THE PARAGENESIS AND ORIGIN
OF THE TENNANT CREEK MINERAL DEPOSITS.

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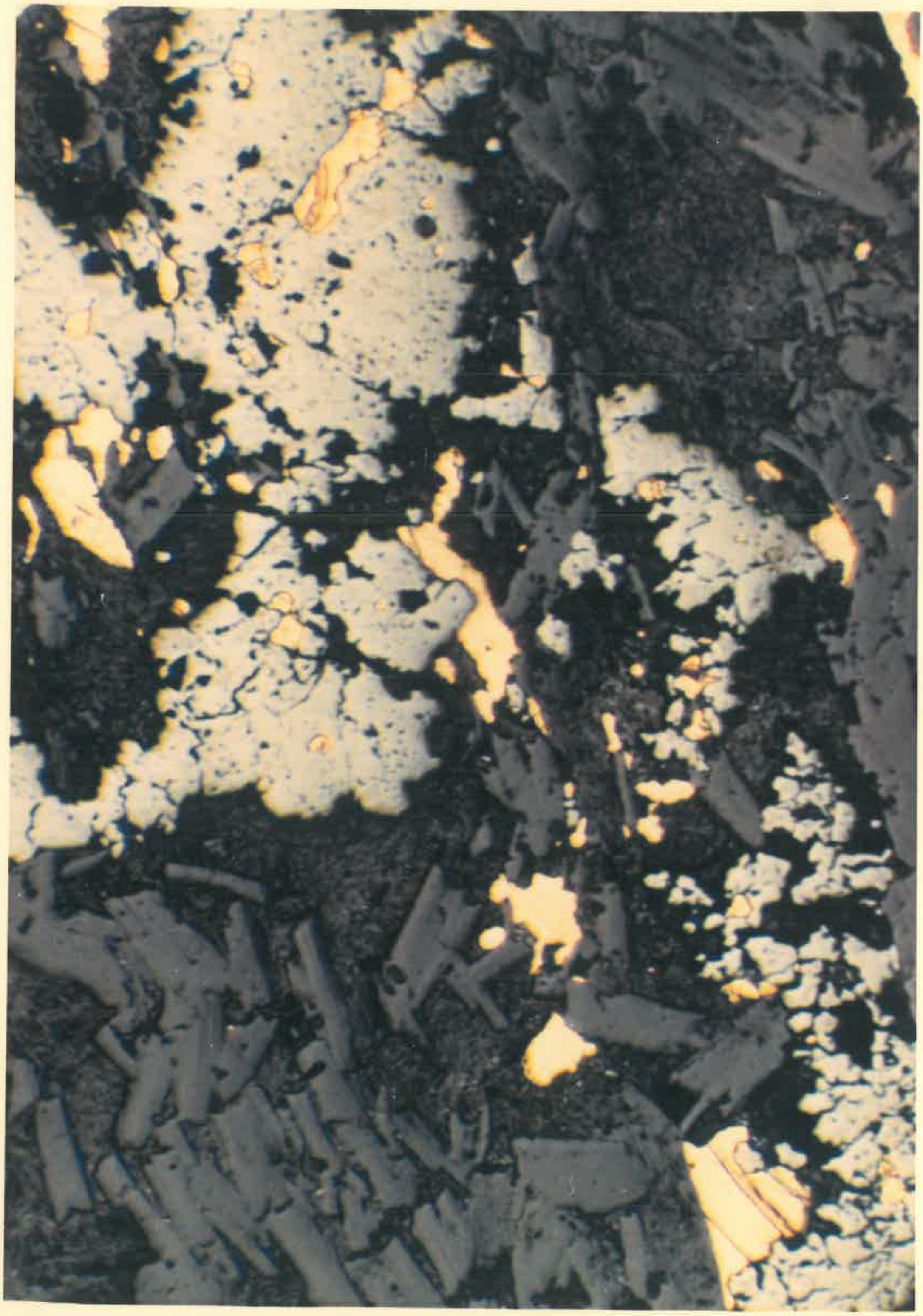
Volume I.

FRONTISPIECE.

A striking combination of advanced argillic alteration, iron metasomatism and bonanza gold shoot development in an area of pitch reversal in Noble's Nob Mine. Hydromica crystals, magnetite subhedra and gold almost completely replaced the fine textured, dark coloured shale host rock.

Polished section x 110, Kodachrome X film.



This thesis contains no material which has been accepted for the award of any other degree or diploma in the University of Adelaide, and to the best of my knowledge and belief, the thesis contains no material previously published or written by any other person, except where due reference is made in the text of the thesis.

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(in pocket at back)

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Bur. Min. Res. Publications.

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1. ABSTRACT.

The origin of the gold and base metal deposits in the Lower Proterozoic rocks of Tennant Creek is attributed to basic and intermediate intrusives which, by virtue of their undeformed fabric and field relationships, prove to be the latest igneous intrusives in the area. These intrusives penetrated the Archaean, and Lower Proterozoic rocks as well as the Middle Proterozoic granite plutons. The disseminated and vein-type epigenetic mineralisation which exists in the Archaean in proximity to these basic intrusives, provides a clue to the origin of both the gold and base metal deposits in the Proterozoic rocks.

The basic intrusives and the magnetite and pyrrhotite in the contiguous gneisses, account for the magnetic anomalies in the known area of Archaean. Basic intrusives with similar associated mineralisation may also occur in the deeper unknown areas of the Archaean basement where magnetic lineaments have been defined.

Similar sequences of wall rock alteration exist in both the base metal and gold deposits thus indicating that these have a common origin. The relative positions in depth of the gold and of the base metal deposits, correspond with the increase with depth of the intensity of wall rock alterations. Gold has a greater depth range than the base metal sulphides for it persists in all types of ore from the deepest sulphides to the shallowest auriferous deposits. The gold deposits contain little sulphide and the sulphide deposits little gold.

The Lower Proterozoic sequence embodies conspicuous tuffaceous facies, in which martite of volcanic origin is a widespread and

prominent clastic. Clastic sulphides are also present, but not in sufficient amount to provide for the base metal ore deposits. The partial solution of disseminated iron oxides in the zone of vadose waters and their subsequent redeposition in closed structures, gave rise to the prominent "ironstone lode formations". These are therefore essentially syngenetic in origin, progressively formed with continuous erosion, and confined to the oxidised zone.

The "ironstone lode formations" are not in themselves, manifestations of mineralisation but they indicate the existence of structures favourable to mineralisation. Those, which embody economic mineral deposits, occupy coincidentally with epigenetic gold or sulphides, the most fully developed structures and are gradational in depth into concentrated epigenetic magnetite with hydromicas, kaolin and muscovite, or with chlorite and talc.

The further development of the mineral resources of Tennant Creek may therefore depend upon the study of the distribution of the basic intrusives in relation to regional magnetic trends and upon the coincidence of these with deeply penetrating structures. This implies a much more extensive examination of the Archaean basement through deeper drilling than has previously been undertaken in the district, and will be aided greatly by concurrent studies of metasomatic rock alterations in the overlying Proterozoic rocks.

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The Board of Directors of Australian Development N.L., taking the opportunity to assist in a research programme, made available the facilities for field studies at Tennant Creek, and provided finance to cover travel, as well as the analytical services at the Australian Mineral Development Laboratories. Their liberal and cooperative attitude is gratefully acknowledged. During the early stages of this investigation, Mr. C. Wegener, then Chief Geologist for this Company, conducted the author on field visits and was most helpful in the discussion of various aspects of the geology. In many ways assistance was forthcoming from other members of the Company staff, especially Messrs. Mansfield, Roach and Turner.

The opportunity to visit, study and sample Peko, Orlando and Ivanhoe Mines was readily afforded by the Management of Peko Mines Ltd., and in particular, Mr. J. Elliston of Geopeko Ltd. provided stimulus and valuable information through both discussion and through his publications.

The author also had the opportunity on several occasions to discuss aspects of the work in the field with officers of the Bureau of Mineral Resources, in particular Mr. J. Ivanac and Dr. W. Oldershaw.

The final and arduous task of typing and proof reading this thesis was undertaken by my wife for whose patience and diligence I am indeed most grateful.

3. INTRODUCTION.

In the national interests, the sparsely populated Northern Territory should be developed and to this end, a major contribution can be made through the study of its mineral resources. One area of considerable geological complexity, which offers much scope for both basic and applied research, is the important mining centre at Tennant Creek.

Gold was first discovered in this area in 1895 by H.Y.L. Brown who was at that time, Government Geologist for South Australia. Shortly afterwards prospectors moved into the district, but on the experience they had gained elsewhere, they confined their attention to the prominent, but barren quartz reefs which outcrop in many parts of the field. Their ensuing lack of success delayed further work in the area for about 30 years.

Ultimately gold was observed in the "ironstone blows", which like the quartz reefs, are also prominent in the area. Thus, in 1933 the rich finds which followed, led to a gold rush and to the first stage of active mining.

In 1935 the Commonwealth Government initiated a systematic geological investigation at Tennant Creek as part of the "Aerial, Geological and Geophysical Survey of Northern Australia". It was fortunate that in the following year, a strong magnetic anomaly was detected at the site of the present Peko Mine. This justified diamond drilling which revealed at shallow depth, a high grade copper lode. From this time on, Tennant Creek became established as a mining field of considerable potential.

The investigations of the Bureau of Mineral Resources were subsequently maintained with the steady increase in mining activity and led ultimately to two major publications, the first by Ivanac and a second and supplementary one by Crohn and Oldershaw. In addition to Government work, detailed investigations in selected parts of the field, were commenced by Elliston of Geopeko Ltd., by Wegener of Australian Development N.L., and others, but the results from these are contained mainly within confidential company reports.

The experience of companies engaged in exploration during the past 15 years, has proved that the magnetic anomalies defined by the Northern Australia Survey constituted valuable information which led to the discovery of all major orebodies after 1950.

The stage has now been reached where the magnetic anomalies, other than those with very deep-seated centres, have been studied and, in most cases drilled. It has therefore become important to attain a further understanding of mineralisation with the object of developing other exploration procedure, to maintain progress in the district. The investigations by the Bureau of Mineral Resources, the C.S.I.R.O. and others led to the initial concepts of the structure, stratigraphy, mineralisation and the age relations of igneous rocks in the Tennant Creek field. It was concluded, as a result of these different studies by individual groups, that mineralisation of all types is associated with the ironstone formations. These formations are magnetic to varying degrees, and are a characteristic feature of Tennant Creek.

A different approach to the problem was employed in the investigations leading to this thesis by making abundant use of petrographic and mineragraphic techniques. This arose out of the author's belief that the manifestations of geological phenomena already recorded from the field by previous able workers, should be revealed in the fabric of both the ores and the country rocks. With this principle in mind, it was anticipated that new data would emerge and lead to a more complete understanding of mineralisation.

Rocks and ores were studied from the field, from underground workings and from numerous diamond drill cores. In addition, both field and underground mapping were carried out in specific places to ensure that the microscopic studies were maintained in proper relation to geological structure and other conditions.

The geology which is recorded in the Tennant Creek One-Mile Sheet was utilised as a basis upon which to commence the investigation. The additional structural and other data accumulated in the field during the course of the investigation, were used in conjunction with the Tennant Creek One-Mile Sheet to produce the geological interpretations presented in this thesis.

The conclusions arrived at differ from those of previous workers, in that the acid igneous intrusives are not regarded as the source of the ores in the Tennant Creek field. No evidence was obtained in the field, under the microscope, or in the results of spectrographic and chemical analysis to indicate that the outcropping granites or porphyries introduced copper or gold, or were responsible for the formation of the ironstone lodes.

The conclusions to this work are based on two main observations which have not been previously recorded. The first of these concerns the presence of basic igneous dykes with marginal sulphide mineralisation in the Archaean basement; the second is the widespread phenomenon of wall rock alteration associated with both the copper and the gold lodes. In the following pages the importance of these features is discussed and finally, they are interpreted in relation to the known geological and geophysical characteristics of the region.

These observations, considered in conjunction with other factors, show that both the base metal sulphides and the gold may have a common ultimate source in basic intrusives in the Archaean basement. The separation of minerals containing iron, copper, lead, zinc and bismuth as well as the gold, arose in the first place from the inability of these metals to enter silicate phases upon consolidation and partial differentiation of basic magma. Their subsequent transport through deeply penetrating shears, faults or breccias to loci of accumulation, was affected by the scavenging action of heated aqueous and chemically active fluids released progressively from the basic rock as it consolidated and differentiated.

The major metals, iron, copper, lead, zinc, gold and bismuth did not concentrate completely separately, but were spread in a sequence which is zonal in respect to depth. Therefore most orebodies contain variable amounts of all of these metals as well as minor quantities of silver, tungsten, molybdenum, etc. However, segregation did attain the stage where orebodies containing dominant copper, or consisting mainly of gold, formed independently at specific depths.

This partial segregation may be attributed in part, to the position in space of structures and lithologies favourable to mineralisation. However, the main control of segregation was essentially geochemical and may be correlated with the tendency of the separating metals to form a succession in accordance with increasing ionic radii and their preference for siderophile, thiophile or lithophile associations. Thus the major copper orebodies which occur at depths greater than those of the major gold orebodies, are associated with more basic and more intense manifestations of wall rock alteration.

The loci of accumulation of metallic material have common features in that they exist mainly in argillaceous facies which were involved in drag folded, or in brecciated structures, the former often displaying pitch reversal. Furthermore, the major gold deposits as well as Peko, the major copper deposit, exist in a common stratigraphic horizon, defined in this thesis as the "Specific Horizon".

With the addition of the theory presented in this thesis, there are now the following three schools of thought in respect to the origin of ore at Tennant Creek:

(1) an epigenetic hydrothermal origin invoking the acidic intrusives as source rocks. This view is held by most workers, especially those of the Bureau of Mineral Resources.

(2) a syngenetic origin based upon the colloidal transfer of metal components inherent in the sediments, followed by their subsequent concentration in pre-consolidation slump structures. This is the view held by Elliston of Geopeko Ltd.

(3) the hydrothermal concept presented in this thesis. This is based upon structural interpretation, upon the microscopic studies of both wall rock alteration and ore mineral textures, and upon the petrology of the Archaean basement.

In each hypothesis the movement of metals to areas of accumulation is implied hence there is general concurrence on this point. There is furthermore, little significant debate in respect to the nature of the areas of accumulation. Although it might appear that slumped structures are advocated in one point of view, these actually provided the inherent weakness in the rock fabric which facilitated the complex drag folding which, by another point of view, is said to have determined the loci of ore emplacement.

The difficult problem is to determine the source of the metals. The geochemical and mineralogical evidence produced in this thesis mitigates against a syngenetic origin within the sediments. It shows furthermore, that the older acidic intrusives have no unusual trace metal characteristics and no manifestations of contact mineralisation other than silicification and kaolinisation.

On the other hand, both abnormal trace metal contents and evidence of sulphide mineralisation at contacts, are revealed by the younger basic igneous rocks. These were intruded after the formation of ore-trapping structures and display no evidence of subsequent tectonic modification in their fabric.

Experimental drilling led to the discovery of both the buried Archaean and the younger basic intrusives south-west of Tennant Creek, thus providing an explanation for the deep-seated magnetic anomalies in this area. This initiated new thought on the origin of mineralisation in this area, and suggests that the probing of deep-seated anomalies elsewhere at Tennant Creek may not only assist in proving the origin of mineralisation, but may also lead to further ore deposits.

4. GEOGRAPHY AND ECONOMICS.

The Tennant Creek mining field is located in the centre of Northern Territory of Australia, approximately 1300 miles north of Adelaide and 700 miles south of Darwin. It is in the torrid zone some 250 miles north of the Tropic of Capricorn, Fig. 1. The region is semi-arid and receives an average of 14 inches of rain annually, mostly during the Summer season. This so-called "wet season" is hot with temperatures as high as 115°F, combined with moderately high humidity. The period from May to September is mild, dry and highly favourable for field exploration work.

The persistent south-easterly wind has prevented the accumulation of soils in exposed places, thus many bare rock outcrops prevail. Between the low hills there are broad expanses of flat "bull-dust" plains where spinifex grows in abundance and various gums and mulgas occur sporadically. Trees are more prolific along shallow water courses, in "soaks" produced by underlying clay pans, granite or porphyry bodies, and along lines of shear in the underlying bedrock.

The overburden which constitutes the "bull-dust" plains is of variable depth and character and consists mainly of transported materials. This does not always lie directly upon the solid underlying bedrock, but is in many places separated from it by grey or buff coloured, partially leached rock derivatives, thin poorly developed soil horizons, or by limonite-enriched residual surface gravel. These thin, residual or juvenile soil profiles exist at varying depths usually no greater than about 50 feet.

Where deep auger drilling was used in exploratory geochemical work, layers of wind-blown clays and fine sands, as well as layers of water-transported coarser sands, gravel and partially rounded boulders, were found to overlie the thin selvedge of materials developed in situ, on the buried bedrock surfaces. Thus the plains were formed over a long period during which there was an accumulation of transported rock degradation products from both wind and water. The gravels and boulders which lie near the base, or which may occasionally be found in thin layers at higher levels, consist of hematite-impregnated Warramunga sediments which have not travelled far from their source. The finer sands and clays, which are mainly wind-borne, may have distant origins and can cause considerable confusion in geochemical investigations.

The section in Fig. 2, which was plotted from auger drill traverses used for geochemical exploration, illustrates a typical subsurface profile and emphasizes the importance of orientation studies in geochemical work in this area.

The characteristic land forms throughout the field, except in the areas occupied by granite, are steep-sided, flat-topped hills of low elevation which derived their peculiar shapes in two ways. One of these relates to the juvenile stage reached in a new cycle of erosion following upon the recent uplift of the originally peneplained surface. The other, which is a preserved fossil feature from the original peneplain, is the widespread enrichment in limonite or in silica, which exists in the uppermost ten feet or so of bedrock. Silicification in the surface layers is a characteristic of the restricted terrains where quartzites of low iron content prevail, whereas limonite, derived from the martite present in all tuffaceous sandstones and shales, exists over most of the area. These hardened surfaces were not formed by the usual process of lateritisation, but were developed through the surface evaporation of ground waters which progressively leached silica or iron oxides from the underlying bedrock.

The economics of mining and the maintenance of a community in this part of the Northern Territory are quite important factors in the development of the natural resources. In order to maintain continuity of mining operations in this area where regular rainfall is restricted to a short period during the Summer season, much attention must be given to the conservation of water.

Underground water obtained from bores is normally used for mill treatment purposes and for rock drilling. Approximately one ton of water is required in the treatment of one ton of ore. Since the underground water is usually salty and is in limited supply, it is necessary to construct surface catchment dams to supply water for domestic services, engine cooling and for the maintenance of gardens. Although the economics dictate the construction of surface catchment dams, bores must also be sunk and maintained to guard against the dry "wet season" which occurs frequently.

Amongst other factors the cost of power and of transport in a remote area like Tennant Creek, adds considerably to the minimum grade of ore which may be economically mined. Thus in a moderately sized operation, copper ore containing less than 3% Cu. and gold ore containing less than 10 dwts. per ton, cannot be developed and treated.

5. REGIONAL GEOLOGY.

(1) The geological environment of the Warramunga Geosyncline.

The Tennant Creek mining field, located in the central portion of the Warramunga Geosyncline, is characterised by low grade metamorphic rocks belonging to the oldest stage of the Lower Proterozoic, Fig. 3. To the south, north and probably also to the west of Tennant Creek, younger members of the Lower Proterozoic overlie the Warramunga rocks and although angular unconformities have been observed in places, it is generally thought that there is little stratigraphic break. The younger Proterozoic rocks to the north are known as the Ashburton Sandstones and those to the south, as the Hatches Creek Group, and together these form major sediments of the Davenport Geosyncline. The characteristic rocks of the Lower Proterozoic are shales and tuffaceous sandstones, whereas the younger Proterozoics are essentially a purely arenaceous facies.

A hundred miles south of the Warramunga and Davenport Geosynclines strongly metamorphosed, more intensely folded and intruded rocks of Archaean age, form the stable and well-exposed Arunta Block. It is generally agreed that an Archaean Block, known as the Sturtian Block lies to the north of the Warramunga Geosyncline, but there are no exposures of this. (Hills 1947).

Both the older and younger Lower Proterozoic sediments were subjected to a major orogeny and uplift at the end of Lower Proterozoic time and the folded mountains that formed, were probably base-levelled before the end of Upper Proterozoic time, when Cambrian rocks were laid unconformably upon them.

Only remnants of the conglomerates and sandstones of the Upper Proterozoic, and of the limestones of the Cambrian, remain in the Tennant Creek area. It is clear that there has been a very long period of continuous erosion since Cambrian times during which the land was reduced to a peneplain and conditions of surface induration developed. Recent uplift rejuvenated erosion and the present topography is that of a dissected tableland.

(2) Mineralisation in PreCambrian rocks.

Noakes (1953) recognised three distinct manifestations of mineralisation in the Northern Territory, each of which has individual paragenetic characteristics and is related to specific conditions of orogeny and igneous activity. These constitute separate metallogenetic epochs, which have the following sequence and characteristics. It will be noted that Noakes postulates a granitic origin for most of the Lower Proterozoic base metal mineralisations.

(a) The Archaean Mineral deposits.

Pegmatites, presumed to be of Pre-Proterozoic age, are common in the Archaean complex of the Arunta Block, where they contain mica, cassiterite, tantalite and a variety of radio-active complex oxide minerals. The quartz-gold reefs of Arltunga were originally thought to be of similar age, but these are now considered to belong to the Lower Proterozoic metallogenetic epoch. This re-interpretation of Arltunga mineralisation, based upon more recent mapping by the Bureau of Mineral Resources, is more consistent with the characteristic paragenesis of Lower Proterozoic metallogenesis.

(b) The Lower Proterozoic Mineral deposits.

Both hydrothermal ores and ore-bearing pegmatites were introduced during the period of orogeny which closed Lower Proterozoic geosynclinal sedimentation. Manifestations of this mineralisation exist in many places, for example, in the Lower Proterozoic rocks of the Pine Creek Geosyncline, and in both the Warramunga and Davenport Geosynclines, Fig. 3.

In the northern portion of the Northern Territory, the separate fields of mineralisation in the Pine Creek Geosyncline have the following characteristic metal associations:- tin-tungsten-tantalite; gold-copper-arsenic-lead-zinc-silver; uranium-copper-gold-mercury. The association which exists between tin, tungsten and tantalite-bearing pegmatites or greisens, and the synchronous granite batholiths in the Darwin region can be demonstrated in the field. In different parts of the same region, hydrothermal deposits of uranium with associated copper, gold and mercury, appear upon field relationships, to be genetically related to granite of slightly later origin but still within the Lower Proterozoic. Quartz-gold reefs which contain minor quantities of the sulphides of copper, iron and arsenic, or of copper, lead and zinc, have no close association with visible granite, but Noakes considers it is reasonable to assume that they may.

In the central region of the Northern Territory, in the Warramunga Geosyncline, the characteristic metal associations are:- gold-bismuth; copper-gold-bismuth; and local lead-zinc-arsenic-silver. Deposits of these metals occur in Warramunga sediments which are almost fully encircled by Lower Proterozoic granitic rocks and related porphyries but a relationship with these is not indisputably established. However, in the western limits of the Warramunga Geosyncline some 200 miles from Tennant Creek, the quartz-gold-pyrite-arsenopyrite reefs of Tanami and the Granites, are quite clearly associated with granite intrusives.

In the southern part of the Northern Territory, in the Davenport Geosyncline, the association of granite with mineralisation is apparent at Wauchope, Barrow Creek and elsewhere. At Wauchope, highly siliceous apophyses which emanate from a granite pluton contain wolfram-pyrite-chalcopyrite-molybdenite-bismuthinite assemblages in a quartz-topaz-fluorite gangue. Further south, the copper deposits of Barrow Creek, the copper-bismuth deposits of the Jervois Ranges and the tungsten veins of Hatches Creek are not found in direct association with acidic plutonic rocks, but it is assumed that underlying granite exists. Some 50 miles east of Wauchope syngenetic copper, lead and zinc sulphides fill vesicles in spilitic basalts which occur as submarine lava flows in the Younger Proterozoic sediments.

(c) The Upper Proterozoic and later Mineral deposits.

Until recently there were only a few insignificant, epithermal type ore deposits of copper, and of lead-zinc, known in the younger rocks in the north-eastern part of the Territory. The copper deposits occur as open space fillings in lavas and the lead-zinc deposits are replacements in Cambrian limestones. None of these has so far proved to be of economic value. However, the discovery of a large deposit of conformable stratiform lead-zinc-silver ore near the MacArthur River in Queensland may ultimately raise the status of the Upper Proterozoic sediments as hosts to mineralisation.

Nevertheless, the major economic mineral deposits of the Northern Territory, appear to have been derived during the Lower Proterozoic Metallogenetic Epoch and many of these can be related to Lower Proterozoic granites. Noakes (op.cit) considers however, that there may have been more than one metallogenetic epoch during Lower Proterozoic time related to different stages in the orogenic activity.

The ore deposits of Tennant Creek are the most important of the Lower Proterozoic mineralisations and continue to support the principal mining industry of Northern Territory. Discoveries of ore have been mainly confined to the area covered by the Tennant Creek One-Mile Sheet because so little is known of the surrounding country which is largely sand-covered. However, in recent years with the aid of aeromagnetic maps, geochemical techniques, versatile transport and mobile drilling equipment, exploration has extended, particularly in a westerly direction, with the result that several new orebodies have been discovered.

Following upon the results from recent geological mapping, and from recently completed age-dating of granites in the Northern Territory, some adjustments to the foregoing outline of the geology and mineralisation will become inevitable. In their latest paper on this subject Walpole, Roberts and Forman (1965) discuss these new concepts.

Geological mapping in certain areas has shown that some of the rocks previously regarded as Lower or Upper Proterozoic, now appear to belong to the Middle Proterozoic. At the time of writing, these re-interpretations had not been applied to the Warramunga sediments, although there was some suggestion that the Ashburton sandstones to the north of Tennant Creek, might be reclassified as Middle Proterozoic.

The chronological investigations on granites in the northern part of the Territory returned ages in the 1700-1800 million year range which relegates them to Middle rather than Lower Proterozoic time. Hence, the mineralisation thought to be associated with these may also be Middle rather than Lower Proterozoic in age.

These authors postulate that there was a major metallogenetic epoch in the Middle Proterozoic to which the intrusion of the granites may be related. Hence, the copper-gold deposits of Tennant Creek are also regarded by them, as possibly Middle Proterozoic in age.

P A R T I.

THE GEOLOGY OF THE TENNANT CREEK DISTRICT.

6. THE GEOLOGY OF THE TENNANT CREEK DISTRICT.

(1) Previous and current investigations.

The early reports by Woolnough (1936), Rayner and Nye (1936), Richardson and Rayner (1937), Richardson, Rayner and Nye (1936), Daly (1957) and others, dealt with specific aspects of Tennant Creek geology. The first comprehensive publication which co-ordinated the geology, structure and mineralisation of the field was Bulletin 22 of the Bureau of Mineral Resources, produced by Ivanac in 1954. This was followed in 1964 by a further publication from the Bureau of Mineral Resources, prepared by Crohn and Oldershaw to supplement Ivanac's work with the addition of petrological and other studies.

The work of the geologists associated with the two mining companies in the district is of considerable importance and has provided much detail in certain areas, but this information is unpublished and may remain so for some time to come. For some years, the author has been the consultant geologist for Australian Development N.L. which operates Noble's Nob Mine and has also had some liaison with Peko Mines Ltd. These capacities have facilitated access to materials and data of great value in pursuing a fundamental study of the paragenesis and origin of the ores.

Over a period of several years, Edwards and Stillwell of C.S.I.R.O. Mineragraphic Section issued a series of mineralogical reports, which will be referred to in subsequent sections. These reports gave the first detailed descriptions of the compositions and textures of the ores from several parts of the field.

Since a number of investigators, specially skilled in different aspects of geological research, have studied the Tennant Creek field, it might appear that there is little point in pursuing the subject further. However, in comparison with most other mining fields in this country, Tennant Creek has had little enough attention in respect to its importance to the future of economic mineral development in Northern Australia.

The principal function of the geologists of the Bureau of Mineral Resources was to produce the Tennant Creek One-Mile Geological Sheet, the supplementary aeromagnetic maps and to study special aspects of the geology which would best assist the Mining Industry. See rear pocket.

The work of the company geologists has of necessity been restricted mainly to the areas over which specific Leases, or Authorities to Prospect, have been held. And, as dictated by the usual urgency of company exploration and development, these geologists are allocated little or no time for research purposes.

On the other hand the investigations by the C.S.I.R.O. were more specific and dealt in detail with mineralogical problems encountered by the companies in the course of their operations. Out of this emerged the first mineralogical information from which concepts of paragenesis might be deduced.

It was not however, the function of any of these groups of investigators to carry out basic research throughout the whole field, since each had a restrictive practical purpose to serve.

The opportunity was therefore available for the author to carry out a detailed and more fundamental investigation on all phases of Tennant Creek geology and mineralisation, unrestricted by specific practical limitations. The basic mapping, statistical data on productions and a certain amount of mineralogical information was already available to provide a starting point. It was anticipated, that out of this research might emerge a clearer understanding of mineralisation phenomena, and at the same time, the practical end might also be served in formulating a fresh approach to exploration.

In spite of the efforts of all past investigators no finality was reached in respect to the origin of the ores and the search for new mineral deposits continues on the originally-defined basis of testing ironstone lode formations. This in itself, justifies any further attention which might be given to the difficult problems of Tennant Creek geology.

(2) General Geology.

The oldest rocks in the area are the Archaean gneisses which do not outcrop but were found during drilling, to exist under desert sands in the south-western corner of the area. The overlying Lower Proterozoic sediments form the most prominent and widespread rock outcrops in the area, although they are considerably dissected and often covered by transported overburden.

Upper Proterozoic, Cambrian and Tertiary rocks have been largely removed by erosion but remnants remain mainly on the northern, north-eastern and southern flanks of the field, as flat-lying higher level formations.

The following sequence, Table 1, prepared by Crohn and Oldershaw (1964) is similar to that originally proposed by Ivanac (1954). It includes the manifestations of igneous activity and mineralisation within the Proterozoic, both of which occurred at a stage somewhat younger than that during which the Warramunga sediments were formed.

The Upper Proterozoic and later sediments in the district were not mineralised. This study was therefore confined to the older rocks containing the ore deposits of Tennant Creek, and little work was done on the younger rocks. In the following pages the results of the petrographic, mineragraphic and other investigations of the Archaean and Lower Proterozoic rocks, are discussed.

(3) Structure.

The mapping of the structure of the sedimentary rocks and of the boundaries of the principal igneous rocks was completed by Ivanac in 1954 (op.cit). Although there has been no significant modification to Ivanac's map, the recently published Tennant Creek One-Mile Geological Sheet presents much more detail of the structural relationships between adjacent areas of outcropping rock, as well as an improved differentiation of the rock sequence on a lithological basis.

Geological mapping at Tennant Creek is difficult, and the correlation of most of the sediments over large distances is virtually impossible because there is an absence of persistent marker horizons. This difficulty is further aggravated by the rapid facies changes which occur both vertically and laterally in the sedimentary sequences. Fortunately, there are thin, but conspicuous hematite-quartzites and

TABLE 1.

Stratigraphic Sequence.

Sequence	Formation	Description
Recent		Alluvium, creek gravels, bull-dust, etc.
Tertiary?		Unconsolidated and poorly consolidated sands, clays, grits and gravels, in part lateritised.
Lower Middle Cambrian	Gum Ridge Formation	Calcareous sandstone, shale, and chert.
? Lower Cambrian	Helen Springs Volcanics	Lavas and pyroclastic rocks.
? Proterozoic	Rising Sun Formation	Conglomerate, sandstone and quartzite, shale.
* Igneous activity and mineral-isation	Late phases	Diorite, dolerite and lamprophyre dykes, ? in part post-dating Rising Sun Formation.
	Early phases	Granite, adamellite, porphyry, quartz veins, quartz-magnetite and quartz-hematite lodes, gold and sulphide orebodies.
** ?Protero-zoic	Ashburton Sandstone and Hatches Creek Group	Sandstone, conglomerate, and quartzite.
Lower Proterozoic	Warramunga Group	Greywacke, siltstone and shale, minor grit and pebble beds, hematite shale.
? Archaean	From diamond drill holes in B.M.R. Reserve No. 3 area.	Quartz-felspar-garnet gneiss, amphibolite, magnetite schist, granitic and gabbroic intrusives.

*, ** now regarded as Middle Proterozoic, vide Walpole, Roberts and Forman, (1965).

hematite-shales in the monotonous sequences of shales and tuffaceous sandstones, and although these permit structures to be followed for considerable distances, they are inevitably interrupted by "bull-dust" plains, and by numerous faults.

An attempt was made in this study to formulate the structural pattern of the field because of its anticipated importance in the origin of mineralisation. The plan and sections shown in Plates 1 and 2 present an interpretation of the structural pattern arrived at by linking together the known hematite-quartzite, or shale horizons, and the majority of the ironstone "lodes", into one specific stratigraphic horizon. The structural data recorded on the Bureau of Mineral Resource's Tennant Creek One-Mile Sheet, was used initially and was supplemented by the author's own field observations. In certain areas, especially between Eldorado and Red Terror Mines, detailed mapping was carried out, supported by oriented thin section studies, to obtain precise structural detail from the homogeneous, apparently massive sediments. It was found that only through thin section examination could bedding be clearly defined, and its relationship to cleavage fully established.

It is difficult to outline a simplified concept of the Tennant Creek field because it was rendered very complex by both folding and faulting. Ivanac presented a simple tectonic sketch in Bulletin 22 (1954,p.35) and a modified form of this appeared again in 1964, on the Tennant Creek One-Mile Sheet. Both sketches accentuated the major structural features which include; several separate systems of faulting , the principal folding on east-west axes, and recurrent pitch changes related to weaker superposed folding on north-south axes. The salient features of these major structures are as follow.

In the southern and south-western parts of the field, the rocks are strongly folded along east-west axial planes. Fold limbs are generally steep and symmetrically inclined. The folding is less intense in a northerly direction and at the contact with the Station Hill and White Hill Granites, the beds dip to the south with little significant folding. The folding in the down faulted eastern block is also comparatively mild and the inclination of the limbs flatten. Throughout the whole area the cleavage is east-west and steeply dipping, although variations occur in certain restricted areas through complex localised folding.

The prominent Station Hill - Rocky Range Fault, which Ivanac traced for 46 miles, divided the field into two areas with distinctive structural characteristics. It was concluded that the movement along this fault was essentially vertical and that the north-east block moved some 5000 feet downward (Crohn and Oldershaw, 1964).

Warramunga rocks which occur on the depressed eastern side of the fault are largely obscured by remnants of the overlying Cambrian limestones and volcanics. The offset of the granite at its intersection with this fault, indicates that it was established after the intrusion and consolidation of the Station Hill Granite. The fault also displaced the line of gold mineralisation which extends from the True Blue Mine to the New Moon Mine, from which it may be inferred that it post-dated mineralisation.

The second prominent structure is a broad photolinear feature which trends north-easterly but does not, unfortunately, intersect outcropping country rock. Its presence was confirmed in the south-western part of the field by a series of bores in the granites of the Cabbage Gum Basin, where manifestations of pneumatolytic alteration of both the granite and the country rocks, may also be observed.

This structure continues in a north-easterly direction, completely obscured by transported soil. It extends past Peko, but does not intersect, or appear as a photo feature beyond the 46-Mile Fault. There are no significant horizontal displacements along this structure and it will be seen from Plate 1, that structures in rocks either side of it, are virtually continuous. This photolinear feature was developed in the southern granites after their consolidation, for mylonitic structures exist in samples of granite obtained from drill holes.

The pneumatolytic modifications of the stressed granite and country rocks in this structure, in proximity to the most important gold deposits in the field, may be manifestations of certain phases of hydrothermal mineralisation. This will become apparent in later sections of this thesis, but at this stage it is important to stress that the photolinear probably acted as an escape route for the fluids involved.

This structure remains an enigma. Its surface expression, manifest in the colour of soils, the density of vegetation and the distance between bedrock outcrops either side of it, suggest a width of nearly one half mile. It is therefore unlike the common faults of the Tennant Creek area, and may be in part, a wide zone of brecciation.

There are also numerous shears, faults, or breccia zones of lesser magnitude and continuity which may be classified into groups according to their respective orientations. These were described in detail by Ivanac (1954) and later by Crohn and Oldershaw (1964).

The shears and fractures which trend north-west and parallel to the Station Hill - Rocky Range Fault, as well as those which trend north-east, are usually filled by barren quartz. Subsequent movements along these faults are manifest in separate stages of secondary quartz impregnation which are visible only in thin section studies of the fabric of these reefs. The original fracture fillings of quartz, enclosed brecciated fragments of Warramunga rocks, granite and porphyry broken from the walls of the reefs. Later movements again fractured these consolidated aggregates which were then healed by further stages of quartz vein fillings.

The earliest and most important set of shears, breccia zones and faults trends in general east-west, although they vary in places to east-north-east, or to west-north-west. Most of them contain magnetite or hematite, with or without quartz and they are of significance because they are the locus of the presently known copper and gold ore deposits. The quartz occupying these structures contains chlorite, which when sufficiently abundant, reveals the presence of numerous closely spaced vertical surfaces of differential movement within the reefs. The surfaces are strongly slickensided and the grooves plunge steeply east or west within the planes of differential movement. It is considered here, that these lineations may be of special significance since they will be shown in a later section to have an orientation comparable with that of the bonanza ore shoots within the Noble's Nob orebody.

Previous workers considered that the movement along these structures was mainly vertical as in the 46-Mile Fault, but the lineations suggest steep easterly, or steep westerly differential movement.

A subordinate group of discontinuities which trend mainly to the north but occasionally slightly to the east or west, are tension fractures with distinctive crustified crystalline quartz filling. These fractures which intersect the Upper Proterozoic Rising Sun Formation are later in origin than all other faults.

The interpretation plan and sections, Plates 1 and 2, incorporate the major structural features outlined above. These Plates also contain the detailed mapping carried out in the more complex areas, as well as the broad classification of facies arrived at from the lithological studies made throughout the field.

It would be a very long task to study detailed structure throughout the whole field thus, for interpretative purposes, one which encompasses the bulk of gold production was selected. The selected area was that including Eldorado, Noble's Nob and Rising Sun Mines.

Lithological studies, structural observations, and a consideration of the distribution, tenor and production of the numerous gold orebodies, suggest that mineralisation was largely confined within one horizon. This is defined here as the Specific Horizon and it encloses most of the hematite lenses and all of the hematite-quartzite, or hematite-shale marker beds. The Horizon so-defined, has a general east-west strike and is repeated in outcrop three times by two principal fold axes. The folding also determines, that in the north the horizon favourable to gold occurrences extends out of the field in a westerly direction, whereas in the south it leaves the field in an easterly direction.

This interpretation accounts for the occurrence of most gold lodes in the drag folds in the limbs of the two major structures. In these situations, many lodes are also specifically controlled by shears within the folds. It is furthermore apparent that the more important gold orebodies such as Eldorado, Explorer 8 and Noble's Nob are located at the positions of pitch reversal within the drag fold complexes. Noble's Nob, which is the major gold producer is probably the best example of this, as may be seen from its complex structure illustrated in Figs. 54 and 55.

The key to this interpretation is the principal anticline which extends from the Rocky Range area through to Skipper Extended Mine six miles west of Eldorado, linking together the groups of hematite lenses, hematite quartzites and gold mines on either side of it. The western limit of this anticline is sheared by the east-north-east trending fault extending from Skipper Extended through to, and beyond Tennant Creek.

The dominantly arenaceous rocks in the Rocky Range region trend east of the major north-west - south-east faults and are lost under desert sands and the flat-lying Cambrian rocks. A comparable and dominantly arenaceous sequence south of the contact of the White Hill Granite is thought to be this horizon reappearing as the north limb of the major syncline. However, through lack of sufficient outcrop this is conjectural and the principal evidence for the existence of a major synclinal axis are the south dipping, continuously faulted and drag folded hematite quartzites and associated hematite lenses which extend east-north-east from Tennant Creek.

The dominantly argillaceous rocks enclosing the Station Hill Granite are involved in a major anticlinal structure along the western contact of the granite. It is postulated that this structure continues with a single broad pitch change through to White Hill. The flatter dips and more open folds determine the broader surface exposures of argillaceous rocks in the northern area compared with the less extensive outcrops of the southern areas, where the dips are steeper.

The smaller granite plutons in the north and in the south-east, therefore appear to have been emplaced with irregular transgression of the sediments, in anticlinal structures rendered partly domal by cross folding. The larger granite pluton in the south exhibits little apparent relationship to structure except for its easterly projection along a probable synclinal axis in the extreme south-east of the area.

The porphyry intrusives, taken together, form a group which trends diagonally across the two major folded structures. However, the individuals within this group are broadly conformable with the east-west trends. Thus, the larger ones are located in the axes of minor folds while others occur along the east-west faults. An en echelon disposition of individual intrusions is the resultant pattern. It is also apparent that most of the porphyry is confined to the steeply dipping, more intensely folded sediments.

Pitch reversal is an important structural characteristic of the Tennant Creek field and this is most strongly expressed in the major anticline which takes in the main gold producers in the southern area. Generally the pitch reversals involve only 20° total variation in the inclination of the fold axes, but an exception exists at Noble's Nob where there is about 60° change in inclination.

It is much more difficult to determine structure in the argillaceous rocks in the northern areas, but the general impression is that pitch changes are less frequent and of less intensity.

The main trends in pitch change along the major fold axes are sympathetic throughout the field, and may be attributed to subsequent folding on a north-south anticlinal axis centred about Tennant Creek, and on a synclinal axis centred some 10 miles to the east of Tennant Creek.

The progressively decreasing south dip of the axial plane of the main anticline from east to west, where it is almost horizontal, is the most striking feature displayed by the interpretation sections, Plate 2. The reason for this is not apparent.

The most easterly section, C - C in Plate 2, suggests that the dislocations along the north-west - south-east faults trending through Rocky Range were of the horst and graben type. There may also be some translation movement on the east-west fault to the south of Rocky Range. The probability of the displacement of the horizon favourable to gold accumulation, has an importance in exploration procedure and dictates the need for a much more detailed study of the structures in the south-eastern area.

(4) Metamorphism.

Most of the sediments in the Tennant Creek area display little evidence of metamorphic modification other than the partial or complete alignment of clastic micas. In only a few instances, e.g. near Rocky Range, was the incipient recrystallisation of clastic sericite to larger muscovite flakes observed.

In proximity to shears, the clastic micas and chlorite show more advanced recrystallisation until at the shears themselves shales or mudstones develop into slate or schist, and the tuffaceous arenites adopt distinct cleavage. There is however, a much greater increase in the amount of chlorite, and in the amount and grain size of sericite-muscovite in the rocks in the approaches to shears mineralised in base metals and in gold respectively. This phenomenon is distinct and is the result of metasomatism rather than metamorphism. It is discussed in detail in a later section where, as part of the sequence of wall rock alterations, it is important in the problem of mineralisation.

There are two surface examples of extreme metasomatic modification in which tremolite, actinolite and talc occur in areas where no sulphide mineralisation has so far been detected. There is however, martitised magnetite in these rocks and they may not be regarded as metamorphic products. The areas referred to, near Red Bluff and south of Mary Lane Mine, have been previously plotted on maps as asbestos occurrences.

The basement rocks on the other hand, are very considerably metamorphosed and form the subject matter of the next section.

7. THE ARCHAEAN BASEMENT.

(1) General characteristics.

Archaean rocks do not outcrop on the Tennant Creek field, but they were encountered in holes drilled for Australian Development N.L. to test magnetic anomalies in the B.M.R.3 Reserve Area, 19 miles west-south-west of Tennant Creek, Fig. 4.

The drill holes were distributed over an area of about four square miles and each is sited on a separate magnetic high. The profile in Fig. 5 illustrates the magnetic contrast between the areas drilled and the surrounding terrain. The cores from the several holes portray a wide variety of igneous and metamorphic rock thus indicating that there is considerable complexity in the Archaean basement in this area.

The detailed microscopic study of these cores led to the recognition in the Archaean gneisses of both intrusive igneous rocks and epigenetic sulphides of post-metamorphic origin. Since these intrusives and sulphides bear certain similarities to those which exist in the overlying Proterozoic rocks, their significance to the study of mineralisation is established.

Sandy plains obscure the bedrock for many miles in and around the B.M.R.3 Area, but the presence of outcropping Warramunga rocks to the south, east, north-west, and in D.D.H. 168 six miles to the north, suggest that the Archaean is not present at shallow depth, other than in the immediate environment. At B.M.R.3 it may be an elevated inlier positioned by faulting.

An ancient pediment of hematite-quartzite and hornblende-bearing gneiss almost wholly obscured by sands, but displaying a distinct east-west trend and a steep northerly dip, occurs for one and a half miles north of the B.M.R.3 Area. It forms a scarcely discernible ridge with an elevation of one or two feet and a general trend of 285° magnetic. Sporadic outcrops of cellular limonite-impregnated breccia, also following this general trend, occur immediately north of B.M.R.3 Reserve. Attempts to penetrate these limonite masses by drilling were frustrated by the existence of numerous underground cavities and interspersed patches of highly silicified fractured rock and it was concluded that they signify a faulted contact, trending 285° magnetic, between the Archaean inlier and the Proterozoic rocks to the north. Fig. 4.

There is no positive evidence of outcropping Archaean rocks on the south side of B.M.R.3 Area, where again sandy plains obscure the surface geology. However, some five miles south, discontinuous outcrops of kunkar rising several feet above the plains, trend at 285° for about 15 miles. These outcrops, as well as the kunkar around the shallow playa lake four miles south-east of B.M.R.3 Area, may be the surface expression of underlying plagioclase gneisses or igneous rocks.

The first exposure of Proterozoic rock exist eight miles south of B.M.R.3 Reserve, where a folded basin structure in grits, quartzites and jaspers with secondary hematite, occupies an area of about three or four square miles. It is therefore probable that the Archaean is also isolated from Proterozoic rocks on the southern side by another completely obscured fault.

Unbroken sandy plains extend indefinitely to the westward but twelve miles east, Warramunga sediments outcrop, and subsurface granite was encountered in the shallow bore holes of the Cabbage Gum Basin. The Archaean may extend as far east as the Cabbage Gum Basin for portions of gneissic or schistose rock, unlike Warramunga sediments, were found with the granite in the cores from the bores. While the Archaean metamorphics may form a faulted inlier elongated in an east-west direction, and extending into the Cabbage Gum Basin, it is also probable that the Proterozoic granite intrusive reaches westward, at increasingly greater depths into the Archaean of the B.M.R.3 Area. The acidic intrusives which were intersected in the drill holes in the Archaean, are probably comagmatic with the Cabbage Gum Granite and may be simply apophyses from it.

(2) Metamorphic petrology.

The study of the drill cores revealed that the types of sediments which gave rise to the metamorphics of the B.M.R.3 Area included shales, quartzites, iron formations, greywackes, tuffs, basic volcanics and highly carbonaceous shales. The metamorphic rank is higher in the east where rocks of the sillimanite zone occur, and somewhat lower rank in the west where rocks of the garnet zone are dominant.

The highest grades of metamorphism were revealed in the cores from D.D.H. 158 and 163. The profile of one of these, viz. D.D.H. 158, is illustrated in Fig. 5. Most of the rocks from these drill holes are moderately high grade regional metamorphics appropriate to the amphibolite facies among which, the two subfacies, the sillimanite-garnet and the garnet-diopside-hornblende are the most common.

Departures from the typical mineral assemblages occur where the sediments were of unusual composition, or where there was the superimposed influence of the post-metamorphic intrusives.

Grunerite-garnet gneiss occurs at several positions in D.D.H. 158, and although it has an influence on the magnitude of the magnetic anomalies, it is not in sufficient abundance to be a dominant factor.

Lit-par-lit injection foliae made up principally of quartz and felspar in graphic intergrowth, are common in the foliae of the gneisses. Quartz, felspar and mica, existing under a condition of disequilibrium at these high grades of metamorphism, are dispersed amongst garnet, sillimanite and andalusite in gneisses of the sillimanite-almandine subfacies.

Although gneisses containing abundant idiomorphic almandite, with sillimanite, quartz and biotite are the most common, some contain also small amounts of andalusite. The anomalous appearance of andalusite may be attributed to the local temperature increase in proximity to post-metamorphic intrusive igneous rocks.

The gneisses of D.D.H. 158 were derived mainly from normal arenaceous and argillaceous sediments, although the incidence of grunerite indicates that there were some highly ferruginous intercalations.

Banded or granulose coarse grained rocks, composed of hornblende, diopside and garnet, are prominent in D.D.H. 163. Although the proportions of these major components, as well as those of the accessory quartz, micas and plagioclase, are variable, it may be deduced that most of these rocks were also derived from igneous rocks, tuffs or greywackes.

Somewhat lower grades of metamorphism which represent the garnet zone, were attained by the rocks penetrated in D.D.H. 161, situated three miles west-north-west of D.D.H. 158. The bulk of these rocks conforms to the assemblages of the chloritoid-almandine subfacies, but many have the special characteristic of abundant and widespread graphite. In many instances these rocks contain as much as 10% graphite in well-oriented flakes, which were responsible for some of the strong Induced Polarisation anomalies in this area.

Sillimanite was not found in the rocks of this western area but hornblende, actinolite or tremolite which are major components in many, are intergrown with garnets, quartz, biotite and acid plagioclase. The original sediments may therefore have contained more basic materials such as the components of tuffs or greywackes.

Although the quartz-biotite-garnet gneisses towards the bottom of D.D.H. 161 contain as much as 20% hematite and about 5% magnetite, no grunerite is visible in them. In view of the abundance of quartz in these gneisses and the presence of much garnet and biotite, it is probable that the iron oxides are epigenetic components, otherwise some reaction between these components at this grade of metamorphism might be expected. Both the hematite and magnetite are subhedral, elongated in the foliation of the rock and associated mainly with biotite. Although the textural relations yield no positive evidence of the replacement of biotite by the iron oxides, the presence of many transgressive quartz-felspar veins in the gneisses containing the iron oxides, suggests these are of epigenetic origin.

(3) Igneous petrology.

It may be seen from the profile of D.D.H. 158, Fig. 5, that there are many dykes or sills of igneous rocks including acid, intermediate and basic varieties. These rocks display varying degrees of departure from the normal textures and mineralogical constitutions appropriate to igneous rocks. In some, not only were the rock textures modified, but the incipient growth of metamorphic minerals may be observed within the primary mineral fabrics. In others their original massive structures are retained and they are composed only of primary igneous mineral assemblages, from which it may be assumed, that they were emplaced after metamorphism. These unaltered igneous rocks may therefore be comagmatic with similar dykes of unmodified structure and composition, which penetrate the Lower Proterozoic rocks and appear at the surface.

A typical older acid intrusive of some 23 feet thickness occurs at 440 feet depth in D.D.H. 158. The fractured and corroded phenocrysts in this microcline porphyry, and the incipient growths of garnet in its completely chloritised groundmass, indicate that it was at least partly involved in high grade metamorphism.

Somewhat later in origin are the gneissic sodic microgranite dykes of 30 feet maximum thickness which occur at 610 feet, 700 feet and 820 feet. These exhibit only structural modifications. Dykes of microdiorite, which occur at depths greater than 1000 feet were modified to hornblende-biotite-felspar gneisses without any mineralogical reconstitution, Fig. 13. The modification of these rocks may therefore have resulted only from the effects of dynamic metamorphism incurred during the folding of the Lower Proterozoic sediments. These then, might be taken into consideration with the unstressed gabbroic rocks with which they are closely associated.

Towards the bottom of D.D.H. 158, eighty feet of massive fine grained, sulphide-bearing quartz dolerite and somewhat coarser gabbro, was intersected but unfortunately this was not fully drilled and its full thickness remains unknown. This rock is of considerable interest for it exhibits neither structural nor mineralogical modifications and it was therefore injected after Proterozoic metamorphism was operative. Its upper surface merges into very coarse grained biotite-amphibolite which forms a transitional zone to the hornblende-garnet gneisses above.

Intrusive rocks are less common in the other drill holes in B.M.R.3 Area, possibly because they are not as deep as D.D.H. 158. In these shallower holes there are dykes of massive, unmodified leucoadamellite which are comparable with the late phase injections associated with foliated granitic rocks in the Lower Proterozoic sediments to the north and south of Tennant Creek.

The older, highly modified igneous rocks are not significant in the study of ore paragenesis, since they can be assumed to be older than Lower Proterozoic. The younger intrusives however, originated after the period during which the conditions of high grade regional metamorphism prevailed within the Archaean rocks, and subsequent to the tectonic disturbances in the overlying Lower Proterozoic rocks.

These must therefore be considered in the problem of ore genesis, since they were generated at a period comparable in age to that of the ore-bodies.

The older intrusives do not exhibit any significant association with the opaque mineral components of the contiguous metasediments. On the other hand the younger, deeper seated and more basic intrusives not only contain unusually large amounts of opaque primary oxide and sulphide minerals, but the gneisses which they penetrated were impregnated by significant amounts of magnetite, pyrite, pyrrhotite and chalcopyrite.

(4) Mineralisation and its implications.

Although the drilling of the magnetic highs in the Archaean failed to satisfy the requirement for a commercial copper mining project, the results provided data of value in the study of ore genesis. The positions of the four main bores are shown in Fig. 4, in relation to ground magnetic contours. Three of these holes provided examples of disseminated epigenetic sulphide mineralisation in deep-seated environments in rocks much older than those presently known elsewhere at Tennant Creek.

The intensity of mineralisation is highest in D.D.H. 158, moderate in D.D.H. 161 and 163 and meagre in D.D.H. 162. The changing intensity of mineralisation corresponds to some extent with that of metamorphism, but the importance of the latter may have been mainly that of providing a more coarsely crystalline, lineated rock fabric more susceptible to epigenetic mineralisation. The principal factor which determined the degree of mineralisation was clearly, the presence of quartz dolerite and gabbro in D.D.H. 158.

Only traces of pyrite mineralisation were encountered in the quartz-biotite-garnet gneisses of D.D.H. 162 and no intrusive rocks were encountered.

Drill hole No.161 penetrated gneissic rocks of the albite-epidote-amphibolite facies to a depth of 722 feet and, in the vicinity of 520 feet, encountered only one leucoadamellite intrusive. At depths below 550 feet, there are no sulphides but large amounts of hematite and minor magnetite which together, constitute in some instances as much as 25% of the bulk of the rock, Fig. 6. It is not possible on the basis of present data to establish whether these oxides are indigenous or epigenetic components, but in either instance there is insufficient magnetite to account for the magnetic anomalies. It is hoped that this drill hole may eventually be deepened to test for the presence of basic rock below.

D.D.H. 163 penetrated garnet-diopside-amphibole granulite to a depth of 550 feet and encountered a few dykes of pegmatite, biotite granite and lamprophyre. There are intermittent concentrations of sulphides throughout the core and frequent thin veins containing various assemblages of felspar, apatite, sphene, ilmenite, pyrite, chalcopyrite and calcite. Figs. 14 - 17. Chalcopyrite, pyrite and calcite occur in transgressive veinlets. Ilmenite and sphene occur in quartz-felspar veinlets, but may also permeate intergranular areas of the granulite in company with pyrite. The sulphide veins generally transect the ilmenite veins which suggests these are later in origin. The pyroxene-garnet granulite was altered to hornblende and chlorite along the borders of the felspar-sphene-ilmenite veins which suggest that these were hydrothermal veins possibly related to the lamprophyres.

Drill hole No.158 penetrated high rank gneisses of the amphibolite facies to a depth of 1305 feet and encountered a greater abundance and variety of igneous intrusives than the other drill holes. The most significant of these is the quartz dolerite of at least 80 feet thickness near the base of the drill hole, Fig. 8.

The quartz dolerite is of massive structure and is composed mainly of labradorite and diallage with subordinate accessory quartz, hornblende, biotite, apatite and opaque minerals. Graphic intergrowths of both quartz and felspar and of pyroxene and ilmenite, Fig. 10, are common in the rock. There is no evidence of the effects of stress, or of any alteration phenomena in this rock which may therefore be confidently considered to have originated after Proterozoic orogeny.

The chief accessory opaque mineral is an exsolution intergrowth of magnetite and ilmenite, Figs. 10, 11, which formed at a temperature of at least 800°C with slow enough cooling for large oriented ilmenite blades to form in the magnetite. Magnetite and ilmenite also exist as separate individuals, mainly as minute granules trapped in the cleavage planes of the pyroxene crystals, or as larger crystal segregations in pyroxene grain boundaries. Pyrrhotite, pyrite, chalcopyrite and small particles of native copper occur in small quantities throughout most of the rock.

Sulphide mineralisation exists in significant proportions in many sections of this core, particularly between 500 feet, where the grunerite-bearing gneisses were first encountered, and 1000 feet, where the younger microdiorite dykes first appeared. Sporadic concentrations of sulphides are also present in the gneissic rocks which were intruded by several microdiorite dykes between 1000 and 1200 feet, after which quartz dolerite is continuous to the end of the drill hole.

Between 500 feet and 1000 feet the disseminated and incipient vein-type mineralisation extends over core lengths of 15 feet to 95 feet. When corrected to true thickness these mineralised zones are from 8 feet to 45 feet wide. Although the total sulphide content of the mineralised zones is generally less than 5%, as much as 15% sulphides may occur over thicknesses of 12 inches or so, Figs. 7, 9, 12. Magnetite is in places, associated with the sulphides and is generally similar to that in the cores of other holes, such as D.D.H. 161.

In some places pyrite, and in others pyrrhotite is the principal sulphide mineral, and both of these enclose small quantities of chalcopyrite and enargite. These sulphides occur mainly in mica or amphibole-rich foliae in the gneisses where they penetrated intergranular boundaries and cleavage planes and formed elongate sulphide bodies. In assemblages where both sulphides and magnetite occur, there was partial replacement of the magnetite by pyrite; and of the combined aggregates of magnetite and the pyrite, by pyrrhotite and chalcopyrite. The order of formation, viz. pyrite-pyrrhotite-chalcopyrite and enargite suggests that the sulphides were successively deposited, either from mineralising solutions, or from interstitial rock fluids which facilitated local remobilization of components already present in the rocks.

In comparing the observations from the several drill holes, it appears that weak mineralisation occurred at shallower depth where intrusives are sparse and of acidic character, whereas in the deeper sections of the drill holes in proximity to the basic and intermediate igneous rocks, mineralisation is widespread and in places, appreciably strong. Where the sulphides are particularly abundant, their textural relationship to the micas, garnets and amphiboles which were already formed in the gneisses through metamorphism, is clearly transgressive.

It is therefore unlikely that the sulphides are syngenetic components of the metasediments and in view of their mode of emplacement and order of formation, they may be regarded as epigenetic in origin. Their source may be in the sills and dykes of intermediate igneous rocks, in the larger more basic dolerite mass, or in a larger, underlying parent basic magma from which these dykes were generated.

8. LOWER PROTEROZOIC SEQUENCE.

(1) General characteristics.

The regional mapping by the Bureau of Mineral Resources has shown that there is a limited and simple sequence of Warramunga geosynclinal sediments at Tennant Creek. These range from coarser arenaceous shallow water sediments in the south and east, to somewhat deeper water argillaceous sediments in the north and north-west. However subordinate horizons of finer sediments exist among the coarser ones and vice versa. Hence it is probable that there were short, irregularly spaced periods of basin instability during prolonged periods in which regular changes from deeper to shallower water sedimentation occurred.

Calcareous horizons are completely absent in outcrop although Elliston (1965), reported the presence of dolomite in the deeper levels of Orlando Mine. Clastic sericite is a common component of almost all sediments and although chlorite exists in many rocks, biotite has never been observed.

The south-eastern portion of the field is occupied principally by light coloured sandstones, quartzites or greywackes which are in places, somewhat tuffaceous. The central and major part of the field is built up of thick sequences of impure, darker coloured tuffaceous sandstones amongst which occur irregularly spaced, relatively thin horizons of argillaceous rocks. The intercalated argillaceous rocks occur more frequently, and in thicker horizons towards the north, until within a mile or so of the Station Hill Granite, the principal country rocks are shales and slates.

The abundance of shales in the north and of quartzites and sandstones in the south, suggest that the source of the sediments was in the south. This concept is consistent with the presence of base-levelled Archaean rocks in the south-western portion of the area, and with the existence of Upper Proterozoic rocks at higher elevation to the north.

During the brief periods of basin instability, uplift occurred causing the widespread distribution of thin pebble horizons and current-bedded sandstones which contain thin heavy mineral lamellae. These fluctuations in basin level also caused in the unconsolidated shelf sediments, widespread interformational slump and brecciation and therefore initiated structures which were of considerable importance in the subsequent mineralisation of the sediments.

These slump, interformatioal conglomerate and brecciated structures are most frequent in occurrence in the central part of the region where there are alternating sequences of arenaceous and argillaceous rocks. Elliston (1960, 1965), first proposed that these structures were the result of the movement of fluidised sediments or turbidites on the sloping surfaces of the basin of deposition. The complex structures formed in this way between the muds and sands prior to their consolidation are according to Elliston, of great importance in the subsequent localisation of ore.

As subsequent work has shown there is no reason to doubt that these initial sedimentary structures were influential in a number of instances, both in providing zones of weakness along which subsequent shears formed, and in providing open space for the easy access of solutions carrying metallic components. However, there are also other factors to be considered in the question of mineralisation and these are discussed in a later section.

The bedding, the slumped and the brecciated structures in both the shales and the sandstones were obscured, or modified, by a strong east-west cleavage which was later imposed on the entire sequence by the orogenic activity which closed the sedimentary cycle later in the Proterozoic. The granite and associated porphyry intrusions which accompanied the orogenic disturbance imposed further structural, and in contact zones, metasomatic modifications on the folded sediments, in particular on the argillaceous ones. The main types of metasomatic modifications which resulted from the acidic intrusives were silicification and kaolinisation.

Subsequently, localised intense shearing and brecciation in the folded rocks so modified the structure of the sediments in certain places, that their recognition in the field is most difficult. In particular, the discrimination between the coarser grained lithic or crystal tuffs, and the porphyries, was rendered well nigh impossible in proximity to the main shear zones.

The most striking feature of the Warramunga sediments is the widespread occurrence of tuffaceous material. While the detrital components of volcanic origin are obvious in the coarser sediments, they are less so in the finer ones, and manifest in the argillaceous facies, only in disseminated euhedra of martite and hematite.

It is seldom possible to distinguish sediments in the field with any degree of precision, consequently thin section studies were essential to the investigation. In the course of this work some hundreds of sections of surface rocks and of diamond drill core samples were examined to ascertain data on facies variations, on the fabric of the rocks and on the nature of rock alteration.

Widespread metamorphic modification of the sediments, other than the development of cleavage, did not occur, and in places where folding was not intense, argillaceous rocks persist as laminated shales. However, in the tightly folded and mineralised areas, highly cleaved slates and schists were formed and against the larger orebodies, chlorite, talc, tremolite or anthophyllite developed in the country rocks through the influence of the hydrothermal solutions involved in mineralisation.

In the Tennant Creek One-Mile Sheet, the geologists of the Bureau of Mineral Resources distinguished three contrasting units of the sedimentary sequence. Although each unit is characterised by the dominance of a particular sedimentary facies, the entire range of Warramunga sediments may be found in greater or lesser amount within any one of them. These sediments were subdivided by Crohn and Oldershaw (1964) into the following broad groups, Table 2.

TABLE 2.

Lithological Units of the Warramunga Sequence.

Map notation	Facies	Geographic range.
Plw_1	Shale with some greywacke and pebble beds.	Northern part of the field.
Plw_2	*Greywacke and shale with some hematite shale bands.	Wide distribution over central part of the field.
Plw_3	Sandstone shale and siltstone with some pebble beds.	Confined to the south-eastern sector.

*Greywacke as used in this table, corresponds to the tuffaceous sandstone of the author.

(2) The Plw_1 group.

The characteristics of this unit are illustrated by rocks from the Mary Lane, Orlando, Red Bluff and White Hill areas and together, these provide the range of sediments proper to the group.

The lowest beds of the unit are transitional into the Plw_2 group in the vicinity of the Mary Lane Mine, and in this area, they are mainly fissile highly micaceous tuffaceous sandstones composed of fragmental particles of quartz and volcanic rock in sericite-rich matrices. Martite and zircon of 0.05-0.5mm diameter, constitute 5 - 10% of these rocks and exhibit even dissemination, except in the thin heavy mineral lamellae which exist at irregular intervals. In proximity to the Mary Lane Shear the rocks are mainly siltstones or slates which were disrupted by numerous micro-reverse faults containing epigenetic quartz-specularite veins. The stress caused both the general recrystallisation of the sericitic matrices and the formation of parallel growths of quartz in stress shadows adjacent to the martite euhedra.

Further north, towards the central part of the unit and especially in its northern limit against the Station Hill Granite contact, highly fissile slate is dominant, although a few thin siltstone intercalations persist. Although the slates consist mainly of oriented sericite, they contain also, irregularly distributed, parallel oriented, flat lenticular intercalations of coarser (0.01-0.05mm) quartz and martite euhedra. Two distinct cleavage patterns are apparent in many of these slates, one of which is the original slaty cleavage while the other is a superimposed fracture cleavage. Quartz-specularite veins are widespread and traverse the cleavage planes or fractures within the slates.

Towards the granite contact, the fracture cleavage intensified into actual fracture and finally into widespread brecciation. The open space produced by this brecciation provided easy access to heated aqueous solutions from the adjacent granite. These solutions filled the spaces with kaolin aggregates. Figs. 18, 19.

An interlaminated sequence of slate and siltstone, differing little from that to the north of Mary Lane, is prominent in drill cores from the Red Bluff and Ivanhoe areas. These sediments along the course of the Mary Lane Shear were sheared, brecciated, chloritised and injected by quartz-felspar veins which emanated from an underlying granitic source. The thin sandstone horizons which occur among these slates, are distinctly tuffaceous and contain abundant detrital zircon, apatite magnetite. Further north from these areas there is a change to a dominant argillaceous facies.

In the north-west sector near Orlando Mine, highly fissile slates are the principal country rocks and these may be examined in fresh condition in the underground workings. Although the country rocks are mainly slate, there are recurrent thin lamellae of sandstone or siltstone, as well as elongate, conformable lenticles composed of clastic quartz.

In proximity to the Orlando Shear, these arenaceous intercalations were fractured, stretched and disrupted while the slate was recrystallised and forced amongst them, to produce flaser rocks with boudinage structure, Fig. 114. The porphyroblastic components of these schistose and flaser rocks are regarded by Elliston as clots of siliceous matter produced in the original sediments by colloidal accretion. He classifies them as "pelletoid conglomerates". According to Elliston (1960, 1965) many of the rocks of the Warramunga Geosyncline were mobile sediments containing "phenocrysts" and "crystalline pebbles" of authigenic origin which were deposited by turbidity currents, mud flows and mud streams. However, from the evidence in thin sections it would appear that the quartz-rich porphyroblasts resulted simply from dynamic metamorphic action.

The tuffaceous nature of the arenaceous intercalations and porphyroblasts in the flaser rocks, schists and mylonites is indicated by the abundance of quartzo-felspathic and glassy volcanic rock fragments and the clastic martite. In places where shear reached maximum intensity, chlorite formed in abundance. The formation of chlorite, and of talc and anthophyllite which later replaced much of the chlorite, was not simply metamorphic but depended upon the magnesium metasomatism which accompanied mineralisation. These changes, common in proximity to copper orebodies, were therefore tantamount to wall rock alteration. These metasomatic changes were accompanied by the injection of minor primary quartz-apatite veins which may be seen occupying tension fractures in the altered slates.

The prominent structure known as the Mary Lane Shear is oriented at approximately 280° magnetic from Mary Lane Mine to Mary Ann Mine. It roughly outlines the boundary between the slates of the Plw_1 unit and the sandstones of the Plw_2 unit, (vide Plate 1). The gradual transition from an arenaceous to an argillaceous facies is again apparent to the north of Mary Ann Mine, although sandstone brought into the sequence by local folding, appears in places. Approximately two miles north of Mary Ann Mine incipient silicification of the slates appears, and it then increases in intensity northwards towards the granite contact. In proximity to the granite contact there is often complete pseudomorphous replacement of the slate in very fine grained quartz.

Near the Racecourse and along the granite contact, the white silicified slate was also brecciated and its fractures were filled by white kaolin in the same way as in the slate to the north of Mary Lane Mine. The incidence of both silicification and kaolinisation was irregular and it was guided by cataclastic structures with the result, that unaltered areas of non-fractured slate persist amongst those which were altered. Since the granite was intruded into cross-folded areas where brecciation was more frequent, contact alteration was accentuated. It was greatest in those places marked by pitch changes in the east-west fold axes, (vide Plate 1).

Further east, in the area north of Mt. Cleland and in proximity to the granite contact at White Hill, there are fine grained sandstones, siltstones and shales. It is questionable whether or not these are Plw_1 sediments, although the B.M.R. geologists classified them as such. One viewpoint proposed is that these represent a change in the environment of deposition, whereby there was a progression towards shallower water conditions in an easterly direction. In this way rather more pebble beds, sandstones and siltstones were deposited. On the other hand, the author considers that there is sufficient structural evidence to suggest that these essentially arenaceous beds are rocks of the Plw_3 group, brought into surface outcrop near White Hill through folding, vide Plates 1, 2.

This change in an easterly direction towards an arenaceous facies, with corresponding decreases in the amounts of tuffaceous and micaceous components, has a bearing on the degree of mineralisation that was possible in these areas. The rocks near the southern contact of the White Hill Granite, like those of the Plw_3 group in the Rocky Range area, are essentially quartzitic, and in the absence of argillaceous rocks, no mineralisation exists in them.

In contrast to this, the Plw_1 sediments in the western and north-western areas, are essentially argillaceous, with intercalated tuffaceous horizons. These are the host rocks for a number of orebodies and may be regarded as a facies more favourable to mineralisation. The reasons for this, which are partly mineralogical and partly structural, will be discussed in a later section.

The trace metal contents of the argillaceous rocks of the Plw_1 group away from areas of mineralisation, was ascertained in two north-south traverses four miles apart. The range in values obtained from samples collected at 300 foot intervals are quoted in Table 3. Apart from a persistent trace of silver and relatively high manganese which results from surface concentrations with limonite, these metal values are neither anomalous, nor significant.

TABLE 3.

Trace metal content of argillites of the Plw_1 group.

(a) Traverse north of Mary Ann Mine.

metal	maximum ppm.	minimum ppm.
Cu	12	4
Bi	5	1
Pb	20	4
Zn	50	40
Mo	2	* 1
W	20	*20
Ag	0.2	0.1
Hg	nil	nil
Mn	100	10
Co	7	1
Ni	25	1

(b) Traverse north of Mary Lane Mine.

metal	maximum ppm.	minimum ppm.
Cu	12	8
Bi	8	3
Pb	6	4
Mo	1	* 1
W	*20	*20
Ag	0.1	* 0.1
Mn	300	15
Co	6	1
Ni	25	1

* - denotes less than.

Analyses by Australian Mineral Development Laboratories.

(3) The Plw_2 group.

These predominantly arenaceous and tuffaceous sediments occur over most of the Goldfields, and enclose the majority of the elongate ironstone lode formations, and consequently, almost the entire group of known gold orebodies.

North of the Station Hill - White Hill Granite complex, i.e. out of the limits of the Goldfields proper, there are also a few gold orebodies. Although little is known of the sediments in this northern area because of widespread sand cover, they also are mainly tuffaceous and are therefore comparable with rocks of the Plw_2 group. It is at present not known, but they may be Plw_2 sediments, repeated by folding, (vide Plates 1 and 2).

The outstanding rock type in this group is massive tuffaceous sandstone which seldom exhibits a bedded structure, except on a very broad scale. There are large and continuous thicknesses of these coarse grained tuffaceous rocks which at intervals, are interrupted by thinner horizons of well-laminated shale or siltstone. Minor, but distinctive and important members of the sequence, include thin well-banded hematite-rich shales or quartzites, as well as lithic or crystal tuffs.

Penecontemporaneous slumped and brecciated structures are common in this unit, particularly in those parts of the sequence where shales and siltstones are intercalated with the coarser tuffaceous sandstones Fig. 20. Folding, faulting, shear and brecciation, caused by tectonic activity subsequent to the consolidation of the sediments, also reached maximum intensity and frequency in these rocks. These two factors are partly responsible for the presence of the greatest number of economic mineral deposits in this unit.

Throughout the field the thick, apparently coarser arenaceous facies, when examined in detail, proved to contain numerous rhythmic sequences of coarser and finer tuffaceous sandstones, grading in places into siltstones. The closely spaced sectioning utilised in the study of drill cores further revealed this widespread characteristic in the gradational bedding in individual beds. It is therefore apparent that numerous short, but repeated changes in sedimentation, occurred during the accumulation of these sediments, Figs. 21, 22.

Little change in mineralogy accompanied these grain size gradations except in the transition to those horizons of an argillaceous type, composed mainly of sericite, clays and some chlorite. The characteristic components of the sediments which are typically tuffaceous and arenaceous, are angular or slightly rounded fragments composed of quartz, quartzo-felspathic aggregates, devitrified volcanic rock, quartzite, gneissic rock, opaque minerals and shards of volcanic glass. The fragmental rock particles from volcanic sources contain much accessory magnetite, Figs, 25, 30. Idiomorphic, or fractured angular portions of hematite, martite or magnetite crystals constitute as much as 15% of the bulk of the tuffaceous rocks. The crystals are generally disseminated through the rock fabric, Fig. 25, but may also be concentrated in thin heavy mineral lamellae Fig. 24, or concentrated towards the base of lamellae of coarser grain size, Fig. 21. Finer grained iron oxides, mingled with sericite, chlorite, clays, minor apatite, sphene and zircon, form the interstitial material between the coarser detrital particles.

In Table 4, the differences in the amounts of the major components in tuffaceous rocks of various grain size is indicated. The quantities were evaluated by micrometric analysis.

TABLE 4.

The amounts of major components in tuffaceous sandstones.

	Clastic quartz and felspar	Clastic volcanics, quartzite, and gneiss	Martite or magnetite	Total matrix materials
Fine grained sandstone (Rocky Range)	35.1	26.2	9.4	29.3 (mainly chlorite, with minor felspar)
Coarse grained sandstone (D.D.H. 151 629 ft. Noble's Nob)	15.7	17.5	3.6	63.1 (mainly quartz, minor felspar, chlorite and sericite)
Coarse lithic tuff (D.D.H. 3 193 ft. Pinnacles)	16.1	40.3	5.1	38.6 (entirely chloritic)

Sparsely distributed, ragged fragments of chalcopyrite were observed in several places in the coarser of the tuffaceous sandstones, e.g. in drill holes in the country rocks adjacent to Noble's Nob, Fig. 31. The sulphide exists among the clastic components in parts of the rocks where there is no evidence of epigenetic mineralisation, transgressive veins or rock alteration, Figs. 26, 46. In many cases the sulphide forms with the quartz, composite clastic grains of the sediments.

In other examples, both pyrite and chalcopyrite were observed with clastic martite in the thin discontinuous heavy mineral lamellae of these sediments. Since pyrite and chalcopyrite, like magnetite, are common accessory components in volcanic rocks, these isolated sulphide fragments are not unexpected clastic components of the tuffaceous sediments. Furthermore, since other components of volcanic origin constitute as much as 30% of the Warramunga sediments, it is to be expected that detrital sulphides as well as magnetite, will occasionally be found in the deeper unoxidised drill cores.

Clastic sulphides and magnetite, are more abundant in the coarser rocks, particularly in crystal and lithic tuffs. Elliston (1965), suggested the presence of a large concordant body of "porphyroidal" sediment (here regarded as crystal tuff) beneath the Peko orebody. He postulated that through mobilisation in the colloidal slate, metals from this sediment moved upward into the Peko structure. The various reasons for this not being an acceptable means of mineralisation in a large orebody, are discussed in later pages.

In some of the very coarse grained arenaceous rocks at Golden

Forty Mine, fragments of gneiss and quartzite were also found among the quartz and fragmentary volcanic rock clastics thus indicating that eroded materials from the Archaean basement were transported with the volcanic products, to the basin of deposition.

There are a limited number of horizons in which volcanic rock fragments are more abundant than clastic quartz, and in such rocks, shards of glass are also prominent. These are tuffs rather than tuffaceous sandstones, and may be considered to have accumulated at certain restricted periods when air-borne volcanic products were the main contributors to sedimentation in the basin. Several varieties of tuff, such as those mentioned below, were distinguished.

Among the rocks to the north of Station Hill are highly tuffaceous horizons comparable with those in the Plw_2 unit of the central Goldfields area. In the vicinity of Bishop's Bore for example, there are bedded lithic tuffs composed of alternating layers containing chilled spháricle volcanic rock particles or lapilli, martite granules, and fine volcanic dust, Fig. 28. Nearby at Bernborough Mine, there are crystal tuffs which contain fragmental crystals of quartz, felspar, mica and magnetite, mingled with amorphous silicate shards and fine, dark red volcanic dust, Fig. 27.

There are among these tuffs, fragmental rocks composed of large angular blocks several cm. in size, which might be regarded as ignimbrites or welded tuffs. The angular rock fragments are enclosed in a fine grained chloritic and quartzo-felspathic rock matrix, characterised by concentric structures comparable with the lithophysae of glassy volcanic rocks.

In their recent investigations of certain ignimbrites on the Tennant Creek field, Crohn and Oldershaw (1964), came to the conclusion that these may have been the original filling in volcanic pipes. However, they were unable to observe a clear contact relationship with the Warramunga sediments and could not ascertain whether this activity was contemporaneous with, or subsequent to, sedimentation.

The crystal and lithic tuffs, as well as the ignimbrites and layered ash beds, occur among the tuffaceous sandstones in several parts of the central portion of the field, although the best exposure of ignimbrite is that described by Crohn and Oldershaw (1964), from the area adjacent to the aerodrome. Further examples of ignimbrite and welded tuff occur with tuffaceous sandstone near Kathleen Mine, and in the Rocky Range area where they may be recognised by their hardness, massive structure, conchoidal fracture and black colour. Crystal and lithic tuffs containing diagnostic shards, also occur near New Hope, Golden Forty, Kathleen and the Pup Mines. Although these are difficult to distinguish from quartz-felspar porphyries which are common in these areas, the presence of shards clearly identifies those which are the tuffaceous sediments.

Very fine grained laminated ash beds indicative of periods of undisturbed sedimentation, occur near the Government Battery and at Rocky Range. These grey coloured rocks, with delicate rhythmic bedding and repeated thin bands of concentrated fine grained martite, are interbedded with the common massive brown coloured coarser grained tuffaceous sediments.

The thick sequences of tuffaceous sediments are interrupted at shorter or longer intervals by relatively thin horizons of siltstones or shales. There is no regularity in the frequency or thickness of these finer arenaceous, silty or argillaceous horizons, nor in the nature of the contact between them and the coarser tuffaceous sandstones. In some examples, the tuffaceous sandstones, by regularly decreasing grain size grade imperceptibly into the finer silt, clay, or sericite-rich horizons; in others the facies changes are abrupt. The perfection in gradational bedding is indicative of undisturbed sedimentation and perhaps also of gentle and repeated changes in the elevation of the basin of deposition.

In many places the bedding interfaces were rendered highly irregular by bulbous masses of arenaceous sediment which penetrated the surfaces of silt or clay lamellae. In these, the sudden facies changes indicate that there was relative movement between contrasting types of sediment through slip on the slopes of the basin of deposition. The larger scale movement of unconsolidated sediments in this manner, is manifest in slump structures and interformational breccias. Thin section evidence therefore confirms the observations made by Elliston in the field.

The common varieties of siltstone contain at least 50% angular quartz and as much as 10% martite, dispersed among extremely fine grained sericite and chlorite. Thin heavy mineral layers in which martites, and occasionally zircons were concentrated, occur in some specimens and accentuate a poorly developed current bedding structure, Figs. 24, 57.

Shales and slates which occur more frequently in the sequence than siltstone, consist mainly of various mixtures of sericite, chlorite and clays with subordinate amounts of silt-grade quartz. These too, contain disseminated, or thin layered concentrations of granular martite which constitutes 5 - 15% of the bulk of most argillites, Figs. 23, 29. In areas of more intense folding or shear, the change from shale to slate resulted from the recrystallisation of sericite and chlorite to individuals of larger size accompanied by the partial segregation of fine quartz into lenticles, or into parallel crystal growths at the extremities of the clastic martites, Fig.78.

The special variety of shale known as the banded hematite-shale, is of restricted stratigraphic range and has a maximum thickness of 20 feet. It is generally associated with ordinary shales which occur in the tuffaceous sequences, and it simply represents an extreme case of a martite-rich shale in which there are numerous closely spaced heavy mineral lamellae. In outcrop it is very resistant to erosion and provides the principal marker horizon on the field. Individual beds of this type in different parts of the field cannot be traced for long distances, since the hematite-shale, like all other sediments, is lens-like and discontinuous.

The profile of D.D.H. 165, sited adjacent to Noble's Nob Mine, is illustrated in Fig. 31. A range of different country rocks, which provided a typical cross section in Warramunga sediments of the Plw_2 type, occurs in this drill hole. The sequence is made up mainly of tuffaceous sandstones of different grain sizes, coarse lithic tuffs and a subordinate number of siltstone, shale or slate beds. Gradational bedding, repeated in rhythmic fashion from horizon to horizon over long lengths of the core, is a characteristic feature.

The main clastic components of the coarse sediments, angular quartz, quartzo-felspathic particles, broken euhedra of magnetite and flat-lying chlorite flakes, are set in a fine grained sericite-chlorite intergranular matrix. The lithic tuffs in this sequence contain in particular, abundant particles of devitrified volcanic glass, rock fragments as well as shards, and as noted earlier occasional particles of clastic sulphides.

The amounts of copper and bismuth, and to a lesser extent of manganese, cobalt and nickel, rise and fall in unison throughout the profile of this drill hole. The higher metal values, which are spread over the sections containing dominant coarse tuffaceous rocks, are thus consistent with the presence of disseminated fragmental sulphides.

The partial chemical analyses of bulked samples of three varieties of the sediments within the Plw_2 group, taken from several widely spaced diamond drill cores, are given in the following table. The partial analyses for each type of rock may be compared by neglecting the silica content of the sediments, since this is only a function of the increasing amount of quartz in the transition from an argillaceous to an arenaceous facies. Since biotite is not present in these sediments, the ratio $K_2O : Al_2O_3$ may be taken to indicate the content of sericite, clay and felspar, whereas the ratio $Al_2O_3 : MgO + Fe_2O_3$ indicates the chlorite, martite and other ferromagnesian contents.

TABLE 5.

Partial compositions of three types of Plw_2 sediments.

	% Al_2O_3	% MgO	% K_2O	total Fe as Fe_2O_3	$\frac{K_2O}{Al_2O_3}$	$\frac{Al_2O_3}{MgO+Fe_2O_3}$
Shale	16.6-18.4	1.7-1.9	5.8-6.3	6.4-7.6	0.35-0.34	2.25-1.92
fine to medium grained tuffaceous sandstone	14.1-16.1	1.5-1.6	4.7-5.4	5.4-6.3	0.33-0.33	2.04-2.04
coarser grained tuffaceous sandstone	10.7	1.1	3.2	4.5	0.30	1.91

(Analyses by Australian Mineral Development Laboratories).

The ratios K_2O : Al_2O_3 and Al_2O_3 : $MgO+Fe_2O_3$, do not vary significantly from one rock type to another, although the actual quantities of K_2O, MgO and Fe_2O_3 increase, as the clastic quartz content decreases in progressively finer sediments. The slightly increased K_2O : Al_2O_3 ratio in the finer sediments, results from the abundance of clays and sericite in the shales and from the presence of sodic plagioclase in the volcanic rock components of the tuffaceous rocks. Similarly, the increase in Al_2O_3 : $MgO+Fe_2O_3$ in the finer sediments is due to the somewhat greater proportion of clastic martite in the coarser tuffaceous rocks.

The similar ratios of these chemical components of the different types of sediments, suggest that each sediment was derived from a similar source and that the quartz content is the main variable.

The partial analyses show, that by comparison with the compostions of average slates and sandstones from other areas, the Tennant Creek slates have higher contents of potash and iron, and the sandstones, higher alumina, magnesia, potash and iron. These unusual compositions and the presence of fragmental volcanic detritus, abundant magnetite, and smaller amounts of sphene, zircon, apatite and tourmaline, suggest that acid-intermediate igneous rocks were abundant in the source area. This supposition is borne out in Table 6, where it is apparent from the ratios of major constituents, that rocks of acid-intermediate composition contributed the aluminous and ferromagnesian components of the sediments.

TABLE 6.

The ratios of specific components in average igneous rocks.

	$K_2O : Al_2O_3$	Al_2O_3 : MgO + total Fe as Fe_2O_3
granite	0.28	4.0
granodiorite	0.26	2.1
syenite	0.30	3.5
diorite	0.14	1.4
gabbro	0.38	1.0

(Data for these calculations taken from Rocks and Rock Minerals by L.V. Pirsson and A. Knopf, 1953, John Wiley & Sons Inc.)

The normal contents of the minor and trace metals in the tuffaceous sandstones and shales of the Plw_2 group, in areas which are not mineralised, are shown in Table 7. These background values, determined for purposes of geochemical survey, were ascertained in a number of north - south traverses across the Plw_2 group, at sample intervals of 300 feet. No significant differences were observed in the ranges of metal values for argillaceous and arenaceous rocks. However, in certain coarse lithic tuffs containing clastic sulphides such as those mentioned above, the copper content reaches 200 ppm while other components remain similar to those in Table 7.

TABLE 7.

Contents of minor and trace metals in Plw_2 sediments.

metal	maximum ppm	minimum ppm
Cu	15	2
Bi	8	1
Pb	20	3
Zn	50	40
Mo	3	* 1
W	25	*20
Ag	0.1	* 0.1
Hg	nil	nil
Mn	40	7
Co	8	1
Ni	10	1

* - denotes less than.

Analyses by Australian Mineral Development Laboratories.

(4) The Plw_3 group.

This is a subordinate sequence in a lower stratrigraphic position which occurs in the south-eastern portion of the Tennant Creek field, and possibly also near White Hill. It differs from the Plw_2 group in that it is essentially an arenaceous facies with no significant shale horizons. The sandstones are weakly tuffaceous in places but they contain relatively smaller amounts of clastic martite, volcanic rock particles, interstitial sericite, chlorite and clays.

The absence of mineralisation and of hematite lenses in the rocks of this group may be attributed to its high quartz content, its low clastic hematite content and to its formation prior to the onset of vulcanism in the source area.

Although this group cannot be fully examined because in its southerly and westerly extensions, it is obscured by transported soils, or by subsequent granite intrusives, it is thought, that it may be the shore line facies of the Warramunga sequence.

(5) The ironstone bodies as syngenetic units.

In most discussions of Tennant Creek geology these have been regarded as epigenetic, and related in origin to the granites or porphyries. There are however, a number of factors which suggest that the ironstone bodies may have been derived from the clastic martite and hematite which accumulated in great abundance, particularly in sediments of the Plw_2 group.

Crohn and Oldershaw (1964) estimated from relative areas of outcrop, that the ironstone bodies occupy, according to their position in the field, from 0.04 - 0.2% of the volume of the country rock. These proportions would increase to approximately 0.2 - 1.0% by volume if the iron oxides which exist in the major shear zones, were also included. Their observations also showed that, within the Plw_2 group, arenaceous sediments contain at least 0.5% clastic iron oxides, argillaceous rocks at least 1.0% and the hematite shales as much as 20% iron oxides. According to the author's experience, the content of clastic iron oxides is however, much higher in the sandstones and shales of the Plw_2 group.

Although these workers generally favoured a hydrothermal origin they conceded, that in view of the large quantity of iron oxides in the adjacent sediments, the ironstones may have been derived by lateral secretion from these.

There are about 700 of these bodies. Most of them are ovoidal in surface outline, others are highly irregular, but all of them display lenticular cross sectional shapes. These masses vary in length and width from a few feet to about 400 feet, and in thickness from a few inches to about 200 feet.

The majority of these bodies are oriented more or less in an east-west direction and are therefore broadly conformable with the regional strike of both the bedding and cleavage in the sediments. Most of them have a steep or vertical attitude thus, while they conform to the strike of the sediments, they often transect the dip of the bedding, but seldom that of cleavage. Previous workers attributed the shape and the attitude of the ironstone formations to epigenetic replacements of the sediments by hematite or magnetite. Such replacements were facilitated by the intersection of steeply dipping shears or breccia zones with the less steeply inclined bedding planes.

It may be seen from the Tennant Creek One-Mile Sheet that these elongate bodies of hematite, or of quartz and hematite, occur mainly in clusters and in proximity to the distinctive hematite-shale horizons. Only a small percentage of the total number occurs as single isolated individuals. It is furthermore apparent that the greater clusters are in the more contorted areas, particularly along the flanks of the major folds where the greatest intensity of drag folding, shearing and brecciation occurred, (vide Plate 1).

At least 90% of the hematite lenses are within the Plw_2 group of sediments and furthermore, the ironstone bodies are largely confined to the Specific Horizon 500-1000 feet thick, depicted on the structural interpretation plan in Plate 1. The ironstones do not display any such spatial relationship to the porphyries.

The incidence of the clusters of ironstone bodies is controlled within this Horizon, by two factors, viz. the complexity and degree of pitch variation in the drag folds on the flanks of major folds; and the presence or absence of hematite shale horizons. In those parts of the Horizon where hematite shale is absent, or drag folding is not apparent, there are few ironstone bodies.

The Plw_2 group of sediments contains a much higher proportion of clastic tuffaceous components than either of the groups Plw_1 or Plw_3. The Specific Horizon itself is the most highly tuffaceous zone within the Plw_2 group and it is characterised by mudstones of unusually high clastic martite content, coarse grained tuffaceous sandstones, as well as lithic and crystal tuffs. The detrital components of the coarser sediments in this horizon display highly angular grain shapes and within the broader lamellae, complete absence of grain size sorting. These features are characteristic of rapid deposition and short transportation from the source area.

The partial analyses in Table 5, which refer to shales and tuffaceous sandstones of the Specific Horizon, depict contents of Fe_2O_3, Al_2O_3, K_2O and MgO which are similar to those obtained from acid volcanics.

The Archaean basement is only a short distance south-west of the field, and since the Lower Proterozoic rocks dip beneath Upper Proterozoics to the north of Tennant Creek, it is probable that the Lower

Proterozoic shoreline was not far south of the Specific Horizon. It may in fact, be represented by the purer arenaceous sediments of the Plw_3 group. The Plw_2 group, and the highly tuffaceous Specific Horizon, although now repeated by folding on east-west axes, may be regarded as having originally extended parallel to this shoreline. The Plw_2 sediments were therefore accumulated close inshore, upon a shelf area sloping generally northerly, during a period when the rapid accumulation of abundant clastic volcanic material was possible.

This sedimentary environment may have been similar to those of Tertiary or Recent times which existed along shorelines adjacent to areas of volcanic activity, e.g. along the west coast of the North Island of New Zealand, and the shores of certain Pacific Islands. The sediments along the North Island shoreline, adjacent to the andesitic volcanic terrain of Taranaki Province, contain, like those at Tennant Creek, large quantities of magnetite amongst which clastic sulphides occur in small quantities.

In discussing the origin of the ironstone bodies it is important to distinguish these from the less frequent, deeper-seated epigenetic concentrations of magnetite and specularite which occur in the major mineralised shears.

Most of the ironstone bodies outcrop and are contained almost wholly within the oxidised zone, although the larger ones which occur in or near mineralised shears, e.g. at Eldorado, Peko and Noble's Nob, merge in depth with epigenetic iron oxides and appear to penetrate below water table level into the primary zone.

Allotriomorphic granular hematite, with more or less specularite and quartz, constitutes the bulk of the barren ironstone bodies in the oxidised zone. Those which coalesce with mineralised shears contain in addition to these components, martitised magnetite with more or less hydromicas, sericite, chlorite and talc all of which increase in quantity with depth, or towards the mineralised shears. In these examples where the ironstone body appears to extend below water table level, the absence of the allotriomorphic granular masses of hematite in depth is significant. The different assemblages of the three varieties of iron oxides in the mineralised, and in the non-mineralised ironstone bodies, suggests two separate modes of origin.

The formation of miniature lenticular concentrations of hematite, or of quartz and hematite in rocks containing disseminated martite, may be observed at many places along the Specific Horizon, particularly in the areas of complex folding, shear and brecciation. The photomicrographs, Figs. 32 to 37, depict various stages in the formation of such concentrations of both hematite and quartz in permeable, brecciated, or sheared sediments. It is suggested that the migration of these mineral components to centres of replacement and accumulation occurred at ambient temperatures in interstitial rock fluids, guided in their flow by the enclosing rock structures.

Many of the coarse grained tuffaceous rocks contain continuous or lenticular magnetite-rich lamellae, Figs. 24, 30, which may also have provided nuclei for accumulation. In most examples however, the open spaces resulting from brecciation, or multiple puckering of lamellae in tight folds, provided the centres of accretions.

There is no hydrothermal or contact alteration in the sediments which enclose the ironstone lode formations, except in those which are known to contain, or merge into, economic deposits of base metal or gold. Thermal phenomena did not accompany the concentration of iron oxides and quartz in the formation of at least 90% of the ironstone bodies. Their introduction from hydrothermal sources seems therefore to be improbable.

The Specific Horizon contains irregular, sporadic and unusually large accumulations of iron oxides and is characterised by current bedding, rapid and rhythmic facies changes, slumped structures, and interformational breccias. It might therefore be considered inherently weak during later tectonic activity.

Within the Specific Horizon, the facies characterised by the above-mentioned features, and containing abundant coarse grained clastics with fine grained interstitial medium, were brecciated. The intercalated less competent argillaceous beds were intricately drag folded and subject to much shear.

The argillites and the siliceous hematite shale beds are much less permeable than the tuffaceous sandstones. The movement of vadose waters has therefore been largely confined within the arenaceous facies, and over a long period of time it is conceivable that considerable amounts of silica and iron oxides may have been transported along these horizons.

Since the ironstone formations are located mainly above water table level, and within the drag folds along the flanks of the major folds, closed structures produced by folds with pitch reversals, may have caused sufficient delay in the movement of the waters to facilitate precipitation of iron oxides and silica. The loci of precipitation within closed, or semi-closed structures were the open textured brecciated areas of arenites, and the sheared sections of the argillites.

The solution of clastic martite and of the finer grained interstitial iron oxides was probably assisted not only by carbonated surface waters which entered the zone of water circulation, but also by the oxidation of small amounts of clastic pyrite and other sulphides contained in the tuffaceous horizons. Subsequently, an increase of pH in areas of slower water movement within the drag folds, facilitated redeposition of the oxides.

The allotriomorphic granular hematite aggregates containing subordinate amounts of quartz, are confined to the oxidised zone where they form the ironstone lenses or lode formations, as they are called. The absence of these in the hypogene zone supports the view that the solution, movement and redeposition of iron oxide and silica took place solely in the oxidised zone. With the progressive base levelling of the terrain and the consequent slow encroachment of the oxidised zone into the hypogene zone, these formations have no doubt been continuously remobilised throughout geological time.

It is submitted that a low temperature origin for the common ironstone lenses is more compatible with their structure, texture, composition and distribution, than is an origin dependent upon hydrothermal phenomena. The small proportion which is mineralised, contains all three varieties of iron oxides, two of which are primary and epigenetic in origin and can be shown to penetrate below the oxidised zone along shears within the country rocks.

9. THE GRANITES.

The granites of different structures and compositions which are conspicuous over considerable areas in the northern and southern parts of the Tennant Creek district, were considered by Crohn (1965) to constitute a penecontemporaneous consanguineous series. The age of the granites, originally determined as Upper-Lower Proterozoic by the K-A method (Walpole and Smith, 1961) has recently been revised by the Rd-Sr method (Leggo, Walpole and Compston, in prep.) and placed in the range 1700 - 1800 million years, i.e. Middle Proterozoic. They are distributed on three sides of the main field of gold mineralisation, and since they might therefore be thought to have a bearing on mineralisation, a detailed examination was made of all the areas of granite to determine their characteristics.

The numerous large and small outcrops of granite, as well as obscured bodies located from bore holes, may be grouped as two separate plutons, and as one smaller group of closely spaced stocks by virtue of field distribution and distinctive petrographic character, Plate 1. It is probable however, that these spatially distinctive groups, each with its own characteristics, are comagmatic in one large batholith beneath the Goldfields. The specific characteristics of each group are considered to have arisen from variations imposed by differentiation and from superimposed tectonic structures of later incidence.

(1) The Northern Granite pluton.

The most northerly granite has a moderately well-defined southern margin which is convex to the south. This contact is almost concordant with the sediments which strike in a broad arcuate structure around the granite and dip southerly away from it. Although the western and eastern margins of the granite are transgressive, and the northern boundary is completely obscured by alluvials, it appears probable that the granite at Station Hill and White Hill, occupies an anticlinal structure, Plate 1.

The outcrops at Station Hill and White Hill are the main surface expressions of the elongate pluton. However, the outcrops of similar granite ten miles to the north-east on the Mt. Isa Road may perhaps be included with those of Station Hill and White Hill, thus outlining a pluton of about 20 miles length and about six miles width.

The most westerly of the outcrops are isolated from the main pluton and appear as small massive biotite granite apophyses two miles north of Curlew Mine.

The continuous area of some ten square miles of the granite centred around Station Hill, is the principal expression of the northern pluton. This is mainly coarse grained and porphyritic with an initial stressed or slightly gneissic structure imposed by flow during intrusion. As a result of weathering, the granite is generally red in colour and outcrops in tor structures developed from its cuboidal joint pattern, one set of which is almost horizontal.

The granite contains phenocrysts of orthoclase, microcline, or microcline-perthite which reach 2 cm. in length, and in some parts of the granite, there is also incipient rapikivi texture where thin white rims of oligoclase are moulded upon the microcline crystals. The rocks are seldom leucocratic but generally contain the usual amounts of muscovite and biotite, zircon,apatite and hematite, as well as a little fluorite and tourmaline. In addition, most of the granite contains appreciable amounts of more uncommon accessories such as cyrtolite, allanite, xenotime and monazite which account for the weak radio-activity exhibited by the pluton.

It was pointed out by Crohn and Oldershaw (op.cit.) that small areas within the Station Hill gneissic granite are massive in structure. The distinctive frozen contacts against the gneissic granite indicate that this unstressed granite was introduced somewhat later than the main intrusive, probably near the close of the tectonic cycle with which igneous activity was associated.

Although most of the granite of Station Hill is only slightly gneissic, the influence of a much later and more severe tectonic activity is manifest in its localised cataclastic or mylonitic structures, and by the north-west-trending 14-Mile Fault and several north-south shears, which transgress the granite. These structures contrast with those produced during intrusion which caused only partial parallel orientation of the micas and possibly also the widespread intergranular comminution within the fabric of the rock, Fig. 39. In the vicinity of later shears, the coarse felspar phenocrysts were rolled, rounded and made conspicuous as porphyroblasts in a mylonitic matrix. These flaser gneisses may easily be confused with sheared porphyry. Fig. 41.

There is little compositional change throughout the Station Hill Granite. Although it was penetrated by a few aplite and adamellite apophyses, and slate xenoliths were scattered through the granite, neither these, nor the enclosing country rock, appear to have made significant modifications to its composition.

The minor metal contents of Station Hill Granite were determined spectrographically from a composite sample made up from fresh rocks collected at regular intervals over the entire outcropping area. The results, shown in Table 8, indicate no extraordinarily large amounts of these metals.

TABLE 8.

Minor metals in Station Hill Granite.

Cu.	Pb.	Zn.	Co.	Ni.	Sn.	Bi.	Ag.	Mo.	Mn.
25,	40,	nil,	5,	5,	nil,	4,	*0.1,	4,	40.

* - denotes less than.

Analysis by Australian Mineral Development Laboratories.

Although the country rocks did not contaminate the granite there was widespread modification of shale and slate in the broad contact aureole which surrounds the granite. Both kaolinisation and silicification are widespread, and in places along the western margin, large quartz-tourmaline dykes penetrated contiguous country rock.

The contact zone of sediments of the Plw_1 type against the Station Hill Granite was studied in two places, one north of Mary Lane Mine and the other north of Mary Ann Mine.

To the north of Mary Lane Mine the alteration is largely kaolinitic although epigenetic quartz was also introduced into some rocks. Both the slates and the interbedded siltstones were extensively veined, and often completely replaced by clay mineral accompanied by more or less quartz and by minor tourmaline. Often the rocks were brecciated as well, but in all areas of alteration there are concentric aggregates of colloform or microcrystalline clay mineral in ladder-vein or ramifying vein structures, Figs. 40, 42, 43, 44, 45.

Although the alteration was progressively more intense towards the granite border, the only significant trend in the variation of minor metals throughout the aureole is the sudden decrease in the amount of lead away from the granite. This is illustrated in Table 9 which presents the metal contents of the granite compared with those of sediments from the contact, to a point one and a half miles south of it.

To the north of Mary Ann Mine both silicification and kaolinisation of the slates are again in evidence and in addition, there is sporadic ferruginisation of the country rocks. These rocks are also brecciated, but instead of clearly defined vein impregnation by cryptocrystalline silica, or by clay minerals, complete permeation of the rocks is more common.

These alteration phenomena also increase in intensity towards the granite contact, but again no significant trends in variation or minor metal contents were observed, Table 10.

The Station Hill Granite may be traced easterly by sporadic outcrops in the alluvium for about nine miles to an unbroken outcrop of some four square miles area, known as White Hill. Although not

TABLE 9.

Minor metal values in the Station Hill Contact aureole.

North of Mary Lane Mine.

Distance from contact.	Cu	Bi	Pb	Mo	W	Ag	Mn	Co	Ni
the granite	25	4	40	4	* 5	*0.1	40	5	5
zero	20	2	8	1	* 5	0.1	-	1	2
400 yds south	8	4	5	* 1	*20	*0.1	15	1	2
800 yds south	12	4	6	1	*20	*0.1	15	4	25
1200 yds south	12	8	6	1	*20	0.1	50	6	4
1600 yds south	8	3	5	* 1	*20	*0.1	40	5	4
2200 yds south	10	3	4	* 1	*20	0.1	40	1	6
2600 yds south	12	3	6	1	*20	*0.1	300	2	1

* - denotes less than.

Determinations by Australian Mineral Development Laboratories.

TABLE 10.

Minor metal values in the Station Hill Contact aureole.

North of Mary Ann Mine.

Distance from contact.	Cu	Bi	Pb	Mo	W	Ag	Mn	Co	Ni
the granite	12	1	5	1	*20	0.1	15	3	1
zero	8	2	3	*1	*20	0.1	200	3	1
300 yds south	10	1	20	1	*20	*0.1	100	1	1
600 yds south	10	1	8	1	20	0.1	40	4	1
900 yds south	5	1	4	1	*20	*0.1	20	1	1
1200 yds south	8	1	5	1	*20	*0.1	50	2	1
1500 yds south	8	2	4	1	*20	*0.1	80	3	1
1800 yds south	10	1	5	1	*20	*0.1	50	7	3
2100 yds south	6	3	5	1	*20	*0.1	20	4	12
2400 yds south	12	2	5	1	*20	*0.2	10	3	1
2700 yds south	8	2	4	1	*20	0.1	60	3	2
3000 yds south	8	2	5	*1	*20	*0.1	40	3	3
3300 yds south	5	1	6	1	*20	*0.1	50	3	3
3600 yds south	4	3	12	1	*20	*0.1	70	3	2

* - denotes less than.

Determinations by Australian Mineral Development Laboratories.

strikingly different from the Station Hill Granite, that at White Hill is of a more acidic character and may therefore be a slightly later phase of the granite complex. It may in fact be syngenetic with the small intrusives of massive, non-porphyritic granite within the gneissic granite of Station Hill. These, as previously mentioned were regarded by Crohn and Oldershaw (op.cit.), as late stage intrusives.

The White Hill Granite has the same red colour as the Station Hill Granite but it is of finer grain size, generally massive in structure but seldom porphyritic. Graphic intergrowths of quartz and potash felspar, generated at a late stage in differentiation, filled intergranular spaces and fractures amongst orthoclase, microcline and oligoclase, Fig. 38. Myrmekite therefore commonly occupies the same positions within the fabric of the granites as coarse grained accessory sphene, rutile, apatite, hematite, zircon and fluorite which formed also, at a late stage in the crystallisation. The abundant and widespread leucocratic granitic and aplitic dykes in the northern section of the White Hill Granite mass, are the larger scale equivalents of this intergranular graphic quartz-felspar.

These leucocratic rocks, characterised by little or no mafic minerals, range from varieties with dominant microcline and perthite, to varieties with dominant albiclase (An_{10}.). While most of the potash-rich rocks contain normal amounts of quartz and are therefore aplites, a few contain so little quartz that they approach syenite in composition. In all the varieties of leucocratic rocks the accessory mineral content is very restricted by comparison with the granites which contain relatively large amounts of coarse grained sphene, zircon and fluorite, mainly concentrated in the biotites.

Table 11 shows that the different varieties of rock, which arose out of the differentiation procedures, display no contrasts in minor metal contents in spite of sharp differences in their accessory mineral contents. Thus, no fractionation of minor metallic components between the quartz, the felspars and the micas occurred although the accessories, sphene, zircon and fluorite, were apparently scavenged from the magma by the micas, and retained in them as inclusions.

Generally speaking the White Hill Granites had no initial flow foliation and acquired subsequent strain only in proximity to widely spaced shears. Their characteristic massive structure therefore contrasts with that of the foliated granite of Station Hill.

The White Hill Granite contact is almost wholly obscured by alluvium, except at its southern margin where concordant siliceous sediments dip gently away from it. Numerous quartz-tourmaline veins emanated from the granite into the contiguous sediments but no evidence of kaolinisation was observed.

Table 12 shows that no significant variations occur in the minor metal contents of a series of the sediments taken at intervals across their strike to a distance of 800 feet from the granite contact. These felspathic quartzites, with zircon and martite in heavy mineral lamellae, were progressively more completely recrystallised to granoblastic aggregates, and extensively replaced by coarser tourmaline,

TABLE 11.

Minor metal contents of White Hill Granites.

rock type	Cu	Bi	Pb	Mo	W	Ag	Mn	Co	Ni
porphyritic microcline-biotite-granite. (abundant accessories)	40	2	10	5	*20	0.1	40	3	15
even grained perthite-biotite-granite. (abundant accessories)	10	2	15	1	*20	*0.1	10	2	3
potassic leuco-granite. (sparse accessories)	20	2	10	3	*20	*0.1	30	1	6

* - denotes less than

Determinations by Australian Mineral Development Laboratories.

TABLE 12.

Minor metal values in the White Hill Contact aureole.

Distance from granite	Cu	Bi	Pb	Mo	W	Ag	Mn	Co	Ni
massive biotite granite	10	2	15	1	*20	*0.1	10	2	3
40 ft south	7	3	4	*1	*20	*0.1	5	1	1
80 ft south	12	5	7	1	*20	0.2	40	2	3
200 ft south	8	1	6	1	*20	0.1	70	2	2
800 ft south	25	8	6	4	*20	0.1	20	3	10

* - denotes less than

Determinations by Australian Mineral Development Laboratories.

towards the granite contact.

The immediate northerly extension of the White Hill Granite is masked by alluvium and also by Cambrian sediments, but outcrops of granite six miles further north may be outlying portions of this northern granite intrusive. These far northerly outcrops which are medium grained, slightly gneissic and contain numerous silicified xenoliths, are therefore very similar to the Station Hill Granite. The granite was cut by many quartz reefs which filled shears oriented at 340° magnetic.

(2) The Southern Granite pluton.

A large area of granite occurs south of the Goldfield, but its margins are poorly defined and much of it is known only from bore holes. Relative to the main road near Eldorado Mine, the granites may be traced easterly on the surface for 14 miles, and westerly in bore holes, for four miles. The granite extends in a southerly direction from a mile south of Eldorado Mine to at least the upper limits of Morgan Creek, a total distance of 20 miles. Its northern, eastern and southern margins may be approximately defined against the enclosing alluvial cover, but the outline of the western edge is unknown. Bore holes in the western limits indicate that it continues at depth beneath the plains, Plate 1.

This pluton is of irregular shape and encloses a large area of altered sediment some seven miles south of Noble's Nob. The western limits of this enclosed mass of sediment is obscured and the granite may therefore be in two separate portions. The outcrops are not continuous, for much of the granite lies at shallow depth beneath the plains. The concept of the extent of the granite was obtained from numerous scattered outcrops and from drill holes in the Cabbage Gum underground water basin.

Throughout the area occupied by the southern pluton, there are many sharp compositional changes. There is also evidence of widespread hydrothermal and pneumatolytic activity along its northern contact, Fig. 40.

The profiles of the cores from the most westerly of the Cabbage Gum bores show that fine or medium grained biotite-granite occurs at shallow depth, and that adamellite generally exists beneath it. The structure of the granites in the western portion of the southern pluton is massive, but in proximity to the major north-east lineament which traverses the pluton east of Eldorado Mine, the granite is strongly gneissic. Most are microcline-perthite granites with variable amounts of intergranular graphic quartz-felspar, minor oligoclase, biotite and muscovite. In this respect, and by virtue of abundant accessory sphene, zircon, apatite and fluorite, they resemble much of the granite in the north of the field.

An elongate zone of adamellite some two miles wide and oriented north-east, occurs between the granite and the major north-east fault. It differs from the adjacent granite only in its greater content of zoned oligoclase which balances the amount of orthoclase, microcline and perthite. The accessory and minor components remain the same. Both the granite and the adamellite exhibit intergranular comminution between quartz and felspar grains, and there was also sufficient mass movement during intrusion to produce a primary gneissic structure in the whole rock fabric. The disturbance of the rock fabric which is confined mainly to movement in grain boundaries, is also a feature of the Northern Granites. Extremely strong gneissic structure in both groups exists only in proximity to later faults.

Stressed and gneissic biotite granites with similar mineral components to those above, were found in the drill holes east of the northeast - southwest fault, but none outcrops at the surface. The granites are completely obscured by alluvium for some five miles east of the Cabbage Gum bores, and the first evidence that granite exists beneath the flat plains is manifest in low outcrops in an area five miles south-east of Noble's Nob.

In this area of approximately ten square miles there are rocks of both diverse compositions and origins. Normal granite is relatively scarce in this area where rocks of more basic composition, such as massive or gneissic hornblende-biotite-adamellite, as well as granodiorite, predominate. Graphic intergrowths of quartz and microcline, or of quartz and plagioclase, permeated the rock fabric and replaced the edges of a large proportion of the crystallised felspars, at a late stage in differentiation. Late-formed accessories, such as sphene, apatite and zircon occupy these same intergranular areas with the graphic quartz-felspar intergrowths.

Among the adamellites and granodiorites there occurs a variety of dark coloured, relatively fine grained dykes composed mainly of hornblende and intermediate plagioclase. These range in composition from syenite through monzonite to diorite, contain progressively less potash felspar, but considerable quantities of plagioclase ranging in the composition from An_{30} to An_{40}. Intergranular micrographic quartz-felspar intergrowths and abundant accessories, especially sphene, are characteristic of most of these rocks, while some of the diorite dykes contain also, accessory pyrite and were partially scapolitised and epidotised.

There are also some larger dykes of even more basic character including finer grained dolerites and coarser gabbros with major labradorite (An_{65}), pyroxene, accessory apatite and pyrite.

These several varieties of intermediate and basic igneous dykes are massive and unstressed and resemble the post-metamorphic intrusives of similar composition which occur in the Archaean. Their sharply transgressive mode of occurrence and the manner in which their composition and structure contrasts with that of the gneissic adamellites which they intrude, precludes any genetic relationship to the granitic rocks. Since the granites intruded the Archaean and are themselves somewhat gneissic, the dykes of basic rock originated after the formation of foliated structure within the granite and may confidently be regarded as comagmatic with the basic rocks in the Archaean.

This complex of calcic granitoid, intermediate and basic rocks extends easterly for a further five miles to a point five miles south-east of Red Terror Mine where the boundary again becomes obscured by alluvials and Proterozoic sediments. The eastern margin of the pluton is probably in this vicinity.

The ill-defined area of altered sediments within the igneous complex appears to be about two miles in width, but again alluvium obscures the boundaries. The area consists of tuffaceous sandstones and shales which were extensively felspathised and penetrated by quartz veins. These rocks extend easterly and merge with the Proterozoic sandstones which enclose the eastern margin of the pluton. Their relationship to the granites in the west is not clear because of continuous alluvial cover.

Immediately south of the altered sediments there is some 50 square miles of coarse grained massive porphyritic adamellite, the northern boundary of which is encountered ten miles south-south-east of Noble's Nob. The relationship of this with the Cabbage Gum granites, with the complex of igneous rock of different compositions and with the altered sediments, is also obscure. The absence of foliation and of intergranular graphic quartz-felspar intergrowth, as well as its more constant composition and distinct suite of accessories, suggest that these extreme southern adamellites may be a separate phase of the Southern Granite pluton. The main components of these massive, unstressed rocks are microcline, perthite, zoned oligoclase, quartz, biotite and muscovite. Apatite and hematite are the usual accessories, while sphene and pyrite appear in isolated areas where there are more basic rocks. Minor amounts of hornblende are present in most of the rocks, but occasionally a greater abundance of hornblende and oligoclase produced small areas of granodiorite.

Throughout most of the intrusive, oligoclase balances the total perthite and microcline, but towards its northern extremity potash felspars dominate the mineral assemblage and the rocks change to granite and leucogranite. In these areas of more felsic rock, tourmaline is very abundant.

The minor metal values of different types of fresh rock from the Southern Granite pluton were determined from composite samples collected in appropriate areas. The absence of significant differences is apparent from Table 13.

The Warramunga sediments along the northern contact of the Southern Granite pluton show evidence of alteration for at least nine miles in an east-west direction. This is expressed mainly in the kaolinisation and silicification of sediments thereby simulating the phenomena observed in contact aureoles in the north of the field. In addition to this, the pneumatolytic alteration of both the sediments and the granite itself was noted in drill cores in proximity to the major northeast lineament which passes through the granite east of Eldorado Mine. This alteration is manifest in veins of quartz-tourmaline-fluorite and in veins of kaolin in the sediments, or in the granite, Fig. 40.

During the course of a geochemical study of this granite-sediment contact many hundreds of auger holes were drilled to study rock alteration and the variation in minor metal values throughout the aureole. Numerous north-south traverse lines, extending from the granite to points three miles north of the contact, were drilled and sampled at 200 foot intervals.

TABLE 13.

Minor metal values in the Southern Granite pluton.

	Cu	Pb	Zn	Bi	Sn	W	Mo
Av. acidic igneous rocks**	16	19-30	30-150	2	50-80	7-80	3-12
massive granite of Cabbage Gum Basin	12	15	25	1	*3	*20	4
adamellite north of the area of altered sediments	10	20	25	1	*3	*20	3
porphyritic adamellite south of the area of altered sediments	12	22	25	2	*3	*20	4

* - denotes less than

** - according to Rankama and Sahama (1949).

Determinations by Australian Mineral Development Laboratories.

It was found that there were no significant variations in the contents of Cu, Bi, Pb, Mo, W, Ag, Cr, Mn, Co, or Ni throughout the aureole, in spite of argillic and siliceous contact alteration phenomena. The range of values for these metals in the sediments remained at the same level as for those in the granite, throughout the series of parallel north-south traverses.

The characteristics of the Southern Granite contact aureole are therefore similar to those of the northern granite, and from this it appears that neither base metal nor gold mineralisation has a genetic relationship with the granite intrusives.

(3) South-Eastern Granite stocks.

This is a small field of granitic intrusives, each less than a square mile area, which outcrops separately within a few miles radius of the Rocky Range Trigonometrical Station. Coarse grained porphyritic red granite of massive structure, containing potassic felspars of 10-20mm in size, is common to all outcrops. However, there are also some patches of finer grained microgranite of similar composition, amongst the coarser granites.

Oligoclase, biotite and muscovite are present in all of the rocks, but in smaller quantities than quartz and potassic felspars. Thus the granites are potash-rich. Both fluorite and tourmaline occur abundantly in these granites in addition to the normal accessories, zircon, apatite and hematite. Tourmaline and fluorite are even more abundant where xenoliths of country rock were enclosed in the granites.

In proximity to the 14-Mile Fault, the red granite was converted to flaser gneiss but the phenocrysts of potash felspar persisted as augen in the finely comminuted matrix of quartz, oligoclase and mica.

The country rocks south-east and east of New Hope Mine, including some areas of the South-Eastern Granite, and the porphyries in this area, were extensively kaolinised with the preservation of their original structures. Kaolin veins with characteristic wavy cross lamellar structure, penetrated felspars in the granite in the incipient stage of alteration, Fig. 44, and in the advanced stages, only quartz remained, Fig. 45. The associated sediments and porphyries were traversed by similar veins, but show also bulk replacement by kaolin.

There are also in this area many manifestations of pneumatolytic activity expressed in quartz-tourmaline and fluorite veins. These veins which are commonly closely associated with the kaolinisation, were observed along the southern margin of the Northern Granites and in places, along the northern margin of the Southern Granite. The significance of these phenomena is discussed below.

(4) <u>The mutual relationships of the granites</u>.

Although there are compositional and textural differences between the three areas of granite on the Tennant Creek field, they exhibit sufficient common characteristics to be regarded as consanguineous. The compositional differences can be attributed mainly to the processes of differentiation with little influence from contamination by country rock. The textural differences are similarly a function of differentiation in that the earlier-formed, weakly gneissic intrusives were injected simultaneously with regional tectonic activity, whereas the massive leucocratic rocks were emplaced later, as dykes or plugs amongst the foliated granites.

The northern pluton and the stocks in the south-east region, are essentially granitic and potash-rich, whereas much of the southern pluton is more basic and calcic in type. The incidence of abundant leucocratic rocks at White Hill suggests prolonged differentiation in this area and consequent late stage intrusion of residual magmatic components into the main body of solidified granite. This is reflected also in the widespread epigenetic quartz-felspar intergrowths in the grain boundaries of the crystallised rock fabric. The less common accessory minerals which are concentrated in biotites and in intergranular spaces in the Northern Granites, may also be a function of late stage magmatic activity. The complete absence of pegmatites may be attributed to the retention of the components of the graphic quartz-felspar intergrowth, as well as the minor components, within the granite itself.

The kaolinisation, silicification and tourmalinisation which exists in the contact aureoles of all three groups of granite, bears some similarity to the hydrothermal alteration phenomena associated with gold mineralisation. This is especially confusing in the areas adjacent to the Specific Horizon along the northern margin of the Southern Granite and in proximity to the South-Eastern Granites east of New Hope Mine.

The two types of argillic alteration are however, distinguishable by virtue of the texture and range of the argillic products, and the size and types of the areas over which they occur. It is more difficult to distinguish between silicification arising from late phases of granitic intrusion and that associated with the end products of hydrothermal mineralisation. Tourmalinisation associated with granitic intrusion is much more intense, on a larger scale and so clearly related to the granite, that there is no confusion with that associated with mineralisation.

Argillic alteration along the granite contacts occupies wide areas and is in many places continuous along the granite margins for some miles. Kaolin was the only mineral involved in this and it occurs in veins with a characteristic wavy cross lamellar structure, Figs. 40, 43, 44, or in very fine grained aggregates which permeate or replace whole sections of rock, Figs. 44, 45.

Argillic alteration associated with gold mineralisation is confined to the lode structures and the immediate wall rocks. A wider range of products was involved, including kaolin, illite, damourite, sericite and muscovite. Although the wavy cross lamellar structures do occur, these minerals mainly exist as individual crystals of considerable dimensions, Figs. 58-65, 68, 69, which are nearly always associated with epigenetic magnetite, specularite and gold.

The granites of Tennant Creek have the following characteristics which confirm that they are intrusive: the common occurrence of zoned plagioclase and large potash felspar phenocrysts; platy flow structure due to the alignment of felspar euhedra and elongate xenoliths; a cuboidal pattern of open tension joints one set of which is nearly horizontal and perpendicular to the steeply dipping flow foliation surfaces; and finally, the complete absence of migmatite.

The whole field of intrusives may be the higher level outcroppings of the irregular surface of an extensive underlying batholith. These granites are therefore similar to those of Group II in Rastall's classification which includes the major plutons in PreCambrian orogenic zones. The compositional variations and the broadly concordant structural relationship with the country rocks are also in keeping with the characteristics of this Group.

10. THE PORPHYRIES, BASIC AND INTERMEDIATE INTRUSIVES, QUARTZ REEFS AND OTHER VEINS.

(1) The Porphyries.

There are many exposures of porphyry at Tennant Creek but these have neither the areal extent, nor the same type of distribution as the granites. Ivanac (1954), showed that the distribution and the elongation of porphyry intrusions, was controlled by the east-west trend of the principal fold axes and although they are in places transgressive, the general relationship of the porphyry to the Lower Proterozoic sediments is concordant. Ivanac also stated that the greatest abundance of porphyry is in areas where there are reversals in the plunge of fold axes.

Most of the porphyry is massive, but shearing along the margins of the intrusives produced peripheral gneissic or mylonitic structures. The unstressed fabric of the central portions of the larger porphyry bodies indicates that they were intruded after the Lower Proterozoic rocks were folded. They are therefore post-Lower Proterozoic in age and the similarity between individual intrusives indicates that they connect in depth.

Porphyry as a group, is distributed diagonally across the field from south-east to north-west in separately outcropping intrusives which are located in the east-west trending structures. Accordingly, the main porphyries form an en echelon series of ovate or arcuate masses controlled by folds, but offset at intervals by faults. Although the diagonal porphyry belt lies mainly between the Northern and the Southern

Granite plutons, it trends around the Southern Granite in the south-east, and around the Northern Granite in the north-west.

Some of the porphyry cannot be positively identified in the field but requires thin section examination to distinguish it from the coarse lithic or crystal tuffs of the Warramunga sequence. The confusion is accentuated in the sheared peripheral zones, and in places where the rocks were impregnated by hematite or quartz.

The work of Elliston over a number of years has led him to the belief that there may be no igneous porphyries at Tennant Creek. Instead, he regards these rocks of inequidimensional granularity as fluidised sediments or "porphyroids". The coarse phenocrystic components of the rocks are considered by Elliston to be colloidal accretions, and the banded structures of the groundmass to be fluidal flow lines acquired during sliding on the shelf of the geosynclinal basin. This concept is not supported in this thesis because it is contrary to the findings from the petrographic study of a large number of thin sections of these rocks from various parts of the field.

In almost all examples the quartz phenocrysts are extensively embayed and the felspar euhedra are rounded at the corners by the fine grained groundmass of the rocks. The presence of irregular areas of twin lamellae, bearing no fixed orientation to crystal edges, may be observed in some of the quartz phenocrysts which are also internally shattered in a manner suggestive of the inversion of beta-quartz to alpha-quartz. Such phenomena preclude an origin through low temperature accretion of colloidal silica in unconsolidated sediments.

In proximity to both the quartz and felspar phenocrysts, there are regular increases in the grain sizes of the components of the groundmass. This texture reflects the normal tendency of progressive enlargement of crystals towards the centres of accretion, prior to the consolidation of the intrusive. No textures of the colloform banded type, or of the concentric or radial types which are typical of colloidal accretions, were observed in the porphyries.

The contacts of porphyry against the Warramunga rocks are frequently marked by silicification, by aureoles of red jasper, or by increases in the hematite content of the enclosing rocks. Although silica originated from the porphyry, the hematite was concentrated from the silicified fragments of the sediments which were incorporated in the porphyry during its intrusion.

Two occurrences of ignimbrite were described by Crohn and Oldershaw, (op.cit.). The association of these with the Lower Proterozoic sediments and the porphyries is not clear since the contacts are partly obscured, but the authors concluded that the ignimbrites were related in some way to the porphyry.

The compositional range of the porphyries was found to be comparable with that of the granites, whereas the geographic distribution of porphyries of different compositions is less regular, and opposite to that of the granite. In the northern, western and central areas the porphyries are equivalent in composition to adamellites, granodiorites or monzonites, whereas in the south-eastern area they are mainly of granitic composition. The Southern Granite on the other hand, is mainly adamellite and granodiorite whereas the Northern Granite is generally more acidic.

The porphyries are of massive structure with dark greenish grey fine grained groundmasses containing well-crystallised pink or white felspars and ovate glassy quartz grains. Flow structure is not generally visible in hand specimens, but is usually apparent in thin section.

In the north-western area near Bernborough, Black Eye and Queen of Sheba Mines, massive dark grey porphyries occur among tuffaceous sandstones, tuffs and ignimbrite. Most of these porphyries have the composition of granite or adamellite and contain abundant phenocrysts of quartz, orthoclase and zoned basic oligoclase (An_{30}), as well as minor chloritised biotite and magnetite. The groundmasses consist of fine grained quartz, felspars and micas with no rock fragments or shards. Quartz phenocrysts are rounded embayed euhedra which frequently exhibit partial internal replacement by chlorite while the felspar phenocrysts remain euhedral, or slightly rounded. A more sodic variety of porphyry near Bernborough Mine is comparable with toscanite in composition. It contains sparse minute phenocrysts of quartz, orthoclase and sodic oligoclase (An_{15}), in a chloritic quartzo-felspathic groundmass with spherulitic structures somewhat akin to lithophysae. Similar concentric structures were observed in the fragmental components of the ignimbrites in this area. These comparable textures in the porphyries and the ignimbrites in this area, supports the view of Crohn and Oldershaw, that some relationship may exist between these rocks, vide p. 65.

Another distinctive porphyry from near Black Eye Mine contains large spherical orthoclase individuals of 10-20mm diameter, as well as rectangular orthoclase euhedra similar to those of the "Baveno" type. These occur in a fine grained quartzo-felspathic groundmass with flow structures, the lines of which encircle the orthoclase spheres.

Near Red Bluff, in the far western area, brecciation, shearing, mineralisation and contamination by xenoliths of contiguous sheared sediment, render the porphyry difficult to identify. However, the massive sections of porphyry which contain quartz and perthite phenocrysts, are clearly of granitic composition but the sheared sections of rock which are mineralised with epigenetic magnetite, chalcopyrite and gold, are unidentifiable.

Near Jubilee Mine in the western area, there are several varieties of porphyry, including those of the "Baveno" type with the rounded felspar euhedra, referred to by Crohn and Oldershaw (1964). There are also massive dark grey varieties of monzonitic composition which have equal contents of sodic andesine (An_{33}), and orthoclase or microcline. The quartz euhedra in these are corroded and partly internally replaced by chlorite, and all phenocrysts are enclosed in chilled rims of finer grained groundmass material.

Biotite exists in the porphyries both as phenocrysts and as a groundmass component. Subhedral martite and sphene are common in the groundmass of the porphyries, but other accessories are poorly represented.

In the central portion of the field smaller porphyry intrusives exist with bedded crystal tuffs and ignimbrites. Near the aerodrome, porphyry of adamellite composition contains accessory sulphides, while two miles further east, chalcopyrite-bearing quartz porphyry is exposed in the vicinity of Kathleen Mine. Some of the porphyry near Kathleen Mine was brecciated, sheared and mineralised by quartz, specularite and hydromica veins, hence these sulphides may be epigenetic and not accessory components of the porphyry. Near Pup Mine there are rocks which have been classed as porphyries, but these are buff-coloured crystal tuffs distinguished by the layered distribution of fragmental opaque minerals, volcanic rock particles and granoblastic quartzite fragments.

Porphyry with the composition of monzonite was encountered in drill holes one and a half miles east-north-east of Tennant Creek, between Peko and Noble's Nob Mines and on the surface at Golden Forty Mine. It is therefore probable that there is underground continuity between the central and south-eastern fields of porphyry.

At Golden Forty Mine the porphyries contain phenocrysts of quartz, orthoclase and sodic andesine (An_{32}-An_{35}), as well as xenolithic rock fragments and grains of pyrite and chalcopyrite which reach a size of 5mm. diameter. These exhibit the effects of shear superposed upon original flow structure. It was observed in some of the drill holes at Golden Forty Mine, that a more acidic porphyry penetrated zones of copper mineralisation. This porphyry contains angular xenolithic fragments of the talc-chlorite-magnetite-actinolite schist with which copper mineralisation is associated, Fig. 47. The enclosure of sulphides and of hydrothermally altered and mineralised rocks, determines that at least some of the porphyry was introduced subsequent to the mineralisation of the Warramunga rocks. In the absence of evidence of multiple intrusions of porphyry, the presence of xenolithic inclusions of this type mitigates against any genetic relationship between porphyry and copper mineralisation.

Porphyries of acidic composition continue east-south-east towards Rocky Range as a series of small elongate sills many of which are strongly sheared, Fig. 48. However microscopic study showed that some of these are not porphyry but sheared tuffs, or tuffaceous sandstones. Those which are porphyry contain mainly quartz phenocrysts and fewer felspar phenocrysts than porphyries elsewhere in the field, thus indicating a trend towards increased acidity in the east. The Rocky Range porphyries may therefore be the last and most acidic of a widespread series of intrusions belonging to one period of igneous activity which affected the eastern, central, western and north-western parts of the field.

Throughout much of the south-eastern area the porphyries, as well as the granites, shales, sandstones and tuffaceous rocks, were subsequently altered. All contain thin veinlets of kaolin, and in extreme cases, kaolin permeated the entire rock through bedding or schistosity planes, or through intergranular boundaries.

It was mentioned in the section on granites, that this phenomenon which is common along the contact of the granites, may be attributed to the late stage hydrothermal phase of granite intrusion. Since the

porphyries, as well as the granites, were affected in this way, both were solidified before the onset of the final hydrolytic and pneumatolytic stages. There can therefore have been little time interval between the separate intrusions since both followed the regional folding. Hence, a genetic relationship between them is feasible.
Bulk samples prepared from outcrops of porphyry in the several separate areas were spectrographically examined for certain minor metals. The results are shown in Table 14.

Due to the difficulty in avoiding mineralised rock, and the influence of secondary metallic minerals, unusually high contents of copper and lead reported in the samples of porphyry from Kathleen Mine, and slightly higher than average values in the porphyry of Red Bluff. Most of the porphyries however, display normal, or low values compared with average acidic igneous rocks. Sulphides were observed in some polished sections of the porphyries from the aerodrome and from Golden Forty Mine, but since these do not reflect in the analyses of the bulk samples, they are not present throughout the entire body of the intrusives.

The results from most of the porphyries, indicate that they are not contributors of base metal mineralisation of the field and that like the granites, they exhibit normal, or lower than normal contents of minor metals. This conclusion is in accord with the presence of particles of sulphides and of xenoliths of talcose rock, the host for copper mineralisation, in some porphyries.

TABLE 14.

Minor metal components of porphyries.

	Cu	Pb	Zn	Bi	Sn	W	Mo
Av. acidic igneous rocks**	16	19-30	30-150	2	50-80	7-80	3-12
Northern Area							
(a) near Bernborough Mine	35	35	30	1	3	20	1
Western Area							
(a) Red Bluff	60	30	30	25	3	20	15
(b) N. of Curlew Mine	14	14	*20	1	*3	* 5	5
(c) Jubilee Mine	16	11	*20	2	*3	* 5	8
Central Area							
(a) Airport	18	25	50	2	8	20	8
(b) Kathleen Mine	400	2500	50	1	4	20	6
(c) Pup Mine	15	20	60	3	8	20	3
South Eastern Area.							
(a) Golden 40 Mine	30	15	60	1	3	20	1
(b) New Hope Mine	14	7	*20	2	*3	* 5	2.5
(c) Rocky Range	10	6	20	1	3	20	2

* - denotes less than
** - according to Rankama and Sahama (1949)
Determinations by Australian Mineral Development Laboratories.

(2) Basic and intermediate intrusives.

Small, often isolated outcrops of intermediate or basic igneous rocks exist in various parts of the field with no apparent genetic relationship to the major acidic intrusives. These occur in the Archaean, in the Warramunga sediments and in the Proterozoic granites.

The range of intrusives which penetrated the Archaean complex was discussed in an earlier section. It was shown that some of these were introduced before the metamorphic changes in the Archaean rocks, while others were introduced at a period later than that in which the Warramunga sediments were folded. On petrographic and field evidence, these comparatively young basic, intermediate and lamprophyric intrusives of the Archaean may be correlated with the intermediate and basic dykes which penetrated the Southern Granite, with the microdiorites which penetrated the Station Hill Granite, and with the diorites and lamprophyres intruded into the sediments.

Some five miles north-west of Tennant Creek, scapolitised and epidotised diorites, as well as lamprophyres, are prominent over an area of several square miles. One of the largest of these diorite dykes which extends for half a mile in the west-north-west direction from the edge of the field of lamprophyres, varies in composition from leucodiorite to tonalite, but maintains throughout, a high content of albite, sphene and apatite. Similar, but smaller dykes extend further north and beyond Grey Bluff Trigonometrical Station and were intersected during drilling at Red Bluff. All of these intrusives are unstressed, often scapolitised and contain accessory sulphides. They are differentiates of the younger basic intrusives in the Archaean basement.

The lamprophyres are mainly minettes composed of biotite and orthoclase, Fig. 49, but kersantites also occur in some places. Other kersantites were encountered in drill holes at Lone Star Mine and in the south near Red Terror Mine. These, like the diorites, are unstressed and were intruded after the folding of the Warramunga sediments. While the diorites are probably high level derivatives from the gabbroic rocks of the basement, the lamprophyres with their coarse granularity and abundant mica and apatite, may be manifestations of the late hydrothermal phase in the differentiation of the basic rocks.

(3) Quartz reefs, jaspers and other veins.

There are numerous barren quartz reefs in the Tennant Creek area, many of which are most prominent and continuous in outcrop. In general these are open space fillings in the series of north-south, north-east and north-west systems of faults which developed after the period of mineralisation.

The largest of the quartz reefs follow the series of north-west trending faults for many miles and often attain thicknesses of thirty feet. Smaller reefs follow the less prominent fault systems which have the characteristics outlined in an earlier section.

The quartz from all of these systems of faults consists mainly of coarse grained subidiomorphic crystals in parallel, or criss-crossing growth structures, enclosing fragments of silicified and brecciated country rock or porphyry, Fig. 50. All reefs were intersected by subsequent systems of smaller quartz veins which filled tension fractures produced by later movements. Most of the original vein quartz contains minute specularite and sericite inclusions, as well as fluidal inclusions which enclose gas bubbles vibrating vigorously under the influence of Brownian movement, Fig. 51.

In some sections of the quartz reefs there is a much greater proportion of specularite formed as tabular crystals in the grain boundaries of the quartz aggregate, Figs. 52 and 53. The proportions of quartz and specularite vary along the strike of the reefs which in places, may contain enough specularite to resemble the quartz-hematite lenses, or lode formations. An example of a quartz-specularite reef of this type may be seen about one mile north of Flynn's Monument on the Stuart Highway.

A less prominent system of quartz reefs, with a north-south trend occurs along the southern limb of the main anticline. These are characterised by crustification structures where the quartz filled open spaces. The quartz-filled fractures cross the Warramunga beds perpendicularly and were formed through tension directed along the bedding.

In addition to the barren epigenetic open space and breccia fillings in the major and minor fault systems, there are smaller quartz reefs, veins or sheets of earlier origin in the rock cleavages, or in the east-west shears which traverse the complex of drag folds along the limbs of the major anticline in the south of the field.

These reefs do not contain idiomorphic quartz but consist of highly stressed, slickensided sheets of "pressure quartz" and oriented chlorite which were involved in the shearing in drag folded areas. The country rock shales in proximity to these shears were converted to slates or phyllites.

The orientation of the slickensides is steep within the plane of the shears and similar to the attitude of the bonanza ore shoots within the Noble's Nob orebody. The association of chlorite and quartz, their age relation to the shears, and the significance of the orientation of the lineations, indicates a genetic relationship between these veins and mineralisation.

Around some of the larger porphyry intrusives there are peripheral zones of cryptocrystalline silica enclosing minor amounts of hematite which together replaced the contact sediments. These areas of jasper owe their origin to siliceous fluids which emanated from the porphyries.

Large dyke-like masses of fine grained schorl rock, or of intergrown quartz, tourmaline, apatite and fluorite, were of late magmatic origin. These are prominent along the margins of the Station Hill Granites, in proximity to the granite stocks in the south-eastern region, and in the area where the north-westerly photolinear structure intersects the Southern Granites. Numerous minute veinlets of the same type have also been encountered in underground workings, in drill cores and from places more or less marginal to the granites. Veinlets of kaolin, such as that depicted in Fig. 40, are frequently associated with these tourmaline-bearing rocks.

FIG. 1.

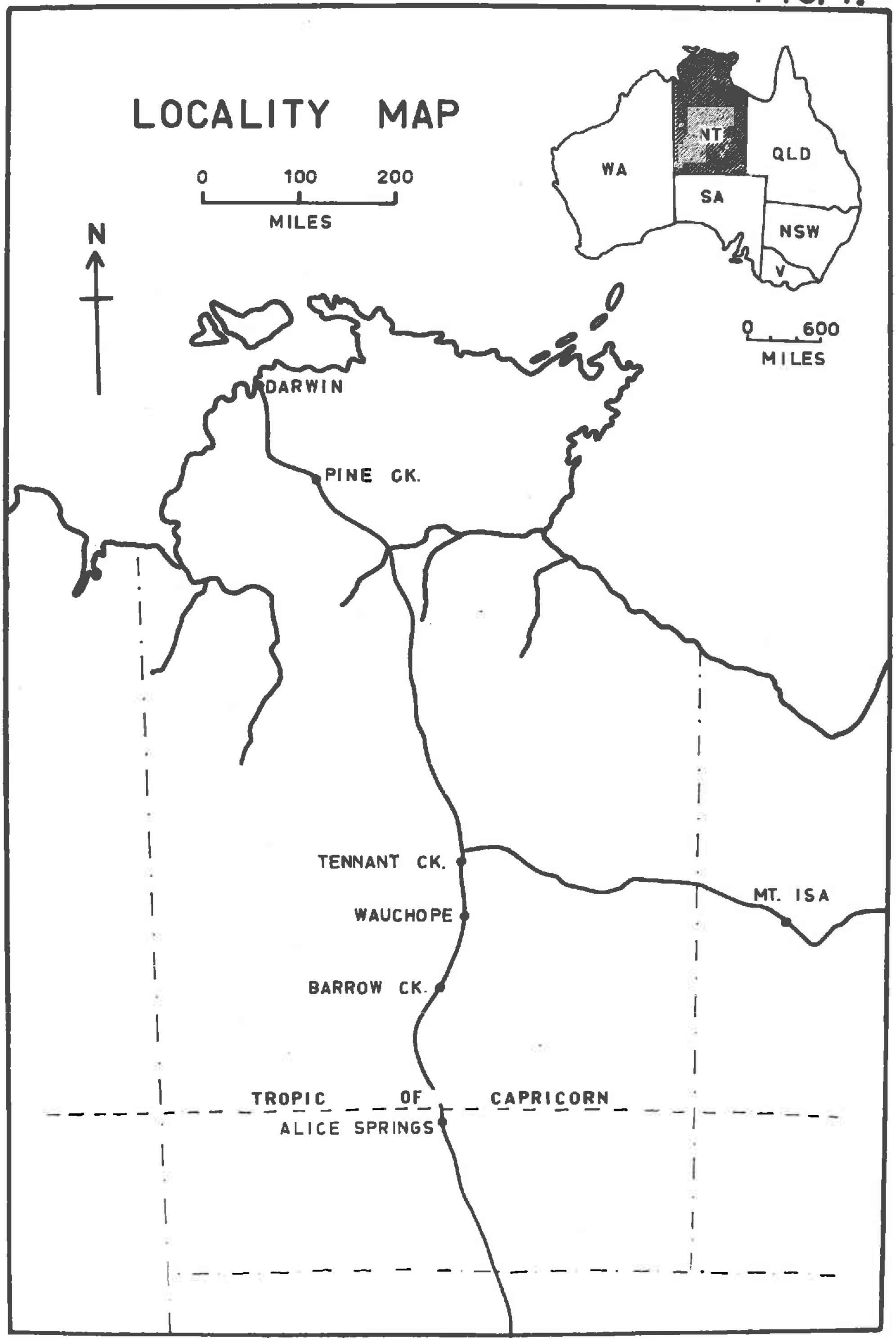

LOCALITY MAP
0
100
200
MILES
N
WA
NT
QLD
SA
NSW
V
0
600
MILES
DARWIN
PINE CK.
TENNANT CK.
WAUCHOPE
BARROW CK.
MT. ISA
TROPIC OF CAPRICORN
ALICE SPRINGS

FIG. 2

SUBSURFACE PROFILE NEAR NOBLE'S NOB

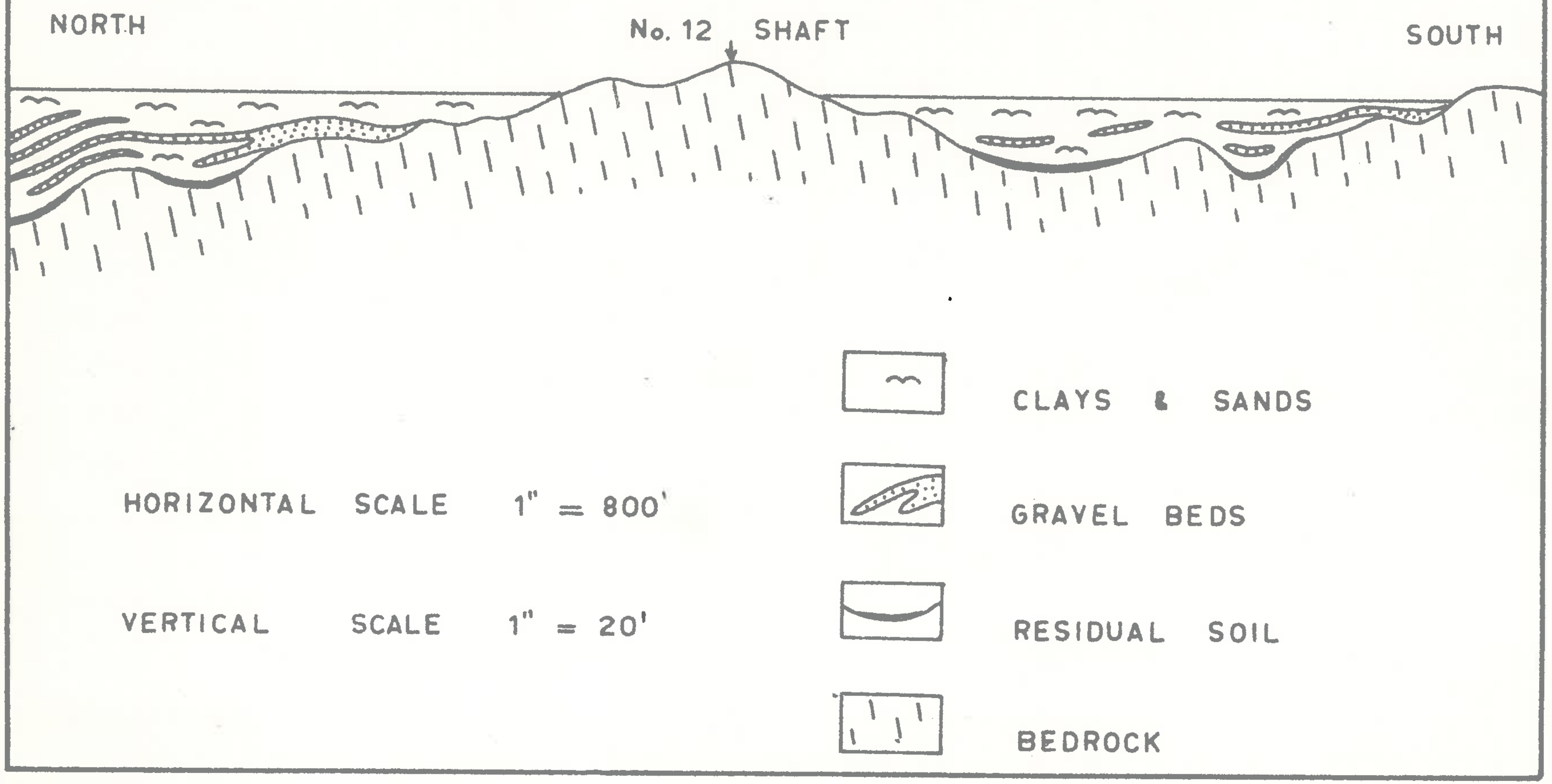


FIG. 3.

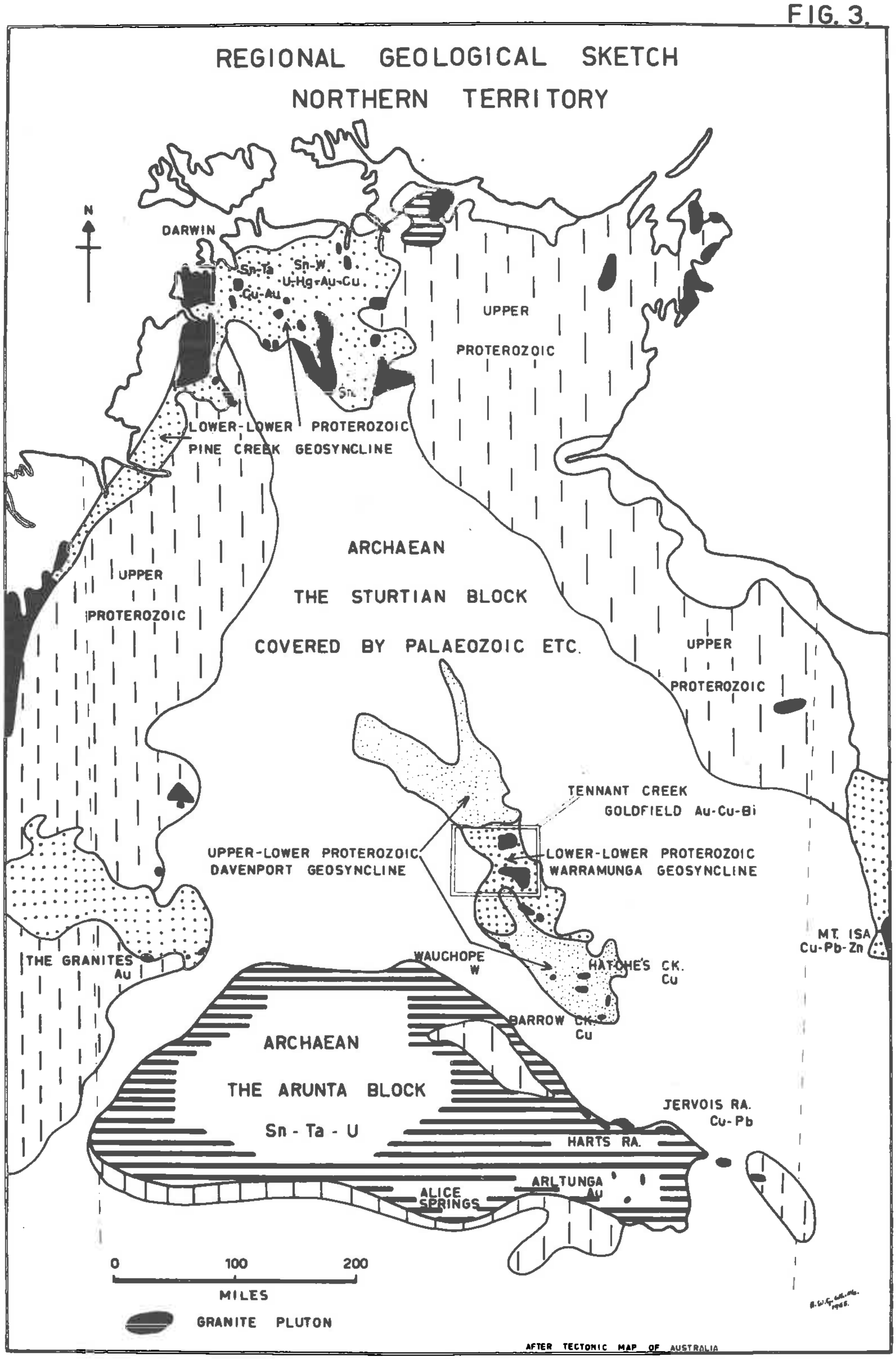

REGIONAL GEOLOGICAL SKETCH
NORTHERN TERRITORY
N
DARWIN
Sn-Ta
Sn-W
U-Hg-Au-Cu
Cu-Au
Sn
UPPER
PROTEROZOIC
LOWER-LOWER PROTEROZOIC
PINE CREEK GEOSYNCLINE
ARCHAEAN
THE STURTIAN BLOCK
COVERED BY PALAEOZOIC ETC.
UPPER
PROTEROZOIC
UPPER
PROTEROZOIC
TENNANT CREEK
GOLDFIELD Au-Cu-Bi
UPPER-LOWER PROTEROZOIC
DAVENPORT GEOSYNCLINE
LOWER-LOWER PROTEROZOIC
WARRAMUNGA GEOSYNCLINE
THE GRANITES
Au
WAUCHOPE
W
HATCHE'S CK.
Cu
MT. ISA
Cu-Pb-Zn
BARROW CK.
Cu
ARCHAEAN
THE ARUNTA BLOCK
Sn - Ta - U
JERVOIS RA.
Cu-Pb
HARTS RA.
ARLTUNGA
Au
ALICE
SPRINGS
0
100
200
MILES
GRANITE PLUTON
AFTER TECTONIC MAP OF AUSTRALIA

FIG. 4.

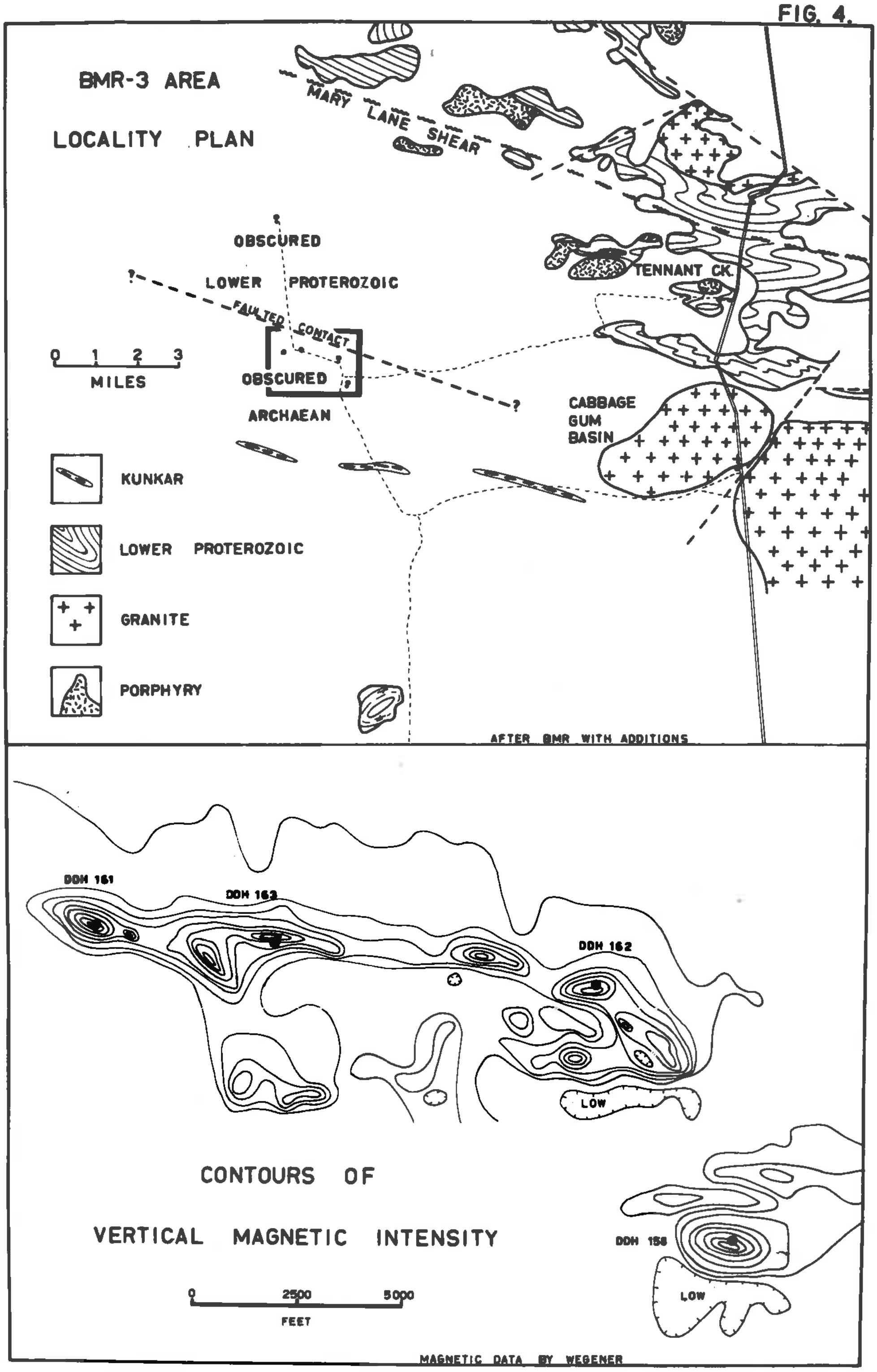
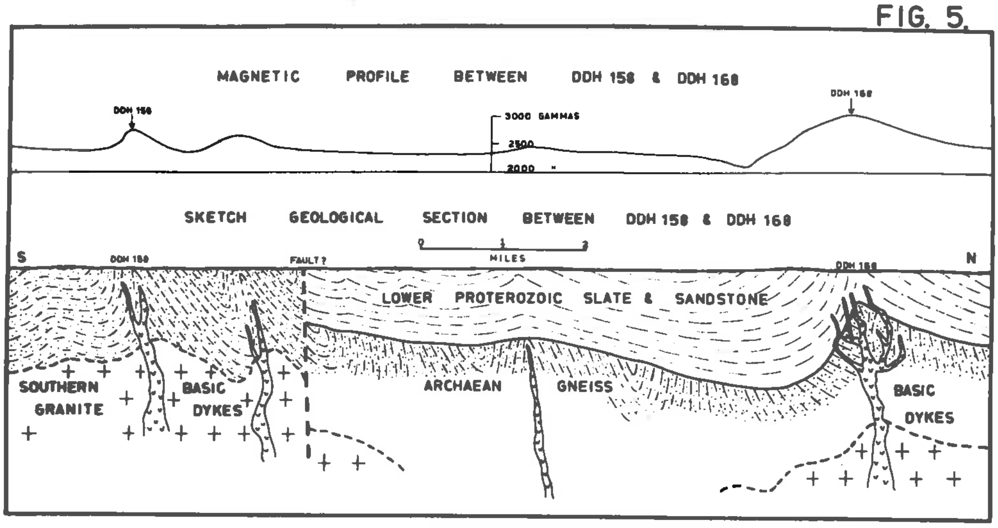
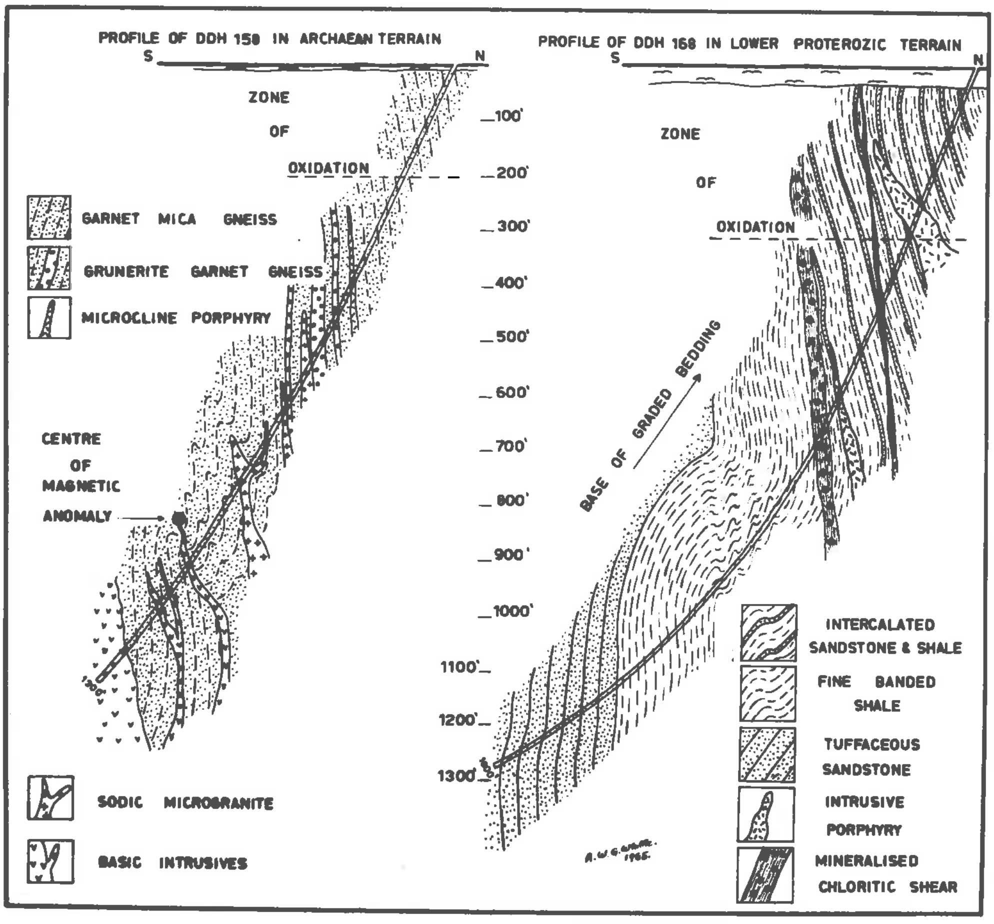

BMR-3 AREA
LOCALITY PLAN
MARY LANE SHEAR
OBSCURED
LOWER PROTEROZOIC
FAULTED CONTACT
OBSCURED
ARCHAEAN
0 1 2 3
MILES
TENNANT CK.
CABBAGE
GUM
BASIN
KUNKAR
LOWER PROTEROZOIC
GRANITE
PORPHYRY
AFTER BMR WITH ADDITIONS
DDH 161
DDH 163
DDH 162
LOW
CONTOURS OF
VERTICAL MAGNETIC INTENSITY
DDH 158
LOW
0 2500 5000
FEET
MAGNETIC DATA BY WEGENER

FIG. 5.



MAGNETIC PROFILE BETWEEN DDH 158 & DDH 168
DDH 158
DDH 168
3000 GAMMAS
2500
2000 "
SKETCH GEOLOGICAL SECTION BETWEEN DDH 158 & DDH 168
0 1 2
MILES
S
N
DDH 158
FAULT ?
DDH 168
LOWER PROTEROZOIC SLATE & SANDSTONE
SOUTHERN GRANITE
BASIC DYKES
ARCHAEAN GNEISS
BASIC DYKES



PROFILE OF DDH 158 IN ARCHAEAN TERRAIN
S
N
ZONE OF OXIDATION
100'
200'
300'
400'
500'
600'
700'
800'
900'
1000'
1100'
1200'
1300'
GARNET MICA GNEISS
GRUNERITE GARNET GNEISS
MICROCLINE PORPHYRY
CENTRE OF MAGNETIC ANOMALY
SODIC MICROGRANITE
BASIC INTRUSIVES
PROFILE OF DDH 168 IN LOWER PROTEROZIC TERRAIN
S
N
ZONE OF OXIDATION
BASE OF GRADED BEDDING
INTERCALATED SANDSTONE & SHALE
FINE BANDED SHALE
TUFFACEOUS SANDSTONE
INTRUSIVE PORPHYRY
MINERALISED CHLORITIC SHEAR

Fig. 6.

Archaean rocks.

polished section x 110.

This section illustrates the high iron content of quartz-biotite-garnet gneiss and the mode of occurrence of both hematite prisms (white) and magnetite subhedra (light grey) in the foliation of the gneiss.

In polished section, the oriented biotite flakes are almost black and the quartz and garnet are dark grey.

D.D.H. 161 - 685 feet.

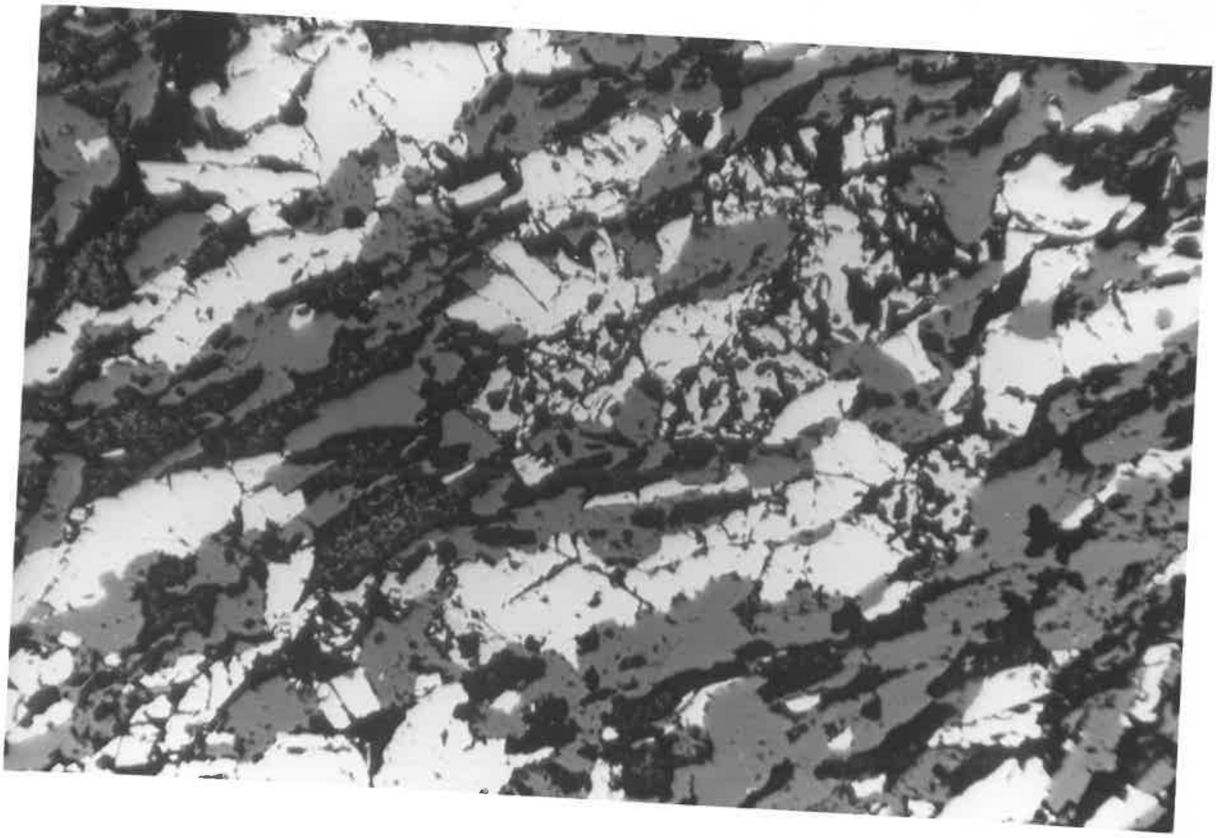
Fig. 7.

Archaean rocks.

polished section x 110.

A strongly mineralised section of quartz-mica-garnet gneiss in which pyrrhotite (rough off-white surface) and pyrite (smooth bright white surface) replaced mainly the micaceous minerals (rough mottled grey surfaces). Quartz (smooth darker grey), and garnet euhedra (smooth lighter grey), were not replaced but were penetrated by thin veinlets of sulphides. Sulphides also formed in the grain boundaries between quartz and the silicates.

D.D.H. 158 - 882 feet.



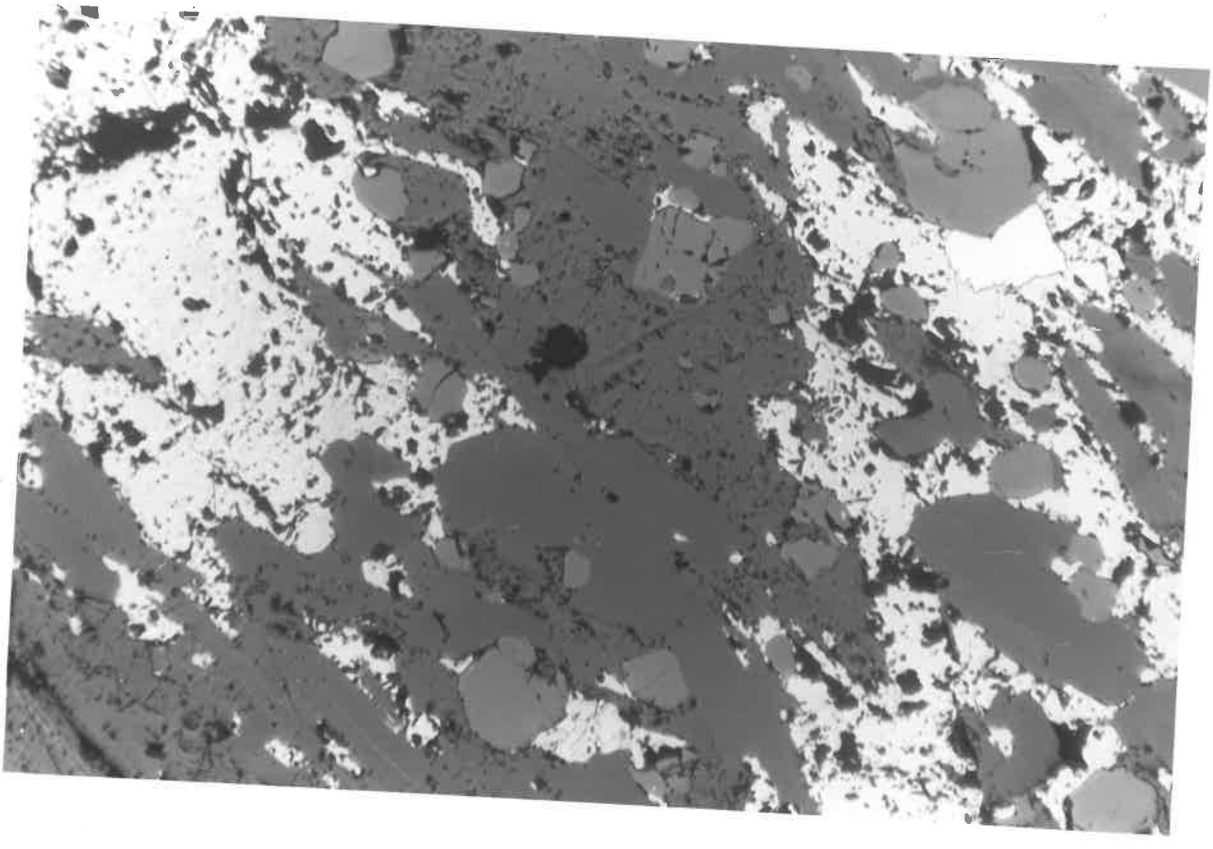


Fig. 8.

Archaean rocks.

thin section x 70.

This section illustrates the massive, even grained, unstressed nature of the post-metamorphic quartz-dolerite. It is composed of labradorite (white), augite (grey) and accessory magnetite and ilmenite in exsolution intergrowths (black).

D.D.H. 158 - 1300 feet.

Fig. 9.

Archaean rocks.

thin section x 110.

Quartz-biotite-garnet gneiss, mineralised by epigenetic sulphides (black) which penetrated the cleavages of biotite (grey) and the intergranular boundaries between quartz (white) and garnet (white, mottled, high relief).

D.D.H. 158 - 900 feet.

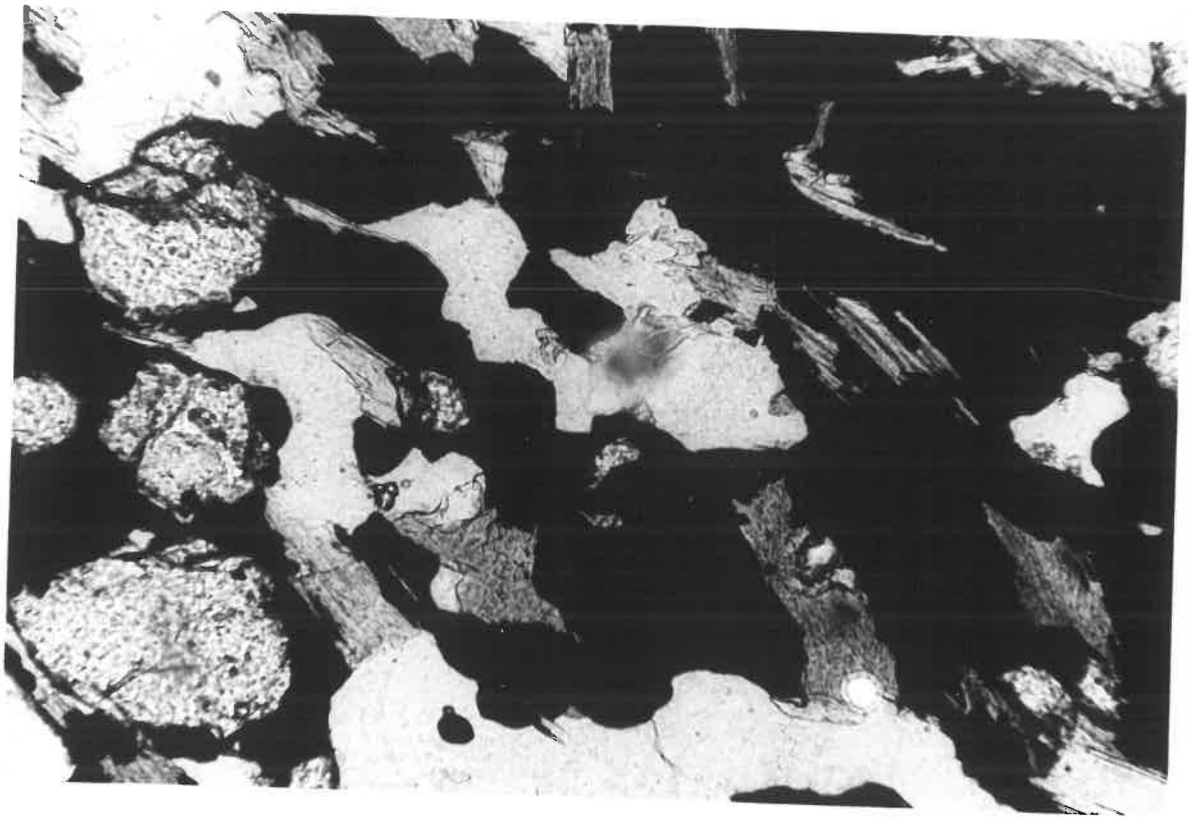


Fig. 10.

Archaean rocks.

polished section x 220.

The section illustrates the graphic intergrowth between ilmenite (light grey) and pyroxene (darker grey) in quartz-dolerite.

Early-formed accessory pyrite and pyrrhotite (both white) were trapped in the graphic intergrowth.

D.D.H. 158 - 1300 feet.

Fig. 11.

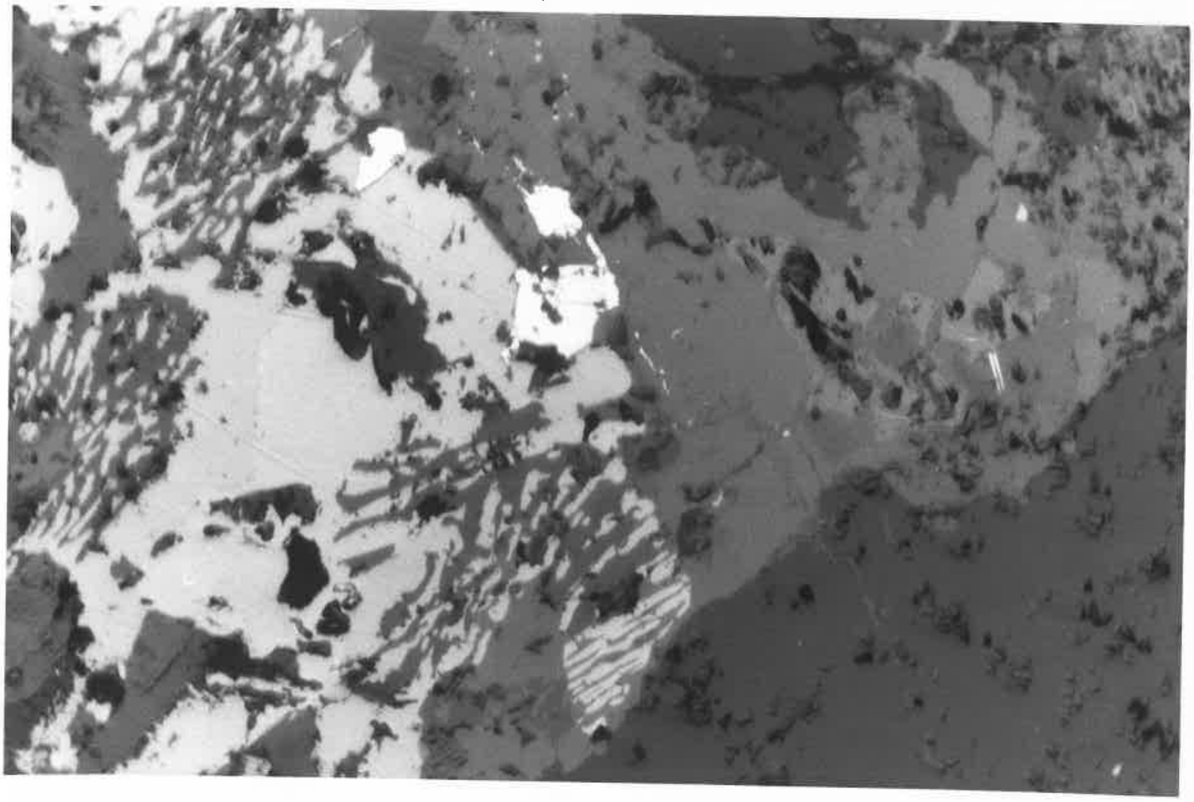
Archaean rocks.

polished section x 330 - oil immersion.

The magnetite (light grey) contains unusually large oriented exsolution blades of ilmenite (medium grey).

Intergrowths of these two minerals are accessory components of the quartz dolerite (black).

D.D.H. 158 - 1300 feet.



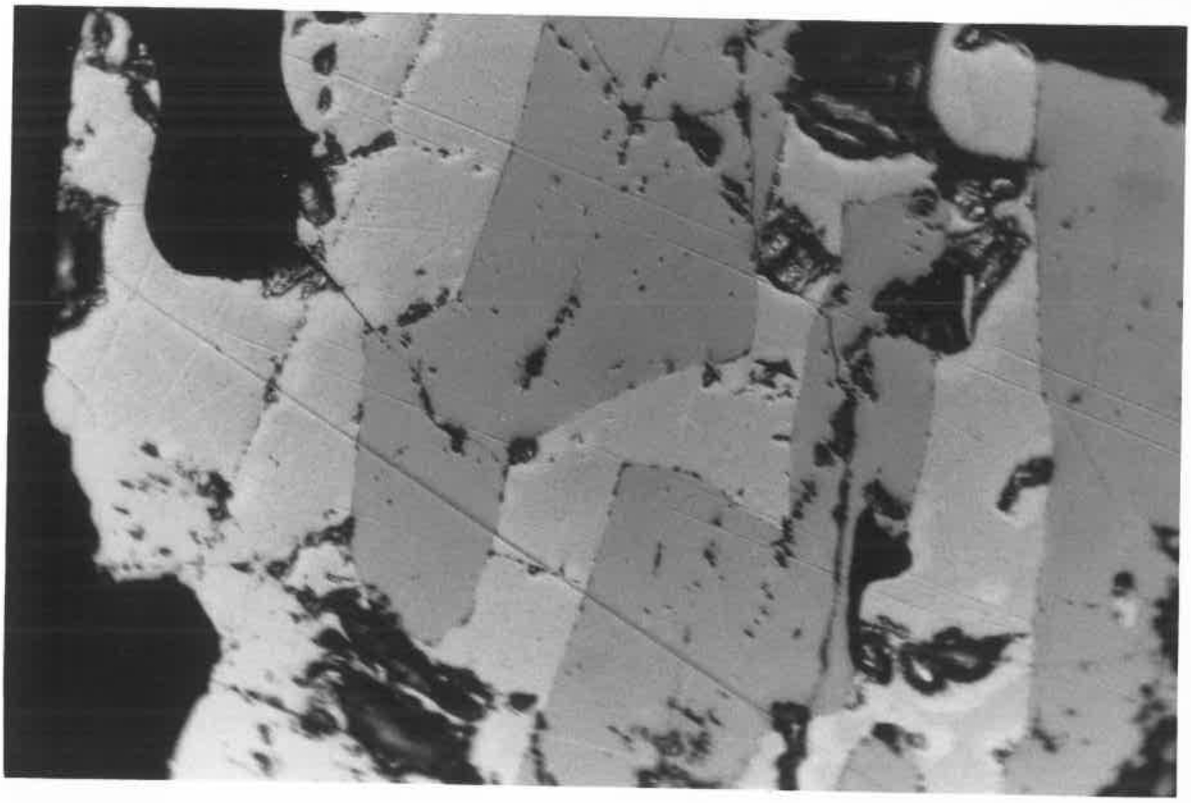


Fig. 12.

Archaean rocks.

thin section x 70.

This section of mineralised quartz-biotite-garnet gneiss shows epigenetic sulphides, mainly pyrrhotite with subordinate pyrite and chalcopyrite (black), emplaced in the gneiss along its foliation, cleavage planes and fractures. The rock contains as much as 20% sulphides in these sections.

D.D.H. 158 - 882 feet.

Fig. 13.

Archaean rocks.

thin section x 70.

The section illustrates the parallel alignment of hornblende prisms and of elongate lenticles of the quartzo-felspathic components in a dynamically metamorphosed microdiorite intrusive.

D.D.H. 158 - 1123 feet.

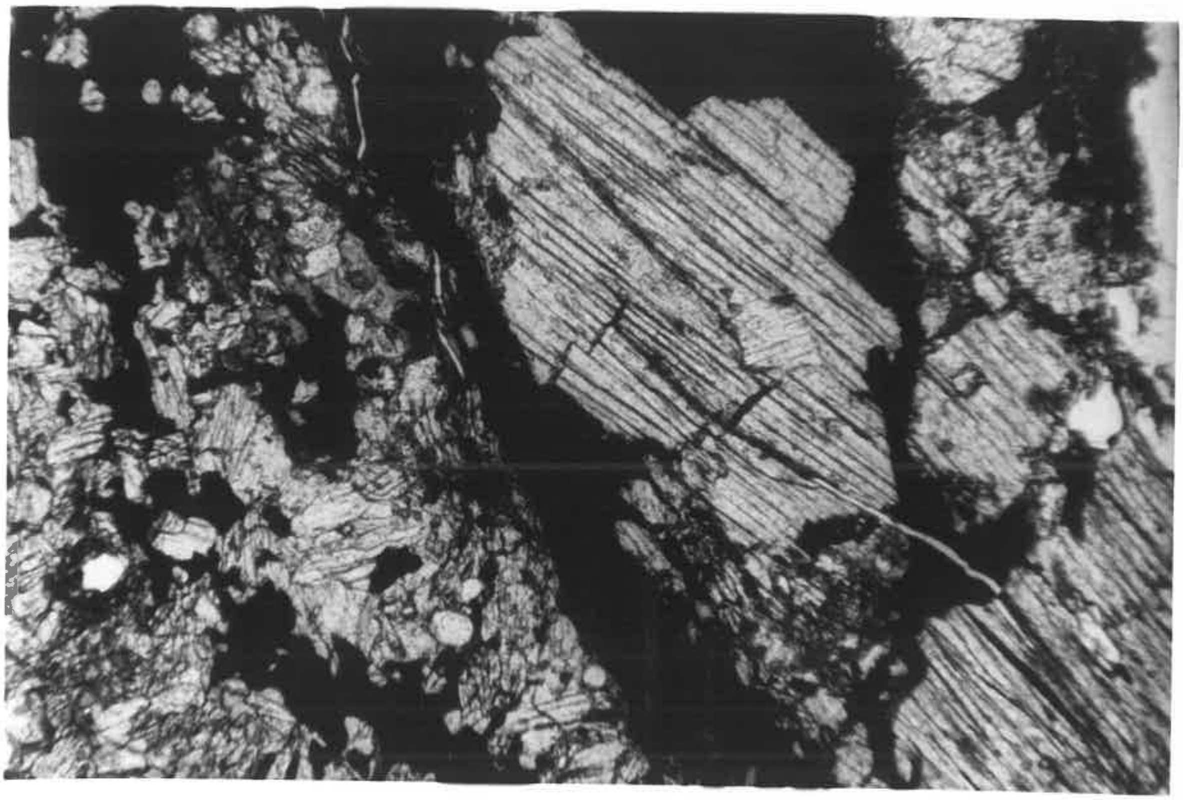


Fig. 14.

Archaean rocks.

polished section x 110.

A section of quartz-biotite-pyroxene granulite containing thin bands of ilmenite, which were intersected by transgressive chalcopyrite-calcite veins.

quartz - Q : ilmenite - I : chalcopyrite - CH : calcite - C

D.D.H. 163 - 421 feet.

Fig. 15.

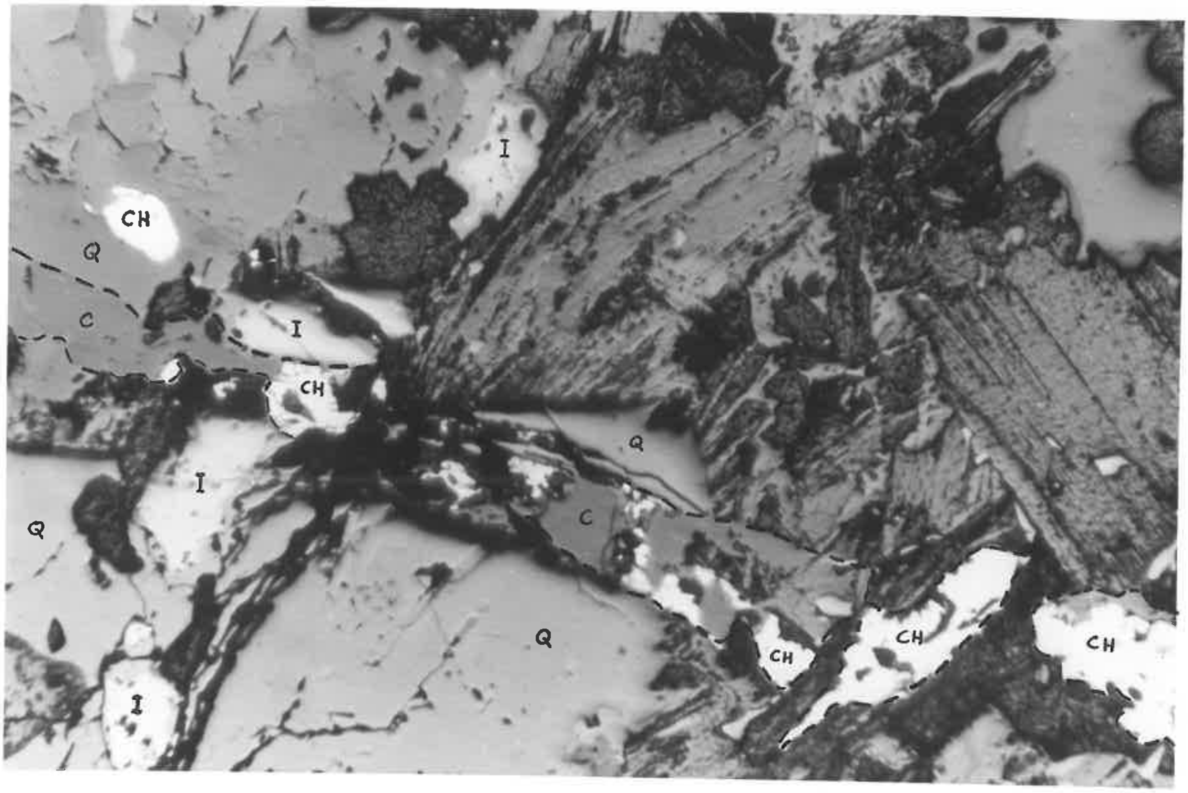
Archaean rocks.

polished section x 110.

The granulite (grey) was intersected by a felspar-pyrite-chalcopyrite vein (sulphides, white and felspars, black).

Both sulphides and felspars moved beyond the confines of the vein into the surrounding granulite via intergranular boundaries.

D.D.H. 163 - 525 feet.


CH
Q
C
I
I
CH
I
Q
I
Q
C
Q
I
CH
CH
CH

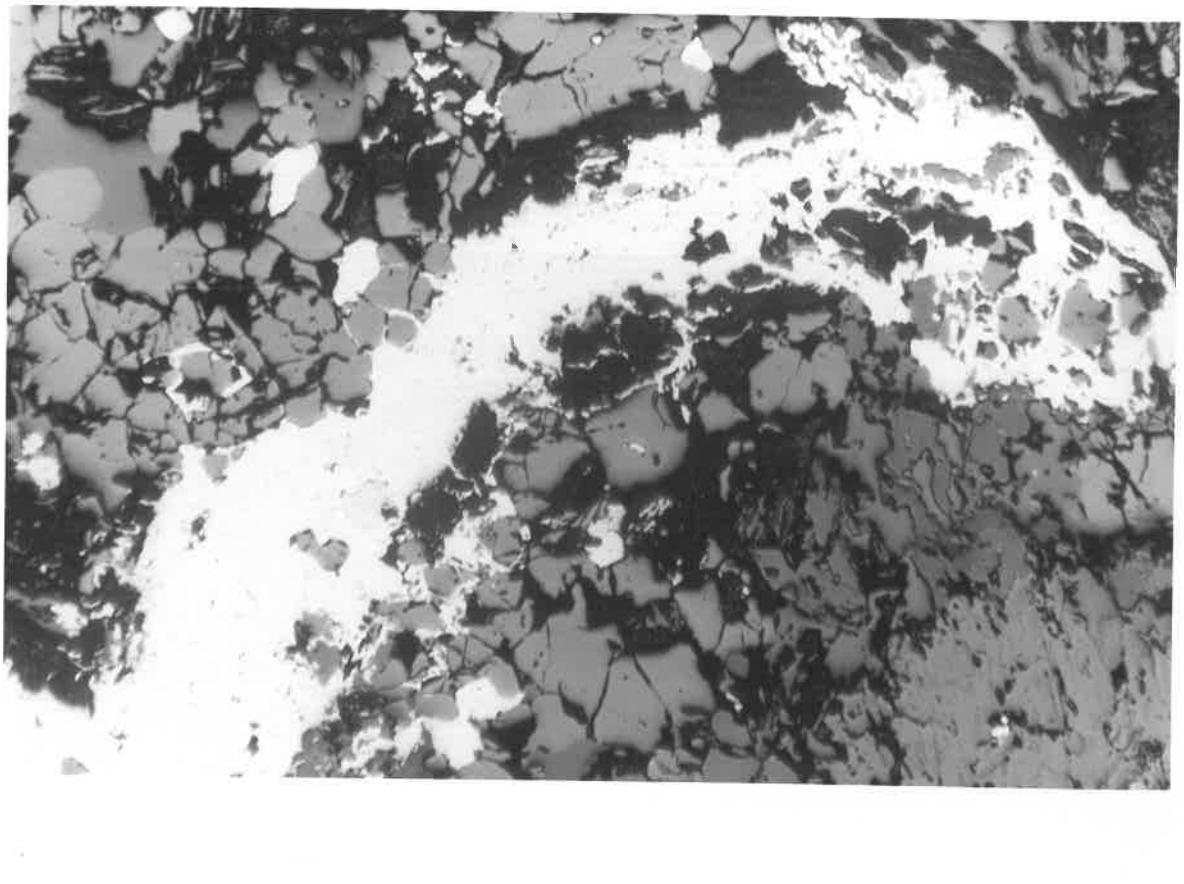


Fig. 16.

Archaean rocks.

polished section x 250 - oil immersion.

The section illustrates the emplacement of ilmenite (light grey) and pyrite (white) in the grain boundaries and in the cleavages of the components of granulite (darker greys and black).

D.D.H. 163 - 525 feet.

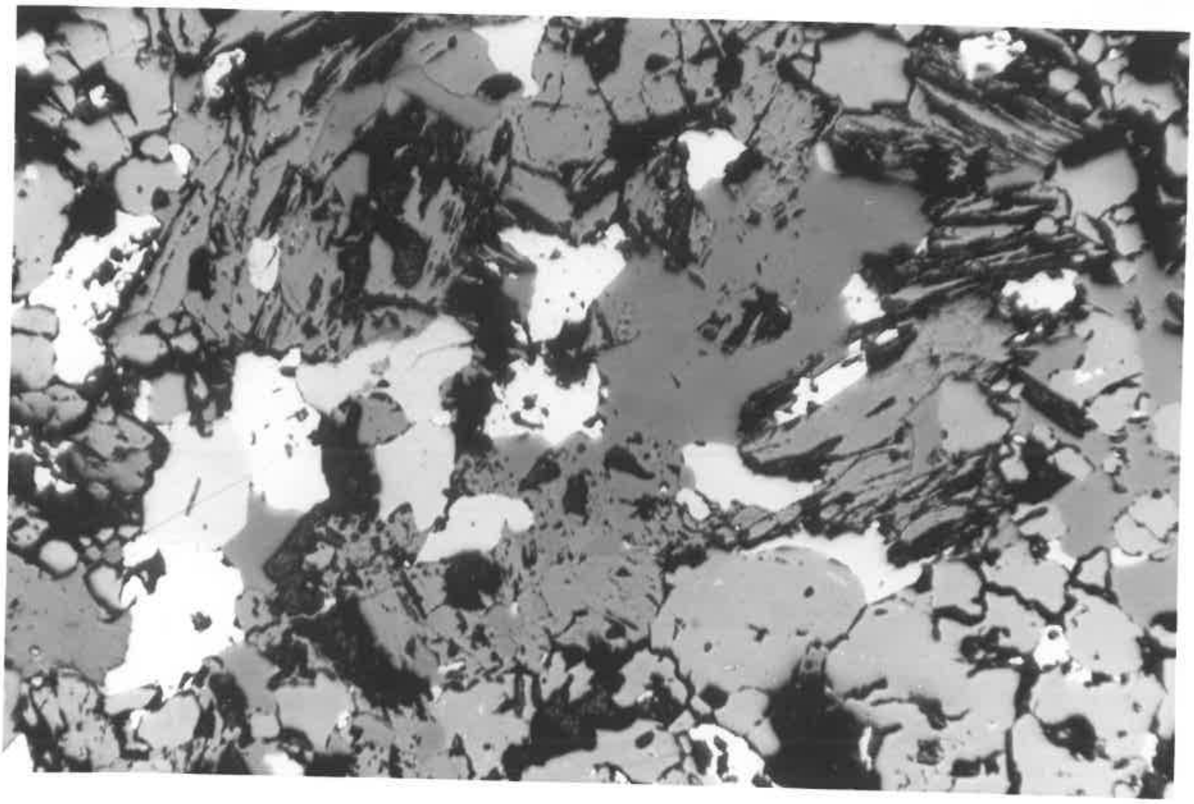
Fig. 17.

Archaean rocks.

thin section x 70.

This section of granulite (fine grained dark grey aggregate of garnet and pyroxene), was traversed by a quartz-pyrite vein (coarse grained lighter grey aggregate containing black opaque sulphide). The sulphide from the quartz vein, and some of the quartz itself penetrated beyond the vein contact into the enclosing granulite.

D.D.H. 163 - 525 feet.



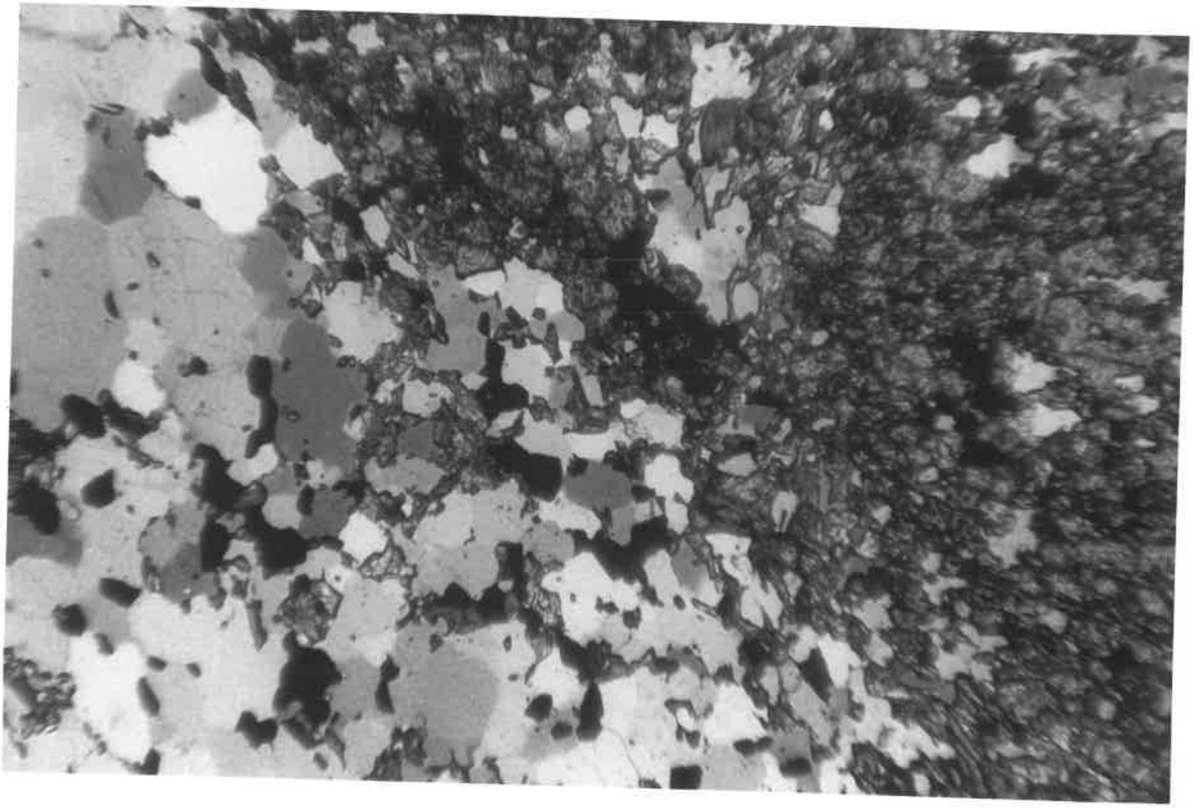


Fig. 18.

Granite contact phenomena.

photomacrograph - natural size.

Slate which was fractured and filled by kaolin. The kaolin was derived from the adjacent granite.

Station Hill Granite contact.

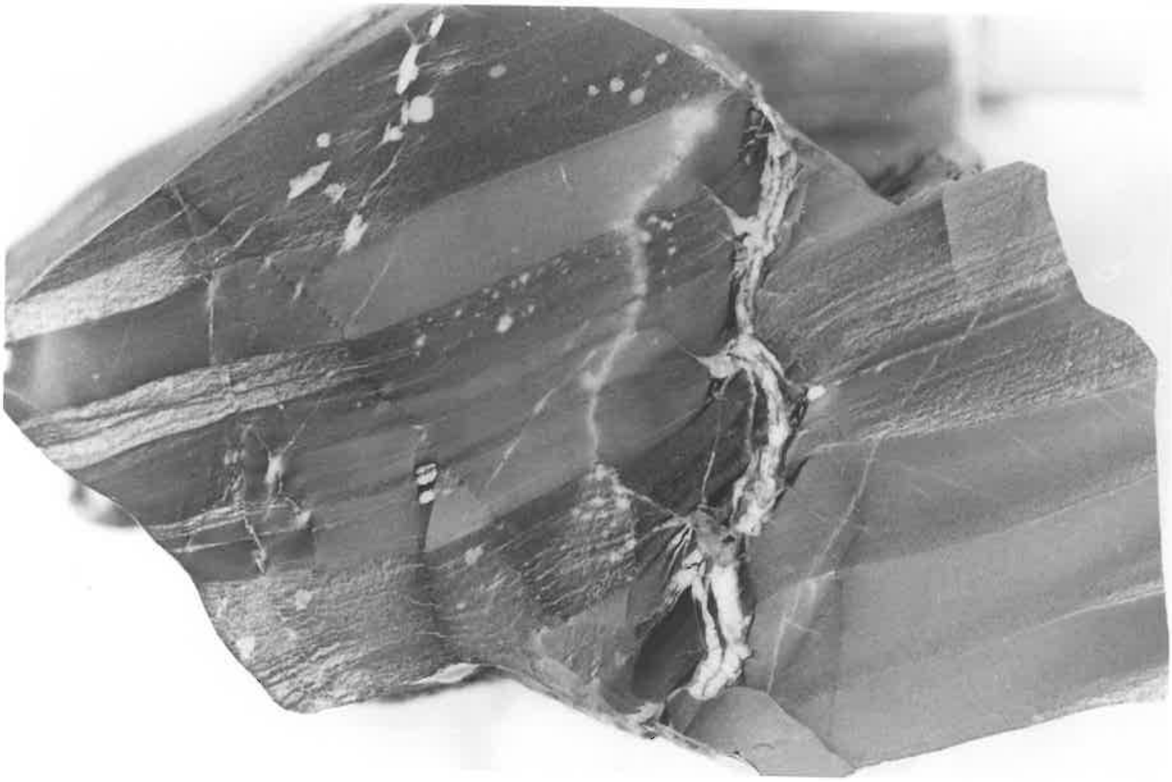
Fig. 19.

Granite contact phenomena.

photomacrograph - natural size.

Slate which was thoroughly brecciated and later filled and veined by clays of hydrothermal origin. These emanated from the adjacent granite.

Station Hill Granite contact.



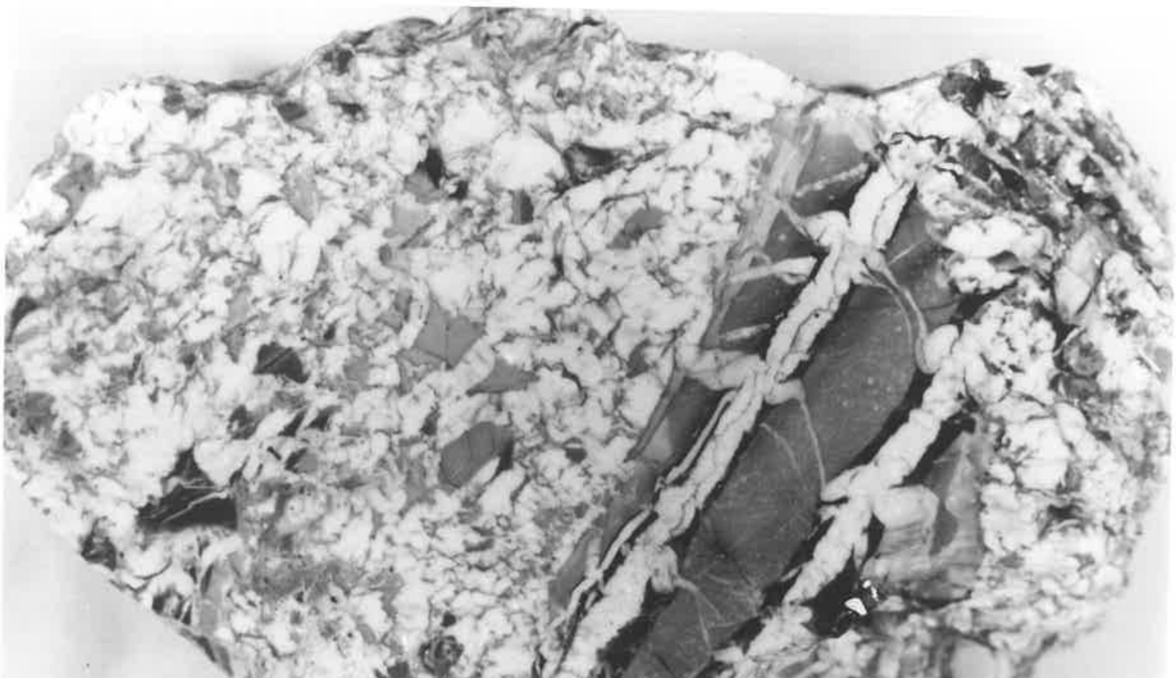


Fig. 20.

Textures of sediments.

photomacrograph - natural size.

The longitudinal section of core, taken from a drill hole in the Plw_2 sediments, shows typical preconsolidation slumped structure in interbedded shale (light grey), siltstone (fine grained dark grey) and tuffaceous sandstone (coarse grained dark grey).

near Noble's Nob.

Fig. 21.

Textures of sediments.

thin section x 70.

Intercalated shale and tuffaceous sandstone from a drill hole illustrating the sharpness of facies changes. The base of the sandstone lamellae is greatly enriched in clastic martite (black) due to natural heavy mineral accumulation. Fine grained clastic martite exists also in the shale.

D.D.H. PN7. - 167 feet.

near Peko Mine.

Fig. 22.

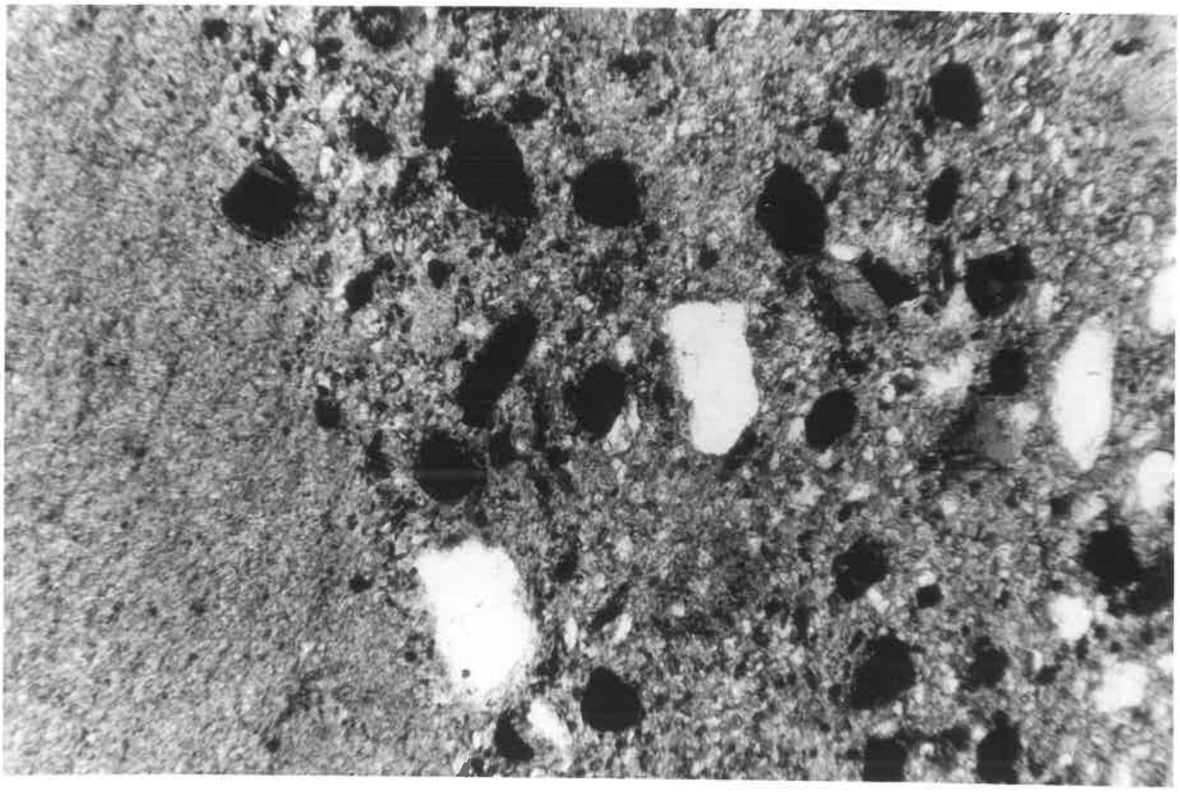
Textures of sediments.

thin section x 70.

Rapid and rhythmic facies variation existing between fine grained tuffaceous sandstone and sericitic shale. The black particles are clastic martite.

D.D.H. 165 - 843 feet.

near Noble's Nob Mine.



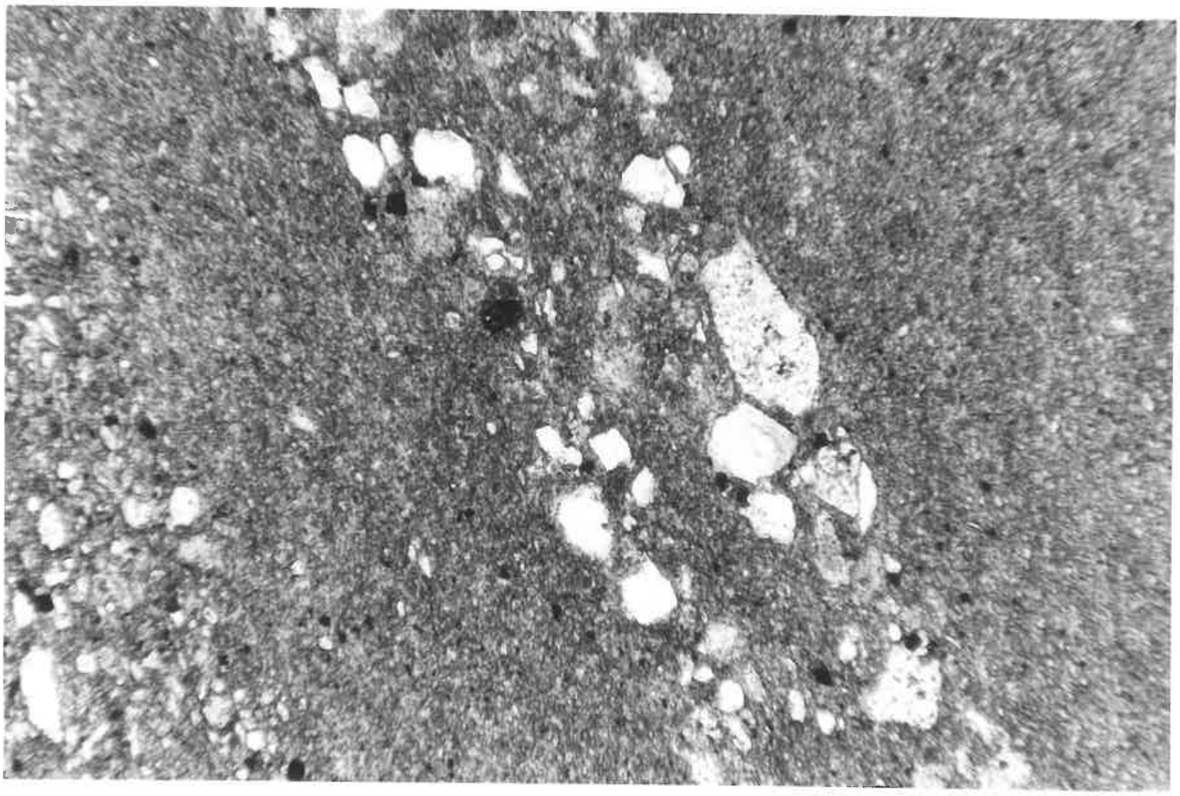


Fig. 23.

Textures of sediments.

thin section x 70.

This shale contains a large content of clastic martite (black) and silt-grade quartz (white). The shale strikes east and west of Noble's Nob forming part of the sequence in which quartz-hematite accumulations are abundant.

from the Specific Horizon, near Noble's Nob.

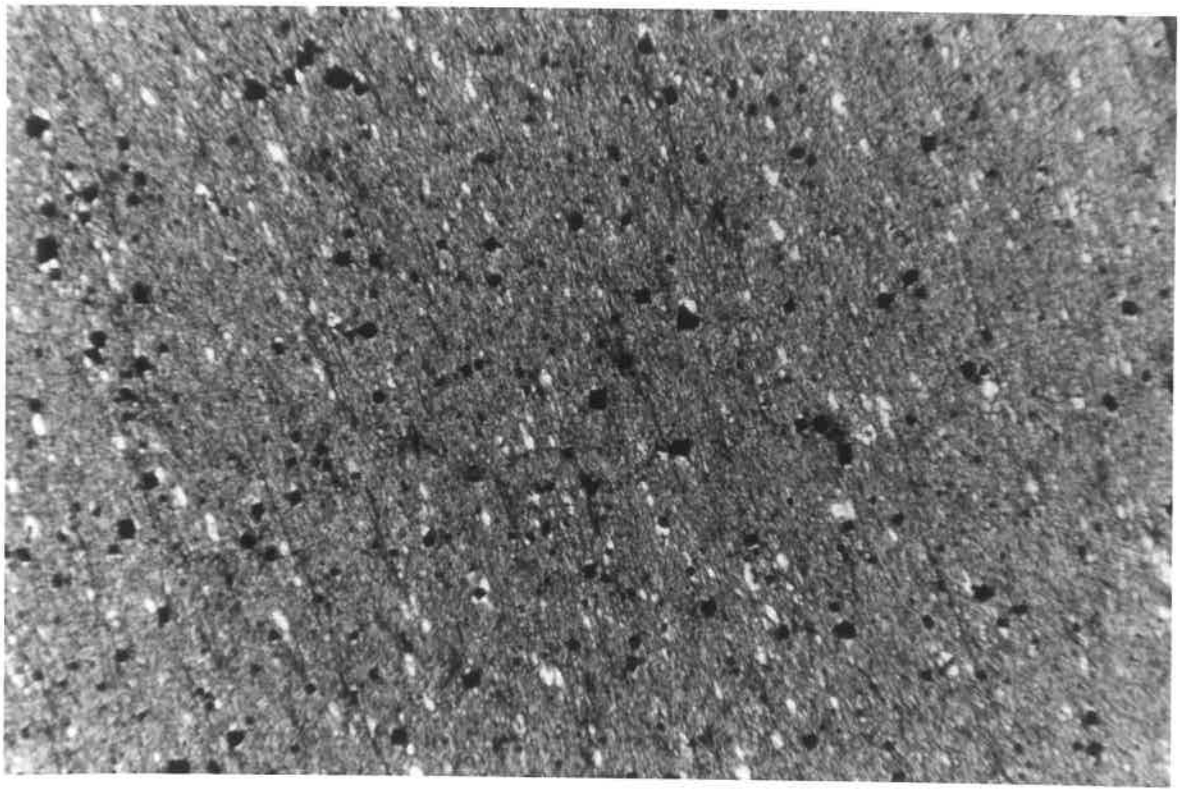
Fig. 24.

Textures of sediments.

thin section x 70.

This section of siltstone illustrates the accumulation of clastic martite in repeated heavy mineral lamellae.

near Noble's Nob Mine.



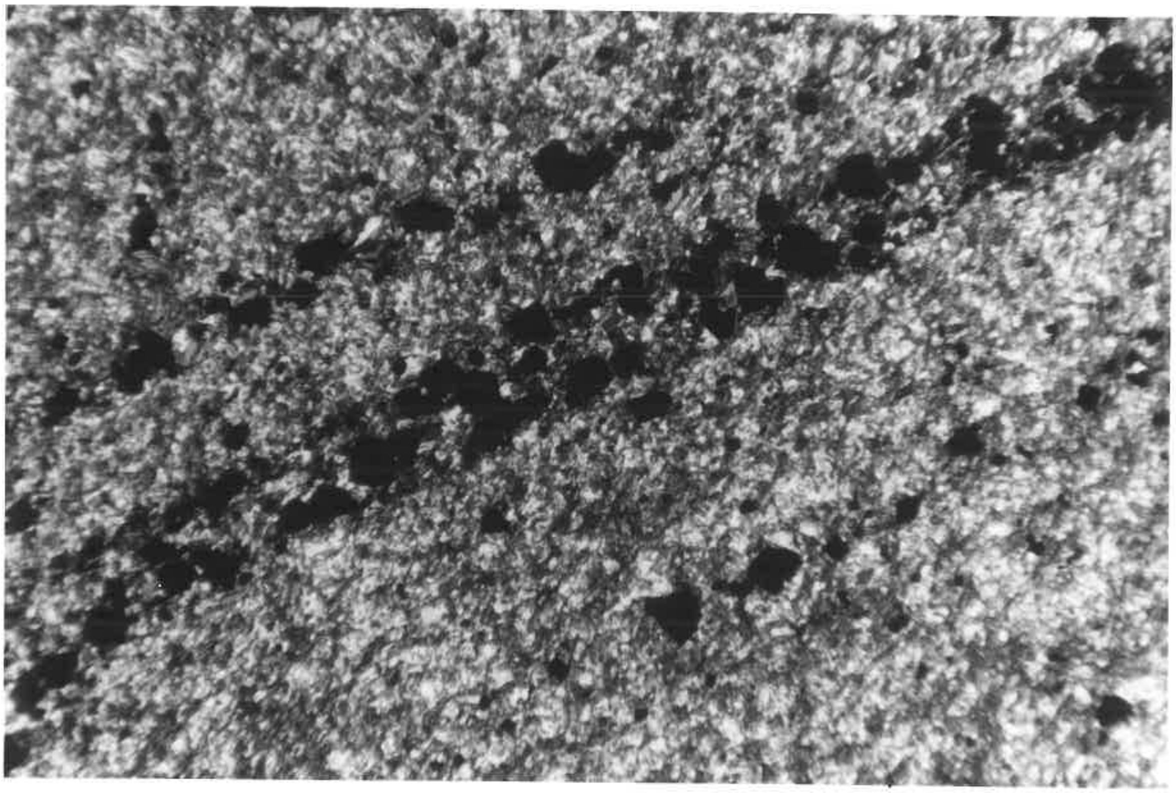


Fig. 25.

Textures of sediments.

thin section x 45.

Tuffaceous sandstone with typical martite-studded volcanic rock particles (dark grey-black), angular quartz fragments (white), thin splinters of volcanic glass (white) and abundant fragmental martite (black). The matrix is a fine grained aggregate of chlorite, quartz and felspar.

Noble's Nob area.

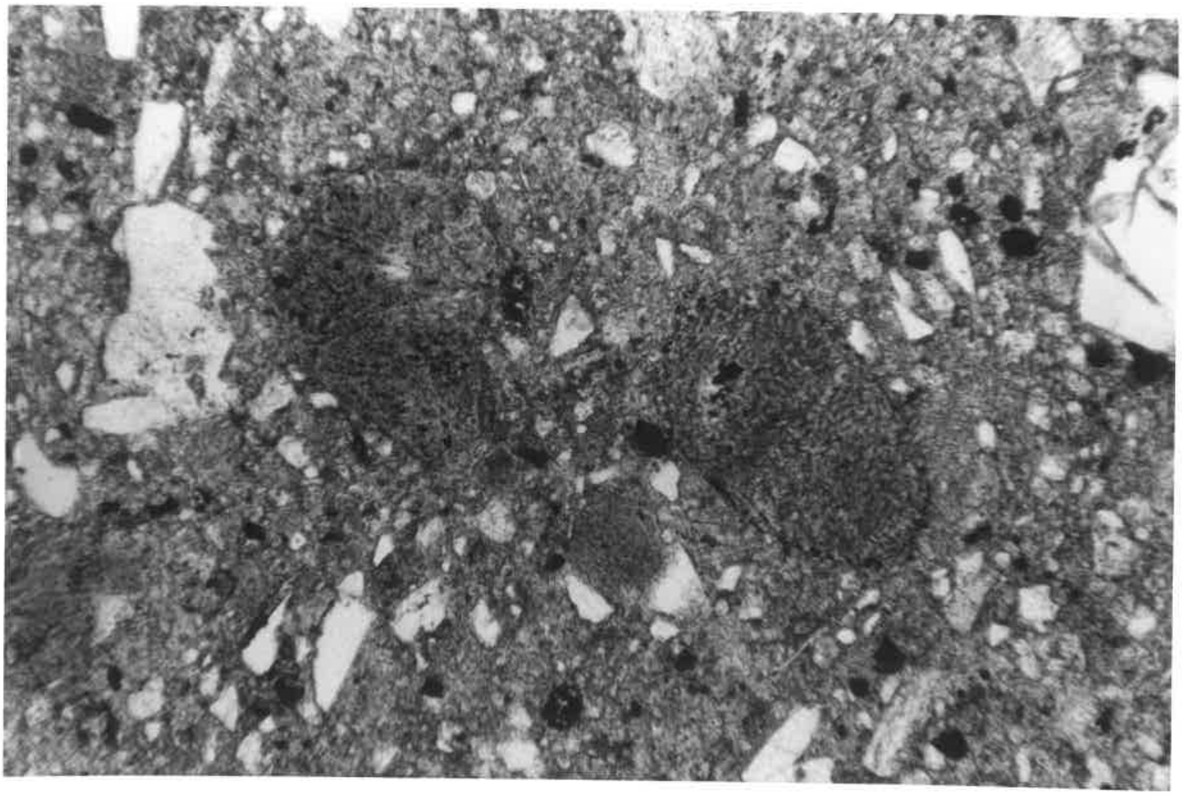
Fig. 26.

Textures of sediments.

thin section x 45.

Ragged fragments of chalcopyrite (black), some of which are attached to quartz (white), in tuffaceous sandstone. Felspar (light grey mottled) and volcanic rock particles (dark grey martite-studded) are dispersed through the rock matrix. These sulphide particles may, like all other rock components, be clastic in origin.

Noble's Nob area.



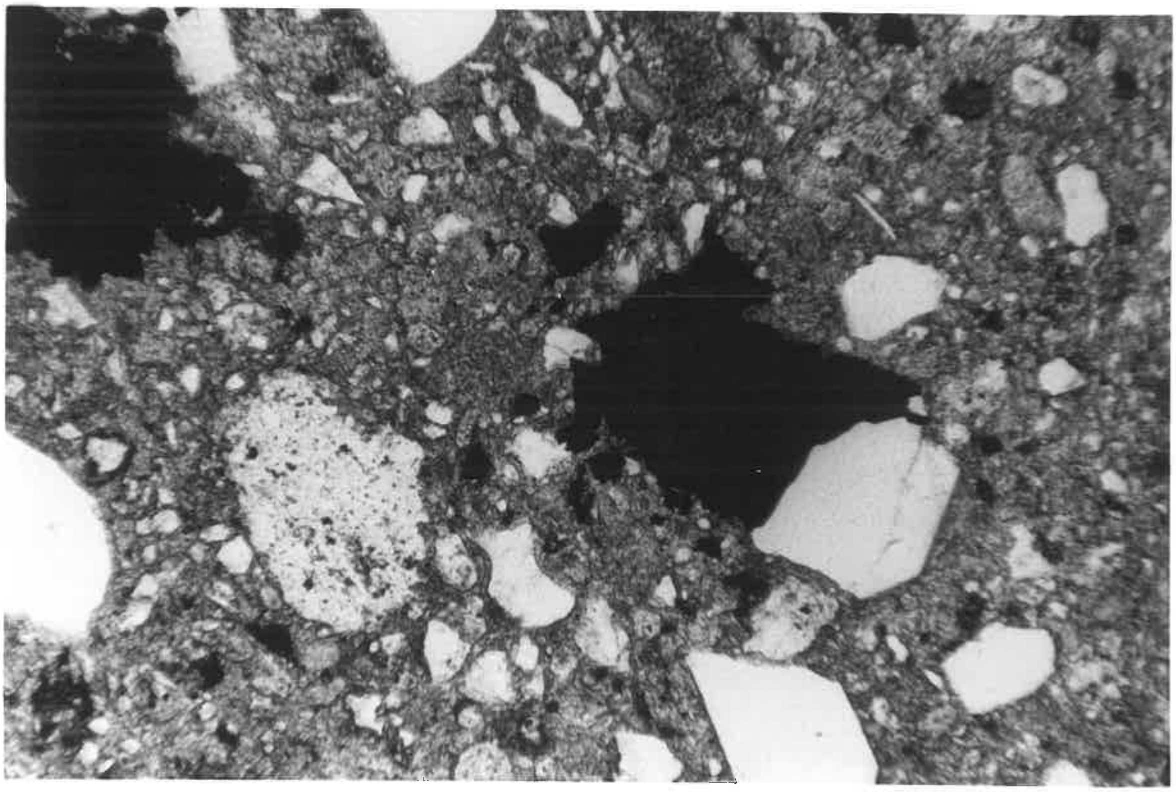


Fig. 27.

Textures of sediments.

thin section x 200.

The crystal tuff shown in this section, contains numerous shards of isotropic silicate glass. The large crystal fragments are felspars and these, with shards and opaque mineral granules, are enclosed in a matrix of fine volcanic ash.

near Bernborough Mine.

Fig. 28.

Textures of sediments.

thin section x 70.

This section of layered lithic tuff shows the distribution of spherical volcanic rock granules (white), and larger rounded lapilli (white) in the laminations of ultra fine grained ash beds.

Bishop's Bore.

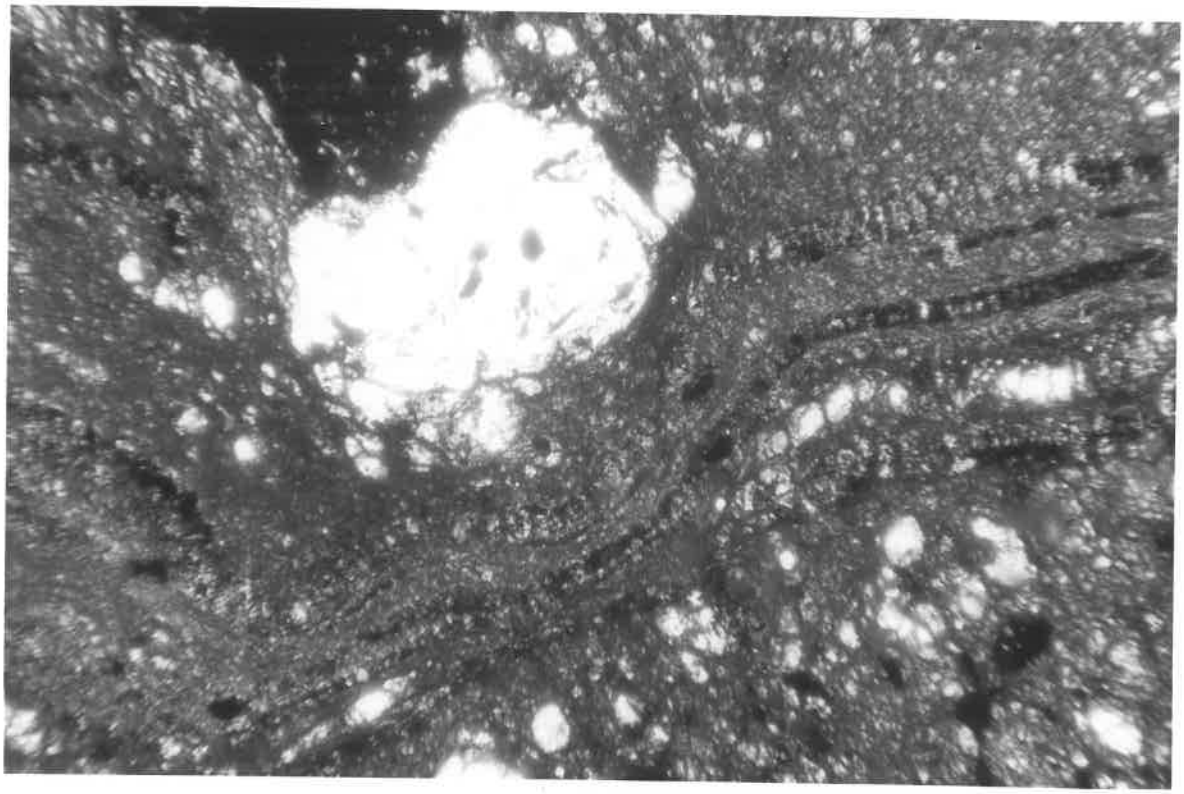


Fig. 29.

Textures of sediments.

thin section x 135.

Typical slate which consists mainly of oriented sericite, 3-5% angular fine grained quartz (white) and 5-10% euhedral clastic martite (black).

near New Hope Mine.

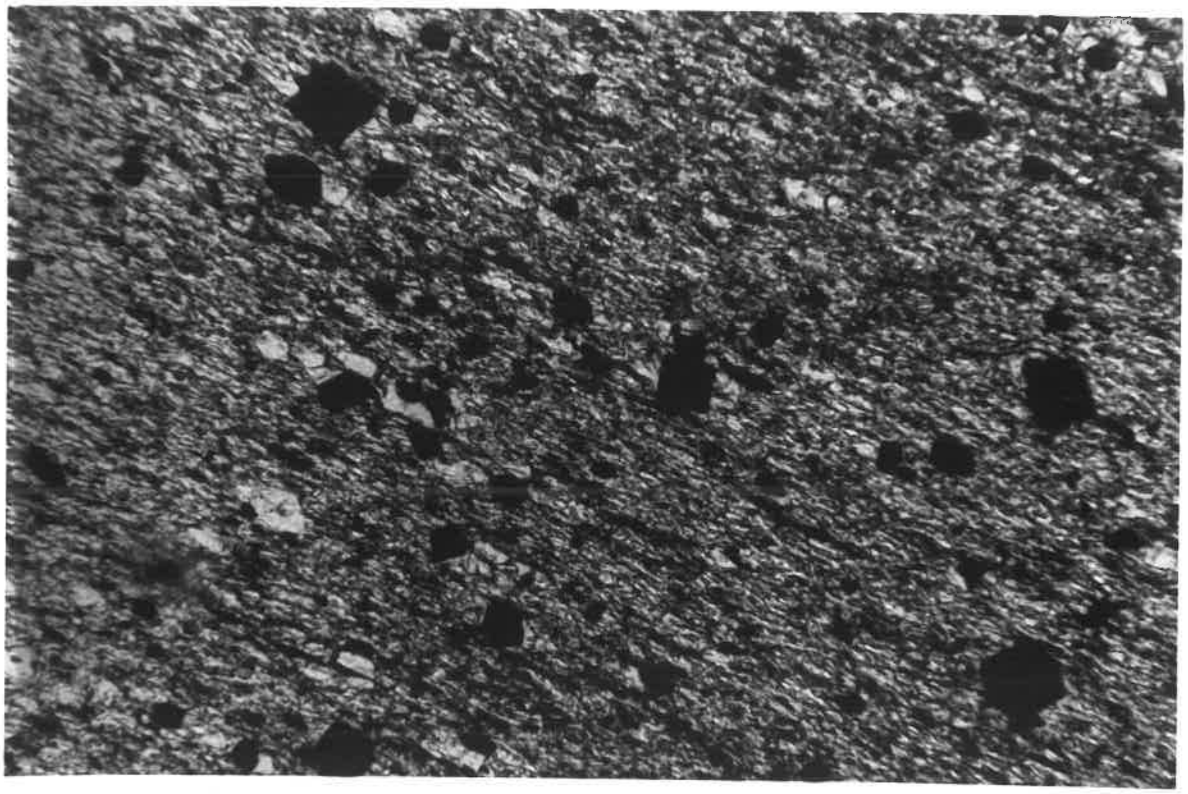
Fig. 30.

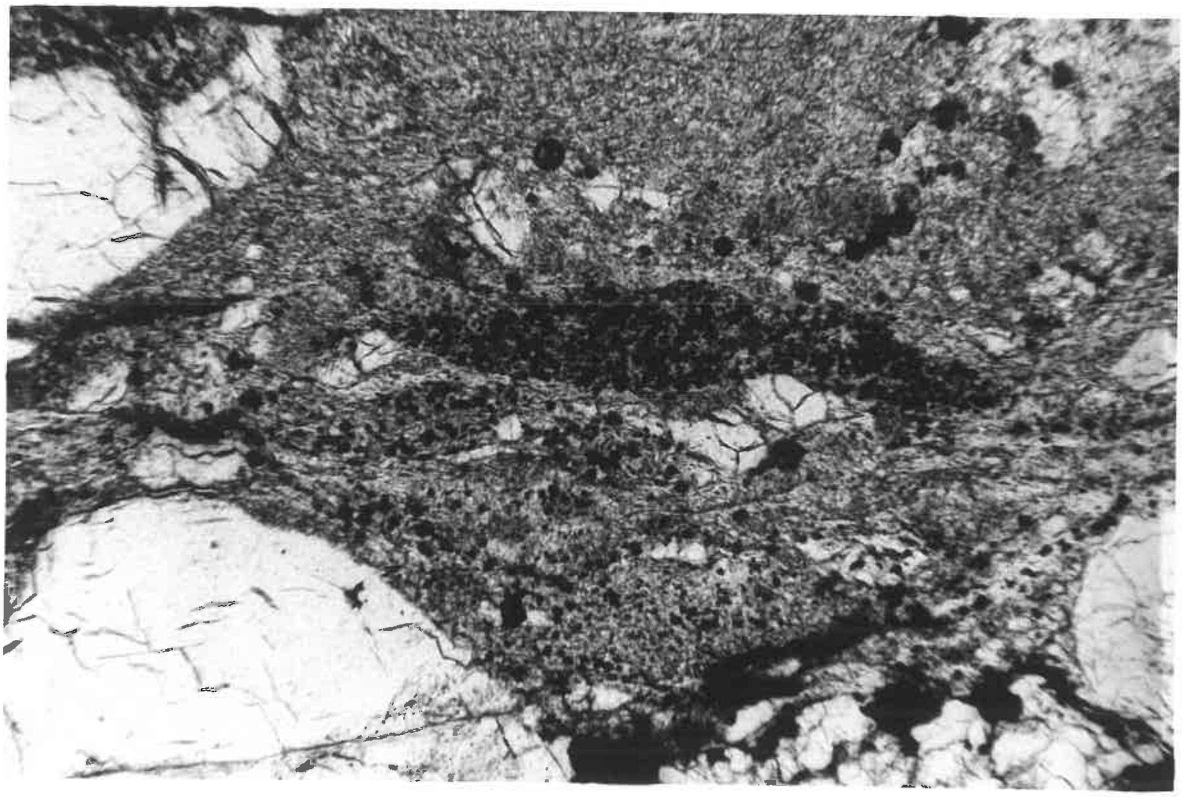
Textures of sediments.

thin section x 45.

Crystal-lithic tuff, which contains a typical assemblage of fragments of quartz phenocrysts (white), elongate fragments of martite-studded volcanic rock (very dark coloured elongate fragments), and abundant clastic martite (black). The matrix is fine grained quartz, sericite and chlorite.

near New Hope Mine.





DDH - 165
STRATIGRAPHIC SEQUENCE & GEOCHEMICAL PROFILE

FIG. 31.

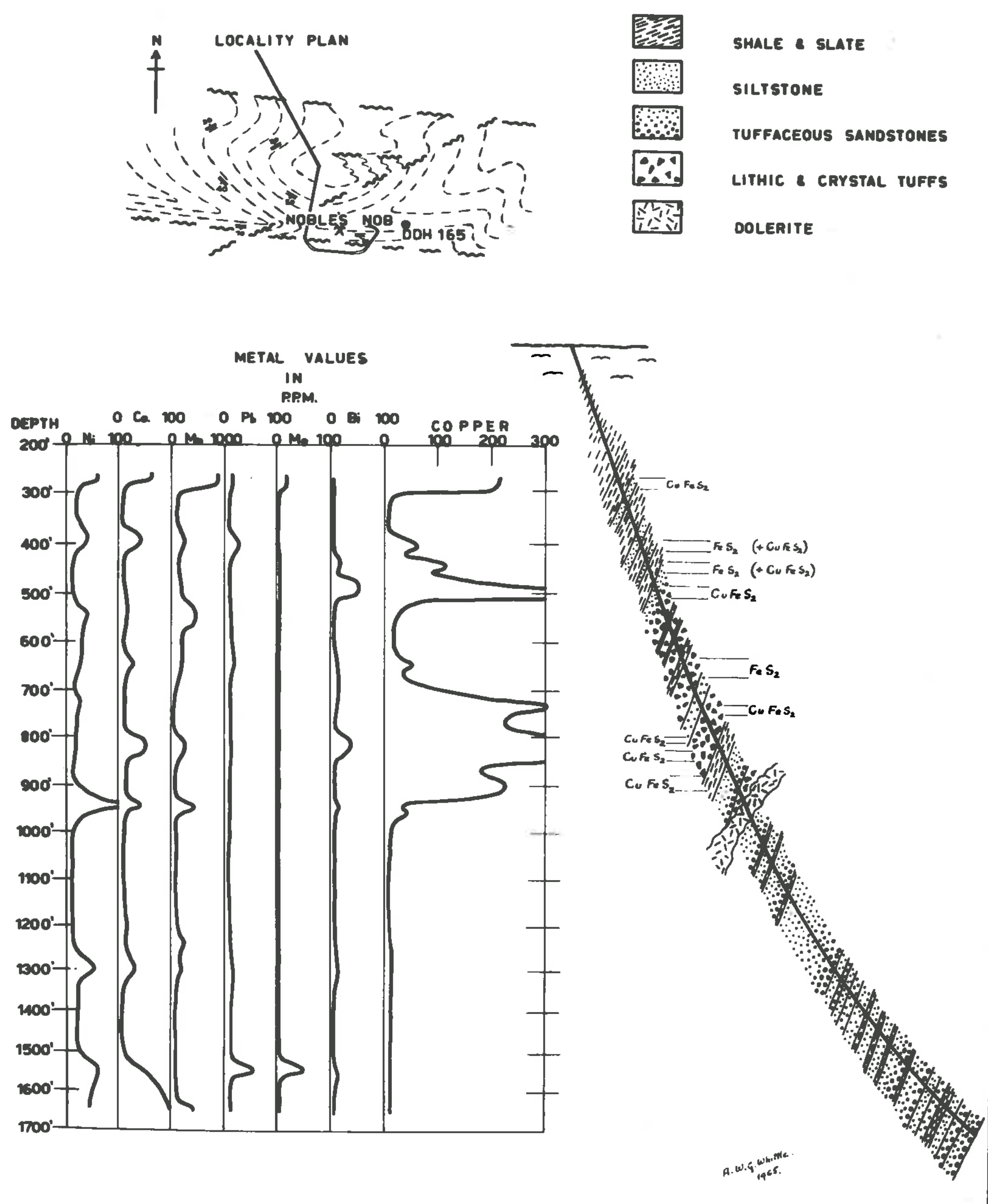


Fig. 32.

Ironstone lode formations.

thin section x 70.

Stressed tuffaceous sandstone situated on the flanks of an ironstone lode in a breccia zone. This section illustrates the incipient stage of ironstone lode formation, where hematite (black) impregnated and in part replaced the fine grained intergranular matrix components of the sandstone.

north of Kathleen Mine.

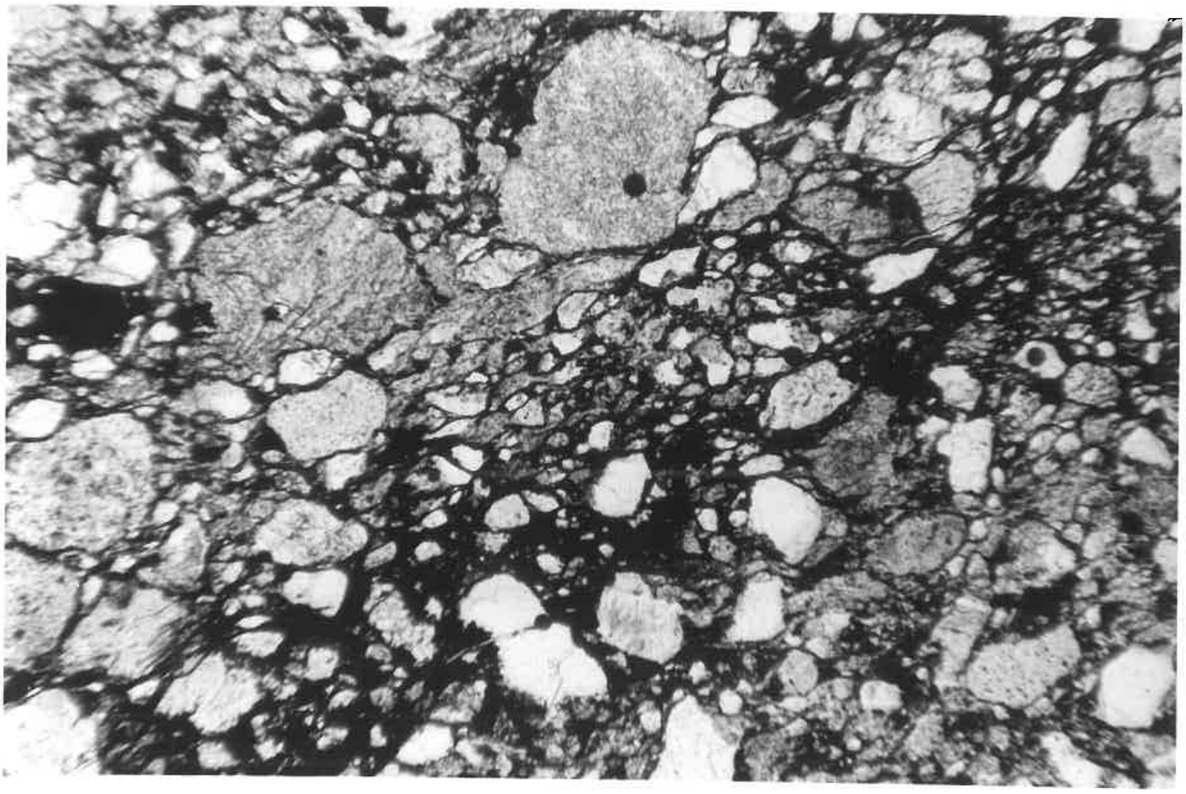
Fig. 33.

Ironstone lode formations.

thin section x 70.

Siltstone in which a miniature lens-shaped quartz-hematite body has formed. Quartz (light grey), is in granular intergrowth with euhedral hematite crystals (black) in the centre of the lens and is surrounded by a halo of hematite granules of gradually decreasing dimensions and density of concentration. Other centres of accumulation occur in proximity to this one, including the subhedral crystal on the right hand edge of the photograph.

north of Kathleen Mine.



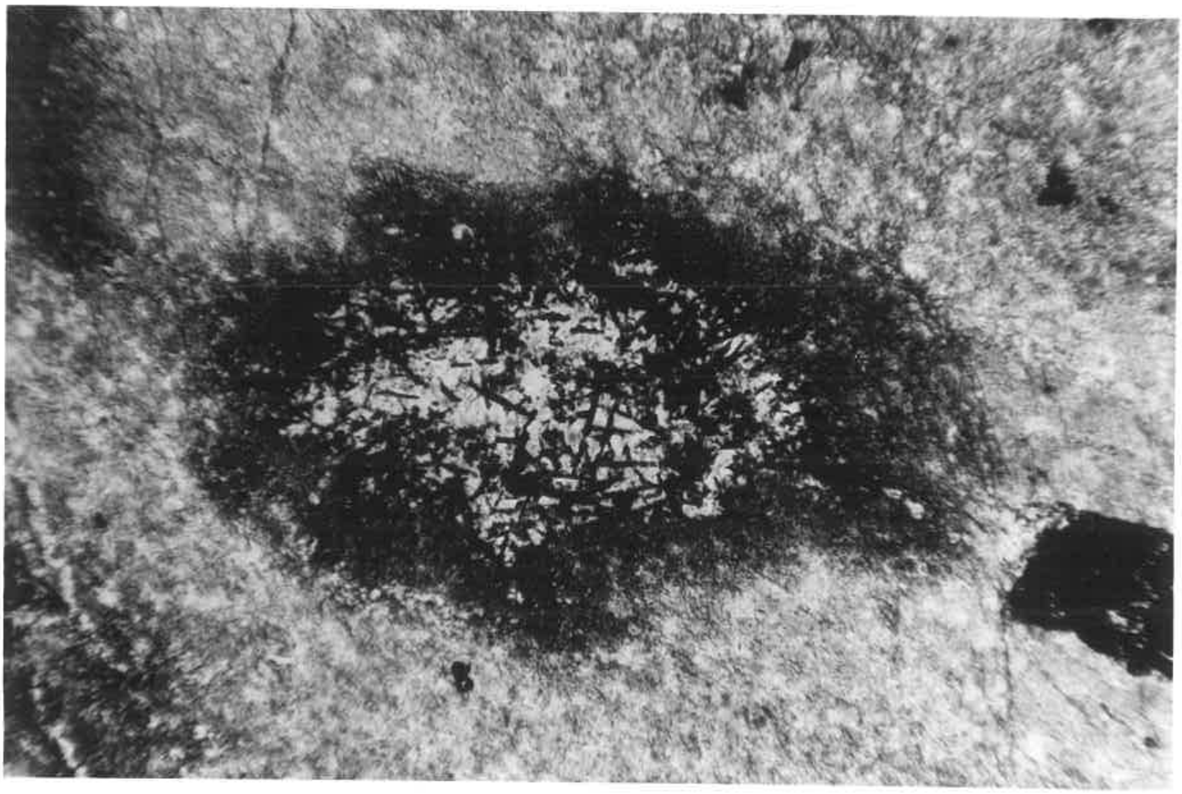


Fig. 34.

Ironstone lode formations.

thin section x 70.

Brecciated tuffaceous sandstone in the marginal portion of an ironstone body, illustrating advanced replacement of tuffaceous sandstone by hematite. All matrix components are replaced and hematite has penetrated individual quartz and silicate grains along fractures contained in them.

north of Kathleen Mine.

Fig. 35.

Ironstone lode formations.

thin section x 70.

Sheared, mylonitic sediment along the margin of an ironstone body. The light coloured lenticular areas are silicified remnants of shale, most of which has been extensively replaced by hematite (black).

The rock was also transected by a quartz vein (white) of much later origin.

near Patties Mine.

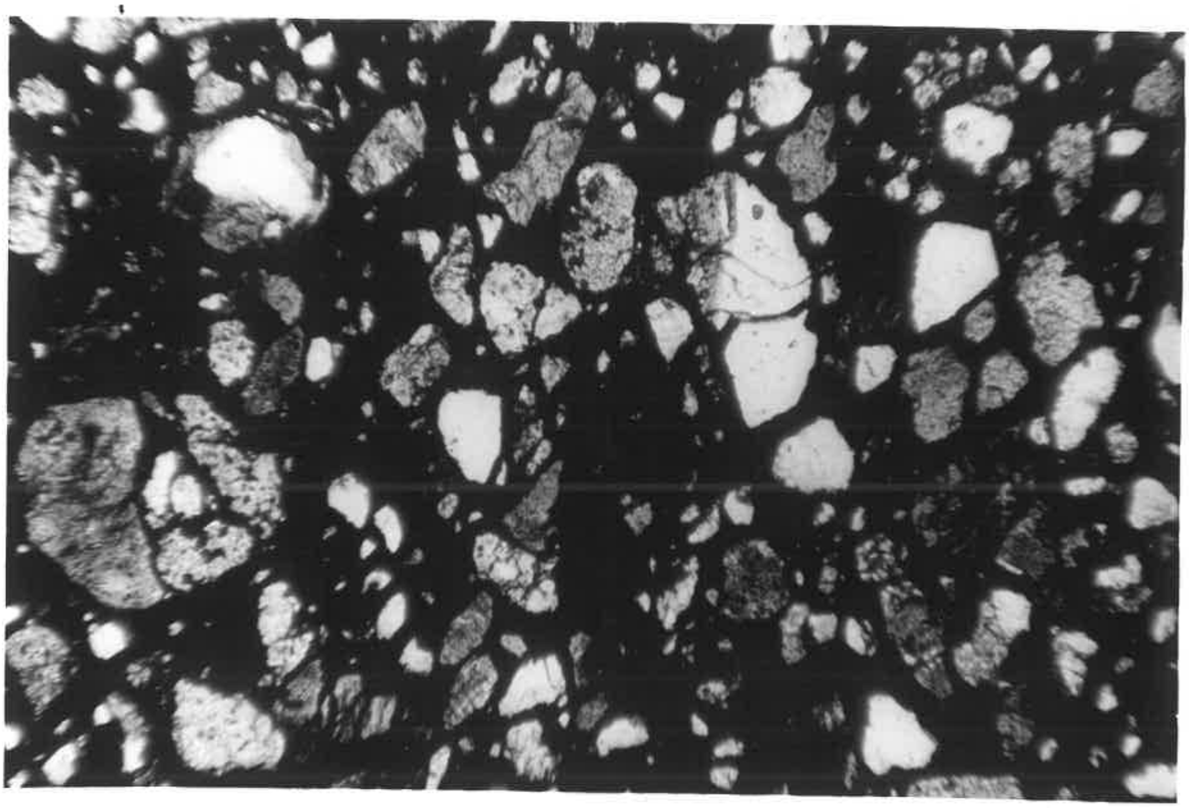


Fig. 36.

Ironstone lode formations.

thin section x 70.

Portion of an ironstone lode displaying the drag folded, banded structure in the quartz-hematite which is a pseudomorph of the structure of the replaced sediment. Hematite (black) and quartz (white).

north of Kathleen Mine.

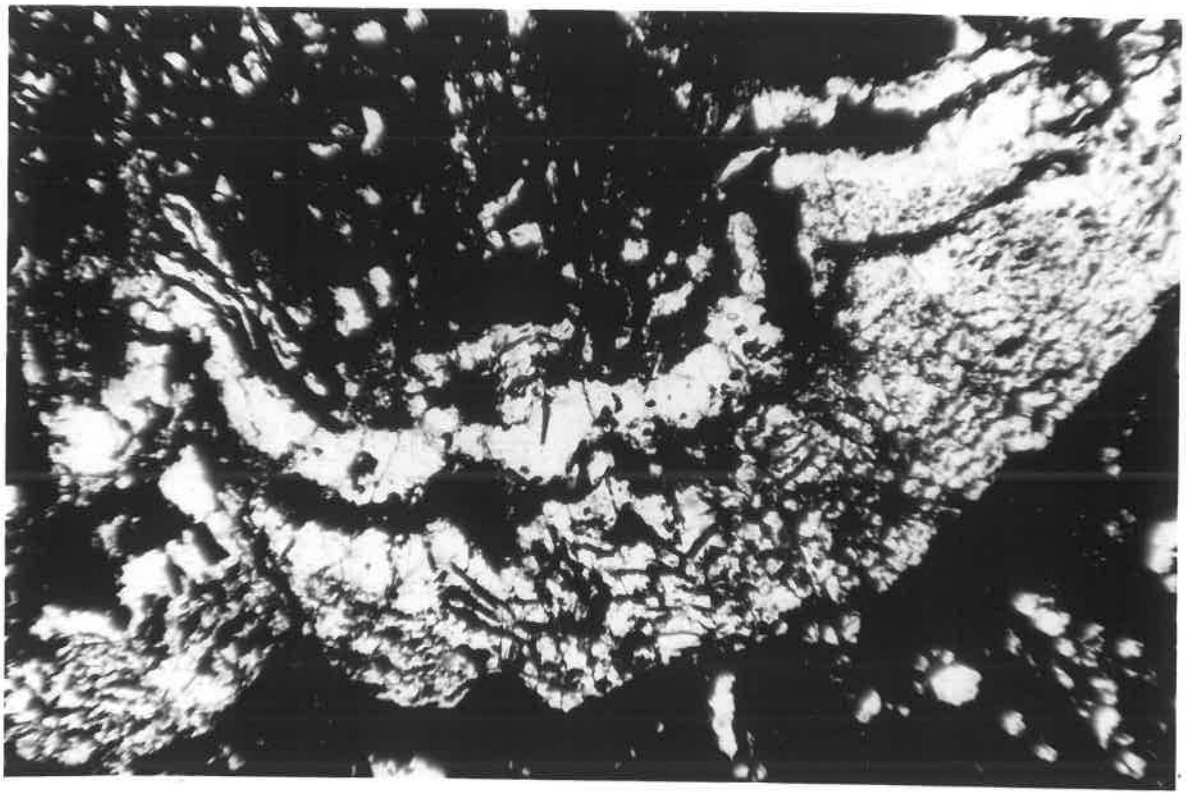
Fig. 37.

Ironstone lode formations.

thin section x 70.

Brecciated shale, several hundred feet away from an ironstone lode formation, showing evidence of open space filling by secondary quartz (white), and by limonite (black).

north of Kathleen Mine.



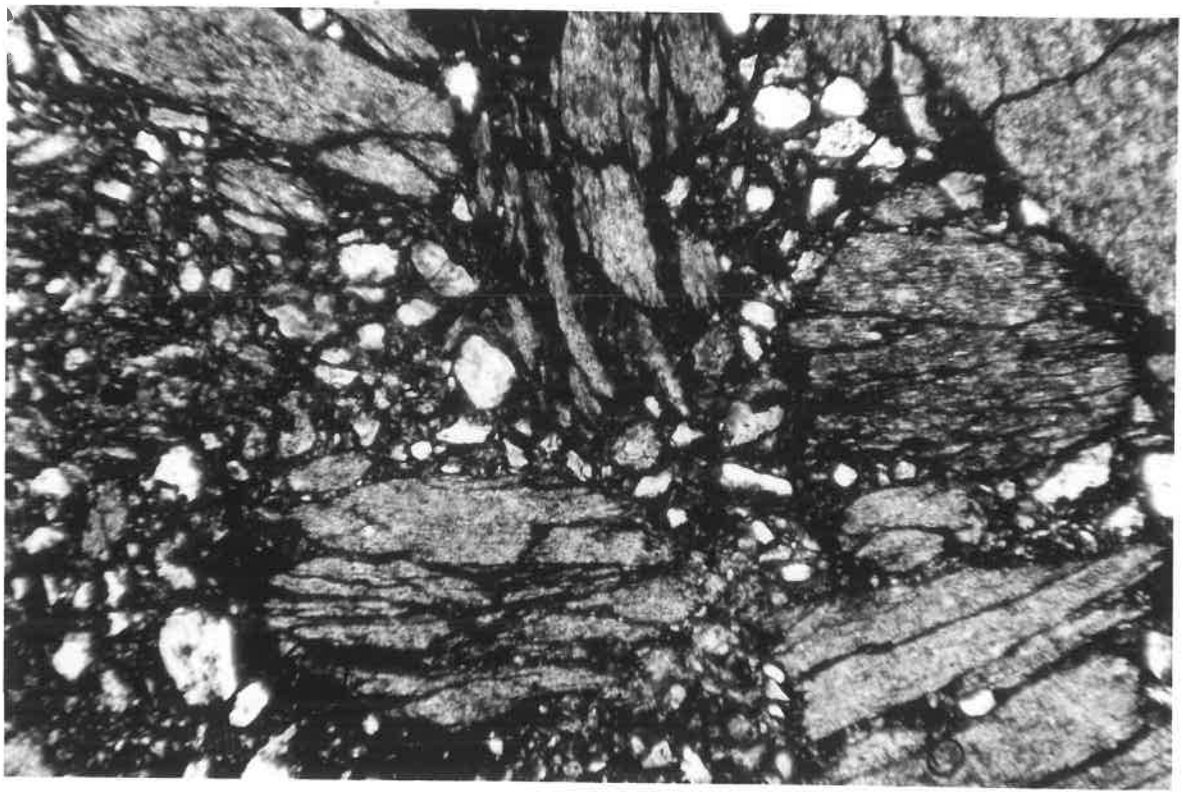


Fig. 38.

Granite.

thin section x 70 - crossed nicols.

Graphic intergrowths of quartz and orthoclase in spaces between orthoclase crystals, O, and quartz, Q.

Station Hill.

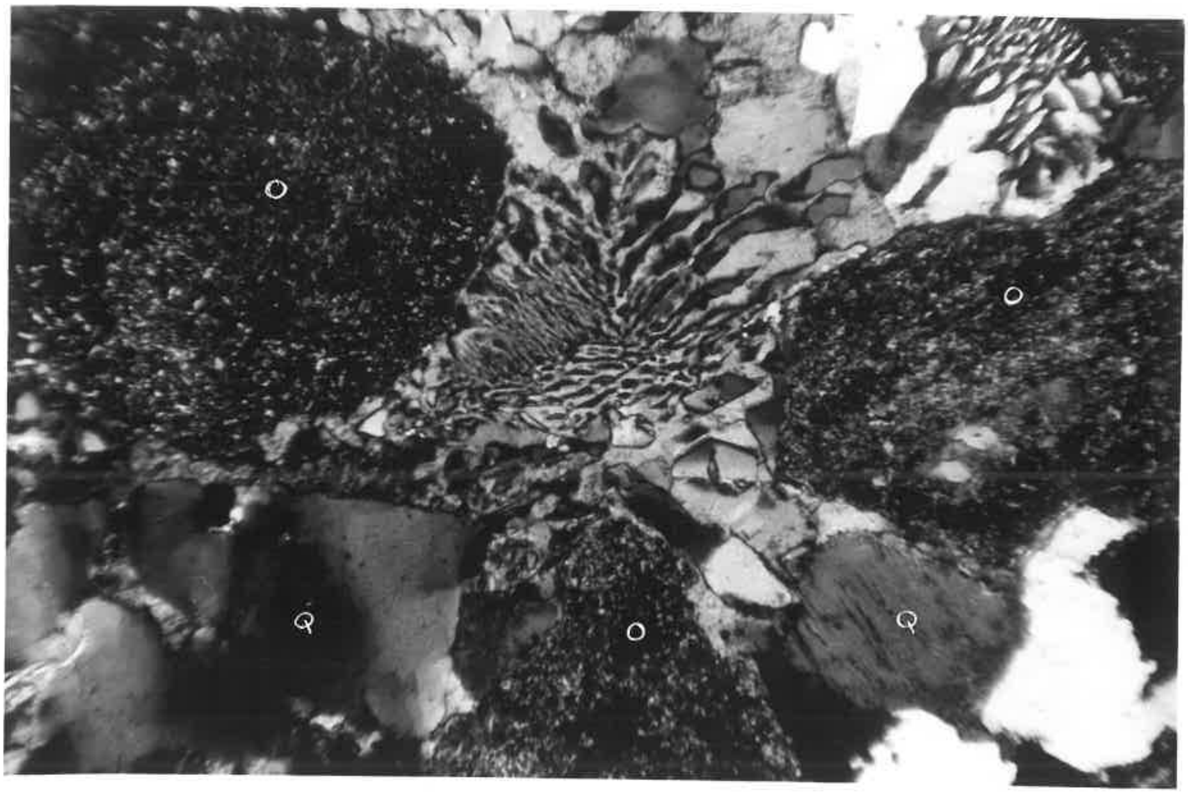
Fig. 39.

Granite.

thin section x 70 - crossed nicols.

Intergranular comminution in stressed granite.
Orthoclase, O, (dark grey with cleavage), quartz (varying shades of light grey and white).

Station Hill.


O
O
Q
O
Q

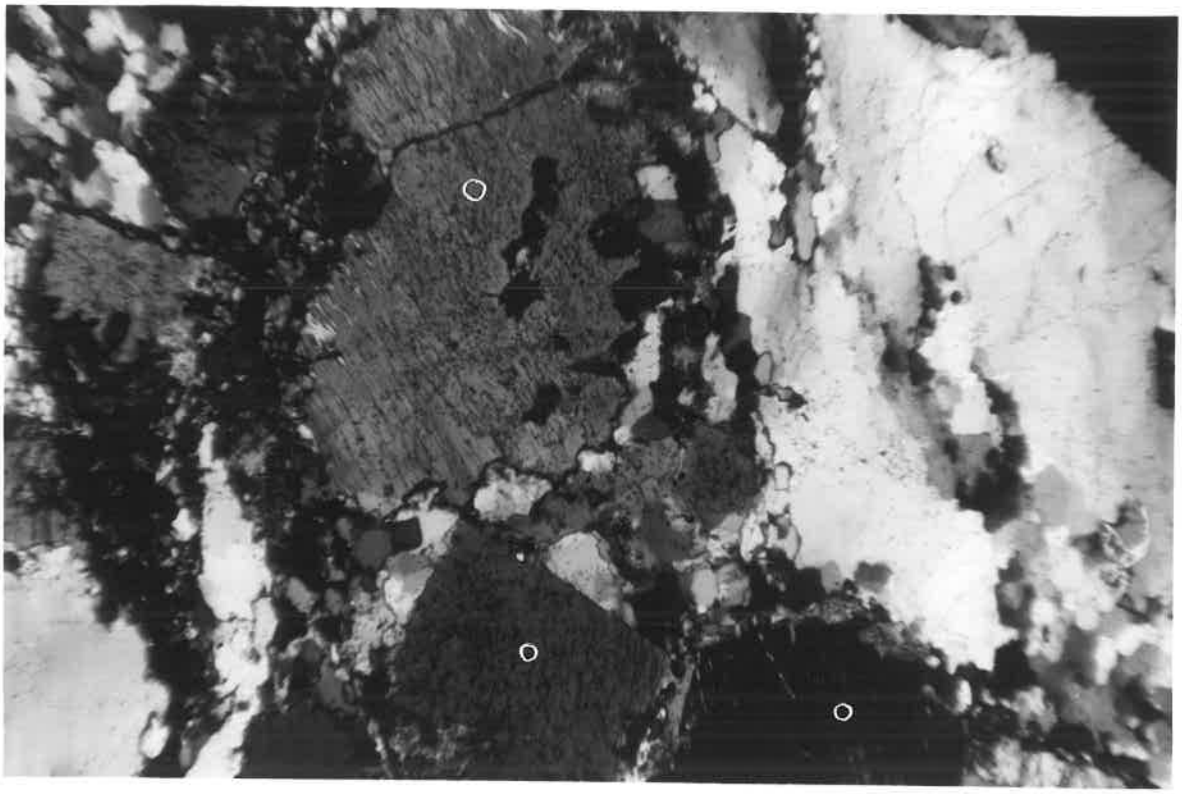

O
O
O

Fig. 40.

Granite contact.

thin section x 70.

Siltstone near the contact of granite with country rock was transgressed by kaolin veins with a cross lamellar structure. These veins may have originated from late magmatic fluids rich in silica, potash and alumina. Although not shown, numerous quartz-tourmaline veinlets also occur in the siltstone, adjacent to the kaolin veins.

Cabbage Gum Bores in northern contact of the Southern Granite.

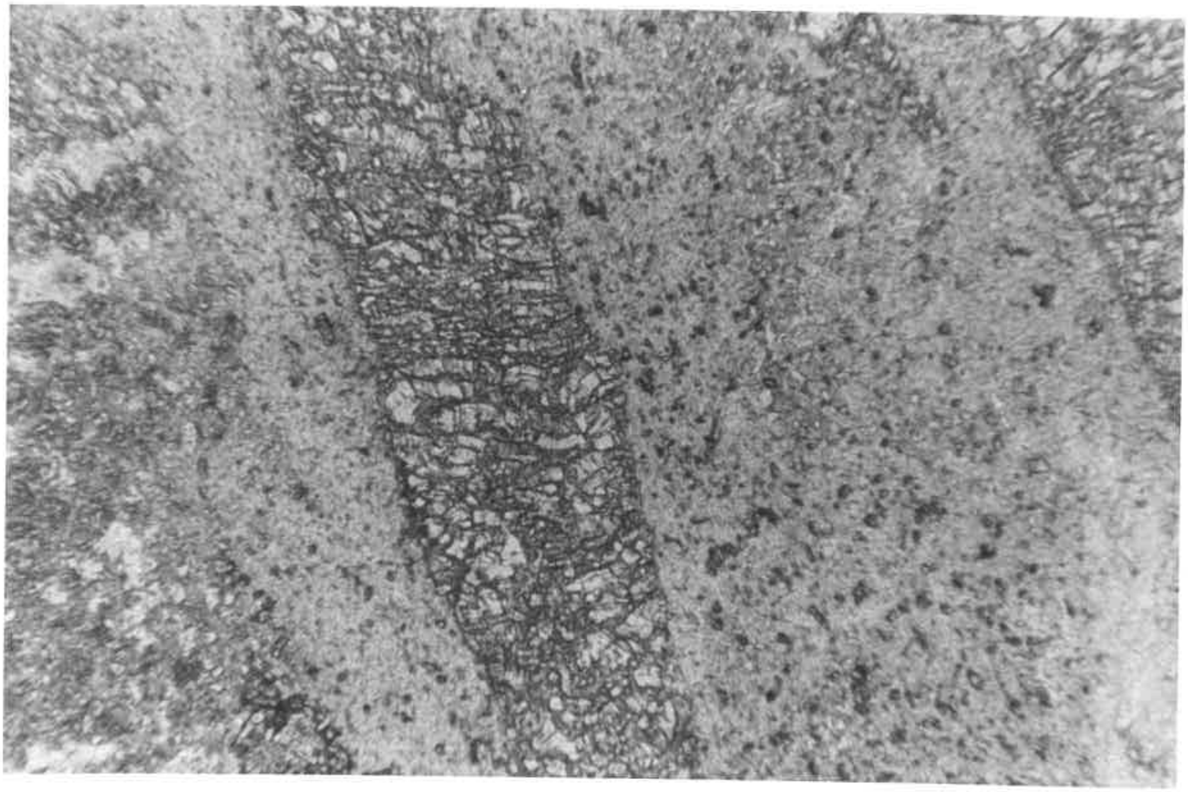
Fig. 41.

Granite.

thin section x 70.

The banded flaser structure with the incipient segregation of quartz and felspar which is characteristic of granite in zones of extreme stress.

adjacent to 14-Mile Fault, Station Hill.



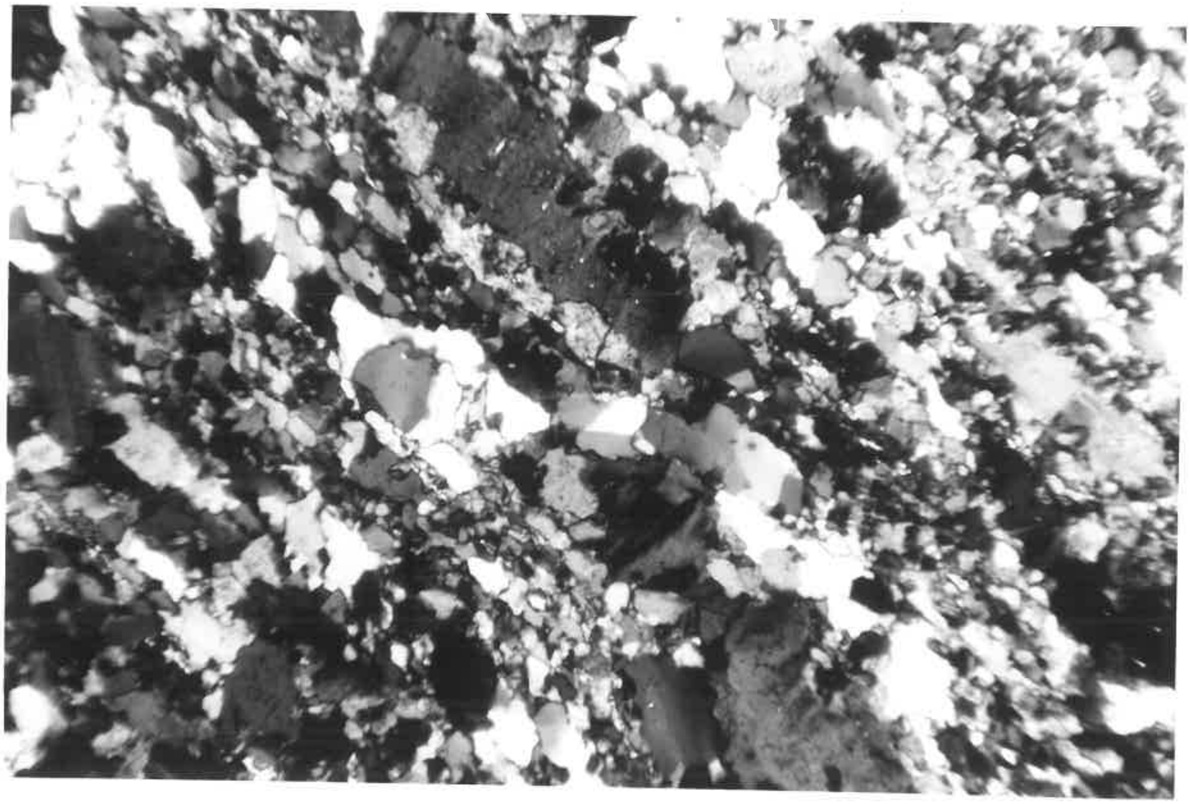


Fig. 42.

Country rock alteration.

thin section x 135 - crossed nicols.

Brecciated, silicified and kaolinised slate, within the granite contact aureole. Fine grained relicts of slate S, amongst coarsely crystalline contorted "pressure quartz" Q, and kaolin aggregates, K.

One and a half miles north of Mary Lane Mine.

Fig. 43.

Country rock alteration.

thin section x 45.

Quartz-kaolin vein with the ladder-type structure which is common in fractures in slates adjacent to the granite contact. Slate, S, in direct contact with the vein, is thoroughly impregnated by limonite, hence the black appearance in thin section. Coarse quartz is white and the curved lamellar kaolin aggregates, K, are dark grey.

Station Hill Granite contact.


Q
S
K
Q
S
K

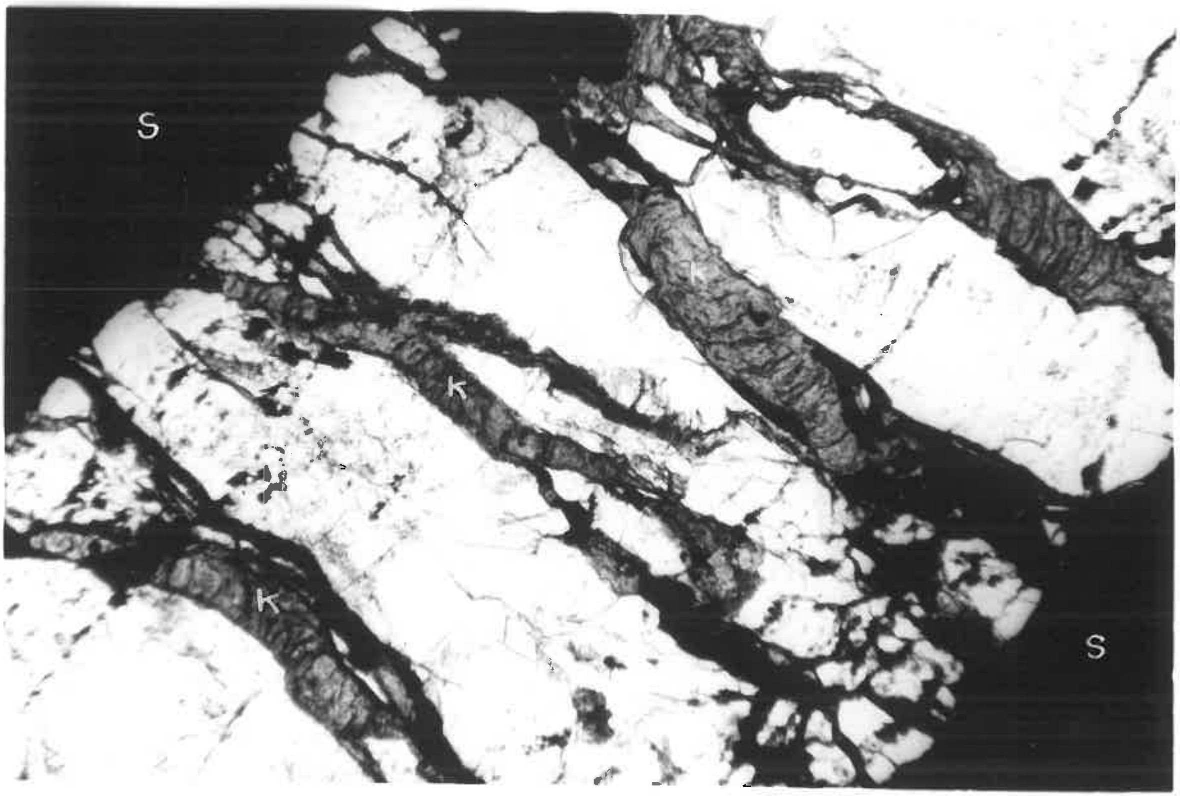

S
K
K
K
S

Fig. 44.

Hydrothermal alteration of granite.

thin section x 135.

A stage in the progressive replacement of granite by kaolin near its contact with country rock. Coarse grained quartz (white) is unchanged while the felspar (dark area) was extensively replaced by kaolin veins with a transverse wavy lamellar structure, and by fine grained amorphous clay-limonite aggregate.

Rocky Range area.

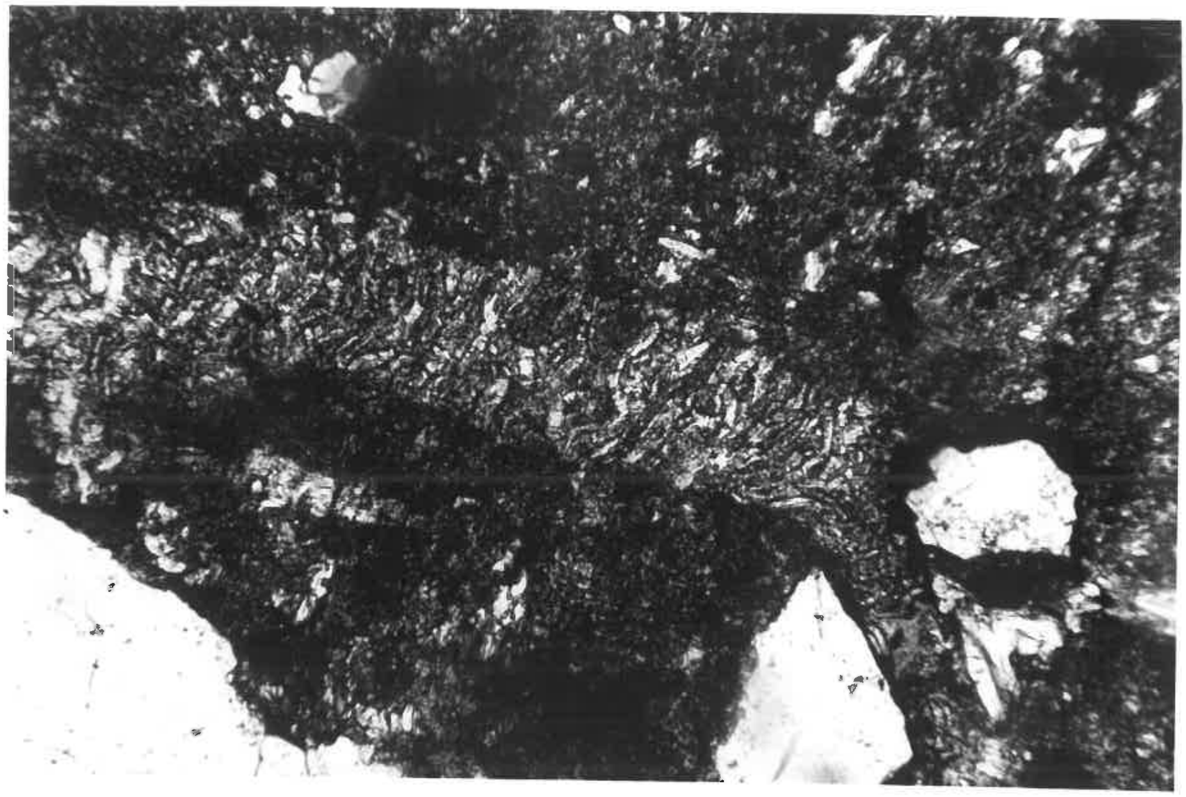
Fig. 45.

Hydrothermal alteration of granite.

thin section x 45.

Completely replaced granite in which unchanged coarse grained quartz (white) persists in a fine grained clay-limonite aggregate enclosing minute disseminated relicts of quartz and micas (white).

Rocky Range area.



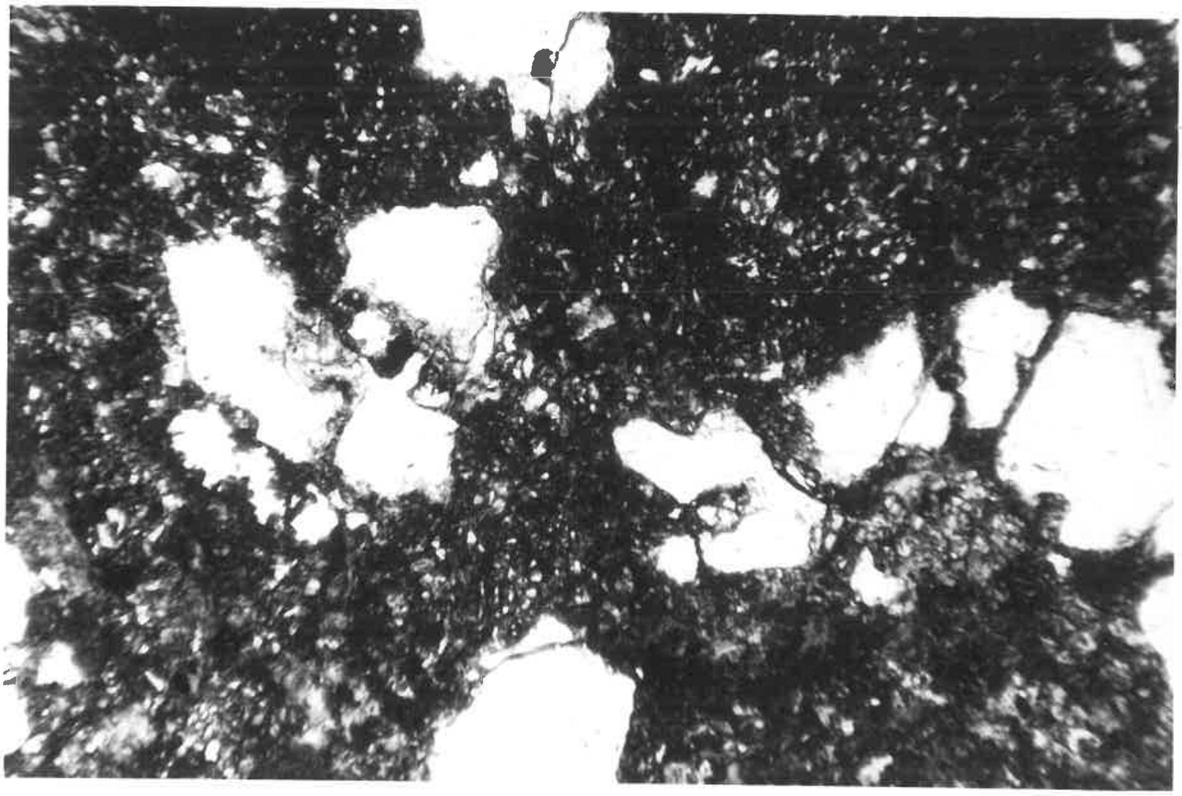


Fig. 46.

Textures of sediments.

polished section x 110.

This section of tuffaceous sandstone contains rounded clastic fragments of pyrite (white) to which are attached small portions of chalcopyrite (faint grey). The sulphides and the disseminated finer grained martites (white) are dispersed through the unmodified sandstone with no apparent relationship to any form of vein or structure. These may all be clastic rock components of volcanic origin.

D.D.H. 165 - 865 feet, near Noble's Nob.

Fig. 47.

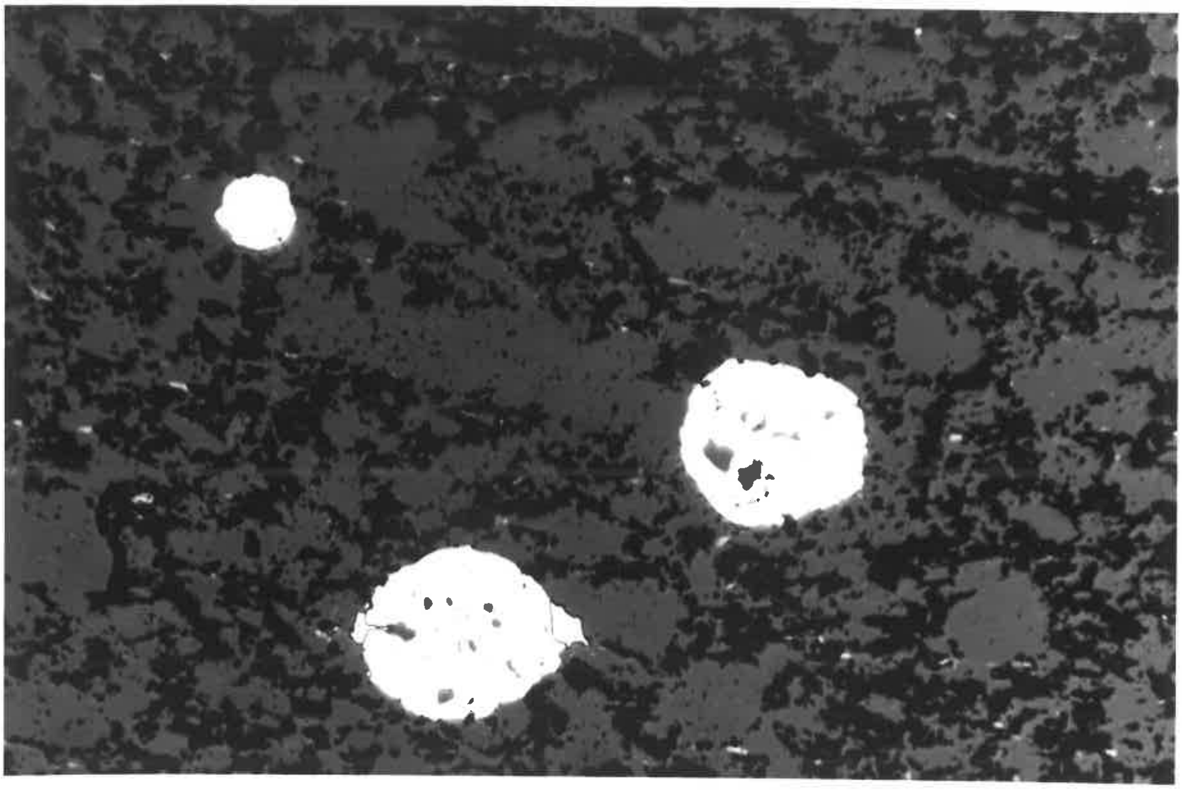
Porphyry.

thin section x 45.

Fragments of talc-chlorite rock (mottled lighter and dark grey), magnetite euhedra (black) and corroded quartz phenocrysts (white), are contained in the fine grained quartzo-felspathic matrix of this porphyry.

The talc-chlorite xenolith is identical with the altered country rocks which enclose copper mineralisation.

D.D.H. G.F.12 - 527 feet, near Golden Forty Mine.



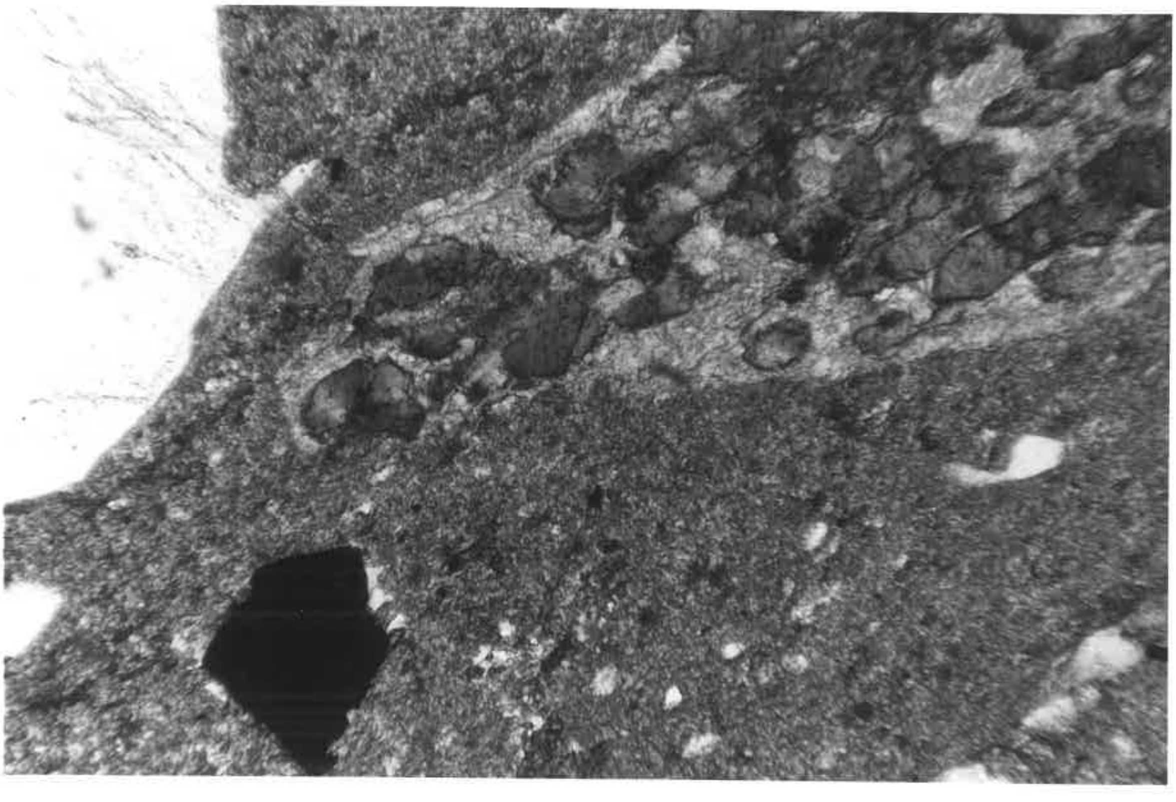


Fig. 48.

Deformation structure in porphyry?

thin section x 70.

Sheared porphyry? of the type which is difficult to distinguish from sheared coarse grained tuffaceous sandstone. This sample is from Rocky Range Area where numerous porphyry sills and tuffaceous sandstones occur together.

near New Hope Mine.

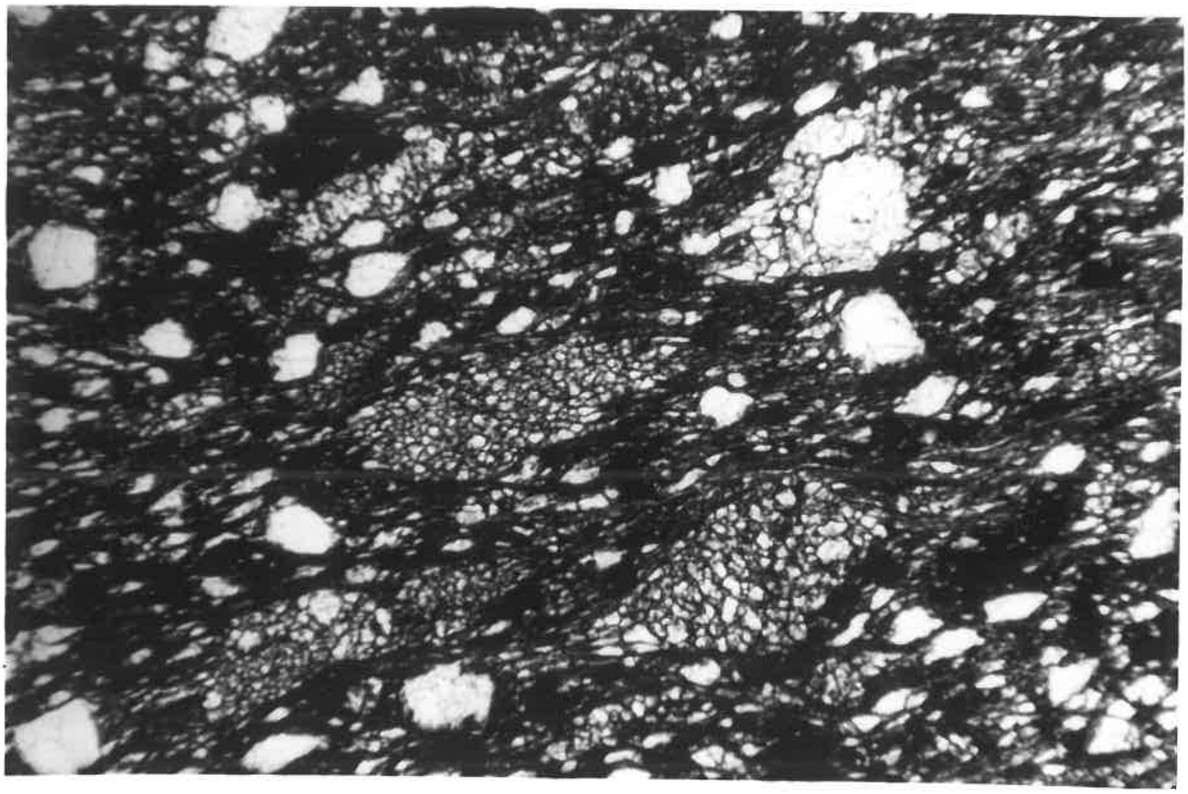
Fig. 49.

Minor intrusives.

thin section x 70.

Lamprophyre which consists of very coarse biotite (dark grey with cleavage), euhedral apatite (white hexagons), and actinolite after hornblende (dark grey-black). These minerals are all included in the one orthoclase crystal (white) which occupies the area of the photomicrograph.

north of Mary Lane Mine.



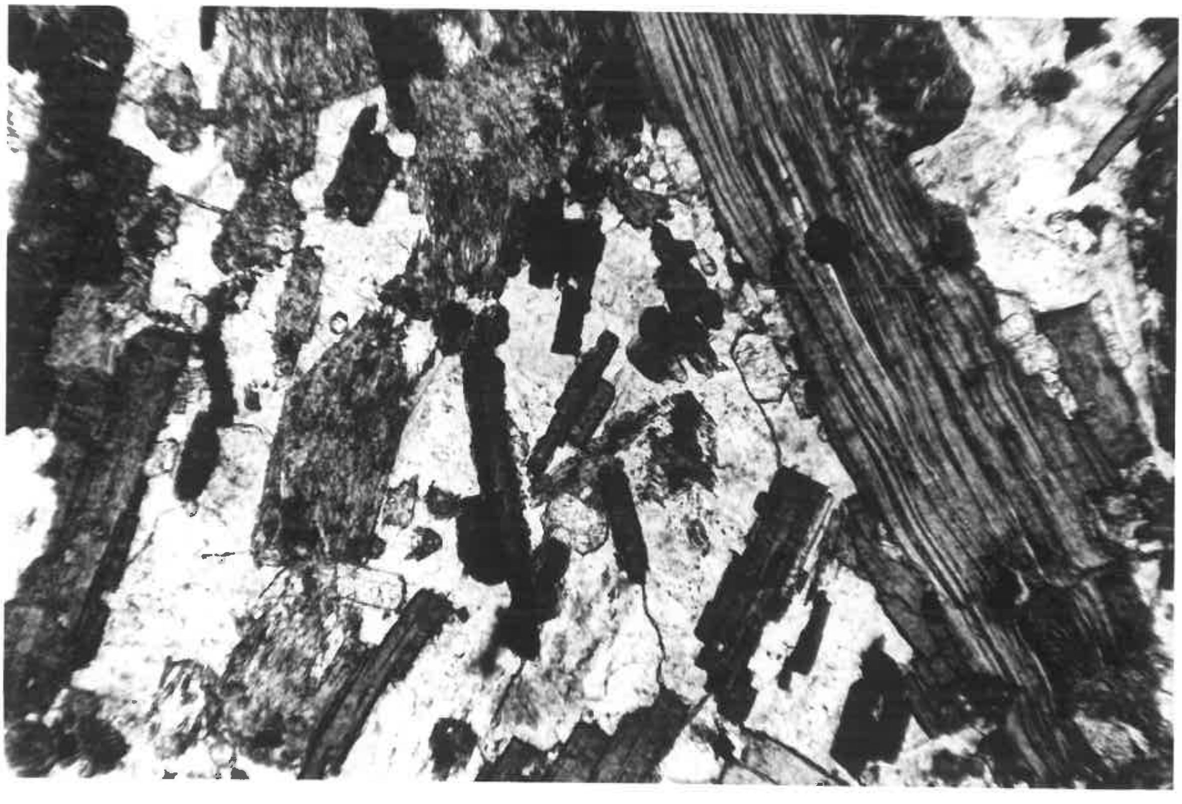


Fig. 50.

Reef quartz.

thin section x 45 - crossed nicols.

Lattice texture formed by intersecting quartz subhedra which contain numerous 5-10 micron inclusions of specularite and sericite (dark spots), as well as fluid-filled cavities.

14-Mile Fault near Rocky Range.

Fig. 51.

Reef quartz.

thin section x 1200 - oil immersion.

Cavities in quartz subhedra. These contain gas bubbles in a fluid medium in which they continuously vibrate through Brownian movement.

14-Mile Fault near Rocky Range.

Fig. 52.

Reef quartz.

thin section x 120.

Tabular specularite crystals (black) in the grain boundaries between quartz subhedra. Opaque dust size granules, probably also specularite, are arranged in rows transverse to the elongation of the quartz crystals.

14-Mile Fault near Rocky Range.

Fig. 53.

Reef quartz.

thin section x 45 - crossed nicols.

Tabular specularite crystals (black) located at various orientations and situated mainly in the grain boundaries of the quartz aggregate.

14-Mile Fault near Rocky Range.