THE GEOLOGICAL SURVEY OF WYOMING

D. L. BLACKSTONE, JR., State Geologist

PRELIMINARY REPORT NO. 10

Taconite in the Wind River Mountains, Sublette County, Wyoming

BY

R. G. WORL

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UNIVERSITY OF WYOMING
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Cover. View looking southeast toward Downs Mountain, across the head of Jakeys Fork. Foreground; diabase intruding granite gneiss.

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INTRODUCTION

Metasedimentary taconite occurs as discrete bodies within the high-grade metamorphic and igneous Precambrian complex that comprises the core of the northern Wind River Mountains. The taconite occurs as one large body in the south central part of T. 39 N., R. 107 W. and as two small bodies in the west central part of the same township. Horizontal land control has not been extended into this area but the larger taconite body is approximately 800 feet long and up to 25 feet wide, with the taconite making up about 60 percent of the exposure. The larger body is not a continuous body in the strictest sense but is composed of smaller discontinuous lenticular layers of taconite in gneiss. Here the taconite occurs in a total area that is 8,000 feet long and up to 3,000 feet wide but the bulk of the taconite occurs in an area 3,600 feet long and 2,500 feet wide where it makes up approximately 60 percent of the exposure.

The larger taconite body is approximately seven and one-half miles east of the outlet of Lower Green River Lake, the end of the road, which is 55 miles by graded road to Pinedale, Wyoming, and 25 miles by jeep trail to Dubois, Wyoming. Both of these towns are at least 60 miles from the nearest railroad. The taconite is within the Bridger Wilderness Area, Bridger National Forest. The easiest access to the taconite is to take an unmaintained horse trail up Roaring Fork and over a divide into Falers Lake. From this point, travel must be on foot, a distance of approximately two miles over rugged terrain.

TOPOGRAPHY AND CLIMATE

The topography of the northern Wind River Mountains is rugged and the elevation ranges from 8,000 feet to 13,000 feet. The large taconite body lies in an open cirque at an elevation of 11,000 feet. The climate at the taconite body is harsh even in the summer. Snow covers the taconite a great part of the year and in some years (such as 1965) it covers half of the taconite exposures all year.

The area is above timberline, and vegetation is limited to scattered patches of bunch grass. Exposure is excellent as most of the area has been glaciated. Indeed, sampling of the taconite is difficult because of the smooth, polished nature of the outcrops.

METHODS

These taconite bodies and surrounding geology were mapped during the summers of 1964 and 1966 at a scale of 1:12,000 directly on U.S. Geological Survey high altitude aerial photograph contact prints. Topographic control was added from the Fremont Peak 30 minute U.S. Geological Survey topographic sheet. This study is part of a regional study of the Precambrian of the northern Wind River Mountains. The Wyoming Geological Survey largely supported the field work. Subsequent petrographic work, X-ray determinations and density measurements were done at the University of Wyoming Geology Department and Colorado State University Geology Department. Amphibole, pyroxene and plagioclase properties were determined through the use of a four axis universal stage and immersion oils. The iron analyses were made by atomic absorption method by J. A. Thomas, U.S. Geological Survey, Analytical Services and Research, Denver, Colorado. The spectrographic analyses were handled by J. C. Hamilton of the same lab. The manuscript was kindly reviewed by Professors R. B. Parker and S. B. Smithson, Department of Geology, University of Wyoming, who also visited the area.

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PREVIOUS INVESTIGATIONS

Previous investigations of the Precambrian rocks of the Wind River Mountains have been scant, especially in the northern portion. Richmond (1945), Baker (1946), Skinner (1960) and Branson and Branson (1941) have studied the sedimentary sequences and structures at the northwest end of the Wind River Mountains but give only brief mention of the Precambrian rocks. Precambrian rocks of the core of the range have been studied and mapped in separate areas in the central Wind River Mountains by Ebens and Smithson (1966), Parker (1962) and Perry (1965). Oftedahl (1953) conducted a reconnaissance study of the Precambrian rocks along the west-central slope of the Wind River Mountains. He noted that the Precambrian was largely a mixture of granite, gneiss and migmatite with metagabbro dikes and late unaltered diabasic dikes. No published account of taconite in the northern Wind River Mountains was found although this taconite has subsequently been reported by Harrer (1966, p. 43). Iron-bearing schists have been reported from the south-central part of the mountains (Harrer, 1966, p. 43) and the large deposit of taconite at Altantic City at the southern end of the mountains is well known (Bayley, 1963).

GENERAL GEOLOGY

Precambrian Rock Types

The great bulk of the area is underlain by migmatite - a "mixed rock" composed of a definite "igneous appearing" felsic portion and a definite "metamorphic appearing" mafic portion (Dietrich and Mehnert, 1961). The physical and mineralogical nature of the migmatite varies from place to place, but in one aspect it is quite homogeneous. It is always layered.

Included in the migmatite are two small bodies and one large body of taconite (Fig. 1) which is the main subject of this paper. The taconite grades laterally into the amphibolite of the migmatite and therefore is part of the mafic portion of the migmatite. Superimposed on all Precambrian lithologies are zones of epidotization associated with Laramide shear zones (Worl, 1968).

The lithologies are quite simple and similar as they are all part of a migmatite in which mixing has taken place on most scales. There are two general lithologic types of felsic material: granite and quartz-plagioclase-biotite gneiss; and two lithologic types of mafic material: amphibolite, including taconite and metadiabase.

Amphibolite. There is field evidence for the presence of both orthoamphibolites and para-amphibolites although the distinction is impossible to make in most places. Relict diabasic textures are present in numerous places and this massive mafic material was mapped as metadiabase. The remaining mafic material was mapped as amphibolite although the implication is not made that it is all para-amphibolite because in places amphibolite boudins contain cores of metadiabase. Commonly where both the metadiabase and amphibolite are present, the metadiabase crosscuts the amphibolite.

The material mapped as amphibolite is quite variable in texture and mineralogy. Massive rocks composed of plagioclase and amphibole are common but so are foliated and layered rocks rich in biotite (40%). All intermediate rock types between true massive amphibolite composed of plagioclase and amphibole and quartz-plagioclase-biotite gneiss can be found.

In hand specimen the medium-to dark-gray amphibolite commonly has a layered aspect due in part to oriented biotite and in part to incipient lithologic banding. This lithologic banding is caused by plagioclase porphyroblasts concentrated into lenses. The plagioclase porphyroblasts also occur as discrete scattered crystals that become numerous enough at times to give the rock an "augen" gneiss appearance. When quartz is present, it weathers into knobs that commonly show preferred orientation so as to simulate the foliation.

The variable amphibolite is composed of plagioclase (An 10-30) (10-40%), amphibole (20-40%), biotite (20-40%), epidote, quartz, chlorite and minor magnetite, sphene, clinozoisite, zircon (?), allanite, and hematite

Quartz-Plagioclase-Biotite Gneiss. Although the gneiss occurs only as felsic bands in the migmatite, the size of these bands is quite variable. There appears to be a rough correlation between the thickness of these felsic bands and the amount of included mafic material; the thinner bands are more mafic. Contacts between the quartz-plagioclase-biotite gneiss and amphibolite are very gradational and there appears to be a complete gradation in texture and lithology between the gneiss and amphibolite.

The gneiss is light gray, medium to fine grained, commonly with oriented porphyroblasts of feldspar in hand specimen. Slight iron staining is common. It has a definite layered appearance due largely to preferred oriented biotite concentrated into lenticular zones, but these mafic zones, from 1 mm to 2 cm in width, are sometimes in a stretched mosaic pattern that still has a well-defined attitude.

The texture of the quartz-plagioclase-biotite gneiss varies with the amount of mafic material present. The biotite-amphibole-rich rocks are finer grained (1-2 mm) and exhibit more foliation while those containing less amphibole and biotite are coarser grained (up to 5 mm) and granoblastic in texture.

In this highly variable unit, quartz and plagioclase (An 8-30), generally about equal in amount, make up 60 to 80 percent of the rock, and biotite comprises 10 to 20 percent. Amphibole, chlorite, microcline and epidote are present in varying amounts (up to 10 percent for any one constituent) and in varying combinations.

Metadiabase. In hand specimen all gradations between a massive, unfoliated rock with contrasting dark, stubby amphibole and light lathlike plagioclase to foliated amphibolite can be seen. In places the plagioclase appears to have been stretched out. The contacts of this rock with the granite and quartz-plagioclase-biotite gneiss are usually sharp, but in the case of the granite there is a small reaction rim within the metadiabase. The contacts with the amphibolite, on the other hand, are complex, in places crosscutting and in others gradational.

This distinctly igneous-appearing mafic rock is composed of subhedral amphibole, lathlike plagioclase and minor biotite and epidote. It differs from the amphibolite in the lack of quartz, magnetite, hematite, clinozoisite, sphene, and the other small indistinguishable grains that are in abundance in the amphibolite.

Granite, including Pegmatite and Aplite. Three main textural varieties of this rock were found: granitic, pegmatitic and aplitic. The light-gray to white, fine-grained aplite is consistent in texture and mineralogy throughout the area. It is always in well-defined dikes 1 to 5 feet in width that have sharp boundaries. Generally occurring in swarms with a northwest strike and vertical attitude, these dikes cut the quartz-plagioclase-biotite gneiss, amphibolite and metadiabase of the migmatite; however their relationship to the granites and pegmatites is unknown.

The pegmatites and granites are genetically related; one often grades into the other. The pegmatites are simple, being composed of quartz, biotite, muscovite and feldspar with K-feldspar phenocrysts. The pegmatites occur mainly as dikes, irregular pods or stringers in the granite. Locally dark-gray quartz stringers cut the pegmatites.

Some of the granites and some of the pegmatites have a reddish hue caused in part by pink K-feldspar and in part by hematite stain. No distinction could be made between the two in thin section although the pinkish granite appears to be later (?) as it occurs unsheared in mylonite zones that cut the gray granite. The remaining granite is light to medium gray.

Both granites are medium to coarse grained and often porphyritic with K-feldspar phenocrysts. Large (up to 10 mm) grains of magnetite with halos are common in the granite. Foliation or xenoliths are not common except along some dike contacts. The mafic constituents are often in clusters. The granite bodies have various shapes and sizes from crosscutting, well-defined dikes to irregular, crosscutting bodies to conformable lenses in the migmatite. Contacts with the other lithologies of the migmatite are usually sharp although many of the conformable lenses grade continuously into the quartz-plagioclase-biotite gneiss. There is a small reaction rim between the metadiabase and the granites within the metadiabase. Cataclastic textures and epidotization are common along and within some of the northwest trending granite dikes.

These rocks crosscut the other four rock types that compose the migmatite and generally lack metamorphic textures. This material although quite variable in texture is usually composed of quartz, plagioclase (An 8-14) and K-feldspar with lesser amounts of biotite, epidote and muscovite (pegmatites) and minor amounts of magnetite, chlorite and clinozoisite. Masses of sericite and epidote occurring as alteration masses after plagioclase are common.

The overall texture is granitic with large (1-10 mm) quartz, twinned plagioclase and antiperthite, lath or bunched biotite, scattered small (1 mm) epidote grains, irregular microcline, small rounded, clear plagioclase and fine-grained masses of sericite and epidote.

STRUCTURE

From a distance the migmatites appear to be well banded with few irregularities, but upon closer examination one can see that this banding is caused by irregular, but parallel, lenticular layers of amphibolite in quartz-plagioclase-biotite gneiss (Fig. 2). The size of the individual layers ranges from millimeters to 30 plus meters. Parallel to this lithologic layering is a distinct foliation in the quartz-plagioclase-biotite gneiss demonstrated mainly by parallelism of the biotite but also somewhat by tabular feldspars. This foliation and the lithologic layering represent S_3, a penetrative planar surface. The large metadiabase bodies in the Downs Mountain taconite area (Pl. 1) are sheet like structures that are approximately parallel to S_3.

It should be emphasized that the lithologic layering is not a relict layering but is strictly of metamorphic origin (Worl, 1968, p. 100). This is a transposed layering that reached its present form as a result of discrete differential movement along S_2, a planar penetrative slip surface.

The major and minor structures illustrated by S_3 are of two distinct types: passive folds and flexural folds (Donath and Parker, 1964). The passive (or slip) folds formed at the same time as the transposed lithologic layering. They represent areas where transposition of the previous layering was not complete. The flexural (true bending) folds formed later. The dip of S_3 throughout most of the northern Wind River Mountains is betwee 10 and 30 degrees. In the Downs Mountain Taconite area (Pl. 1) the dips are generally to the southeast. The passive folds are recumbant isoclinal types with nearly horizontal fold axes and the flexural folds are open folds with nearly horizontal axes and nearly vertical axial planes.

The granites, including aplites and pegmatites occur mainly in northwest-trending dikes. These usually occur in swarms, and in places have cataclastic zones developed within the dikes that parallel the trend of the dikes. Some transposition of S_3 has taken place along these dikes.

There are three major Laramide fracture trends: 45°, 335°, and 300°. Fractures here include joints, faults and shear zones, all of which are well developed in the northern Wind River Mountains. The 335° trend includes the major fractures of the area; the shear zones and the White Rock Thrust (Richmond, 1945) along the northwestern flank of the mountains. The 300° trending fractures are the most recent as they offset fractures of the other two trends. The fractures of 45° trend are mainly joints that are commonly curved.

TACONITE

Sampling Plan

The taconite was sampled according to the following design. Six lenticular taconite bodies were picked at about equal distance from each other (Pl. 1). From each outcrop five samples were taken:

a) at the contact with the quartz-plagioclase-biotite gneiss,

b) six inches in from the contact,

c) one foot in from the contact,

d) two feet in from the contact,

e) at the center of the taconite layer.

A sample of the gneiss was also taken and all pertinent data, i. e. the size and shape of the taconite layer, distance to and size of any granitic bodies in the vicinity, and the amount of fracturing, were recorded. These samples were used for all additional study and description. Other samples were collected to make certain that all assemblages noted in the field would be represented.

Field Relations

The large taconite body is not a continuous structure but is defined by discontinuous, lenticular bodies of taconite in quartz-plagioclase-biotite gneiss (Pl. 1). These lenticular bodies are 2 to 30 feet thick and up to 500 feet long and are consistent throughout their length. Within each lenticular body there is well-defined, continuou layering that probably represents relict sedimentary layering. This layering is often highly contorted, but is generally parallel to the lenticular bodies which are not contorted.

The contacts between the quartz-plagioclase-biotite gneiss and the taconite are sharp and generally conformable. In places the lenticular bodies of taconite are boudinaged. The northwest-trending granite dikes cros cut the taconite which is often upturned next to the contact. There is commonly a reaction zone in the taconite composed of a black, highly foliated mass of biotite, amphibole and chlorite(?).

The taconite grades laterally and across strike into amphibolite. There is lateral, lithologic consistency in any one relict sedimentary layer but there is no pattern to the alternation of layers. The lenticular bodies composed mainly of amphibolite are very irregular and gradually grade into quartz-plagioclase-biotite gneiss. Many of the lenticular taconite bodies terminate by grading into amphibolite which grades into the gneiss by becoming highly contorted and quartz- and feldspar-rich. Across the strike of the internal layering there is a sudden change at the edge of the taconite-bearing lenticular bodies to typical migmatite. There is apparently no increase in magnetite inward from this contact. The amphibolite layers in the migmatite generally conform to the structure of the taconite body for a short distance from the contact although they are highly irregular and the structure is not homogeneous.

Megascopic Descriptions

The resistant, dark-green to dark-brown taconite stands in sharp contrast to the surrounding light, medium-gray migmatite. In hand specimen the consistent layering, defined by alternating quartz and/or feldspar-rich layers and amphibole, pyroxene and/or magnetite-rich layers, determines the fabric. These layers are up to 10 cm thick but are mostly 1 to 2 mm thick. Each individual layer is consistent in lithology and thickness, except where folding has caused thickening and thinning.

All gradations from a well-banded quartz-magnetite rock to well-foliated amphibolite can be found, often in one hand specimen. The lenticular bodies mapped as taconite are not composed entirely of quartz, magnetite and ferruginous amphiboles but contain intercalated layers (1 mm to 10 cm thick) of amphibolite, magnetite-rich amphibolite, biotite schist, amphibole schists, pyroxene schist, garnet schists, magnetite schists, and quartz and feldspar schists. There is always an abundance of magnetite in the lenticular bodies but it is not always dispersed throughout the entire body; it may be confined to one or several layers.

The physical properties of the taconite depend upon the various mineral assemblages which are segregated into and reflect the layering. The following samples illustrate the most common hand specimen varieties found in the field.

a) Sample 33A. Dark gray to dark green on fresh surface, brown on weathered surface with little outward sign of layering. Massive, with a smooth, rounded, exposed surface. Fracture faces have a glassy appearance, caused by a large percentage of quartz.

b) Sample 32B. Finely-laminated rock with alternating bands of quartz, magnetite, quartz and feldspar, and magnetite and amphibole and/or pyroxene. The amphibole and/or pyroxene-bearing zones can be readily distinguished with a hand lens.

c) Sample 33D. Coarsely-banded rock (up to 10 cm) with alternating bands of quartz, often with associated garnet, and amphibole and/or pyroxene. The quartz weathers granular as does the garnet giving the rock a gritty texture. The amphibole and/or pyroxene is lathlike.

d) Sample 36E. Dark-green, felted rock composed of fine-felted masses of amphibole with larger porphyroblasts of magnetite and occasionally layers of quartz and feldspar.

Mineralogy

The properties of the minerals found in the taconite will be listed, where applicable, and will not be repeated again in the discussion.

Biotite	Dark brown, often very dusky and altered to chlorite.
Plagioclase	Equal amounts of twinned (An 10-50, mostly 35-40) and untwinned. Alteration mild.
K-feldspar	Occasional grains of microcline and perthite. Some of the perthite has hour-glass form.
Magnetite	Mainly as separate bands or associated with amphibole, although scattered throughout. No noticeable intergrowths and no TiO_2 was detected by analysis although up to .7 percent TiO_2 is present in the rock.
Hypersthene	Pleochroic light green to clear and very pale brown to pale green, parallel extinction, $2V_x = 68\text{-}80°$, Z = C.
Amphiboles	
Anthophyllite -	Dusky, light-brown color with numerous small inclusions accentuating cleavage. Lathlike or fibrous. $2V_z = 85\text{-}88°$, Z = C.

Amphiboles

Cummingtonite-Grunerite - Colorless, irregular grains commonly fibrous. Simple twinning on (100) is ubiquitous. $2V_x = 80\text{-}92°$, $Z \wedge C = 14\text{-}17°$.

Brown Hornblende - Dark brown to pale yellow brown pleochroic. Idioblastic grains with few inclusions. $2V_x = 70\text{-}76°$, $Z \wedge C = 14\text{-}16°$.

Blue-green Hornblende - Pleochroic dark blue-green to pale blue-green. Mostly irregular, unaltered grains. $2V_x = 70 (\pm)$, $Z \wedge C = 14°$.

Epidote — Colorless, but slightly dusky grains scattered throughout.

Garnet — Pale-pink almandine in irregular but slightly rounded grains.

Others — Quartz- apatite, sericite, and chlorite.

Assemblages

The most significant mineral assemblages in the taconite are those of the individual layers as they best represent closed, chemical systems. It must be kept in mind that these individual layers are millimeters to centimeters in thickness, therefore many of the assemblages listed below can and do occur in one thin section.

Assemblage 1: Hypersthene-anthophyllite-garnet-magnetite

Rounded garnet (2-5 mm) in irregular bands, scattered magnetite (1 mm), interstitial quartz (1 mm), and anthophyllite (1-5 mm) with hypersthene cores constitute this assemblage. All mineral contacts except those of anthophyllite are sharp. The anthophyllite and hypersthene contacts are a hazy, gradational zone. Often all that is left of the pyroxene is a dusky-brown area with poor pyroxene cleavage in the center of an anthophyllite grain. Anthophyllite needles extend into the quartz causing a hazy contact zone between these two minerals.

Assemblage 2: Anthophyllite-grunerite-quartz-garnet-magnetite

This assemblage is composed of masses of anthophyllite and grunerite with interstitial quartz, minor garnet and scattered magnetite. The sheaves of grunerite are commonly but not always in the center of the anthophyllite, the position held by hypersthene in Assemblage 1. The contacts of anthophyllite and other minerals are hazy, gradational zones as they are in Assemblage 1.

Assemblage 3: Brown hornblende-quartz-plagioclase-microcline-grunerite

Strongly preferred oriented, poikiloblastic, brown hornblende (1-10 mm) with irregular included grains of quartz, plagioclase and microcline defines some layers. Minor grunerite occurs as an alteration product of hornblende. All mineral contacts, with the exception of the hornblende-grunerite contacts, are sharp.

Assemblage 4: Hypersthene-anthophyllite-quartz-magnetite

Large, irregular poikiloblastic grains of hypersthene with small rims of anthophyllite make up the bulk of this assemblage. Irregular, interstitial grains of quartz and scattered magnetite, often with rims of quartz are also present. The hypersthene is generally free of inclusions and alteration other than the rims of anthophyllite.

TABLE 1. MODAL ANALYSES*, DENSITIES AND IRON CONTENT OF TACONITE

Sample	Densities Powder	gm/cc Bulk	Quartz/ Feldspar	1. Garnet 2. Biotite 3. Sericite-Chlorite-Epidote	Magnetite	Pyroxene	Amphibole 1. Anthophyllite 2. Grunerite 3. Blue-green Hornblende 4. Brown Hornblende	Total Fe as Fe_2O_3%
1a	3.45	3.45	29.6	20.6(1) 3.0(3)	5.0	16.5	24.8(1)	33.5
1b	3.32	3.37	48.3	1.3(1) 1.0(3)	10.3	6.3	25.8(1) 6.4(3)	33.0
1c	3.07	3.09	25.6	3.3(2) 3.3(3)	0.6		3.3(2)62.7(4)	16.0
1d	3.57	3.67	28.0	34.0(1) 8.0(2) 1.6(3)	7.0	20.0	9.0(1) 9.3(2)	41.3
1e	3.49	3.70	40.3	3.3(1)11.3(3)	9.3	30.0	5.9(1)	40.0
2a	3.13	3.21	18.6	0.6(3)	2.3		78.3(4)	20.8
2b	3.48	3.61	36.5	3.5(2) 1.0(3)	23.0		18.0(2)18.0(3)	47.0
2c	3.67	3.67	23.6	5.5(2) 7.5(3)	14.3		23.0(1)22.0(2) 5.0(3)	50.0
2d	3.60	3.49	36.3	2.6(2) 4.6(3)	32.0	5.0	11.8(1) 7.8(3)	47.0
2e	3.31	3.31	11.2	9.0(3)	2.6		11.6(2)65.4(4)	19.2
3a	3.29	3.13	70.0	0.6(2) 2.0(3)	0.6	24.0	2.6(3)	35.3
3b	3.30	3.37	56.3	1.6(2) 5.6(3)	25.6	9.6	1.0(3)	38.4
3c	3.50	3.33	51.3	0.6(2) 4.3(3)	4.3	36.6	4.0(3)	42.0
3d	3.24	3.69	30.6	32.3(2)11.3(1) 0.6(3)	6.6	6.0	6.0(1) 6.3(2)	32.0
3e	3.74	3.13	20.6	0.3(2)	20.3	59.0		52.0
4a	3.20	3.36	32.3	0.7(1) 3.0(3)	18.6		18.6(1)18.6(2) 8.1(3)	35.0
4b	2.94	2.97	62.0	8.0(2) 3.0(3)	0.6		10.3(1)16.3(2)	18.5
4c	3.25	3.33	33.3	12.3(1)18.6(2) 0.6(3)	15.0		18.1(1)12.2(2)	35.0
4d	3.41	3.69	37.3	3.3(2) 6.3(3)	30.3		10.3(1)12.3(2)	43.5
4e	3.02	3.13	15.0	4.6(1)51.9(2)14.3(3)	5.0		3.6(1) 5.0(2)	25.0
5a	3.46	3.48	38.0	0.5(2) 3.0(2)	33.0		5.0(1)21.0(2)	48.0
5b	3.52	3.59	21.6		40.0		7.7(1)30.7(2)	52.5
5c	3.28	3.32	40.0	1.3(2) 1.0(3)	25.6		6.5(1)25.8(2)	40.0
5d	3.25	3.28	37.0	1.3(1) 3.3(2)10.0(3)	2.3		4.8(1)19.2(2)	38.0
5e	3.23	3.25	2.3	8.3(2)30.3(3)	16.6		8.3(1)36.0(2)	34.9
6a	3.45	3.61	27.9	1.6(2)	2.3	65.0	1.0(1) 2.0(2)	32.8
6b	3.39	3.50	28.0	9.0(1) 0.3(2) 5.6(3)	3.6	40.2	8.0(1) 5.0(2)	32.6
6c	3.17	3.23	58.7	3.0(3)	7.0	25.0	3.0(1) 3.3(2)	26.1
6d	3.61	3.78	11.3		11.6	45.6	2.0(1) 3.0(2)	39.5
6e	3.48	3.48	32.0	2.0(3)	8.0	35.3	4.3(1) 3.1(2)	34.7
Mean	3.35	3.43	33.4	(1) 3.38 (2 & 3) 9.8	12.8	14.1	(1 & 2) 16.5 (3 & 4) 8.9	36.1

Based on 400 counts across the layering.

Assemblage 5: Hypersthene-bluegreen hornblende-quartz-magnetite

This assemblage is the same as Assemblage 4 except for the presence of minor blue-green hornblende.

Assemblage 6: Quartz-magnetite

Mosaic quartz with scattered magnetite grains, ranging in size from dust specks to 2 mm, constitute this assemblage. The quartz is clear except for the magnetite.

Assemblage 7: Magnetite-grunerite-bluegreen hornblende

Magnetite, grunerite and blue-green hornblende in decreasing order of abundance constitute this assemblage. The magnetite occurs in a wide range of sizes, from dust specks to 4 mm but is generally sub-rounded in shape. The amphiboles in intimate mixture occur interstitially to the magnetite. The grunerite is often fibrous while the blue-green hornblende is idioblastic. The two amphiboles are often optically continuous.

Assemblage 8: Grunerite-anthophyllite

Fibrous grunerite and anthophyllite (?) in felted masses with round grains of magnetite make up this assemblage. Most of the green, felted mass is of too small a grain size to enable exact determination of the mineralogy. Therefore much of this material could be chlorite.

Analyses

Table 1 contains modal analyses, bulk densities, powder densities and total iron contents of the thirty samples of taconite taken according to the previously mentioned sampling plan.

The densities were determined using a Beckman model 930 air comparison pycnometer. For bulk determinations each 4" x 4" sample was split and then random replicate density determinations were made of each split. The splits were then crushed and ground and the resulting powder was composited to form one sample which was then split, one half being used for random replicate powder density determinations and the other half being used for chemical analyses.

The bulk density figure given then is the average of four separate determinations on each sample, two replicates on each sample split. The powder density figure given is the average of two determinations upon the powder split. The standard deviation of the bulk determinations is 0.25 gm/cc although the analytical error is only 0.015 gm/cc. This reflects the heterogeneous layered nature of each taconite sample. The standard deviation of the powder determinations, which in this case is the analytical error is 0.006 gm/cc. Analysis of variance (Table 2) of the results of the two methods indicated that there is no significant difference between the two methods at the 0.05 probability level. Note that the powder densities are consistently slightly lower than the bulk densities. This may represent the fact that two different machines in different laboratories were used for the bulk and powder determinations.

TABLE 2. AOV TABLE OF DENSITY DETERMINATION METHODS

Source	Sum Squares	Degrees of Freedom	Mean Squares	$F(\alpha = 0.05)$
Blocks	2.432	29	0.025	
Treatments	0.068	1	0.068	2.83 NS
Error	0.111	29	0.024	
Total	2.611	59		

The bulk density determinations were analyzed in a four-way nested analysis of variance design (Table 3). The design is nested because the interest is in where the variation is in a population - the densities - not between populations. The factors (outcrops, samples, sample splits, repetitions) are nested inside each other and there is no chance for interaction between factors of the same level and rank. As can be seen from the analysis of variance table (Table 3) there is significant variation within samples; therefore it would be fruitless to draw conclusions on the nature of the variation at larger scales. This reflects the finely layered nature of the taconite.

TABLE 3. AOV TABLE OF NESTED BULK TACONITE DENSITIES

Source	Sum Squares	Degrees of Freedom	Mean Squares	$F(\alpha = 0.05)$
Outcrops	0.60	5	0.12	0.55
Samples w/i	5.19	24	0.26	27.00
Splits w/i	0.252	30	0.008	32.00
Replications w/i	0.015	60	0.0002	
Total	6.06	119		

TABLE 4. MULTIPLE REGRESSION ANALYSIS OF DENSITIES, MODES AND IRON CONTENTS OF TACONITE

Variable:

1. Powder Density (Bulk Density)
2. Quartz and Feldspar
3. Garnet
4. Other
5. Magnetite
6. Pyroxene
7. Anthophyllite and Grunerite
8. Hornblende
9. Total Fe as Fe_2O_3

Correlation Matrix

	1	2	3	4	5	6	7	8	9
1	1.00 (1.00)	-0.17 (-0.26)	0.15 (0.11)	-0.40 (-0.35)	0.40 (0.41)	0.39 (0.52)	0.07 (0.01)	-0.30 (-0.32)	0.78 (0.76)
2		1.00	-0.11	-0.32	-0.06	0.01	-0.21	-0.30	-0.01
3			1.00	0.15	-0.22	0.04	0.05	-0.17	-0.01
4				1.00	-0.15	-0.32	0.08	-0.13	-0.23
5					1.00	-0.28	0.42	-0.29	0.72
6						1.00	-0.51	-0.29	0.15
7							1.00	-0.27	0.31
8								1.00	-0.55
9									1.00

Bulk

Fe% = -78.24 + 33.35 (Density)

Standard Errors 18.33 5.34

S = 6.0

Powder

Fe% = -105.05 + 42.12(Density)

Standard Errors 21.17 6.31

S = 5.55

The densities were determined in hopes that they could be related to some chemical or mineralogical attribute, mainly the total Fe content. If so they could then be used as an easily measured indicator of that property To test the relationship between all variables in Table 1, multiple regression analysis was used. The result is the correlation coefficient matrix listed in Table 4. The correlation coefficient between the powder densities and total iron is .78 with the regression line being -105.5 + 42.12 (density). This correlation is good enough so that the densities, either bulk or powder since there is no significant difference between their results, can be used as a reconnaissance type tool in estimating the total iron content. This is assuming that the same procedures are used in determining the densities as were used when obtaining the regression equation. At .95 confidence level the following confidence limits can be placed on the value of Fe_2O_3 percent obtained from the regression equations.

	Powder	Bulk
1) Using density values near the mean	$\pm$ 2.1% Fe_2O_3	$\pm$ 2.2% Fe_2O_3
2) Using density values near the extremes	$\pm$ 5.0% Fe_2O_3	$\pm$ 5.4% Fe_2O_3

TABLE 5. SEMIQUANTITATIVE 6-STEP SPECTROGRAPHIC ANALYSES OF TACONITE

Symbols used are: G - greater than 10%
N - not detected at limit of detection
L - detected, but below limit of determination

	Mg	Ca	Ti	Mn	Ba	Be	Co	Cr	Cu	Nb	Ni	Pb	Sc	Sr	V	Y	Zr	Ge	Si	Al	Na	K
31a	3.	.7	.15	1500	30	N	15	100	70	N	50	N	15	N	70	30	70	L	G	5.	N	N
31b	3.	.7	.15	1500	50	N	15	70	30	N	50	N	15	15	70	30	150	L	G	3.	.15	N
31c	5.	7.	.7	1500	50	N	70	150	70	N	70	10	70	200	500	70	150	N	G	G	1.5	1.5
31d	3.	.7	.15	1500	70	N	30	200	30	L	70	N	30	N	150	200	150	L	G	7.	.07	N
31e	3.	.3	.15	1500	15	N	15	15	70	10	50	N	15	N	30	30	N	L	G	1.5	.07	N
32a	3.	5.	.7	1500	150	1.5	70	15	3	N	70	L	70	300	300	70	150	N	G	7.	1.	1.5
32b	2.	1.5	.07	1000	50	1	7	30	30	N	30	N	L	30	30	30	20	L	G	2.	.3	N
32c	1.5	.3	.03	1000	30	N	10	10	15	N	30	N	N	15	15	N	N	L	G	.7	.05	N
32d	3.	.7	.07	1000	30	N	7	30	7	N	30	N	L	15	30	30	N	N	G	1.5	.2	N
32e	7.	5.	1.5	1500	70	1.5	100	1000	3	10	700	N	70	300	500	50	150	N	G	7.	.7	1.5

Table 5 contains semiquantitative spectrographic analyses of the thirty samples of taconite taken according to the previously mentioned sampling plan. Si, Al, Fe, Mg, Ca, Na, K, and Ti are reported in %; all others in ppm. Results are to be identified with geometric brackets whose boundaries are 1.2, 0.83, 0.56, 0.38, 0.26, 0.12, etc., but are reported as mid-points of these brackets, 1., 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, etc. The precision of a reported value is approximately plus or minus one bracket at 68% or two brackets at 95% confidence.

The following elements were also checked for but were not detected in any sample: Ag, As, Au, B, Bi, Cd, La, Mo, Pd, Pt, Sb, Sn, Te, U, W, Zn, P, Ce, Hf, In, Li, Re, Ta, Th, Tl, and Eu.

Structure

The taconite structures differ strikingly from those of the migmatite. The more competent parent rocks of the taconite were less affected by the processes of metamorphism, migmatization and tectonism than were the surrounding less competent lithologies. The internal relict sedimentary layering and the foliation defined by the lenticular bodies are considered as S_{T_3}, which described the structure. Determining attitudes in the taconite is difficult because the area has been glacially scoured and the abundance of magnetite in the rocks makes the use of a Brunton compass impossible. The contacts of the taconite and the surrounding quartz-plagioclase-biotite gneiss are quite sharp and deformed only into broad, open folds. The internal layering of the taconite, on the other hand is often highly contorted, but still retains a general strike parallel to the lenticular bodies of taconite.

The most obvious structural feature of the taconite is the large fold shown by its outcrop pattern (Pl. 1). The term "antiform" or "synform" has not been used for reasons which will become obvious. Smaller folds

Fig. 1. View to the north at the southwest portion of the taconite body. The light-gray rock is migmatite, silicic rich, and the dark-gray is taconite. The small vertical hands are weathering streaks.

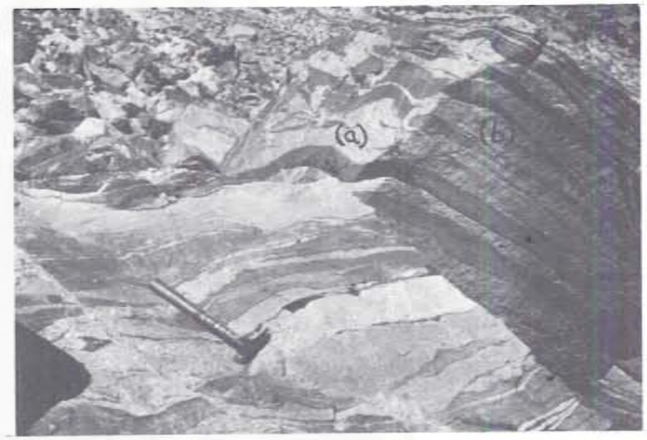

Fig. 2. Picture of a large boulder showing the irregular but still parallel nature of the migmatite layering.

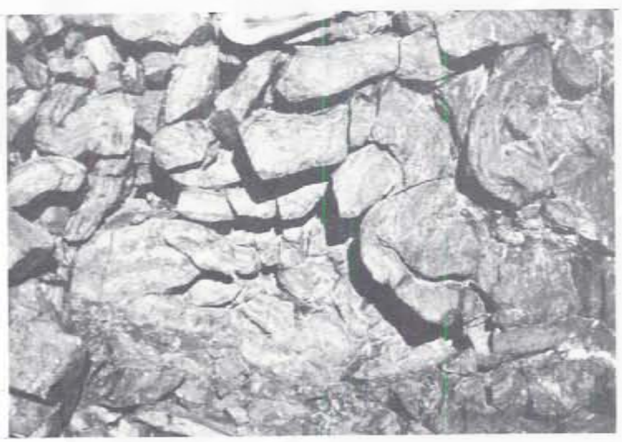

Fig. 3. Minor flexural folds found in Subarea Tac. II.

Fig. 4. Highly contorted layering in taconite.

ranging from millimeters to 3 meters across are common, although most are around 10 centimeters across. All folds noticed were flexural. Two groups were readily noted - those with nearly horizontal axes, and those with nearly vertical axes. The axial planes of all minor folds are nearly vertical.

The taconite body can be broken down into two structurally homogeneous subareas (Pl. 1). The structure of the taconite body was defined through various methods of structural analysis (Worl, 1968, p. 105) which will not be covered here. In essence the taconite body (although not a continuous body in the strict sense) is a refolded structure. Folds with nearly horizontal fold axes were refolded around a nearly vertical axis.

The first generation of folding which was around a nearly horizontal axis is illustrated by the structure in Subarea Tac. II and by numerous minor folds with nearly horizontal axes scattered throughout both subareas (Fig. 3). In this central part of the taconite body the attitudes of S_{T3} range from horizontal to vertical. Contorted internal layering is not common. The most obvious structural features are small (four inches to two feet across) flexural folds with nearly horizontal axis. The π diagram (Fig. 5) for S_{T3} in the subarea shows a rough distribution around a nearly horizontal axis.

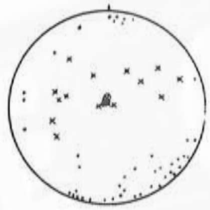

Fig. 5. π diagram for S_{T3} in Subarea Tac. II.

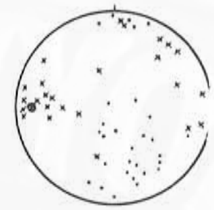

Fig. 6. π diagram for S_{T3} in Subarea Tac. I.

The refolding around a nearly vertical axis is best illustrated by the structure in Subarea Tac I. In this outer shell of taconite most of the dips are steep and highly contorted internal layering is common (Fig. 4). A few folds up to twenty feet across with vertical axes can be found. Most of the minor folds however are tight nearly isoclinal folds with nearly horizontal, but often bent, axes. Large, up to 10 feet across, isoclinal folds with horizontal axes and vertical axial planes are well exposed in the southwestern part of this subarea. The nature of these exposures and the folded gneiss-taconite contacts suggest that the taconite body is a relatively thin, but sharply folded sheet, about 300$\pm$ feet thick. The π diagram (Fig. 6) for S_{T3} in this subarea shows distribution on a great circle about a nearly vertical axis.

The diagrams of (Fig. 7) illustrate the sequence of events that lead to the development of this body. The taconite was originally a nearly horizontal sheet parallel to the migmatite layering, S_3. The sheet was then folded flexurally about a nearly horizontal axis into a series of parallel folds. These were small folds with amplitude of 500$\pm$feet. Next, the whole wrinkled sheet was bent into one large structure around a nearly vertical axis. As this was taking place the taconite lenses were fractured, pulled apart, and highly attenuated with quartz-plagioclase-biotite gneiss filling the intervening spaces. The previous folds with nearly horizontal axes were tightened up into nearly isoclinal folds in the hinge area of the large structure. Later erosion exposed the taconite in its present setting.

Taconite Metamorphism

Iron-rich sediments are useful as metamorphic indicators because of sensitive mineral stability changes brought about by environmental changes. However, because of their scarcity, especially in higher grade metamorphic terranes, there has not been much work on stability relations of phases in the various Fe-, FeO-, and Fe_2O_3 containing systems. Most of what is known about the stability fields of the iron oxides and silicates has been deduced from field relations.

When working with banded ironstones, one must bear in mind that each individual band, no matter how small, started with a given bulk chemistry that may have been entirely different from that of the surrounding bands. This is why the assemblage of each band should be considered separately, which is how the taconite was described under Assemblages. The following pertinent points should be obvious from the descriptions:

1) Hypersthene and brown hornblende to a minor extent are partially replaced by anthophyllite and/or grunerite.

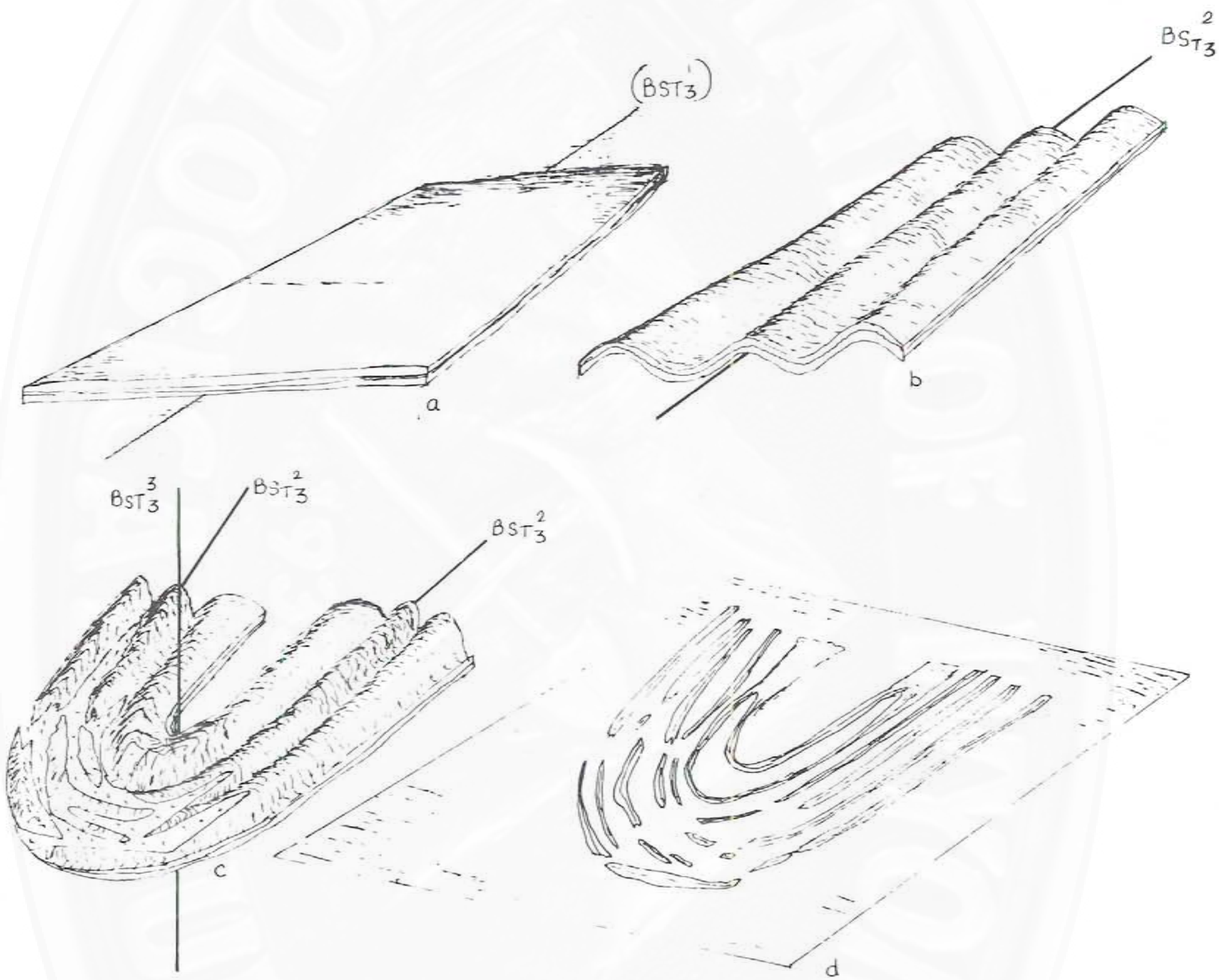

Fig. 7. Diagrams illustrating the sequence of structural events affecting the taconite body. (a) Sheet of taconite lying approximately horizontal. This lies in the plane of S_2 and S_3. (b) Open flexural folding of the taconite sheet around B_{ST3} a nearly horizontal fold axis. (c) Flexural folding of the taconite sheet including the B_{ST3}^2 folds around a nearly vertical fold axis, B_{ST3}^3. At the same time the B_{ST3}^2 folds were tightened up into tight, nearly isoclinal folds in places. The taconite also became highly attenuated and pulled apart with gneiss filling the intervening spaces. (d) Erosion exposing the gneissic cores of the folds. The result being a surface exposure of lenticular beds of taconite in gneiss.

2) Anthophyllite and grunerite are often in an intimate fibrous mixture.

3) Grunerite and blue-green hornblende are often intimately intergrown and optically continuous.

4) Magnetite is the only iron oxide and it contains no visible inclusions or detectable TiO_2.

5) Both hypersthene and brown hornblende occur in strongly preferred oriented, large poikiloblastic grains containing quartz and magnetite.

6) Grunerite and anthophyllite may be a reaction zone between magnetite and quartz in that assemblage.

There is evidence for two major periods of regional metamorphism, the first belonging to the granulite facies and a later belonging to the amphibolite facies (Worl, 1968, p. 69).

CONCLUSIONS

This taconite is in all appearances similar to metasedimentary banded iron formations elsewhere with the exception that it is surrounded by what would often be called a "granite complex". The taconite is of great academic interest but will never be of economic importance. The larger taconite body appears to be a relatively shallow sheet, 300± feet thick, thus precluding any large scale operations. The cost of building a road into this area alone would probably not be covered by the amount of taconite present. Other factors against considering the taconite as economic include the fact that it lies within a wilderness area and even though the average iron content of the taconite is 25 percent the taconite makes up only 50-60 percent of the exposure, the rest being granite gneiss.

An aerial magnetic survey of the northern Wind River Mountains may point out other similar bodies that are closer to existing roads. A large area of Precambrian rocks at the head of Fish Creek (Pl. 1) is partially covered by glacial debris. A hidden taconite body in this area could be of economic importance if large enough.

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