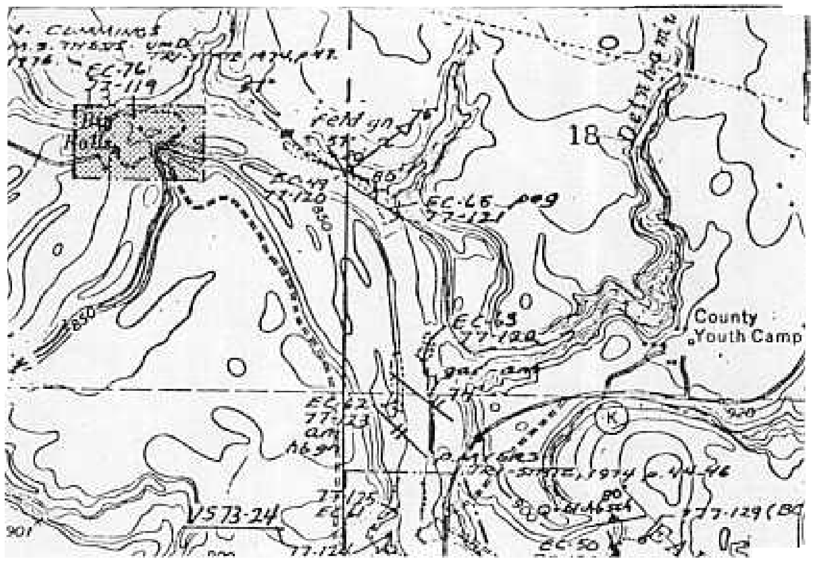
TITLE: Geology of the Big Falls Area

LOCATION: Eau Claire River, NW /4, SE 1/4, SEc. 13, T.27N., R.8W, Eau Claire County



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DATE: September, 1974

SUMMARY OF FEATURES:

Precambrian gneiss and schists at Big Falls County Park are composed of alternating hornblende-rich and plagioclase-rich bands. Structural and petrographic studies indicate three deformational events accompanied by extensive recrystallization and followed by three episodes of faulting. Composition suggests a gabbroic protolith differentiated to anorthositic gabbros and gabbros. The complex is older than 1840 m.y. and possibly Archean in age.

DESCRIPTION:

Precambrian amphibolite gneisses and schists crop out along and in the Eau Claire River at Big Falls County Park in northcentral Eau Claire County (Sec. 13, T.27N., R.8W.). The Precambrian rocks are overlain with angular unconformity by cross-bedded, conglomeratic-to medium-grained Upper Cambrian Mt. Simon Formation. Slumped blocks of Mt. Simon sandstone along the west river bank (Fig. 1), have slid along the green clay layer between Precambrian and overlying Cambrian rocks. Glacial outwash caps the sandstone and overs most of the river valley.

Four Precambrian gneiss and schist units were mapped (Fig. 1): (1) banded amphibolite gneiss (b.a.g.), (2) amphibolite schists (a.s.), (3) transition gneisses (t.g.) between the amphibolite schists, and (4) feldspathic gneiss (f.g.)

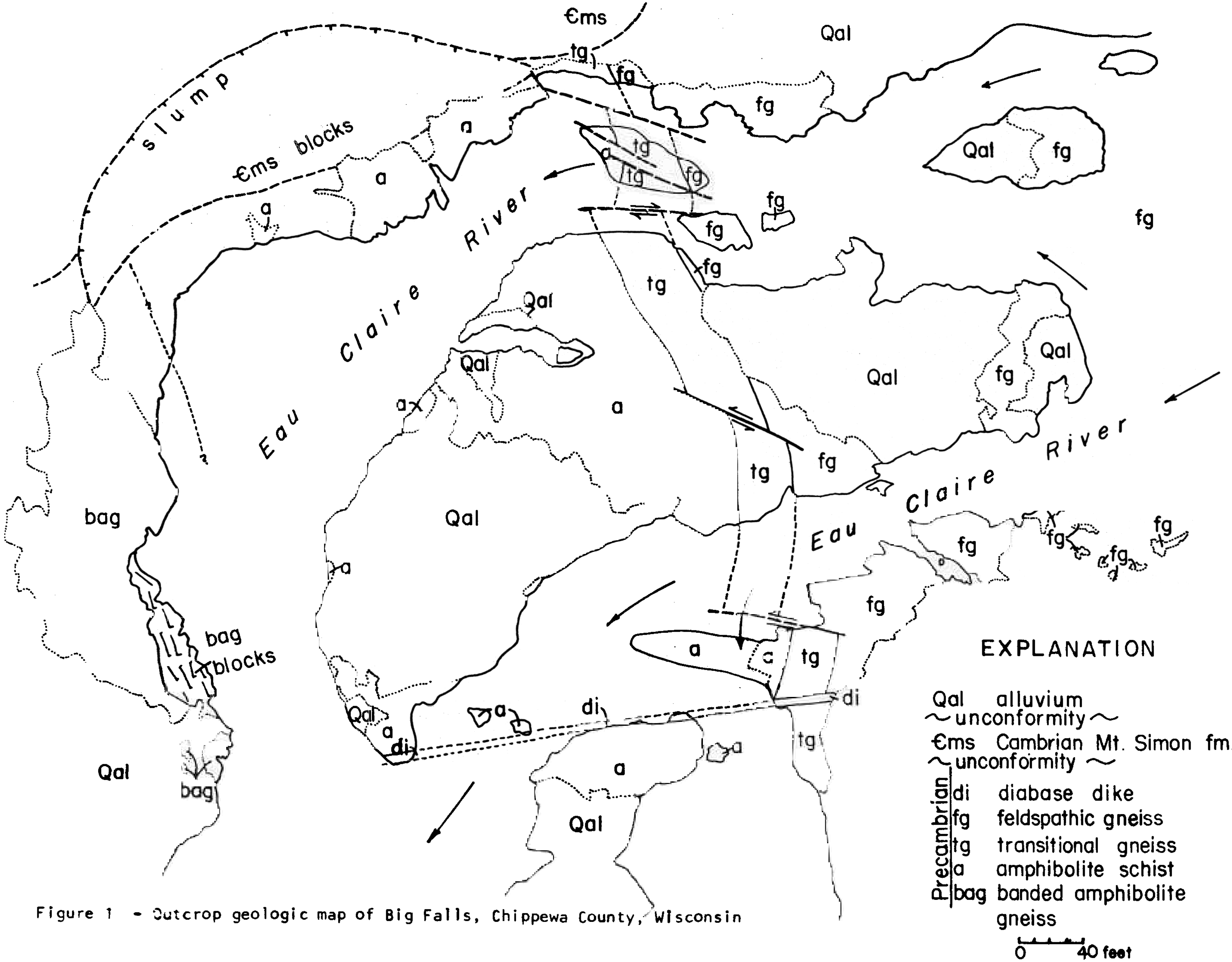

Figure 1 - Outcrop geologic map of Big Falls, Chippewa County, Wisconsin

The banded amphibolite gneiss is characterized by alternating hornblende-rich and plagioclase-rich bands. Hornblende-rich bands are from 0.6 cm to nearly 20 cm wide, but more commonly in the range of 0.12 to 2.5 cm wide. The plagioclase-rich bands are generally 0.6 cm to 31 cm side. Garnet porphyroblasts to 13 cm in diameter are present in parts of the outcrop.

The amphibolite schist is a unit with compositional variation most apparent as changes in the percentage of hornblende. Garnet porphyroblasts up to 2.5 cm in diameter define one compositional band while garnet porphyroblasts up to 0.6 cm in diameter associated with cummingtonite form another persistent compositional band. Thinly banded hornblende-plagioclase rocks are the most typical.

The transition geniss east of the amphibolite schist is characterized by lenticular segregation of hornblende and plagioclase. The segregations are usually 2.5 cm to 3.8 cm long and 0.6 cm to 1.3 cm wide. Thin hornblende and plagioclase bands are also present. A second transition gneiss is composed of thin hornblende and plagioclase bands and common development of silver-gray chlorite.

Compositional banding in the feldspathic gneiss is poorly defined. The percentage of plagioclase is usually greater than 80% of the rock, and compositional banding results from a slight increase in abundance of hornblende.

Most work was concentrated on the banded amphibolite gneiss and the amphibolite schist because of definable structures and less intense faulting.

EVIDENCE FOR DEFORMATIONAL EVENTS

Structural elements in the rocks suggest three deformational events, followed by faulting and joingint. Evidence for each event will be presented and correlated with the textural evidence.

Evidence for the earliest deformation, although sparse, includes: (1) intergrowths of hornblende in large, shattered garnet porphyroblasts wrapped by compoistional banding and (2) lack of structural continuity between rootless intrafolial folds and external foliation.

The second deformation is responsible for the gross structures in the rocks. During the second deformation foliations were wrapped around earlier-formed garnet porphyroblasts and intrafolial folds were transposed. Fold forms and boudinage suggest a high degree of plasticity and flowage. In the banded amphibolite gneiss, the mechanism of deformation suggested by the folds is slip along certain major hornblende-rich bands with folding of the rocks between the major slip planes. The west side of the folds is typically moved south, suggesting a left-handed couple across the folds. Compositional banding is wrapped around axes plunging north 40° to 57°. Folds have nearly vertical axial planes.

Deformation in the amphibolite schist followed the same pattern with movement along discrete planes and folding of the intervening rock. Fold axes plunge south between 20° and 38°, and axial planes are vertical to steeply dipping. Some fold forms show axial plane development of shear planes resulting in shearing out of axial surfaces. Microscopic investigation indicates that faulting occurred late in the deformation, but prior to final recrystallization. The nearly vertical faults have strikes between N10°W and N25°W and show apparent left-lateral displacement. The faults are best observed in the banded amphibolite gneiss, but are obscure in the amphiobolite schist.

The third deformation was neither intense nor penetrative. Narrow shear bands, granulated textures along a 5 to 8 km shear zone, and rotated blocks are the major observable features. Additional petrographic evidence for the third deformation is described later.

Structures produced by three major deformations are overprinted by two different types of faulting. The oldest fault set is responsible for the development of lens-shaped bodies of rock bounded by shear planes Deformation appears confined to the edges of the lenses and to the shear planes with little internal effect. Type and amount of movement is not knonw. Lens forms are vaiable in size, and the banded amphibolite gneiss shows a development of smaller lenses along zones of interference between larger lenses.

The lens structures are cut by two fault sets. The first trends N85°E and is apparently right-lateral with displacements as much as 6 m. The second fault set is N70°W and is left-lateral with displacements up to 4.5 m.

EVIDENCE FOR RECRYSTALLIZATIONS

Evidence for three main deformational episodes is supported by petrographic studies and phase relations. Three separate recrystallizations of the rocks are proposed. The following section summarizes textural evidence for each recrystallization, correlates the features of recrystallization with their reasonable counterparts resulting from deformation, and presents chemical data.

The first recrystallization may have been synchronous with the first deformational event. Evidence for it is sparse. Garnet is the only mineral from this event. In the banded amphibolite gneiss, the farnets are intergrown with coarse hornblende formed during the third recrystallization. This hornblende is of different compoistion than other hornblende in the rocks (see Table 10-2), and has similarites to the enclosed garnet, i.e., low TiO_2 content. Coarse hornblende forms sheaths around the garnets. Textural evidence and compositional differences suggest reaction of the garnets with their surroundings after formation. The reaction may reflect retrograde reaction before the second recrystallization or during the second prograde recrystallization. Similar evidence of garnet reaction is present in the amphibolite schist. Chemical analyses of the garnet porphyroblasts (Table 1) were performed by microprobe. No attempt was made to map compositional zoning within the crystals. Garnets in the amphibolite schist are higher in the almandine end member (70%) than those from the banded amphibolite gneiss (58%) which are higher in grossular (24% vs. 11%).

Ratios of 100 Mg/(Mg+Fe) also indicate the greater proportion of ron in the amphibolite garnets (13% vs. 20%).

The second recrystallization produced a medium-grained texture that appears relict in thin section. Minerals which crystallized during the second event are hornblende, plagioclase, and probably cummingtonite, plus accessory minerals. Recrystallization occurred late or after the second deformation, as orientations are weak or absent in plagioclase and hornblende.

The third recrystallization only partially destroyed earlier textures. The most thorough recrystallization seems to have been in the amphibolite schist, where much of the rock is texturally equilibrated. HOrnblende, plagioclase, epidote, cummingtonite, and sphene recrystallized in the third event. Plagioclase, produced during the second recrystallization, was trained and commonly granulated during the third recrystallization. During destruction of coarse plagioclase grains, the first observable feature is strained twin lamallae followed by development of patchy compositional zoning with compositions varying from An_{59} to An_{49} in a single crystal. The coarse crystal is segregated into 1 mm grains that are untwinned and do not show compositional zoning. Plagioclase in the amphibolite schist is commonly recrystallized, and exhibits reverse compoistional zoning with cores of approximately An_{25} and rims of An_{44}. The contact between core and rim is sharply defined. The observed zoning may result from destruction of a calcium-rich phase, i.e., epidote, during metamorphism with the released calcium taken up by the plagioclase.

PHASE GEOCHEMISTRY

Amphiboles in the banded amphibolite gneiss are hornblendes, while in the amphibolite schist, hornblende and cummingtonite coexist. Three hornblende grains were analyzed from the banded amphibolite gneiss (Table 2). Sample WP-7 is from a hornblende-rich band and represents a product of the third recrystallization. Sample WP-7 P2-1 is from the same thin section as WP-7 P1-1, but it is from a plagioclase-rich band that developed during the second recrystallization. Number 7-29-72 is also a third recrystallization project and is intergrown with the garnet porphyroblasts. Hornblende WP-7 P1-1 and WP-7 P2-1 are similarly saturated with respect to cummingtonite molecule. Sphene is an important accessory mineral, especially in hornblende-rich bands. Development of sphene is probably the result of the expulsion of TiO_2 from the hornblende lattic during the third recrystallization. As titanium content in hornblended is controlled by temperature (Leake, 1972), this implies that the third recrystallization took place at lower temperature than the second, when titanium was still in the hornblende lattice.

The amphibole plases in the amphibolite schist are hornblende and cummingtonite. Hornblende W-29 lTable 3) is a "typical" hornblende of the amphibolite schist and is the result of the third recrystallization. Hornblende W-24, which contains fine opaque inclusions concentrically in and around the core and along fractures, is considered relict from the second recrystallization. Hornblende W-21, cummingtonite W-21, and garnet W-21 are from the same sample. The two amphiboles are considered to have recrystallized during the third recrystallization. The cummingtonite molecule is common in all hornblendes from the amphibolite schist. Hornblende W-24 and W-29 are similar in composition, but W-24 contains an opaque phase which microprobe analysis indicates contains at least 11 weight percent titanium. These opaque inclusions formed during the third recrystallization by the expulsion of titanium from hornblende formed during the second recrystallization.

Hornblende W-21 is subcalcic with cummingtonite molecule present at the expense of calcium and alumina. Ionic formulas for hornblende and cummingtonite indicate more Mg than Fe per formula unit (Table 3). This results in high magnesium content. Cummingtonite-bearing bands are low in calcium. The increasing demand of plagioclase and hornblende for calcium and alumina with rising temperature results in preferential development of cummingtonite and subcalcic hornblende.

Whole rock chemical analyses were made of two samples of banded amphibolite gneiss selected to represent extremes in abundance of hornblende (Table 4). The results indicate low silica with high alumina and calcium. The high alumina and calcium reflect high modal percentage of plagioclase. Oxidation ratios for 2 Fe_2O_3 + FeO) in W1-C and W2-C are 0.371 and 0.362 respectively. These values are abnormally high compared with values of 0.20 or less for most garnet-bearing rocks. Oxidation of the rocks strongly affects the crystallization of garnet. The ratio suggests that the third recrystallization was accompanied by higher oxygen fugacity than the previous two. Epidote, formed during the third recrystallization, contains 0.83 ions of Fe^{3+} of a possible 1.0 ions per formula unit and indicates a relaxation during the third recrystallization. The ratio of K_2O/Na_2O is extremely low (0.103, W1C and 0.135, W2C). Low values of K_2O/Na_2O are characteristic of old rocks, especially Archaen rocks, where K_2O/Na_2O is generally less than 1% (Engel, et.al., 1974). The values of K_2O/Na_2O at Big Falls suggests an Archaen age.

In summary, the gneisses and schists at Big Falls County Park have been deformed and recrystallized during three metamorphic and deformational events with late faulting and alteration. Whole rock chemical analysis of the banded amphibolite are compatible with a protolith of an anorthositic gabbro while individual phases analyzed in the amphibolite schist are not incompatible with a magnesian mafic rock such as a norite. The Big Falls gneisses and schists are a possible part of a differentiated gabbroic intrusive that was emplaced before 1900 m.y. and may be Archaen in age.

REFERENCES:

Leake, B.E., 1972, Garnetiferous striped amphibolites from Connemara, Western Ireland, Mineralogical Magazine, vol. 38, no. 298, pp. 649-665.

Engel, A.E.J., Itson S.P., Engel C.G., Stichney, D.M., 1974, Crystal evolution and global tectonics: a retrogenic view, GSA Bulletin, vol. 85, no. 6, pp. 843-858.

TABLE 10-1 - GARNET PORPHYROBLASTS FROM THE BANDED AMPHIBOLITE GNEISS AND THE AMPHIBOLITE SCHIST

Oxide	7-29-72 Weight %	W-21 Weight %
SiO_2	38.02	37.62
Al_2O_3	20.34	19.46
TiO_2	0.12	
FeO^*	25.69	29.11
	3.56	2.65
Mn	1.66	2.80
CaO	8.40	3.59
	97.79	95.23

Number of ions in structural formula * +

	7-29-72		W-21	
Si	6.11		6.26	
Al	3.81	$\Sigma Y^{+3} = 3.82$	3.78	$\Sigma Y^{+3} = 3.78$
Ti	0.01			
Fe^{+2}	3.45	$\Sigma X^{+2} = 5.98$	4.05	$\Sigma X^{+2} = 5.75$
Mg	0.85		0.66	
	0.23		0.40	
Ca	1.45		0.64	

* All iron as FeO
\+ Structural formula $X_6 Y_4 Si_6 O_{24}$

Molecular % in terms of garnet end members

	7-29-72	W-21
Alm.	57.7	70.4
Spess.	3.8	6.9
Pyr.	14.2	11.5
Gross.	24.2	11.1

TABLE 10-2 - HORNBLENDE FROM THE BANDED AMPHIBOLITE GNEISS

Oxide	WP-7 P2-1 Weight %	WP-7 P1-1 Weight %	7-29-72 Weight %
SiO_2	43.43	41.97	42.59
Al_2O_3	14.07	13.65	18.76
TiO_2	1.18	1.12	0.27
MgO	7.59	7.99	6.87
MnO	0.35	0.42	0.48
FeO*	18.64	17.79	15.44
CaO	11.18	11.21	10.92
Na_2O	0.58	0.43	0.59
K_2O	0.34	0.34	1.13
	97.36	94.92	96.46

Number of ions for structural formula *+ based on 23 oxygen

	WP-7 P2-1		WP-7 P1-1		7-29-72	
Si	6.51	8.00	6.46	8.00	6.31	8.00
Al	2.46 < 1.49 / 0.97		2.45 < 1.54 / 0.91		3.24 < 1.69 / 1.55	
Ti	0.13	5.19	0.13	5.21	0.03	5.07
Mg	1.70		1.83		1.52	
Mn	0.05		0.06		0.06	
Fe^{+2}	2.34		2.28		1.91	
Ca	1.80	.97	1.85	1.98	1.73	.90
Na	0.17		0.13		0.17	
K	0.06	0.06	0.07	0.07	0.21	0.21

* Total iron as FeO

\+ Structural formula $A_{0-1}\ X_2\ Y_5\ Z_8\ O_{22}\ (OH,F)_2$

TABLE 10-3 - AMPHIBOLES FROM THE AMPHIBOLITE SCHIST

Oxide	Weight %	W-24 Weight %	Hbe. W-21 Weight %	Cumm. W-21 Weight %
SiO_2	40.32	41.78	46.85	53.79
Al_2O_3	14.02	13.12	8.04	1.06
TiO_2	0.75	0.90	0.40	0.02
FeO*	15.83	16.93	21.29	23.24
MgO	10.90	10.91	14.68	16.96
MnO	0.29	0.48	0.36	0.52
CaO	10.37	10.76	5.20	0.08
Na_2O	0.67	0.62	0.77	
K_2O	0.34	0.22		-
	93.49		97.59	96.11

Number of ions per structural formula + unit based on 23 oxygen

			W-24		Hbe. W-21		Cumm. W-21	
Si	6.26	8.00 (Si + 1.74 Al)	6.35	8.00 (Si + 1.65 Al)	6.96	8.00 (Si + 1.04 Al)	7.96	8.00 (Si + 0.04 Al)
Al	2.56 (1.74 / 0.82)		2.35 (1.65 / 0.70)		1.41 (1.04 / 0.37)		0.18 (0.04 / 0.14)	
Ti	0.09		0.11		0.09			
Fe^{+2}	2.05	5.52	2.16	5.53	2.65	6.41	2.94	6.93
Mg	2.52		2.48		3.25		3.79	
Mn	0.04		0.06		0.05		0.06	
Ca	1.72	1.92	1.76	1.94	0.83	1.05	0.08	0.08
Na	0.20		0.18		0.22			
K	0.07	0.07	0.04	0.04				

* Total iron as FeO

\+ Structural formula $A_{0-1}\ X_2\ Y_5\ Z_8\ O_{22}\ (OH,F)_2$

TABLE 10-4 - WHOLE ROCK CHEMICAL COMPOSITIONS FROM THE BANDED AMPHIBOLITE GNEISS

	W1-C	W2-C
Oxide	Weight %	Weight %
SiO_2	49.35	47.75
Al_2O_3	23.72	25.63
Fe_2O_3	1.23	1.28
FeO	4.17	4.53
MgO	3.05	1.55
MnO	0.08	0.08
CaO	12.89	14.61
K_2O	0.32	0.31
Na_2O	3.09	2.29
TiO_2	0.28	0.33
P_2O_5	0.11	0.11
CO_2	0.22	0.26
H_2O	1.32	0.95
	99.83	99.68

Analyst: K. Ramlal, University of Manitoba, Winnipeg, Manitoba.