PROVENANCE OF THE BASS BASIN SANDSTONES

REPORT AUST-67
ESSO STANDARD OIL AUSTRALIA LTD.

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August, 1967.

CONTENTS

ABSTRACT

Petrological and dipmeter evidence indicates that the source of clastics comprising the sandstones of the Bass Basin originated mainly from the northeast Tasmania - Bassian Rise basement arc, with a marginal source from the northwest Tasmania - King Island trend. The mineralogical character of quartz, felspar, tourmaline and lithic fragments point to a mixed granitic and low-grade metamorphic source, as found in northeast Tasmania. Dipmeter analysis shows consistent south-southeasterly strike directions of channel fill sands and deltaic build outs, thus supporting the conclusions reached from the petrological study.

Mineralogically, the sandstones do not change down the section reflecting the constancy of the source area through time. At the base of Bass-3 however, the influence of northwest Tasmania - King Island trend becomes more marked. The regional extent of the intra-Latrobe unconformity is questioned.

It is concluded that more open marine conditions are expected towards the northwest of the Basin and good reservoir rocks are anticipated. Also, in this direction, the impervious cap rock will be retained, while towards the source area (eastwards) the cap rock will change to a porous facies.

INTRODUCTION

Petrological and dipmeter analysis of the three Bass Basin wells was made in the hope of determining the provenance of the sandstones. With their provenance established the region appearing the most conducive for the storage of hydrocarbons can be anticipated. Two factors are involved; the porosity and permeability of the reservoir rocks; and the retention of a seal in any stratigraphic play.

POROSITY AND PERMEABILITY OF SANDSTONES WITHIN THE BASS BASIN

Porosities of sandstones within the Bass Basin range from 15% to greater than 30%. Generally, they average around 20% and 25% but not consistently over any depth of section. Bass-3 has the only relatively constant series of porosities within any one core, however most of these are between 15% and 20%.

Permeabilities also display a large range of values from less than 0.1 md to a maximum 328 md. The variability of values is even more marked than shown by porosities.

Of the 50 or so measurements made, the majority of permeabilities are less than 50 md, a few are in the hundreds, only one above 300 md. Usually the larger permeabilities do not correspond to higher porosities.

Overall, the sporadic distribution of the generally low porosities and permeabilities do not lend themselves to good reservoir rocks.

The poor quality of the reservoir sands in the three Bass wells is due to their immaturity. These sands developed by supply of sediment into a low-energy environment, thus sandstones having greater reservoir capabilities will be found where there is energy available for sorting and winnowing of fine material. The sea would provide the energy and a means for the development of good reservoir sands.

The immaturity of the sandstones in the three Bass wells is reflected mineralogically and texturally.

Mineralogically, variable amounts of felspar were found in most thin sections studied, giving a low quartz over felspar ratio. If this ratio is taken as a qualitative measure of mineralogical maturity, then the sands are immature. Also, the source area, low-grade metamorphics and granite is deficient in felspar, and erosion would result in a felspar-deficient sand. This does not occur, and the sands are probably more immature than the ratio would suggest.

Texturally, the presence of large volumes of clay and the general poor sorting of the sands points to their immaturity. The prevalence of interstitial clay markedly reduces the capabilities of the sandstones to act as reservoirs. The clay is detrital, deposited simultaneously with the quartz grains. When found at depth, the clay is partially recrystallized, but is generally a very fine felted mass of illite, chlorite or kaolinite. Authigenic clay growths are also probable, but are not of any great volume or consequence relative to porosity.

Most of the sands are poorly sorted. The presence of angular silt sized fragments between the larger coarse grains obviously reduces the pore space available. The poor sorting could also be a function of the source area. Much of the original material is composed of silts and slates giving a large supply of fine material to the basin.

The poor sorting, and more so, the interstitial clay, collectively destroy the sand's reservoir capabilities.

PROVENANCE OF THE BASS BASIN SANDSTONES

From dipmeter and petrological analysis the Latrobe sandstones originated primarily from northeast Tasmania - Bassian Rise basement arc. Supply of clastics from the pre-Cambrian in northwest Tasmania - King Island trend was generally found to be marginal. However, below Core No.9 in Bass-3 petrological change indicates a greater influence of this area during the early development of the basin. Elsewhere down the section no obvious change in mineralogy of the heavy minerals, lithics, quartz or felspar within the sandstone demonstrates the constancy of the source area through time - even across the supposed Eocene unconformity.

Petrological examination of cores suggest derivation from a mixed granitic and low-grade metamorphic area. The mineralogy of the quartz grains, detrital tourmaline, muscovite and felspar point to a granitic source, while the lithic fragments and abundant chert grains indicate a low-grade metamorphic area. The Mathinna Beds, which are low-grade metamorphics intruded by granites, are found to the northeast of Tasmania and were petrologically very similar to the lithics within the Bass Basin sands, as well as providing abundant fine material. The lithic fragments at the base of Bass-3 were identical to the more refractory pre-Cambrian metamorphosed sediments exposed on King Island and northwest Tasmania.

A problem associated with this provenance study is the early regional extent of the Jurassic dolerite. If the dolerite covered most of the northeast of Tasmania, erosion of this area would provide large quantities of clay. To date there are no appreciable thicknesses of shale within the Latrobe Complex. However, the dolerite may have supplied much of the interstitial clay of the sandstones if erosion occurred at the same time as the granite and low-grade metamorphics.

A report by the Utah Mining Company showed a system of old stream channels in northeast Tasmania leading into the Bass Basin. The Furneaux Group of Islands has a similar system of old stream channels. These stream channels have coarse "granite wash" and intercalated carbonaceous muds infilling them, and are representative of the material carried into the basin. Carbonaceous material from these channels has been dated palynologically, showing the existence of the streams since Eocene time. At the present time these channels are known to progress out into the basin and will be infilled with essentially the same material found outcropping. This is considered to be of prime importance when considering source of clastics and the existence (or absence) of a seal over the sandstones in the southeast of the basin.

Dipmeter analysis shows that the sandstones have developed partly by prograding deltas and partly by channel fill deposits. Foreset bedding developed within the deltas and channel strike directions show a strong orientation of azimuths pointing to the transport of sediment from the southeast quarter. Correlation of any particular deltaic unit between wells is difficult because the sediments are considered to have been supplied by a large number of small streams with coalescing deltas and channels. Thus, processes and conditions of sedimentation at any particular time would be different at various parts of the basin.

A. PETROLOGY

The mineralogy of the rock forming minerals of the Bass Basin sandstones has been compared petrologically to suites of rocks from northern Tasmania with regard to their provenance.

(i) Quartz

The detrital quartz grains have been primarily derived from a granitic source. Evidence for this conclusion is based on

(a) occasional large angular quartz grains possessing fragments of euhedral tourmaline and potassium felspar adhering to their edges;

(b) interpolated hypidiomorphic muscovite flakes;

(c) rare examples of myrmekitic intergrowths of quartz and felspar;

(d) minute inclusions of euhedral rutile and tourmaline usually found as thin needles and columnar crystals;

(e) some grains display a "domain" style of extinction which is typical of simultaneous growth of several quartz crystals within a granite;

(f) angular nature of nearly all the detrital quartz. This suggests one cycle of sedimentation from a primary source and not clastics from a reworked older sediment.

(g) undulose extinction and fractured quartz grains are uncommon. Therefore, derivation from a metamorphic source area is doubtful.

These points generally and specifically indicate granite as a source of much of the quartz material. However, most of these inherent characteristics are only found in the coarse grained sands and the very fine to silty sands do not exhibit any diagnostic features. This is probably due to their size and resolution of the microscope. As such, it is difficult to assign any particular origin to the finer grains and they could have been derived from either low grade metamorphics, granite, or both. Other evidence would suggest both.

The most persistent inclusion found within nearly all the detrital quartz grains are the abundant thin streams of lacunae and vacuoles. The density of these inclusions varies considerably between quartz grains but are always present. Comparison with quartz crystals from the granites of northeast Tasmania, coarse clastics from low grade metamorphics (Mathinna Group), and pre-Cambrian metamorphics from northwest Tasmania proved inconclusive. All groups of rocks possess quartz grains having similar inclusions. Fracturing, undulose extinction and strain lamellae are generally minor features of the grains. Usually, these characters have developed subsequent to burial. Strain lamellae for example can be attributed to stress at points of contact between quartz grains. Similarly, fracturing is due to rupture at sharp points of contact. Only rarely can stress be considered primary.

(ii) Felspar

Most sandstones contained variable amounts and types of felspar. By far the most abundant is orthoclase (K-felspar) with minor microcline and plagiocalse. The petrology of the felspar indicates a granitic source and precludes derivation from meta-sediments which are felspar deficient.

In particular, occasional perthite fragments and myrmekitic intergrowths are found which are textures peculiar to granites and their origin is irrefutable.

Down the section in all three wells, except the base of Bass-3, the amount and type of felspar is typical of an eroded granite. This even distribution reflects the constancy of the source area through time. However, below Core 11 in Bass-3 felspar becomes sparse to absent. This supports the conclusion (from other mineralogy changes), that the influence of the felspar-deficient pre-Cambrian metasediments in northwest Tasmania - King Island trend was more marked in the early development of the Basin.

Orthoclase occurs as fresh to partially altered, fine to coarse detrital grains. All fragments are sub angular, demonstrating swift transport into a low energy environment. Post depositional fracturing is common, due to its less refractory nature relative to the quartz framework and incipient alteration to sericite weakening the structure.

Plagioclase and microcline are usually found as fine, sub angular detrital grains, only rarely attaining a coarse size. Their distribution and quantity is more restricted than orthoclase, which is sympathetic to their relative abundance in granite. Because of the fine nature of the plagioclase and partial alteration, it was impossible to determine their composition by flat stage techniques.

(iii) Lithic Grains.

As noted previously, the mineralogy of the sandstones does not change with time, except towards the base of Bass-3. Apart from volume variations, the relative abundance of different lithics remains constant down the section in all wells.

There are three main lithic types; cryptocrystalline mosaics of quartz (chert fragments), indurated sericitic siltstone and low-grade metamorphics quartzites and schists. By far the most abundant and persistent lithic types are the chert fragments. Generally associated with these, but rather spasmodically distributed, are the indurated sericitic siltstone lithics.

(a) The quartzitic lithics are found through the section, but between Cores 10 and 11 in Bass-3 they become very numerous at the expense of the other lithic types.

The textures are typical of a metamorphic style. The edges of the quartz grains are welded together, leaving no intergranular space. Border crushing and subsequent healing produces a granulated effect peripheral to the individual quartz crystals.

Many of these lithics are of a "clean" nature, but many possess interpolated fine muscovite crystals which may show a rough lineation. Occasionally these lithic grains will also contain chert fragments which are a common accessory in the metamorphosed clastics of the pre-Cambrian.

These lithics are texturally and mineralogically similar to the thin sections studied of the metasediments of northwestern Tasmania and King Island. This shows the influence of these areas during the early development of the basin. Probably the area was of higher relief than other source areas at that time.

(b) The sericitic silt lithics are very similar to the

Siluro-Devonian Mathinna Beds found in the northeast Tasmania and Furneaux Group of Islands. This sequence of rocks is intruded by large, regional massifs of granite, and simultaneous erosion of both would produce the mineralogy of the existing sandstones.

These lithics are less metamorphosed than the quartzitic type, and are principally well indurated clastics. Usually they consist of silt-sized quartz grains with an interstitial matt of sericitic material, i.e. tending towards a shale.

(c) Chert fragments are ubiquitous. They occur as lithics in all the clastic metasediments of north Tasmania and sandstones of the Bass Basin. When found in the Bass Basin sandstones they are generally rounded to sub rounded in contrast to the angular detrital quartz grains. The inference is that they are predominantly reworked. Erosion of existing clastics has built up a concentration in the later sandstones. Certainly there are no great volumes of chert available for erosion into the basin. The Cambrian inliers have the only appreciable thicknesses of chert in Tasmania and these are thin and discontinuous.

The chert fragments are a microcrystalline mosaic of interlocking quartz crystals. The individual quartz crystals vary in size due to partial recrystallization, giving veining and radiating crystal growth patterns. Occasional grains feature a poorly developed banding due to concentration of black opaque material which is probably composed of iron oxides. These lithics do not appear to be diagnostic regarding provenance.

(iv) Heavy Minerals

Heavy minerals are very common throughout the sand section, especially tourmaline. Zircon, monazite and rutile occur spasmodically with rare detrital garnet.

Black opaque heavies are generally thought to be predominantly pyrite with minor detrital grains of either magnetite or haematite.

(a) Tourmaline is found in all slides almost without exception. Many of these grains are reworked from the eroded metasediments of northern Tasmania. However, a large number of tourmalines are angular fragments and are possibly not reworked. Information derived from the Tasmanian Mines Department indicated that the granites in northeast Tasmania possess tourmaline as an accessory mineral. Also, the quartz grains containing tourmaline crystals verify this origin and at least part of the tourmaline is sourced from these granites.

The coarse clastics of the Siluro-Devonian Mathinna Beds and the pre-Cambrian metasediments contain detrital tourmaline. However, the pre-Cambrian tourmalines are predominantly a pale green - colorless pleochroic type (Elbaite) and the Bass Basin sandstones contain only colorless - yellow - yellow brown - brown - slate blue pleochroic types.

It would seem that most of the angular to sub angular tourmaline is derived from the granites in the northeast of Tasmania.

(b) Monazite and zircon detrital grains are invariably fine sub rounded to rounded. Many are obviously reworked from older sediments but some are first derivatives.

Origin of these grains is confused because of the mixture of reworked and eroded grains and also because of the lack of particular features which would be diagnostic. It is probable that many are derived from the granite areas as zircon and monazite sands are found today along the beaches of Flinders and Cape Barren Islands.

(c) Opaques consist of mainly pyrite and marcasite. These are a product of the environment of deposition, but some have a detrital aspect. It is interesting to note the reported occurrence of large amounts of marcasite in the abandoned stream channels of northeast Tasmania.

Other heavy opaques are probably present but identification was not made.

Limonitic staining occurs frequently through many of the sands giving an orange-yellow stain to the interstitial matrix. Oxidation of the iron sulphides in situ would produce the interstitial staining by movement of formation water.

(v) Mica

Muscovite is a common accessory mineral throughout the section. Generally the micas are very fine, thin, elongate flakes found interstitially mixed with clay material. Rarely the flakes define bedding attitudes and only when they reach larger sizes. Compaction has usually moulded and broken these larger flakes against the quartz grains.

Excepting the idiomorphic muscovite found interpolated within the quartz grains, the muscovite has no source significance.

(vi) Matrix Material

There are two major matrix types; mixed clays and calcium carbonate. Some of the clay material has intermixed carbonaceous material.

(a) Clay matrix is abundant in nearly all sandstones studied. Textural relationships show the clays to be primary detritus brought in with the quartz grains. Clays are predominantly mixtures of illite and chlorite with minor occurrences of kaolinite. The illite (or hydromica) and chlorite are generally represented as fine fibrous crystals forming an interstitial matt. Kaolinite is found as fine crystals or as large recrystallized "books" peculiar to this mineral.

The origin of the clay could not be deduced from the information available. This would require extensive X-ray diffraction studies to determine if weathered felspar or dolerite sourced the clay.

(b) Calcite occurs as an intergranular cement. Distribution is very sporadic and does not have any apparent controlling factors. Often the calcite has a nodular texture being concentrated around a particular point which is randomly distributed. Partial replacement of quartz grains and secondary overgrowths occurs indicating recrystallization of the calcite.

Relationships between the calcite and quartz do not affirm or dispute theories for the primary origin of the carbonate, and anticipation of the extent and volume of carbonate cannot be attempted.

(c) Carbonaceous material is very common in the finer grained clastics but can usually be associated with the clay matrix in most. Much of the carbon occurs as intergranular films between quartz grains, but also as thin, discontinuous wavy laminae associated with clays.

(vii) Diagenesis

Very little diagenesis has been noted in the sections. Development of secondary overgrowths of quartz begin to take place at depth but are not widespread and would not markedly affect porosity. Diagenic clay has been mainly confined to recrystallization of detrital material with probable incipient growth by alteration of felspar.

(viii) Glauconite

This mineral is found only in the top of the Bass-3 sandstone section. The grains are associated in a detrital manner with quartz grains. Due to compaction the softer glauconite has yielded around the quartz grains. These sands still have relatively good reservoir qualities.

B. DIPMETER ANALYSIS

Units within the Latrobe Complex from the three Bass Basin wells are arbitrarily chosen by virtue of dip and azimuth characteristics. These units are listed below and the probable origin of the sandstones are interpreted purely on dipmeter character and occasionally from logs.

From this study the intra-Latrobe unconformity has been re-defined in Bass-2 to 4463 feet. Note that in Bass-1 and Bass-3 the dipmeter does not show any change in character at the unconformity boundary as picked. The validity of the correlation and the unconformity is questioned on dipmeter evidence.

Another point to emege was the correlation of the change into Upper Cretaceous in Bass-3 with a change in dipmeter style.

Bass-1

5935-6250	Sand has poorly developed bedding characteristics and is generally dispersed. The few patterns developed show a high angle foreset bedding. Direction of transport appears to be from the north-northeast.
6250-6550	Dips are very chaotic in direction and distribution. However, a predominance of blue patterns indicates foreset bedding of a deltaic sequence.

6550-7050	Those dips which are consistent indicate numerous bar sands and channel fill deposits trending northwest-southeast, thickening towards the southwest. Blue pattern suggests source to the south.
7050-7400	Concentration of dispersed azimuths and dip angles with blue patterns predominating. Deltaic sedimentation built out by supply from the north-northeast.
7400-7710	Dips and patterns are very irregular, but red patterns in shales above some of the sandstone indicate possible development of bar sands.

The dips and azimuths are by no means consistent. Dispersion within each unit, arbitrarily defined on similar patterns, is very apparent. The Eocene unconformity within the Latrobe Deltaic Complex is not indicated by any change in character of the dips.

Deltaic sedimentation is indicated by the dipmeter over 3 units, totalling 1500 feet in thickness. It is interesting to note that in each case coal becomes a prominent constituent.

Between the deltaic sequences strong red patterns in the sandstones indicate possible channel fill deposits. These are especially evident between 6550 and 7050 and towards the bottom of the hole.

The foreset beds build out from the north, but a minority of blue patterns indicate source to the southeast. This diversity is derived from the poor data.

Strike directions of the channel fill and bar sands are northwest-southeast with blue patterns defining sediment direction from the southeast.

Quality of data is very poor.

Bass-2

3828-4000	The sand unit within this interval has very poorly developed dip patterns. The data is certainly not good enough for interpretation of its origin.
4000-4460	Red dip patterns are strongly developed throughout this section, indicating channel fill deposits. Azimuths generally show thickening of the channels to the northeast with a few small sand bodies thickening to the west. Axis of channels run northwest-southeast and the few blue patterns point to a southeast source.
4460-5000	A change in dip patterns occurs over a short interval and becomes very consistently blue. These blue patterns exhibit regular low angle foreset bedding typical of a deltaic sequence. Azimuths are uniformly distributed about the southeast which is the direction of transport.

5000-5511 Dip distribution and patterns alter over a large interval at 5000 feet. Dips become widely dispersed down the section but azimuths are relatively constant to the north-northwest. Both red and blue patterns are equally represented which confuses interpretation. Possible channel fill deposits with minor intercalated deltaic buildouts gradually change to completely deltaic about 5000 feet.

This dipmeter is rather well developed when compared to the other two wells. Of particular interest is the consistent repetition of blue patterns over the interval 4460 and 5000 feet which gives a reliable estimate of direction of buildout and transport of detritus. This supports the interpretation of many of the more poorly developed patterns, allowing more confidence to be placed on them.

BASS-3

5300-5800 The dipmeter is characterless over this interval. There are no patterns developed that can be interpreted with any confidence.

5800-6200 Dips are irregularly dispersed, having no preferred dip or azimuth direction which precludes interpretation of probable origin.

6300-7100 Over this interval a change from massive sand bodies into a sand shale section occurs. At the top of this unit blue patterns indicate deltaic type of sand development. Below this individual sandstone bodies have definite associated patterns and they are interpreted with reference to their electric Log characters as well.

At 6415 the sand body could have developed as a bar.

At 6650 this could also be a bar sand.

6800-6840 (Contains the gas found in this hole). Dips, azimuths and S.P. curve suggest a point bar or channel fill deposits.

At 6950 the sand body appears to be a channel fill deposit.

At 6990 there is development of a bar sand.

Trends of most of the bar and point bar sands are in a north-south direction.

7100-7830 The section in this unit becomes a massive sand section after passing through a large homogeneous shale section. The dipmeter indicates a fluvial-channel sand deposition.

The last interval directly corresponds to the change into Upper Cretaceous sediments as defined by palynology. The coincidence of the dipmeter and mineralogical change with the paleontological change allows more confidence to be placed on the interpretations based on dipmeter analysis.

CONCLUSIONS

The provenance study indicated a clastic source peripheral to the southeast of the basin and a marginal source to the southwest. More open marine conditions are expected towards the northwest and good reservoir rocks are anticipated in this area as energy from the sea would have been available for the separation of fine material from the coarse. Also, towards the northwest, the cap rock (Demons Bluff Formation) would not change to a porous facies by sand build-up. However, towards the source area (eastward) a build-up of a sandy facies through the Eocene and Miocene is expected to occur. This means the loss of an impervious seal over the reservoir allowing escape of any migrating hydrocarbons.

From this analysis, the most promising reservoir area would be the northwest flank of the Bass Basin and, to a lesser extent, the southwest.

APPENDIX

THIN SECTION DESCRIPTIONS

BASS-1

Core No.12 6422' Quartz arenite; and interlaminated silty shale; the arenite is composed of poorly sorted, fine, silt sized angular quartz, minor felspar grains and lithic fragments. Interstitially are found aggregates of silt sized sub rounded grains, gaving high R.I. and birefringence (monazite or zircon?). These aggregates are very widespread interstitially, forming a very coarse matrix with a very fine, dark orange-brown, possibly limonitic stained, clay mineral.

Quartz grains; very angular, all containing varying amounts of inclusions. Tourmaline and rutile are commonly found, but the most abundant inclusions are thin streams of lacunae and vacuoles. Fractured and strained grains are rarely found.

Felspar laths and equidimensional grains are common constituents. The grains are generally fractured and altered to some extent. Orthoclase predominates over microcline and plagioclase.

Lithic fragments consist almost entirely of fine, sub angular grains of an interlocking mosaic of quartz.

Mica is a common constituent; laths and flakes of colourless muscovite oriented parallel to bedding planes. Bent and broken flakes due to compaction common.

Tourmaline; fine, blue to brown, angular fragments, garnet; red, equidimensional grains, pyrite; as very fine, crystalline aggregates associated with the argillaceous laminae are all common accessory minerals.

The rock has a loose framework of quartz grains, between which are small aggregates of silt sized monazite (?) or zircon (?) grains. A dark yellow-brown amorphous stain associated with minor illitic clay minerals forms part of the matrix. Thin laminae of irregular, discontinuous, resinous, carbonaceous material moulded between quartz grains are common. These grade into thicker laminae of orientated fine fibres of illitic clays and silt sized aggregates of monazite and zircon. One large concretionary pyrite containing fine to very fine, angular, quartz grains.

6423' Quartz arenite; poorly sorted, very coarse to fine, sub rounded to angular quartz and very coarse potassium felspar. Very little interstitial clay. Tourmaline, pyrite and lithic fragments are accessory minerals.

The quartz grains are generally equidimensional and provide the supporting framework of the rock. As a consequence most are fractured. The voids between the large grains are partially filled by aggregates of fine to very fine, angular to sub angular quartz. Some of the very coarse quartz show sutured contacts within themselves displaying domain-type of

extinction. These domains and sutures are primary. Many show strain lamellae and slight undulose extinction. Inclusions are mainly streams of lacunae and vacuoles.

Felspar occurs as fine to very coarse, sub angular grains. Orthoclase predominant over microcline. One grain of a myrmekitic intergrowth of quartz and felspar. Alteration to clay minerals advanced and all are fractured, being less refractory than the quartz framework.

Abundant lithic grains are composed of a mosaic of interlocking quartz in fine to medium, sub rounded grains. one or two grains of sutured quartz with thin flakes of interstitial colourless muscovite. One of these contains a chert lithic within a lithic. Muscovite is rare, as colourless laths and flakes, generally unoriented, bent and broken.

The matrix consists of a yellow, dark brown to black, carbonaceous, limonitic and pyritic mixture. Occasionally occurring as thin, irregular laminae and concretions. No apparent continuity or relationship to bedding attitudes is evident. Overall the rock is an inhomogeneous mixture of various sized quartz grains and matrix material.

6410' Quartz arenite; very poorly sorted, very coarse to fine, sub rounded to angular quartz grains and minor coarse to fine, sub rounded to angular (mainly orthoclase and microcline). The matrix is composed of minute flakes of illitic clay and a homogeneous yellow-brown opaque mineral, probably carbonaceous and pyritic which has partially altered to give a limonitic staining through most of the interstitial material. Sparsely distributed muscovite flakes, fine tourmaline and grains of zircon or corundum.

The larger quartz grains show intergrowths of different crystals. This gives a domain type of extinction over a single grain. Inclusions are common, generally as thin streams of lacunae and vacuoles, forming a lattice-work structure. Minor euhedral rutile and tourmaline are also found. Rarely graphic intergrowths with felspar are found. Fracturing and partial points of interpenetration of grains at contact are common.

Felspar is a common constituent, occurring as very coarse and fine, sub angular grains. Partially altered, but always severely fractured along cleavage planes. Orthoclase predominant with only rare grains of microcline.

Lithic grains of an interlocking mosaic of quartz generally fine to medium, sub rounded grains; the individual quartz crystals are found as very fine, microcrystalline and larger macrocrystalline types.

Accessory minerals and mainly tourmaline and pytire. Tourmaline; fine to medium, sub angular, slate blue to brown detrital grains. Pyrite occurs interstitially with the matrix and as small finely crystalline aggregates. Rare grains of zircon or corundum are found sporadically. Muscovite 5%.

The matrix is a mixture of yellow to dark brown illite, pyrite and carbonaceous matter. Limonitic staining occurs through most of the interstices.

There is a very rough banding developed due to variation in grain size and matrix content. Overall the rock is a framework of very coarse quartz grains with fine to medium interstitial detrital quartz. Thin discontinuous stringers of carbonaceous matter in irregular high angle attitudes are common.

6405' Quartz arenite; well sorted, fine to very fine, angular quartz, with a patchy yellow-brown illitic matrix. Only rare felspar and lithic grains. Interstitially are found silt sized aggregates of colourless, high R.I. and birefringence grains.

Colourless, tabular muscovite common and tourmaline crystals are the other main accessory minerals.

Quartz grains form a generally homogeneous framework due to its well sorted nature. Nearly all grains are angular, with many sutured contacts at the sharp points of contact. Inclusions are common, mainly fine streams of lacunae and euhedral tourmaline and rutile crystals.

Felspar is rare, orthoclase and a few fragments of plagioclase. Generally fractured and partially altered.

Lithic fragments are common. Sub rounded grains of quartz composed of a microcrystalline interlocking mosaic. Numerous sub angular grains of a mosaic of crystalline quartz with fine laths of muscovite, irregularly dispersed between the quartz crystals.

Large tabular flakes of muscovite disrupted from bedding plane attitudes are common. Usually colourless to a very pale brown. Minor equidimensional tourmaline fragments, pleochroic yellow-brown to pale blue.

Matrix consists of a mixture of yellow-brown illitic clay, pyrite, limonite staining and patchy aggregates of unidentified high R.I., birefringence material. Small pockets of colourless kaolinite are sporadically distributed.

Very scarce scattered zircon grains, sub rounded, silt sized.

Overall, the rock is very evenly textured, homogeneous, no development of bedding characteristics, other than general alignment of muscovite laths at a microscopic scale.

Core No. 13 6932' Quartz arenite and wacke; moderately well sorted, fine to very fine, sub angular quartz with a varying concentration of dark yellow brown matrix material. Lithic fragments are very common, muscovite flakes become increasingly numerous when matrix concentration increases. Minor amounts of heavy minerals, tourmaline, pyrite and aggregates of a colourless high R.I. birefringence interstitial mineral (unidentified).

The quartz grains are predominantly equidimensional, with some rather elongate. Inclusions consist of the usual thin lacunae streams and vacuoles with some grains containing large amounts of euhedral tourmaline, and rutile. Very few grains are fractured or display strain lamellae, probably because of the close framework partitioning the load. Suturing of contacts and secondary quartz overgrowths is common where there is a high concentration of quartz grains.

Felspar is rarely seen as very fine angular grains. Microcline, orthoclase and plagioclase are represented partially altered and fractured.

Lithic fragments of fine, sub-angular to sub-rounded mosaics of quartz crystals are abundant. Some of these contain fine, orientated tabular muscovite. There are two different sized moxaics, the interlocking crystals of one type are larger forming a coarser mosaic.

Muscovite flakes are common, reaching lengths of 1 mm. Generally define a bedding attitude, but most tabular flakes have been moulded around compressing quartz grains disrupting lineations. The larger flakes are concentrated along thin laminae containing abundant clay and carbonaceous material. Only rare tourmaline and zircon grains. Matrix consists of an inhomogeneous mixture of fine illitic clays, pyrite and carbonaceous matter. Scattered irregularly are aggregates of a yellow-colourless high R.I. birifringence mineral. Occasional intergranular pockets of a colourless kaolinitic clay.

The rock has a relatively homogeneous appearance with bedding defined by thin sub-parallel laminae of dark brown to black carbonaceous limonitic material, containing concentrations of mica. The thickest laminae is ½ mm thick and most are less than 1/16th mm. Within these stringers are found globular masses of pyrite.

6940' Quartz arenite; and interbedded sandy shale;
The arenite is moderately well sorted to poorly sorted when approaching the shale laminae. The quartz grains are angular, medium to fine sized with abundant dispersed felspar and lithic fragments. Matrix material consists of patchy yellow-brown illitic clay and intergranular kaolinite. Heavy minerals of tourmaline and rounded zircon grains.

Quartz grains are generally equidimensional. Most grains show fracturing to varying degrees. The larger grains are generally broken to a greater extent. Inclusions are common to sparse in most fragments. Thin streams of lacunae, vacuoles and minor euhedral tourmaline - rutile crystals. Many grains show strain lamellae and undulose extinction, with a few having a domain style of extinction. Separated by sutured contacts. Development of secondary overgrowths and pressur solution at points of contact.

Felspar grains are predominantly angular, medium to fine size. Mainly orthoclase and microcline, with only minor plagioclase fragments. One large grain displays exsolution of plagioclase along cleavage planes. All grains are partially altered, have rather diffuse boundaries and are usually fractured to a great extent.

Lithic fragments consist of fine to very fine sub angular grains of an interlocking mosaic of microcrystalline quartz, some showing a distinct crystal radiating growth texture. Thin, colourless, tabular muscovite flakes are rare; light blue to yellow, pleochroic, tourmaline occurs as sparsely distributed, very fine, sub angular detrital grains; colourless, rounded zircon rare.

Matrix material is patchy, consisting of yellow to brown and colourless illitic clay and pockets of radiating crystalline chlorite. Occasional thin laminae of shale composed of orientated flakes of illite, carbonaceous matter and silt sized grains of quartz.

Carbonaceous laminae divide thick bands of quartz arenite. Bedding is sub parallel with the laminae at high angles to each other, discontinuous and wavy.

Core No.14 7431' Siltstone; composed of angular, equigranular quartz, with a small amount of interstitial illitic and organic matrix. Muscovite and tourmaline detrital grains are common. Only an occasional silt sized detrital felspar (plagioclase) and lithic fragments of a micromosaic of quartz.

Quartz grains are generally evenly sized and equidimensional. An occasional grain shows euhedral inclusions of tourmaline and/or rutile. The close framework of the quartz grains would suggest a certain amount of secondary overgrowth forming a cement in the voids.

Muscovite occurs interstitially moulded against adjacent quartz grains. Flakes reach a length of ½ mm, but the majority are very thin and small. Generally where muscovite becomes prevalent interlaminated organic material also increases in content. The organic material is found as microscopically discontinuous, intergranular films between quartz grains.

Tourmaline is distributed spasmodically as silt sized detrital grains, pleochroic brown to colourless. Lithic fragments consist of an interlocking micromosaic of quartz crystals. These grains are disseminated throughout the rock. Felspar is very rare, plagioclase and orthoclase are found partially altered.

The quartz grains form a close framework of interlocking detrital grains. Interstitial clay and mica form only a thin rim surrounding the quartz grains. Thin, discontinuous, slightly undulating laminae of argillaceous, carbonaceous material form generally even, parallel bedding, each unit of which is cross bedded. Microscopically the laminae are composed of thin intergranular, carbonaceous films.

7442' Quartzwacke; moderately well sorted, very fine to fine, angular quartz. Matrix material consists of a mixture of illitic, detrital muscovite, and carbonaceous material. Lithic fragments, tourmaline and felspar, are rare.

Quartz grains are fine and angular. Occasionally, euhedral rutile/tourmaline inclusions are found

in the larger grains. Where the quartz grains are aggregated they become a very close fitted framework with sutured contacts and secondary overgrowths developed.

Lithic grains are predominantly an interlocking mosaic of microcrystalline quartz. Size of the individual mosaics vary in size from lithic to lithic. A few detrital grains are a foliated sericitic siltstone.

Tourmaline occurs as scattered, very fine to silt sized detrital grains. Usually pleochroic, brown colourless. Felspar fragments are rare, with plagioclase and orthoclase being represented.

The quartz framework is broken by thin intergranular films and discontinuous laminae of carbonaceous material. The numerous laminae are cross bedded, undulating and wavy, giving the rock an inhomogeneous texture.

Core No.15 7692' Quartzwacke; poorly to moderately well sorted, fine to medium, angular quartz. Matrix material consists of recrystallized illitic material, generally occupying most of the intergranular spaces. Muscovite is common accessory, slightly lineated parallel to bedding planes. Lithic fragments are common, felspar, both orthoclase and less plagioclase. Tourmaline is a rare detrital. Calcite is spasmodically distributed interstitial component of small volume.

Quartz grains show very little inherent characteristics. The usual streams of lacunae, disseminated vacuoles and minor euhedral crystals of rutile, tourmaline are found as inclusions. The grains are generally well spaced, but when they tend to aggregate secondary overgrowths and interpenetration will cement them together. Fracturing and undulose extinction are very rare.

Lithic grains are common, reaching up to 2% of the rock. Two distinct types are present. An interlocking mosaic of microcrystalline quartz predominates. Fragments consisting of a mass of sutured, interpenetrated, silt sized quartz and foliated, interpolated, euhedral flakes of sericite.

Felspar is a relatively common detrital grain. Orthoclase predominates over plagioclase; both are altered to some extent. Fracturing is a notable feature, probably related to their refractoryness. Muscovite occurs as detrital flakes moulded against adjacent quartz grains, but still preserving a semblance of orientation parallel to bedding. Tourmaline detrital grains are disseminated throughout the slide as fine, angular grains, generally fractured irregularly.

Matrix consists of a matt of recrystallized illite, occupying most of the available pore space. Occasional pocket of kaolinite and minor thin, intergranular films of carbonaceous material. Calcite cement occurs spasmodically, partially replacing the quartz.

The rock is generally massive, homogeneous, with only thin microscopically discontinuous films of carbonaceous material delineating bedding attitudes.

7698' Quartz arenite; essentially as above, with less matrix. Moderate to poorly sorted, fine to medium, angular quartz. Lithic fragments, felspar are common. Tourmaline and muscovite are rare. Matrix consists of recrystallized mat of illite. Generally the quartz grains form a very close interlocking framework and as such sutured contacts and development of secondary overgrowths are prevalent. The rock is massive, homogeneous, with thin, irregular, intergranular films of carbonaceous material defining bedding attitudes.

7703' Quartzwacke; and interbedded silty shale; as above. Variation in number and thickness of carbonaceous laminae, which become more frequent and display even to slightly undulating cross-bedding. Variations in grain size of the quartz also defines the bedding. Where the carbonaceous illitic laminae become thick the quartz grains generally are silt sized.

7716' Quartzwacke; and interbedded silty shale; as above. The silty shale laminae are much more prevalent. They are even, parallel, slightly undulating. The band of sand shows distinct cross bedding defined by thin, intergranular, carbonaceous laminae, which are discontinuous microscopically.

BASS - 2

Core No.5 4141' Quartzwacke; poorly to moderately sorted, fine to very fine, angular quartz, becomes slightly silty in part. Thin, resinous laminae of a dark, resinous, carbonaceous matter associated with very thin flakes of orientated muscovite. Minor plagioclase and orthoclase grains, generally angular, fine grained. Heavy minerals, pyrite, tourmaline and zircon accessory.

The quartz grains tend to be concentrated in thin lenses or are found sporadically dispersed between the matrix material. Elongate or platate grains are abundant, preferentially aligned parallel to the bedding attitude. Most of these are fractured. Vacuoles and fine streams of lacunae are common, with a few having euhedral tourmaline and rutile crystals. Slightly undulose and even extinction most common; very few exhibit strain lamellae or undulose extinction.

Felspar is a rare accessory; orthoclase and plagioclase are partially corroded and have diffuse edges.

Muscovite, colourless tabulae, preferentially orientated parallel to the bedding plane. Flakes are bent and moulded against quartz grains due to the effects of compaction. Concentrations occur at various horizons, usually associated with increase in volume of matrix material.

The matrix consists of an inhomogeneous mixture of muscovite illitic clay and a dark resinous, carbonaceous material which could be slightly pyritic.

Scattered pleochroic, yellow-brown-colourless tourmaline grains and rare rounded zircon fragments. Staurolite may be present.

Lithic fragments are common, being composed of a mosaic of quartz crystals and interposed tabula of muscovite.

Texturally the rock is an inhomogeneous mixture of detrital grains and matrix material. Varying concentrations of detrital grains and thin discontinuous laminae define a very irregular and poorly developed bedding.

Core No.7 4742' Lithic Arenite; moderately well sorted, sub angular, fine to very fine quartz, with a sporadic dolomitic matrix (occupying up to 15% of volume). Lithics are composed of an interlocking mosaic of microcrystalline quartz. Some quartz grains have a domain style of extinction due to different optical orientations of the very fine crystals of quartz.

4749' Lithic Arenite; as above, with the calcite - dolomitic cement becoming more localized and patchy.

4753' Quartz Arenite; decrease in the volume of lithics, otherwise similar to above. Traces of rounded zircon detrital grains.

4759' Quartz Arenite; as above, partially dolomitized.

Core No.8 5075' Quartzwacke; moderately well sorted, very fine, angular quartz - slightly silty in part. Sporadic concentrations of calcite - dolomitic matrix. Thin laminae of dark carbonaceous material and minor detrital pyrite grains. Rare lithic fragments and tourmaline. Interstitial muscovite flakes common. Quartz grains are very fine and silt sized, generally equidimensional. They do not form a close framework but are found remote from each other separated by either a carbonate or pyritic, carbonaceous clay matrix. The grains have the usual streams of lacunae and minute euhedral crystals of rutile and/or tourmaline.

Calcite and dolomite occurs as a localized cement sporadically disseminated. Partial replacement of quartz grains by the recrystallized calcite.

Muscovite is commonly found orientated parallel to the bedding plane. Thin flakes moulded against quartz grains and an occasional aggregate forming radiating "books" interstitially.

Tourmaline is a rare accessory, yellow-brown-colourless (pleochroic), very fine, sub angular detrital grains; lithic fragments are also rare but were difficult to resolve. Minor plagioclase and orthoclase grains.

Very thin even parallel continuous laminae are well developed, but at a micro level are found to be due to concentrations of thin, discontinuous, wavy, carbonaceous and clay material.

BASS - 3

Core No.6

5334' Glauconitic quartz arenite; well sorted mixture of angular, very fine quartz and very fine glauconitic grains (20% to 30%). Most grains are equidimensional with a minority elongate. Glauconite appears to have an interstitial relationship to the quartz during compaction. Fine flakes of mica are aligned along sub-parallel bedding planes which have styolitic-like concretions of a dark brown illitic clay material. Generally these bedding planes contain minor fine zircon, tourmaline and heavy opaque minerals.

5325' Glauconitic quartz arenite; with thin laminations of argillaceous material, well sorted, angular, very fine to fine, equidimensional quartz and fine, light green glauconite grains. Minor mica flakes are orientated parallel to the general bedding plane and heavy opaques are concentrated in these layers. Some evidence or organic activity in the argillaceous layers. Dark orange-brown illitic clay laminations, sub-parallel, discontinuous, contorted. arcuate shapes.

Slight development of secondary quartz overgrowths. No peculiarities of the quartz that could be diagnostic. Most are clear with minor vacuoles, some contain fine rutile needles. Extinction is even to slightly undulose (probably igneous quartz). Porosity and permeability reduced by fine, angular nature of sand, but is enhanced by lack of matrix material and good sorting.

5319' Quartz arenite; moderately well sorted, fine to very fine angular quartz with a dark orange-brown matrix of illitic material. Up to 5% glauconite as very fine grains moulded against adjacent quartz grains. Minor very fine k-felspar fragments showing marked alteration and deterioration to clay minerals, very fine lithic grains, commonly rounded, consisting of a mosaic of interlocking quartz.

The majority of the quartz grains have been fractured. Inclusions are thin streams of fine lacunae and vacuoles. Some contain fine euhedral needles and prismatic inclusions. Extinction of grains is generally even or slightly undulose with some displaying strain lamellae.

Accessory minerals of brown to light blue, yellow pleochroic tourmaline, clear zircon and opaque heavy minerals. The opaque mineral is predominantly pyrite, occurring as a concretion or replacement product and as an interstitial cementing agent.

The pyritic material tends to be concentrated along thin extremely irregular laminae. Lamina development is erratic with much evidence of organic activity.

5315' Impure quartz arenite; well sorted, fine to very fine, angular quartz and 2 to 5% fine, sub angular to sub rounded k-felspar.

The felspar shows alteration and deterioration into clay minerals. Due to its hardness, relative to quartz, the grains are more rounded. The quartz grains are generally clear with even to slightly undulose extinction. A minority possess minute inclusions of euhedral tourmaline and acicular rutile. Many, if not all, have fine 'streams' of vacuoles and dust rims. Fractured quartz grains with strain lamellae are not as common as 5319'.

A little dark orange-brown clay matrix is found peripheral to sand grains but tending to occur in thin, irregular lamina associated with pyrite and silt sized quartz.

Lithic fragments are found to be very fine, sub angular to sub rounded grains of a fine interlocking mosaic of quartz..

Very thin, compressed mica flakes, very fine equidimensional tourmaline and minor silt sized garnet grains are found sporadically disseminated. Minor development of secondary quartz overgrowths.

Core No.7 5638' Sandy Siltstone; moderately ill sorted, slightly argillaceous. Quartz grains are sub angular to angular, equidimensional with minor elongate grains, preferentially aligned to bedding planes. The fine tb very fine, sub angular quartz grains tend to be elongate or oblate and concentrated at certain horizons. Most quartz grains have even to slightly undulose extinction, very few are fractured. Inclusions of euhedral tourmaline and acicular rutile are rare. Thin lacunae 'streams', vacuoles and dust traces common. The grains are fairly close packed with a colourless to light orange-yellow kaolinite matrix filling the interstices.

Abundant colourless mica flakes generally aligned in bedding plane attitudes, are slightly disrupted by compaction effects. The flakes reach a maximum length of ½ mm. K-felspar is only a minor constituent the grains are silt sized, sub rounded to sub angular and badly corroded.

The main feature of this thin section is the remarkable abundance of accessory minerals, garnet, zircon, tourmaline, carbonaceous grains, pyrite and probably topaz. Garnet occurs as a deep red angular equidimensional grain. Zircon and tourmaline are generally euhedral to rounded. Zircon and topaz are colourless. Tourmaline is light blue to brown.

The opaques are evenly distributed with the carbonaceous detrital grains predominant over the interstitial pyrite.

Core No.8 5918' Calcareous quartz arenite; moderately to ill sorted, very fine to fine, angular to sub angular quartz, in a matrix of cryptocrystalline calcite, silt sized quartz and colourless kaolinite. The interstitial calcite occupies up to 20% of the rock, such that many of the quartz grains are not in contact with each other. Where this occurs the calcite replaces the quartz grains, giving the edges a ragged texture.

The majority of the quartz grains show even extinction and have only few inclusions. A few grains possess large numbers of acicular rutile and/or rutile.

Accessory minerals consist mainly of resinous, carbonaceous films compressed between quartz grains; pyrite, as scattered fine crystalline aggregates; felspar - microcline; orthoclase and plagioclase occur spasmodically as sub rounded grains generally altered to sericitic material. Abundance of lithic fragments (1% to 2%) comprised of an interlocking mosaic of quartz in sub angular, very fine grains.

Tourmaline and muscovite are rarer accessories. Muscovite is found as thin, very fine flakes, compressed

between quartz grains; tourmaline, pleochroic yellow - light blue to brown, sub rounded to euhedral grains. Detrital, very fine carbonaceous grains are common. Texturally, the rock has thin, sub-parallel laminations, expressed by the dark carbonaceous stringers which are concentrated at certain horizons, but discontinuous microscopically.

The quartz grains are sometimes remote from each other as the interstitial calcite acts as a buttress when reaching a high proportion. This would lower any primary porosity and permeability markedly.

5916' Calcareous quartz arenite; poorly sorted, mixture of interstitial silt sized and fine to very fine, sub angular to angular quartz. Up to 20% interstitial cryptocrystalline and recrystallized calcite. Microcline, orthoclase and plagioclase occur as fine to angular grains. Rare tourmaline, angular sub-rounded grains.

The quartz grains are generally a mixture of equidimensional and elongate types. The edges show replacement effects by calcite giving them a ragged texture. Inclusions are common within the quartz, mainly as thin streams and irregularly distributed vacuoles and lacunae. A few grains possess euhedral and anhedral equidimensional tourmaline crystals. Extinction is generally even and slightly undulose. Fracturing and strain lamellae are rarely found. Secondary quartz overgrowths are found developed around some grains which have subsequently been partially replaced by recrystallized calcite.

This thin section shows a large amount of recrystallized calcite reconstituted from the aphanitic interstitial type.

Lithic fragments of an interlocking mosaic of quartz are common. Generally sub angular or partially replaced.

Muscovite flakes are abundant, preferentially aligned parallel to bedding attitudes, but slightly disrupted due to compaction around refractory detrital grains.

Thin, discontinuous stringers of carbonaceous material (occurring as sub angular detrital grains also) indicate bedding attitude. The laminations have a deep red to black colour and are moulded against adjacent grains.

Kaolinite may be a minor matrix material, but was difficult to resolve in this case.

Core No.9 6432' Quartzwacke; moderate to poorly sorted, fine to medium, sub rounded quartz. Detrital felspar reaches up to 2% by volume. Orthoclase predominates over microcline and rarer plagioclase. Matrix material varies considerably with a spasmodic calcite rim peripheral to many detrital quartz grains (commonly partially replacing them). Patchy pockets of an illitic clay and recrystallized radiating "books" of kaolinitic material. Lithic fragments are very common consisting of an interlocking mosaic of microcrystalline quartz; a few large detrital grains composed of very fine quartz grains in sutured contact with each other and sometimes separated by only a thin film of illitic material (probably derived from quartzitic source). Detrital tourmaline is very common, reaching

a maximum of ½ mm in size. Muscovite is rare. Pyrite and limonitic staining is common.

Quartz grains generally show very little inherent characteristics. Inclusions of euhedral rutile and tourmaline are rare; most possess thin 'streams' of lacunae and disseminated vacuoles. A few grains show a domain style of extinction - due to varying optical orientation of the individual quartz crystals. Extinction is mostly even with a few being slightly undulose.

Felspar grains are common. Orthoclase is predominant, usually having many inclusions and probably exsolved calcic phases. Alteration is partly completed. Microcline and plagioclase are rarer and generally finer grained. Occasionally the felspar is found in direct crystalline contact with quartz.

Lithic fragments vary in type. Mosaics of microcrystalline quartz, aggregates of very fine welded quartz grains, and crystalline tabula of muscovite interpolated between sutured quartz. Tourmaline occurs as fine, sub rounded detrital grains, pleochroic brown - colourless. Generally has irregular fractures.

Matrix is an inhomogeneous mixture of calcite, pyrite, limonite, illite and kaolinite clay. Distribution is very haphazard, found as thin, irregular, discontinuous layers between quartz grains, spasmodic concretions and thick homogeneous bands.

6422' Quartzwacke; illsorted, very fine to medium, sub angular to angular quartz. Matrix is a relatively homogeneous matrix of very fine illitic clay material, with yellow-brown limonitic staining and thin, black, resinous bands of carbonaceous material. Felspar and lithic fragments are sparser than in 6432'. Orthoclase and only minor plagioclase fragments. Lithic grains are of two types - a mosaic of cryptocrystalline quartz and an aggregate of sutured quartz grains with euhedral tabulae of minute muscovite. Tourmaline is common accessory, generally irregularly fractured. A rough banding is developed by virtue of an increase in the amount of matrix material occurring as very thin irregular, discontinuous, dark brown carbonaceous and clay material.

Core No.10 6432' Quartzwacke; relatively well sorted, fine to medium, sub angular to angular quartz. Very rare felspar grains, tourmaline and lithic fragments are minor. Muscovite laths up to 1 mm in length are disseminated throughout. Matrix consists of a recrystallized kaolinite clay. The crystals are very coarse, occurring as radiating "books". Calcite cementation occurs spasmodically in small nodules.

Quartz grains tend to occur in small aggregates separated from each other by only a thin interstitial clay layer. Secondary overgrowths in these aggregates form the cementing agent. A few grains display a domain style of extinction. Inclusions of dust, streams of lacunae, euhedral rutile and tourmaline and possess a few crystals of topaz or zircon.

Lithic grains are common. Fine sub rounded detrital grains of an interlocking mosaic of quartz and grainsof an aggregate of sutured quartz grains with interpolated, very fine euhedral crystals of muscovite. One detrital grain shows a gradation from the mosaic type into the "domain" style of grain. Also one of the mosaics shows a lineated structure. The lineation is due to different sizes of

the individual crystal mosaics.

Matrix consists of large "books" of crystalline kaolinite with a sparse amount of illitic clay. Calcite cement is spasmodically distributed in small localized concentrations.

Muscovite is found as large flakes up to 1 mm in length. Generally aligned parallel to bedding plane but in detail are moulded against adjacent quartz grains. Tourmaline occurs as fine detrital grains. Pleochroic yellow-brown, colourless. Most grains are irregularly fractured.

The rock is generally of a massive aspect with only a few thin laminae showing bedding attitudes. The laminae are irregular and discontinuous. A slight mottled effect is given by the localized concentrations of calcite cement.

6924' Quartz arenite; similar constituents to the above, but has less kaolinitic matrix and is poorly sorted. Large black laminae of carbonaceous material are more strongly developed than above.

The very coarse detrital quartz grains show inclusions of very fresh laths of muscovite, and euhedral crystals of either zircon or topaz. Tourmaline is a common associated mineral. No cementing calcite.

6929' Quartzwacke; as 6432'. Moderately sorted, massive, with localized crystalline kaolinite matrix. Lithics tourmaline common, lack of felspar.

Core No.11 7435' Quartzwacke; illsorted, fine to medium, angular quartz, lithic fragments and detrital tourmaline grains are very common. Kaolinitic matrix is very coarsely crystalline. Muscovite flakes are disseminated interstitially, but are not common. A localized calcite cement occurs partly replacing the quartz grains. Only a few felspar fragments. Orthoclase only.

Quartz grains are not evenly distributed, but tend to occur in aggregates with little interstitial matrix. They are separated from other aggregates by isolated quartz grains in a large amount of clay. In these aggregates secondary quartz overgrowths infill the pores and form a cement. Inclusions are commonly streams of lacunae and disseminated vacuoles with minor rutile and tourmaline crystals. Fracturing undulose extinction and strain lamellae is very rare.

Lithic grains are very common and are of three types. A sub rounded interlocking mosaic of microcrystalline quartz; a foliated mixture of quartz and minute flakes of muscovite and/or sericite (sericitic schist ?), aggregates of very fine sutured quartz grains and interpolated muscovite.

Tourmaline occurs as very fine to fine, pleochroic brown to colourless detrital grains. Muscovite is rare as moulded flakes against adjacent quartz grains. Felspar is rare and generally altered - orthoclase ?

Matrix material consists of very coarsely crystalline kaolinite. In part reaches a volume up to 30%, but where the quartz grains are aggregated it becomes very sparse. Local concentrations of calcite form a cement, however, the calcite is patchy.

Generally, a massive homogeneous rock with a slight mottled aspect due to the local concentrations of calcitic cement and aggregated quartz.

7439' Quartzwacke; illsorted with large amounts of lithic fragments, tourmaline and patchy calcitic cement. Essentially as above.

7445' Quartzwacke; very poorly sorted, silty to very coarse angular quartz. Very inhomogeneous mixture of illitic and kaolinitic clay matrix, with disseminated flakes of muscovite. Up to 10% lithic fragments of quartzite, foliated sericitic quartz and microcrystalline mosaics of quartz. Felspar (orthoclase) is rare, tourmaline common accessory mineral. Small patches of calcite are found interstitially.

Quartz grains are either coarse or fine to silt sized. All are angular. Inclusions are common, consisting of streams of lacunae, disseminated vacuoles, fresh crystalline muscovite laths, euhedral rutile and tourmaline crystals and incorporated contiguous tourmaline. The grains are rarely fractured or display evidence of strain. A number of quartz grains have a domain style of extinction due to various orientations of adjacent quartz crystals.

Lithic fragments are many and varied. Aggregates of a sutured mass of very fine to fine quartz grains, with minute, interstitial, crystalline tabulae of sericite. Microcrystalline quartz grains forming a regular mass with interpolated, foliated sericite. One large grain of a sutured, interlocking mass of quartz. Some fragments show a distinct banding structure due to variations in the size of the mosaic. Also found are thin, irregular lamina of dark carbonaceous material forming a cross bedded attitude to these bands. Tourmaline occurs as fine, angular, pleochroic, brown to colourless detrital fragments. Muscovite is spasmodically distributed interstitially, generally having very diffuse, ragged edges. Very rare zircon grains. Felspar (orthoclase) usually very altered.

Matrix consists of pockets of coarsely crystalline kaolinite clay and a mixture of illitic clay with silt size quartz grains. Occasional calcite cementing.

Due to the extreme bad sorting and matrix mixture the rock is very inhomogeneous. Only a very rough banding due to variation in grain size can be seen.

7446' Quartzwacke; extremely illsorted, becoming silty in part. Up to 50% matrix material of illite and kaolinite. Lithic grains, felspar, tourmaline and muscovite, as above. Zircon detrital grains common.

7453' Quartzarenite; Moderately well sorted, very coarse to medium, sub angular quartz. Abundant lithic

fragments and detrital grains (tourmaline). Matrix is generally a mixture of crystalline, kaolinite and minor illite, with localized patchy calcite cement between quartz grains.

Quartz grains show very little inherent characteristics. Inclusions of disseminated vacuoles and streams of dust lacunae. Only minor amounts of crystalline rutile, tourmaline and muscovite. A few show a domain style of extinction, very few display any strain lamellae or undulose extinction. Fracturing is rare, occurring only at sharp points of contact between quartz grains. Development of secondary overgrowths cementing the quartz grains is rare.

Lithic fragments are numerous and are of many types; aggregates of sutured quartz grains with interpolated sericitic material; occasional foliated quartz sericite; an interlocking micro-crystalline mosaic of quartz which is seen to grade into the aggregate type.

Tourmaline, zircon, occur as very fine, angular to sub-rounded detrital fragments. Generally both are fractured to some extent. Muscovite is a rarer accessory found moulded interstitially against quartz grains. Flakes reach a maximum size of ½ mm.

Matrix is a mixture of very coarsely crystalline kaolinite and minor illite. Patches of calcite form a cement between quartz grains, but is not continuous. Their distribution is random. Partial replacement of quartz is apparent.

The quartz grains in this rack form a definite framework with partial interpenetration of grains and calcite cement providing the supporting strength. The voids are partially filled with clay and minor silt sized quartz. Overall the rock is of a massive, homogeneous nature.