Report on the Hartz Range

Ruby Mine Site

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Introduction

The following report is based on a preliminary photointerpretation of the area surrounding the Ruby Mine site made from 1:15000 colour air photographs on observations made during a period of two days (1st and 2nd April, 1981) at the mine site and surrounding areas and a brief inspection of some thin sections of samples collected. This report is intended to describe and document the findings of our work, detail the conclusions postulated regarding the form, scale and possible origin of the mineralised zone, and outline our recommendations regarding the work presently being carried out by the Adelaide University M.Sc. student, Mr. R. W. Lawrence.

Preliminary Photointerpretation

The photointerpretation map (fig. 1) was made on overlays of the 1:15000 colour air photos using a Carl Zeiss Stereo Interpretoscope. The following notes and conclusions derived from the interpretation were tabulated prior to our field excursion in order to increase our understanding of the large scale geologic pattern and to expedite planning of the details of the excursion.

Notes on preliminary photointerpretation - Hartz Ranges.

1. Most dips are of well developed layering, mainly observed on dip slope surfaces. Most dips are shallow (<45°), many regionally subhorizontal. General strike is roughly north-south with most dips inclined to the east. Some westerly and northerly dips present.

2. Plunges are observed by intersection lineations on northerly dipping surfaces. Plunges typically shallow (5 - 10°) to the north.

3. Very prominent system of white, presumably qtz-feldspar pegmatites variably distributed across the map. Post tectonic, they trend almost due E-W with vertical to steep N. dips. Generally more resistant to erosion they stand up as ridges. (Shown in red on map).

4. Few major fracture lineaments observed on the map. General trends are NE-SW, SE-NW or E-W parallel to pegmatites. Not generally observed displacing layering, but probably more are present as evidenced by frequent linear scarps (shown in green on map).
5. Central area of map is generally well layered with colour layering of 100 m. to 1 km. apparent thickness. Stratigraphy should be able to be worked out especially with limited ground control (see later).

6. Mainly peripheral areas of v. homogeneous probably orthogneissic or granitic lithologies. Some, e.g. in the east, with prominent fracture orientations. All cut by pegmatites or fractures. Possibly either syntectonic or presectonic plutonic bodies (domes?) or recumbent sheets within layered sequences. Margins generally concordant.

**Lithological Distribution and Stratigraphy**

From our joint fieldwork, a preliminary sketch map showing the distribution of lithologies was produced for the areas immediately adjacent to the mine (see fig. 2).

Depending somewhat on the validity of the structural interpretation (see below) the following sequence of lithologies is suggested:

- **> 100 m.** upper amphibolite - olive brown hornblende, plagioclase, with abundant accessory sphene.

- **20 m.** garnet-sillimanite-biotite-plagioclase-quartz gneiss (metapelite)

- **20 m.** plagioclase-rich gneiss - scattered olive hornblende and/or cummingtonite and accessory corundum (= ruby) and spinel - encloses lenticular bodies of ultramafic rock of variable size (2 - 10 m diam?) - the ultramafic rock consists of an intergrowth of the amphibole cummingtonite and iron poor chlorite and some talc.

- **>100 m.** lower amphibolite - hornblende and plagioclase ± garnet and sphene

The form and distribution of the major lithologies is to a large extent controlled by the complexity of geological structure in the area (fig. 1). This structural pattern has been divided into five main periods of deformation each of which is characterised by a distinct style of structural development.

The large scale interlayering of distinct lithologic units described in the previous section (and shown in fig. 2) is likely to be part of a larger stratigraphic sequence on a more extensive scale throughout the area (as illustrated
in fig. 1). This sequence which is largely recumbent is the primary cause of the interesting and apparently complex geological outcrop pattern outlined on the preliminary photointerpretation map (fig. 1). On the scale of the map (fig. 2) in the vicinity of the mine, it is unlikely, due to the nature of the lithotypes present, that the large scale layering defined by major lithological boundaries, reflects either a single stratigraphic sequence or represents in a sedimentary/stratigraphic sense simple sedimentary formations. The recognition of early complex structures in the sequence substantiates this view.

In the brief inspection of the mesoscopic structures of the area, the earliest visible structure is a moderate well developed metamorphic fabric ($S_1$) observed only in pods of ultramafic and plagioclase rich gneiss in the plagioclase rich gneiss unit. The $S_1$ fabric was recognised as early by its discordant relationship to both the pod margins and the strongly developed external foliation (see figs. 3 and 4). The $S_1$ orientation was further striking in that the discordance with the generally flat lying external foliation led to it having a uniformly steep inclination.

As the later recumbent structures are so pervasive and intensely developed, no $D_1$ (i.e. associated with the first deformation) structures other than the $S_1$ fabric are expected to be found. However, on the map scale, $D_1$ major fold hinges (which would undoubtedly be highly transposed) and/or tectonic dislocations (slides) might be present, and if so, would be important in tracing the continuity of lithologic units and in the recognition of stratigraphic correlations e.g. inverted sequences, both of which would be important in delineating the mineralised horizon.

On a smaller scale, the detailed microstructure of the $D_1$ fabric ($S_1$), especially in relation to the mineral assemblages present (including corundum) would help to further elucidate the possible origins and time of formation of the mineralisation.
Fig. 3 Quarry section with boudins of ultramafic and layered mafic gneiss. Boudins show an echelon arrangement and steeply inclined $S_1$ fabric. Horizontal layering and $S_2$ fabric.

Fig. 4 Lower ultramafic boudin with inclined discordant $S_1$. Upper well layered plagioclase rich gneiss with train of tabular boudins containing oblique $S_1$. 
The dominant layering and foliation on all scales in the area, and the most complex structures, appear to have formed during a second period of intense recumbent deformation ($D_2$). This deformation is thought to be the main event over much of the Hartza ranges.

On the macroscopic scale, $D_2$ is thought to have caused the flattening and parallelism of all earlier discordances to produce the well layered continuous parallel lithological units now observed as a single sequence within the mine site area (see fig. 1 and 2). The recognition of major recumbent $F_2$ folds, which must be isoclinal and would consequently produce large scale sequence inversions and other structures, such as major axial plane discontinuities (slides), is a task which could only be accomplished by detailed structural mapping of the area around the mine site. (This is one of the main facets of the work currently in progress by Mr. Lawrence).

On a small scale the main product of $D_2$ was an intense and pervasive tectonically produced layering and layer parallel fabric. The form of the layering is largely dependent on the form of pre-existing structures and that of the fabric is compositionally controlled. It is likely that features such as relict bedding or igneous layering, migmatitic veining, pillow structures and other preexisting structures are masked by the pronounced $D_2$ flattening and attenuation (see figs. 5A and 5B).

In the amphibolites, garnet-biotite-sillimanite gneisses and the plagioclase rich gneiss, the layering develops on a uniformly fine scale of 2-5 cm alternations. Layering is largely compositional with alternating concentrations of amphibole and plagioclase in the amphibolites and plagioclase rich gneiss. However, occasional grain size dependent layering occurs in the plagioclase rich gneiss, possibly reflecting the deformation of early (post $D_1$, pre $D_2$) migmatitic veins. Within the plagioclase rich gneisses some thin layer parallel amphibolite bands (fig. 5c) may represent early mafic dykes.
Fig. 5a - Flattening and curvature of layering in plagioclase rich gneiss around a partly hidden layered mafic body.

Fig. 5b - Complex interlayering of plagioclase rich and ultramafic gneiss with strong flattening fabric.

Fig. 5c - Plagioclase rich gneiss with fine layering, partly dyke and late offset porphyrite.
Parallel to the D_2 layering is a variably developed mineral and mineral aggregate preferred orientation (tectonothermal fabric) which is in the form of a regularly lineated foliation (S_2-L_2). This fabric is defined by amphiboles in the amphibolite, of sillimanite and biotite in the metapelite (fig. 6) and by platy corundum (ruby) and some amphibole in the plagioclase-rich gneiss. In most lithologies, however, and especially amphibolites and plagioclase rich gneisses, the dominant microstructure has a granoblastic polygonal form suggesting that the D_2 deformation progressed very slowly at elevated temperatures by the process of syntectonic recrystallisation.

The S_2 fabric and associated D_2 layering is generally near flat lying throughout the area, though some notable vertical "zones" occur and will be discussed later. The well-developed regular elongation/mineral lineation (L_2) in the S_2 foliation plane trends uniformly N-S.

Most D_2 minor structures were observed in the plagioclase rich gneiss unit, where the greater heterogeneity of lithotype (mafic/leucocratic variants), and of course the excellent exposures afforded by the ruby workings, combined to create an excellent display, of a variety of D_2 forms. The most important (economically) and most frequently observed of these features comprise the pods included in a variety of lithologies which together display all the characteristics of classic tectonic boudinage structures. The D_2 boudins consist of plagioclase-rich gneiss in both hornblende-biotite gneiss (fig. 7) and layered plagioclase rich gneiss (fig. 4), and of ultramafic gneiss and schist in plagioclase rich gneiss (fig. 4). Most boudins show little internal fabric, some have only a layering, whilst some contain the well developed S_1 layer parallel fabrics previously described (fig. 4). In many of the boudin sections (in the two dimensional quarry faces) observed the relationship between the recumbent external (S_2) enwrapping fabric and internal (S_1) steep fabric is dextral. However, sinistral fabric relations also occur, and the further detailed mapping of these vergence variations could help to elucidate the location of major D_2 structures. (It is again hoped that this is a task
Fig. 6  Fine layering and very strong S, fabric in biotite-garnet-sillimanite gneiss
Fig. 7 Upper biotite-garnet-sillimanite gneiss. To left, quartz layer flattened around elliptical band in plagioclase rich gneiss in hornblende-biotite gneiss. Centre, isoclinal fold of mafic - plagioclase gneiss boundary.
presently being undertaken by Lawrence). The recognition of D₂ fold domains via the mapping of vergence variations would be of great value in attempting to predict the location of ruby occurrences associated with the major mafic and ultramafic pods such as is shown in fig. 8a.

The association of ruby with the ultramafic boudins is obviously one of the most important economic features. Therefore, a greater understanding of these tectonic pods is vital to further exploration and exploitation of ruby at the mine site. The pods do not appear to have been previously recognised as tectonic boudins of D₂ age. It appears that the ruby was formerly recognised as being related to the upper areas of domes or arches above ultramafic pods of indeterminate origin. Their recognition as tectonic boudins has important implications, because of their morphology which must have a bearing on the possibility of finding other sites for the corundum. Boudins are typically known to be bilaterally symmetrical approximate ellipses in section. Therefore, the authors find no reason to doubt that if the upper parts are mineralised then the symmetrically opposite position on the lower parts of pods should be similarly mineralised (fig. 8b). Also in three dimensions boudins are known to vary from roughly oblate ellipsoidal pillow shapes to highly elongate flattened tubes. With the intensity of D₂ lineation as great as it is in this area, it is most likely that the latter form predominates, with the greatest length trending N-S (fig. 8c). Additional structural work (of R.W. Lawrence) should hopefully confirm this view which could be further substantiated by drilling or excavation.

The third deformation in the mine area appears to have produced a distinctive refolding of the D₂ fabric on horizontal or gently inclined axial planes with a uniformly N-S trending fold axis. Examples of the folds are not ubiquitous but occur in a variety of lithologies. In the amphibolites they are close-tight with a similar style (fig. 9). In the plagioclase
Fig. 8a - Possible large scale variation of $S_1$ and $S_2$

Fig. 8b Location of mineralisation associated with boudinage

isolated pods
(pancake)

chains of pods
(chocolate tablet)

flattened tube
(most likely for Harz Ranges)
Fig. 9 Similar style, angular, tight F₃ fold in finely layered amphibolite. Note recumbent axial plane. Fold plunges shallowly northwards.

Fig. 10 Plagioclase rich gneiss with asymmetrical angular F₃ folds.
rich gneisses they appear to be more geniculate in form, a feature which illustrates their character as typically asymmetric folds (fig. 10). An important character of the $F_2$ folds is that they refold all earlier structures but develop no new axial planar fabrics.

On a large scale $D_2$ folds are characterised by the production of N-S zones of steeply inclined layering and $S_2$ layer parallel fabrics which reach up to a few tens of metres in width, trending N-S. This rapid upturning of the layering around presumably the hinges of major $D_2$ folds is responsible for the dramatic and often confusing patterns of air photo trends and the outcrop patterns of the major lithological boundaries which can be clearly seen in figs. 1 and 2. Detailed mapping of these folds, where possible using minor fold vengence criteria, should assist greatly in understanding the significance of the overall stratigraphy, and in tracing the continuation of the ore horizons, if desired, underground.

The structures associated with the $D_4$ deformation can only be assumed from their apparent effect on the earlier structures. As such at this time it is not clear whether they can actually be proposed as belonging to a separate deformation phase (separate from $D_3$) or whether they represent merely a continuation of the $D_3$ event. $D_4$ would be represented by the very large scale and open upright warping of the recumbent stratigraphy about a shallow plunging to horizontal north-south trending axis. It would be responsible for the overall change from shallow easterly dips in the east of the area to shallow westerly dips in the west of the area, (see figs. 1 and 2) as these dips also involve a change in the inclination of minor $D_3$ axial planes. Further work should clarify this position.

The final deformation labelled $D_5$ is represented by a distinct set of E-W trending open warps of the earlier structures. On a small scale they appear to warp the layering (plus $S_2$, $L_2$, $F_3$ and presumably $F_4$) into 10-15°
northerly or southerly inclinations (fig. 11) and on a large scale are obviously responsible for the major culminations and depressions through the area.

Ruby occurrence

Very little ruby was seen during the two day traverse of the mine area. From the few occurrences that were observed, however, and from the nature of samples stockpiled near the campsite, it is obvious that the host rock is the plagioclase rich gneiss. Within the plagioclase rich gneiss a further limitation on the distribution of the corundum (=ruby), as already noted, is its restriction to the vicinity of the ultramafic "bodies" within the plagioclase rich gneiss. It was further noticed that at the contact between the ultramafic rock and the plagioclase rich gneiss, thick (up to 10 cm. diameter) masses of green brown hornblende are commonly concentrated, particularly at those localities where ruby occurs, in the plagioclase rich gneiss. In some places, also, ruby is actually in contact with the green brown hornblende concentrations and even enclosed by the hornblende.

Crystallisation of the ruby is considered to result from interaction of chlorite in the ultramafic pod and calic plagioclase in what is now the plagioclase rich gneiss. A reaction somewhat as follows is postulated

\[
\begin{align*}
\text{Mg}_5\text{Al}_2\text{Si}_3\text{O}_{10} \text{(OH)}_8 + 2\text{CaAl}_2\text{Si}_2\text{O}_8 + \text{Ca}_2\text{Mg}_5\text{Al}_7\text{Si}_2\text{O}_{22} \text{(OH)}_2 + 3\text{Al}_2\text{O}_3 + 6\text{(OH)} \\
\text{chlorite} & \quad \text{Plagioclase} \quad \text{hornblende} \quad \text{ruby}
\end{align*}
\]

This suggests a retrogradation of the original ultramafic pyroxene to chlorite, perhaps during \(D_1\), and that \(D_2\), during which the ruby is thought to have crystallised, was a prograde event.
Fig. 11 $S_3$ surfaces of finely layered amphibolite with strong N\$S trending $L_3$ lineation. Surface and lineation warped by open upright non-cylindrical, E-W trending folds ($F_5$?)
Conclusions

In the ruby bearing area a distinct sequence of layered lithologies is recognised, viz. from top to bottom, upper amphibolite

meta pelite
plagioclase rich gneiss with ultramafic
boudins
metapelite
lower amphibolite

Ruby, where present, is found within the plagioclase rich gneiss in the vicinity of the ultramafic boudins and, also, within the boudins themselves.

At least five tectonic events, have affected the area. Schistosity within the ultramafic boudins is almost the only manifestation of $D_1$.

Boudinage of the ultramafic took place during $D_2$ which was responsible also for the development of the widespread layering.

In view of the apparent association of the ruby with the boudins, the shape and orientation of the boudins is important with regard to the locating of ruby occurrences.

$D_3$ was responsible for the macrofolding and the consequent distribution of the layered units in the area. The near-horizontal attitude of much of the layering and the vertical attitude in some places is a manifestation of large scale recumbent $D_2$ folds imposed on an earlier also near recumbent sequence.

Detailed mapping of the $D_3$ structures is essential for tracing the distribution, on the surface and for underground extrapolation, of the plagioclase rich layer.

Detailed mapping and description of the complex sequence of observed structures should be an invaluable aid to further exploration of the mineral potential of the area. An interesting feature noted was the general lack of clearly observable brittle fault structures with major transcurrent offsets. This fact should also be an aid to the interpretation of the structural geometry of the area as a whole.
Verification of the postulated reactions responsible for the crystallisation of the ruby must await further microscope study of thin sections and chemical analysis of rocks and minerals in the laboratory.
THE GEOLOGY OF THE HIGH/WHITE CONGLOMERATE OCCURRENCE AT NAKID HILLS, NORTHERN TERRITORY.

Prepared for MINE RES HQ
by K.G.G. Naffan, BA, DipGeoscience

OPENFILE
SUMMARY AND CONCLUSIONS

(1) Beneath the 'noll' and in the vicinity of the open cut in grid A, is the most promising area for continuing and potential economic production of ruby corundum.

(2) There have been two episodes of desilication between the ultramafic and the hornblende gneiss. Idioblastic corundum is associated with the major period of desilication which took place during the second period of isoclinal folding during D2.

(3) Although there is always a zone of desilication between the ultramafic and hornblende gneiss, corundum is a comparatively rare, spasmodically occurring phase. Often the corundum is highly flawed and/or of inferior colour to be of economic significance; this is especially so with respect to the present mining situation involving heavy machinery. A gouging operation involving three to four personnel would be more appropriate.

(4) Visual inspection of ultramafic outcrops is not sufficient to determine if they are likely to be of economic significance.

(5) The mine sequence within the mitchell amphibolite has been subjected to several periods of metamorphism due to stress. The author recognises at least four and possibly six events:

D1 - tight isoclinal folding of gneisses and intercalated sediments. Folding was contemporaneous with the high grade regional metamorphism of the stratigraphic sequence to hornblende gneiss facies assemblages.

D2 - second period of isoclinal folding which resulted in the tight folding of the hornblende gneiss and ultramafic. A second period of desilication took place during D2, resulting locally in the formation of ruby corundum.

D3 - tectonic folding.

D4 - east-west folding.

D5 - north-south folding.

D6 - regional tilting of the stratigraphic sequence towards the north.

D1, D4 and D5 may have been contemporaneous in nature.
Harts Range forms part of the northeast portion of the Arunta Block. The Arunta Block consists of an extensive complex of early Proterozoic (possibly older) sedimentary and igneous rocks which have been subjected to complex deformation and metamorphism, accompanied by intrusions of granitic and mafic rocks, and liquidation. The regional stratigraphic sequence exposed in the Harts Range is shown in Table 1.

**Table 1  Regional Stratigraphic Sequence**

<table>
<thead>
<tr>
<th>Ghaly Shale</th>
<th>纹理 Shale</th>
<th>Riddock Amphibolite</th>
<th>Arunta Shale</th>
<th>Shita Shale</th>
</tr>
</thead>
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(a map to be provided which shows the relationship of these units)

**Site 2, July**

The stratigraphic sequence exposed at the mine site is a section of the Riddock Amphibolite. The Riddock Amphibolite consists of a sequence of intercalated sediments and basic volcanics which have been regionally metamorphosed to hornblende granulite facies. The Riddock Amphibolite is situated on the western flank of a much larger intrusion, the Iukamulla Dome.

Major rock units of the mine sequence consist of the Upper Amphibolite, Diorite-Granite-Silicate Schist, Iococratic to Mafic Amphibolite-Hornblende Schist (locally hornblende gneiss), Diorite-Granite Schist, Lower Amphibolite, Calc-Silicate (has a variable mineralogy), and Psammite.

The mine sequence is a remarkably consistent sheet which has been warped and folded, with minor faulting. For a more detailed description of the mine sequence see legend of detailed 1:500 geological maps (in final preparation).
Dr. Brown is presently preparing a comprehensive report on the structural geology. Accordingly, only a brief account will be given here. The first episode of deformation (D1) was extensive, with isoclinal folding resulting in a well-defined foliation (S1) at a small angle to bedding or lithology (90°).

Folding, episode D2 (F2), consisted of complex, steeply plunging, to vertical, asymmetrical, similar isoclinal folds. Later deformation was consistent of superimposed east-west, central, and north-south folds, followed by regional tilting towards the north.

**Figure**  
*Structural East-West Cross-section Of Riddock Amphibolite*

Structural analysis of S1 orientations indicates that the mine sequence is plunging at about ten degrees towards 355 degrees. In addition, the analysis of S1 shows that there is a pitch reversal of the east-west fold axis, which has been cross folded by the north-south fold system. Since there is no obvious pitch reversal concerning the north-south fold axis, it may be concluded that the east-west folding is of an earlier generation.

**Salient Features of Sections**

**Cross-section 7510 N from 4750 E to 5240 E**

(a) Shows open north-south folds.

(b) Most of the ultramafic horizon has been weathered off.

(c) Where the ultramafic horizon was not present, it could be intersected within a day.
Cross-section along 322° E, from 310° E to 312° E 
(a) Shows general folding, the top of the swell is within the fold axis. 
(b) Also open northsouth folds. 
(c) Where the ultramafic horizon has not been weathered off, the ultramafic horizon would generally be intercepted at a depth of less than five metres, and up to a depth of approximately ten metres.

SECTION OF THE ROCKS AND MINERAL OCCURRENCES

Rocks and very occasional has formed at the contact between the ultramafic and the hornblende gneiss.

Description of Ultramafic

The ultramafic is a dense dunite or sill, originally only a few metres thick. Locally, the ultramafic has been thickened and folded, and on the north side it has been thinned due to tension. Notwithstanding these variations, the mineralogy and mineralogy in the ultramafic rocks, the mineralogy is remarkably consistent. Essential mineralogy consists of varying proportions of green amphibole, chlorite, minor feldspar, and carbonate. Texture varies from fine to coarse grain; coarse enclaves of chlorite are not uncommon. A well-developed foliation is a prominent feature in surface outcrops, in addition to one or two lesser-developed fracture cleavages. The most prominent foliation is usually at a much higher angle than the orientation of compositional layering, in the enclosing hornblende gneiss, and is commonly deformed in response to the central and north-south folds.

Originally, the ultramafic was most likely a pyroxenite which was intruded into a sedimentary pile at depth in the crust.

See accompanying appendix for an overview of ultramafic and related rocks.
Description of Normalite Group

Controversy exists concerning whether this unit is of sedimentary or volcanic origin. Field evidence suggests that this unit is most likely a sediment, possibly an impure limestone with scattered quartz-feldspar lenses rich in ferromagnesium minerals as opaques. Evidence supporting a sedimentary origin is listed below:

1. The normalite schists contain a coherent lens of fine-grained quartz - feldspar - plagioclase granite which exhibits a pelitic clastic texture.

2. Schists derived from pelitic schists occur above and beneath the normalite amphibolite.

3. There is a gradual change in mineralogy and texture between the normalite schists and the pelitic schists (i.e., biotite - garnet schists, sometimes with aluminite as an additional phase). The schist at the top grades into relatively more basic granitic granulite schists, which in turn grades into granulite-metamorphic gneiss.

In the normalite gneiss we also see a intrusive, a sharp, well-defined contact such as that between the gneiss and the ultramatic rocks of exposed between the schist and gneiss. Lines and lenses of more basic composition with garnet as a common additional phase are common throughout the normalite gneiss, such bulk changes in chemical composition are compatible with this unit having a sedimentary origin.

The mineralogy and texture of the normalite gneiss varies along and across strike. Textural variations include typical gneissic banding and granulose textures. When the texture is granulose, the normally well-developed foliation is absent.
other known occurrences:

1. Corunum - kyanite hornfels, King Island, Tasmania
2. Corunum - spinel - anthophyllite - cordierite - clinohlore regional metamorphic from Tooyab, western Australia.
3. Corunum - spinel - pelidasp hornfels, Mount Painter, South Australia.
5. Corunum and gem quality sapphires of various colours occur as xenocrysts in volcanic plugs of the Mount Hoy basalt in Central Queensland, where they are won from ancient river gravels.

Corunum is a common accessory mineral in metamorphic rocks such as limestones, schists and gneisses. It may be an original constituent of silica deficient rocks such as basalt, gneisses, granites, and as magnetic segregations in other quartz free igneous rocks.

The most common corundum forming process is associated with desilification reactions between acid and more basic rocks. The reaction occurs at the contact between the two rock types. Corunum has been found in large masses in zones separating peridotites from adjacent country rocks. In the Transvaal, corunum occurs as veins where basic rocks have cut pegmatites.

The formation at corunum at Australia's north range prospect has been derived from a desilification reaction between the leucocratic, hornblende gneiss and the ultramafic.

Nature of the desilification reaction at north range

There is a notable difference between the ruby occurrence at Hart's Range and other corunum formations derived from desilification. At the mine site most of the corunum has been produced during D2. The major zone of desilification is between the hornblende gneiss and ultramafic where the two rocks have been tightly folded together during the second period of isoclinal folding. Very little corunum has been derived from initial desilification between the gneiss and ultramafic when the latter was first intruded. Accordingly, the result has been two distinct generations of corunum formation.
First generation ruby corundum is generally very pale in colour and highly inclusion-free. It occurs as rare irregular masses, and its occurrence is rare.

Second generation ruby corundum is strongly associated with the E2 isoclinal folds where extensive dessication has occurred. The anorthosite rock which is a product of this alteration commonly contains large idiomorphic porphyroblasts of ruby corundum. The hexagonal crystals range in size from half a centimetre to five centimetres in diameter. The smaller crystals are most common, and are usually only three to four millimetres thick. Hexagonal crystals exceeding one centimetre in thickness are rare. Idiomorphic crystals rarely occur in the hornblende-rich rock where it mainly occurs as large irregular masses.

E2 isoclinal folds are so tight that the hornblende gneiss has sometimes been pinched out so that it occurs as boudins and lenses. Temperatures and pressures during metamorphism of this region have been more than sufficient for the observed reaction to have taken place. Temperature and pressure in the Valley more area reached 700 degrees centigrade with a confining pressure of between 7 and 9.5 kbar at the peak period of metamorphism. Corundum is a stable phase above 50 degrees centigrade. During this intense period of metamorphism the hornblende gneiss has reacted with the ultramafic rock to produce two distinct zones.

Zone A Rarely exceeds five centimetres in thickness adjacent to the ultramafic. This zone is essentially composed of coarse laths of matted green amphibole (up to 1 cm in length) 50 to 70 percent, plus idiomorphs 30 to 40 percent, carbonate five to ten percent, and irregular shaped ruby corundum usually less than five percent.

Zone B Very hard anorthosite rich zone with less than five percent carbonates. This zone may contain up to ten percent idiomorphic porphyroblasts of corundum. The zone varies in thickness from several centimetres to half a metre. Extreme hardness of this zone makes it difficult to release the crystals without damage to them when breaking the anorthosite up. However, this material is suitable for sale as specimens. Amphibole in this rock is fine-grained and green in colour, in contrast to the black amphibole which occurs in the hornblende gneiss away from the zones of dessication.
Although the development of corundum is closely associated with Fe-Ti oxide, it is not always present in zones of desilicification. The ultramafics next to the shall have so far been barren of corundum, even though there are extensive zones of desilicification associated with nodular Fe-Ti oxide. Ultimately, geochemistry has controlled the distribution of corundum within zones of desilicification.

Figure: Distribution of Corundum

- Generally barren of ruby corundum, hard band, 5-15 cm in width.

- Hard, anorthosite containing hexagonal ruby crystals (Zone A)
  - Coarse amethyst, plagioclase carbonate rock, contains rare hexagonal crystals, but frequently contains larger irregular masses of corundum (Zone A).

Both generations of corundum have probably been derived from the desilification of calcium plagioclase in the hornblende gneiss:

\[
\text{Ca}_3\text{Al}_2\text{Si}_3\text{O}_{12} \rightarrow \text{corundum} + 3\text{SiO}_2 + \text{Ca}_2\text{Ti}_2\text{O}_7 + \text{H}_2\text{O}
\]

Corundum and quartz cannot coexist unless the corundum is encased against attack. Evidence suggestive of the above reaction is indicated by sericite coatings around most corundums and by the dolerite presence of carbonate which has filled the diapiric gashes in Zone A. Free silica produced during the reaction was probably taken up by the crystallisation of the coarse olivines and secondary anorthite. Corundum cannot crystallise until there is an excess of aluminium over that required to combine with silica to produce plagioclase felspath or an aluminosilicate. Where there has not been an excess of alumina, corundum has not been produced. The secondary reaction and chemical equilibrium for the formation has occurred at random, or at least seemingly so.
The colour of the corundum is a function of the amount of chromium present during crystallisation. Many of the corundums show colour zoning which indicates that the amount of chromium which could be scavanged during crystallisation was variable.

**Alteration of Corundum**

Alteration of ruby corundum to pale bright green diasporite is not uncommon. Alteration may be partial or complete. Diasporite is a hydrated aluminium oxide and is a product of hydrothermal alteration.

\[
\text{CORUNDUM} + \text{WATER} \rightarrow \text{DIASPORITE}
\]

\[
2 \text{Al}_2\text{O}_3 + 2 \text{H}_2\text{O} \rightarrow 2(\text{Al}_2\text{O}_3\cdot 2\text{H}_2\text{O}) + 3\text{OH} + \text{oxygen}
\]

Although the above reaction is reversible, the reaction has proceeded from left to right as evidenced by corundum cores in diasporite. This phase of alteration has contemporaneous with boron metasomatism which has resulted in local alteration of the anorthosite to tourmaline. It is proposed that this hydrothermal alteration was coincident with the emplacement of the pegmatite sykes during the Alice Springs Orogeny. Accordingly, tourmaline is not a guide to the likely occurrence of corundum which it postdates.

**Deformation of Corundum**

It is rare for the corundum to be free of fractures. First generation corundum has been subjected to several periods of deformation and usually occurs as euhedral fragments. Second generation corundum has crystallised in a stress field which is why the anatexial crystals occur as thin plates. Early formed second generation crystals were probably fractured due to continued folding during P2, and then subjected to further deformation during subsequent periods of folding. It is postulated that corundum relatively free of flaws probably crystallised late during P2, and was not adversely affected by P2 isoclinal folding. Anatexial crystals from the most southern workings commonly show deformation in the form of warped plates.
The detailed 1:50 000 geological map shows a number of outcrops of ultramafic. Geologically, that of the ultramafic has been reported due to high-grade mineralization. Although the ultramafic immediately west of the mine area appears to be barren of copper, considerable care is required in evaluating copper deposits of ultramafic. Visual inspection of outcrops is not sufficient to determine economic significance, nor is just outlining on the top. Outcrops must be continued before they can be fully evaluated. Figure 3 shows some that in this instance the rock would be at the surface, even in the top of the ultramafic has a vein. Accordingly, all known occurrences of ultramafic must be treated to determine the existence of diagenetic effects. Figures similar to those shown in Figure 3 were found, the zone of desilication must be prospected carefully for copper. Keeping in mind that since it occurs at random, the first cut across the zone of desilication may not show any sign of copper.

**Figure 3**

![Diagram](image)

The geometry of the contact between the ultramafic and hornblende gneiss is not well defined. The zone of desilication twists and turns in response to superimposed fold systems. It is not possible to predict in advance what the contact will do. The best method to prospect and mine this deposit is to follow ore-bearing desilication zones using labor-intensive exploratory methods. In addition, there is little likelihood that material not being noticed which can easily be missed; therefore, techniques are being used.
Appendix. Descriptions of Hand Specimens.

Sample Form No. 4 Cut - 29 meters 215 degrees from 4970E 9100N.

General Comment
At this locality the ultramafic has been tightly folded with the leuco-gneiss resulting in each rock type occurring as enclaved contained pods of one rock type within the other, or as zones where the two types are complexly mixed. Accordingly, on a macro scale, this relationship between the leuco-gneiss and the ultramafic has appropriately been described as a mixed zone, and this terminology has been used throughout this report.

Hand Specimen Descriptions

Sample 1 - Ultramafic: chlorite - amphibole schist taken from outcrop. Relatively unaltered dark green rock mottled with laths of black amphibole. Lepidoblastic chlorite and nematoblastic amphibole are oriented in the direction of the most prominent foliation (S1). Carbonate veins are common and roughly follow the S1 foliation; less commonly carbonate veins parallel to a less distinct parting normal to S1. Grain size is not constant and varies between fine and medium.

Sample 2 - Ultramafic and leuco-gneiss from the mixed zone taken from outcrop. Granular feldspar with minor chlorite, green amphibole, and pale pink corundum between two layers of ultramafic composed of medium to coarse grained nematoblastic green amphibole with fine grained lepidoblastic chloritic biotite. The corundum is partly altered to diaspore. The ultramafic layers are rich in carbonate which occurs in sheets sub-parallel to the S1 foliation.

Sample 3 - Ultramafic and leuco-gneiss from the mixed zone; this sample was float. This sample is a feldspar-chlorite- amphibole-carbonate rock containing rare hexagonal ruby corundum plates. A major feature of this rock is the occurrence of very coarse dark green amphibole laths which are up to 1 cm in length. The amphibole laths and the corundum approximately lie in the plane of foliation. In this specimen the coarse amphiboles form only one layer on the surface. Elsewhere the amphiboles, the coarse amphiboles were probably removed in reaction with water or other fluid. The rock appears to have been introduced after the finer amphiboles.
Sample 4 - Plagioclase - chlorite - corundum - biotite
granulite, this sample was float. This rock is probably
leuco-gneiss which has been subjected to further alteration.
Secondary chlorite and biotite occurs in the plane of
foliation, and has also crystallized in fractures in the
corundum. Some of the corundums are rimmed by diaspore,
indicating that they were not in equilibrium with the
introduced fluids.

Sample 5 - Ultramafic containing pale pink corundum.
This rock is similar to Sample 1, it is composed of fine
grained chlorite and amphibole with rare porphyroblasts of
corundum. The corundums are small - less than 5 mm. One
corundum is oriented normal to the plane of foliation and
is highly fractured, suggesting that the corundum probably
precedes the development of the foliation. This would be
expected if the corundum formed from a desilication reaction
between the leuco-gneiss and the ultramafic.

Sample 6 - This sample is almost identical to the next
sample which is described in some detail. However, this
sample contains more corundums than Sample 7; some of the
smaller corundums have been altered to diaspore, a bright
pale green mineral. This sample shows the zoning referred
to in the next description, and the fairly sharp contact
between the ultramafic and the leuco-gneiss.
Sample 7 - Float from No. 4 Cut.

A zoned enclave consisting of feldspar - chlorite - amphibole coronands.

This is an unusual sample, an important one when considering that McColl has reported that large masses of ruby coronand were associated with masses of tourmaline. Essentially this sample was a zoned inclusion (the sample has now been destroyed for further examination) consisting of three well-defined bands.

The outer zone consisted of idiomorphic tourmaline porphyroblasts, porphyroblastic calcite, and masses of fine to medium-grained tourmaline and feldspar grains resembling a sieve texture.

The middle zone consisted of fine-grained feldspar and minor fine-grained chlorite. The core of the enclave consists mainly of feldspar with thin layers of idiomorphic chlorite, minor scattered biotite and quartz, and green amphibole-rich regions with disseminated idiomorphic ruby coronand porphyroblasts, which have frequently been entirely or partially altered to diasporic.

This sample was either a leucocratic xenolith which reacted with the ultramafic-magma forming coronand from a desilication reaction and subsequently altered by hydrothermal metamorphism, or an inclusion produced by folding and plastic deformation which has been subsequently altered.

Evidence for hydrothermal metamorphism as opposed to penecontemporaneous alteration is based on boron metasomatism; alteration of coronands to diaspor by the reaction $2(Al_2O_3) + 2(H_2O) \rightarrow 2(AlO_2) + 2OH$; recrystallization of feldspar in the middle zone; and the development of locally coarse green amphibole.
Sample 6: Several samples of leucocratic plagioclase-amphibole - chlorite - corundum - granulite float.

This rock is easily recognised by its white, green appearance, higher specific gravity, lower degree of weathering and not so prominent foliation when compared to the leuco-gneiss. With the exception of tourmaline, all the mafic minerals are green or bronze in colour. These samples consist of granulose calcic feldspar with lepidoblastic chlorite and bronze mica (not positively identified), and nematoblastic dark green amphibole. Chlorite and a phylite occurs as thin layers in the granulose feldspar. The colour of the corundum varies between pale pink and ruby red; the latter colour being comparatively rare. With rare exception, the corundums occur as hexagonal plates, usually very thin, not more than two or three millimeters thick.

The orientation of 36 corundums relative to the foliation was recorded. Sixteen corundums lay in the plane of foliation, twelve were at a low angle to the foliation, and eight were approximately normal to the plane of foliation. Accordingly, it may only be fortuitous that crystallisation of the corundums appears to have been controlled by the foliation.

Sample 7: Corundum bearing ultramafic float. Chlorite and green amphibole are the dominant phases. Feldspar rich pockets are not uncommon, and carbonate commonly fills fractures. A considerable amount of corundum occurs in these specimens. However, it is of inferior colour, usually pale pink. It occurs as irregular masses and is often very fractured.

Sample 10: Leuco-gneiss from fifteen meters from the contact with the upper contact with the ultramafic. The rock is grey colour, generally fine grained, and consisting of alternating bands of granulose feldspar and bands rich in leuco amphibole. This specimen is moderately weathered and
Sample 11  Ecousgneiss from contact with the ultramafic pod. This rock is relatively altered, and parts easily along the foliation. Feldspars are partially altered to clay minerals, and secondary chlorite and green amphiboles are orientated in the plane of foliation. The feldspars are fine grained and exhibit granulose texture. Carbonate is present, and is mainly restricted to the planes of foliation. Although the contact between the two rock types is sharp, there has been considerable movement of fluids between the two. No ruby corundums were found along this contact.

See page 43 for description of sample 12.

Sample 12  Ultramafic from outcrop. The weathered surface is dotted by orange/brown iron staining. On a fresh surface the ultramafic is a light to dark green mottled rock consisting essentially of lopidoblastic chlorite and nematoblastic green amphibole. The sample is strongly foliated.

Sample 13  Corundum bearing anorthosite - a white medium grained rock consisting of greater than 75 percent plagioclase with minor disseminated fine grained chlorite. The texture is granulose. Corundum is pale to dark pink in colour and of poor quality. This sample shows a thin selvage of corundum partially altered to diaspora.

Samples A to D  see accompanying cross-section X-Y.

Sample A  Hornblende gabbro gneiss - a fine grained grey coloured rock consisting of granulose feldspar, nematoblastic black amphibole and fine disseminated bronze coloured mica or chlorite. This rock is very fissile.
Sample 2 Chlorite bearing amphibolite or plagioclase - chlorite granulite. This rock is generally fresh and extremely fine, grey in colour with patches of white coarser grained feldspar, with minor disseminated chlorite or epidote. Rare very fine grained red corundum can be seen with a hand lens. The tough nature and higher specific gravity of this rock suggests that it may be siliciclastics. However, corundum and quartz cannot co-exist unless the corundum is armoured by sericite or white micas; it is therefore unlikely that this rock contains free silica.

Sample 3 Ultramafic - pale to dark green in colour with orange/brown iron staining on the exposed surfaces. This sample is fine grained, and consists of chlorite, green amphibole, and minor carbonate.

Sample 4 Relatively unweathered hornblende gabbro gneiss; banded grey coloured rock consisting of fine to medium grained granulose feldspar with layers rich in nematoblastic black amphibole. An alternative name for this rock would be plagioclase - hornblende granulite, which reflects the grade of metamorphism that this sample has been subjected to.

Sample 5 Ultramafic - medium to coarse grained amphibole, biotite and chlorite. Biotite and amphibole occur separately as enclaves in chlorite rock.
Sample 12  From No. 2 Cut - 22 meters & 145 degrees from 5970 E 9610 N.
Three samples of ultramafic from outcrop.
(1) Pale green/greyish rock speckled with bronze coloured chloritic biotite. A fine grained massive rock consisting of matted, fibrous and sometimes green amphibole (probably actinolite ?), and chloritic biotite.
(2) A fine grained pale to dark green rock consisting of lepidoblastic chlorite and nesotoblastic green amphibole, and minor carbonate.
(3) Moderately weathered mottled schist - brown/brown-coloured rock mottled with small green boudins. The boudins are very fine grained and probably consist of chlorite with amphibole and epidote. Source: Lepidoblastic brown/brown-chlorite and/or chloritic biotite wraps around the green boudins.

Sample 16  Two samples from ultramafic outcrop, 4745 E 9030 N.
(1) Moderately dark green fine to medium grained rock consisting of lepidoblastic green chlorite and nesotoblastic dark green amphibole; iron staining occurs on exposed surfaces.
(2) Similar to (1) above. However this sample contains bands rich in a colourless fibrous mineral; possibly tremolite amphibole.

Sample 17  Ultramafic and related rocks from No. 3 Cut - 22 meters & 162 degrees from 5970 E 9520 N.
In general the ultramafic is moderately weathered and is typically a chlorite-amphibole-carbonate rock matrix pocket. A minor band of clearly serpentinised chlorite - magnesite - chlorite granulite (a
Specimens I and II: Highly brecciated anorthositic rock, very mottled in colour. Fine-grained discoloured chlorite and/or chloritic biotite. These samples contain pale pink/mauve corundum which has been badly fractured due to brecciation.

Specimen III: Medium to coarse-grained dark green lathy and fibrous amphibole; a sample from a hornblend e enclave.

Specimens IV & V: Samples from the mixed zone; feldspar and quartz? rich bands in fine to coarse-grained matted dark green amphibole with minor chlorite.

Specimens VI & VII: Weathered, fissile ultramafic from outcrop.

(VI) Green, bronze in colour consisting of bronze chlorite and/or chloritic biotite, minor feldspar and carbonate, and a fine-grained granular clear green mineral, probably epidote.

(VII) Highly fissile dark green rock stained with iron oxides. This rock consists mainly of chlorite and green amphibole.

Sample 10: Corundum bearing enclave and ultramafic samples from 5120 E 9093 N.

(10A) Highly brecciated crumbling plagioclase - chloritic biotite granulite, with pale pink corundum. Not only is the corundum of inferior colour it has also been brecciated into small fragments.

(10 B) Three specimens of ultramafic outcrop.

(1) Highly brecciated soft rock consisting of granular feldspar, nonclastic green amphibole and lepidoblastic chlorite.

(10 C) Highly weathered green fissile rock, mottled with patches of yellow/brown iron staining. The pale colour is due to a high carbonate content which fills many of the cleavage fractures. The green colour is due to fibrous amphibole and chlorite.
Sample 12: Ultramafic outcrop from 4740 E 9085 N.
Specimen 1: Relatively unweathered felsite, pale to dark green rock consisting of fine-grained epidote-chlorite and serpentine amphibole. A notable feature of this sample is an enclave of very dark green-black serpentinite enclosed in a felsite enclave in (1) above.

Sample 13: Ultramafic outcrop from 4647 E 9010 N.
Fine-grained felsite green rock with minor iron staining, consisting of epidote-chlorite and serpentine amphibole, with minor plagioclase and carbonate.

Sample 14: Ultramafic outcrop from 4635 E 9036 N.
Fine to medium grained felsite green rock with iron staining along fractures. Mineralogy consists essentially of epidote-chlorite and serpentine amphibole.

Sample 15: Ultramafic outcrop from 4704 E 9010 N.
Similar to #1 above, with minor feldspar and carbonate.

Sample 16: Three samples from mixed zone along southwest track, site of aboriginal diggings. These samples are fresh, and on a hand specimen scale may be appropriately termed hornblende granulites. The amphibole is very dark green almost black, which is in contrast to the green amphibole usually found in the mixed zone. Pale pink fractured cordierite is common in the ultramafic which consists of epidote-chlorite green chlorite and serpentine dark green amphibole.