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Description of Drill-hole V111V Core from the Jabiluka Unconformity-type Uranium Deposit, Northern Territory, Australia

by

C. J. Nutt[1]

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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.

[1]USGS
Box 25046, MS 916
Denver, CO 80225

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Description of Drill-hole V111V Core from the Jabiluka Unconformity-type Uranium Deposit, Northern Territory, Australia

By C. J. Nutt
U.S. Geological Survey, Denver, Colo. 80225

INTRODUCTION

The Jabiluka unconformity-type uranium deposit is one of four large unconformity-type deposits in the Alligator Rivers Uranium Field in the eastern part of the Pine Creek geosyncline, Northern Territory, Australia (fig. 1). These unconformity-type uranium deposits occur as veins, disseminations, and breccia matrix in metasedimentary rocks of the Lower Proterozoic Cahill Formation and are near a regional unconformity that separates the Cahill from the sedimentary rocks of the Middle Proterozoic Kombolgie Formation.

The study of unconformity-type deposits--a new type of uranium deposit typified by deposits discovered in the past 15 years in Australia and Canada--is part of the U.S. Geological Survey uranium program; funding was also provided by the U.S. Department of Energy National Uranium Resource Evaluation (NURE) program. Pancontinental Mining Limited kindly gave us access to Jabiluka core and made their geological and geophysical data available for inclusion in our reports. Data and interpretations from the study of Jabiluka should aid in defining characteristics and setting of these world class deposits and guide exploration for similar deposits in the United States.

Jabiluka ores are hosted by the the Cahill Formation, which was multiply folded and metamorphosed to amphibolite facies during a 1,800-m.y. event (Needham and Stuart-Smith, 1976). In the vicinity of Jabiluka, as well as the other unconformity-type deposits, extensive chloritic alteration has affected the rocks, which now have predominantly greenschist-facies mineral assemblages. Nutt and Grauch (1983) described the regional and mine geology at Jabiluka; that paper was the first in a series of open file reports on Jabiluka (Nutt, 1983) and was written to provide information on the regional geologic setting and on the geology of the ore deposit as background for detailed petrographic reports on samples from the drill holes.

The deposit at Jabiluka consists of two orebodies: Jabiluka 1, the first discovery, and Jabiluka 2, the larger of the two orebodies. Ore occurs as veins, breccia matrix, and disseminations in a chloritized and brecciated sequence of quartz - chlorite ± muscovite ± sericite ± graphite schists. Figure 2 shows the general stratigraphic column of the Cahill Formation at Jabiluka. Rocks in core from Jabiluka display foliation best defined by muscovite and chlorite. Small-scale crenulations and isoclinal folds deform foliation and possibly mimic large-scale structures that affect the area.

This paper is a detailed description of core from the Jabiluka drill-hole V111V, located on the western edge of Jabiluka 2. Figure 3 shows the location of V111V and figure 4 is the north-south cross section that contains drill-hole V111V. V111V was drilled to a depth of 178 m through the Kombolgie and Cahill Formations, but only minor uranium concentration was encountered. The

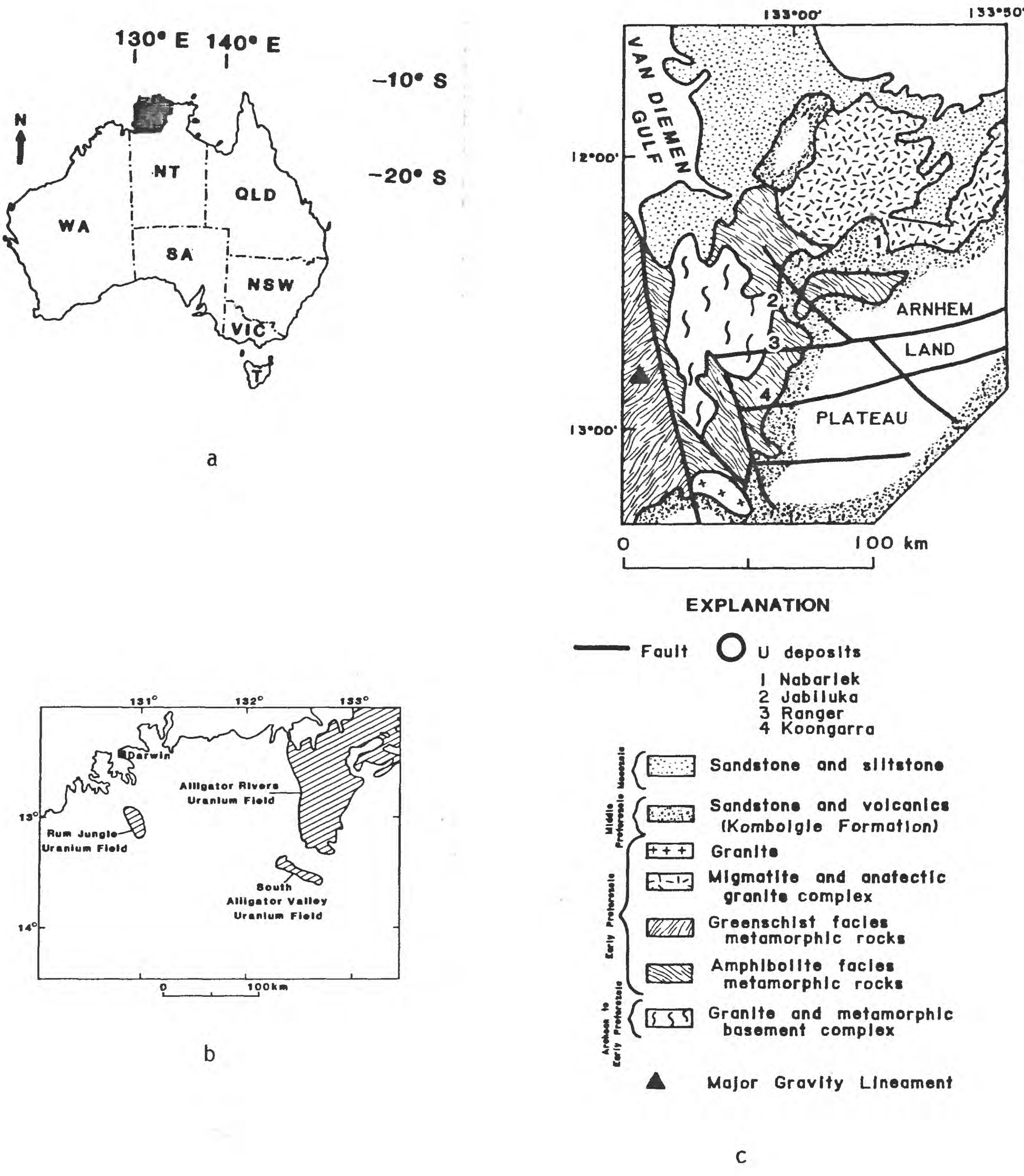


Figure 1. Locality maps of (a) the Pine Creek geosyncline, Northern Territory, Australia; (b) the Alligator Rivers Uranium Field in the Pine Creek geosyncline; and (c) the four major uranium deposits in the Alligator Rivers Uranium Field.

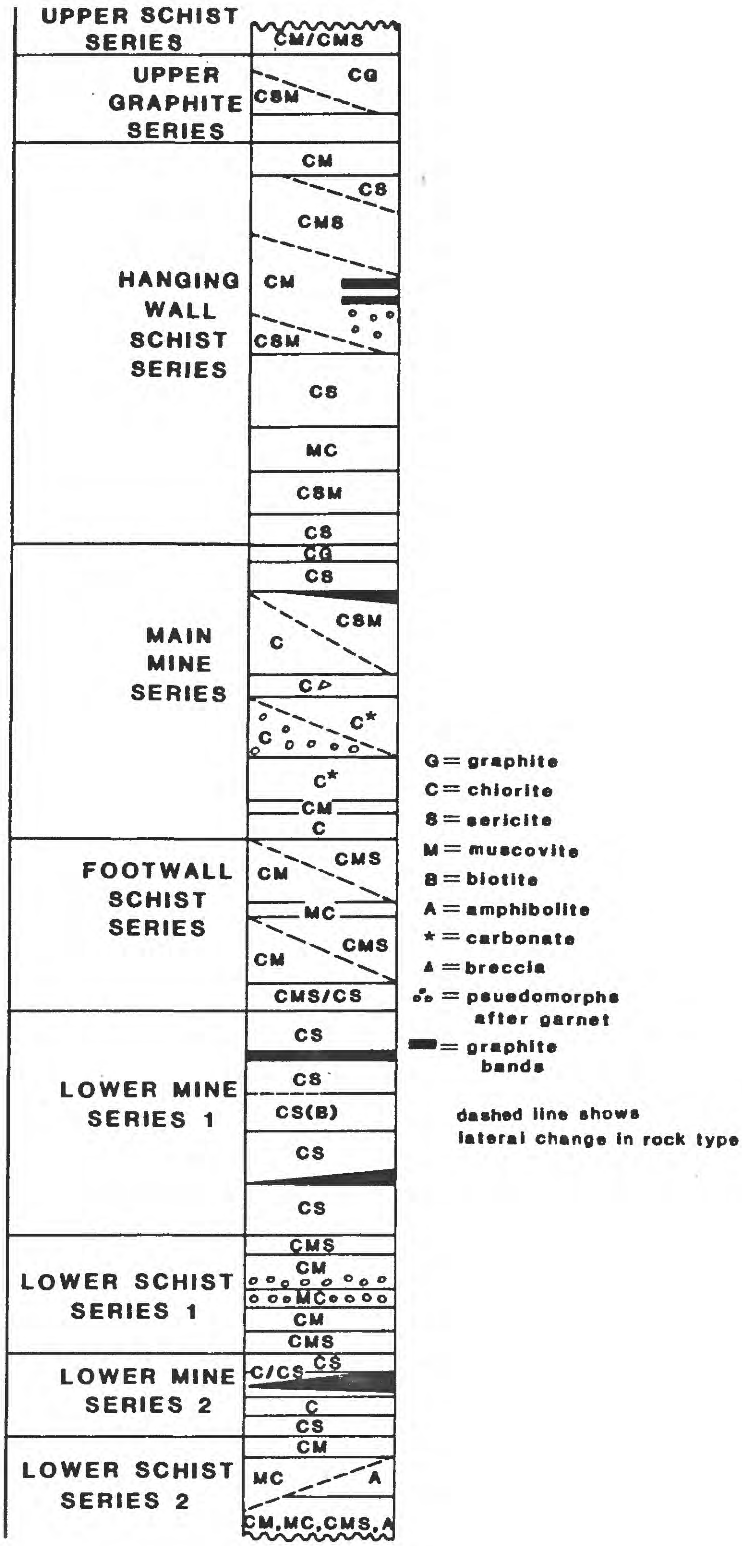


Figure 2. Generalized stratigraphic column of the ore-bearing Cahill Formation at Jabiluka; modified from information supplied by Pancontinental Mining Limited.

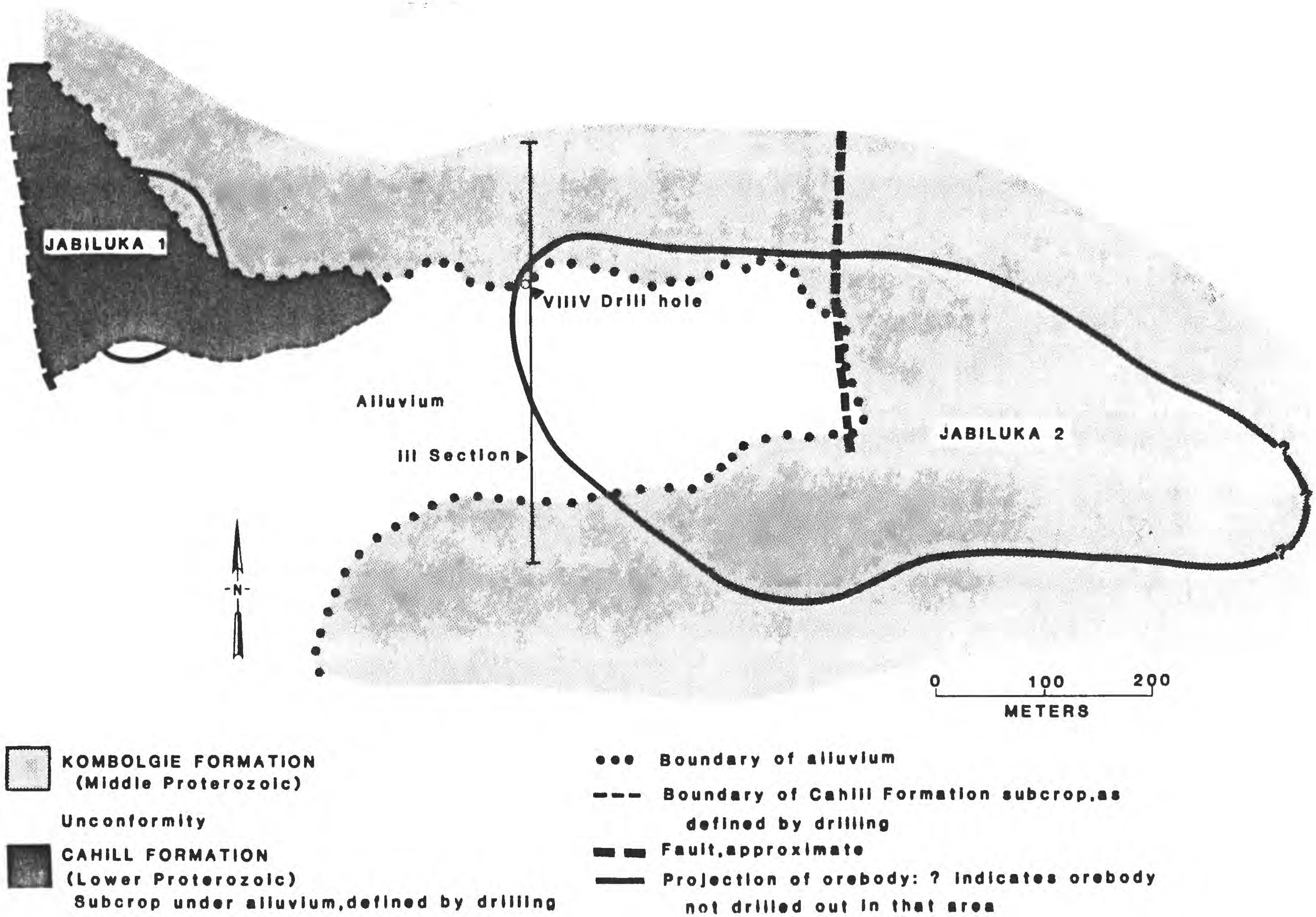
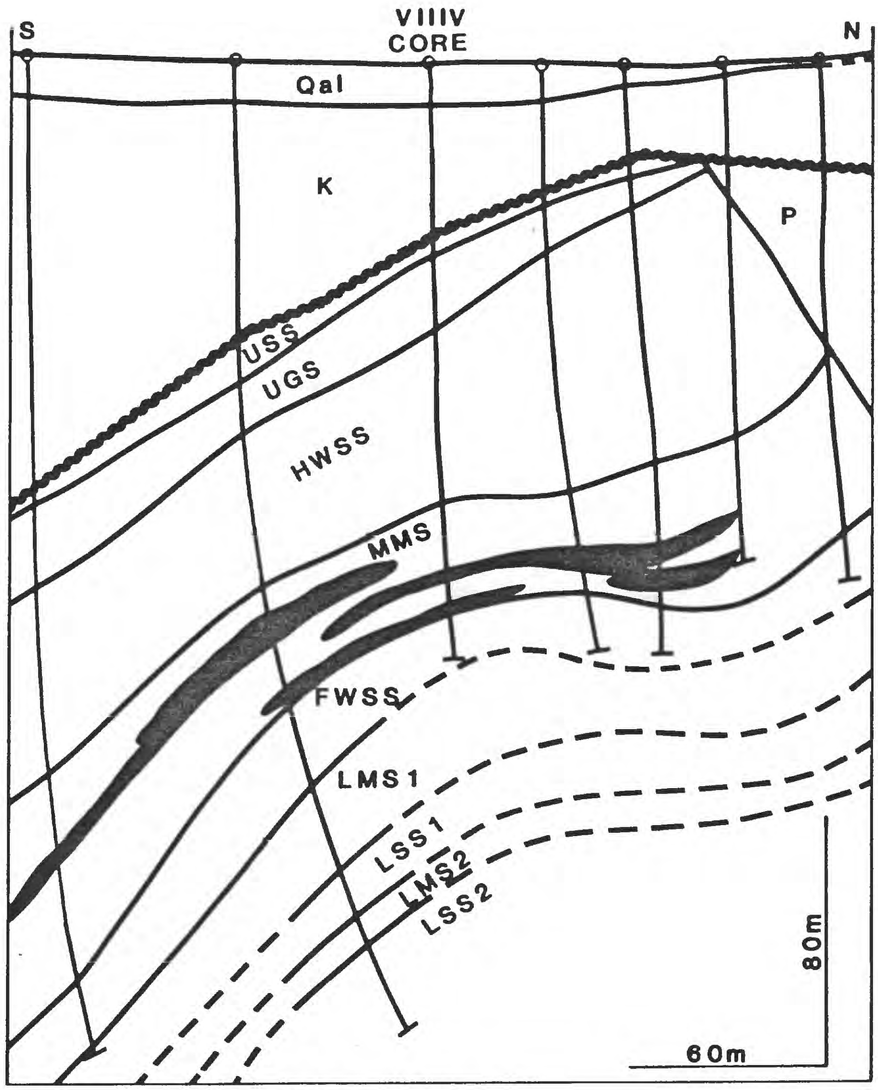


Figure 3.--Location map of drill-hole VIIIV and the III section line and geologic map of the area containing the Jabiluka orebodies. Geologic map modified from data provided by Pan-continental Mining Limited.



EXPLANATION

Quaternary		Qal sand, soil	
Middle Proterozoic	Kombolgie Formation	K	
Lower Proterozoic	Cahill Formation	USS	Upper schist series
		UGS	Upper graphite series
		HWSS	Hanging wall schist series
		MMS	Main mine series
		FWSS	Footwall schist series
		LMS1	Lower mine series 1
		LSS1	Lower schist series 1
		LMS2	Lower mine series 2
		LLS2	Lower schist series 2
Intrusive pegmatite		P	

Unconformity
Contact, dashed where uncertain
Drill hole
Ore zone

Figure 4. Cross section along V111V section line. Locations of section and drill-hole V111V are shown on figure 3. Cross section is modified from data provided by Pancontinental Mining Limited.

V111V core is described in a stratigraphic column from 0-178 m (fig. 5) compiled from Pancontinental Mining Limited and my logging record. Also included are brief descriptions of rock types and minerals (identified by petrographic microscope, microprobe Energy Dispersive System (EDS), powder X-ray diffraction, and powder camera), thin-section descriptions of selected samples (table 1), and discussion of the distribution of veins and uranium.

Nutt (1983) described the core from drill-hole T129V that penetrates ore zones in Jabiluka 2. Comparison of the rocks in the two holes shows both similarities and differences between ore-bearing and barren rocks.

ROCK TYPES

The V111V core contains schists similar to those found throughout the Cahill Formation at Jabiluka (see Nutt and Grauch, 1983, for detailed descriptions of the rock types), as well as carbonate rocks which occur only locally in the orebodies at Jabiluka. The metamorphic rocks consist of quartz, chlorite, muscovite, dolomite, magnesite, and graphite in a fine-grained matrix of chlorite and (or) sericite. The matrix minerals are <0.1 mm in size and make up <5 percent to 45 percent of the schists. The metamorphic rocks encountered in V111V are chlorite - muscovite $\pm$ sericite schist, muscovite - chlorite $\pm$ sericite schist, chlorite - sericite schist, sericite - chlorite schist, graphite schist, chlorite schist, carbonate rock, and quartzite (all schists contain quartz). The schists are fine grained and locally contain pseudomorphs (most commonly chlorite after garnet) up to 1 cm in diameter and coarse-grained muscovite and chlorite as large as 2.5 mm in length.

An about 10 m-thick interval of carbonate rocks interlayered with chlorite and chlorite - graphite schists is included in the main mine series by the geologists at Pancontinental Mining Limited. The carbonate rocks are brecciated, recrystallized, and locally silicified. Fragments of chlorite $\pm$ graphite schist are in the brecciated carbonate rocks and are largest (≤ 2 cm) and most abundant along the upper and lower contacts of the carbonate sequence. Within the carbonate interval, chlorite that is along the edges of carbonate grains imparts a light-green color to the rocks. During logging this chlorite was identified as matrix; however, petrographic examination of thin sections reveals that at least some of this chlorite occurs as deformed chlorite fragments.

The Kombolgie Formation sandstone in V111V is fine to medium grained and is locally silicified, kaolinitized, and cut by chlorite, quartz, and hematite veins. The contact between the Kombolgie and Cahill is brecciated and chloritized.

MINERALOGY

The mineralogy of the V111V core is fairly simple, consisting of quartz, chlorite, muscovite, sericite, septechlorite, graphite, carbonate minerals, tourmaline, apatite, TiO_2 minerals, sulfides, and hematite.

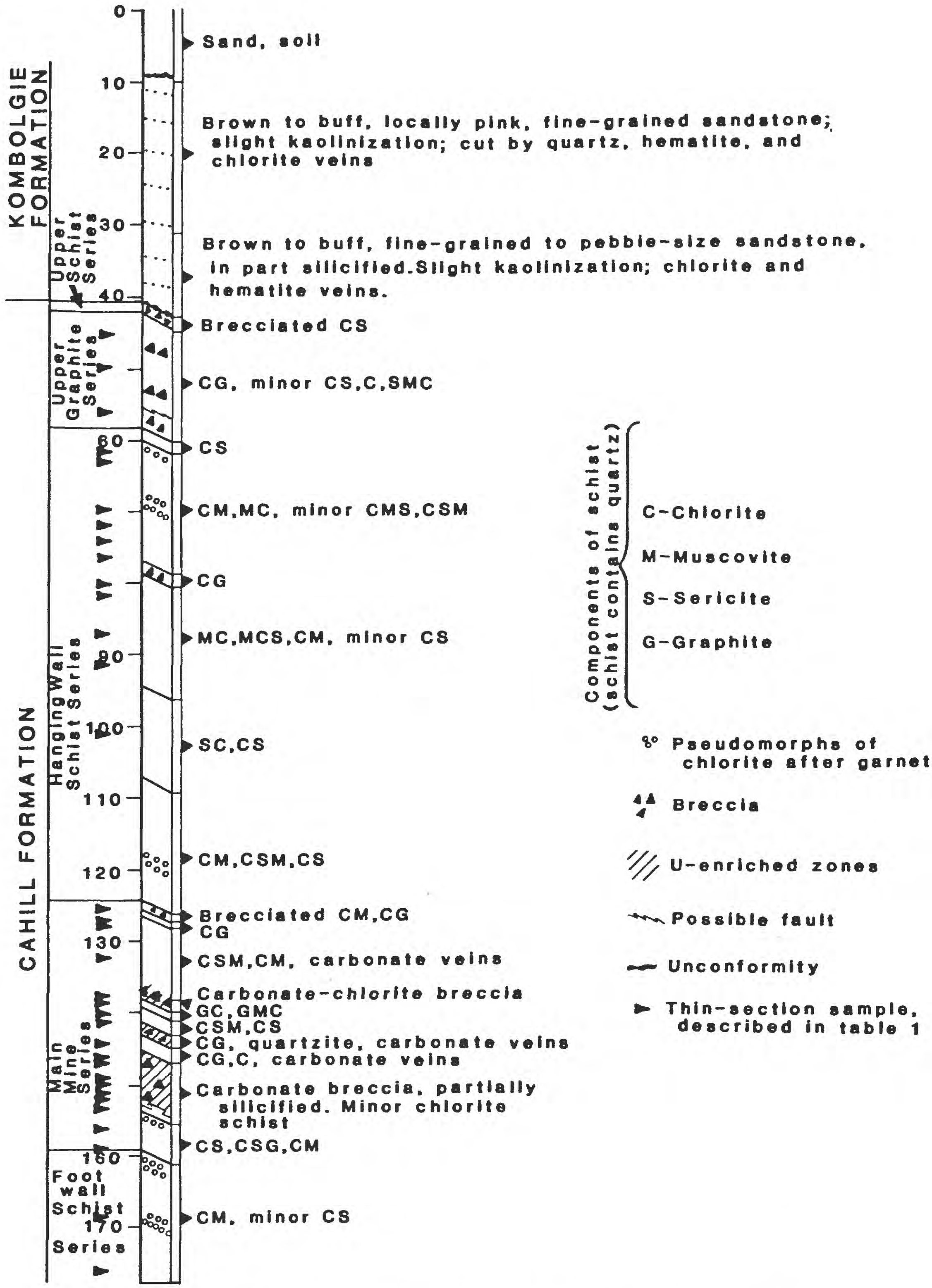


Figure 5.--Stratigraphic column of drill-hole VIIIV.

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 in quartzite and where it is not the most abundant mineral. Rock type is schist unless noted otherwise. Mineral abundances are estimated. Other abbreviations used in the table are: chl=chlorite, septechl=septechlorite, cpy=chalcopyrite, gn=green, yw=yellow, wt=white, bwn=brown, lt=light, dk=dark, crypto=cryptocrystalline, undiff=undifferentiated, x-cutting=cross-cutting, //=parallel (to foliation), w/=with, ✓=present, --=not present.

Stratigraphic unit	Sample number=depth in meters	Rock type	Texture	Breccia matrix	Pseudomorphs	Major Minerals				Matrix Minerals			Accessory Minerals				
						quartz	chlorite	muscovite	others	chlorite	septechlorite	sericite	TiO_2	tourmaline	apatite	pyrite	others
	45	SMC	Foliated	--	--	✓	--	✓	--	Gn (undiff), 5-10% of the rock	--	20-25% of the rock	✓	--	--	✓	Graphite
	50	GMCS	Foliated	--	--	✓	--	✓	Graphite	Bwn-gn (undiff), 5-10%	--	5-10%	✓	--	--	✓	--
Upper Graphite Series	56.3	Quartz-chlorite breccia	Brecciated	Chl	--	Coarse angular grain fragments	--	--	--	Gn (undiff), 10-15%; pods of gn 15-50-µm w/hematite	--	<5%	✓	--	✓	--	Hematite
Hanging Wall Schist Series	61.9	MC	Foliated	--	Chl, sericite after garnet	✓	Bright gn	--	--	Gn (undiff), ≤5%	--	<5%	✓	1-2%	--	--	--
	63.1	CMS	Foliated	--	Chl after garnet	✓	Bright gn	Ragged	--	Lt-gn (undiff), 15-20%	--	15-20%	✓	✓	--	--	--
	74	MC	Foliated	--	Chl after garnet (?)	✓	Bright gn	✓	--	Gn (undiff), ≤5%	--	<5%	✓	1-2%	--	--	Hematite, graphite
	76.5	MC	Foliated	--	--	✓	Bright gn	Some ragged	--	Gn (undiff), ≤5%	--	<5%	✓	--	✓	✓	--
	80.2	MCS	Foliated, crenulated	--	--	✓	Bright gn	Some ragged	--	Gn (undiff), ≤5%	--	10-15%	✓	--	✓	✓	Zircon, sphene, garnet, hematite
	81.9	CSQ	Massive	--	--	✓	Bright gn	--	--	Bwn-gn (undiff), 25-30%	--	25-30%	✓	--	--	✓	Graphite
	87.3	MCS	Foliated	--	--	✓	✓	✓	--	Gn to bwn (undiff), 5-10%	--	<5%	✓	✓	✓	--	--
	91.4	MCS	Foliated	--	--	✓	✓	Some ragged	--	Gn (undiff), 5-10%	--	10-15%	✓	✓	✓	--	--

Table 1.

		Veins					Uranium			Comment
	Dravite	quartz	chlorite	septechlorite	carbonate	others	distribution	uraninite	coffinite	
45	--	--	--	--	--	--	--	--	--	Hand specimen is yellow-green
50	--	--	--	--	--	--	--	--	--	--
56.3	--	--	--	--	--	--	--	--	--	Fragments are quartz, quartzite, GC, and C±M±S. Apatite rims contain hematite inclusions.
61.9	--	--	--	--	--	--	--	--	--	Inclusions of quartz, tourmaline, chlorite, and muscovite are in muscovite grains that cut across foliation.
63.1	--	// to foliation, 0.5-1.5 cm	--	--	--	--	--	--	--	Apatite and tourmaline selvages are along the edges of 0.5-cm-thick quartz veins
74	--	--	--	--	--	--	--	--	--	Bright-green chlorite grains 1 to 1.5 mm cut across foliation. Muscovite grains are both wrapped around chlorite grains and included in the margins of chlorite grains.
76.5	--	--	--	--	--	--	--	--	--	--
80.2	--	--	Gn to yw-gn, radial extinction	--	--	Hematite	--	--	--	Veins and pods of green to yellow green chlorite have radial extinction; chlorite grains are surrounded by white chlorite with extinction continuous to that of the green chlorite.
81.9	--	--	--	±chl, ±marcasite, ±quartz	--	--	--	--	--	Veins are along and cutting across foliation. Quartz within veins is embayed.
87.3	--	--	--	--	--	--	--	--	--	--
91.4	--	--	--	--	--	--	--	--	--	--

Table 1.--continued

Stratigraphic unit	Sample number=depth in meters	Rock type	Texture	Breccia matrix	Pseudomorphs	Major Minerals: quartz	Major Minerals: chlorite	Major Minerals: muscovite	Major Minerals: others	Matrix Minerals: chlorite	Matrix Minerals: septe-chlorite	Matrix Minerals: sericite	Matrix Minerals: TiO_2	Accessory Minerals: tourmaline	Accessory Minerals: apatite	Accessory Minerals: pyrite	Accessory Minerals: others
Hanging Wall Schist Series	100.9	SC	Foliated	--	--	Few grains corroded and strained	✓	Some ragged	--	Gn (undiff), 5-10%	--	10-15%	✓	✓	✓	--	--
	125.6	GC	Foliated	--	--	✓	✓	--	Graphite	Gn to bwn (undiff), 5-10%	--	<5%	✓	--	--	✓	Muscovite
Main Mine Series	127.4	Dolomite vein	Coarse-grained	--	--	Euhedral to subhedral	--	--	--	--	--	--	--	--	--	--	--
	128.	CS	Foliated	--	--	✓	✓	--	--	Gn (undiff), 25-30%	--	10-15%	✓	--	✓	✓	Graphite, zircon, muscovite
	132.6	CMS	Foliated	--	--	✓	✓	Some ragged	--	Yw-gn (undiff), 25-30%	--	≤5%	✓	--	--	✓	Graphite in lenses
	137.7	Carbonate breccia	Brecciated	Car-bonate, minerals, quartz	--	Elongate, with inclusions, radial extinction, in rosettes	--	--	Carbonate, anhedral, ragged, large size variation	--	--	--	✓	--	--	✓	Hematite, cpy, marcasite
	138.5	GMC	Foliated	--	--	✓	--	✓	Graphite	Gn-bwn (undiff), 10-15%	--	--	✓	--	--	✓	--
	140.1	CS	Foliated	--	--	✓	✓	--	--	Lt-gn (undiff), 20-25%	--	10-15%	✓	--	--	✓	Muscovite, graphite, zircon
	141.4	QG	Foliated	--	--	✓	--	--	Graphite	Gn (undiff), <2%	--	--	--	--	--	✓	Muscovite, chlorite
	144.2	CG	Massive to foliated	--	--	✓	✓	--	Graphite	Lt-gn crypto, dk-gn 15-50 µm	--	--	Altered	--	--	✓	--

Table 1.--continued

	Veins: Dravite	Veins: quartz	Veins: chlorite	Veins: septechlorite	Veins: carbonate	Veins: others	Uranium: distribution	Uranium: uraninite	Uranium: coffinite	Comments
100.9	--	--	--	--	--	--	--	--	--	--
125.6	--	--	--	--	--	--	--	--	--	--
127.4	--	--	--	--	Dolomite, quartz, marcasite, cpy, // foliation	X-cutting pyrite	--	--	--	Vein quartz with inclusions is euhedral to subhedral, coarse-grained, strained in places, and locally has radial extinction.
128.	--	+pyrite, x-cutting, 0.5 mm thick	--	--	--	--	--	--	--	About half the quartz occurs in aggregates of corroded and strained quartz.
132.6	--	--	X-cutting	--	--	--	U associated w/vein; no minerals observed	--	--	Chlorite vein consists of dark-green 15-50-μm and light-green cryptocrystalline chlorite, apatite with hematite inclusions, and quartz. The dark-green 15-50-μm chlorite is in pods within the cryptocrystalline chlorite. Quartz has comb structure
137.7	--	--	--	--	--	--	U in schist fragments, along edges of sulfides	--	Surrounds sulfide grains.	Fragments in breccia are C, CG. Recrystallized (?) domains within coarse-grained carbonate
138.5	--	--	--	--	--	--	--	--	--	--
140.1	--	X-cutting, $\leq$ 0.5 mm, anhedral and strained quartz	--	--	--	--	--	--	--	--
141.4	--	--	--	--	Carbonate, zoned quartz, 1.5 mm thick	--	--	--	--	Quartz is 85-90 percent of the sample. Quartz boundaries are irregular to straight edges. Difference between sericite and muscovite is in grain size
144.2	--	--	Pockets of dk-gn 15-50-μm, wt chl in matrix	--	--	--	--	--	--	Where matrix chlorite is abundant, only "ghosts" of coarse chlorite in the matrix are present.

Table 1.--continued

Stratigraphic unit	Sample number=depth in meters	Rock type	Texture	Breccia matrix	Pseudomorphs	Major Minerals: quartz	Major Minerals: chlorite	Major Minerals: muscovite	Major Minerals: others	Matrix Minerals: chlorite	Matrix Minerals: septe-chlorite	Matrix Minerals: sericite	Accesory Minerals: TiO_2	Accesory Minerals: tourmaline	Accesory Minerals: apatite	Accesory Minerals: pyrite	Accesory Minerals: others
	146.5	Carbonate breccia	Brecciated	Carbonate, quartz	--	✓	--	--	Carbonate	--	--	--	--	--	--	✓	Marcasite, hematite
	147	Carbonate breccia	Brecciated	Carbonate, quartz	--	W/ inclusions, elongate, radial extinction	--	--	Carbonate	--	--	--	--	--	✓	--	--
	149.4	Carbonate breccia	Brecciated	Carbonate, quartz	--	Euhedral w/carbonate cores; euhedral to subhedral, strained	--	--	Carbonate	--	--	--	--	--	--	--	Hematite
	150.5	Carbonate breccia	Brecciated	Carbonate, quartz	--	Elongate w/inclusions, radial extinction, rosettes; euhedral w/carbonate in cores	--	--	Carbonate	--	--	--	--	--	✓	--	--
Main Mine Series	151.5	Silicified carbonate rock	Massive, brecciated	Quartz	--	Elongate, with inclusions, radial extinction; fine-grained quartz	--	--	--	--	--?	--	--	--	✓	--	Hematite, marcasite
	152	CM	Foliated	--	--	✓	✓	✓	--	Lt-gn crypto, 25-30%	--	--	✓	✓	✓	✓	Hematite
	153.5	Carbonate breccia	Massive	Carbonate, quartz	--	Euhedral to subhedral, carbonate inclusions	--	--	Carbonate	--	--	--	--	--	--	✓	Hematite, cpy
	156.1	SCG	Foliated	--	--	--	Bwn	--	Graphite	Gn (undiff), 10-15%	--	25-30%	--	--	✓	✓	Quartz
Foot-wall Schist Series	159.5	CMS	Foliated, crenulated	--	Chl, sericite, muscovite, quartz, TiO_2, apatite after garnet	✓	✓	✓	--	Gn (undiff), 10-15%	--	10-15%	✓	✓	✓	--	--
	168.5	CM	Foliated, crenulated	--	Wt to gn chl, rutile, dravite, tourmaline after garnet?	✓	✓	✓	--	Gn (undiff), 20-25%	--	--	✓	✓	✓	✓	--
	176.1	CM	Foliated	--	--	✓	✓	✓	--	Gn to bwn (undiff), 20-25%	? irregular distribution ≤5%	--	--	--	✓	--	--

Table 1.--continued

		Veins					Uranium			Comment
	Dravite	quartz	chlorite	septe-chlorite	carbonate	others	distribution	uraninite	coffinite	
146.5	--	--	--	--	--	--	In schist fragments, w/ sulfides	--	1 grain along edge of fragment	CG fragments are in breccia.
147	--	--	--	--	--	--	--	--	--	Apatite contains hematite inclusions. Chlorite schist fragments are about 5% of the rock.
149.4	--	--	--	--	--	--	--	--	--	--
150.5	--	--	--	--	--	--	--	--	--	Fragments are chlorite schists. Apatite contains hematite inclusions. Quartz-carbonate contacts are irregular to straight edges.
151.5	--	--	--	--	--	--	In schist of quartz fragments	Rare	Along edges of quartz grains, sulfides	Chlorite schist fragments are in quartz that replaces carbonate. Apatite contains hematite inclusions.
152	--	--	Pockets of dk-gn 15-50 μm	--	--	Pyrite, <0.5 mm, x-cutting, along foliation	--	--	--	--
153.5	--	--	--	--	--	--	--	--	--	Rare chlorite schist fragments or matrix are present.
156.1	--	--	Pockets of dk-gn 15-50 μm	--	--	--	--	--	--	Chlorite was identified as biotite in hand specimen.
159.5	Pods in coarse chl, pseudomorphs	--	--	--	--	--	--	--	--	Muscovites have pick-up-sticks appearance. Muscovite wraps around and is included in pseudomorphs.
168.5	Pods in coarse chl, pseudomorphs	--	--	--	--	--	--	--	--	--
176.1	Sprays in chl, w/bwn coating (septechl?)	--	--	--	--	--	--	--	--	Hand specimen is whitish-green in color. Brown coating is tentatively identified as septechlorite.

Table 1.--continued

Quartz

Quartz is the most abundant mineral in the schistose sequence of V111V. Most of the quartz is subhedral, 0.05 to 1.5 mm in length, and slightly strained. Boundaries between quartz grains range from irregular to straight edges and, locally, triple junctions occur. In a few samples two types of quartz exist together: unaltered quartz and corroded, highly strained quartz which in some places occurs in aggregates. Quartz grains surrounded by the matrix minerals chlorite and sericite are commonly embayed and replaced along the edges by the matrix minerals.

In the carbonate sequence quartz, which replaces carbonate minerals, makes up 5 to 80 percent of the rock. The replacement quartz ranges from euhedral crystals (about 0.15 mm in size) with carbonate cores to coarse-grained ($\leq$2.5 mm) bladed quartz that contains unidentified inclusions, has radial extinction, and locally occurs in rosettes.

Chlorite

In the V111V core chlorite occurs as coarse grains, matrix, and vein material.

Coarse chlorite

Coarse chlorite occurs as subhedral grains as large as 2.5 mm in length. Optically, the chlorite is length slow, has a negative sign, and has a low 2V (0-15°). In the upper part of the core, within the hanging wall schist series, the chlorite is green in hand specimen and is optically a distinctive pleochroic bright green to light brown. Elsewhere the chlorite is green in hand specimen and pleochroic green to brown in thin section except near the bottom of the hole where hand speciman chlorite is so brown that the chlorite was identified as biotite during logging. Inclusions of TiO_2 needles indicate coarse chlorite replaced biotite.

Coarse-grained chlorite is both parallel to and cutting across foliation. The bright green chlorite in particular occurs as large grains that have no preferred orientation and cut foliation.

Matrix chlorite

In V111V core, matrix chlorite forms as much as 30 percent of the rock, but is commonly $\leq$10 percent. There is little variety in the matrix chlorites, most of which can be included in the category of undifferentiated chlorite: light green to green brown in color and $\leq$50 μm in size. Rare light-green cryptocrystalline, white 15 μm, and dark-green 15 to 50-μm chlorites are present. Dark-green 15 to 50-μm chlorite was also observed in and along the epges of schist fragments in carbonate breccia.

Vein chlorite

Chlorite veins are restricted to a few samples in the V111V core. The most common chlorite in cross-cutting structures is dark-green 15 to 50-μm chlorite, which occurs in thin veins and pods in chlorite matrix; in many places white <15 μm chlorite fills the center of these pods and veins. Light-green cryptocrystalline chlorite, dark-green 15 to 50-μm chlorite, quartz, and apatite occur in one cross-cutting vein; in this vein the dark-green 15 to 50-μm chlorite occurs as pods in the light-green cryptocrystalline chlorite. A mixture of light-green chlorite and septechlorite forms veins parallel to foliation in sample V111V-81.9. Sample 80.2 has a vein or pod consisting of wormy grains of chlorite, as large as 0.5 mm in length, that has radial extinction and pleochroism of bright green to yellow green. Enclosing this chlorite is white chlorite with extinction continuous to that of the wormy chlorite.

Muscovite

Muscovite-rich rocks are easily identified by their characteristic silvery sheen and the coarse-grain size of muscovites that are as large as 1.5 mm in length. Euhedral to subhedral muscovite grains commonly define foliation, but muscovite cutting across foliation was also observed. Three types of muscovite were identified petrographically: euhedral to subhedral muscovite that is parallel to foliation; euhedral to subhedral muscovite that cuts foliation and contain inclusions of quartz, chlorite, tourmaline, and muscovite; and ragged muscovite with low birefringence. The ragged muscovite, which commonly cuts foliation, has irregularly-shaped inclusions of chlorite, suggesting that the muscovite formed by replacement of chlorite. This replacement of chlorite by muscovite is most pronounced along crenulations.

Sericite

Sericite-rich hand specimens have a characteristic fine-grained dull yellow-green appearance. Subhedral sericite, ≤0.1 mm in length, is mixed with chlorite in the matrix. Locally, sericite forms as much as 30 percent of the matrix, but more typically is ≤5 percent. Embayed edges of muscovite and coarse chlorite grains are invaded by sericite, suggesting incipient replacement.

Septechlorite

Light brown septechlorite is rare in the V111V core. Only one sample, V111V-81.9, contains veins composed of septechlorite and light-green chlorite. The deepest sample in the core, V111V-176.1, has brown alteration, tentatively identified as septechlorite, associated with dravite.

Graphite

In the V111V core, graphite is in the upper graphite series and the main mine series. The amount of graphite ranges from accessory in chlorite-rich schists to major in graphite schists. Tabular grains of graphite, <0.2 mm in length, define foliation and, locally, crenulations.

Carbonate Minerals

Subhedral carbonate grains in brecciated carbonate rocks and veins range from 0.05 to 3 mm; grain size is highly variable within hand specimens. In the brecciated carbonate rocks, both dolomite and magnesite were identified in X-ray patterns, but petrographically the two cannot be differentiated. Dolomite is the carbonate mineral in veins.

Tourmaline

Tourmaline occurs disseminated in schists and rarely concentrated in sprays. Pleochroism of the disseminated tourmaline is green to brown within euhedral to subhedral grains as large as 0.3 mm in diameter. Locally, disseminated tourmaline grains have blue cores. Tourmaline grains are concentrated in layers, especially muscovite-rich strata, where they form as much as 5 percent of the layer.

Sprays of tourmaline, identified by X-ray diffraction to be dravite, are restricted to a few samples in the lower part of the V111V core. Dravite is $\leq$0.5 mm in length and optically clear to light green in color with no visible pleochroism. Typically the sprays occur in pseudomorphs and along the cleavage planes of coarse chlorite. Within pseudomorphs, dravite locally surrounds disseminated tourmaline inclusions, but this relationship is not widespread.

Apatite

Euhedral to subhedral apatite grains as large as 0.5 mm are predominantly in silicified carbonate rocks and carbonate rocks, but are also found disseminated in schists and in a vein of dark-green 15-50-μm, light-green crypotocrystalline chlorite, and quartz. The apatite in the silicified carbonate rock, carbonate rock, and the vein is a distinctive euhedral apatite that contains hematite inclusions and in thin section occurs in nearly square cross sections.

TiO_2 Minerals

Subhedral to anhedral disseminated TiO_2 minerals, which are <0.2 mm in size, occur as anatase and rutile. Rutile needles are concentrated in coarse-grained chlorite after biotite.

Sulfides

Subhedral grains of pyrite and chalcopyrite, which are <0.5 mm in length, are present in small amounts (<1 percent) in schists and veins. Pyrite lenses up to 2 mm thick occur in graphite schists; the lenses consist of both massive pyrite and elongate grains folded with the enclosing schists. Marcasite is in a chlorite-septechlorite vein and, along with pyrite and chalcopyrite, is in the carbonate rocks. Within the carbonate sequence, marcasite and pyrite form euhedral to subhedral grains as large as 2 mm.

Hematite

Hematite occurs in accessory amounts throughout the V111V core and, locally, in veins. A hematite-quartz vein contains euhedral hematite; elsewhere the hematite grains are anhedral.

VEINS

Veins are rare in the V111V core and where present are generally thin (<3 mm thick) and discontinuous. Those veins observed are composed of chlorite, sericite, quartz, carbonate, and, less commonly, pyrite, chalcopyrite, marcasite, and hematite.

Chlorite and sericite are the most common veins observed in V111V. Thin sericite veins occur locally along fractures in pseudomorphs and along foliation. Chlorite veins, discussed in the chlorite section, are restricted to a few samples.

Dolomite veins cut the schistose rocks near the brecciated carbonate sequence. The veins are both vertical and parallel to foliation, and in some places contain chlorite schist fragments. Veins are most commonly thin (2 to 3 mm thick), but larger veins (cms thick) also occur.

URANIUM DISTRIBUTION

Only minor amounts of uranium are concentrated in the rocks of drill-hole V111V. Where present, uranium is localized in the carbonate sequence and in one vein composed of quartz, light-green cryptocrystalline chlorite, dark-green 15 to 50-μm chlorite, and apatite with hematite inclusions. The vein has no visible uranium minerals, but a radioluxograph revealed the presence of uranium.

In the carbonate sequence, uranium is in brecciated sections, especially along contacts between chlorite schist and carbonate rocks, and in silicified rocks. Radioluxographs show that the uranium, either in submicroscopic grains or incorporated in chlorite or another mineral, is disseminated in chlorite schist fragments (fig. 6). Uranium is only rarely in the carbonate-rich portion of the rocks, and then only along the edges of sulfides or schist fragments. In the silicified rocks, coffinite is along quartz boundaries and around sulfides.

COMPARISON OF ROCKS FROM V111V AND T129V DRILL HOLES

Comparison of rocks from the weakly mineralized V111V core and the ore-bearing T129V core shows that although the rocks in both cores are predominantly quartz + chlorite $\pm$ muscovite $\pm$ sericite $\pm$ graphite schists, differences in rock types and structures do exist and are probably the critical factors in uranium concentration. Brecciated zones, a major site of uranium concentration in T129V, are only locally developed in V111V. Barren and ore-bearing veins are rare in V111V; in T129V uraniferous and barren veins extensively cut the rocks. Chloritic alteration is much less intense in V111V than T129V, probably because V111V lacked the channelways provided by

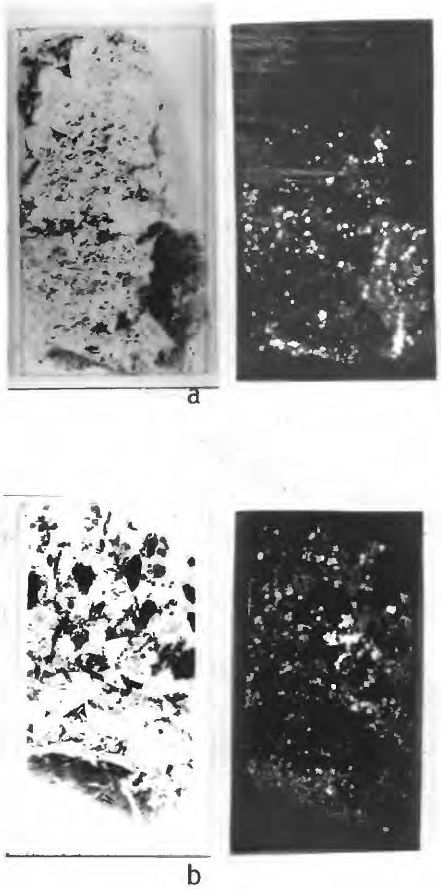


Figure 6. Thin sections and corresponding radioluxographs of carbonate breccia. Dark areas of the thin sections are chlorite ± graphite schist fragments and, locally, pyrite and marcasite. Radioluxographs show that radioactivity, which shows as light spots, is concentrated in schist fragments and near sulfides. Carbonate matrix, which is light in thin section, contains little radioactivity. a) Sample V111V-137.7. Radioluxograph exposure time was 75 hours. b) Sample V111V-146.5. Radioluxograph exposure time was 75 hours.

brecciation and veins. Brecciated and partially silicified carbonate rocks, which are absent in the T129V core, contain the minor uranium concentration encountered in the V111V core.

Alteration is not only more intense in T129V, but is also more varied. Seven types of matrix and vein chlorite were recognized in T129V (Nutt, 1983); most chlorite in V111V has no unique characteristics and was therefore classified as undifferentiated. Septechlorite and tourmaline (dravite) alterations are widespread in breccia matrix, veins, and schist matrix of T129V, but are only rarely observed in V111V.

The division of coarse chlorite into coarse-chlorite 1 and coarse-chlorite 2 that was used in describing T129V core (Nutt, 1983) is not applicable in the description of V111V core. In part, this may be because rocks in V111V have less chloritic alteration; coarse-chlorite 2, commonly associated with light-green cryptocrystalline chlorite in T129V, is thought to be an alteration of coarse-chlorite 1 (Nutt, 1983).

Where matrix and vein chlorites are distinguishable in V111V cores, the occurrence and association of chlorites are similar to those found in T129V. Light-green cryptocrystalline chlorite, associated with uranium minerals in T129V, is vein material in the one uraniferous vein in V111V core. Dark-green 15 to 50-μm chlorite occurs in both cores in late-forming veins and pods locally filled with white <5 μm chlorite.

Accessory minerals in T129V and V111V are predominantly tourmaline, apatite, pyrite, and TiO_2 minerals. A distinctive euhedral apatite with hematite inclusions is associated with dark-green 15 to 50-μm chlorite in both cores, but in V111V this apatite is also found in carbonate and silicified carbonate rocks. TiO_2 minerals are widespread in both cores; however, the clumps of the altered(?) TiO_2 observed in T129V ore zones are not seen in V111V rocks. Hematite, not abundant in either core, has a greater distribution in V111V. Marcasite occurs in the carbonate sequence and veins of V111V, but was not observed in T129V.

Organic matter, which occurs in the ore zones of T129V, is not present in V111V.

COMMENT

Observations of the V111V core may be significant and should be compared with core from T129V and other drill holes. The following generalizations have been formulated for that purpose.

1. Minor uranium concentration is in a brecciated carbonate rock sequence. One chlorite vein is also enriched in uranium.

2. Within the carbonate-rich sequence, uranium occurs predominantly as submicroscopic disseminations in chlorite ± graphite schist fragments. Radioluxographs show that uranium is not associated with carbonate minerals.

3. Coffinite is in silicified portions of the carbonate-rich sequence.

4. Marcasite is in the carbonate rocks.

5. Apatite with hematite inclusions, similar in appearance to apatite found with dark-green 15 to 50-μm chlorite in T129V rocks, is in the carbonate-rich sequence, most noticably in silicified portions.

6. Muscovite locally contains ragged inclusions of coarse chlorite and TiO_2 minerals. The chlorite inclusions may be altered remnants of biotite that was replaced by muscovite during prograde metamorphism.

7. Sericite invades and locally partially replaces both coarse chlorite and muscovite.

8. Although most commonly aligned along foliation, late-forming muscovite and chlorite cut across foliation, suggesting that a late metamorphic or metasomatic event affected the rocks.

9. Similar to their occurrences in T129V rocks, dark-green 15 to 50-μm chlorite occurs in veins and pods cutting other chlorites and a light-green cryptocrystalline chlorite vein is enriched in uranium.

10. In comparison with the ore-bearing T129V core, the rocks in the core from V111V: 1) are less mineralized, 2) are less brecciated, 3) are less chloritically altered, 4) contain fewer varieties of chlorite, 5) are cut by fewer veins, 6) have only rare septechlorite and dravite, 7) contain no organic matter and 8) include a sequence of carbonate rocks.

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