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GEOLOGY AND PETROLOGY OF THE GRAY CREEK AREA NORTH QUEENSLAND

by

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A. ABSTRACT

In the western part of the Gray Creek area, probably in Proterozoic times, a sequence of calcareous and quartzose sediments were deposited unconformably on amphibolite and schist regionally metamorphosed to the amphibolite and albite-epidote amphibolite facies. The sediments were folded and low grade regionally metamorphosed in a late Precambrian or Lower Palaeozoic orogeny. They were intruded along a linear belt by serpentinite and gabbro intrusions (the Sandalwood Serpentinite). These intrusions were syn-kinematic or pre-kinematic since the serpentinite has been low grade regionally metamorphosed to antigorite, talc, chlorite and tremolite-actinolite. The serpentinite intrusions were followed by intrusion of post-kinematic mica granite.

In the Silurian and probably also the Ordovician a sequence mainly of quartz greywacke and siltstone was deposited in the eastern part of the area. Basaltic volcanism took place closely associated and in part contemporaneous with growth of biohermal limestones of Lower Silurian or Upper Ordovician age near Gray Creek. In the Middle Silurian tectonic movement, probably mainly uplifted the Precambrian block to the west and initiated rapid deposition of greywacke conglomerate and greywacke later with some biohermal limestone.

The greywacke sedimentation ceased in the Lower Devonian when there was another orogeny and ultrabasic and basic rocks were intruded into the Palaeozoic sediments. Also during the Lower Devonian orogeny two major ultrabasics were intruded and differentiated to yield dunite, peridotite diallagsite, diallage peridotite, gabbro and microdiorite. These layered intrusions, the Gray Creek Complex and Boiler Gully Complex were folded following differentiation.

Extensive limestone reefs were formed in the Middle Devonian in the southern part of the area and in Upper Devonian or Lower Carboniferous the sedimentation changed to dominantly fresh-water and this continued into the Middle Carboniferous. A major orogeny in the late Carboniferous folded the area along north-east axes and was accompanied by intrusions of hornblende granodiorite. In the Upper Palaeozoic some quartz-feldspar porphyry was intruded and in the Tertiary a mature erosional surface was lateritized and local basalt extended.

B. INTRODUCTION AND ACKNOWLEDGEMENTS

The area discussed in this report is situated 120 miles south of Mount Garnet and 100 miles west of Ingham, in North Queensland. The area lies partly within the Clarke River and Einasleigh 4-mile Sheets (see locality map, plate 1) of the National Grid of Australia.

The field mapping was carried out in 1957 by a combined Bureau of Mineral Resources and Geological Survey of Queensland Party under the leadership of D.A. White and consisted of J.R. Stewart, C.D. Branch, and the author, of the Bureau of Mineral Resources, and D.H. Wyatt of the Queensland Geological Survey. The Archaean Metamorphics near Hall's Reward Mine, and the northern end of the Gray Creek Complex were mapped on a scale of roughly 1,300 feet to 1 inch using enlarged aerial photographs and the geology has been described by White, Branch and Green (1958). The remainder of the area was mapped at a scale of one mile to one inch and has been described by White et.al. (1959).

The stratigraphy described by White, Stewart, et.al. (1959) has been recently modified (White, Best, et.al., 1959) following recognition of several fauna breaks by Dr. D. Hill of the University of Queensland.

This report deals mainly with a petrographic examination of about 160 thin sections, mostly of the ultrabasic and basic rocks collected during 1957 and 1958 in the Gray Creek area. Some of the petrology has previously been described by White, Branch and Green (1958), but for completeness it is included with other descriptions in this report.

C. PHYSIOGRAPHY

The Gray Creek area is drained by the Burdekin River system a few miles east of the divide between the west-flowing Einasleigh River system and the east-flowing Burdekin River system. The Burdekin River is a permanent stream and other streams, including the main tributary Gray Creek, are intermittent and usually cease to flow during the dry winter season. The exception to this is Spring Creek, a tributary of Gray Creek, which originates as a spring at the western contact of the Gray Creek Complex and the Wairuna Formation.

The dominant physiographic feature of the area is the mature lateritized Tertiary surface present as isolated plateaus. The edges of these plateaus are commonly marked by 10 - 20 feet vertical scarps. The original surface was undulating with relief of at least several hundred feet as shown by the presence of lateritized surfaces at several heights. The most prominent features consist of serpentinite ridges and prominent sedimentary hills east of Gray Creek. In some areas lateritization is quite deep and laterites are formed, and in other areas the surfaces are simply rubbly outcrop with little lateritic soil profile.

The Burdekin River is entrenched generally 50 feet to 60 feet in alluvial river deposits. Gray Creek is entrenched to a lesser depth. This may indicate some rejuvenation of the drainage system, but since in exceptional wet seasons the Burdekin River regularly overflows its banks it is more probable that the entrenchment is due to the seasonal variation of the river.

D. STRATIGRAPHY

(1) ?ARCHAEAN

(a) Hall's Reward Metamorphics

The Hall's Reward Metamorphics consist of a regionally metamorphosed sequence of quartz-mica schist, garnet-quartz-mica schist, thick-bedded micaceous quartzite, thin-bedded quartzite and migmatite. Schistosity is well-developed and in many places it is parallel to bedding. The schists are commonly crenulated and complex minor folding is common in the thin-bedded quartzite but uncommon in the thick-bedded quartzite. Garnet is in some schists. The metamorphics are best exposed in Copper Creek north of Hall's Reward Mine and near the mine itself.

South west of Hall's Reward Mine the metamorphics are strongly veined and impregnated by granitic material to form migmatites. More commonly stringers and augen of colourless quartz are present in the quartz-mica schists.

The Hall's Reward Metamorphics are conformable with some interlayering of the Stenhouse Creek Amphibolite. They are unconformably overlain by the Paddy's Creek Formation and faulted against the Ordovician-Silurian Wairuna Formation. They are regarded to be Precambrian in age and tentatively ?Archaean.

(b) Stenhouse Creek Amphibolite

The Stenhouse Creek Amphibolite consists of banded amphibolite and diopside granulite with rare marble. The rocks have been regionally metamorphosed mainly to the amphibolite facies but are partly in the albite - epidote amphibolite facies. The rocks are well exposed in Stenhouse Creek (south-west of Hall's Reward Mine), after which the metamorphics are named.

The Stenhouse Creek Amphibolite is interlayered with the Hall's Reward Metamorphics and probably it underlies the metamorphics and occupies the core of a tight anticline trending N.N.E. near the Hall's Reward Mine. The Hall's Reward Metamorphics and the Stenhouse Creek Amphibolite form the basement rocks of the Gray Creek area and are tentatively regarded to be ?Archaean.

In thin section the rocks have a directed texture due to the alignment of the amphiboles. The amphibole crystals are aligned in the plane of schistosity and may show a lineation within this plane. The granulite bands containing diopside, epidote and saussuritized plagioclase are not obviously aligned. The rocks generally are fine to medium-grained although in the granulite bands diopside may be up to 1 cm. grain size and amphibole needles may also be this size. Throughout the rocks saussuritization of the feldspar is extensive and the composition of the feldspar is rarely determinable. Saussuritization is not so complete in the several specimens from the Hall's Reward Mine and this raises the possibility that the saussuritization is due to slight retrogressive thermal metamorphism by later intrusions such as the Boiler Gully Complex.

The compositional banding of the rocks varies in thickness but commonly is about 0.5 - 2 cm. In some specimens the banding is very persistent and in others it is discontinuous and the mineral variation is expressed in lenses rather than bands. The amphibolites have the mineral compositions shown in Table 1. Specimens "a" to "m" probably belong to the amphibolite facies and specimens "n" to "r" to the albite-epidote amphibolite facies. Specimens "a" to "k" were collected from the southern part of the area and it is possible that the grade of metamorphism decreases to the north.

(2) ?PROTEROZOIC

(a) Paddys Creek Formation

The Paddys Creek Formation consists of quartz siltstone, quartz sandstone, phyllite and quartzite. Several prominent quartzite beds outcrop as prominent ridges. Typical outcrops are along Paddys Creek after which the formation is named.

The Paddys Creek Formation interfingers with and mainly conformably overlies the Lucky Creek Formation, south of Hall's Reward Mine. It overlies the Hall's Reward Metamorphics with an angular and metamorphic unconformity. West of Halls Reward mine it is downthrown against the ?Archaean metamorphics by the Lucky Downs Fault. The thickness of the Paddy's Creek Formation is not precisely known but it is probably greater than 3,000 feet.

The Formation is unfossiliferous and the age is unknown. It has a faulted and sheared contact against the Silurian Wairuna Formation in the Halls Reward area, and it is overlain probably unconformably, by the Upper Ordovician-Lower Silurian Wairuna Formation near Dinner Creek. It is tentatively regarded to be late Precambrian in age, possibly Proterozoic, although it could be Cambrian or Ordovician.

(b) Lucky Creek Formation

The Lucky Creek Formation consists of a well bedded calcareous siltstone, calcarenite, calcareous greywacke and local limestone. The Formation has been locally thermally metamorphosed adjacent to the Dido Granodiorite (White et.al., 1959). Throughout the area of outcrop the Formation has been low grade dynamothermally metamorphosed to form a distinct cleavage, chlorite, epidote and actinolite. Typical exposures of the Formation occur along Lucky Creek after which the Formation is named.

The Formation interfingers with and largely conformably underlies the Paddys Creek Formation.

(3) PALAEOZOIC

(a) Wairuna Formation

The Wairuna Formation consists mainly of rapidly varying clastics of quartz-greywacke and quartzose sediments. Two members, the Carriers Well Limestone and the Everett's Creek Volcanics, can be distinguished within the Formation. The other minor constituents of the Formation consist of feldspathic sandstone, quartz greywacke, quartz greywacke siltstone, quartz sandstone, brown and black shale and some calcareous siltstone, slate and conglomerate. The Formation is exposed farther north from the area of plate 1 and extends to Wairuna Homestead after which it is named.

In the northern part of the area the Wairuna Formation is faulted against the ?Archaean Halls Reward Metamorphics. The fault continues S.S.W. and separates the Paddys Creek Formation from the Wairuna Formation. In this area the fault is not so clearly defined since the Wairuna Formation is sheared and is locally phyllitic over a wide zone adjacent to the fault. However, there is a lithological break and an overall metamorphic difference between the two formations. East of Burges Dam quartz greywackes, greywackes and fine greywacke breccia (lithologies in part typical of the Wairuna Formation and in part of the Carrier's Well Limestone Member) have shallow dips, no metamorphism and very little shearing and are distinct from and considered to unconformably overlie quartzite and quartz phyllite of the Paddys Creek Formation.

The formation is unconformably overlain to the south by greywacke conglomerate (Crooked Creek Conglomerate) and greywacke of the Graveyard Creek Formation. To the east it is faulted against greywacke and quartz greywacke conglomerate, sandstone and siltstone of the Greenvale Formation.

East and south of the Gray Creek Complex quartz greywacke, sandstone and siltstone are the dominant sediments of the Wairuna Formation. West and north of the Complex feldspathic and gritty quartz sandstones are more common and are associated with thin-bedded blue-grey calcareous siltstone and grey-black slate. The latter sediments are common on the north-western margin of the Complex. A chert bed forms a prominent ridge east of the northern end of the Gray Creek Complex and in the southern part of the Complex below the Crooked Creek Conglomerate small bodies of basalt and dolerite are associated with quartz greywacke and quartz greywacke siltstone of the Wairuna Formation.

A very common rock type adjacent to the Carrier's Well Limestone and outcropping particularly in the northern part of Gray Creek consists of large and small bodies, generally of quartz greywacke enclosed in a schistose matrix of quartz greywacke siltstone. Some outcrops appear to be more competent sandstone beds in interbedded quartz greywacke sandstone and siltstone and have been fragmented during incompetent shearing and now are lenticular and sub-rounded bodies in a sheared matrix. There is a grain-size difference between matrix and boulders. Other outcrops contain limestone and other boulders and appear to be a sheared greywacke conglomerate in which there was originally an abnormally high percentage of matrix. A possible explanation is that the rocks represent landslip or mudflow deposits from gravitational slip of virtually unconsolidated quartz greywacke material. This might explain the extreme size range of the 'boulders' present in a single outcrop. The associated sediments, biohermal and oolitic limestones and basaltic volcanics, some of which were sub-aerial, suggest an active volcanic environment in which gravitational mud flows might occur. Intense shearing of relatively unconsolidated sandstones and siltstones may explain the observed sediments.

Trilobites were collected in 1958 from the Wairuna Formation immediately below the Crooked Creek Conglomerate in Gray Creek near the south-east corner of the Gray Creek Complex. They are Late Lower Silurian species (White, Best et.al., 1959).

(i) Carrier's Well Limestone Member: This is lenticular, massive, biohermal and rarely oolitic limestone. Associated with the limestone is red and green fine greywacke breccia and conglomerate, calcareous greywacke, calcareous siltstone and sandstone. The thickness of the limestone ranges from about 1,000 feet to 2,000 feet. It crops out in the neighbourhood of Gray Creek and immediately east of the Gray Creek Complex. The typical exposures occur in Spring Creek, and in Dinner Creek south of Carrier's Well, after which the Member is named.

To the east and north of the limestone near Spring Creek the sediments of the Wairuna Formation form a conformable sequence. However, the structure is not clear and the position of the Carrier's Well Limestone in the Wairuna Formation is not known. At the northern end of the Gray Creek Complex fine greywacke breccia similar to that in the Carrier's Well Limestone immediately east of the Complex, is also exposed on the western side of the Complex. Farther south the Carrier's Well Limestone is overlain by and in part contemporaneous with the Everett's Creek Volcanics and underlain by quartz greywacke and siltstone of the Wairuna Formation.

A thin section of specimen (No.97654) a red and green fine conglomerate from Spring Creek has been examined. The rock is a fine-grained greywacke conglomerate and most pebbles are well rounded. The matrix contains quartz, feldspar, calcite, magnetite and chlorite, both calcite and chlorite are recrystallized along veins and shears and along pebble edges. Many of the pebbles are basalt containing feldspar phenocrysts in a groundmass of felspar laths, magnetite and probable chlorite. The feldspar is probably albite but is altered and difficult to determine. There are also many small spherulitic bodies consisting of a central small calcite grain surrounded by a spherulitic zone of low birefringent colourless material containing scattered calcite grains.

The thin section confirms the field association between the Carrier's Well Limestone and the basic volcanics of the Everett's Creek Volcanics. It is evident that erosion of part of the volcanics took place during the deposition of the Carrier's Well Limestone and possibly in a depositional environment in which biohermal limestones grew near an active volcanic centre, so that locally sediments containing some volcanic detritus were deposited adjacent to the growing biohermal limestone.

Some of the limestone lenses are biohermal and richly fossiliferous, others are massive and unfossiliferous and a few are oolitic indicating a shallow water environment. Examination of fossils from Localities G.C.D. 1 and G.C.D. 2 by Dr. D. Hill (University of Queensland) has shown that the Carrier's Well Limestone is probably Silurian (Wenlockian) in age although some species suggest a late Ordovician age. The fossiliferous limestone (?Silurian) about 4 miles east of the Gray Creek Complex (Fossil Locality G.C.D. 2168) is correlated with the Carrier's Well Limestone on lithological and palaeontological evidence. In this area also it is closely associated with basalts and these are not nearly as well developed as in the typical exposures of Gray Creek. A fossiliferous limestone lens (locality G.C.D.3) in Dinner Creek west of the Gray Creek Complex is also correlated with the Carrier's Well Limestone. The fauna from this limestone may be slightly younger than those in the limestone to the east.

Along the contact with the Gray Creek Complex the Carrier's Well Limestone is locally metamorphosed to marble, and calcareous, chlorite and biotite schists. This is evident near Carrier's Mill and locally north and south of Spring Creek. However, more commonly the contact zone is strongly sheared with platiness in both basic rocks (green schists) and sediments.

(ii) Everetts Creek Volcanic Member: The Everetts Creek Volcanics consist of albitized basalt (spilite) and basaltic agglomerate, with lesser amounts of dolerite, tuff, graded bedded greywacke and calcareous greywacke. The typical exposures are in Gray Creek near its junction with Everett's Creek, from which the Member is named. The thickness of the Member probably does not exceed 3,000 feet.

The volcanic Member is closely associated with and mainly overlies the Carriers Limestone. Therefore its age is probably Upper Ordovician or Silurian. At the southern end of the Gray Creek Complex it is unconformably overlain by the Carboniferous Clarke River Formation.

The area at the southern end of the Gray Creek Complex shown to be Wairuna Formation contains occasional basalts and dolerites. Here low grade amphibolites within the Gray Creek Complex were originally basalts and dolerites. These volcanics are probably equivalent to the Everetts Creek Volcanics but are not mappable as a unit. Both these and the basalts with the Carrier's Well Limestone three miles east of Gray Creek are not as well exposed as in the type area. In Dinner Creek, west of the Gray Creek Complex a small area of basic volcanics resembles the typical Everett's Creek Volcanics and is overlain by thin bedded quartz-greywackes and greywackes with some conglomerate, which are correlated with the Wairuna Formation. Both rock types are faulted against and probably are unconformably overlain by the boulder conglomerate of the Crooked Creek Conglomerate.

In the type area along Gray Creek the basalt flows are vesicular but show no pillow structure. One exposure one hundred yards north of Dinner Creek - Gray Creek junction contains a sharp, chilled, slightly undulating contact of one basalt flow overlying the more vesicular top of an earlier flow. The contact, with the absence of pillow structure in either flow and of any sediment between flows, strongly suggests sub-aerial extrusion of the flows.

A number of specimens from the Everetts Creek Volcanics and from rocks related to them have been examined in thin section. Specimens No.97650 and No.97651 from near the junction of Dinner Creek and Gray Creek have a basaltic texture with altered phenocrysts in a groundmass of albite laths with calcite, chlorite, epidote and possibly clinopyroxene. The groundmass commonly has distinct flow texture around phenocrysts. Calcite-filled vesicles are common. In 97650 there are patches of magnetite, haematite, chlorite and carbonate which are alteration products from the preexisting phenocrysts (probably olivine). Partially, chloritized pigeonite is also present as phenocrysts. Of interest in the rocks is the marked increase in interstitial iron ore granules towards the margins of vesicles.

Specimen No.97649 is from a fine grained dyke intruding a basalt flow (97650). The rock contains euhedral albite (40%) laths with interstitial chlorite and epidote (35%), quartz (15%), iron ore grains (10%), and possibly some pyroxene. The texture is basaltic rather than the typical ophitic dolerite texture. The rock is a fine grained, albitized intrusive basalt or fine dolerite.*

Specimen (97648) is a fragmental rock containing fragments of fine grained basalt with feldspar phenocrysts in a fine grained matrix of feldspar, calcite, iron ore, chlorite and some quartz. The phenocrysts are albite containing patches of green, turbid saussurite. The fragments commonly are very fine-grained, possibly consisting of devitrified glass. The rock is a basaltic agglomerate.

Specimen 97637 was collected farther south in Gray Creek and is from a medium grained blue-green bedded rock associated with basalt and basaltic agglomerate. The rock consists of albite (45%), quartz (30%), chlorite (5%) and iron ore (5%). The albite is euhedral to sub-hedral, quartz is anhedral and rarely sub-rounded and calcite is in irregular patches and one large coarsely crystalline patch. The rock is a fragmental rock and it is considered to be a crystal tuff with some admixture of non volcanic elements (calcite and quartz mainly). It is problematical, if this conclusion is correct, whether the albite was deposited as such or whether more calcic original feldspars have been albitized since deposition. The latter origin is forwarded since the albite contains many small inclusions, many of them being calcite. The chlorite and calcite within the rock both show evidence of low temperature recrystallization.

Specimens 97653 and 97652 were collected from the west and east respectively of the chromitite-ultrabasic body south of Gray Creek. The rocks in hand specimen are mainly fine-grained blue-green basic rocks occurring with occasional outcrops of greywacke breccia. Specimen 97653 is porphyritic rock consisting of feldspar phenocrysts (up to 0.5mm long) in a very fine grained groundmass of euhedral feldspar laths (55%), in some places showing flows alignment, euhedral and anhedral magnetite grains (10%), irregular patches and veinlets of pale green, pleochroic chlorite (25%) and small anhedral clear ?quartz grains. The feldspar was determined as albite. The lack of ferromagnesian phenocrysts, the presence of quartz and the small amount of ferromagnesian minerals present suggest that the rock is an albitized lava of intermediate composition - it can be termed a keratophyre rather than a spilite.

Specimen 9[illegible]652 from the eastern side of the chromitite ultrabasic body contains about 50% of zoned, twinned feldspar laths of average length about 0.5mm in random orientation. Interstitial to the feldspar is anhedral ragged actinolite (45%) with anhedral pyrite grains as a common accessory mineral. The feldspar composition ranges from at least acid labradorite ($Ab_{47}An_{53}$) at crystal cores to andesine ($Ab_{67}An_{33}$) at crystal edges. The composition of the feldspar and the texture of the rock suggest a fine-grained rather basic microdiorite. The actinolite is probably secondary after clinopyroxene but the feldspar has been little altered. The rock is probably related to the keratophyre to the rest but has not been albitized.

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* In similar basaltic rocks from the southern part of the Gray Creek Complex, discussed in a later section, partial replacement of labradorite by albite is evident, hence his use of the term "albitized basalt" for these rocks. The albite definitely seems to be secondary and not primary.

Specimens from the southern part of the Gray Creek Complex which proved to be basalts and dolerites and are believed to be related to the Everetts Volcanics will be described in a later section on the petrology of the Gray Creek Complex.

(b) Greenvale Formation

The Greenvale Formation consists of irregularly bedded quartz greywacke and clayey siltstone with lenses of grit, conglomerate and breccia. The rudites consist largely of boulders of quartz, quartz greywacke and quartz greywacke siltstone. Greywackes are common yellow brown in colour and not rhythmically interbedded with siltstones as are the blue-grey greywackes of the Graveyard Creek Formation. The sandstones are commonly soft and friable and graded bedding is evident in some beds.

The relationships of the Greenvale Formation are not clear. It is unconformably overlain to the east in the Camel Creek area by the Kangaroo Hills Formation, a sequence correlated with the Siluro-Devonian Graveyard Formation. Its western boundary is faulted against the Wairuna Formation, which is unconformably overlain by the Graveyard Creek Formation. There seems to be two alternatives for the Greenvale Formation:

1. It is younger than and unconformable on the Wairuna Formation, this formation being the source for some of the sediment.

2. It is conformable with the Wairuna Formation but divided therefrom by a major fault.

The first alternative requires two orogenies in the Silurian Period, one to close the Wairuna sedimentation and commence the Greenvale sedimentation and one to close the Greenvale sedimentation and commence the Graveyard and Kangaroo Hills sedimentation. The second alternative requires one orogeny at the close of the Wairuna and Greenvale sedimentation and the commencement of the Graveyard and Kangaroo Hills sedimentation.

(c) Graveyard Creek Formation

The Graveyard Creek Formation is a greywacke sequence consisting of greywacke conglomerate (the Crooked Creek Conglomerate Member) at the base overlain by alternating 1 - 3 inch beds of greywacke and greywacke siltstones showing well developed graded bedding. Typical exposures of the Formation occur along Gray Creek and Graveyard Creek after which the Formation is named.

The thickest and most typical development of the greywacke is in the area south-west of the Gray Creek Complex. The thickness in this area is of the order of 10,000 to 12,000 feet. Several limestone lenses occur at the top of the Crooked Creek Conglomerate in the southern part of the area and these are associated with reef breccia. Immediately south of the Gray Creek Complex and on the eastern part of the basin of deposition the typical greywackes are replaced in part by quartz greywacke and siltstones with also a fossiliferous limestone lens. This is most probably due to distance from the source area which lies mainly to the west although the Wairuna Formation to the north was also partly eroded into the Graveyard Formation.

The Formation unconformably overlies the Paddys Creek Formation and intrusive granite in the west and to north and east of this it unconformably overlies the Wairuna Formation, the Carrier's Well Limestone and Everett's Creek Volcanics. The Formation is unconformably overlain by the Broken River Limestone.

Determination by Dr. D. Hill of the fossils from several lenses of limestone overlying the Crooked Creek Conglomerate south of the Gray Creek Complex (Localities G.C.D. 2104, 2090. B.R.S. 17, 69 & 70) indicates an upper Middle to Upper Silurian (Upper Wenlockian or Ludlovian) age for this part of the formation. The large limestone lenses immediately below the Broken River Formation south of Gray Creek are Upper Silurian or possibly Lower Devonian in age.

(i) <u>Crooked Creek Conglomerate Member</u>: The Crooked Creek Conglomerate is a greywacke conglomerate outcropping at the base of the Graveyard Creek Formation. Typical exposures are in Crooked Creek and Dinner Creek. The thickness of the member ranges from about 500 feet to 3,000 feet, the thickest and coarsest development being to the west of the Gray Creek Complex.

The greywacke conglomerate ranges in size from a boulder conglomerate to a pebble conglomerate. In Dinner Creek, Crooked Creek and Bauhinia Creek and particularly adjacent to the contact with the Paddys Creek Formation and the Precambrian granite the conglomerate contains boulders up to four feet in diameter. These boulders consist of granite, gabbro, amphibolite, serpentinite, gneiss, phyllite and limestone which clearly indicate a local provenance.

The conglomerate becomes progressively finer towards the top of the member and in the eastern areas of outcrop. Along the western and southern margin of the Gray Creek Complex it contains few basic boulders and is generally a cobble conglomerate containing micaceous quartzite, quartz mica phyllite, quartz, sandstone and siltstone with rare limestone and basalt boulders locally at the base. In the south-west part of the Complex the base of the member is a thick-bedded quartz greywacke sandstone which is overlain by the cobble conglomerate - here a quartz-greywacke conglomerate rather than a greywacke conglomerate.

A most significant point about the Crooked Creek Conglomerate is that it contains boulders of metamorphosed gabbro and serpentinite and is also intruded by gabbro and serpentinite thus clearly demonstrating at least two ages of serpentinite and gabbro intrusion.

<u>Petrological Examination of the Boulders in the Crooked Creek Conglomerate and their significance in deducing the Source Area</u>:-

The Crooked Creek Conglomerate contains boulders of basic igneous and ultrabasic rocks especially in its coarser basal parts. In order to make a comparison of this with the basic and ultrabasic rocks outcropping to both east and west thin sections were cut from a number of these boulders.

Specimen <u>97314</u> was collected as a typical boulder of sheared gabbro tentatively considered to have been derived from the sheared gabbro intruding the Paddys Creek Formation and intruded by the ?Precambrian granite south of Dinner Creek.

In thin section it is an actinolite schist with elongate actinolite crystals showing excellent alignment and with interstitial areas of fine grained, turbid, indeterminate material secondary after feldspar. Extremely small veinlets of a cross fibre mineral (?chalcedony) commonly occur marginally to the actinolite grains - they are nonstressed and a late feature. Texturally the rock is identified with specimen 97631 from the sheared gabbro south of Dinner Creek. There is a mineralogical difference in that specimen 97314 does not contain albite and epidote as does 97631 but instead a fine grained feldspar alteration product. Specimen 97317 from the conglomerate is a very similar rock consisting of about 60% tremolite-actinolite as parallel, acicular crystals in a fine grained turbid groundmass (probably sericitized feldspar) containing common small crystals of clinozonite.

Specimen 97320 lacks the mineral orientation present in specimens 97314 and 97317. It contains tremolite-actinolite in ragged inclusion-filled crystals averaging about 1 mm. grain size but as there is pronounced clusterings of these crystals it is probable that the secondary amphiboles were derived from a coarser pyroxene. Albite occurs as inclusion-packed anhedral interlocking crystals, commonly untwinned but some showing albite and albite pericline twinning. Chlorite is quite common in some areas and prehnite is in the albite and in veinlets. Specimen 97319 is very similar to 97320 and consists of large anhedral plates of green actinolite with common inclusions of smaller actinolite grains. Actinolite also is in large areas comparable in size with the larger crystals but consisting entirely of a fine aggregate of anhedral crystals. The actinolite is considered to be secondary after coarse pyroxene grains. Untwinned albite in various degrees of sericitization is a major constituent and clusters of epidote crystals are common. ?Ilmenite surrounded by veins of sphene, is an accessory mineral.

Specimens 97319 and 97320 are considered to be amphibolites of the albite-epidote amphibolite facies resulting from the alteration of rather coarse grained gabbro. They differ from the typical altered gabbros outcroppings south of Dinner Creek in lacking directed texture but are of similar metamorphic grade.

Specimens 97316 and 97315 were from boulders in the conglomerate considered to be derived from ultrabasic rocks. The greater part of 97316 consists of fine-grained talc with occasional cores of relict pyroxene pseudomorphed by parallel laths of talc with magnetite dust, lesser chlorite and rare tremolite. Pale green commonly euhedral garnet is common. There are irregular patches containing a fine-grained mineral with a very low birefringence and low refractive index - these are probably serpentine. Magnetite is common as irregular veinlets and patches and brown chromite occurs in several anhedral dendritic grains which have a form identical with that occurring interstitially and as symplectic intergrowths in the ultramafic rocks. Small colloform veinlets and irregular vug-like patches of chalcedonic and opaline silica are common and dolomite is present in some of these. There is a poorly developed schistosity evident in the hand specimen, but this is not obvious in the thin section.

Section 97315 is very similar to 97316 but there has also been extensive addition of or replacement by (?)dolomite with associated opaline silica along irregular cracks and veinlets. Talc (with associated chlorite, tremolite and magnetite) pseudomorphs after pyroxene are common and in places are crossed by irregular cracks containing small garnet crystals.

From the thin section examination it is apparent that these rocks are thermally metamorphosed ultrabasics with later low temperature formation of chalcedonic silica and dolomite. The serpentinite bodies south of Dinner Creek have been metamorphosed with the formation of antigorite but no rocks with talc and garnet have been observed in the field. The ?Precambrian granite is intrusive into the gabbro and serpentinite but no contacts of serpentinite and granite have been examined. It is probable that the garnet-tal rocks have been formed from the serpentinite in such contact zones.

It is considered that the altered ultrabasics and basics present in the Crooked Creek Conglomerate were derived from the serpentinite and gabbro in the Bauhinia Creek area and probably the northward extension of this belt towards the Halls Reward area. This is supported by the presence in the conglomerate of many boulders of mica granite correlated with the Precambrian mica granite and by the coarsening of the conglomerate to the west adjacent to the area.

Within the conglomerate any particular outcrop shows a dominance of one particular rock type suggesting erosion from a restricted adjacent source area. This is apparent in the northern area of outcrop where quartz sandstones and siltstones derived from the Wairuna Formation to the north and quartz-mica phyllites from the inliers of Paddys Creek Formation are locally dominant within the conglomerate.

(d) Broken River Limestone

The Broken River Limestone outcrops on the southern edge of the area of Plate 1. The formation consists of massive and bedded, lenticular, richly fossiliferous, coralline limestone with associated calcareous siltstone and sandstone, quartz greywacke, shale and lenses of pebble conglomerate. The formation unconformably overlies the Graveyard Creek Formation and in most places the unconformity is marked by a basal grit or conglomerate. It is overlain, possibly unconformably by the Carboniferous Bundock Creek Formation.

The faunas of the richly fossiliferous limestone range from Lower Devonian to the top of the Middle Devonian or possibly Upper Devonian. The thickness of the formation is not accurately known but may be over 10,000 feet. The limestones are most extensively developed near the base of the formation and siltstones predominate higher in the formation.

(e) Clarke River Formation

The Clarke River Formation in the Gray Creek area consists of quartz conglomerate, grit and sandstone, feldspathic sandstone and some quartz greywacke sandstone and rare siltstone. The formation is typically thick-bedded and the quartzose beds somewhat silicified. Prominent features of the conglomerates is an abundance of red jasper pebbles intermixed with the dominant white quartz and quartzite pebbles.

The Formation is probably mainly a fresh water deposit, plant fossils having been found at two localities near the base of the sequence east of Gray Creek. However east of Gray Creek in the Burnt Coat area a limestone suggests a marine intercalation near the base and western edge of the Clarke

River Formation. Similar basal limestones are exposed east of the area of Plate 1. These are at Blue Range and Gill Creek.

East and south-east of Gray Creek the thickness of the Formation is 2000 - 3000 feet. The Formation near Gray Creek unconformably overlies the Wairuna Formation, the Everett's Creek Volcanics and the Carrier's Well Limestone. Farther east the Formation unconformably overlies the Wairuna Formation and the Greenvale Formation and the major fault boundary between them.

Plant fossils determined by Mary White (1958) from localities G.C.D. 2308 and 2273 east of Gray Creek include *Lepidodendron veltheimianum*, *Sigillaria* sp. and *Stigmaria ficoides* and indicate a Lower Carboniferous age for the Clarke River Formation in this area.

The Formation is probably correlated with the upper part of the Upper Devonian-Carboniferous Formation which conformably or unconformably overlies the Broken River Formation south of the area of plate 1.

(i) Limestone. Limestone exposed at Burnt Coat Greenvale holding is bedded, richly fossiliferous and interbedded with calcareous sandstone and outcroppings near the crest of a small anticline east of Gray Creek. The thickness of the member is about 50 feet.

The fauna from the member collected from locality G.C.D.2259 includes brachiopods, gastropods, pelecypods and a straight nautiloid, of which a preliminary determination indicates an Upper Devonian or Lower Carboniferous age.

(4) TERTIARY

(a) Basalt

Basalt occurs locally as flat-lying sheets in the area. Near Paddys Creek there is a small remnant basaltic plug with a basalt flow extending south therefrom. The basalt crops out as boulders and does not appear to be lateritized. South of Gray Creek and west of Pandanus Creek Homestead there is a large area of basalt forming a mesa capping and its upper surface is lateritized.

(b) Laterite and lateritic earths

Many of the Tertiary mature erosional mesas are capped by lateritic earth commonly consisting of a red brown to reddish yellow earth containing common angular rock fragments from the underlying rock types. Locally on the serpentinite of Gray Creek and Boiler Gully Complexes there is a capping of deep red-brown pisolitic laterite. The varying thickness of this laterite is due to it having been formed on an undulating surface and it may be 30 feet or more thick in some areas.

In the area west of Gray Creek, the divide between the Einasleigh and Burdekin River systems, the laterite is overlain by deep soil cover. In this area the surface has not been affected by the rejuvenation of the erosive cycle since Tertiary times.

(5) RECENT

(a) Alluvium and Recent Deposits

The major streams of the area commonly flow through alluvial black soil plains. The black soil generally forms a surface layer overlying thick yellow-brown to red-brown alluvial soils with common pebble conglomerates. In the north-eastern part of the area Miner's Lake is the remnant of a much larger area extending south of Gray Creek in which a series of lake sediments including conglomerate, sandstones and siltstones have been deposited in Pleistocene to Recent times.

E. ULTRAMAFIC AND BASIC INTRUSIVES

(1) SANDALWOOD SERPENTINE

(a) Occurrence

The Sandalwood Serpentinite consists of lenticular serpentinite and altered gabbro typically exposed in a linear zone on the eastern margin of the ?Archaean metamorphics near the Halls Reward Mine (Plate 1). From the Halls Reward area the intrusives extend about 17 miles south-west to the Bauhinia Creek area and crop out intermittently for at least 4 miles N.N.E. of the Halls Reward Mine. In the Halls Reward area they intrude the ?Archaean Halls Reward Metamorphic and Stenhouse Creek Amphibolite but farther south they intrude phyllites of the Proterozoic Paddys Creek Formation. The intrusives are named from Sandalwood Homestead, north of Halls Reward Mine.

In the Halls Reward area, the serpentinite bodies are regionally concordant with the ?Archaean metamorphics but in detail their contacts transgress the bandings and schistosity of the metamorphics. In other places the schistosity of the metamorphics is deflected by the serpentinite intrusives. Near the southern margin of the ?Archaean block serpentinite bodies occupy an anticline between two basins of Paddys Formation but were not observed to cross the unconformity.

South-west of the Halls Reward area and north of Spring Creek the Sandalwood Serpentinite consists of a single elongate serpentinite body in strongly sheared gabbroic rocks. South of Spring Creek there are a number of strongly sheared serpentinite lenses in sheared gabbro. An area of recent soil cover near Dinner Creek obscures, the continuity of the belt but south of Dinner Creek there is a large area of the typical dynamothermally altered gabbro with small bodies of serpentinite.

(b) Petrography and Petrology

In the northern part of the belt serpentinite is the most common rock type with gabbro much less common. Farther south gabbroic rocks become much more abundant.

The serpentinite characteristically consists of antigorite partly or completely replacing bastite and mesh-textured serpentinite. The end result of this replacement is a rock consisting of randomly arranged micaceous flakes of antigorite. The rock is distinct in its random, disordered texture from the rectangular ordered mesh-textured serpentine with scattered bastite pseudomorphs after orthopyroxene.

Specimens 97615 (from south of the Halls Reward Mine) and 97621 (from the Bauhinia Creek area) are typical end products of this alteration consisting of 90 - 95% antigorite * with 10 - 15% magnetite grains. Specimen 97626 from the Halls Reward area shows an arrested stage of alteration of mesh-textured serpentinite.

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* The antigorite shows first order deep yellow interference colours. These are of higher order than is usual for antigorite. The fibrous habit, positive elongation, low to moderate relief and straight extinction are all consistent with the properties of anthophyllite as well as antigorite. However, two cleavages at 60° do not occur and the mineral is biaxial negative with a variable 2V ranging from 15-20° to 40-50°. The 2V is consistent with antigorite but not with anthophyllite (biaxially positive, 2V = 70°-90°). The mineral is thus identified as antigorite.

In the Halls Reward area the serpentinite bodies commonly have a local marginal phase of a chlorite rock with magnetite porphyroblasts and accessory vesuvianite (specimen 97614). Similar rocks contain epidote (specimen 97614) or tremolite-actinolite (specimen 97623) porphyroblasts in the chlorite groundmass. Massive and schistose forms of talc and pods of coarse grained acicular tremolite are common throughout the serpentinite bodies, occurring in the headwaters of Spring Creek and farther south but being most common in the area immediately south of the Halls Reward Mine.

In the Halls Reward area the serpentinite bodies are transgressively intruded by small bodies of garnetiferous mica granite. These have altered the serpentinite. Specimen 97617 is typical of the normal serpentinite consisting of partly antigoritized mesh texture serpentine and with later development of cross-fibre chrystolite veins. Specimen 97616 was collected nearby but only 10 yards from a granite contact. It is a similar rock but the serpentine minerals have been partly replaced by carbonate (possibly dolomite). Specimen 97618 was collected only two yards from a contact between serpentinite and garnetiferous granite. The rock consists largely of carbonate (dolomite) and a fine grained quartz aggregate with relict magnetite, chromite, chlorite and serpentine from the original serpentinite. Specimen 97619 from closer to the contact contains dolomite, silica and magnetite. A rock similar to these, specimen 97622 consists of about 40% of clusters of carbonate crystals in a groundmass of antigorite, fine carbonate, haematite and possibly very fine-grained quartz. Although the field relationships are not clear this rock seems to be another example of alteration of a serpentinite by neighbouring granite. Although the silicification and dolomitization of the serpentinite increases towards the granite intrusion it is thought to be a later process than the growth of antigorite from the mesh-texture serpentine, a process which does not appear to be related to metamorphism by the granite.

The gabbroic rocks of the Sandalwood Serpentinite are medium to coarse-grained with a well-defined schistosity and mineral orientation. They are characterized by tremolite-actinolite, albite, and epidote, with accessory quartz, sphene and chlorite. The mineral assemblage belongs to the albite-epidote amphibolite metamorphic facies or the top of the green-schist facies and the texture shows that the metamorphism was associated with strong shearing.

There is little evidence of the original gabbroic texture of the amphibolites but in specimen 97624 (Halls Reward area, south of Stenhouse Creek) the effects of shearing are not strongly developed and the hand-specimen has the appearance of a coarse-grained gabbro. In thin section the rock consists of large tremolite-actinolite crystals (with many inclusions and considered to be secondary after coarse pyroxene crystals) in a groundmass of saussurite with clinozoisite, tremolite and accessory sphene. Specimen 97627 from nearby is a strongly sheared rock with excellent alignment of tremolite-actinolite crystals in a groundmass of aligned tabular zoisite and small amphibole crystals. Prehnite is in a small vein.

A third specimen (No. 97625) from the Halls Reward area contains 55% of a carbonate (calcite or dolomite) and appears to metasomatically replace the original rock which consisted of large partly sericitized albite grains with zoisite inclusions and tremolite-actinolite with chlorite. Yellow-brown ?sphene is a minor accessory mineral. The replacement of the rock by carbonate is probably a similar effect to that in the serpentinite described above and due to the action of granite.

Specimen 97628 was collected from the headwaters of Spring Creek and is a strongly schistose rock containing 45% actinolite, 30% clinozoinite, 20% quartz, 5% chlorite and accessory yellow-brown sphene with limonite. The high percentage of quartz is anomalous for an amphibolite derived from a basic igneous rock as this is believed to be, mainly because of its uniformity and lack of compositional banding in the field and on the association with serpentinite. Specimen 97631 was collected from the large area of uniform, strongly schistose medium grained gabbroic rock south of Dinner Creek. The hand specimen and field appearance is typically that of a coarse grained basic igneous rock altered under strong shearing stress. In thin section the rock contains 40% green actinolite, 30% albite and 25% epidote and all constituents show a high degree of mineral orientation.

The degree of recrystallization of the gabbroic rocks is variable and this also applies to the degree of antigoritization in the serpentinites. The metamorphism of the serpentinite is consistent with that of the gabbros since Wilkinson (1953) and Hess, Dengo & Smith (1952) have shown that antigoritization of serpentinite takes place at the top of the greenschist facies or low in the albite-epidote amphibolite facies of regional metamorphism.

(c) Age of the Sandalwood Serpentinite:

The boulders of metamorphosed serpentinite and actinolite amphibolite in the Crooked Creek Conglomerate are considered to be derived from the Sandalwood Serpentinite, in particular from that part which outcrops south of Dinner Creek. The boulders of ultrabasic rocks in the conglomerate had been thermally metamorphosed prior to deposition with the consequent development of talc, garnet and dolomite. The ultrabasic and basic rocks of the Sandalwood Serpentinite have been intruded by granite in both the Halls Reward area and the area south of Dinner Creek.

A specimen (97630) of basic rock collected adjacent to a small granite intrusion has been thermally metamorphosed and consists of pale green hornblende porphyroblasts in a fine grained groundmass of prismatic scapolite. Quartz is present in patches and veinlets, magnetite is quite common and calcite and sphene are accessory minerals. The rock has no directed texture.

In both the Halls Reward and Bauhinia Creek areas the granite is a yellowish-white muscovite granite, commonly pegmatitic and quite distinct from the hornblende granodiorites intruding the Lucky Creek Formation to the west and the southern part of the Gray Creek Complex.

Thus the Sandalwood Serpentinite post-dates the ?Proterozoic Paddys Creek Formation but pre-dates the intrusions of mica granite and the Silurian Graveyard Formation. The Paddys Creek Formation and Lucky Creek Formation have suffered low grade dynamothermal metamorphism producing phyllitic rocks with a N.E. to N.N.E. trend. The muscovite granite is unstressed and apparently unaffected by this metamorphism. The Sandalwood Serpentinite has been strongly stressed and suffered low-grade regional metamorphism and superimposed on this a thermal metamorphism and meta-somation due to the granite intrusions. It is thus considered that the Sandalwood Serpentinite was emplaced during a period of folding and low grade regional metamorphism following the deposition of the Paddys Creek Formation and Lucky Creek Formation. This orogeny was probably late Precambrian or Lower Palaeozoic in age. The muscovite granite was probably intruded in the waning phase of this orogeny.

(2) THE BOILER GULLY COMPLEX

(a) Occurrence:

The Boiler Gully Complex is a large (5 square mile approximately) intrusion, triangular in plan, of ultrabasic rocks mainly serpentinite and gabbro exposed in the southern part of the ?Archaean metamorphics of the Halls Reward area. Linear serpentinite trend N.N.E. from both the north-east and northern corners. The southern limit of the Complex is not clear owing to extensive soil cover in this area. Its relationship in this area to the strongly sheared basic rocks of the Sandalwood Serpentinite is likewise not clear due to soil cover and intervening rubble of Paddys Creek Formation sediments.

(b) Petrography and Petrology

(i) Serpentinite: The serpentinite of the Boiler Gully Complex is usually massive and contains bastite and mesh texture serpentine pseudomorphs after orthopyroxene and olivine respectively. Chlorite rocks, talc and antigorite serpentinite which are typical of the Sandalwood Serpentinite, are absent and small bodies of acicular tremolite (probably of hydrothermal origin) are apparently restricted to the margins of the main serpentinite core or the small serpentinite bodies of the N.N.E. trending belts of the northern and north-eastern corners.

No unserpentinized primary ultramafic rocks were found in the field but on examination of thin sections (Nos. 97328, 97330-36, 97338) shows that the serpentinite was derived from ultramafic rocks varying from dunite through enstatite olivinite to enstatolite. The nature of the original rocks is usually readily deducible from the serpentinite which is generally in the form of perfectly developed irregularly cellular mesh-textured serpentine, replacing olivine and platy bastite pseudomorphs and some regular, rectangular mesh-textured serpentine replacing orthopyroxene, probably enstatite. Brown chromite is present as primary constituent in most of the rocks. It generally has an anhedral habit and appears to have formed interstitially to olivine and orthopyroxene.

Commonly the chromite forms symplectic intergrowths with mesh-textured serpentinite (after olivine). Accessory anhedral to sub-hedral magnetite is present, usually along irregular lines marking the cracks in the original olivine. The magnetite has developed as a result of serpentinization.

The original rock types were quite variable. Specimen 97336 contains 60% bastite pseudomorphs with interstitial mesh-textured serpentine symplectic chromite. About 30% of typical flare-texture antigorite is formed along cracks and small shear zones. The original rock probably contained 80% to 90% orthopyroxene. As a contrast specimen 97331 consists entirely of mesh-textured serpentine except for a small amount of interstitial chlorite, antigorite and magnetite. The latter minerals show alignment between the "grains" of mesh texture serpentine and have either developed along very irregular cracks owing to shearing or an initial stage in serpentinization along original olivine grain boundaries. A common rock is typified by specimens 97332-3, both of which consist of 20% to 25% bastite pseudomorphs in mesh-texture serpentine with accessory primary chromite and secondary magnetite.

The amount of antigorite in these rocks varies considerably. In many rocks (97332-3, 97328, 97330) antigorite is entirely absent and there has been no replacement of the mesh-textured and bastite pseudomorphs. In specimen 97336 as mentioned above antigorite is a replacement along irregular cracks and shears and it is apparent that shearing was important in its formation. In specimens 97331, 97334-5 the antigorite is closely associated with chlorite and magnetite grains and occurs as narrow irregular veinlets in which the antigorite and chlorite are commonly aligned. It is very likely that these veinlets are actually narrow zones between grain boundaries. If this is correct it is possible that crystallization of antigorite and chlorite has occurred during intergranular movement in a late stage of crystallization. Under normal conditions the intergranular material may have crystallized to give interstitial clinopyroxene as in some of the rocks from the Gray Creek Complex. Whatever is the origin of this antigorite it is important that it bears an interstitial rather than a replacement relation to the mesh-textured serpentine.

Small cross-fibre chrysotile veinlets are fairly common in the serpentine. In specimen 97328 at least one of these is a non-dilational replacement vein whereas in 97330 at least one of a series of parallel chrysotile veinlets is dilational.

Near the south eastern margin of the serpentinite core there is an outcrop of a small lens of chromitite containing 85-90% coarse grained chromite in a serpentine matrix. In this same area, within the margin of the serpentinite, are also outcrops of coarse grained altered gabbroic rocks. The linear outcrops of the various rock types (97331-4, 97347) have a north to north-east trend and suggest a large scale compositional banding. 97347 is an altered coarse grained gabbro from this area. It contains about 70% of patches consisting of a fine matte of acicular tremolite-actinolite crystals and platy micaceous chlorite crystals. In some areas chlorite is dominant and in others amphibole is dominant. These areas are considered to be secondary after coarse pyroxene crystals, the crystal form of which is very evident in hand specimen. The remainder of the rock consists of clinozoisite with small amphibole and chlorite crystals.

Specimen 97348 from the same area consists of 20% to 30% of fine grained tremolite-actinolite patches similar to 97347, and the rest of the rock consists of large crystals of saussuritized plagioclase and poikiloblastic zoisite. The original rock appears to have been a coarse grained feldspar-rich calcic gabbro, possibly approaching an anorthosite in composition.

(ii) The Diallagites: In the northern part of the Complex are two small bodies of rocks consisting largely of actinolite (70%) without directed texture. The actinolite (specimens 97349-50) are large prismatic crystals, commonly poikilitic towards smaller actinolite crystals and small quartz crystals. There is about 20% of turbid fine grained secondary material with cores of clinopyroxene (diallage or augite). Accessory quartz and epidote are present. In specimen 97350 a large grain of clinopyroxene shows marginal alteration to actinolite. It is considered that these rocks have altered from original pyroxenite (diallagites?) but their relationships to the other rocks of the Complex are problematical, particularly since they do not show the stress effects of the altered gabbro nearby.

(iii) The Basic Rocks: In the Boiler Gully Complex basic rocks form a mantling zone to the serpentinite core except adjacent to or within fault zones on the eastern and western margins. The basic rocks are medium-grained, consisting generally of tremolite-actinolite and saussuritized feldspar. They are uralitized and saussuritized gabbros. The rocks have a well defined foliation owing to parallelism of lenses of amphibole and altered feldspar. The retrogressive mineral alteration and the foliation were probably developed in the late magmatic or deuteric stage of cooling of the gabbro resulting in alteration of pyroxene to lenticular amphibole aggregates and saussuritization and other alteration of the feldspar.

Specimens 97339, 97344-46 are typical of these altered gabbros. Specimen 97344 consists of lenticular clusters of acicular tremolite-actinolite crystals showing moderate orientation in a groundmass of saussuritized feldspar. Clinozoisite is an uncommon accessory mineral. In this rock small relict primary clinopyroxene (colourless augite?) crystals, are generally partly altered to tremolite actinolite. Rare opaque iron ore granules are present. Specimen 97339 is similar to 97344 consisting of 40% saussurite and 60% lepidoblastic tremolite-actinolite in lenticular clusters. The boundaries between saussurite and amphibole are generally irregular, one mineral embaying the other suggesting a primary sub-ophitic texture. There is incipient growth of prehnite from the saussurite.

Specimen 97346 differs from other specimens in lacking the strongly developed foliation present in the rocks above, there being only several minor shears present. Tremolite -actinolite is platy with many inclusions of smaller crystals and the saussurite contains some relict indeterminate feldspar. Clinozoisite or zoisite is a rare accessory. Specimen 97345 is very similar to 97344 but the amphibole is distinctly green in colour, suggestive of actinolite. Saussuritized plagioclase with "ghost" twinnings is present, but there is also a small amount of secondary albite and epidote. Sphene, chlorite and possibly quartz are accessory minerals.

Specimen 97340 was originally a very coarse grained rock. It now consists of prehnite containing patches of fine grained, pale green tremolite-actinolite. Green spinel forms

5-10% of the rock and is generally rimmed by indeterminate fine-grained alteration products. The rock is considered to be a retrogressively altered spinel bearing pegmatitic gabbro. It was collected near the ultramafic - basic boundary in the northern limb of the complex.

(iv) The Microdiorites: In the northern part of the Complex there are small bodies and veins of hornblende microdiorite. Examples of these are specimens 97353-4, 97355-6, 97341. Specimens 97353-4 consist of variable (25-50%) amount of medium to coarse grained altered plagioclase (relict andesine in specimen 97334) with a pale buff to pale brown pleochroic hornblende. The hornblende is clear and unaltered, occasionally twinned and has a poorly developed orientation although crystals are intergrown one with another rather than a lepidoblastic or granular texture. Where relict feldspar occurs the texture is suggestive of eutectic crystallization. The texture is interpreted to be due to crystallization of a dioritic magma under slight stress causing lenticular clustering of the amphibole and feldspar. Very similar rocks occur in the Gray Creek Complex (specimens 97303-6) again as a minor constituent in small dykes and veins and probably of late formation.

Specimens 97355-6 are essentially similar but andesine (Ab_{60} An_{40}) is the main constituent and in 97356 there is only about 5% of amphibole. In 97355 the feldspar and amphibole occur in an eutectic, sub-ophitic intergrowth.

Specimen 97341 consists of green hornblende, saussuritized plagioclase and 10% quartz with accessory chlorite and epidote. It has a porphyritic texture and is apparently a hornblende quartz microdiorite.

(c) The Structure of the Boiler Gully Complex:

The foliation in the altered gabbros parallels the margin of the serpentinite core and dips outwards from it. To the north of the Boiler Serpentinite the dip averages about 55°N but is vertical or very steep on both eastern and western margins. The gabbro contains a number of faults which are perpendicular to the margin of the serpentinite and to the foliation in the gabbro. The foliation and faulting in the gabbro are related to the serpentinite core and interpreted to be caused by forcible emplacement of the serpentinite, possibly as serpentinite or in an ultramafic crystal mush state, causing doming, foliation and radial faults in the gabbro, possibly while this was in the late magmatic and deuteric stage of crystallization.

The bodies of gabbro in the northern part of the Complex are generally concordant with the strikes of the Archaean metamorphics and these have been domed by the emplacement of the Complex. This is seen immediately north of the Complex where the strike of the Archaean metamorphics is east-west and the dip to the north. This strike is almost at right angles to the strongly developed N.N.E. trend developed during regional metamorphism.

Strong local shearing of the north-north-east trending serpentinite on the eastern side of the Complex has produced local serpentine schist and mylonitic rocks. In this area also antigorite is a minor replacement of mesh-textured serpentine apparently due to local shearing (specimen 9736). Marginal shearing during emplacement of the serpentinite and movement in the transcurrent fault zone in the north-east corner of the Complex are probably responsible for these local stress effects. Both gabbro and serpentinite have also been sheared by the Lucky Downs Fault.

(d) The Age of the Boiler Gully Complex:

In the northern part of the Complex the foliation of the gabbro is at right angles to the strong vertical schistosity of the ?Archaean metamorphics. In addition the Complex is not affected by regional metamorphism of the amphibolite and albite-epidote amphibolite facies. These features show that the Complex post-dates the regional metamorphism of the ?Archaean metamorphics.

The dentral transcurrent fault in the central southern part of the ?Archaean block is probably the major movement plane along which metamorphics and gabbro were displaced to make room for the ultramafic core. The fault apparently continues south-west along the linear serpentinite body into the north-east cormer of the serpentinite core. Farther east the fault displaces and is clearly younger than the Sandalwood Serpentinite. The Sandalwood Serpentinite contains dynamothermally metamorphosed rocks of the upper greenschist and albite-epidote amphibolite facies. The Serpentinite of the Boiler Gully Complex is generally quite unmetamorphosed and the microdiorites similarly are unmetamorphosed. The gabbro shows alteration to the greenschist facies and this can be related to stress effects during the emplacement of the Complex. The modes of occurrence of the two serpentinites are also very different.

These features all suggest that the intrusion of the Boiler Gully Complex was separate from and later than that of the Sandalwood Serpentinite. Against this suggestion is the fact that south of the Boiler Gully Complex in the area of extensive soil cover it is very difficult to delimit the boundary between the two complexes and the Sandalwood Serpentinite trends south-west approximately on line from the north-north-east trending linear arm of the Boiler Gully Complex.

The Sandalwood Serpentinite is intrusive into and later than the Paddys Creek Formation and this also applies to the western margin of the Boiler Gully Complex. The main body of the Complex is apparently unaffected by the low grade dynamothermal metamorphism and north-east structures of the Paddys Creek Formation although eastern and western margins show shearing in this direction, which is however, also the trend of the Palaeozoic orogenies.

One slender piece of evidence for the age of the intrusion is that the transcurrent fault associated with the intrusion of the Boiler Serpentinite intercepts the Post-Silurian Halls Fault at a low angle on the eastern margin of the Archaean block. The low angle junction and the sharp swing to the north-east in the Halls Fault at this junction suggests that the faults may have been contemporaneous. If this is so then the intrusion of the Boiler Gully Complex is post-Silurian.

A preferred hypothesis is the intrusion of the basic and ultrabasic rocks to be contemporaneous with movement on the Halls and Lucky Downs Faults bounding the Precambrian block. It is possible that the uplift of the Archaean basement on the Halls Reward area was largely caused by the forcible intrusion of the Boiler Serpentinite.

A post-Silurian age for the Complex is supported by its similarity to the Gray Creek Complex intruding Siluro-Devonian sediments. Both these complexes contain unmetamorphosed serpentinite cores surrounded by gabbro with minor development of microdiorite.

(3) THE GRAY CREEK COMPLEX

The Gray Creek Complex is an elongate body 15 miles long and up to 3 miles wide outcropping along the western side of the Gray Creek valley. The Complex intrudes Palaeozoic sediments and consists mainly of serpentinite, pyroxenite and gabbro, with diorite, granodiorite and amphibolite.

(a) Petrography and Petrology of the Igneous Rocks

(i) Serpentinized Ultramafic Rocks: The main body of serpentinized ultramafics crops out adjacent to the western margin of the northern part of the Complex and is about 4 miles long and up to one half a mile wide.

Specimens (97322-4) of serpentinite from the northern end of the Complex have been examined in thin section. The serpentinite is grey and has a granular or cellular texture (after olivines) with some platy grains (after pyroxene). In thin section the rocks consist mainly of mesh-textured serpentinite with some large grains and many veinlets of magnetite. Some areas consist of elongate and parallel laths of bastite separated by rectangular blocks of sub-isotropic serpentinite resembling the mesh-textured type rather than bastite. These composite areas are apparently secondary after orthopyroxene. In contrast to these other areas have irregular mesh-texture serpentine typical of the replacement of olivine. Specimen 97322 was probably originally a dunite, specimen 97323 an enstatic olivinite and specimen 97324 a peridotite in which orthopyroxene was more abundant than olivine.

The serpentinite generally forms linear outcrops and these appear to be due to vertical banding on the eastern and western sides of the body. Further south in the centre of the serpentinite there is sub-horizontal layering formed by massive three to six feet bands of silicified serpentinite. The cause of this banding is unknown but it could possibly be due to variation in the original ultramafic magma between dunite and enstatolite. The banding appears to form an anticlinal arch, being sub-vertical on the eastern and particularly the western margins and sub-horizontal within the body.

The effect of shearing on the serpentinite is shown in the northern part of the body where a north-east trending shear zone cuts across it. There the serpentinite consists of small blocks of unsheared serpentinite in a pale green or vari-coloured serpentinite schist. The blocks have polished slickensided surfaces and are pod-shaped or rounded. A microdiorite dyke has been brecciated and the fragments have polished slickensided surfaces and are surrounded by serpentinite schist. In thin section (97322) the schistose material is variable, some being so perfectly aligned and fine grained to appear to be a single mineral plate whereas other areas have small drag folds with complex folding and shearing. Cross-fibre crysotile veins in the included blocks have in many cases become a place of movement producing slip-fibre veins. It seems that the schistose serpentinite in this area has been produced by local shearing, possibly accompanied by temperature rise and increased plasticity on the movement planes, of the massive mesh-textured and bastite serpentinite forming the unsheared blocks. Wilkinson (1953) has shown that in southern Queensland schistose serpentinite is due to a second and later intrusion brecciating an earlier mesh texture serpentine.

The serpentinite body crops out in a high ridge which is capped with several areas of pisolitic laterite. Below this the serpentinite is largely a silica boxwork with an increasing amount of relict serpentinite cores at depth. The formation of the silica boxwork is considered to be due to prolonged weatherings of a stable land surface with leaching of the serpentinite by ground waters, probably during lateritization.

The western margin of the serpentinite and particularly the northern end of the body have been silicified to a brown glassy rock with a conchoidal fracture and many colloform veinlets of opaline and chalcedonic silica. Specimen 97321 is typical of these rocks and consists of pale brown fibrous patches in a brown glassy groundmass with common grains and veinlets of iron ore. The pale brown patches were probably orthopyroxene but are now orientated talc laths separated by fine grained chalcedony. The groundmass consists of fine grained spherulitic and aggregate chalcedony with possibly rare and relict serpentine. Magnetite is common as anhedral grains and small veinlets and chlorite is a rare accessory. The silicification does not seem to be related to the topography or to lateritization. The silicified serpentinite has a poorly developed schistosity and it is likely that along the western and northern margins of the body the silicification is due to silica migration along the sheared western edge of the body. Similar features apparently occur along fault zones in the Coastal Ranges of California (Williams, Turner & Gilbert, 1954, p.85).

South-west of the main serpentinite small serpentinite bodies are within pyroxenite. North of Dinner Creek serpentinite is on the western margin of the Complex, again in association with pyroxenite. A sheared serpentinite body with talc and magnetite on its eastern edge is in contact with sheared Carrier's Well Limestone in Dinner Creek.

In the central southern part of the Complex a small serpentinite body is associated with pegmatitic gabbro and both appear to be intruded by granodiorite exposed to the west. In thin section the rock consists of a fine rectangular mesh-textured serpentine, the mesh having a constant orientation over the whole rock. Several small chrysotile veinlets have grown parallel to these mesh directions. In irregular patches throughout the rock and in thin irregular veins the mesh-textured serpentinite has been altered to random-textured antigorite showing the typical flare texture. Alteration to antigorite has affected approximately 35 - 40% of the rock and is attributed to metamorphism by the nearby granodiorite.

In the southeastern corner of the complex serpentinite lenses are exposed in a shear zone in Gray Creek. On the eastern side of Gray Creek a large body of serpentinite trends south-south-west for about five miles along a major fault, the Spring Creek Fault. This serpentinite contains chromitite lenses and coarse-grained altered gabbro. South-west of this area serpentinite with altered gabbro forms a prominent ridge. The serpentinite outcrops are linear and show little silicification. Much of the serpentinite has been strongly sheared to a serpentinite schist owing to movement on the Spring Creek

Fault. Farther south small lenses of serpentinite in the fault zone have probably been re-intruded as plastic bodies during faulting.

(ii) The Clinopyroxene Rocks - Pyroxenites and Peridotites: Pyroxenite surrounds the serpentinite core of the northern part of the Complex except along the sheared north-western and northern margins. The pyroxenite extends farther south beyond Spring Creek and small bodies are near the western margin of the Complex north of Dinner Creek. The continuity of the main body is apparently interrupted near Dinner Creek but smaller bodies are in Dinner Creek near the track crossing and also near the western margin. South of Dinner Creek are two areas predominantly of pyroxenite and which are surrounded by gabbroic and dioritic rocks. Minor pyroxenite also contains chromitite and gabbro east of Gray Creek in the south-eastern part of the Complex.

The pyroxenite ranges in grain size from medium to coarse-grained. Diallagites are most common but olivine and orthopyroxene-bearing rocks occur with less common serpentinite or partly serpentinized peridotite. Steeply dipping compositional banding is exposed in a few outcrops, particularly in the pyroxenite on the western margin of the Complex north of Dinner Creek. In the field the clinopyroxene rich rocks appear to grade with increase in interstitial calc-silicate minerals into melagabbros as represented by specimens 93697-99.

A brief description of the thin sections examined illustrates the range in the rock types. In the northern part of the Complex the rocks immediately east of the serpentinite core include a diallage peridotite (specimens 97683-5) containing 25-35% anhedral, intergranular olivine with 75 clinopyroxene (probably diallage). The olivine is largely converted to mesh-textured serpentine but in specimen 97683 relict cores of magnesian olivine ($2V = 90^{o}$) do occur.

One mile farther south a series of specimens (Nos. 97686-88) was collected from the pyroxenite body. Specimen 97686 consists of large anhedral clinopyroxene (probably diallage) in mesh-textured serpentine containing common cores of unserpentinized olivine. The olivine is colourless, biaxial positive with a very large 2V. The release of magnetite along irregular cracks during serpentinization shows it is an iron-bearing olivine. Colourless tremolite is marginal to some pyroxene grains and rare chlorite, secondary after the clinopyroxene, is present. Olivine and clinopyroxene are roughly equal in proportions and the rock is a partly serpentinized diallage peridotite or "wehrlite".

Specimen 97687 is a spinel-bearing diallagite and consists of large anhedral platy crystals of colourless diallage with interstitial fine-grained sub-hedral granular clinopyroxene, colourless ?tremolitic amphibole, chlorite, ?clinozoisite and common (15% of total rock) deep green, isotropic spinel - probably chlorospinel. Both chlorite and amphibole are also large platy crystals secondary after clinopyroxene. In the granular interstitial material small crystals of spinel, amphibole and clinopyroxene are often included within a single plate of ?clinozoisite. The appearance of this interstitial material suggests that the amphibole, chlorite, spinel and ?clinozoisite have formed in a late magmatic or deuteric stage of crystallization - in part they are secondary after clinopyroxene but in part a direct crystallization from interstitial fluids. This observation seems to be fairly general for the tremolitic amphibole common in these rocks - in part it replaces pyroxene and is then usually rich in orientated laths or larger grains of magnetite and commonly with many very small inclusions. In part however, the amphibole is clear, small subhedral interstitial crystals and these are possibly of primary late magmatic or deuteric crystallization.

Specimen 97688 consists of large plates of colourless diallage generally containing orientated lamellae of magnetite or haematite and usually with a distinct rim of larger magnetite or haematite grains. Tremolite, in part interstitial and in part definitely secondary, is common and the rock contains about 5% of olivine having an interstitial relationship to the clinopyroxene. The olivine is partly converted to deep yellow-orange bowlingite, generally forming a single crystal plate replacing the olivine. The olivine is evidently of late crystallization and its alteration to bowlingite rather than serpentine suggests it may be an iron-rich variety. The clinopyroxene with the exsolved iron oxide lamellae was also possibly a more iron-rich variety than that in 97686-7. The rock is an olivine diallagite.

The main rock type from the pyroxenite-serpentinite body on the western margin of the Complex, north of Dinner Creek, is a coarse to very coarse (5 cm. crystals) pyroxenite (Specimens 97678, 97660) consisting of primary augitic or diallagic clinopyroxene with secondary replacement by tremolite amphibole and in some cases (specimen 97660) interstitial clinozoisite (15%) probably secondary after plagioclase feldspar. The rocks contain many irregular patches of feldspar and quartz and in some places an intrusion breccia containing a quartz-feldspar rock has intruded the pyroxenite and altered pyroxene to amphibole.

Specimens 97679, 97681-2 are typical of a medium-grained banded peridotite which has a sharp contact against the coarse pyroxenite described above. The sharp, vertical, rolling contact shows no evidence of finer grain or contact metamorphic effects in either rock. The banding of the peridotite ranges from three inches to twelve inches thick and its trend is almost at right angles to the trend of the contact.

Specimen 97679 was originally a websterite containing about 60% orthopyroxene with about 40% interstitial clinopyroxene. The latter has altered to a mosaic of colourless tremolitic amphibole with abundant orientated lamellae of magnetite. The orthopyroxene has largely altered to serpentine with some cores of talc and relict of orthopyroxene.

Specimen 97681 was collected from a neighbouring band and is a diallage peridotite containing about 20% euhedral and phenocrystic olivine in a mosaic of clinopyroxene with marginal and interstitial tremolitic amphibole, some of which is probably of late magmatic or deuteric crystallization. A similar rock type (specimen 97682) from farther south originally contained about 25% euhedral to anhedral clinopyroxene (diallage?).

(iii) Gabbro: Gabbro comprises a large proportion of the Gray Creek Complex but the distinction in the field mapping between gabbro, diorite and amphibolite was very difficult and these rock types have not been completely delineated on Plate 1. However, rocks typical of gabbro are best developed marginally to the pyroxenite in the northern part of the Complex. These rocks appear to grade into ultrabasic pyroxenite with decrease in feldspar content. Most of the rocks are melagabbro containing a low feldspar content and very melanocratic. Xenoliths of amphibolite are in the gabbro and it is intruded by small bodies of xenocrystic dioritic rocks.

In hand specimen the rocks are heavy, massive, dark green and medium to coarse-grained. Thin sections Nos. 97698 (from the southern part of the Complex, in the northern tributary of Everetts Creek) and 97700 (from the northern part of the Complex north of Spring Creek) show the primary features of the gabbro most clearly. Specimen 97698 is medium-grained with a hypidiomorphic granular texture and contains about 60% hornblende, 25% plagioclase, 8% opaque iron oxides, 5% quartz and minor epidote. The feldspar is lath shaped or anhedral, slightly zoned and twinned on Albite, Pericline and Carlsbad laws or combination of these. The composition is bytownite (Ab_{16} An_{84}) and ranges to at least labradorite (Ab_{32} An_{68}) on crystal edges. Saussuritization is variable and small epidote crystals have formed in some feldspars.

The hornblende crystals are generally anhedral with ragged edges. The hornblende is distinctive showing strong pleochroism (Z = deep greenish blue; Y = deep leaf green; X = straw yellow) and the large extinction angle ($Z\wedge c \approx 29^\circ$). There is no relict pyroxene within the hornblende crystals but inclusions of quartz, feldspar and most commonly of hornblende of a different orientation, are common. Alignment of magnetite lamellae within the cores of some hornblende crystals is apparently unrelated to the hornblende orientation and suggests an exsolution origin from primary clinopyroxene.

Quartz grains are small anhedral and interstitial commonly with undulose extinction. Several twinned feldspar crystals have elongate quartz parallel to twinning and apparently replacing the feldspar. Acicular euhedral amphibole crystals projecting into the quartz suggest a crystallization of quartz following or contemporaneous with that of the amphibole. The iron oxide generally is rather large anhedral crystals and is probably primary. Secondary epidote usually occurs on the margins of the hornblende crystals.

Specimen 97700 is similar to the above except that cores of relict clinopyroxene are common amongst the amphibole crystals. The clinopyroxene is colourless, biaxially positive with 2V 50° and is possibly augite as the diallagic parting is not prominent. The amphibole is similar to that of 97698 although the pleochroic colours are not quite as deep and the maximum extinction angle ($Z\wedge c$) measured was 22°. The feldspar is largely saussuritized with small amounts of zoisite or clinozoisite present. Extinction measurements of three grains showed that the feldspar is at least as basic as acid labradorite (Ab_{48} An_{52}). Anhedral sphene is a fairly common accessory and is probably secondary after ilmenite.

Specimen 97697 is a similar rock type collected from north of Dinner Creek. The rock contains about 50% hornblende (the same as in 97698); 30% feldspar and its alteration products; 15% quartz (probably secondary) and 5% accessory minerals including ilmenite, leucoxene and veinlets of prehnite. The feldspar is saussuritized but shows relict zonal structure and cleavage. Andesine is a clear rim around saussurite and one crystal has a rim of andesine sharply divided from a core of labradorite or more calcic feldspar. It is probable that the andesine is secondary feldspar due to metamorphism.

Specimen 97699 was collected from Spring Creek immediately west of the main pyroxenite body. The rock contains about 50% blue green hornblende, 45% feldspar and its alteration products and 5% leucoxene. It contains several small shears and has a slightly lepidoblastic texture due to parallelism of elongate hornblende crystals. Prehnite has grown from the saussurite in some places and zoisite is marginal to hornblende and secondary albite.

(iv) Microdiorite: Small bodies of microdiorite are common throughout the Complex, particularly in the northern area. They are in all rock types from serpentinite to gabbro and amphibolite, generally as small dykes to veins which are definitely of igneous origin. The rocks are of two types. One is a uniform very hard fine or medium grained blue grey rock and the other a distinctive mottled rock consisting of a very variable percentage of large dark green amphibole clusters, commonly with a core of a single pale green pyroxene crystal, in a granular aggregate of quartz, feldspar and hornblende. In some rocks these "xenocrysts" have been stretched into elongate schlieren giving the rock a pronounced lineation probably due to flowage of partly crystallized magma. In many rocks the original pyroxene "xenocrysts" have completely altered and the only evidence of their former occurrence is the clustering of amphiboles in schlieren (specimen 97304). The two rock types appear to grade one into the other in some outcrops and their modes of occurrence and distribution is similar.

Specimen 97303 was collected from a medium grained dyke within pyroxenite. The rock consists of approximately equal proportions of hornblende and oligoclase ($Ab_{75}\ An_{25}$) with accessory magnetite. The texture is granular with poorly developed alignment of the hornblende crystals. The margins of the hornblende are commonly curved and embayed by oligoclase is rarely twinned and is not zoned. The hornblende is pleochroic with Z = pale greenish brown (more brown in cores, greenish on rims); Y = pale buff or very pale green; X = colourless: $Z > Y > X$, $Z \wedge c \approx 22^{\circ}$.

Specimen 97302 was collected from the eastern margin of the Complex near Carrier's Well. It contains patches of a coarser more quartz-rich rock of similar composition within the medium grained micro-diorite. The microdiorite contains about 50% hornblende, 45% feldspar (oligoclase-andesine) and its alteration products and 5% quartz. The hornblende is similar to that of 97303 with pleochroism Z = pale brown, Y = pale greenish yellow, X = colourless or very pale green; $Z > Y > X$; $Z \wedge c \approx 23^{\circ}$. The texture is sub-ophitic to granular.

Specimens 97304-5 were collected from a small intrusion within the pyroxenite at the northern end of the Complex. The body is about 6 feet by 3 feet in plan and consists of rocks of similar type but in part with a district foliation (97304) and in part massive (97305). Specimen 97304 contains about 60% partially saussuritized plagioclase. (About andesine $Ab_{68}\ An_{32}$), 20% subhedral pale brown hornblende and 20% quartz. Uncommon plagioclase phenocrysts are partly crushed and saussuritized - they may be xenocrysts rather than phenocrysts. The hornblende is a pale brown variety pleochroic from pale brown to pale buff and similar to that of specimens 97302 and 97303. The hornblende occurs in schlieren as if a cluster of crystals had been elongated by shearing or flow in the magma.

Specimen 97305 is very similar to 97304 except that the hornblende occurs in clusters of medium-sized grains rather than schlieren. In hand specimen some of these clusters appear to be rectangular as if originally pyroxene phenocrysts or xenocrysts which have been altered to amphiboles in equilibrium with the dioritic magma. Andesine (about Ab_{65} An_{35}) comprises about 70% of the rock and quartz is absent. Brown biotite, sphene and iron ore are accessory minerals. The hornblende is paler than that of 97304 and faint lilac suggesting that it may be slightly sodic.

Specimen 97304 is a porphyritic or more probably xenocrystic hornblende microgranodiorite and 97305 is a porphyritic or xenocrystic hornblende microdiorite. They are definitely of igneous origin and this supports the suggested igneous origin for 97302 and 97303 which contain a very similar hornblende. It is significant that microdiorites containing a similar distinctive pale brown hornblende are minor bodies in the Boiler Gully Complex.

Specimens 97301 and 97306 differ from the above in preserving more common xenocrysts and a lower proportion of feldspathic matrix. Both rocks, on field occurrence, are igneous dykes. 97306 contains xenocrysts of a core of a single clinopyroxene crystal surrounded by a rim of medium-grained sub-hedral hornblende. The hornblende is strongly pleochroic in blue and green apparently identical with the secondary hornblende previously described from the gabbros. It is significant that the xenocrysts consist of single pyroxene crystals and are not xenoliths of pyroxenite. The clinopyroxene crystals show partial alteration to large hornblende crystals containing many inclusions, often of smaller euhedral to sub-hedral crystals. The enclosing rock consists of completely saussuritized turbid feldspar, hornblende rarely interstitial quartz and grains of ?clinozoisite and prehnite. Specimen 97301 is a very similar rock but although the hornblendes contain many inclusions and their form is similar to that of 97306 they contain no relict clinopyroxene cores. Interstitial feldspar (composition of andesine about Ab_{57} An_{43}) is largely saussuritized and quartz comprises about 15% of the rock.

The rocks described are considered to be genetically related and their distribution, including the association of similar rocks with the Boiler Gully Complex suggests that they are related to the basic-ultrabasic suite, possibly as a very late differentiate. In the examples 97301, 97304-5, 97306 the dioritic magma is considered to have incorporated xenocrysts of clinopyroxene - it is conceivable that the magma was the interstitial fluid in a partly crystallized gabbro and has been squeezed out taking with it common pyroxene crystals and less common feldspar crystals. In specimens 97304-5 there were relatively few of these xenocrysts and they have reacted completely with the dioritic magma whereas in 97301 and 97306 the very common xenocrysts have reacted to a lesser extent. In these rocks the reaction yielded the blue-green hornblende which occurs in the gabbro and not the pale brown hornblende of 97304-5.

(v) Granodiorite and Diorite: Massive, medium to coarse-grained granodiorite grading to diorite is common in the Complex, particularly in the southern portion. The main areas of this rock have been delineated but in the field mapping the diorite phase was commonly very difficult to separate from amphibolitized gabbro. Smaller bodies of finer grained diorite outcroppings particularly in the north-eastern part of the Complex were difficult to separate from many amphibolites and the microdiorites previously described.

Specimens 97657-9 were collected from granodiorite at the southern end of the Complex and illustrate its petrography. Specimen 97658 consists of about 40% green hornblende (Z = deep green with bluish tint, Y = deep green, X = yellow-green, Z c 27°) and 40% zoned, twinned plagioclase crystals with sub-hedral and euhedral form, particularly relative to the interstitial quartz (20%). The feldspar ranges from andesine (Ab_{61} An_{39}) at crystal cores to oligoclase (Ab_{73} An_{27}) at crystal edges. Euhedral and anhedral magnetite is an accessory mineral. The feldspar is commonly slightly saussuritized and a little chlorite, secondary after hornblende, is also present. The rock is a hornblende granodiorite but is abnormally rich in hornblende. This richness may be due to contamination by the basic rocks (basalts, dolerites, etc.) which the granodiorite intrudes.

Specimen 97657 is very similar containing 30% zoned and twinned andesine (Ab_{54} An_{46} in a crystal core to Ab_{65} An_{35} at a crystal edge), 30% interstitial quartz, 35% green hornblende, 5% green-brown biotite and accessory magnetite. The rather calcic feldspar and the high quartz with high hornblende content are unusual.

Specimen 97569 was collected farther south and from a more leucocratic rock with few ferromagnesian grains. The rock consists of similar proportions of quartz and feldspar with interstitial patches of green-brown biotite and chlorite. Epidote is a common secondary mineral, particularly associated with finely granular quartz in a shear zone. The feldspar is generally turbid and some crystals contain clusters of epidote. Many feldspars are untwinned and it is possible that some of these are orthoclase as suggested by the pink colour of some feldspars in hand specimen. However, this could not be proven and examination of multiply-twinned crystals show that albite is present possibly in association with a more calcic feldspar - some crystals appear to have a refractive index greater than that of balsam and the presence of cores of epidote in some albite crystals suggests that these may have replaced a more calcic feldspar. The rock is a granite or granodiorite depending on whether the albite is primary or secondary. A granodiorite seems likely and it is considered that an original granodiorite consisting of quartz (40%), plagioclase feldspar (50%), and biotite (10%) has suffered slight retrogressive alteration, possibly during shearing in the deuteric or late magmatic stage of cooling.

Specimen 97656 is a similar granodiorite containing a metamorphosed xenolith of porphyritic dolerite. The granodiorite contains only about 10% interstitial anhedral green amphibole and about 5% magnetite associated with sphene and ?chlorite. The feldspar is andesine-oligoclase (Ab_{70} An_{30}). The rock is veined by prehnite and calcite.

Specimens 97662-3 were collected near to the western margin of the Complex north of Dinner Creek. Both rocks contain ultrabasic xenoliths in a more leucocratic matrix. In specimen 97663 the xenoliths consist of about 85% hornblende more coarsely crystalline at the xenolith margin, 7% chlorite, 5% saussurite and 3% opaque oxides. The leucocratic enclosing rock contains hornblende of the same type as in the xenolith, set in a groundmass of opaque white saussurite with prehnite in various stages of growth from the saussurite. The prehnite has excellent spherulitic and bow-tie structure. Owing to this extensive alteration the original feldspar is not known. The hornblende is strongly pleochroic (Z = olive green, Y = pale leaf green, X = extremely pale yellow-green or blue-green to colourless;

$Z > Y > X$; $Z \wedge c \approx 23^{o}$) but is distinct from the deeply coloured blue green hornblende of the melagabbros.

Specimen 97662 is a typical example of an intrusion breccia. The intruded rock is a diallagite c.f. Specimen 97678, and relict clinopyroxene remains in the cores of larger xenoliths. The xenoliths have been largely recrystallized to granoblastic hornblendite and the hornblende in the xenoliths and in the enclosing rock is the olive green variety described in 97663 although the colours are a little paler. The enclosing rock consists of 30% sericitized plagioclase showing relict zoning, 10% epidote, 30% hornblende and 30% quartz. The plagioclase is sodic. The quartz is fine-grained suggesting a recrystallized mylonitic texture. It occurs in stringers with a dimensional orientation and seems quite definitely to be a late introduction veining and replacing the previous minerals. In both 97662 and 97663 the intruding magma was probably dioritic. In the same area there are many veins, in part pegmatite, intruding the pyroxenite and considered to be related to the dioritic magma which has formed the intrusion breccia. In specimen 97660 a pegmatitic vein consisting of andesine (about Ab_{66} An_{34}) with interstitial quartz intrudes a rock of diallagic clinopyroxene. Specimen 97661 is from a one to two foot vein cutting medium grained banded ultrabasic rocks. The vein is largely composed of very coarse grained anhedral albite but varying apparently from albite to oligoclase (Ab_{95} An_{5} to Ab_{87} An_{13}). The plagioclase shows minor strain effects including undulose extinction and displaced twinning, and the presence of fine grained albite along the grain boundaries may mean that the rock has suffered some granulation. Interstitial to the albite are medium or coarsely crystalline patches of clinozoisite with lesser spherulitic chalcedony. The rock contains small veins of prehnite. The vein is considered to be formed at low temperature associated with the granodiorite intrusions - in overall composition it is probably similar to 97660 but the minerals are all lower temperature types.

In the north-eastern part of the Complex within the area shown to be undifferentiated basic rocks a common rock is a fine or medium-grained leucocratic rock commonly intruded and brecciated by a slightly coarser rock apparently of the same composition. The proportions of the two rocks range from one outcrop to another but in all cases the coarser grained rock appears to be the later. In some cases the finer grained rock has a poorly defined lineation. Specimen 97655 shows that their mutual contact is sharp although texturally and mineralogically the two rocks are almost identical.

The coarser phase (average grain size 1 mm.) consists of about 50% hornblende, 45% zoned oligoclase and 5% opaque iron oxides. The feldspar is normally zoned (core - Ab_{77} An_{23}; rim - Ab_{85} An_{15}) and rarely oscillatory zoned (core - Ab_{79} An_{21}: mid-zone - Ab_{76} An_{24} and rim - Ab_{82} An_{18}). The hornblende is strongly pleochroic distinct from that of the microdiorites described previously. It has the pleochroic scheme Z = deep green-brown with occasionally a bluish lint in the cores of crystals, Y = deep olive green, X = pale yellow; $Z > Y > X$; $Z \wedge c = 26^{o}$. The texture of the rock is granular with some penetration of hornblende by oligoclase. This texture and the zoning of the minerals establish the rock as an igneous diorite.

The finer phase (average grain size 0.2 mm) contains oligoclase (Ab_{80} An_{20}) and hornblende (the same type described above) in similar proportions. The difference between the two rocks is grainsize and the lack of zoning and twinning of the oligoclase of the finer rock.

The coarser grained rock commonly shows flowage banding with some alignment of hornblende and schlieren of slight compositional difference parallel to the contact with the finer rock. The rock is considered an intrusion breccia resulting from brecciation of an early-formed finer grained marginal phase containing fragments in later crystallizing more slowly cooled magma of the same composition.

(b) Petrography and Petrology of the Metamorphic Rocks:

(i) Amphibolite: Amphibolite is common throughout the basic and diorite marginal areas of the Complex, particularly in the area north of Spring Creek. The rocks have compositional banding and a distinct directed texture. However, their mineral composition with hornblende and plagioclase as the major constituents is similar to that of the diorite, microdiorite and amphibolitized gabbro. Hence it was found impossible to map boundaries between the rock types on field examination alone, since many of the igneous rocks possess a flow structure similar to the metamorphic mineral orientation of the amphibolite. In the north-eastern part of the Complex the banding and foliation in the amphibolite bodies generally strikes N.N.E. - S.S.W. to N - S and dip at moderate to steep angles to the west. The amphibolite is in places interbanded with quartzite, mainly pure but in some cases feldspathic and micaceous.

The amphibolite is characterized by the mineral assemblage common green hornblende, andesine, diopside, epidote, quartz, rare grossular and accessory minerals including sphene and magnetite. The texture is lepidoblastic and the rocks are derived in part from calcareous sediments and in part from basic igneous rocks. In the field the only area where the metamorphics could be traced into relatively unmetamorphosed rocks is in the south-eastern part of the Complex where a thin synclinal cover of sediments is metamorphosed by the underlying diorite and gabbro. In this area quartz feldspar - biotite hornfels can be traced along strike into almost unmetamorphosed quartz greywacke and thin bedded epidote-actinolite hornfels can be traced with a rapid transition into hornblende-feldspar banded amphibolite.

Examination of thin sections of the rocks has shown clearly the presence of both igneous and sedimentary rocks altered to amphibolite, i.e., both ortho- and para- amphibolites. This is illustrated by specimens 97667 and 97669. Specimen 97667 is a thinly banded amphibolite with a three-quarter inch melanocratic vein cutting across the banding at an inclination of about 20°. The cross-cutting body is clearly intrusive and a similar one inch concordant body occurs in the same outcrop. In thin section the vein is inhomogeneous consisting near the margins of about 45% hornblende, 30% altered feldspar and 25% diopside whereas near the centre of the vein it consists of 70% hornblende, 20% altered feldspar and 10% diopside. The hornblende is euhedral or sub-hedral, rather coarse grained near the centre of the vein and has a weak orientation parallel to the margin of the vein.

The enclosing rock is strongly banded (quarter inch bands). The white band contains about 10% green hornblende, 50% diopside and 40% saussuritized feldspar in uneven lenticular patches and grain size up to 0.5 mm. The dark green bands contain about 55% hornblende, 25% altered feldspar and 20% diopside and have a lepidoblastic texture and grain size averaging about 0.1 mm. The mineral orientation is parallel to the compositional banding except adjacent to the contact with the vein where there is a tendency to parallel the contact. The hornblende is identical in both rocks and is the typical green hornblende of the amphibolites differing in form and pleochroism from that of the gabbro and diorite. It is strongly pleochroic with Z = green, Y = olive-green; Z = Y X and Z c 27°.

Specimen 97669 is very similar to 97667 and both were collected in the eastern part of the Complex north of Spring Creek. In 97669 the vein rock contains about 90% hornblende crystals and uncommon interstitial saussuritized feldspar. Small crystals of diopside probably with some epidote, are in the vein close to the contact with the banded amphibolite but are absent or very rare towards the centre of the vein. The feldspar in the banded amphibolite is partly saussuritized andesine, which in some cases exhibits reverse zoning with a more calcic rim (Ab_{54} An_{46}) than core (Ab[illegible] An_{41}). The hornblende of the vein is aligned parallel to the contact with the banded amphibolite and not to the banding within the amphibolite.

Both the vein rocks and the banded amphibolite have been metamorphosed to the same degree by the same period of metamorphism. There is no evidence that the banded amphibolite has suffered two periods of metamorphism and the banding is most reasonably interpreted as original composition differences in thin bedded impure calcareous sediments. The vein rocks were probably dolerite but no trace of their original texture remains. The metamorphism was probably largely thermal since minerals tend to be orientated and controlled by the primary sedimentary banding in the para-amphibolite and by the vein margin of the ortho-amphibolite rather than by a uniform stress field producing a penetrative texture expected under regional or dynamic metamorphism. The mineral assemblage is consistent with the cordierite - anthophyllite sub-facies (thermal metamorphism) of the amphibolite facies.

Specimen 97668 is typical of the banded para-amphibolite from north of Spring Creek. It contains lenticular bands of dark and light green hornblende-rich material and is associated in the field with a thin quartzite band. The rock is lepidoblastic containing green hornblende and saussuritized plagioclase in comparable proportions and variable quartz, epidote and opaque iron oxide. In thin section a pale green band consists of about 50% zoisite (in a complex partly zoned growth with clinozoisite and epidote) uncommon garnet and common diopside and hornblende.

Specimen 97672 was collected west of the track at Dinner Creek crossing. In thin section the rock can be divided into two distinct types. Both of these consist largely of green hornblende and partially saussuritized feldspar (andesine) in lepidoblastic texture. The coarser rock (with hornblende crystals averaging about 0.25 mm. in length) contained 10% to 20% of diopside scattered irregularly throughout, with the exception that adjacent to a clinozoisite and chlorite vein are diopside and feldspar almost to the exclusion of hornblende. The vein may originally have been calcite. The fine grained rock (0.1 mm. grain size) lacks diopside except within 1 mm. of the junction with the coarser phase and has several lenticular patches containing epidote and some chlorite - these patches were probably originally calcite.

Specimens 97670-1 were collected from the south-eastern part of the Complex. Specimen 97670 is a fine-grained hornblende rich rock with a well defined schistosity but no compositional banding. It is in sharp contact with specimen

97671; although the schistosity of both rock types is parallel there is no gradation between them and each preserves a uniform character for at least ten feet from their contact. Specimen 97671 is a gneissic rock containing irregular bands and schlieren of white feldspathic material and green acicular amphibole.

Specimen 9767? is distinctly lepidoblastic and contains about 50% green hornblende, 40% plagioclase, 5% iron oxides and accessory sphene (with opaque ?magnetite cores) chlorite and clinozoisite. The plagioclase is slightly zoned, the cores being andesine (Ab_{64} An_{36}) and the veins acid, andesine or basic oligoclase. Albite twinning is common and combined albite-pericline twinning also occurs. The absence of diopside and quartz, the uniformity of the rock, the presence of sphene with ?magnetite cores and probably derived from ilmenite, the similar percentages of hornblende and plagioclase and the zoning and twinning of the feldspar favour a primary basic igneous origin for the rock (basalt or dolerite) i.e., it is probably an orthoamphibolite.

In section 97671 the main constituents (hornblende and andesine Ab_{56} An_{44}) seggregate into schlieren and lenses and vary in grain-size. Epidote is common, particularly in the hornblende-rich areas and a colourless mineral with high relief, probably zircon, is commonly associated with the feldspar. The andesine is not zoned. The shearing of the rock which has evidently either preceded or accompanied its recrystallization has obscured any primary features and the original rock may have been igneous or sedimentary although the latter origin is favoured.

Specimen 97666 is a medium grained rock consisting of about 50% hornblende, 40% andesine and saussurite, 10% quartz and rare anhedral magnetite grains. The rock is lineated (not a planar schistosity as in most of the amphibolites) and is uniform and non-banded. The hornblende is rather similar to that of the gabbros as it has a faint bluish tint. It is subhedral to anhedral, is grouped in clusters and commonly has embayed, concave margin against quartz, saussurite and andesine giving a skeletal appearance to some crystals. Small inclusions are common within the crystals. The anhedral andesine and saussurite are closely associated and it appears that the andesine has grown from the saussurite. The quartz is clear anhedral and unstressed and probably belongs to the same period of growth as the andesine. The rock is an amphibolite consistent with the grade of metamorphism of the rocks previously described. The similarity of the hornblende to that in the gabbro suggests that the rock could be derived from the gabbro or at least from a basic igneous rock of similar composition.

In the amphibolite described above the problem arises of distinguishing between ortho-amphibolite and para-amphibolite. In 97667 and 97668 the orthoamphibolites are closely distinguished by their intrusive nature. They differ from the para-amphibolite also in the lack of compositional banding and the absence of common epidote. The diopside present in the orthoamphibolite is common on the margins of the veins but decreases markedly towards or is absent from the centre of the veins. This seems to be a clear case of migration of calcic material across the contact during metamorphism in an approach to chemical uniformity over the whole rock. In the rocks examined, the absence of compositional banding, the absence of diopside in particular and to a lesser extent of epidote and quartz and the presence of sphene surrounding magnetite cores (secondary after ilmenite) seem to be valid criteria for distinguishing ortho-amphibolites.

Using these criteria then in specimen 97672 described above the coarser rock containing 10% to 20% diopside would be interpreted as an original sediment. Similarly the finer grained rock in contact with it in which diopside and quartz are absent would be derived from igneous rocks - the presence of lenticular patches of coarse epidote in the rock may indicate that it was a basalt with calcite amygdales similar to those in the Everetts Creek Volcanics. It is notable that in 97672 diopside is in the fine grained rock within 1 mm. of the contact - this appears to be another example of migration of calcic material across a boundary between two rock types during metamorphism.

In summary it is apparent that throughout the marginal basic part of the Gray Creek Complex are inclusions of rocks of the amphibolite facies probably derived largely by thermal metamorphism. These rocks were derived in part from small basic intrusives and probably extrusives. The serpentinite, pyroxenite, gabbro and diorite-granodiorite do not show metamorphism to this degree and there may have been an earlier phase of small basic intrusions.

The Everetts Creek Volcanics contain basalt flows, basaltic agglomerate, tuffs and greywackes, calcareous greywackes and are intruded by small basaltic sills and dykes. This appears to be the sequence necessary to produce the amphibolite. The distribution of the Everetts Creek Volcanics points to a source area adjacent to or east of the present Gray Creek Complex. An hypothesis favoured is that the orthoamphibolites within the Complex represent metamorphosed basalts and dolerites of the feeder-phase to the Everetts Creek Volcanics and possibly in part the volcanics themselves. Immediately east of the northern end of the Complex several outcrops of thin-bedded grey-green calcareous siltstone occur below the Carrier's Limestone. Similar rocks occur in the south-eastern corner of the Complex and there they are on strike from typical banded amphibolites. It is considered that this calcareous siltstone, intruded by dolerites and basalts and later thermally metamorphosed by the basic- ultrabasic rocks and probably also by later granodiorite - diorite gave rise to para-amphibolites.

(ii) Lowgrade Basic Hornfels from the Southern Part of the Gray Creek Complex: In the southern part of the Gray Creek Complex sediments of the Wairuna Formation are intruded by pyroxenite, gabbro (e.g. specimen 97698 described previously) and small serpentinite bodies and by larger bodies of granodiorite grading to diorite. The field mapping revealed the presence of probable basalt and dolerite associated with the calcareous siltstone, quartz greywacke sandstone and siltstone, slate and rare limestone. The rocks in this area are part of the Wairuna Formation but differ from those of the type area in the presence of basaltic rocks and limestone - they show some of the features of the Carrier's Limestone and Everetts Volcanics members of the Wairuna Formation. Specimens 97632-6, 97638-9 were collected as typical of these fine basaltic rocks.

Specimen 97636 is medium grained and subophitic. It contains plagioclase (35%), pyroxene or its alteration products (55%) and opaque iron oxides (10%). The plagioclase is strongly zoned from labradorite-bytownite (Ab_{30} An_{70}) in the cores to andesine-labradorite (Ab_{50} An_{50}) at crystal edges. Pigeonite is common and augite is probably also present. However, the pyroxene remains in cores, the greater part having altered to actinolite. The actinolite is pleochroic similar to but much lighter than that of the gabbro and has the typical low extinction angle $Z \wedge c \approx 19^{\circ}-20^{\circ}$. The rock is a typical dolerite that is slightly metamorphosed. Pigeonite, doleritic texture and field occurrence in small bodies suggest a relationship with the Everetts Creek Volcanics rather than with the peridotite and gabbro of the Gray Creek Complex.

Specimen 97362 is a very similar rock consisting of 50% plagioclase laths in subophitic intergrowth with anhedral actinolite. The plagioclase is normally zoned from labradorite (Ab_{37} An_{63}) to andesine (Ab_{52} An_{48}). It is incipiently altered to saussurite and locally to epidote. The actinolite commonly has cores flecked with magnetite dust and small quartz inclusions and appears to be secondary after clinopyroxene.

Specimen 97632 was a similar doleritic rock but has been metamorphosed to a slightly greater extent so that no clinopyroxene remains and the feldspar has altered to epidote. The amphibole is a blue-green actinolite.

Specimen 97633 contains common clusters of feldspar phenocrysts and uncommon amphibole porphyroblasts (after pyroxene phenocrysts probably) in a medium grained groundmass feldspar, actinolite and quartz (interstitial and in myrmekitic intergrowth with feldspar). The feldspar is strongly zoned from bytownite (Ab_{20} An_{80}) in the cores to labradorite (Ab_{47} An_{53}) towards the rims. The rock is a feldspar-rich porphyritic quartz dolerite which is low grade thermally metamorphosed.

Specimen 97638 is a porphyritic rock with clusters of green actinolite, considered to be secondary after pyroxene phenocrysts. The fine grained groundmass consists of comparable amounts of actinolite and partly altered plagioclase. The latter commonly has rims of clear feldspar (probably albite) about a turbid core of labradorite. There is no evidence of flow orientation of grains in the groundmass. The original rock was probably a porphyrite basalt but the field and thin section examination does not show whether it was intrusive or extrusive.

Specimen 97634 contains about 70% blue-green actinolite or hornblende, 30% clinozoisite and rare sphene. The porphyroblasts of amphibole contain ragged edges and inclusions of clinozoisite. It occurs commonly as a group of two or three crystals. The groundmass is fine grained amphibole and clinozoisite. It is probable that the rock was originally a porphyritic basalt which has been low grade thermally metamorphosed.

Specimen 97635 has a basaltic texture with elongate feldspar laths (probably bytownite) in part aligned by flowage parallel to the margins of several large feldspar phenocrysts. The phenocrysts have been altered to albite with ?epidote and prehnite inclusions. The interstitial material between the feldspar laths in the groundmass is largely fine grained actinolite.

Specimen 97656 consists of a fine grained basic xenolith in coarse grained granodiorite. The xenolith contains about 40% plagioclase, 30% actinolite, 10% epidote, 10% quartz and 10% euhedral to subhedral magnetite. The actinolite occurs as rare porphyroblasts and common smaller crystals. It commonly shows deformation twinning. The feldspar is sericitized, contains many inclusions and shows relict zoning. The composition is now about andesine-oligoclase. The rock was originally a porphyritic dolerite, resembling 97633-4, which has been thermally metamorphosed by the granodiorite.

All the specimens described above were collected from the neighbourhood of Everetts Creek and near the western margin of the Complex in this area. Specimens 97640-1 were collected further north on the western margin of the Complex near Crooked Creek where small basic intrusives occur within the siltstones of the Wairuna Formation. To the south are areas of granodiorite, and quartz and aplite veins occur in the area.

Specimen 97640 consists of about 70% of stubby porphyroblasts of actinolite in a fine to medium grained groundmass of amphibole and saussuritized feldspar with albite and epidote in some areas. The actinolite has a poorly developed colour zoning in large crystals and common opaque ?magnetite inclusions in the cores of many crystals. It is secondary after pyroxene phenocrysts and the rock is a pyroxene-rich porphyritic micro-gabbro (the texture of the groundmass is not dolerite).

Specimen 97641 is a quartz-albite-actinolite amphibolite consisting largely of fine-grained pale green actinolite, fine-grained clear colourless albite and quartz, scattered laths of brown biotite and common opaque iron oxide granules. In some areas the felsic material forms 60% to 70% of the matrix and in others amphibole forms 70% to 80%. Scattered through the rock are small (0.1mm.) anhedral patches of clear quartz, larger (0.5 - 1.5mm) tabular patches of epidote possibly containing zoisite and probably secondary often tabular feldspar crystals, and 0.5 - 1mm. grains of actinolite, usually as single crystals. The matrix has a lepidoblastic texture. The rock has been formed by metamorphism, probably mainly thermal, of a fine ?tuffaceous siltstone containing scattered larger grains of feldspar, pyroxene or amphibole and quartz.

The specimens described in this section contain similar mineral assemblages and except 97641 appear to be derived from dolerite or basalt. The rocks are intrusive and possibly extrusive and related to the Everetts Creek Volcanic Member of the Wairuna Formation rather than to the ultramafic-gabbro suite of coarse grained intrusives of the Gray Creek Complex. The rocks have been low grade thermally metamorphosed by the later intrusives, possibly mainly the granodiorite-diorite which outcrops in the vicinity. If this is correct the rocks are probably the low grade metamorphic equivalents to the amphibolites described in the previous section from the north and eastern parts of the Complex.

(iii) Greenschists Produced by Local Shearing in the Complex: Along the margins of the Gray Creek Complex strongly sheared platy rocks are quite common. The shearing is parallel to the contact and the sheared rocks commonly appear to be fine or medium-grained dolerite. South of Spring Creek a south-plunging fold occurs on the eastern flank of the Complex and in the core of this are strongly sheared fine-grained rocks, some of which are igneous and some sedimentary xenoliths. The shearing appears to be parallel to the axial plane of the fold. Specimens 97673-4 were collected from this area.

Specimen 97673 is a fine grained lepidoblastic rock containing about 50% actinolite (Z = pale green, Y = deeper green, X = colourless; Z Y X: Z c , 18°) and 50% feldspar and saussurite. Small untwinned grains of feldspar (probably albite) appear to be secondary and have grown from larger patches of saussuritized feldspar. The composition of the feldspar is unknown but the presence of clinozoisite and ?prehnite within the saussurite indicates a calcic composition. The rock is an albite-actinolite schist of the greenschist facies probably derived, by strong dynamic metamorphism, from a fine-grained basic igneous rock. The absence of quartz and the presence of saussurite after calcic plagioclase suggest a basic igneous origin rather than a relation to the xenoliths of yellow-brown quartz siltstone which have been sheared with the basic rock. Specimen 97674 is a coarser grained rock but otherwise very similar. In this rock actinolite grains wrap around saussuritized feldspar grains suggesting that the feldspar was present as large grains prior to shearing. Accessory quartz (in veinlets) prehnite, sphene and albite are present, the albite having grown from the saussurite. The rock is an actinolite schist of the greenschist facies derived from a medium grained gabbroic or dolerite rock by strong dynamic metamorphism. The increase in grain size in the primary igneous rocks of 97673 and 97674 is due to increase distance from the contact with the sediments, specimen 97693 being collected in the contact zone and specimen 97674 about 70 yards west of this.

In Dinner Creek east of the track crossing specimens are variable generally fine grained sheared basic rocks. Some of these are possibly amphibolites but others (such as specimen 97675) appear to be of low metamorphic grade and to be sheared igneous rocks which ranged from gabbro to melagabbro. Specimen 97657 consists of about 30% actinolite, 40% albite and sericitized albite and 30% saussurite and clinozoisite. The actinolite occurs as clusters of grains suggesting a derivation from a previous coarser-grained mineral. The saussurite and clinozoisite have relict cleavage, and zoning from former feldspar. The rock is of the greenschist facies and has suffered strong dynamic metamorphism. It was probably originally coarse-grained consisting of pyroxenes and feldspar.

Specimen 97677 was collected from the sheared contact between the Gray Creek Complex and the Carrier's Well Limestone. In the field the rock was thought to be a dolerite which was sheared and retrograde metamorphosed. The rock has a platy fracture and consists of a central band of medium grained basic crystalline rock flanked on both sides by a fine grained lepidoblastic sheared grey-green rock. The fine-grained (0.04mm) parts of the rock consist of zoisite (40%) pale-green tremolite-actinolite (40%) with chlorite (20%) and rare accessory small sphene granules. The medium-grained rock contains about 45% zoisite, 25% chlorite, 25% tremolite-actinolite and 5% quartz. The texture of the rock is granular and does not indicate whether the original rock was sedimentary or igneous. The composition of the rock is consistent with derivation by retrogressive metamorphism of a basic igneous rock in which the shearing was localized leaving less sheared but similarly recrystallized rock between.

(iv) Metamorphism of the Serpentinites: The replacement of the serpentinite at the northern end of the main Gray Creek serpentinite body has previously been discussed. The serpentinite examined in sections 97322-4 does not show any thermal metamorphism post-dating serpentinization. It is only locally sheared.

Specimen 97325 from a small serpentinite body in the central south part of the complex has been previously described and this rock has apparently been metamorphosed by the adjacent granodiorite so that 30% to 40% of the mesh-textured serpentinite has altered to antigorite.

Outcropping in Dinner Creek immediately west of the track crossing are several small crosscutting serpentinite dykes occurring within amphibolite, altered pyroxenite and pegmatitic gabbro (specimens 97672, 97695-6). Specimen 97327 is typical of the serpentinite of a 3 to 6 feet cross cutting dyke. The rock consists of irregular random-textured sub-isotropic serpentine with a refractive index less than that of balsam. It lacks the typical antigorite texture and is probably a form of chrysotile. There is about 40% turbid material containing much fine grained iron oxides. Chlorite is a rare accessory associated with magnetite grains. The rock contains a large number of veins and patches of fine granular quartz, colloform opal and chalcedony and spherulitic chalcedony associated with lenses of cross-fibre chrysotile and a pale yellow-green moderately birefringent serpentine mineral. The eastern contact of this dyke shows that serpentinite passes outwards through a thin zone of talc (half-inch or more) into a one inch zone of finely fibrous tremolite-actinolite and then into a zone of chlorite with magnetite or haematite porphyroblasts.

This latter zone is also on the western contact and in thin section (97626) the following mineral variation is evident in it:-

(The edge of the thin section adjacent to the serpentinite is taken arbitrarily as the zero point.)

0 - 0.2 inches	0% clinozoisite
Chlorite - Rich Zone	25% magnetite
	40 - 50% actinolitic hornblende
	35 - 25% chlorite

SHARP CONTACT WITH RAPID CHANGE IN PROPORTION OF CHLORITE

0.2 - 0.5 inches	
Amphibole - Rich Zone	5 - 40% clinozoisite
	20 - 0% magnetite
	75 - 60% actinolite hornblende

GRADATIONAL CONTACT

0.6 - 0.7 inches	65% clinozoisite
	35% actinolitic hornblende.

In the chlorite-rich zone the magnetite occurs as octahedral porphyroblasts quite definitely having grown in situ. In the amphibole-rich zone the uncommon magnetite is clusters of small grains elongate parallel to the schistosity. The schistosity is apparent as a mineral orientation parallel to the contact and is particularly strong on the chlorite and amphibole-rich zones.

The features of the contact are probably due to metamorphic differentiation or reaction at a contact between serpentinite and hornblende-clinozoisite amphibolite c.f. Phillips and Hess (1936); Pabst (1942). The actual original contact between the two contrasting rocks was probably between the chlorite-magnetite zone and the amphibole-clinozoisite zone. The increase in chlorite towards the contact is typical of the low temperature hydrothermal alteration of such contacts; the development of euhedral magnetite crystals within the chlorite zone is also a common feature.

In the examples previously reported the zonation is from country rock with increase in chlorite to a chlorite-rich zone with minor magnetite, then an actinolite zone (absent in some cases), a talc zone and finally serpentine (with talc and magnetite in some cases) The inner talc and actinolite zones are in this example on the eastern contact and described above but are not present in section 97326. This example differs in the high actinolitic hornblende * content of the neighbouring amphibolite and, with the decrease in clinozoisite towards the chlorite zone, amphibole becomes dominant in a zone outside the chlorite zone. This feature has not been described in previous examples where the country rock has been siliceous and not calcareous or basic as in this case.

In this locality there has been metamorphism and hydrothermal alteration following the intrusion of the serpentinite. It is not possible to say whether the metamorphism is similar to that which produced the amphibolite or a later period affecting a contact between amphibolite intruded by serpentinite, although the former hypothesis is favoured. The agent of metamorphism was probably the diorite-granodiorite exposed to the west.

(v) Metamorphism of the Clinopyroxene-Rich Rocks: At the southern end of the main pyroxenite body, pyroxenite is associated with melagabbro and amphibolite. The area is intruded by a number of quartz-feldspar aplite veins and in one place by a small body of massive quartz diorite. In this area outcrops of finely acicular amphibolite have a weathered surface and a knotted medium-grained appearance of the pyroxenite. In thin section (97694) the rock contains about 85% of an iron-poor hornblende (Z = very pale blue-green, Y = very pale brownish green, X = colourless; $Z < Y > X$; $Z \wedge c \approx 24^{\circ}$) with interstitial talc (10%) in some cases growing in continuity with the hornblende. The larger amphibole crystals have cores that are slightly darker in colour and contain small inclusions. The amphibole is a replacement of calcic clinopyroxene and the original rock a diallagite as described previously. The agent of metamorphism is quartz diorite and associated aplite veins in the vicinity.

Specimen 97693 is a similar rock outcropping south of Spring Creek. It consists of 95% iron-poor, pale coloured hornblende with rare interstitial talc and chlorite crystals and magnetite which has grown by coalescence of several smaller crystals. The cores of larger amphibole crystals are commonly darker and contain many orientated magnetite lamellae. As in 97694 the hornblendite was derived from pyroxenite by local thermal metamorphism.

Diallagic clinopyroxene is altered in partial stages to pale green faintly pleochroic amphibole in specimen 97660 adjacent to an andesine-quartz vein and in the coarse diallagite of specimen 97678. In these rocks the secondary amphibole contains many inclusions, among them magnetite lamellae and has many darker mottled patches.

In the diallage peridotite (97679-82), the clinopyroxene has altered partly or completely to colourless tremolite with an abundance of orientated magnetite lamellae in

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* Pleochroism Z = pale greenish blue, Y = pale yellow green. X = colourless; $Z > Y > X$; $Z \wedge c \approx 24^{\circ}$.

an exsolution intergrowth controlled by the orientation of the original clinopyroxene. In section 97681 tremolite also is clear, subhedral interstitial crystals between clinopyroxene crystals. This may be due to complete interstitial recrystallization with redistribution of the iron ore lamellae usually present in the secondary tremolite into larger grains or some of this amphibole may be a primary late magmatic mineral as in some of the diallage peridotites described from the northern part of the Complex.

In specimens 97662-3, previously described in the section as the granodiorite, pyroxenite has been included as xenoliths within the diorite-granodiorite magma and metamorphosed to hornblendite. In these rocks the amphibole is more strongly coloured. In 97662 it has the properties Z = light olive green to blue green, Y = leaf green, X = pale yellow to colourless; Z Y X; $Z \wedge c \approx 24^{\circ}$. In both rocks orientated magnetite lamellae are absent though some small anhedral magnetite crystals occur. A similar rock (specimen 97692) collected from near the contact between granodiorite and pyroxenite in the southern part of the Complex consists of actinolite with interstitial and prehnite and patches of secondary quartz. The rock was thermally metamorphosed and recrystallized and was probably originally a diallagite or pyroxene-rich gabbro.

Specimens 97689-91 were collected from the contact between pyroxenite and a lenticular limestone in the southern part of the Complex. Specimens 97689-90 were collected to represent the pyroxenite, 97690 being finer grained and nearer the contact. Specimen 97689 consists of 90% colourless tremolite and about 10% magnetite. The tremolite has orientated magnetite lamellae in the cores, surrounded by clear amphibole with larger anhedral magnetite grains. Specimen 97690 is similar but instead of being colourless tremolite the amphibole is a pleochroic hornblende (Z = pale blue-green, Y = pale green, X = colourless, $Z \wedge c \approx 25^{\circ}$) and is lacking iron ore inclusions either as lamellae or anhedral grains. Cores of the amphibole are commonly darker green and in some crystals there are relict cores of partly amphibolitized clinopyroxene.

Specimen 97691 was considered in the field to be part of the metamorphosed limestone. In hand specimen it appears to consist of large tabular pale green clinopyroxene crystals. In thin section these are evident as areas of fine-grained minerals showing an overall orientation and relict cleavage. The original rock was a coarse grained holocrystalline rock probably consisting entirely of clinopyroxene. The original large crystals now consist of an aggregate of carbonate (calcite?), antigorite serpentine, less common chlorite, tremolite and talc and common anhedral magnetite grains, often aligned in rows. Veinlets of calcite with some quartz are common within the rock. The rock is an impure marble formed by retrogressive metamorphism of a monomineralic pyroxene rock. It appears that thermal metamorphism (by the granodiorite) of a contact between limestone and pyroxenite has generally altered the pyroxenite to amphibolite except immediately adjacent to the limestone contact where pyroxenite is replaced to a large extent by calcite. This is probably due to mignation of material (mainly of the carbonate iron probably) from the limestone.

It is considered that the alteration of the pyroxenites described above is due to thermal metamorphism of the diorite-granodiorite bodies. Low grade metamorphism altered clinopyroxene to tremolite amphibole with exsolved orientated lamellae of magnetite. Higher grade metamorphism redistributed this magnetite into larger anhedral grains and probably absorbed magnetite and epidote inclusions in forming pale green actinolitic amphibole. Where the pyroxenite has been included in the dioritic rocks it has been altered to a more strongly coloured hornblende lacking magnetite or epidote inclusions.

Immediately west of the Dinner Creek track crossing is a complex area consisting largely of amphibolite (e.g., specimen 97672 previously described) intruded by small serpentinite dykes (e.g. specimens 97336-7) previously described, and by pyroxenite (97695-6) with cores and irregular patches of pegmatitic gabbro (97676).

The pegmatitic gabbro consists of large crystals of green hornblende with rare cores of clinopyroxene in a granular mosaic of coarse and fine grained epidote containing some ?chlorite. Sphene is a rare accessory mineral. The rock is extremely coarse-grained and massive and the field occurrence and thin section examination suggest that this rock was a pegmatite gabbro crystallizing probably as a residuum from the coarse grained pyroxenite which surrounds the pegmatitic gabbro cores. The rock has been thermally metamorphosed, the feldspar altering to epidote and the pyroxene altering partly to hornblende.

Specimen 97695 illustrates the contact of a coarse pyroxenite and a fine-grained strongly sheared amphibolite. The latter rock consists of well-aligned elongate laths of pale green actinolitic hornblende, transgressed by euhedral porphyroblasts of the same amphibole but showing no orientation or strain effects and apparently replacing the orientated amphibole. There are several veins of prehnite with an accessory euhedral, tabular, fine-grained, unidentified mineral. These veins are also later than the deformation.

Towards the contact with the amphibolite the pyroxenite shearing becomes extremely strong and porphyroblasts are uncommon. The contact is not sharp however, as relict turbid pyroxene is in strongly sheared amphibolite up to one-quarter of an inch from the contact proper. The pyroxenite (diallagite) adjacent to the contact is largely altered to hornblende (again the same as in the amphibolite) along crystal margins and cleavages. Interstitially to the larger pyroxene crystals fine-grained hornblende crystals are aligned parallel to those in the amphibolite. The features of the thin section are interpreted as due to intrusion of the pyroxenite into country rock during a period of dynamothermal metamorphism. The marginal, partly crystallized pyroxenite was granulated during intrusion and altered to a monomineralic fine grained hornblende schist. Towards the centre of the body the deformation was less intense and the zone of complete shearing-out of the coarse pyroxenite grades into a zone of intergranular movement with production of intergranular films of hornblende schist.

Following this period of emplacement under elevated temperature and stress conditions (which it is suggested were due to the emplacement of the ultramafic - basic and micro-diorite suite of rocks of the Complex) a later period of thermal metamorphism caused growth of hornblende porphyroblasts replacing the hornblende schist and further alteration of diallage to hornblende along crystal cleavages and edges. The later period of thermal metamorphism is related to the intrusion of the granodiorite-diorite part of the Complex. As described above this has thermally metamorphosed the pyroxenite in a similar manner throughout the southern and central part of the Complex.

(vi) Metamorphism of the Gabbro and Microdiorite: No primary unaltered gabbro has been observed in the thin sections examined. In all rocks primary clinopyroxene has partly or completely altered to deep blue green strongly pleochroic hornblende. The primary bytownite varies in saussuritization and alteration to albite, epidote, prehnite and similar secondary minerals. Primary ilmenite is generally altered to leucoxene or sphene. The alteration of the gabbro is considered to be due to thermal metamorphism by the granodiorite-diorite bodies.

The microdiorites (97304-5) from the northern end of the Complex show no thermal metamorphism. This also applies to the serpentinite and clinopyroxene rocks (97683-4, 97321-4) in the same area and it is significant that no outcrops of diorite-granodiorite are known in this area. Further south the xenocrystic rocks grouped with the microdiorites contain clinopyroxenes which are partly or completely altered to blue-green hornblende similar to that in the gabbros. However, this is due to their inclusion within the microdiorite magma and not to any later period of thermal metamorphism affecting the whole rock.

(c) Relationships of the Rock Types and Internal Structure of the Gray Creek Complex:

(i) Structural Setting of the Complex: The Gray Creek Complex occupies the core of a large anticline in the Siluro-Devonian sediments. The culmination of the anticline is apparently about one and three-quarter miles north of Spring Creek. At this point the anticline is flanked on each side by two south-plunging synclines and the main anticline probably also plunges south from this point. North of this culmination the Complex is interpreted as occupying the core of a simple but strongly sheared north-plunging anticline. Throughout its length the western margin of the Complex is more strongly sheared than the eastern margin. On the eastern side of the Complex are two south-plunging minor anticlines in the Carrier's Well Limestone and Everett's Creek Volcanics. These are situated one and a half miles north of and one and a half miles south of Spring Creek.

At its southern end the Complex bifurcates and is divided by a south-plunging syncline. The eastern part continues across Gray Creek and further south as a strongly sheared zone.

(ii) Internal Structure and Rock Relationships: In the northern part of the Complex zonal arrangement of rocks is apparent. In this area a core of serpentinized peridotite is surrounded by diallage peridotites and diallagites and then by mélagabbro grading to gabbro. This relationship is also true south of Spring Creek but is complicated, particularly south of Dinner Creek, by irregular bodies of granodiorite-diorite intruding the peridotite-gabbro suite. In the north-eastern part of the Complex small bodies of granodiorite and diorite also add further complications in the predominantly basic area owing to its mixture of gabbro, ortho- and para-amphibolite, and xenocrystic microdiorites.

The peridotite, pyroxenite, melagabbro and gabbro appear to form a structural unit typified by the zonation mentioned above. Contacts between the last three rocks appear to be gradational. The contact between serpentinized peridotite and clinopyroxene-rich rocks is sheared and appears sharp in the field. However, thin section examination of the rocks reveals that the clinopyroxene-rich rocks vary from diallagite with 100% clinopyroxene to peridotite with 50% olivine and orthopyroxene. Serpentinite and partially serpentinized peridotite are in the clinopyroxene-rich areas and it is likely that this contact was also transitional but serpentinization of the peridotite core, and later shearing and relative movement between the two rocks have made the contact appear a sharp one. The rocks mentioned above are genetically related and originally formed part of a layered differentiated sequence.

This concept is clearly demonstrated if the down-plunge method of viewing the structure of the Complex is applied. As has been mentioned above the culmination and reversal of plunge of the anticline occupied by the Complex is about one and three-quarter miles north of Spring Creek. Looking down-plunge to the north and assuming this to be the structure of the Complex in section then the north-plunging portion of the Complex has the form of a sheared assymmetrical anticline with a diapiric core of serpentinite intruding through the pyroxenite and gabbro along the more sheared western margin. (Text figure 1.)

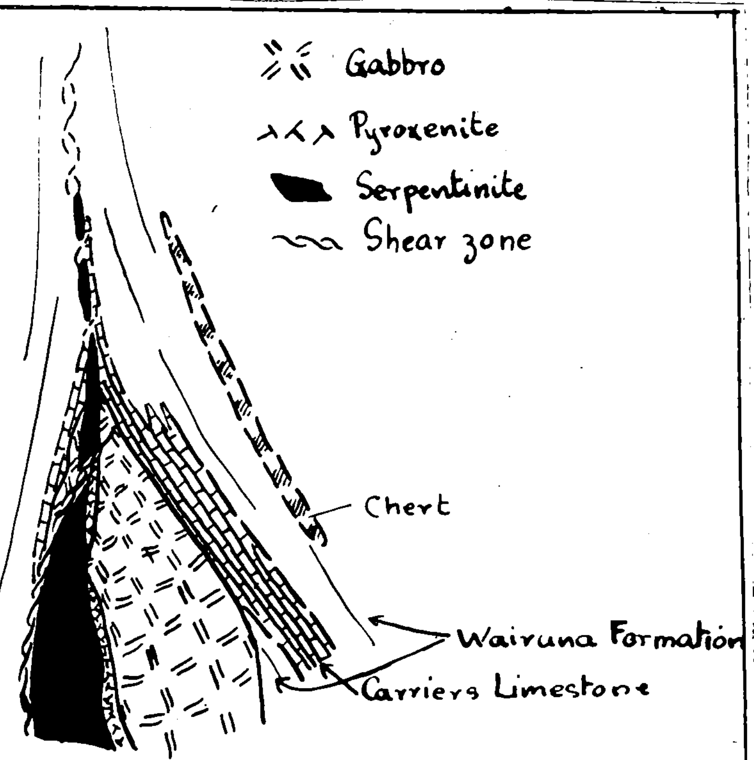

Fig 1. Diapiric structure of the Gray Creek Serpentinite [Sketched from the down-plunge method of viewing structure, looking north from the plunge reversal south of Wallaces Well

The south-plunging part of the Complex passes out of the western marginal shear zone and has a well-developed zonal structure. The ultramafic rocks in the core, pass out into clinopyroxene peridotite and gabbro. South of Spring Creek there is probably a local reversal of plunge, and the serpentinite within the pyroxenite about half-way between Spring Creek and Dinner Creek probably represents a minor culmination. Immediately east of this a minor south-plunging anticline and syncline branches from the main structure.

South of this point the zonation of the body appears much less perfect and a major part of the Complex is complicated by later intrusive granodiorite-diorite bodies. Pyroxenite does occur as several large bodies and may mark structural highs. Mapping in this area was less detailed however, and little is known about the relationships between gabbro, pyroxenite and serpentinite except that these rock types occur in bodies of smaller extent and more complex relationship than the simple zonal relationship to the north.

The only rocks observed which show definite layering of igneous origin are the diallagic peridotites (specimens 97678-82) from the western margin of the Complex north of Dinner Creek. The apparent banding of the serpentinite core north of Spring Creek has been discussed and its origin as original compositional banding suggested. Compositional banding appears to be also the explanation for the variation in mineral composition of the diallage peridotites.

The xenocrystic microdiorites and related rocks occur as small dykes intrusive into amphibolite, gabbro and the ultrabasic rocks. Beyond the observation that they are most common along the eastern side of the Complex north of Spring Creek no generalization about their relationships to the other rocks can be made. The presence within the rocks of single crystals (xenocrysts) of amphibolitized clinopyroxene and less often of feldspar rather than xenoliths of pyroxenite or gabbro indicate derivation from a late-crystallizing part of the gabbro-pyroxenite suite rather than connection with the later granodiorite-diorite intruding the Complex.

A further point favouring this is that the hornblende in the microdiorite 97302-3 and in the xenocrystic microdiorites 97304-5 is a distinctive very pale brown variety, very similar to that observed in microdiorites (97353-6) from the northern part of the Boiler Gully Complex.

In the Boiler Gully Complex there are no intrusions of hornblende granodiorite and the microdiorites are genetically related to the ultramafic-gabbro suite. The hornblende of the microdiorites is also quite distinct from the strongly pleochroic, deep green-brown hornblende present in the granodiorite-diorite suite.

(4) COMPARISON OF BOILER GULLY AND GRAY CREEK COMPLEXES

The Boiler Gully Complex resembles the Gray Creek Complex in possessing a central ultramafic core surrounded by mantling gabbro and a small amount of microdiorite. In the Boiler Gully Complex the intermediate zone of clinopyroxene-rich rocks is absent. However, the mantling basic rocks have concordant foliation and perpendicular radial fractures indicating that the ultramafic core continued its intrusion as a diapiric body after the main cooling and crystallization of the gabbro. It is quite probable that the mantling clinopyroxene-rich zone has been sheared out during this continued movement as it would most probably be less responsive to plastic flow, i.e., have a higher rheidity than the serpentinized ultramafic core. A similar process has occurred at the northern end of the Gray Creek Complex where, viewing the structure down the plunge, the serpentinite core has intruded through the mantling pyroxenite and gabbro zones to directly intrude the sediments.

As well as the similar structure between the two Complexes they contain similar rock types. The ultramafic rocks of the cores of both Complexes vary from rocks originally consisting of olivine with few bastite pseudomorphs to rocks consisting almost entirely of orthopyroxene. The outcrops in the Boiler Gully Complex are linear, suggesting an original compositional banding, and coarse gabbro occurring near the margin of the serpentinite core may be part of a banded sequence.

(5) GENESIS OF THE GRAY CREEK BOILER GULLY COMPLEXES

The Gray Creek and Boiler Gully complexes are of similar genesis. The ultramafic-basic suite probably originated as a horizontal differentiated layered body consisting of the following layers:-

(a) A basal, layered crystal accumulate of peridotite consisting of varying proportions of olivine and orthopyroxene.

(b) An intermediate layered crystal accumulate transitional form 'a' with rapid increase in diallagic clinopyroxene. The layering is due to different percentages of orthopyroxene and olivine with the clinopyroxene.

(c) An upper gabbroic layer transitional from 'b' with increase in bytownite feldspar and elimination of olivine and orthopyroxene. This layer was probably partly crystallized magma containing clinopyroxene and plagioclase crystals in a magma more dioritic in composition. This magma probably became more sodic in its higher levels but probably never differentiated sufficiently to yield ferro-gabbro and granophyre.

The body was probably surrounded by a marginal and roof zone of crystallized dolerite or gabbro - the marginal chilled zone. The marginal area probably contained xenoliths of sediments and associated basic volcanics and these were largely metamorphosed to amphibolite.

Horizontal compression of the magma chambers following differentiation caused folding of the differentiated magma. In the Boiler Gully Complex the initial magmatic intrusion was largely concordant with the general strike of the ?Archaean metamorphics although it must have displaced them to some extent. The magma differentiated in place yielding a basal ultramafic layer. The area was compressed following this differentiation and probably also after the main cooling phase of the body and this compression resulted in vertical plastic movement of the ultramafic core so that this intruded diapirically into the overlying gabbro layer. This intrusion formed a mantling foliation in the gabbro, radial faults and domed the gabbro and surrounding sediments. As mentioned above a clinopyroxene-rich zone between the gabbro and the ultramafic core was probably sheared out during this diapiric intrusion.

The Gray Creek Complex behaved essentially as a stratified sequence folded into an anticlinal structure. During this movement much of the interstitial uncrystallized magma in the upper part of the sequence was squeezed into fractures as small dykes, and formed the microdiorites. Where this material carried with it early formed pyroxene and feldspar crystals the xenocrystic microdiorites formed.

The Complexes were probably differentiated from an olivine basalt magma, possibly the parent magma to the Everett's Creek Volcanics. If this was so then, as there is a large amount of the ultrabasic differentiate, a considerable volume of acid differentiate probably should occur. This is probably represented by the microdiorite. The magma may not have differentiated sufficiently in its final stages of cooling before the folding occurred, for there to be any true granophyre formed, the most acid rocks crystallizing being andesine- quartz- and hornblende-bearing diorites.

Following cooling and crystallization of the Gray Creek Complex continuing compression and local movement and the effects of a later orogeny caused local shearing to yield the greenschists and sheared serpentinite described previously, and the strong shear zone in the adjacent sediments.

The intrusion of the ultramafic- basic suite in the Gray Creek area was followed by intrusion of hornblende granodiorite grading to diorite. These intrusions were mainly in the southern part of the Complex and locally thermally metamorphosed the ultramafic-basic suite; the clinopyroxene-rich rocks were particularly susceptible to metamorphic recrystallization.

(6) SMALLER SERPENTINITE AND BASIC INTRUSIVES

A number of small bodies of sheared serpentinite and gabbro intrude the Siluro-Devonian Crooked Creek Conglomerate in the area between the Gray Creek Complex and the Precambrian metamorphics. One line of serpentinite lenses with small fine grained gabbroic bodies is in a sheared anticlinal crest near Dinner Creek Well. East of this are several small serpentinite lenses and also bodies of coarse to medium-grained gabbro. Both serpentinite and the conglomerate surrounding it are generally sheared. The gabbro (specimen 97629) consists largely of tremolite and saussurite. Saussurite is in anhedral areas commonly with a poikilitic to aplitic relationship to large platy tremolite crystals. The texture is typically igneous although both saussurite and colourless tremolite are secondary after feldspar and clinopyroxene respectively. Small amounts of zoisite, chlorite and tremolite are closely associated with the saussurite but no albite is evident.

The tremolite occurs as large crystals probably directly pseudomorphing clinopyroxene and in some places contains small cores and strips of chlorite, possibly secondary after relict clinopyroxene rather than an alteration from the tremolite. Tremolite also occurs in areas of fibrous matted amphibole and chlorite wisps and some of this material is in shear zones crossing the rock. The rock is a uralitized gabbro and the retrogressive alteration probably due to shearing during intrusion and possibly due to absorption of water from the intruded sediments. A boulder of metamorphosed gabbro occurring in the conglomerate (specimen 97320) near the gabbro intrusion is an albite-tremolite amphibolite supporting the concept of an older metamorphosed gabbro and younger post-Silurian gabbro. The gabbro and serpentinite intrusions into the Crooked Creek Conglomerate containing boulders of these rock types (metamorphosed) is clear evidence of at least two ages of serpentinite and gabbro intrusion.

East of Gray Creek in the southern part of the area a large body of serpentinite occurs parallel to the Spring Creek Fault. The serpentinite is generally very strongly sheared especially adjacent to the fault zone. At the northern end of this body elongate outcrops of serpentinite with associated coarse grained altered gabbro contain small lenses of a coarse-grained chromitite. This rock consists of 60 - 70% brown chromite in a matrix of greenish white serpentine.

Chromitite also occurs with gabbro and pyroxenite in a smaller intrusion into the Everett's Creek Volcanics three miles farther south. The intrusive rocks in the area are generally sheared and hydrothermally altered, particularly the serpentinite in places along the fault zone where they have been extensively carbonated to yield rocks resembling a marble in hand-specimen.

Specimen 97647 contains 50% to 60% chromite in a matte of very fine-grained antigorite serpentine. The rock is banded in some outcrops, due to varying proportions of chromite and serpentine. It is also possible that the chromite varies in composition in the different bands as in the more chromite-rich band the chromite is a translucent red-brown colour whereas in the bands containing about 50% chromite the chromite is very deeply coloured and almost opaque. The chromite has curved boundaries against the serpentine in mat cores but is invariably broken by many irregular cracks which contain a thin film of serpentine. The serpentine is very fine grained (antigorite probably) and has a directed texture showing a dominant schistosity and parallelism of wisps and a lesser orientation perpendicular to this. The schistosity swings around the chromite grains in many places and it appears that considerable plastic movement in the serpentine has stressed the chromite grains so that these have become shattered and moved apart along many irregular cracks. The chromite is generally black and completely opaque along the margins against the serpentine and this may be due to some alteration of the chromite.

Specimen 97642 was collected as a "serpentinite" associated with the chromitite. The rock originally consisted of two essential components with accessory magnetite. It was coarse-grained with an almost poikilitic texture, component 'B' occurring as anhedral patches within the more abundant component 'A'. Component 'A' was originally a clinopyroxene and some relict clinopyroxene remains although it is largely altered to a serpentine mineral containing many tiny flakes of secondary amphibole. Component 'B' consists of fine grained material in places randomly arranged but elsewhere forming a very fine poorly defined rectangular mesh. The fine grained mineral is probably a chlorite. The rock was originally a coarse grained basic and ultrabasic igneous rock but has been extensively low temperature hydrothermally altered.

Specimens 97643-4 are from the same area as 97642 but are gabbroic rock types. Specimen 97643 is a fine grained aggregate of secondary minerals cut by a number of veins of prehnite. The original rock consisted of coarse pyroxene and feldspar. The clinopyroxene has been completely altered to an extremely fine aggregate of colourless chlorite. The calcic areas consist of a fine grained aggregate of turbid minerals which include prehnite and probably epidote. The rock contains one large relict grain of red-brown chromite of the same appearance as that in the chromitites. Specimen 97644 is very similar to 97643 consisting of a fine aggregate of secondary minerals including chlorite and prehnite. The distinctive feature of the rock from 97643 is the presence of zoisite in quite large patches. The zoisite is the pale pink manganiferous variety thulite. Sphene is also quite common as small euhedral to subhedral grains.

Specimen 97645 is a striking coarse-grained rock collected from the serpentinite adjacent to the Spring Creek Fault about one mile east of the southern chromitite outcrops. It consists of about 50% of very large (up to two cms) set in a matte of fibrous minerals. Talc is the major constituent of this material but chlorite and serpentine are also present.

Some areas of this fibrous material show relict cleavage from a coarse grained tabular mineral - possibly orthopyroxene. The original rock probably was a coarse pyroxenite consisting of similar amounts of orthopyroxene and clinopyroxene. This rock is exposed only locally in this area, the most common rocks being serpentine schists or carbonated serpentinites.

A few small serpentinite lenses and larger areas of fine to medium-grained dolerite intrude the Wairuna Formation and Carrier's Well Limestone about two and a half miles east of Gray Creek. These bodies may occur along the axial zone of the next major anticline east of the Gray Creek Complex but the structure is not clear due to the intervening unconformable cover of the Clarke River Formation. These areas of fine dolerite seldom outcrop well and it is possible that some of the rocks are actually basalts of the Everett's Creek Volcanics rather than later intrusive dolerites.

Specimen 97646 from the dolerite body containing small serpentine lenses, in the south-eastern part of Plate 1 has been examined in thin section. The rock is a porphyritic dolerite containing phenocrysts of clinopyroxene and more common plagioclase in a medium grained groundmass of euhedral plagioclase laths and interstitial colourless to pale green amphibole with accessory chlorite. The feldspar is at least partly bytownite (Ab_{20} An_{80}) but is commonly zoned and there has been selective alteration of some zones to albite so that some crystals have a core of albite while othere have optically continuous veins and cores of calcic plagioclase with an intermediate zone of albite. Prehnite occurs in several veinlets and there is a larger vein of extremely fine aggregate chalcedony. The original rock was very calcic as suggested by the early crystallization of bytownite phenocrysts and the interstitial relationship of the ferromagnesian minerals to the feldspar in the groundmass. The dolerite is slightly altered with uralitization of the interstitial ferromagnesian minerals and incipient albitization of the bytownite. The rock is similar to the porphyritic dolerites described from the southern end of the Gray Creek Complex and also to fragments of feldspar-porphyritic basic rocks in the Everett's Creek Volcanics. However, it seems to be an intrusive dolerite rather than part of the volcanics. Similar bodies occur to the north, to the east of Plate 1 and to the south.

These small serpentinite, gabbro and dolerite intrusions described above are related to the peridotite-gabbro suite of the Gray Creek Complex. The rocks are altered at low temperatures and may be mainly a deuteric alteration accompanied by shearing. They do not normally show thermal metamorphism by the granodiorite-diorite intrusions as the rocks of the Gray Creek Complex do.

(7) AGE OF THE BASIC AND ULTRAMAFIC INTRUSIONS

The age of the Sandalwood Serpentinite has been discussed previously and evidence presented for believing it to have been emplaced during an upper Precambrian or Lower Palaeozoic orogeny. In spite of the uncertainty in the distinction between basics of the Sandalwood Serpentinite and Boiler Gully Complex in the southern part of the latter it is considered from evidence in the Hall's Reward Mine area that the Boiler Gully Complex was emplaced later than the Sandalwood Serpentinite. The similar lithology and structure of the Boiler Gully Complex to the Gray Creek Complex suggest that these two complexes have a similar genesis and were probably emplaced at about the same time.

It is quite certain that there are at least two ages of ultramafic-basic intrusion but it is not certain that there are not more than two. This depends on whether the smaller ultramafic and basic intrusions are of the same age as the ultramafic-basic suite of the Gray Creek Complex. If they are then this phase of intrusions can be accurately dated.

The ultramafic-basic suite of the Gray Creek Complex is intrusive into and has locally metamorphosed the Wairuna Formation and Carrier's Limestone. In most areas though, the contact is a sheared one obscuring the effects of thermal metamorphism. North of Dinner Creek the western contact of the Complex is apparently between the Crooked Creek Conglomerate and pyroxenite and serpentinite. The actual contact is not exposed however, so that it cannot be determined whether the conglomerate is thermally metamorphosed. In the south-east corner of the Complex the Crooked Creek Conglomerate has been thermally metamorphosed but this is attributed to the granodiorite in the area rather than the ultramafic-basic suite. In summary it can be said that the ultramafic-basic suite of the Gray Creek Complex intrudes the Silurian Wairuna Formation and probably but not definitely also intrudes the Siluro-Devonian Graveyard Creek Formation. It is also significant that no boulders of unmetamorphosed ultramafic or basic rocks such as occur in the Gray Creek Complex, particularly in the northern area, occur within the Upper Silurian Crooked Creek Conglomerate.

The small ultramafic and basic intrusions intrude the Graveyard Creek Formation as well as the Wairuna Formation south-west of the Gray Creek Complex, (in the corner of Plate 1). The intrusion does not continue across the unconformity between the Broken River Formation and the Graveyard Creek Formation and thus is clearly dated to intrude during the orogeny at the close of the Graveyard Creek sedimentation, i.e., in the orogeny in the Lower Devonian. Accepting these intrusions as part of the same intrusive phase as the Gray Creek and Boiler Gully Complexes then the latter intrusions are similarly dated as Lower Devonian.

F. ACID INTRUSIONS

(1) PRECAMBRIAN GRANITE

A large body of granite intrudes the Paddys Creek Formation and the Sandalwood Serpentinite in the area at the headwaters of Crooked and Bauhinia Creeks. The granite is generally a yellowish muscovite granite and is commonly pegmatitic. It has contact metamorphosed the gabbro of the Sandalwood Serpentinite south of Dinner Creek and boulders of thermally metamorphosed serpentinite occur in the Crooked Creek Conglomerate and are derived from a contact of serpentinite and the granite.

Several small bodies of pegmatitic granite north-east of the main body and a farther 15 miles N.N.E. small bodies of granite intrude the Hall's Reward Metamorphics, Stenhouse Creek Amphibolite and Sandalwood Serpentinite. This granite is similarly a muscovite granite and commonly pegmatitic but differs in generally containing small garnet crystals. A garnet-rich granite examined in thin section (No. 97312) consists of 50% euhedral to subhedral large garnet crystals with interstitial quartz (20%), sericitized indeterminate feldspar (15%) and less common muscovite (5%), biotite (5%) and magnetite and chlorite. The mineral composition of the rock is that of a metamorphic rock it garnet is rarely as common as this and the bodies are quite definitely discordant and intrusive. Their contact metamorphism of the Sandalwood Serpentinite has previously been described.

In the mapping of the Hall's Reward Mine several specimens of the footwall "soapstone" were collected and later examined in thin section. Specimen 97310 is a strongly altered rock containing about 30% of dkeletal or lath-shaped biotite crystals (0.5 - 2.5 mm. long) in a sericitic matte (45%) with irregularly distributed anhedral quartz grains (15%). Apatite is common throughout the slide and usually associated with the quartz, some of which is in veinlets and introduced patches. Colourless, isotropic, unaltered garnets are scattered throughout the section and calcite occurs as rare veinlets. The biotite laths are randomly distributed and orientated, for the most part they are strongly pleochroic brown biotite but green biotite also occurs. The sericite matte often shows a rectangular mesh texture and is probably an alteration from coarse feldspar.

The original rock contained large unorientated biotite flakes, scattered garnet, probable feldspar and 10 - 15% quartz. Of the rocks in the neighbourhood this is the most similar to the garnet-bearing granite. The rock type occurs in a shear zone between amphibolite to the west and quartz-mica and garnet-quartz-mica schists to the east. The complete absences of schistosity and lack of orientation of mica in specimen 97310 is strong evidence against it originally being a garnet-quartz-mica schist. Specimen 97311 also collected from the footwall of the mine is a similar rock but is more extensively altered. It consists of fine sericite in a mesh type of texture and scattered relict patches of green biotite. Specimen 97309 is even more strongly altered and is completely composed of sericite material forming an irregular very fine mesh with a few larger flakes and groups of crystals. Scattered throughout the rock are tiny grains of red-brown ?ilmenite and also small stringers of tiny indeterminate grains with high relief. These stringers also are in the biotite crystals of 97310-11.

The rocks described above were probably derived from a garnet bearing granite body intruded along the contact between amphibolite and quartz-mica schist. The alteration is a low temperature hydrothermal process of sericitization.

(2) PALAEOZOIC GRANODIORITE

The granodiorite outcropping in the southern part of the Gray Creek Complex has been previously discussed in the section on the Complex. This granodiorite is intrusive into the ultramafic-basic suite and also into the Wairuna and Graveyard Creek Formations.

In the Broken River about fifteen miles south of the Gray Creek Complex a body of fine dolerite intruding the Silurian sediments is intruded and metamorphosed by a granodiorite. It is a hornblende granodiorite of a type similar to and correlated with the granodiorite of the Gray Creek Complex. About five miles south-east of this granodiorite a similar granodiorite, the Craigie Granodiorite, intrudes the Middle Devonian Broken River Limestone. The three granodiorites are tentatively correlated. If this correlation is valid then the granodiorite intrusions are dated as post-Middle Devonian. If there was an orogeny in the Upper Devonian prior to the Clarke River and Bundock Creek Formation sedimentation then they may have been intruded at that time but, in view of the doubtful existence of this orogeny it seems more probable that

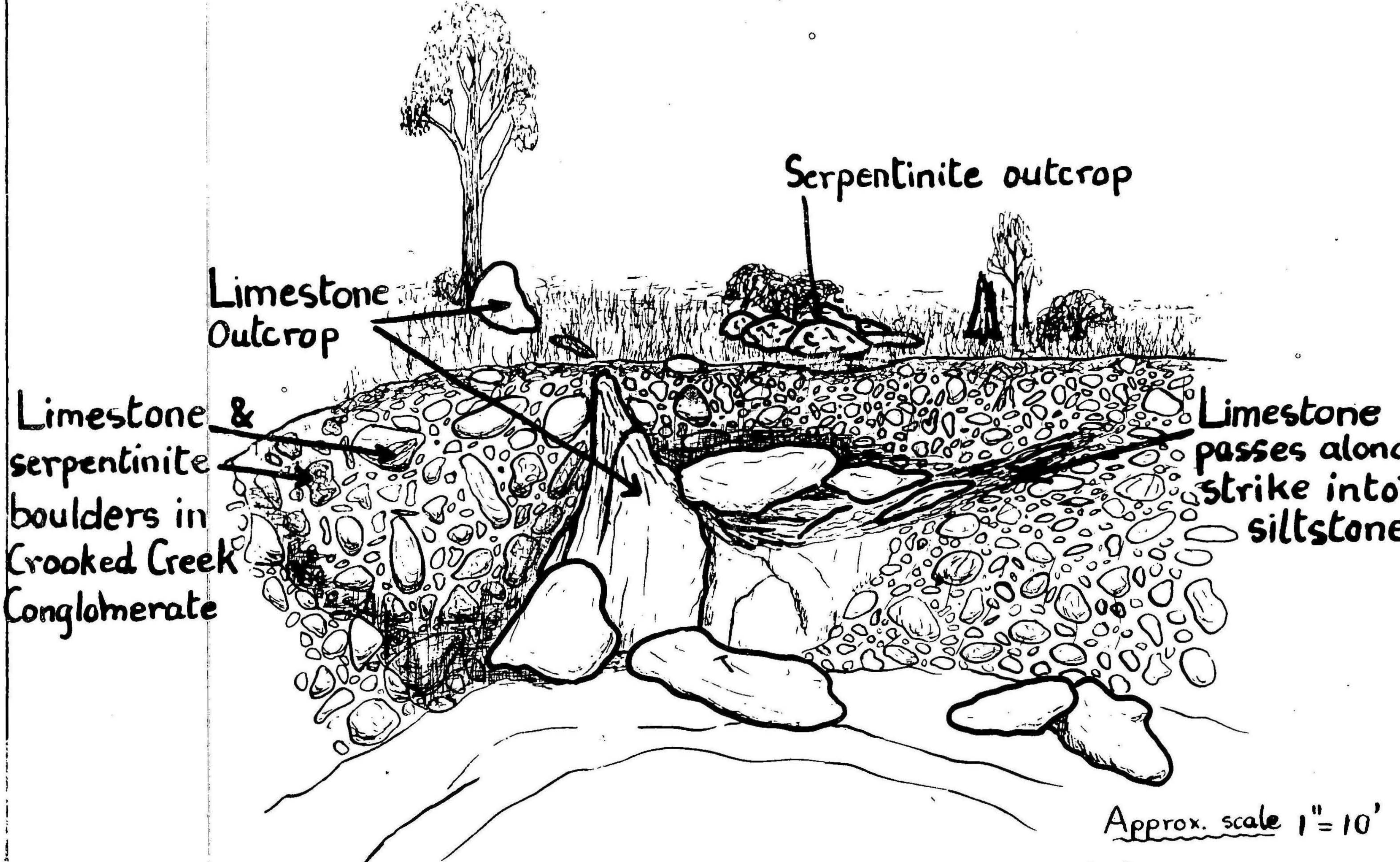

Fig 2. Sketch of the unconformity at the base of the Crooked Creek Conglomerate, northern bank of Dinner Creek

they were intruded in the Carboniferous orogeny following the Lower Carboniferous sedimentation.

On the western margin and north-western corner of Plate 1, are areas of massive hornblende-biotite granodiorite. This intrudes the ?Proterozoic Paddys Creek Formation and Lucky Creek Formation and has contact metamorphism of these rocks. Adjacent to the contact in Lucky Creek contaminated rocks have been produced, some of them being hornblendites. This intrusion is possibly related to the Palaeozoic granodiorites but as it intrudes Precambrian sediments only, then this cannot be verified.

(3) UPPER PALAEOZOIC PORPHYRIES

Within the area of Plate 1 there are several small irregular bodies of quartz-feldspar porphyry. One of these occurs as an unsheared body within the Lucky Downs Fault zone and a second body two and a half miles west of the Halls Reward Mine. Near the headwaters of Spring Creek a massive soft, kaolinitic rock adjacent to the Sandalwood Serpentinite may possibly be such an intrusion that has been hydrothermally altered.

Three small bodies of quartz-feldspar porphyry are similar to the very large areas of acid porphyry, rhyolite and related granite which form an igneous province in this part of North Queensland. The porphyries intruded the Carboniferous Bundock Formation to the south-west of the area of Plate 1. and are Upper Palaeozoic in age.

G. STRUCTURAL GEOLOGY

(1) UNCONFORMITIES

(a) Base of the Paddy's Creek Formation

About five miles S.S.W. of the Hall's Reward Mine the Hall's Reward Metamorphics and Stenhouse Creek Amphibolite are unconformably overlain by sediments of the Paddys Creek Formation. There is a distinct metamorphic difference between the rock types, the Hall's Reward Metamorphics being mica schists, quartzites and quartz-mica schists with common quartz veining, whereas the Paddys Creek Formation consists largely of phyllitic sandstones and, in the eastern basin, some thin bedded siltstones which locally are quite gently folded. Adjacent to the unconformity the Paddys Creek Formation is in most cases steeply dipping and somewhat sheared. There is no basal conglomerate evident.

There is no doubt that the two basins of Paddys Creek Formation in this area are younger than and unconformable on the ?Archaean metamorphics but the boundaries to the basins have been sheared and the unconformity complicated by this shearing and by the intrusion of a line of serpentinite bodies along a ridge of basement between the two basins.

The western boundary of the ?Archaean block is a wide shear zone (the Lucky Downs Fault). Again in this area there is a distinct metamorphic break between the two metamorphics.

(b) Base of the Wairuna Formation

Nowhere in the area has an actual unconformity been observed between the Wairuna Formation and the Paddys Creek Formation. Through-out its occurrence the Paddys Creek Formation only becomes locally phyllitic in shear zones, particularly adjacent to the Halls Fault. There is also a sedimentary difference discussed in the section on stratigraphy - the Paddys Creek Formation is a micaceous sandstone and siltstone sequence whereas the Wairuna Formation is much more varied particularly in the vicinity of the Gray Creek Complex.

In the area near Dinner Creek the Halls Fault appears to fade out. In Dinner Creek west of this fault zone a small area of volcanics correlated with the Everett's Creek Volcanics is overlain by quartz greywacke and greywacke sandstones and siltstones with lesser conglomerate. Similar rocks overlie the Everett's Creek Volcanics in Dinner Creek. These rocks occur farther north, again west of the fault zone, and are gently dipping and unmetamorphosed. Immediately west of them is a quartzite and west of this are intrusions of sheared gabbro. There is a metamorphic break in this area and it is considered to coincide with an unconformity between quartz-greywacke of the Wairuna Formation and quartzite and quartz-phyllite of the Paddys Creek Formation.

East of the Halls Faults in this area are two small areas of micaceous quartzite and phyllite which are considered to be inliers of the Paddys Creek Formation within the Palaeozoic sediments. The eastern one of these inliers is unconformably overlain by sedimentary breccia at the base of the Crooked Creek Conglomerate. However, immediately west of the western inlier are unmetamorphosed quartz greywacke sandstone and siltstone. To the south-west along strike of the ridge are similar rocks, generally sheared, and farther south-west in Dinner Creek there is the lens of limestone correlated with the Carrier's Well Limestone of the Wairuna Formation (Fossil Locality G.C.D.3). The quartz-greywacke and limestone are part of the Wairuna Formation resting with sheared unconformity on the inlier of quartzite and phyllite correlated with the Paddys Creek Formation.

(c) Base of the Graveyard Formation

The Crooked Creek Conglomerate is exposed at the base of the Graveyard Creek Formation and the unconformity below it is exposed in several localities. In the south-west part of the area a coarse boulder conglomerate overlies the Precambrian granite with simple unconformity. Similarly in the south-west part of the Gray Creek Complex volcanics and sediments within the Wairuna Formation are overlain by thick-bedded quartz greywacke and conglomerate of quartz-greywacke to greywacke type. The unconformity is not exposed but strikes within the Wairuna Formation vary compared with the regular strike of the Graveyard Creek Formation.

In the south-eastern part of the Gray Creek Complex a long, faulted synclinal fold of conglomerate unconformably overlies rocks of the Everett's Creek Volcanics and Wairuna Formation. The conglomerate is generally fine to medium quartz-greywacke conglomerate but locally a coarse greywacke conglomerate containing basalt and Silurian limestone boulders.

In the area near Dinner Creek Well and north of Dinner Creek the unconformity at the base of the Crooked Creek Conglomerate is folded and heared. In Dinner Creek Well a lens of pink fossiliferous limestone, passing along strike into pink siltstone, outcrops in the creek bank and swings in strike in an arc from N.W.-S.E. to north-east (See text figure 2). On the southern side of the limestone is a very coarse boulder conglomerate with limestone and serpentinite boulders. In the bank to the north of and above the limestone and siltstone there is similarly but finer conglomerate. The first interpretation of the outcrop was that a limestone lens is included within the conglomerate but recognition of an unconformity below the conglomerate elsewhere makes it appear that this limestone (correlated on fossil evidence with the Wenlockian or Upper Ordovician Carrier's Well Limestone) is below the unconformity. The limestone probably stood up as a prominent outcrop that was surrounded and overlain by the coarse basal conglomerate.

Two miles N.N.E. of this area the Crooked Creek Conglomerate unconformably overlies crenulated and micaceous quartzite of the Paddys Creek Formation. The basal rocks of the Crooked Creek Conglomerate are medium to coarse breccias of local derivation from the Paddys Creek Formation. East of this area near the Gray Creek Complex similar conglomerates and some breccias containing fragments of siltstone, sandstone and phyllite are tightly infolded with the rocks which they unconformably overlie, so that they have the appearance in some creek sections of being interbedded with the sandstone and siltstone of the Wairuna Formation.

(d) The Base of the Broken River Limestone

The unconformity between the base of the Broken River Formation and the Graveyard Creek Formation is chiefly evident from regional mapping since there is considerable variation in thickness of the Graveyard Creek Formation between the base of the Broken River Formation and the top of the Crooked Creek Conglomerate. Also the trends of the Graveyard Formation folds south of the Gray Creek Complex and those in the Broken River Formation to the south are discordant.

The unconformity is commonly marked by a thin pebble conglomerate bed.

(e) The Base of the Clarke River Formation

The unconformity at the base of the Clarke River Formation is well-exposed at the Gray Creek-Spring Creek junction and east therefrom. In Gray Creek the base of the Clarke River Formation overlies and contains basalt boulders of the Everett's Volcanics. East of Gray Creek there is an angular unconformity and the base of the Clarke River Formation consists of breccia containing boulders from sandstones and siltstones of the Wairuna Formation.

About eight miles farther south the western edge of the eastern basin of the Clarke River Formation dips at a rather steep angle to the east. The Wairuna Formation to the west is parallel in strike but locally has a shallower dip and in this area unconformity is not obvious.

South of the area of Plate 1 the Bundock Creek Formation overlies the Broken River Formation. The upper part of the Bundock Creek Formation contains fossils of Lower Carboniferous age and is lithologically similar to the Clarke River Formation. The relationship between the Bundock Creek Formation and the Broken River Formation is not clear. Palaeontological evidence suggests a faunal break between the formations. If there is no unconformity between the Broken River Formation and the Bundock Formation then it is evident that the Broken River Formation and lower part of the Bundock Creek Formation were deposited in a basin generally south of the area of Plate 1 and it was only in Lower Carboniferous time that sedimentation at the top of the Bundock Formation spread north to unconformably overlie the older Silurian rocks and to yield the rocks of the Clarke River Formation. It is more likely that there is a break in sedimentation between the two formations.

South-east of Plate 1 the Clarke River Formation is in fault contact with the Broken River Formation but again no proof of unconformity between them is apparent.

(2) FOLDING

(a) ?Archaean

The folding of the ?Archaean rocks has a N.N.E. trend. Complex minor folding is common and these minor folds and the crenulations in the mica schists generally have a vertical or sub-vertical plunge. In the schists quartz augen are very common and these also tend to have their long azes sub-vertical although there is no constancy of the angle of plunge. In the thicker bedded quartzites to the south particularly, subhorizontal minor folds are not uncommon.

(b) ?Proterozoic

The folding in the ?Proterozoic rocks has a N.N.E. trend roughly parallel to that of the ?Archaean and Palaeozoic trends. In the northern part of the area the Paddys Creek Formation is folded into broad folds plunging to the north and are tighter to the east near the ?Archaean block. The structure is clearly defined by quartzite beds in the northern part of the area but to the south-west the lack of distinctive beds in the Lucky Creek Formation and the effect of the granite intrusions has obscured the broad structures.

West and south-west of the Boiler Gully Complex the Paddys Creek Formation and Lucky Creek Formation have low dips, generally in a northerly direction, and the structure is not clear. A similar area of variously plunging minor folds and shallow dips occur immediately south-west of the Boiler Gully Complex. This feature appears to be local as farther south the rocks trend again north-north-east and are strongly sheared especially adjacent to the Halls Fault. The shallow dips may have been due to doming by the Boiler Gully Complex. The area also lies on a plunge reversal - folds to the north in the Paddys Creek Formation plunge N.N.E. and those to the south-west plunge S.S.W.

(c) Plaaeozoic

At least three and possibly five orogenies have affected the Palaeozoic sediments. These are marked by the unconformities at the base of the Graveyard Creek Formation, the Broken River Formation and the orogeny following deposition of the Clarke River Formation and possible orogenies at the base of the Greenvale Formation, Clarke River and Bundock Creek Formations.

The Palaeozoic structure appears strongly controlled by the margin of the Precambrian block as delineated by the Halls Fault. Each period of folding has emphasized the previous structures and generally it is not possible to date the structures as being formed in one particular orogeny.

The Gray Creek Complex occupies the core of a large anticline and between this and the structural high of the Precambrian block is a strongly sheared synclinal zone. Near the headwaters of Spring Creek there are two south-plunging synclines in the Wairuna Formation. Farther south in Dinner Creek there is at least one synclinal axis but the beds east and west of this are sub-vertical and there may be further fold axes present.

At the southern end of the Gray Creek Complex the synclinal fold axes in the Crooked Creek Conglomerate appear to wrap around the end of the Complex. This is most probably due to doming by the granodiorite-diorite intrusions. The fold axes immediately south of the Gray Creek Complex in the Graveyard Creek Formation trend north-south and their trend is inclined at about 30° to the fold axes in the Broken River Formation. However, anticlines and synclines of the two formations roughly correspond and the post-Broken River folds have been controlled by the earlier anticlines and synclines formed in the folding of the Graveyard Creek Formation.

It is generally true that folds in the Lower Devonian orogeny have a more north-south trend and the folds in the late formations have a N.N.E. to N.E. trend. This is very evident in the basin of the Clarke River Formation immediately east of Gray Creek. The general trend of the basin is almost north-south and it probably overlies a major syncline in the Wairuna Formation with east and west limbs delineated by the Carrier's Limestone. However, the small folds within the basin have a pronounced north-east trend. The effect of the cross-folding is also shown in the Carrier's Well Limestone by the 135° change in strike of the major limestone lens three miles east of Dinner Creek yard. This corresponds to the axis of a north-east anticline in the Clarke River Formation.

(3) FAULTING

The dominant direction of faulting is N.N.E. generally paralleling the fold trends. In a number of cases it is not possible to say in which orogeny the faults occurred.

The Halls Fault is the major one and generally faults the ?Precambrian against the Palaeozoic formations. The fault is well exposed north of Halls Reward Mine and consists of a crush zone about fifteen feet wide in which elongate rods of quartz are common. These rocks are sub-horizontal with a gentle plunge to the south. In the sheared silts of the Wairuna Formation to the east, drag folds, similarly with a gentle southerly plunge, are common and vertical slickensides are well exposed. A porphyry dyke in the fault zone has been fractured into lenticular boulders. These features show that the movement on the fault zone has been vertical and not transcurrent. The shearing and compressional features of the fault zone suggest that it may have been the Precambrian basement which was the active block upthrusting through the Palaeozoic sediments. The fault in this area dips steeply to the east.

The southern end of the Halls Fault is difficult to trace into the Crooked Creek Conglomerate. Since it has faulted part of the Crooked Creek Conglomerate it is definitely post-Upper Silurian in age. In the discussion on the Boiler Gully Complex it has been suggested that the transcurrent fault south of the Hall's Reward Mine and the Halls Fault itself moved together and that movement occurred during the emplacement of the serpentinite of the Boiler Gully Complex. The same conclusion probably applies to the Lucky Downs Fault to the west of the Boiler Gully Complex. Since the Boiler Gully Complex was probably emplaced in the Lower Devonian orogeny this suggests a Lower Devonian age for the faulting. This is consistent with the evidence from the southern end of the fault.

The major fault between the Greenvale Formation and the Wairuna Formation is part Lower Silurian in age. Since at its southern end a strip of Clarke River Formation crosses the fault without displacement then it is pre-Lower Carboniferous in age. This fault may also have occurred in the Lower Devonian orogeny.

The Spring Creek Fault is a major lineament and continues south of the area of Plate 1 for a farther fifteen miles as an arcuate, subvertical fault, generally with a narrow clear zone. The throw is difficult to estimate due to the unconformity between rocks on either side but it is probably not greater than 2,000 feet. The fault passes into the western limb of a south plunging syncline at its northern end. Near the south-eastern corner of the Gray Creek Complex the fault zone is more complex and changes in direction from N.N.E. to north. In this area the northwest-facing limb of an anticline in the Clarke River Formation is turned through 90° in the fault zone, which suggests some transcurrent movement.

The eastern side of the basin of Clarke River Formation east of Gray Creek is partly bounded by a north-south fault. Although the western fault is parallel to the major fault to the east the movement on it has occurred much later in the Carboniferous orogeny. In the central eastern part of this area are a group of north-east trending faults which occurred in the Carboniferous orogeny and were probably associated with the north-east folding.

In the south-eastern and southern part of the Gray Creek Complex is a small group of faults which displace the Graveyard Creek Formation and have a generally east-west trend. These may have been formed during the emplacement of the Gray Creek Complex.

H. SUMMARY OF THE GEOLOGICAL HISTORY

The earliest geological event recorded was the deposition of a series of interbedded quartzose and calcareous sediments which were later in a Precambrian orogeny, regionally metamorphosed to yield the Hall's Reward Metamorphics and Stenhouse Creek Amphibolite. The metamorphism was sufficient to produce metamorphics of the amphibolite facies and locally to produce migmatites by the introduction of granitic material.

Probably in the Proterozoic or possibly in the Lower Palaeozoic a sequence of calcareous sandstone and siltstone with some limestone interbedded with but largely underlying quartz sandstone and siltstones were deposited unconformably on the regionally metamorphosed ?Archaean rocks. These were later folded along N.N.E. axes in a late Precambrian or early Lower Palaeozoic orogeny. During this orogeny the lenticular serpentinite and gabbro of the Sandalwood Serpentinite were intruded along a linear belt to form part of a hinge-line during later Palaeozoic sedimentation. Also low grade regional metamorphism formed phyllite from the sediments and antigorite serpentinite and albite-epidote amphibolite from the Sandalwood Serpentinite. In the final stages of the orogeny pegmatitic muscovite granite was intruded and in the northern part of the area the granite was contaminated to yield garnet.

The beginning of the Palaeozoic sedimentation (the Wairuna Formation) is not dated but the oldest fossils within the Wairuna Formation show that it is at least as old as Lower or Middle Silurian and may be Upper Ordovician. Th linear belt containing the Sandalwood Serpentinite intrusion formed a hinge zone controlling the area of Palaeozoic sedimentation. West of this was a stable cratonic Precambrian block which received no Palaeozoic sedimentary cover (or shallow local cover only) and to the east there was active and thick sedimentation from Silurian to Carboniferous in a tectonically mobile belt.

The early Palaeozoic sedimentation was initially clastic with variable quartz greywacke and siltstone beds. In the Silurian (or possibly Upper Ordovician) a local basaltic volcanic centre developed adjacent to Gray Creek. The distribution of the volcanics suggests a source along or east of the line of the present Gray Creek Complex. Associated with the volcanics, probably particularly in the early stages, were local lenticular biohermal limestones interbedded with fine greywacke conglomerate and breccia containing basalt fragments. This probably developed marginally to the volcanic centre perhaps as intermittent reefs surrounding volcanic islands. The intensity of the volcanic activity increased, resulting in cessation of the limestone deposition and deposition of a thick sequence of basaltic agglomerates and basalts. Some of the volcanics were sub-aerial so that at some stages the volcanic source area was above sea-level.

There is some uncertainty of the events in the Middle Silurian as the age and stratigraphic position of the Greenvale Formation is not known. The Graveyard Creek Formation is upper Middle Silurian or Upper Silurian to lower Lower Devonian in age and the Kangaroo Hills Formation unconformably overlying the Greenvale Formation is of similar age. Since the Wairuna Formation possibly extends into the Middle Silurian, then if the Greenvale Formation is unconformable on the Wairuna Formation, then it must be middle Wenlockian (middle Middle Silurian) in age with orogenic movement both at the base and top of the Wenlockian. However, if the Greenvale Formation is actually conformable with the Wairuna Formation then there was probably only the one orogeny in the Wenlockian, bringing the Wairuna-Greenvale sedimentation to a close and commencing the Graveyard Creek and Kangaroo Hills sedimentation. With the rather close approach of the ages of the faunas from the Carrier's Well Limestone and the Graveyard Creek Formation it seems less likely that there are two orogenic movements, with a period of possibly local sedimentation in between, during the Middle Silurian.

The Graveyard Creek Formation sedimentation commenced by uplift of the western margin of the Palaeozoic sedimentation area, especially in the Bauhinia Creek area so that this became the source for coarse boulder conglomerate at the base of the Graveyard Creek Formation. There was probably lesser uplift in the area north and east of the Gray

Creek Complex so that although essentially contemporaneous, the Graveyard Creek Formation and the Kangaroo Hills Formation to the east were deposited in separate basins.

The Graveyard Creek sedimentation was brought to a close by a major orogeny in the Lower Devonian. Since the limestones at the top of the Graveyard Creek Formation probably go into the lower Lower Devonian and there is a distinct faunal break between these and the oldest (lower Middle Devonian) limestones of the overlying Broken River Formation then this orogeny is quite accurately dated as Lower Devonian. It is noteworthy that the conditions and type of sedimentation immediately below and above the unconformity, particularly the large lenticular limestones, were very similar and the orogeny caused no sudden change in the type of sedimentation but rather changed its location.

The Lower Devonian orogeny folded the Wairuna and Graveyard Creek Formation and during this orogeny the ultramafic and basic rocks were intruded. Ultramafic and basic rocks are not known to intrude the Broken River or Clarke River Formations. The basic and ultrabasic rocks typically are intruded along anticlines in the Palaeozoic rocks. The Gray Creek Complex and Boiler Gully Complex are the major intrusives during the Lower Devonian orogeny but smaller lenticular serpentinites with some gabbro and, particularly east of Gray Creek, fine-grained dolerite with some serpentinite are more widely distributed.

The ultramafic-basic suites of the Gray Creek Complex and the Boiler Gully Complex were originally differentiated layered bodies in which differentiation was due to gravitational crystal settling in the normal manner of basic intrusives. Compression in the Lower Devonian orogeny caused vertical diapiric intrusion of the partly crystalline, differentiated magma resulting in the concentrically zoned, domal complexes of Gray Creek and Boiler Gully. The compression also initiated further differentiation by filter-press action to yield the microdiorites derived from the partly crystalline gabbro. The Boiler Gully Complex was intruded adjacent to the old Precambrian serpentinite belt and the hinge line of Palaeozoic sedimentation. The intrusion probably uplifted the ?Archaean block. The Gray Creek Complex apparently intruded along a parallel line one to two miles west of the Silurian basaltic vulcanism.

Following the Lower Devonian orogeny sedimentation began in a southern basin with deposition of the Middle Devonian Broken River Formation. This sedimentation was dominated by the deposition of richly fossiliferous lenticular biohermal limestone with calcareous sandstone and siltstone probably in a fairly shallow water environment. Sedimentation of the Broken River Formation continued into the upper Middle Devonian and fossils of probable Upper Devonian age have been found in the overlying Bundock Creek Formation. There appears to be an unconformity and faunal break between the Broken River Formation and the Bundock Creek Formation and a change from a marine to a dominantly fresh-water environment.

In the area of Plate 1 the Lower Carboniferous Clarke River Formation correlates with the upper part of the Bundock Creek Formation. If there was conformable sedimentation to the south from the Middle Devonian to the Lower Carboniferous, then by Lower Carboniferous time the southern basin had evidently filled up sufficiently so that the Lower Carboniferous sediments spread north to rest with sharp angular unconformity on the Silurian strata. Movement may have caused the change in sedimentation without actually causing unconformity.

Following the Lower Carboniferous sedimentation there was a major orogeny in which the Palaeozoic sediments were folded along north-east axes. This folding largely accentuated and was controlled by the major structures of the earlier Palaeozoic orogenies. Probably in this orogeny hornblende granodiorites were emplaced causing local thermal metamorphism.

In later Palaeozoic time (Carboniferous or Permian) there was extensive intrusion of granitic rocks as porphyries, ring-dyke complexes and granites. These mainly are on the Precambrian cratonic block to the north and west but quartz-feldspar porphyries are locally present in the area of Plate 1.

The only post-Palaeozoic events recorded are the extrusion of basalts from local centres in the Tertiary and erosion to form a mature lateritized land surface, which is dissected by recent erosion.

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TABLE I. MINERALS OF STENHOUSE CREEK AMPHIBOLITE

* Denotes major constituent (10%). ÷ Denotes minor constituent (10%). o Denotes accessory constituent (about 1%).

Specimen	Specimen No.	Hornblende	Diopside	Plagioclase (Saussuritized)	Epidote	Clinozoisite	Prehnite	Calcite	Quartz	Sphene	Apatite	Opaque Iron Oxides	Chlorite
a	97601	*(green)	-	*					÷				
b	97602	* "	-	*(andesine?)					*			÷	
c	97603	* "		* Oligoclase)	÷		o	o	÷				
d	97604	* "	÷	*		÷(vein)			÷				
e	97605	*(pale green)	÷ to * (bands)	*	÷					o	÷(Band)	o	
f	97606 (dark band)	*(80%) (green-brown)		*									
g	97606 (light band 1)	÷	*	*									
h	97606 (light band 2)	*	÷	*	÷								
i	97607 (dark band)	*(light green)		*	÷								
j	97607 (light band)	÷	*	*		*			÷				
k	97608 (dark band)	*		*	÷ or	÷							
l	97608 (light band)	÷	*	*	*								
m	97608 (veinlet)		÷	÷			*	÷	÷				
n	97610	*(Actinolite)		*					o				
o	97609 (dark band)	*(Actinolite)		÷		*				o			
p	97609 (light band)		*	÷	*	-	*?			o			
q	9730	*(pale blue-green)		÷(andesine)	*			÷	÷				÷
r	97308	*(pale blue-green)		*(albite)	*	*				÷		o	o

TABLE 2. STRATIGRAPHIC TABLE - GRAY CREEK AREA

AGE	UNIT	THICKNESS	LITHOLOGY
Recent	Alluvium and Soil Cover	Variable	
	Laterite and lateritic earths	Variable 0-30'	Lateritic earth and local true laterite developed on mature Tertiary erosion surface.
	Basalt		Slightly vesicular basalt flows derived from local sources.
Upper Palaeozoic	QUARTZ-FELDSPAR PORPHYRY INTRUSIONS		
Carboniferous	OROGENY - folding on N.E.-S.W. axes, hornblende granodiorite intrusions		
Lower Carboniferous	Clarke River Formation	3000' approx.	Quartz conglomerate, grit, sandstone; Plant Fossils.
	Limestone Member	50'	Bedded richly fossiliferous limestone.
?upper Upper Devonian	Possible OROGENY - disconformity or unconformity		
Lower to Middle Devonian possibly to Upper Devonian	Broken River Formation	10,000' approx.	Massive and bedded lenticular coralline limestone with calcareous siltstone and sandstone.
Late Lower Devonian	OROGENY - folding on N.-S. to N.N.E.-S.S.E. axes. Ultrabasic and basic intrusions including 2 large differentiated bodies and the layered complexes later folded.		
Upper Silurian to Lower Devonian	Graveyard Creek Formation	10,000-12,000'	Graded bedded greywacke and greywacke siltstone, lenticular limestone at top of sequence.
	Crooked Creek Conglomerate Member	Variable 500-3,000'	Greywacke boulder and cobble conglomerate.
Middle to Upper Silurian	OROGENY - folding along N-S to N.N.E.-S.S.W. axes. Uplift of western Precambrian block		
?Middle Silurian	Greenvale Formation	?	Quartz-greywacke, quartz-greywacke siltstone with lenses of grit, conglomerate.
?Middle Silurian	Possible OROGENY - relationship between Greenvale and Wairuna Formations uncertain.		
Lower to Middle Silurian probably commencing in Ordovician	Wairuna Formation	?	Rapidly varying sequence mainly of sediments of the quartz-greywacke and quartzose suites.
	Everett's Creek Volcanic Member	2000-3000' (Vble.)	Albitized basalt and basaltic agglomerate with lesser dolerite, tuff, greywacke and calcareous greywacke.
	Carrier's Well Limestone Member	1000-2000'	Lenticular limestone with fine greywacke breccia and conglomerate, calcareous greywacke, calcareous sandstone and siltstone.
Lower Palaeozoic or Upper Proterozoic	OROGENY - folding on N.N.E.-S.S.W. axes; low grade regional metamorphism; intrusion of pre-Kinematic or syn-Kinematic serpentinite and gabbro; intrusion of post-Kinematic granite.		
Proterozoic	Paddys Creek Formation	?	Quartz sandstone, siltstone and some quartzite - low grade phyllitic metamorphism.
	Lucky Creek Formation	?	Calcareous siltstone, calcarenite, calcareous greywacke and local limestone; low grade regional metamorphism general; local thermal metamorphism near granodiorite.
	OROGENY - regional metamorphism		
?Archaean	Hall's Reward Metamorphics	?	Quartz-mica schist, quartz-mica-garnet schists regionally metamorphosed.
	Stenhouse Creek Amphibolite	?	Hornblende-plagioclase amphibolite with some diopside granulite - regionally metamorphosed, amphibolite and albite-epidote amphibolite facies.

GEOLOGICAL FIELD SHEET, 1957-58.

GRAY CREEK AREA, NORTH QUEENSLAND.