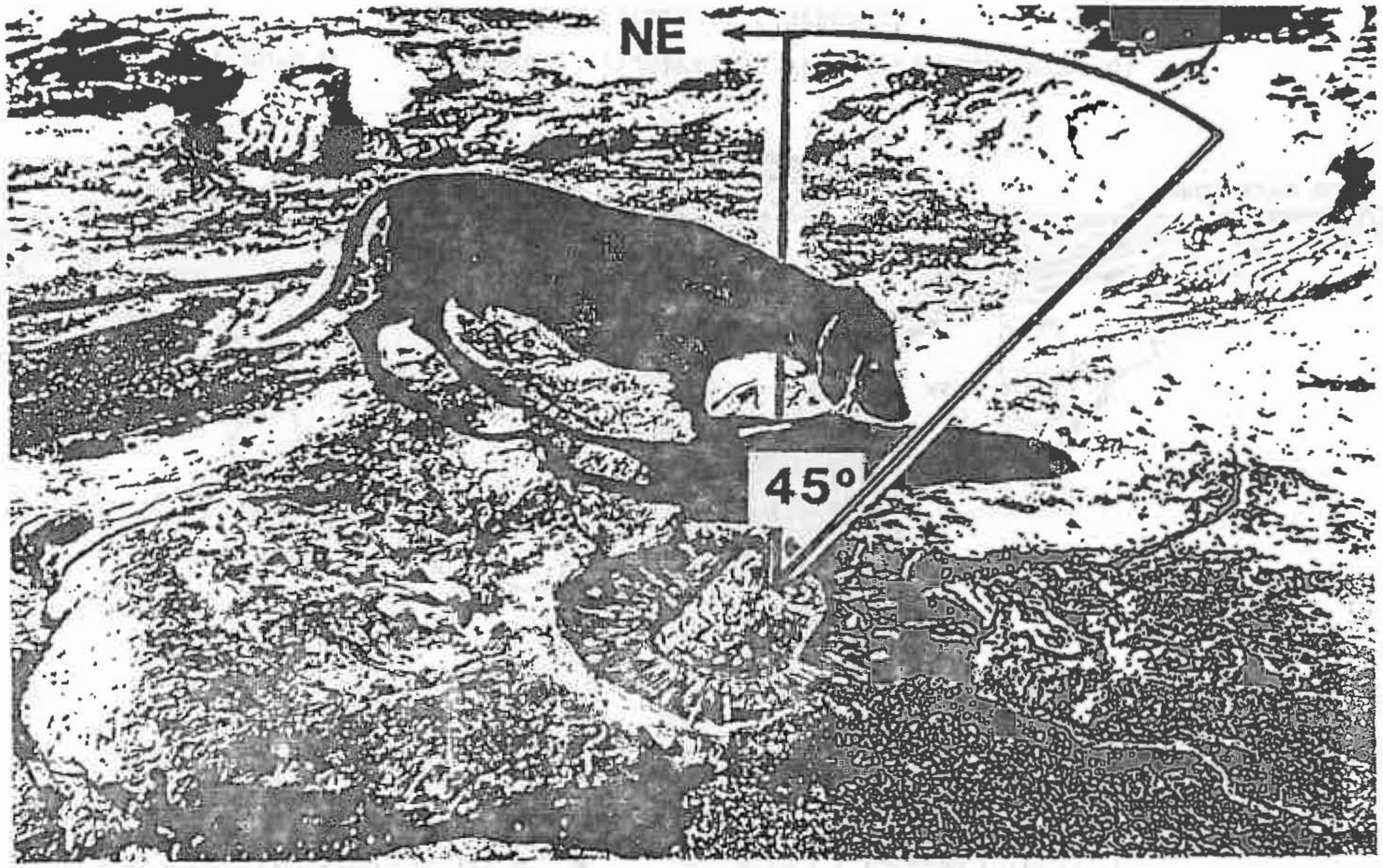


Figure.7. Tilted tree stumps embedded in pyroclastic surge deposit above the Lower Pilot Seam on wave-cut platform at Spoon Rocks south of Newcastle, N.S.W..

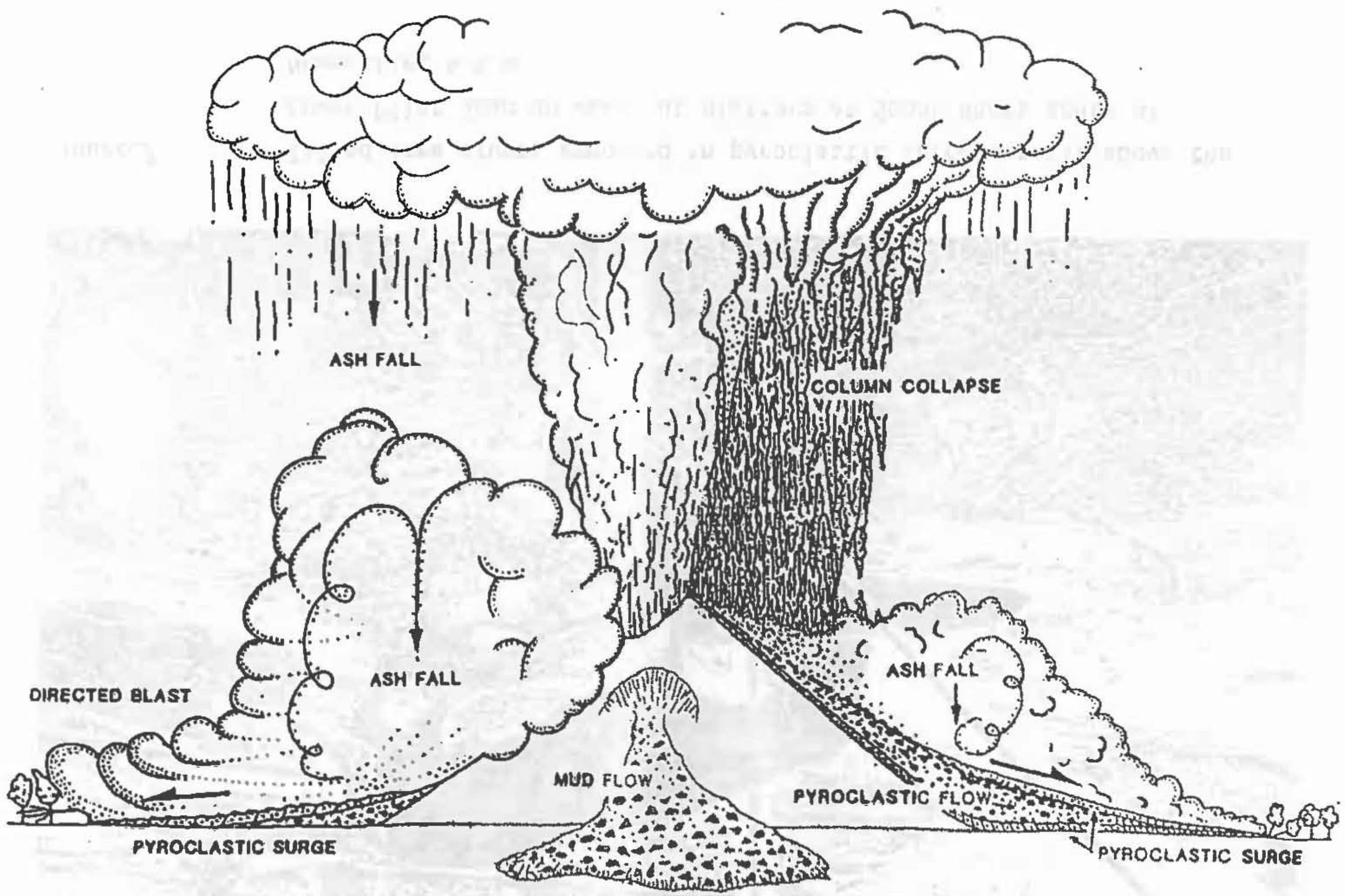


Figure 8 Schematic illustration of the various modes of generating pyroclastic deposits.

standing of transportation and deposition of volcanic ash (Sparks and Walker, 1973; Fisher, 1979; Self and Sparks, 1980; and Lipman and Mullineaux, 1981) three mechanisms have been distinguished, namely pyroclastic fall, flow and surge. Their characteristics have been discussed by Walker, 1980. In the first case, ash particles which have been explosively ejected from a vent, for example, as part of a Plinian column, fall through the air and settle on the ground as an <u>ash fall deposit</u>. A lateral component may be imposed on the settling trajectory by wind drift, lateral expansion of the ash plume, and initial lateral velocity resulting from the shape of the vent. An extreme case of the latter is the <u>directed blast</u> which proved to be so destructive in the Mount St. Helens explosion of 18th May 1980. Although its main result is the formation of a pyroclastic surge, turbulences within the blast cloud lift ash particles high into the air from which they will settle as an ash fall. The same happens when a ground surge and flow develops following the (partial) gravitational collapse of a Plinian ash column. The resulting ash fall deposits are crystal poor, they display mantle bedding, good to moderate sorting, almost exponential decrease in bed thickness and particle size with distance from vent and, when water flushed, accretionary lapilli may be common. Multiple falls show pronounced parallel bedding.

<u>Pyroclastic flows</u> can be generated in various ways (Wright et al., 1980) among which the collapse of an explosion column seems to be the most common one. They consist of a fluidised system in which the continuous medium is hot gas and the particle/gas ratio is high. According to Sparks and Walker (1973) they are the pyroclastic equivalent of mud flows in that they are a concentrated particulate flow but unlike mud flows (Lahars) they are hot which is shown by welding of glass shards near the vent and carbonization of plant remains for tens of kilometres beyond the zone of welding. Flow deposits are poorly sorted, non- or poorly bedded and high in crystal content. Lapilli and blocks of various kinds occur throughout but mainly in the upper portion of thick proximal flow units which, distally, thin in an irregular manner due to the development of a lobe-and-cleft configuration resulting from a vortex-like lateral expansion of the flow (Taylor, 1958; Fisher, 1979). In view of their relatively high density they tend to fill depressions resulting in very irregular lower bounding but relatively level upper bounding surfaces.

<u>Pyroclastic surges</u> differ from pyroclastic flows by their lower solid/gas ratio. Several surge types have been distinguished but all have in common that the pyroclasts are "carried laterally entrained in turbulent gas as a ground-hugging dilute particular flow" (Walker, 1981). The deposits

formed by pyroclastic surges consist of relatively thin units with good separation into different particle sizes, they are often cross-bedded with erosional basal contacts. Draping of topography is common and individual beds may be planar, wavy, or rippled including formation of antidunes. Particle sizes decrease and sorting improves with distance from the source.

The three main types of pyroclastic surges are (a) the base surge which is a phreatomagmatic phenomenon and probably of no major concern here, (b) the ground surge, and (c) the ash cloud surge. In Figure 8 ground surge deposits have been attributed to two modes of formation. To the left of the vent a situation is depicted which relates to the 18th May 1980 explosion of Mount St. Helens. According to Lipman and Mullineaux (1981) a "directed blast was generated by massive explosions that occurred when an enormous landslide released the confining pressure on a shallow dacite cryptodome and its associated hydrothermal system. Propelled by expanding gases and gravity, the mixture of gas, rock, and ice moved off the volcano as a catastrophic, hot, ground hugging, turbulent pyroclastic cloud at velocities of as much as 300m/s. Within a few minutes the directed blast had extended about 25km and carried off or knocked down all trees in its path." From the blast cloud a pyroclastic surge deposit was formed which can be divided into a thick and coarse basal unit covering an area of $140km^2$ up to a distance of about 14km from the vent. This ground surge deposit is overlain by a fine upper unit which covers an area of $600km^2$ up to 30km away from the vent and is better sorted, more thinly bedded and "consists of several superimposed tabular cross-sets that resemble migrating straight-crested dunes" (Moore and Sisson, 1981). This fine upper unit which probably represents an ash cloud surge deposit is overlain by the ash fall deposits mentioned above.

Both ground surges and ash cloud surges can also be generated in conjunction with ash flows from collapsing eruption columns. In that case a low density ground surge precedes the high density flow resulting in the deposition of fine grained, well stratified and cross-bedded tuff in front of and below the thicker, massive and coarse grained flow deposit.

Apart from the turbulent ash cloud surge which accompanied and extended beyond the ground surge of the abovementioned Mount St. Helens eruption, ash cloud surges have been observed to elutriate and segregate from the turbulent tops of pyroclastic flows which they override and leave behind. In the Bandelier Tuff of New Mexico, Fisher (1979) observed that the first ash cloud surge deposits appear on top of flow deposits several kilometres from the vent as discontinuous lenses, less than 2cm to 5cm thick and about 0.5 to 1m long. Distally the lenses thicken to 35cm and combine to form continuous beds with internal lamination 0.5 to 3mm thick which consist of alternations of crystal-rich and crystal-poor laminae. Dunes, unidirectional low-angle internal cross-stratification, pinch-and-swell structures unrelated to buried topography are all characteristic features of ash cloud surge deposits.

All the features mentioned in the above discussion of the various pyroclastic deposits occur in the tuffs of the Newcastle Coal Measures. The variety in textures and structures, as well as in composition shown by the thick interseam tuffs and claystones indicates that they represent successive eruptive episodes and different modes of emplacement. Many parallel bedded tuffs, such as those of Unit 1 in Figure 8 probably are ash fall deposits but some reveal lateral transportation by their internal cross-stratification which could be due to wind drift or water transportation although there is no reason to believe that the latter was involved. It is suggested that some pyroclastic surge deposits too are represented in Unit 1, after all, it contains the downed trees which are underlain by about 30 to 50cm of ash fall tuff.

Units 2 and 4 also represent multiple eruptions although many laminae appear to be the result of shear separation rather than of discrete volcanic events. Since Unit 3 shows all the characteristics of a pyroclastic flow deposit it is tempting to refer to Unit 2 as a ground surge and regard Unit 4 as an associated ash cloud surge deposit. The reason for suggesting that Unit 3 was formed by a pyroclastic flow is the massive nature of the rock, the inverse grading and its composition which is characterised by approximately equal proportions of crystals (quartz, plagioclase and biotite) and glass shards. The latter are not welded which suggests that Unit 3 might be part of a distal lobe of an ignimbrite.

Whether or not the underlying Unit 2 represents a ground surge deposit is difficult to say. It appears to be the result of several volcanic events which may have been separated in time. The interpretation of Unit 4 as an ash cloud surge deposit seems to be more certain. It is finer in particle size, internally laminated with dune structures occurring directly on top of the underlying flow deposit (Unit 3). The dunes are mantled by finer laminated material and in several cases climbing megaripples have been observed up to a thickness of 0.5m. Lateral changes from rippled to flat-bedded structures is probably due to regional variations in flow regimes at the time of deposition. Where this unit occurs at its maximum thickness of approximately 2m several discrete eruptions seem to be represented.

Part 2

The Greta Coal Measures (after P.R. Warbrooke: Depositional Environments of the Upper Tomago and Lower Newcastle Coal Measures, New South Wales. Ph.D. Thesis, Newcastle, N.S.W., 1981).

The Greta Coal Measures are a thin wedge of terrestrial coal bearing strata conformably lying between the marine Dalwood and Maitland Groups. Their lateral extent is limited and they are commonly only 60 to 75m thick (Basden, 1969). The coal measures have been described by David (1907), Jones (1939), Basden, (1969) and Britten (1975). The Greta Coal Measures have been subdivided into four formations (Figure 9). The section contains two major coal seams which are subject to complex splitting (Figure 10).

Currently three mines are operating in the Greta Coal Measures. The coals are high volatile (40%) low ash (4-10%) with a high sulphur content (usually >1%). The vitrinite content is high (60-70%) and the vitrinite reflectance ranges from 0.60 to 0.70% at relatively shallow depth. In the past the coal was used in industry, the railway and in the manufacture of town gas. Today most is sold to Japan for gas making and as chemical feed stock, as well as an additive to coking coal blends.

Neath Sandstone

The Neath Sandstone (Figure 9, 10) is a fine to coarse grained, massive sandstone with minor conglomerate and siltstone phases. Although devoid of other fossils, it is bioturbated towards the base. The unit appears to be a thick (10-20m) sheet like deposit. Jones (1939) used this unit for correlation of the Greta Coal Measures.

Kurri Kurri Conglomerate

The Kurri Kurri Conglomerate (Figure 9, 10) consists dominantly of pebble conglomerates with minor sandstone, siltstones and shales and contains the Homeville seam. This seam is up to 8m thick and is split into the Upper and Lower Homeville seams over much of the area.

Kitchener Formation

The Kitchener Formation (Figure 9, 10) comprises the Greta seam and associated sandstones and shales. The seam varies from 3 to 11m thick and is split into the Upper and Lower Greta seams by the Kearsley Lens which consists of shales and sandstones.

Paxton Formation

The Paxton Formation (Figure 9, 10) is composed of conglomerate, sandstones and shale and contains the Pelton seam which is a split off the Greta seam. The Pelton seam is up to 1.5m thick.

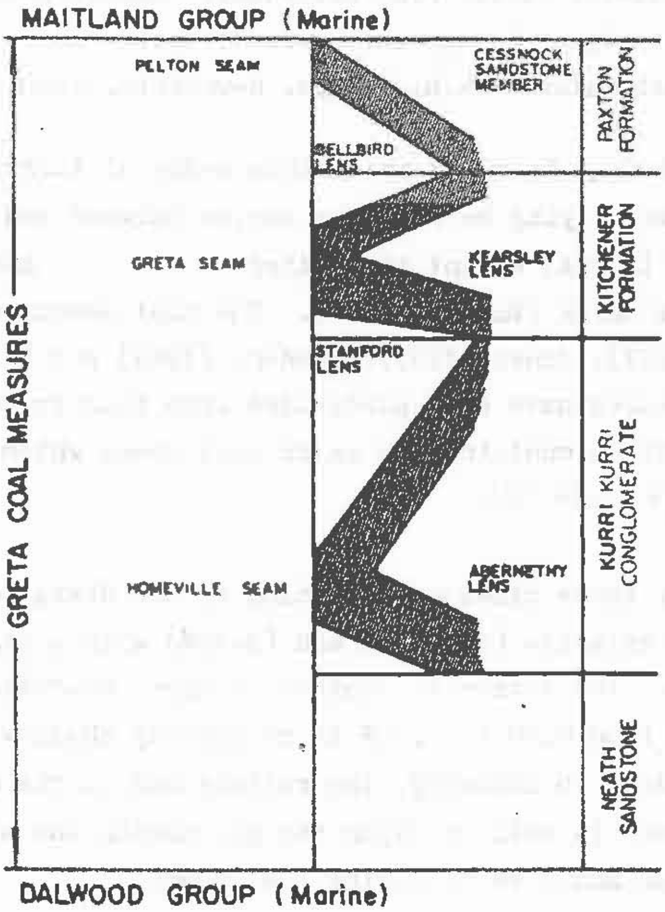


Fig 9 STRATIGRAPHY OF THE GRETA COAL MEASURES
(Modified after Britten 1975)

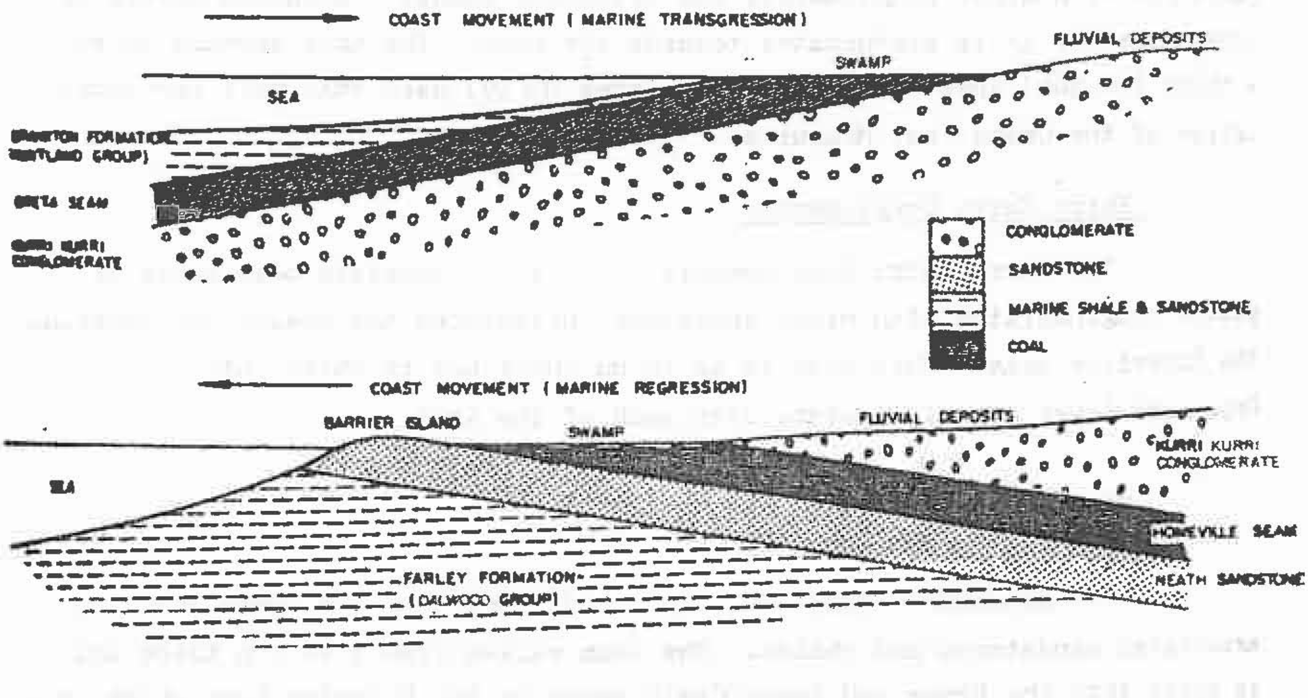


Fig 10 STAGES IN THE DEPOSITION OF THE GRETA COAL MEASURES
(Diagrammatic)

Depositional Environment

Uplift in the New England Fold Belt marked the onset of a short lived marine regression which produced the Greta Coal Measures. The influx of sediments from a proximal source was rapid, depositing coarse grained sediments almost directly into the shallow Dalwood sea. The sheet-like Neath Sandstone probably represent the barrier island deposit which protected the terrestrial sedimentation from the sea. This unit has some similarities with the Waratah Sandstone (N.C.M.) which is also believed to be a barrier island deposit, i.e. a 10-20m thick, massive, very even grained, sheet-like sandstone.

Behind this barrier island system swamps developed depositing peat which was eventually to become the Homeville seam. River systems flowing through the swamp gave rise to seam splitting.

The peat was eventually overlain by fluvial sediments deposited from the north or north-west. The coarseness of the sediments (generally pebble conglomerates) and nature of the deposits suggest a proximal source. It appears that the sediments were dumped almost directly into the swamp where alluvial fans of coarse conglomeratic material built into thick sheets. Braided streams probably predominated in this region while further to the south the alluvial fan deposits gave way to meandering stream deposits. The "fining-up" sequences in the coal measure clastic sections are typical of point bar and flood plain deposits of meandering streams.

Waning sediment supply from the source area resulted in the onset of a marine transgression. Swamps formed between the sea and land depositing peat which was to become the Greta seam (Figure 9,10). Rivers flowing through the swamps gave rise to seam splitting.

Eventually the Greta seam was overlain by marine sediments of the Branxton Formation from the Maitland Group. A thin conglomerate unit which sometimes occurs at the coal measure - marine boundary may represent the transgressive deposit which results from the concentration of coarser material due to reworking by wave action during the transgression.

It is this last aspect of the depositional environment, i.e. the change from coal measure sedimentation to marine conditions which will receive particular attention during the excursion.

STOP 4. Aberdare North Colliery

An underground visit will be made to Aberdare North Colliery in order to inspect the Greta Seam and its immediate roof strata. The area to be investigated (Figure 11) has been affected by severe roof disturbances and clastic intrusions into the coal which appear to be the result of thixotropic liquefaction and viscous flow. Blocks of laminite, torbanite and other sediments overlying the Greta Seam appear to have been broken up and rafted into lobate erosion channels cut into the underlying coal.

The clastic intrusions into the coal take various shapes and forms. Relatively widespread are small, slightly wedge-shaped clastic infillings of fissures which protrude sub-vertically from an otherwise undisturbed sandy and gravelly seam roof into the top coal. Due to compaction the intrusions have a zig-zag outline and a depth of 20 to 30 cm not unlike fossil mudcracks but an origin related to a cold climate seems more likely.

A different kind of clastic intrusions is represented by large dyke- and sill-like protrusions from the disturbed seam roof into the coal (Figure 12). These clastic apophyses range in particle size from silt to gravel and they display pseudo-bedding and de-watering structures. There appears to be little doubt that the intrusions have been forcibly injected into the coal whilst it was still at the peat stage but the exact mechanism is not at all clear.

The phenomena to be seen at Aberdare North Colliery have been observed also in other collieries which worked the Greta Seam in the Lower Hunter Valley. They do not seem to occur in the Greta Coal Measures of the Muswellbrook area nor are they common in Late Permian Coals. Since there are other indications suggesting cold climate sedimentation during Greta time it is possible that a combination of frigid conditions and seismic activity has been responsible for the emplacement of these features.

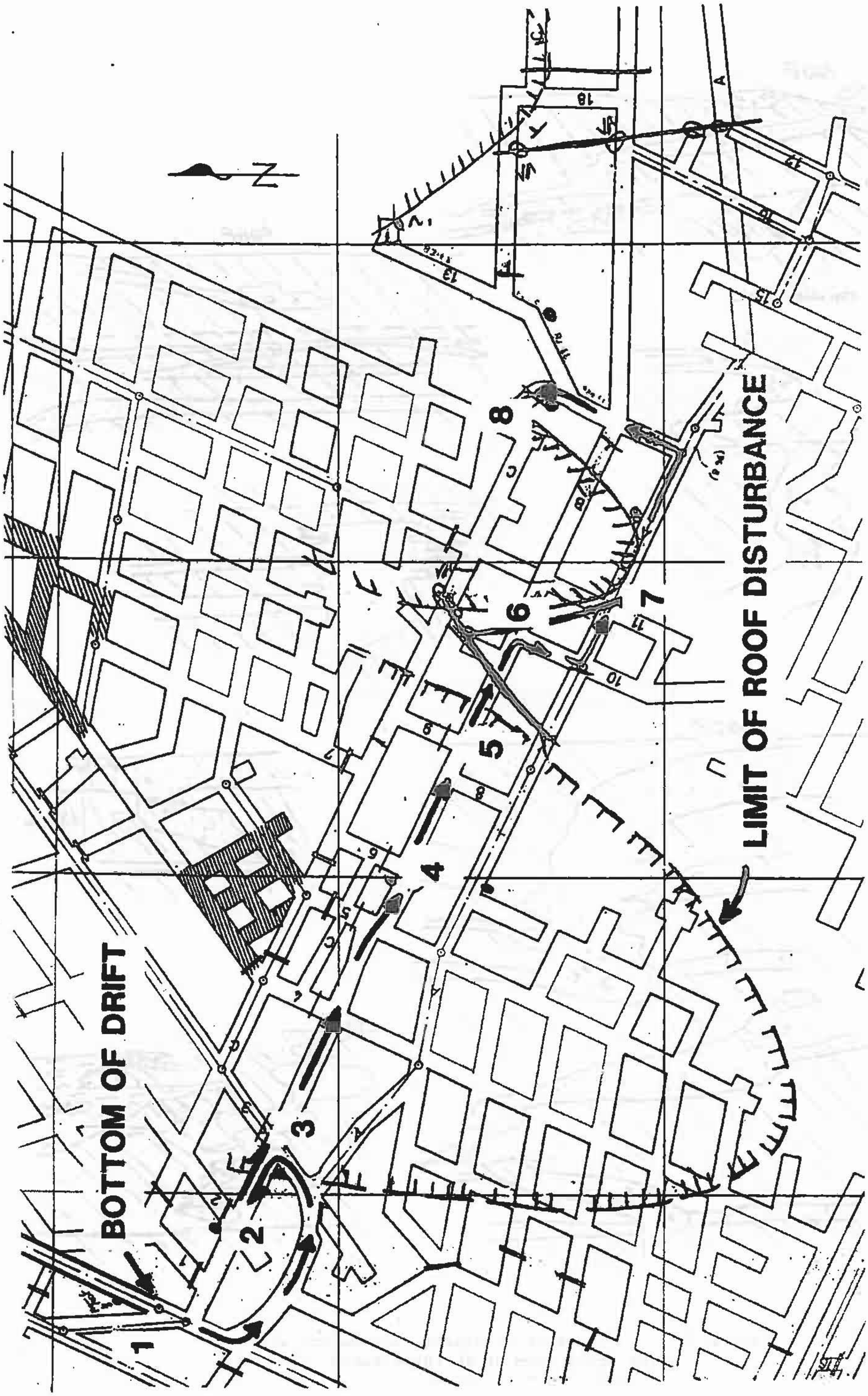


Figure 11 Locality plan for the mine visit at Aberdare North Colliery.

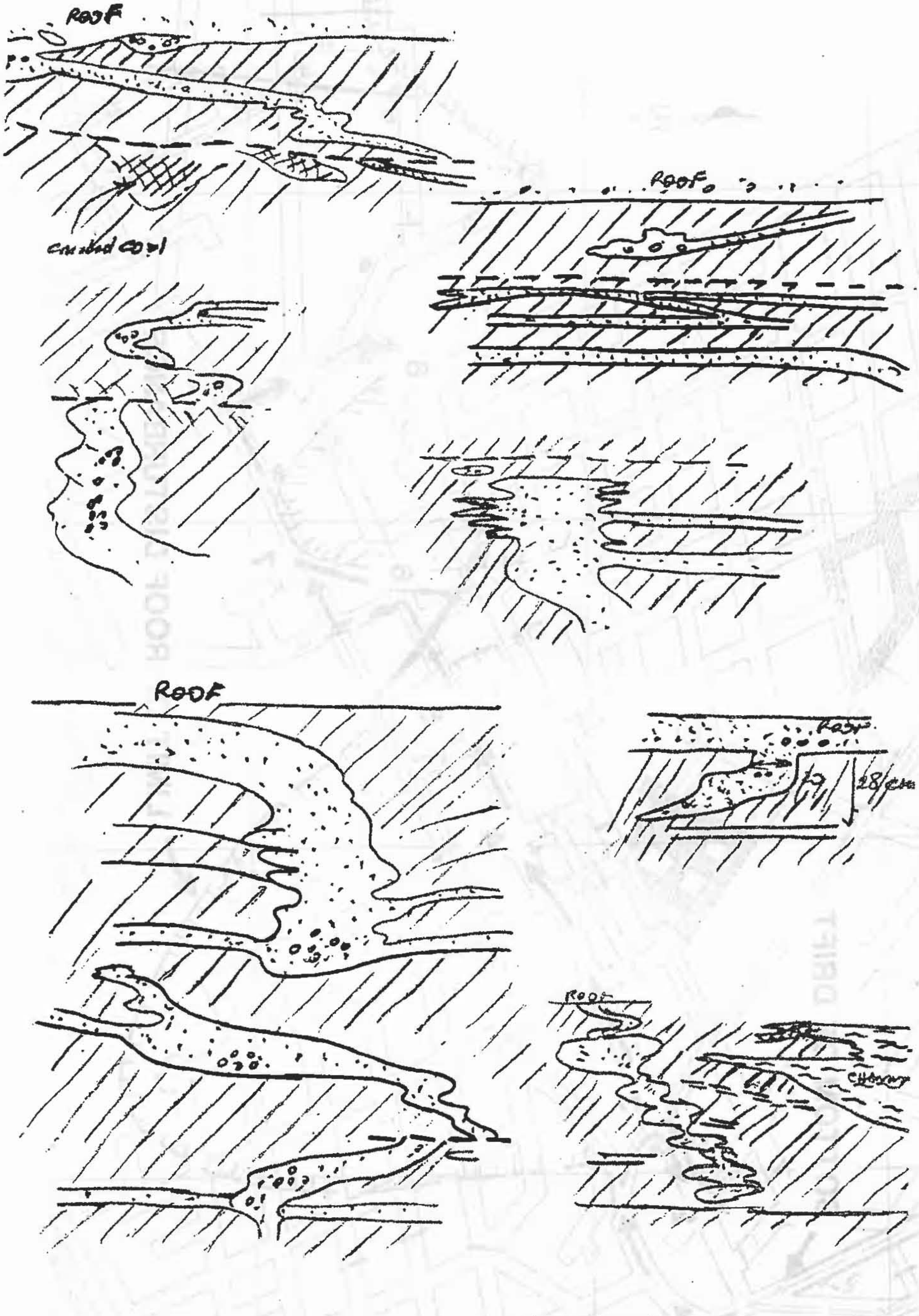


Figure 12 Sketches of clastic intrusions into the Greta Seam at Aberdare North Colliery by I.P. Martini.

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