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Description of Drill-hole T129V Core from the Jabiluka Unconformity-type Uranium Deposit, Northern Territory, Australia

By

C. J. Nutt

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature

Introduction

The Jabiluka unconformity-type uranium deposit is one of four major unconformity-type deposits in the Alligator Rivers Uranium Field in the Pine Creek geosyncline, Northern Territory, Australia (fig. 1). The unconformity-type deposits occur as veins, breccia matrix, and disseminations in metasedimentary rocks of the Cahill Formation and are near a regional unconformity separating the Lower Proterozoic Cahill Formation from the Middle Proterozoic sedimentary rocks of the Kombolgie Formation. The deposit at Jabiluka consists of two orebodies: Jabiluka 1, the first discovery, and Jabiluka 2, the larger of the two orebodies.

The study of unconformity-type deposits--major sources of uranium that were discovered in the past 15 years in Australia and Canada--was part of the U.S. Department of Energy National Uranium Resource Evaluation (NURE) program. Pancontinental Mining Limited kindly gave Dick Grauch and I access to Jabiluka core and made their geological and geophysical data available for inclusion in our reports. Samples were collected from 19 cores. Data and interpretations from the study of Jabiluka should aid in defining characteristics and settings of these world class deposits and guild exploration for similar deposits in the United States.

This paper is a description of drill-hole T129V, located in Jabiluka 2 (fig. 2). Nutt and Grauch (1983) gave a description of regional and mine geology at Jabiluka; that paper provides the regional geologic setting of drill-hole T129V. Figure 3 shows the general stratigraphy of the mine sequence. T129V drill hole was drilled to a depth of 232 meters through the Kombolgie and Cahill formations. Figure 4 shows the north-south 129 cross section through Jabiluka 2 that contains drill-hole T129V. Both ore and barren zones were cored.

Description of the core consists of a stratigraphic column from 60 to 232 m (fig. 5), compiled from Pancontinental Mining Limited and my logging record; brief descriptions of minerals, identified by microscope, microprobe Energy Dispersive System (EDS), and powder camera; and thin-section descriptions from selected samples (table 1). Uranium distribution and veins are also described.

Rock types

The rocks in T129V are typical of the Jabiluka sequence (Nutt and Grauch, 1983, gave detailed descriptions of the rock types). The metamorphic rocks, consisting of quartz, chlorite, muscovite, and graphite in a matrix of chlorite and (or) sericite, are: chlorite schist, chlorite - muscovite ± sericite schist, chlorite - sericite ± muscovite schist, and graphite schist. These schists are fine grained with occasional pseudomorphs (most commonly chlorite after garnet) and coarse-grained muscovites and chlorites as large as 2 mm. Tourmaline-bearing pegmatite is the only recognizable igneous rock in T129V. Hybrid zones of mixed pegmatite and metamorphic rocks occur along pegmatite contacts. The Kombolgie Formation is a quartz-rich sandstone; above the unconformity, the sandstone has interstitial chlorite and cross-cutting veins of chlorite and hematite.

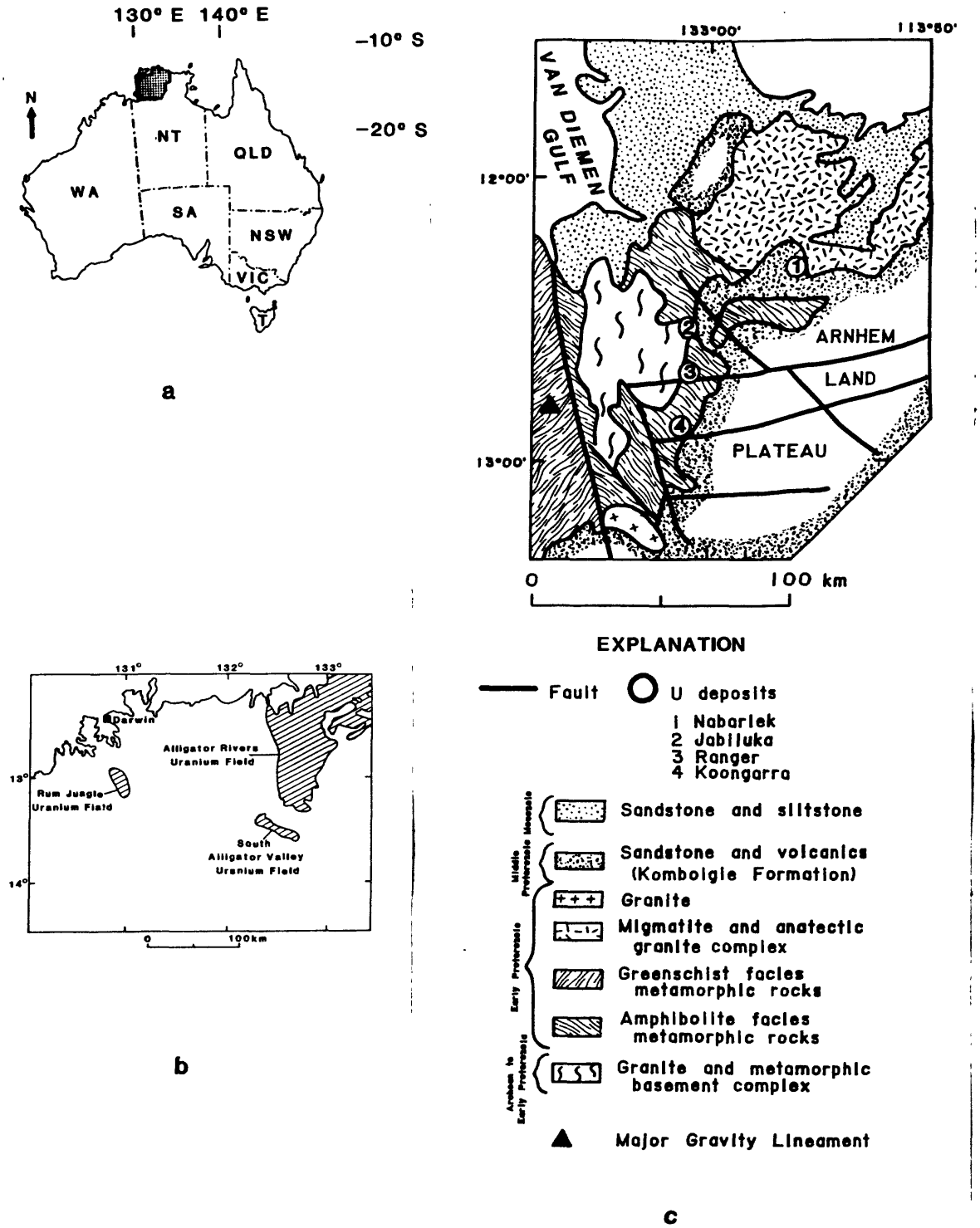


Figure 1. Locality maps of (a) the Pine Creek geosyncline, Northern Territory, Australia; (b) the Alligator Rivers Uranium Field in the Pine Creek geosyncline; and (c) the four major uranium deposits in the Alligator Rivers Uranium Field.

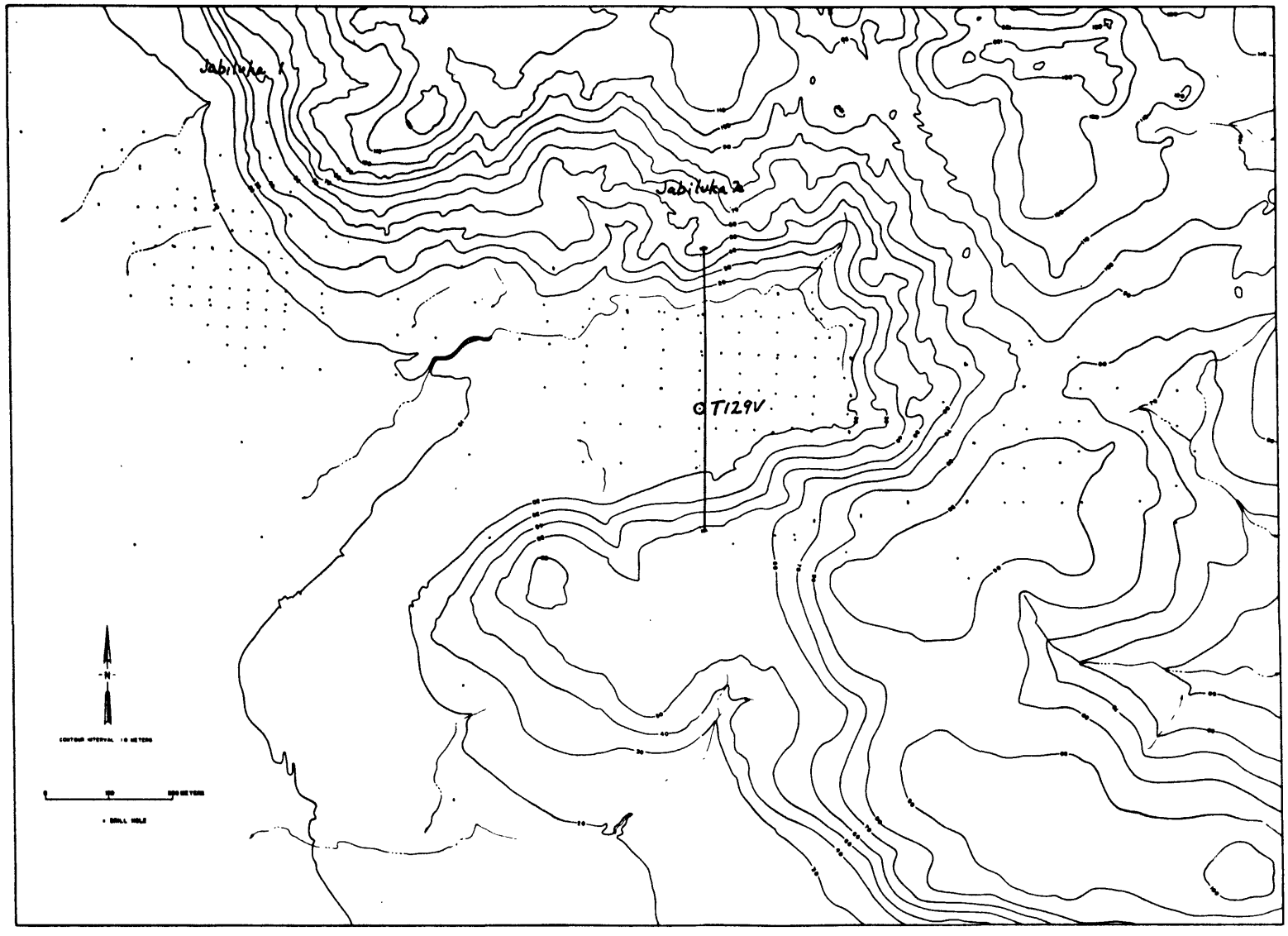


Figure 2. Drill-hole localities at Jabiluka. Sampled T129V core and cross-section line containing drill-hole T129V are shown. The figure is modified from Pancontinental Mining Limited map.

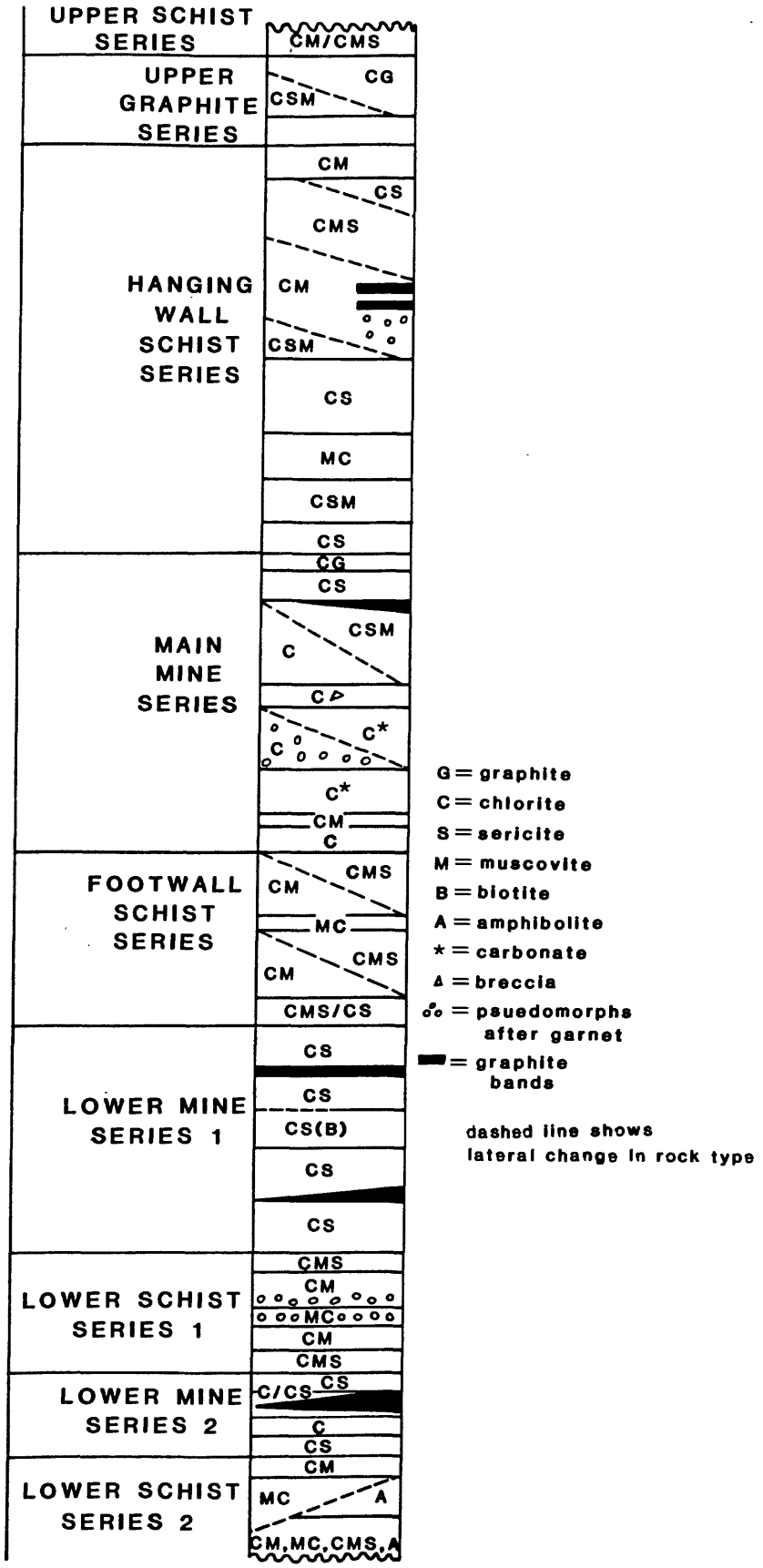
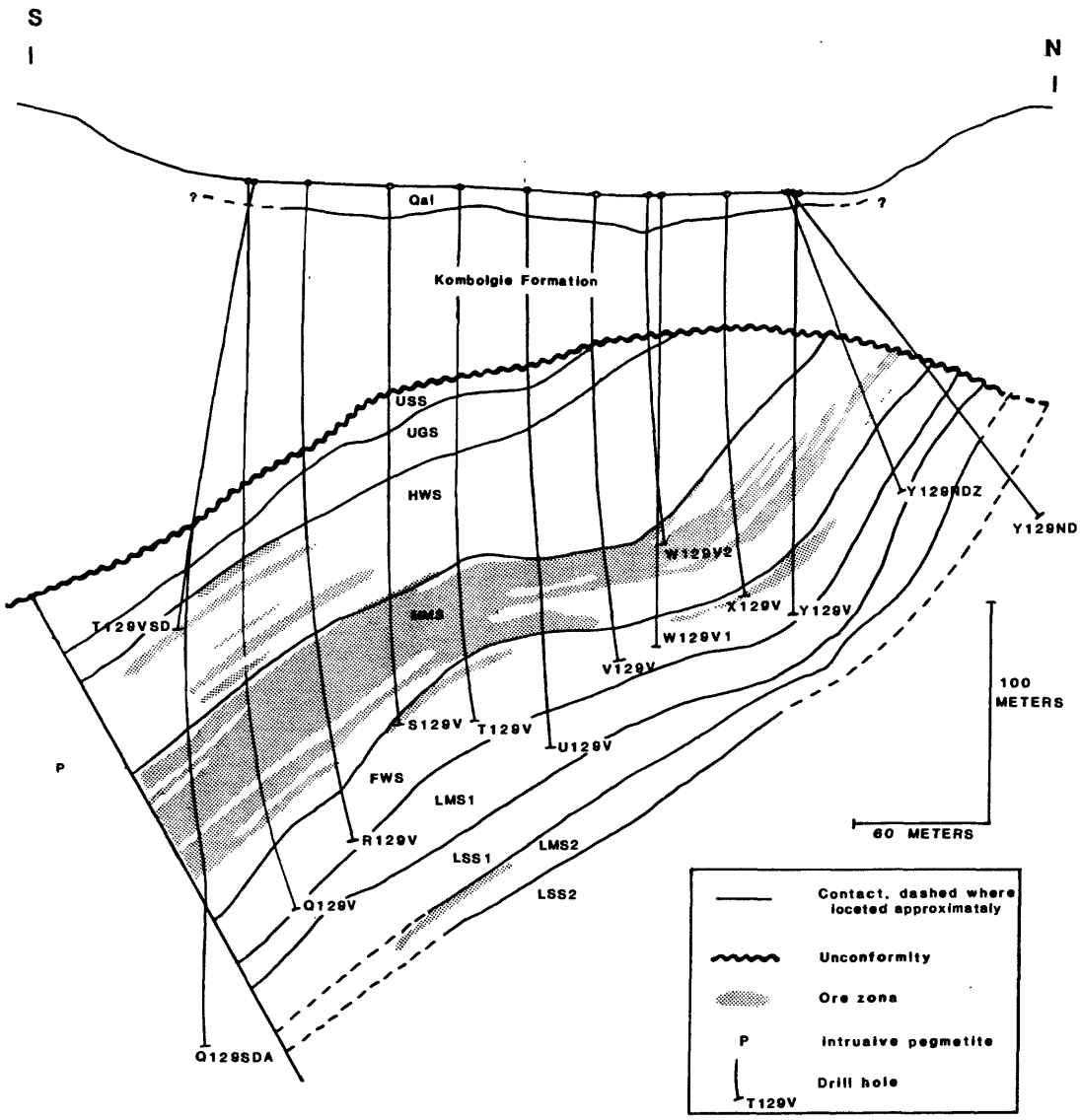


Figure 3. Generalized stratigraphic column from the Jabiluka deposit; modified from information supplied by Pancontinental Mining Limited.



Quaternary		Qal	Sand, soil
Middle Proterozoic	Kombolgie Formation		
Lower Proterozoic	Cahill Formation	USS	UPPER SCHIST SERIES
		UGS	UPPER GRAPHITE SERIES
		HWS	HANGING WALL SCHIST SERIES
		MMS	MAIN MINE SERIES
		FWS	FOOTWALL SCHIST SERIES
		LMS1	LOWER MINE SERIES 1
		LSS1	LOWER SCHIST SERIES 1
		LMS2	LOWER MINE SERIES 2
		LSS2	LOWER SCHIST SERIES 2
	Intrusive pegmatite	P	

Figure 4. Cross section along 129 section line. Locations of section and drill-hole T129V are shown on figure 2. Cross section is modified from data provided by Pancontinental Mining Limited.

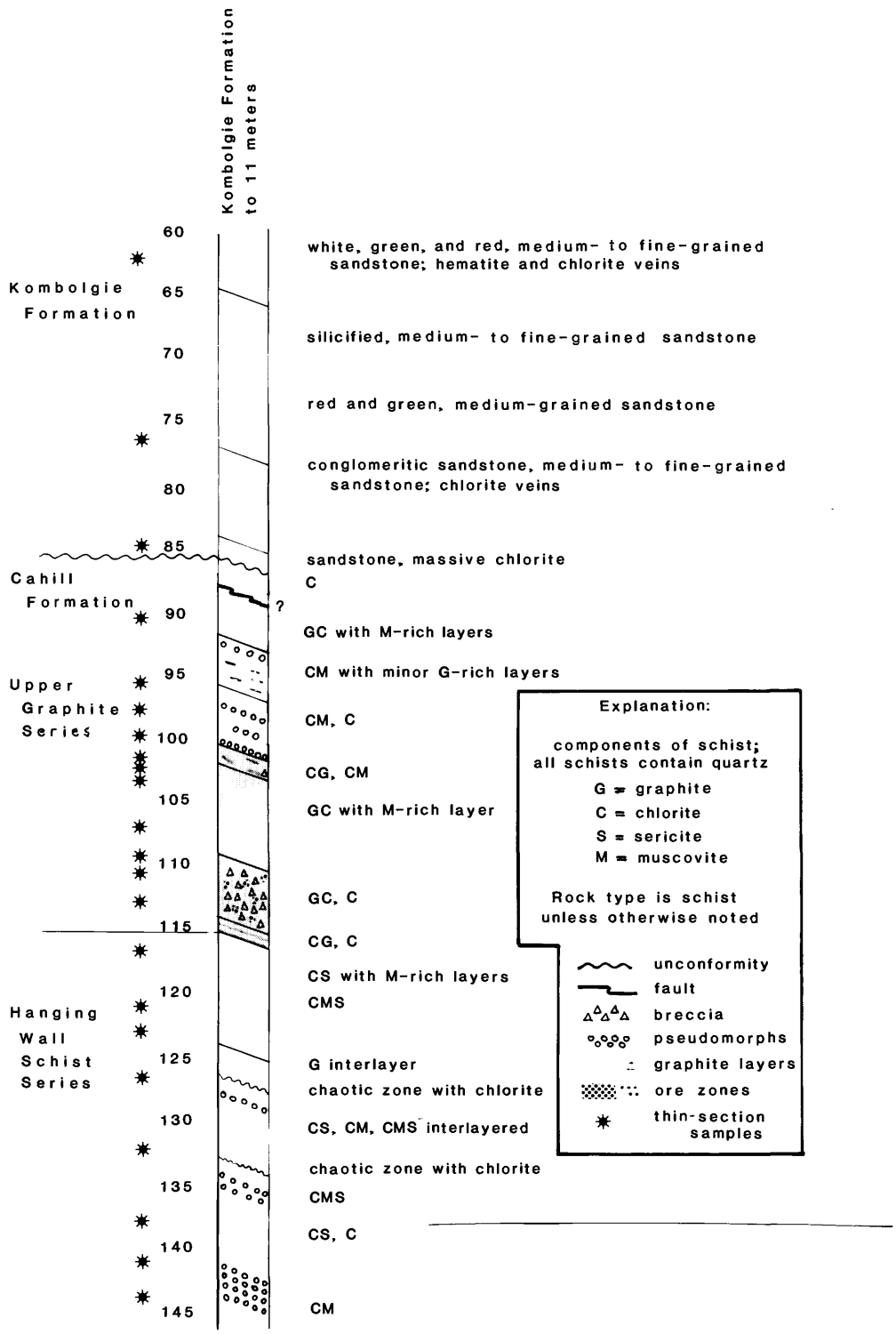


Figure 5. Stratigraphic column of T129V core shows predominant rock types from 60 - 232 meters.

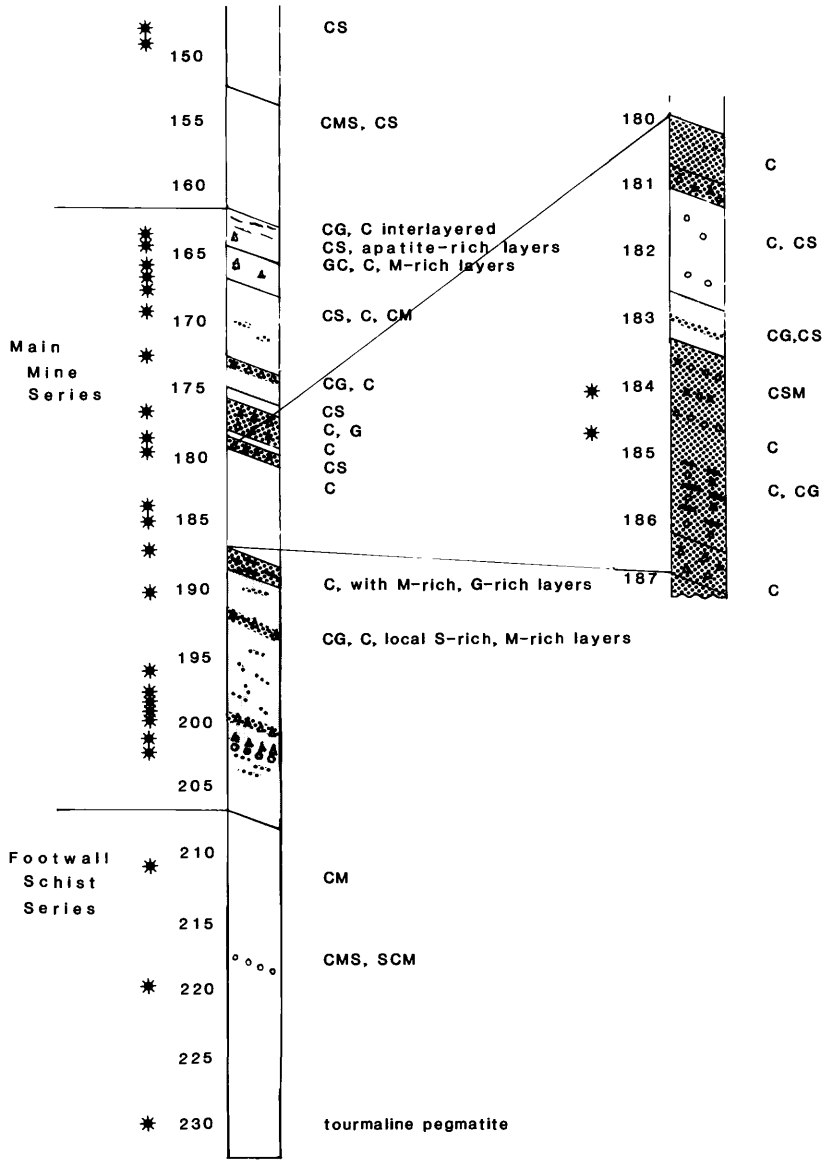


Figure 5 continued.

The metasedimentary Cahill Formation was multiply folded and metamorphosed to amphibolite facies during a 1,800-m.y. event. In the vicinity of the unconformity-type deposits, extreme chloritic alteration has affected the rocks, which now have greenschist-facies mineral assemblages. The degree of chlorite alteration is variable; rocks range from graphite schist or quartz-rich schist with <5 percent chlorite matrix to massive chlorite schist composed of 90-95 percent chlorite.

Ore, primarily uraninite and coffinite, is localized in highly chlorite-altered and (or) brecciated rocks. In T129V core, ore is concentrated in the Main Mine Series (fig. 5). The altered and brecciated areas, being more susceptible to the entry of fluids, have more veins--both barren and containing ore minerals--than the more coherent schists.

Mineralogy

The mineralogy of the Jabiluka rocks is fairly simple, consisting predominantly of quartz, chlorite, muscovite, sericite, septechlorite, graphite, and, present in lesser quantities, TiO_2 minerals, tourmaline, garnet, apatite, florencite, sulfides, organic matter, and uranium minerals. Multiple generations of most minerals, however, obscure mineral associations and paragenetic sequences. Included in the following descriptions are major silicate minerals, tourmaline, apatite, florencite, TiO_2 minerals, graphite, organic matter, and uranium minerals.

Quartz

Quartz, the major constituent of most of the Jabiluka schists, is commonly embayed and partially replaced by chlorite, and in many places is strained. The replacement of quartz by chlorite is highly variable, and, in some schists, both corroded and non-corroded quartz are present. Where adjacent to other quartz grains, quartz boundaries range from irregular to straight edges and locally triple junctions occur. Euhedral to subhedral quartz in the matrix is probably open-space filling; in some places this quartz is strained and (or) zoned. Rarely, quartz grains in the matrix contain dravite inclusions. This quartz-dravite association is found in late-forming veins and open-space filling, suggesting that the quartz with dravite inclusions may not be original metamorphic quartz but instead open-space filling in the matrix. Other than the dravite inclusions, this quartz appears similar to the other quartz in the schists.

Chlorite

Coarse chlorite

Coarse chlorite, from about 0.2 mm to 2.0 mm, has been grouped into a corroded pleochroic green to brown chlorite (coarse-chlorite 1) and a pleochroic green to yellow-brown chlorite (coarse-chlorite 2). Both chlorites have a low 2V (0-15) and negative sign, and are length slow. Coarse-chlorite 2 commonly has anomalous blue and purple birefringence. Titanium-bearing (rutile ?) needles are abundant in coarse-chlorite 1 and are present, but less common, in coarse-chlorite 2.

Coarse-chlorite 1, which was in some places identified as biotite in hand specimen, probably formed after biotite during retrograde metamorphism. Coarse-chlorite 2 replaces coarse-chlorite 1 in a few samples, suggesting that coarse-chlorite 2 formed later during a chlorite alteration event.

Matrix and vein chlorites

Fine-grained matrix and vein chlorites, forming as much as 95 percent of the rock, are light to dark green. These chlorites range in size from cryptocrystalline (that is, too fine grained to see distinct grains with the microscope) to about 50 μm, and can be separated into the general group sizes of cryptocrystalline, <15 μm, and 15-50 μm. In thin section, the color of the chlorites ranges from white to dark green. All are so fine grained (generally <25 μm) that optical properties, except for color and low birefringence, cannot be determined. The finer grained chlorites (<15 μm) are equidimensional, compared to the more elongate form of the coarser (15-50 μm) chlorites. Preliminary X-ray studies indicate that the chlorites are similar, although color differences suggest variations in iron/magnesium. Detailed powder camera and microprobe work might show structural and chemical differences.

Seven types of matrix and vein chlorite have been identified using color, size, and mode of occurrence. Although these divisions may eventually prove to be artificial or not applicable in other core studies, they are used here in the spirit of working hypotheses. The seven categories are as follows.

1) Undifferentiated, green to brown, cryptocrystalline to 15 to 50-μm chlorite is usually the matrix of rocks in the barren zones.

2) White to rarely light-green, cryptocrystalline to <15-μm chlorite is predominantly in breccias, commonly in the ore zones. In some samples, this chlorite has an irregularly distributed brown coating (septechlorite ?).

3) Light-green, cryptocrystalline, rarely <15 μm, chlorite is in veins and the matrix of rocks in the ore zones. This chlorite is associated with uranium minerals and coarse-chlorite 2. Within layers of the chlorite, quartz is extensively embayed.

4) Light-green, 15 to 50-μm chlorite is commonly with white chlorite in ore zones and breccias.

5) Green, 15 to 50-μm chlorite forms haloes around ore minerals.

6) Dark-green, 15 to 50-μm chlorite occurs in cross-cutting veins and pods in the other matrix chlorites, indicating it was emplaced late. The chlorite is found in both barren and ore zones and is only rarely associated with uranium minerals. Equant apatite, septechlorite, and white chlorite are associated with this dark-green chlorite.

7) Black to dark-green, <15-μm chlorite (?) is in cross-cutting veins and within pods of dark-green, 15 to 50-μm chlorite. This black material is tentatively labeled chlorite because chlorite is the only mineral, except for traces of septechlorite, identified using the powder camera. It may later be identified as a mixture of chlorite and (or) septechlorite and another mineral(s).

To summarize, the cryptocrystalline white and light-green chlorites are the most common chlorites in the ore zones. The white chlorite is commonly associated with the light-green 15 to 50-μm chlorite. Ore minerals are surrounded by green 15 to 50-μm chlorite. The dark-green 15 to 50-μm, black <15-μm, and, in some places, white chlorites occur in veins and pods cross-cutting the other matrix chlorites.

Septechlorite

Septechlorite is in veins parallel to and cutting across foliation, in pods within the matrix, and, rarely, in pseudomorphs. In hand specimen, the septechlorite is waxy light green. However, this appearance cannot be used as the sole criterion for identification because chlorite in some samples looks similar. In thin section, septechlorite is either brown and cryptocrystalline or white and 15-50 μm. Brown septechlorite occurs mixed with chlorites, especially the dark-green 15 to 50-μm chlorite. Both brown and white septechlorite veins cut across matrix chlorites, suggesting the veins were emplaced late.

Septechlorite is in both barren and ore zones. Although locally associated with coffinite, little correlation exists between uranium ore and septechlorite. In fact, radioluxographs show barren septechlorite veins in samples adjacent to ore.

Muscovite

Muscovite, both parallel and oblique to foliation, is common in the Jabiluka sequence. The muscovite-rich rocks, in many places containing chlorite pseudomorphs after garnet, are easily recognized by their silvery sheen. Muscovite grains are about 0.1 mm to 1.0 mm in length and have sharp to ragged boundaries. "Ghosts" of muscovite in matrix chlorite are observed with crossed nicols. In sample T129V-178.9, ragged muscovite defines a foliation at an angle to the dominant foliation of chlorite. In crenulated rocks, some muscovite grains are oriented along the axial plane of the small-scale folds, and kinked muscovites are present.

Muscovite and sericite are generally in alternating layers: rocks are either muscovite or sericite rich. The difference between muscovite and sericite in T129V appears to be a gradational change in size. Grains of embayed muscovite floating in sericite matrix suggests that, in some places, sericite has replaced muscovite.

Sericite

Sericite-rich rocks are very fine grained and dull green to yellow green. The sericite, <0.1 mm in length, occurs with chlorite in the matrix. Sericite is either disseminated in random orientations within the chlorite or is the dominant component of the matrix. Sericite also forms pseudomorphs after muscovite and potassium feldspar; the potassium-feldspar pseudomorphs consist of a cross-hatched pattern of sericite and chlorite.

In the T129V core, no apparent relationship exists between sericite and ore.

Tourmaline

Five types of tourmaline occur in the T129V core: porphyroblasts of colorless to straw-yellow tourmaline about 1 mm in diameter; fine-grained, green tourmaline; colorless tourmaline intergrown with carbonaceous blebs in

an ore zone; sprays of colorless dravite (as identified by powder camera); and blue tourmaline from 0.5 mm to 5.0 mm in cross-cutting pegmatites.

Pleochroic green to colorless tourmaline is found disseminated in most schists, but is also concentrated in layers where it is as much as 15 percent of the layer. These layers are folded along with the enclosing schists. Grains are euhedral to subhedral and 0.01 to 0.3 mm. Commonly, these green tourmalines have a blue core.

Sprays of dravite, with grain sizes from 0.05 to 0.1 mm, occur in pods in the matrix and in chlorite pseudomorphs after garnet, in veins, and along the edges of breccia fragments; sprays also replace coarse chlorite. In some samples, thin layers of schist have been entirely replaced by dravite. Dravite commonly occurs with euhedral and zoned quartz; in these places quartz is in the center of dravite pods and veins. Dravite sprays also are locally included in the matrix quartz of chlorite schists. A brown alteration, which may be septechlorite, occurs with much of the dravite.

Dravite veins and pods cut across matrix chlorites, and, therefore, the dravite formation appears to be a late event. Although dravite occurs throughout T129V in both schists and a hybrid pegmatite zone, the sprays are more abundant in the barren than in the ore zones.

Apatite

Apatite is disseminated, concentrated in schist layers, and in veins. One sample (T129V-163.8) consists of alternating apatite and quartz layers; the apatite layers are folded and broken, and show an apparent grading in grain size. Apatite is associated with dark-green 15 to 50-μm chlorite in veins and chlorite layers; this apatite is usually equant and, in some instances, contains hematite (?) inclusions.

Florencite

The rare-earth-bearing mineral florencite was identified in the hybrid pegmatite zone. The grains have low birefringence and are <0.05 mm in size. Florencite is most abundant in pseudomorphs and altered coarse chlorite grains.

TiO_2 minerals

Dark-brown to black titanium-bearing minerals <0.2 mm in length are disseminated throughout the schists. The term TiO_2 is used to describe these minerals composed predominantly of titanium (EDS analyses) and presumably oxygen. Although in some places these minerals appear to be pseudomorphous after sphene, no calcium was present in EDS analyses. A uniaxial figure with a positive sign indicates some of the TiO_2 is rutile, but anatase is probably present too. Coarser grained TiO_2 (about 0.2 mm), which occasionally contains blebs of iron sulfide (?), is in graphite schists.

Graphite

In the T129V core, graphite is in both barren and ore-bearing rocks of the upper graphite series and the main mine series. The amount of graphite varies from accessory in chlorite schist to major in graphite schist. Tabular grains of graphite $\leq$0.2 mm in length define foliation and, locally, crenulations. Graphite is commonly in or near ore-bearing rocks.

Organic matter

Two types of organic matter (also called carbonaceous matter) are recognized in the T129V core: coarse carbonaceous spheres (organic-matter 1), and carbonaceous blebs (organic-matter 2). Organic-matters 1 and 2 are only observed in ore zones.

Organic-matter 1, found only in the slightly brecciated graphite schist of sample T129V-166a, consists of carbonaceous spheres with uraninite inclusions. Spheres as large as 1 mm are black in hand specimen and gray to light brown with distinct bireflectance in polished thin section. The organic spheres are similar in appearance to thucholite, but EDS analyses do not contain the thorium found in strictly defined thucholite. Because of this lack of thorium and the fact that the term thucholite has been used to describe a variety of mixtures of organic matter and uranium, in this paper the spheres will be labeled organic-matter 1. Detailed chemistry of the spheres has not been completed, but preliminary EDS analyses show the presence of carbon, sulfur, and uranium.

Organic-matter 2 is blebs of carbonaceous matter found in ore-bearing rocks. In thin section, organic-matter 2 is brown and fractured; in some samples the carbonaceous matter exhibits bireflectance. EDS analyses show the presence of sulfur and minor iron (submicroscopic pyrite ?). The organic matter is commonly intergrown with pyrite, galena, titanium-bearing minerals, uranium minerals, and, rarely, tourmaline. In many places the intergrowths consist of alternating carbonaceous matter and minerals, resulting in a concentric pattern. These intergrowths may be as large as 0.5 mm, but are generally 0.02-0.15 mm. The presence of graphite inclusions (?) in organic-matter 2 in T129V-187.1 and the bireflectance of some samples suggest a relationship, not understood at this point, between the organic-matter 2 and graphite.

Uranium minerals

Uranium occurs in uraninite, in a uranium-silicate phase(s), in a titanium-uranium phase or mixture, and with organic matter. Uraninite and uranium-silicate phase(s) are the most abundant uranium-bearing minerals. The uranium-silicate phase(s), which has been identified by the presence of uranium and silicon in EDS analyses, will be referred to as coffinite in this report. X-ray and quantitative microprobe analyses will positively identify the phase(s).

Uraninite is massive (in veins) or is in euhedral to subhedral cubes <0.15 mm. Grains of uraninite are commonly replaced by coffinite; in some places a preferential replacement results in a pattern of alternating

uraninite and coffinite. Formation of uraninite along chlorite cleavage planes and along the edges of dravite crystals produces what looks like pseudomorphs of uraninite after chlorite and dravite.

Coffinite, opaque to translucent brown and <0.15 mm in length, occurs in reniform grains or as pseudomorphs after uraninite. Commonly, reniform grains show color banding. Inclusions of uraninite, pyrite, and galena are found in coffinite. Coffinite, along with uraninite and graphite (?), is locally included in pyrite, forming what resembles sieve texture in the pyrite.

Titanium-uranium oxide is an informal term describing either a titanium-uranium mineral or an association between a titanium oxide and uranium. Although uranium may be incorporated in a titanium-rich mineral (brannerite?), EDS analyses of this material show an irregular distribution of titanium, uranium, ±silicon, ±lead; this composition suggests a broken-down titanium-uranium phase (brannerite?) or adsorption of uranium on an altered titanium-bearing phase. In thin section, this material is brown to black, massive to rarely tabular, and irregular and diffuse in outline. The tabular form is suggestive of brannerite or brannerite pseudomorphs. Internal reflections are seen with crossed nicols in reflected light. Rarely, uraninite inclusions are present in this material.

Distribution of uranium

Uranium in veins and breccia matrix and as disseminations is concentrated in brecciated and (or) highly chlorite altered rocks. Interlayered coherent schists, regardless of composition, rarely contain appreciable amounts of uranium. Although most commonly in structures, in some samples the uranium appears stratabound (fig. 6).

a b

Figure 6. Radioluxographs of thin sections from T129V core. a) Uranium minerals are stratabound parallel to foliation (shown by black lines) in T129V-187.1. Radioluxograph exposure time was 7 hours. b) Uranium is disseminated in chlorite matrix of T129V-169.7a. Radioluxograph exposure time was 48 hours.

Veins in the T129V core are predominantly sub-parallel to foliation, although strongly cross-cutting veins do occur. In T129V-198.2a, a few of the sub-parallel veins are so resticted to specific areas that they resemble stratabound layers. Ore veins are primarily composed of uraninite, with coffinite common along the edges. Graphite is locally present along the edges or scattered in the vein. Galena and coffinite veinlets cut uraninite veins. Green 15 to 50-μm chlorite is common along the edges of uraninite veins and cuts uraninite, and light-green cryptocrystalline chlorite forms in bands parallel to a uraninite vein.

Breccias, ranging from quartz-cemented brecciated graphite schist and chlorite schist to massive chloritic and siliceous breccias, contain both uraninite and coffinite, and lesser amounts of titanium-uranium oxide. In the quartz-cemented breccias, uranium minerals are along the edge of the open-space quartz filling in some samples but are also disseminated and in veins. In these samples it does not appear that the primary mineralization is associated with the quartz cement; in fact, in T129V-198.2, quartz cement cuts a uraninite vein. The massive chloritic and siliceous breccias have disseminated uranium minerals. Cryptocrystalline green and white chlorites are the predominant chlorites in these breccias. In the siliceous breccia, uranium minerals (associated with organic-matter 1) are in both the matrix and breccia fragments.

Uranium occurs in disseminated coffinite, titanium-uranium oxide, uraninite, and chlorite. Coffinite, in some places with uraninite cores, and titanium-uranium oxide are the most common disseminated uranium minerals. Locally reniform coffinite is along the edges of quartz grains. Sample T129V-184.15 has coffinite in chlorite pseudomorphs after garnet; although interesting, this is probably an example of uranium disseminated in chlorite and (or) septechlorite. Radioluxographs of chlorite matrix show evenly distributed uranium (fig.6), either as submicroscopic grains or incorporated in the chlorite.

Organic-matter 1 spheres with uraninite inclusions are concentrated along the edges of a quartz-dolomite-chalcopyrite-pyrite-galena-sphalerite vein/breccia fill in a carbonaceous schist. This carbonaceous schist also contains disseminated uraninite and titanium-uranium oxide.

Blebs of concentrically arranged organic-matter 2 (or graphite ?), pyrite, galena, titanium-bearing minerals, and uranium minerals are disseminated in layers within ore zones. Similar carbonaceous matter containing graphite inclusions is found within aggregates of uraninite.

The variety or uranium occurrences -- veins, breccias, and disseminations -- suggests multiple generations of uranium mineral formation. The different types of breccias, including chloritic, siliceous, and quartz-cemented, are indicative of repeated brecciation events. The relationship between brecciation and mineralization is unclear: mineralized fragments and matrix in the siliceous breccia suggest some mineralization before brecciation, whereas in the samples with coarse-grained quartz fill it is unclear if uranium minerals are associated with the quartz breccia fill or if the quartz cuts and disrupts mineralized rock.

Coffinite, with uraninite cores and along the edges of uraninite veins, appears to form, at least in part, after uraninite. Coffinite formation may be the result of silica introduction, uranium remobilization, or reaction between quartz and uraninite; probably, all processes occurred to some extent, perhaps at different times and, in some cases, long after the main mineralizing event(s).

Veins, other than ore veins

Quartz veins

Quartz veins can be categorized as follows.

1) Quartz veins, about 0.5 cm thick, occur parallel to foliation. These veins, probably either metamorphic segregations or pre-metamorphic veins that were emplaced in the sedimentary sequence, are abundant throughout the sequence, especially in the muscovite-rich rocks. Because they are so common, each vein occurrence has not been noted in the thin-section descriptions.

2) Thin (1-2 mm) quartz veins cut across the foliation.

3) Fine-grained (0.01-0.02 mm) quartz veins with a brown coating cut across foliation and are fragments in breccias.

4) Veins of euhedral, coarse-grained (up to 0.5 cm) quartz, with inclusions that define zoning, fill breccia open-space and occur in veins cutting across foliation. These quartz veins contain rare grains of pyrite, chalcopyrite, carbonate, and sphalerite. In some samples the quartz grains have been strained and partially recrystallized, suggesting that all these veins and breccia fill were not emplaced at the same time or that certain sections of the sequence were subjected to higher sheer stress.

Carbonate veins

Carbonate veins cut across the schist and breccia fill, indicating these veins were emplaced late in the sequence of events at Jabiluka. In those samples large enough to X-ray, the carbonate was identified as dolomite.

Chlorite and septechlorite veins

The light-green cryptocrystalline chlorite, the dark-green 15 to 50-μm chlorite, the black chlorite (?), and septechlorite are in cross-cutting veins. The dark-green 15 to 50-μm chlorite, black chlorite (?), and septechlorite are commonly associated in veins that cut across the other types of chlorite.

Comment

Observations of the T129V core may be significant and should be compared with what is seen in the other cores. The following generalizations have been formulated for that purpose.

1) Uranium is concentrated in the rocks that have been most brecciated and affected by chlorite alteration.

2) Uranium is in veins and breccias and is disseminated. Veins are primarily composed of uraninite; disseminations are coffinite, titanium-uranium oxide, and, slightly less common, uraninite; uranium is also disseminated in chlorite and, locally, septechlorite. Interesting, but not significant, is minor coffinite in chlorite pseudomorphs after garnet.

3) Coffinite, commonly with uraninite cores, formed, at least in part, after uraninite.

4) Organic matter (organic-matter 1, organic-matter 2) commonly occurs in ore zones and is even intimately mixed with ore. The extent and significance of this association is unknown.

5) Ore-bearing breccia fragments suggest more than one period of mineralization.

6) Titanium-uranium oxides, probably in part altered titanium oxides, are in the ore zones. In barren rocks, the titanium oxides do not have the diffuse and irregular boundaries observed in the titanium-bearing minerals in the ore zones.

7) Seven types of matrix chlorites exist: undifferentiated, white cryptocrystalline, light-green cryptocrystalline, light-green 15-50 μm, green 15-50 μm, dark-green 15-50 μm, and black <15 μm.

8) The matrix chlorite in ore zones and breccias is composed predominantly of cryptocrystalline light-green and white chlorites.

9) Green 15 to 50-μm chlorite is in haloes surrounding uranium minerals, especially massive uraninite.

10) A greater variety exists of fine-grain chlorites and veins in the ore zones than in the barren rocks. Barren rocks are essentially a monotonous sequence, whereas the ore zone rocks are varied and more complex.

11) Septechlorite, only a minor constituent of the T129V rocks, is in both barren and ore-bearing rocks. Septechlorite is only rarely associated with ore minerals; in general, no correlation exits between septechlorite and ore.

12) Two types of coarse chlorite are present: one replaces biotite; the other appears to have formed during chlorite alteration, perhaps after the first chlorite.

13) A dravite alteration event has affected the rocks in T129V. This alteration is not associated with mineralization. The dravite alteration post-dates formation of the matrix and the formation of the hybrid pegmatite zone.

14) Dravite, dark-green 15 to 50-μm chlorite, black chlorite (?), and septechlorite are in cross-cutting pods and veins; these minerals were emplaced late, after the major mineralization event(s).

15) In the mine sequence, a quartz-apatite schist and schists with tourmaline-rich layers are present. Apatite and tourmaline-rich layers are folded along with the enclosing schists. Both this apatite and the green tourmaline appear to be metamorphic minerals.

16) Equant apatite with hematite inclusions occurs in veins and pods.

17) In T129V core, carbonate (dolomite) is only observed in minor cross-cutting veins.

18) The Kombolgie Formation has interstitial undifferentiated chlorite in sandstone near the unconformity.

Table 1.--Descriptions of selected thin-section samples.

Abbreviations used in column headed "rock type" are: C=chlorite, M=muscovite, S=sericite, G=graphite, and Q=quartz. Quartz (Q) is recorded only where it is not the most abundant mineral. Rock type is schist unless noted otherwise. Mineral abundances are estimated. Circled numbers, i.e. (1) , refer to detailed notes accompaning the tables. Other abbreviations used in the table are: chl=chlorite, septechl=septechlorite, cpy=chalcopyrite, gn=green yw=yellow, wt=white, bk=black, bwn=brown, lt=light, dk=dark, crypto=cryptocrystalline, undiff=undifferentiated, w/=with; //=parallel (to foliation), x-cutting=cross-cutting (to foliation), ✓=present, and --=not present.

Stratigraphic unit	Sample number = depth in meters	Rock type	Texture	Breccia matrix	Pseudomorphs	Major Minerals (other than matrix minerals)				Matrix Minerals			Accessory Minerals				
						quartz	chlorite	muscovite	others	chlorite	septe-chlorite	sericite	TiO_2	tourmaline	apatite	pyrite	others
Kombolgie Formation	62.3	Sandstone	Moderately-sorted, medium-grained	--	--	--	--	--	--	Gn to yw-gn (undiff), 10-15% of the rock	--	--	--	--	--	--	Zircon
	76.3	Sandstone	Moderately-sorted, medium-grained	--	--	--	--	--	--	Gn to yw-gn (undiff), 10-15%; bwn coating of oxide(?) or hydroxide(?)	--	--	--	--	--	--	--
Cahill Formation	84.85	Massive C	Brecciated	Chl	--	--	--	--	Carbonate	Lt gn to yw-gn (undiff), 75-80%	--	--	--	--	--	--	Zircon
	90.8	GCM	Foliated	--	--	--	--	--	Graphite	Yw-bwn (undiff), 10-15%	--	--	--	--	--	--	--
	95.6	CM	Foliated	--	Wt to bwn chl after garnet	--	#1, #2	--	--	Yw to bwn (undiff), 10-15%	--	Scattered, <5%	--	Gn	--	--	Graphite
Upper Graphite Series	97.5	CM	Foliated, slightly disrupted	--	Chl after garnet	--	#1, #2 (1)	Ragged, replaced by chl; not ragged // to foliation	--	Yw-gn (undiff), 20-25%; bwn alteration(?) on some chl	--	--	--	Gn	(2)	--	Graphite, cpy, hematite
	99.3a	CMS, C	Foliated	--	--	Corroded in areas	#2, #1	Ragged	--	Yw-gn (undiff), 25-30%	--	<5% (1)	--	--	--	--	Zircon, graphite
	99.3b	CM	Foliated, disrupted by veins	Euhedral zoned quartz, minor dravite	--	--	#1	--	--	Lt gn (undiff), 10-15%	--	--	--	Gn	--	--	Graphite
	101.3	C, CG fragments	Brecciated, foliated	Quartz, chl, dravite	--	--	#1	--	--	Gn to bwn (undiff), 20-25%	--	--	--	--	--	(1)	Cpy, graphite

Table 1 continued.

	Veins						Uranium					
	Dravite	quartz	chlorite	septe-chlorite	carbonate	others	distribution	uraninite	coffinite	Ti-U oxide	organic matter	chlorite associated with uranium
62.3	--	--	--	--	--	Hematite	--	--	--	--	--	--
76.3	--	--	--	--	--	--	--	--	--	--	--	--
84.85	--	--	--	--	--	--	--	--	--	--	--	--
90.8	✓	--	--	--	--	--	--	--	--	--	--	--
95.6	--	--	--	--	--	--	--	--	--	--	--	--
97.5	Pods in pseudomorphs	Nearly// to foliation	--	--	--	--	--	--	--	--	--	--
99.3a	--	<0.5 mm, // to foliation; 0.5 mm, x-cutting foliation	--	--	--	--	--	--	--	--	--	--
99.3b	5-10% of rock; bwn alter-ation(?), septechl(?) ①	X-cutting, <0.5 mm	--	--	--	Dravite, // to foli-ation	--	--	--	--	--	--
101.3	②	--	Dk gn 15-50-um chl, equant apatite, dravite, septechl	X-cutting veins, pods ③	--	--	--	--	--	--	--	--

Stratigraphic unit	Sample number = depth in meters	Rock type	Texture	Breccia matrix	Pseudomorphs	Major Minerals (other than matrix minerals)				Matrix Minerals			Accessory Minerals				
						quartz	chlorite	muscovite	others	chlorite	septe-chlorite	sericite	TiO_x	tourma-line	apatite	pyrite	others
Upper Graphite Series	102.1	GMC	Foliated	--	--	✓	#2, #1	// to foliation, not ragged	Graphite	Gn to bwn (undiff), ≤5%	--	--	✓	--	✓	✓	--
	103.1	GMC	Foliated	--	--	✓	#1	Not ragged, // to foliation	Graphite	Gn to bwn (undiff), ≤5%	--	--	✓	--	--	✓	--
	107.0	GMC	Foliated, crenulations	--	--	✓	#1	①	Tourmaline porphyro-blasts, graphite	Bwn (undiff), 5-10%; pods of dk-gn 15-50-μm and wt chl	Surrounds pods of dk-gn 15-50-μm and wt chl	--	✓	Gn	--	✓	--
	109.1	GQC	Foliated, crenulations	--	--	✓	--	--	Tourmaline porphyro-blasts, graphite	Wt to bwn, 5-10%; pods of dk-gn 15-50-μm and wt chl	--	--	✓	--	--	--	--
	110.6	C	Brecciated ①	Chl; zoned, strained, and broken quartz	--	✓	--	--	--	Wt, lt gn 15-50-μm, 35-40%	Scattered in breccia matrix	--	✓	--	--	✓	--
	112.7	GC breccia	Brecciated	Quartz	--	✓	--	--	Graphite	Gn to bwn (undiff), bk, 10-15%	--	--	--	--		--	--
Hanging Wall Schist Series	116.5	MCS	Foliated	--	--	✓	#1	// and x-cutting foliation	--	Lt gn (undiff), 5-10%	--	≤5% ①	✓	--	✓	--	--
	120.8	CMS	Foliated	--	--	✓	--	Not ragged and ragged, // and x-cutting foliation	--	Yw-gn (undiff), bk, 20-25% ①	--	5-10%	✓	--	Pink	✓	Zircon
	122.8	CSM	Foliated	--	--	✓	#1, #2	Not ragged and ragged, replaced by chl	--	Yw-gn (undiff), 25-30%	--	≤5%	✓	--	✓	--	Zircon

	Veins						Uranium						
	Dravite	quartz	chlorite	septe-chlorite	carbonate	others	distribution	uraninite	coffinite	Ti-U oxide	organic matter	chlorite associated with uranium
102.1	W/ chl in vein	Vein // to foliation	Dk-gn 15-50-μm, wt chl, dravite	--	--	--	--	--	--	--	--	--
103.1	--	--	Dk-gn 15-50-μm, wt chl, dravite	--	Dolomite ①	Dravite // to foliation	--	--	--	--	--	--
107.0	--	--	--	--	--	--	--	--	--	--	--	--
109.1	--	--	--	--	--	--	Dissemi-nated in chl matrix	--	--	--	--	Wt to bwn chl
110.6	--	--	--	--	--	--	Dissemi-nated in chl; coffinite	--	②	--	--	Wt and lt-gn 15-50-μm chl
112.7	--	Fine grained quartz w/ bwn coating, fragmented	--	--	--	--	Along edges of fragments; disseminated in chl	--	--	--	--	Gn to bwn chl
116.5	②	--	--	--	--	--	--	--	--	--	--	--
120.8	In quartz ②	--	--	--	--	--	--	--	--	--	--	--
122.8	--	--	--	--	--	--	--	--	--	--	--	--

Stratigraphic unit	Sample number = depth in meters	Rock type	Texture	Breccia matrix	Pseudomorphs	Major Minerals (other than matrix minerals): quartz	chlorite	muscovite	others	Matrix Minerals: chlorite	septechlorite	sericite	Accessory Minerals: TiO_2	tourmaline	apatite	pyrite	others
Hanging Wall Schist Series	126.5	Chaotic chl schist	Massive	--	Bwn pseudomorphs of chl and sericite	--	--	--	--	Wt to yw, bk, coarse gn chl ≤0.2mm, 90-95% (1) (2)	--	--	--	--	✓	✓	Quartz
	132.2	CS, MC	Foliated	--	Chl after garnet (1)	✓	#1	✓	--	Yw-gn (undiff), 20-25%	--	≤5% (2)	--	Gn	(3)	✓	Zircon, garnet (4)
	137.6	C	Foliated	--	--	✓	#1	Ragged, // and x-cutting	--	Gn to bwn (undiff), 20-25%	--	--	--	Gn	✓	--	Muscovite, sericite, zircon
	140.7	CMQ, CQS	Foliated	--	Chl after garnet (1)	✓	#1	Not ragged	--	Wt to lt gn, 30-35%	--	≤5%, cross-hatched appearance	✓	Gn	✓	--	--
	143.8	CM, massive chl layer	Foliated, massive chl may be breccia zone	Massive chl, wt to bwn w/ veins and pods of dk-gn 15-50-μm chl; pockets of equant apatite w/ hematite inclusions	--	✓	#1	(1)	--	Yw-gn to bwn (undiff), 25-30%	--	--	✓	Gn	(2)	--	Zircon
	148.0	CS	Foliated	--	--	✓	#2	--	--	Lt yw-gn to bwn(undiff), 15-20% (1)	--	15-20%	--	--	--	✓	Muscovite
	149.0a	C	Foliated	--	--	Ragged	#1	--	--	Olive-gn and lt gn (undiff), 45-50% (1)	--	--	--	--	✓	✓	Sericite
	149.0b	CS	Foliated	--	--	✓	#1	--	--	Olive-gn and lt gn (undiff), 15-20%	--	15-20%	--	--	✓	--	Muscovite

	Veins						Uranium					
	Dravite	quartz	chlorite	septechlorite	carbonate	others	distribution	uraninite	coffinite	Ti-U oxide	organic matter	chlorite associated with uranium
126.5	--	Associated w/ bk chl	Wt to yw chl	--	--	--	--	--	--	--	--	--
132.2	--	--	--	--	--	--	--	--	--	--	--	--
137.6	Rare, included in quartz	--	--	--	--	--	--	--	--	--	--	--
140.7	Pods in pseudomorphs	--	--	--	--	--	--	--	--	--	--	--
143.8	--	--	Dk-gn 15-50-μm chl w/ apatite	--	--	--	In massive chl layer	Corroded cubes	✓	✓(?)	--	Wt to lt bwn chl; dk-gn 15-50-μm chl w/ apatite
148.0	--	--	--	--	--	--	--	--	--	--	--	--
149.0a	Included in quartz grains	Quartz and bk chl, x-cutting	Bwn chl(?) x-cutting	--	--	--	--	--	--	--	--	--
149.0b	--	Quartz is anhedral, fine grained, w/ bwn coating; 1 mm, cross-cutting	--	--	--	--	--	--	--	--	--	--

Stratigraphic unit	Sample number = depth in meters	Rock type	Texture	Breccia matrix	Pseudomorphs	Major Minerals (other than matrix minerals)				Matrix Minerals				Accessory Minerals			
						quartz	chlorite	muscovite	others	chlorite	septe-chlorite	sericite	TiO_2	tourmaline	apatite	pyrite	others
	163.8a	C-apatite-pyrite ①	Foliated	--	Chl after garnet ②	✓	#2, also x-cuts pseudomorphs	--	Apatite ③	Wt, yw-gn (undiff), 20-25%; near pyrite is yw bwn	--	W/ yw-gn chl; <5% ④		--	--	--	--
	163.8b	CQ-apatite-septechl	Massive, brecci-ated	Chl, septechl, quartz, apatite	--	✓	#2	--	Apatite ①	Gn (undiff), bk, dk gn 15-50-μm ; 35-40%	Bwn 10% ②	--	✓	Blue	--	--	Hematite
	164.1	CMG	Foliated, cut by near vertical vein system	--	--	✓	#1	✓	Graphite	Lt gn (undiff) 20-25%	--	--	✓	--	--	✓	--
Main Mine Series	166.0a	GQC	Slightly brecciated	Quartz-dolomite-cpy-pyrite-sphalerite	--	✓	#2	--	Graphite	Dk gn 15-50 μm 5-10% ①	<5%	--	✓	--	✓	✓	--
	166.0b	GCM	Foliated	--	--	✓	#2	--	Graphite	Gn (undiff), <5%	--	--	✓	--	--	✓	--
	166.4	GQCM	Brecciated	Wt, lt gn 15-50-μm chl, euhedral and zoned quartz, ① dolomite, pyrite, ②	--	✓	#1	✓	Graphite	Gn to bwn (undiff), <5%	--	--	✓	--	--	✓	--
	167.5	CM, C, quartz accessory	Foliated, slightly brecciated	--	--	--	#1	--	--	Wt to lt-gn chl cut by veinlets of dk-gn 15-50-μm chl, 65-70%	Concentrated in specific layers 5-10%	--	✓	--	As large as 1mm	✓	Quartz zircon
	169.2a	C	Foliated	--	--	Half the #2 quartz is corroded and embayed		--	--	Lt gn (crypto), 25-30% ① bwn coating in some areas	--	--	✓	--	--	--	Sericite, muscovite, zircon ②

	Veins						Uranium					
	Dravite	quartz	chlorite	septe-chlorite	carbonate	others	distribution	uraninite	coffinite	Ti-U oxide	organic matter	chlorite associated with uranium
163.8a	--	--	--	--	X-cutting	--	--	--	--	--	--	--
163.8b	--	--	--	--	--	--	Disseminated in breccia, concentrated in spots	In one place surrounds apatite grains	Surrounds pyrite, TiO_2	--	--	Matrix chl, septechl
164.1	--	--	Dk gn 15-50 µm and apatite ①	--	①	Galena	In vein system; associated w/ chl, not carbonate	Disseminated, veins ②	③	--	--	Dk-gn 15-50-µm chl, lt-gn chl
166.0a	--	Fills breccia open space; w/ dolomite, cpy, pyrite, sphalerite	Dk gn 15-50 µm, w/ septechl	✓	--	--	Along edges of breccia fill/ vein, disseminated in schist	②	②	②	Organic matter[1] ③	Dk-gn 15-50-µm chl, septechl surrounds uranium minerals
166.0b	--	Quartz zoned, w/ inclusions, x-cutting	Dk gn 15-50 µm, w/ septechl	W/ dk-gn 15-50-µm chl, // and x-cutting ①	--	--	--	--	--	--	--	--
166.4	--	--	--	--	X-cutting matrix	--	Disseminated	②	✓	③	--	Wt chl, lt-gn 15-50-µm chl
167.5	--	--	Dk gn 15-50 µm	--	--	--	Disseminated-in chl and U-minerals; concentrated in brecciated area, layers w/ high pyrite content	Cubes occasionally surrounded by TiO_2	Surrounds TiO_2, pyrite; w/in pod of dk-gn 15-50-µm chl	--	--	Wt chl, dk-gn 15-50-µm chl
169.2a	--	// to foliation	Lt gn (crypto), same as matrix chl; x-cutting	--	--	--	Disseminated evenly through chl matrix	--	--	--	--	--

Stratigraphic unit	Sample number = depth in meters	Rock type	Texture	Breccia matrix	Pseudomorphs	Major Minerals (other than matrix minerals)				Matrix Minerals			Accessory Minerals				
						quartz	chlorite	muscovite	others	chlorite	septe-chlorite	sericite	TiO_2	tourmaline	apatite	pyrite	others
Main Mine Series	169.2b	Massive C; C schist fragments; quartz accessory	Brecciated	Chl	--	--	#1	✓	--	Wt, cut by lt-gn 15-50-μm and bk chl; same in breccia and chl schist, 80-85%	--	--	✓	--	--	✓	Quartz galena, cpy
	172.6	C, fragments of GC, pyrite	Brecciated	Chl, septechl	--	✓	--	--	--	Wt, lt gn 15-50 μm, 50-55%	≤5%	--	--	--	--	--	--
	176.7	CQ	Partially brecciated ①	Chl	--	✓	#1 in schist, #2 in chl vein	--	--	Wt, lt gn 15-50 μm; bwn coating (septechl?), 60-65%	--	--	--	--	--	--	--
	178.9	CM	Foliated ①	--	--	✓	#2	Ragged, // and x-cutting	--	Lt gn to wt, lt gn 15-50 μm, bk, 30-35%	--	--	✓	--	✓	--	--
	179.6	CSQ	Foliated	--	--	✓	#2	--	--	Lt gn (crypto), 25-30%	--	25-30%	✓	Gn, 10-15% of one layer	--	--	--
	184.15a	MC	Foliated	--	Chl, septechl after garnet ①	✓	#1	Ragged, not ragged	--	Lt gn (crypto), gn (undiff), 5-10%	≤5%	--	--	--	✓		--

	Veins						Uranium					
	Dravite	quartz	chlorite	septe-chlorite	carbonate	others	distribution	uraninite	coffinite	Ti-U oxide	organic matter	chlorite associated with uranium
169.2b	--	--	Wt chl ① lt-gn 15-50-μm chl	--	--	--	Disseminated in schist and breccia fragments, concentrated along edges of fragments; not in wt chl	Along edges of wt chl vein(?)	✓	✓	--	U-minerals surrounded by gn 15-50-μm chl; U not in wt chl
172.6	--	--	--	--	--	--	Predominantly in GC fragments; lesser amounts in matrix chl	--	--	✓	--	--
176.7	--	Vein of euhedral zoned quartz, embayed and replaced in breccia; fragments of vein of fine grained quartz w/ bwn coating	Lt-gn chl (crypto), // to foliation	--	Cutting across breccia	--	Disseminated in schist, breccia, chl vein; concentrated along contact between schist and breccia	Predomi-nantly in breccia	In schist and breccia ②	--	--	Lt gn (crypto) chl, lt-gn 15-50-μm chl, wt chl
178.9	--	--	--	--	--	--	--	--	--	--	--	--
179.6	Throughout matrix, 10% of rock	--	Lt-gn (crypto) chl in vein // to foliation; same as matrix chl	// to foliation	--	Dravite, x-cutting	Disseminated	Pseudomor-phic after dravite(?)	Surrounds pyrite, associated w/ dravite	--	--	--
184.15a	✓	--	--	// to foliation, w/ dk-gn 15-50-μm, wt chl	--	--	In pseudomorphs, septechl vein	--	✓	--	--	Septechl

Stratigraphic unit	Sample number = depth in meters	Rock type	Texture	Breccia matrix	Pseudomorphs	Major Minerals (other than matrix minerals)				Matrix Minerals			Accessory Minerals				
						quartz	chlorite	muscovite	others	chlorite	septechlorite	sericite	TiO_2	tourmaline	apatite	pyrite	others
	1B4.15b	CM	Foliated	--	Wt to lt-gn chl, septechl after garnet	✓	#2	Ragged, not ragged	--	Lt gn (crypto), along edges and invading pseudomorphs	--	--	✓	Gn	--	--	Sericite, graphite
	1B4.15c	CM	Foliated, slightly brecciated	Euhedral zoned quartz; dk-gn 15-50-μm, wt chl; septechl	--	✓	#1	Mostly ragged	--	Lt gn (undiff), ≤5%	--	--	--	--	--	✓	Cpy
Main Mine Series	184.85	CQ	Massive to foliated	--	--	✓	#2 ①	--	--	Wt to lt gn (crypto), ② 75-80%	--	--	--	--	--	--	--
	187.1	C, quartz layers inter layered w/ QC	Foliated, folded	--	--	✓	#1	--	--	Gn to bwn (undiff), lt gn 15-50 μm, 20-25%; coarse chl w/ wavy extinction similar to that in 126.5 5%	--	--	✓	--	✓	✓	Cpy (1-2%), graphite
	190.4	CGS	Foliated	--	--	✓	#1	--	Graphite	Lt gn (crypto), 20-25%	W/ gn 15-50-μm chl and equant apatite ≤5% ①	≤5% ②	--	--	✓	✓	--
	196	CSG	Foliated	--	--	✓	#1	--	Graphite	Lt gn (undiff), 5-10%	--	15-20%		2-5%	--		Muscovite, ragged
	197.5	C	Brecciated	Quartz, chl, uraninite ①	--	✓	#2	--	--	Lt gn to wt, lt gn 15-50 μm, 30-35%	--	--	--	--	--	②	Hematite, galena, cpy

	Veins						Uranium					
	Dravite	quartz	chlorite	septechlorite	carbonate	others	distribution	uraninite	coffinite	Ti-U oxide	organic matter	chlorite associated with uranium
184.15b	--	--	--	Septechl and wt chl	--	--	In pseudomorphs, disseminated in matrix chl	✓	✓	--	--	--
184.15c	--	--	--	--	--	--	In breccia matrix, along edges of fragments in matrix, in pseudomorphs	✓	✓	--	--	--
184.85	In pods in the matrix, ≤5%	--	--	--	--	--	Disseminated; high U content in areas w/ coarse-chl #2, gn matrix chl, dravite	✓	Color zoning well developed	✓	--	Lt gn (crypto) chl
187.1	Very fine grained, <2%	// to foliation	--	--	Carbonate-cpy-coffinite, // to foliation	--	Stratabound in chl-rich layers, x-cutting foliation along axial plane of fold ①	✓	Includes uraninite, galena, Ti-U oxide, TiO_2; cuts quartz grains	②	Organic-matter along edges and w/in mix of uraninite, Ti-U oxide, coffinite, graphite ③	--
190.4	--	--	Dk-gn 15-50-μm chl, apatite ①	W/ dk-gn 15-50-μm chl ①	--	--	--	--	--	--	--	--
196	--	--	--	--	--	--	--	--	--	--	--	--
197.5	--	--	--	--	--	Cpy veinlets cut uraninite	Disseminated in schist and in breccia; along edges of quartz breccia cement	✓	✓	✓	--	Gn 15-50-μm chl surrounds uraninite

Stratigraphic unit	Sample number = depth in meters	Rock type	Texture	Breccia matrix	Pseudomorphs	Major Minerals (other than matrix minerals): quartz	chlorite	muscovite	others	Matrix Minerals: chlorite	septechlorite	sericite	TiO_2	Accessory Minerals: tourmaline	apatite	pyrite	others
Main Mine Series	198.2a	C-uraninite; quartz accessory	Foliated, slightly brecciated	Quartz (1), chl, uraninite (2)	--	--	#1, #2	--	--	Lt gn (crypto), 45-50% (3)	--	--	--	Gn, clear (4)	--	(5)	Graphite, quartz, hematite, cpy, galena
	198.2b	C, MC, GC	Foliated	--	--	Embayed and cut by chl	--	--	Graphite	Lt gn (crypto), dk gn 15-50 μm, 20-25%	W/ dk-gn 15-50- μm, chl <5%	--	✓	Gn, as much as 5% of layers	--	✓	--
	198.6a	CQG, M layers, G layers	Foliated	--	--	Corroded and cut by chl	#1	--	Graphite	Lt gn (crypto), dk gn 15-50 μm, 20-25%	(1)	--	✓	Gn, as much as 10-15% of layer	--	✓	Muscovite, galena, cpy
	198.6b	CMG	Foliated, crenulated	--	--	--	✓	✓	Graphite	Wt, 55-60%	--	--	--	Gn	--	--	Quartz
		C (1)	Brecciated	Quartz (2) chl	--	--	--	--	--	Lt gn (crypto), gn 15-50 μm, 80-85%	--	--	--	--	--	--	--
	199.4	Siliceous breccia, chl schist fragments	Brecciated	Quartz, chl	--	✓	#1	--	--	Lt gn 15-50 μm, bk, 5-10%	--	--	--	--	--	--	Carbonate, graphite, pyrite, cpy
	201.0	CM, G layers	Foliated, crenulated	--	--	✓	#1	✓	Graphite	Gn to bwn gn (undiff), 10-15%	--	--	--	Gn	✓	✓	--

	Veins						Uranium					
	Dravite	quartz	chlorite	septechlorite	carbonate	others	distribution	uraninite	coffinite	Ti-U oxide	organic matter	chlorite associated with uranium
198.2a	--	X-cutting, (6) corroded quartz, repaced by chl, vein about // to foliation	Dk-gn 15-50-µm chl, w/ septechl	In veins and pods, w/ dk-gn 15-50-µm chl	--	--	Disseminated; layers/vein sub-parallel to foliation	(7)	✓	--	Organic-matter 2 (4)	Gn 15-50-µm chl surrounds and cuts uraninite
198.2b	✓	--	X-cutting dk-gn 15-50-µm chl and euhedral quartz (1)	--	--	--	--	--	--	--	--	--
198.6a	--	--	Lt gn (crypto), // to foliation	--	--	--	Disseminated	✓	Veins and surrounding pyrite	--	--	--
198.6b	--	--	Dk-gn 15-50-µm chl	--	--	--	Disseminated in schist; vein	Predominantly in veins and breccia	Predominantly in schist	Predominantly in schist	--	Gn 15-50-µm chl surrounds uraninite vein
	--	--	Dk gn 15-50 µm in pockets (3)	--	Along the edges and cutting across quartz cement	--	Veins sub-parallel to foliation, disseminated	✓	✓	✓	Organic-matter 2, graphite	
199.4	--	Fragments of a vein of anhedral quartz w/ bwn coating	--	--	--	--	Vein; disseminated in matrix and breccia fragments	✓	✓	✓	Organic-matter 2	Gn 15-50-µm chl surrounds uraninite in vein
201.0	--	--	--	--	--	--	Disseminated in crenulated and graphite-rich areas	✓	✓	--	--	Gn 15-50-µm chl surrounds uraninite

Stratigraphic unit	Sample number = depth in meters	Rock type	Texture	Breccia matrix	Pseudomorphs	Major Minerals (other than matrix minerals)				Matrix Minerals				Accessory Minerals			
						quartz	chlorite	muscovite	others	chlorite	septe-chlorite	sericite	TiO_2	tourmaline	apatite	pyrite	others
Main Mine Series	202.0	MC	Foliated	--	--	--	#1	--	--	Wt to lt gn, 10-15%	--	--	--	Gn	--	--	--
	210.6	SMC	Foliated	--	--	--	#1	--	--	Wt to lt gn, ≤5%	--	25-30%	--	Gn	--	--	--
Foot-wall schist series	219.4	SCM	Foliated	--	--	--	#1	--		Lt gn (undiff), 5-10%	--	20-25%	--	--	--	--	--
		Hybrid pegmatite zone ①	Pegmatoid	--	Dravite, after chl	Anhedral, strained	Lt yw chl, radial extinc-tion	--	Tourmaline; zoned, alternating blue and gn color; apa-tite; up to 30% of layer	Lt gn. (undiff), ≤5%	--	--	--	--	--	--	Florencite
	230.2	Tourmaline pegmatite	Coarse-grained	--	Sericite after potassium feldspar	Anhedral, strained	--	Occurs in clumps	Tourmaline; zoned lt to dk blue	--	--	--	--	--	--	--	Florencite

	Veins						Uranium					
	Dravite	quartz	chlorite	septechlorite	carbonate	others	distribution	uraninite	coffinite	Ti-U oxide	organic matter	chlorite associated with uranium
202.0	--	--	--	--	--	--	Vein/layer uraninite // to foliation	✓	✓	--	--	Gn 15-50-μm chl in uraninite vein
210.6	--	--	Dk gn 15-50 μm, x-cutting	--	--	--	--	--	--	--	--	--
219.4	--	--	--	--	--	--	--	--	--	--	--	--
	Replacing coarse chl	--	--	--	--	--	--	--	--	--	--	--
230.2	--	X-cutting	--	--	--	Sericite, x-cutting	--	--	--	--	--	--

97.5 ① Coarse-chlorite 2 cuts across pseudomorphs, replaces coarse-chlorite 1, and replaces matrix chlorite. ②Clear apatite is in clusters and in quartz layer/vein parallel to foliation.

99.3a ① The variation in size between muscovite and sericite is gradational.

99.3b ① Dravite sprays surround breccia fragments, replace layers of chlorite schist, and are in veins.

101.3 ① Pyrite is corroded and is surrounded by a brown alteration. ②Dravite surrounds and replaces breccia fragments; dravite makes up 5 to 10 percent of the rock. ③Septechlorite, which is white to brown, is in veins cutting across the matrix chlorite; septechlorite is associated with dark-green 15 to 50-μm chlorite.

103.1 ① Carbonate vein of dolomite, quartz, and pyrite is parallel to the foliation.

107.0 ① Some muscovite is oriented along the axial plane of the crenulations.

110.6 ① Breccia fragments are composed of graphite schist, chlorite schist, and quartz vein. ②Coffinite (only a few grains identified) is associated with pyrite.

116.5 ① Sericite is along the edges of muscovite grains. ②Dravite pods are along the cleavage planes of the coarse chlorite.

120.8 ① Black chlorite (?) is concentrated in layers; this chlorite surrounds corroded minerals. Layers that contain the black chlorite (?) are light yellow green in hand specimen. ②Dravite is associated with the black chlorite (?).

126.5 ① Coarse chlorite, an open-space filling, has undulatory extinction. ② Sequence of chlorites, from early to late, appears to be coarse, white, and black.

132.2 ① Pseudomorphs are as much as 20 percent of some schist layers. ②Crude orientation of sericite is \\\~///~\\\~ , at angles to foliation. ③Euhedral to subhedral, 0.05 to 0.1 mm apatite is as much as 5 to 10 percent of apatite-rich schist layers. ④Garnets $\leq$15 μm are preserved in a quartz layer.

140.7 ① Chlorite pseudomorphs, which are surrounded by chlorite and sericite matrix, are easily identified because the chlorite is cryptocrystalline.

143.8 ① Well-developed muscovite and "ghosts" of muscovite in the chlorite matrix are both present; the "ghosts" of muscovite are at an angle to the foliation. ②Equant apatite, with hematite (?) inclusions, occurs in pockets in the uranium-rich area.

148.0 ① The presence of brown chlorite and (or) sericite corresponds to the light-yellow color of hand specimen.

149.0a ① The light-green chlorite appears to be late and to be replacing the olive-green chlorite. The presence of the light-green chlorite and (or) sericite corresponds to a lighter green color on the hand specimen; an irregular contact separates the hand specimen into light- and dark-green colors.

163.8a ① The rock consists of apatite, quartz, and pseudomorph-rich layers. ② Pseudomorphs are composed of white chlorite; the pseudomorphs consists of a number of domains in which chlorite has filled open space, resulting in this type of pattern: ③Apatite, $\leq$0.05 mm and euhedral to subhedral, is in layers that are folded, broken, and rotated; within some layers, there is a gradational change in grain size. Where apatite is in a chlorite matrix, apatite is elongate and euhedral. ④Sericite is in a cross-hatched pattern (after potassium feldspar ?). The sericite and chlorite matrix surrounds an isotropic phase pseudomorphous after garnet.

163.8b ① Apatite is euhedral, elongate, and at random orientation; this apatite is similar to the 163.8a apatite that is in chlorite matrix. ② The septechlorite appears to be a coating on chlorite breccia fragments.

164.1 ① Uranium is associated with a vertical carbonate vein system, but the uranium is not actually in the carbonate veins; uranium minerals are in light-green chlorite, associated with dark-green 15 to 50-μm chlorite and equant apatite. The carbonate vein probably entered along an earlier vein system or zone of brecciation. ②Uraninite veins and galena veins are present in the vein system. Uraninite cubes contain pyrite and galena cubes. ③Coffinite is along the edges of pyrite, as well as replacing uraninite.

166.0a ① Dark-green 15-50-μm chlorite and septechlorite are along the edges of the breccia matrix. ② Uraninite, coffinite, and titanium-uranium oxide are disseminated in the schist. ③ Spheres of organic-matter 1, composed of carbon, sulfur, and uranium, are along the edges of the breccia cement; the spheres contain uraninite.

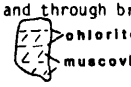
166.0b ① Radioluxographs show no association of uranium with the septechlorite veins.

166.4 ① This quartz cement is strained and probably brecciated. ② Pyrite cuts across and partially surrounds uraninite; pyrite is also concentrated along edges of the breccia cement. ③ Titanium-uranium oxide has rare uraninite inclusions.

169.2a ① Chlorite, identified as light-green cryptocrystalline, is in this sample coarser grained than usual. ② Schist layer (a heavy mineral concentrate ?) consists of 5 to 10 percent zircon and titanium-bearing mineral.

169.2b ① Coherent chlorite schist, with a white chlorite matrix, is cut by vein (?) of white chlorite; both schist and "vein" are brecciated and cut by veinlets of light-green 15 to 50-μm and black chlorite (?).

176.7 ① Foliation can be followed from schist into and through brecciated region. ② Coffinite commonly surrounds pyrite; coffinite is within quartz and chlorite.

178.9 ① Two foliations are seen on hand specimen: 

184.15a ① Pseudomorphs consist of chlorite, septechlorite, apatite, dravite, pyrite, and coffinite.

184.85 ① "Layers" of coarse-chlorite 2 are not continuous along foliation:

② Coarse-chlorite 2, dravite, and uranium minerals are concentrated with the green chlorite. The difference between white and green matrix chlorite is graditional.

187.1 ① Uranium is predominantly in aggregates and mixtures of titanium-uranium oxide, uraninite, and coffinite; coffinite replaces the other two uranium minerals. Graphite is along the edges and within these uranium mineral mixtures. ② Titanium-uranium oxide, especially where disseminated, has the tabular crystal form of brannerite. ③ Graphite is near to and within blebs of organic-matter 2, suggesting a gradational change between the two phases. Graphite is concentrated with ore: it is rare in the matrix.

190.4 ① Septechlorite, dark-green 15 to 50-μm chlorite, and equant apatite are in cross-cutting veins, in pods, and along the edges of quartz layers. ② Parallel extinction of sericite suggests it has replaced muscovite.

197.5 ① Uraninite is along the edges of some quartz breccia cement; the quartz is euhedral and zoned. It appears that veins of chlorite and uraninite cut across the quartz cement, but they may also be inclusions. ② Pyrite with sieve texture consists of pyrite cut by veins or containing inclusions of uraninite and coffinite.

198.2a ① Breccia cement, which consists of euhedral and zoned quartz, cuts across uraninite layer. ② Uraninite is along edges of a fragment in the quartz breccia cement. ③ Chlorite is banded parallel to the uraninite vein. ④ A schist layer contains blebs of organic-matter 2 and (or) graphite and one or more minerals concentrically arranged; these minerals are pyrite, galena, coffinite, and a titanium-bearing mineral. The blebs are intergrown with and concentrated in layers with clear tourmaline. ⑤ Pyrite with sieve texture contains uraninite, coffinite, TiO_2, and carbonaceous matter (organic-matter 2 or graphite). Corroded pyrite has uraninite inclusions. ⑥ Cross-cutting quartz vein cuts uraninite vein. ⑦ Veins of massive uraninite are cut by galena and coffinite veinlets. Along the edges of the veins, uraninite mimics chlorite (replacement along cleavages ?). Very fine grained graphite is associated with uraninite, especially along the edges of veins.

198.2b ① Where the vein cuts quartz layers, the vein is composed of quartz.

198.6a ① Septechlorite is along the edges of quartz layers and is around pockets of dark-green 15 to 50-μm chlorite.

198.6b ① The sample consists of CMQ and chlorite schist, separated by a brecciated zone. ② Quartz breccia cement, which is euhedral and zoned quartz, is cut by a coffinite veinlet. It appears that the quartz breccia cement cuts uraninite layer/vein. ③ Vein consists of dark-green 15 to 50-μm chlorite, white chlorite, quartz, coffinite, TiO_2, marcasite, and galena.

219.4 ① Muscovite, apatite, and tourmaline are concentrated along the contact between the schist and the hybrid tourmaline pegmatite zone.

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