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A Silurian (?) Unconformity at Flanders Bay, Maine

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ABSTRACT

Reexamination of exposures of conglomerate and greenstone at the head of Flanders Bay has resulted in the recognition of an unconformity believed similar to that exposed on Spectacle Island on the east side of Frenchman Bay. It is proposed that the conglomerate is part of the Bar Harbor Formation of Siluro-Devonian age; the underlying greenstone is probably of Silurian age.

The rocks above the unconformity consist of pebbly siltstone and polymict, matrix-supported conglomerate in which clasts are predominantly of felsic volcanic rocks and quartz. A depositional model is proposed in which gravels derived from a volcanic source terrane, and transported in a high energy fluvial system, were mixed with basin-margin muds to produce debris flows.

Chemical analyses of the underlying greenstone show it to be andesitic, but to have substantial differences in composition from Silurian and Lower Devonian basalts and basaltic andesites from the Machias-Eastport area.

INTRODUCTION

In his study of the stratigraphy of the Bar Harbor Formation in the Frenchman Bay area, Maine, Metzger (1979) briefly mentions exposures of pebble conglomerates that contain clasts of volcanic rocks and quartz at several isolated outcrops at the head of Flanders Bay, in the vicinity of Jones Cove (Fig. 1). The conglomerates are associated with a weakly foliated greenstone. He concluded that the conglomerates are intraformational within a sequence of greenstones rather than belonging to the conglomerates of the Bar Harbor Formation that he describes from Spectacle, Turtle, Flat and Heron Islands on the east side of Frenchman Bay (see also Gates, in press). There, polymict basal conglomerate of the Bar Harbor Formation containing clasts of quartzite, epidote clots, greenstone, felsites, basalt, and granite, unconformably overlies a greenstone having numerous veins and "amygdules" of white quartz, the latter being flattened in the plane of a prominent spaced cleavage that strikes N70°E and dips 60 degrees to the south. Metzger correlated the greenstone of Spectacle Island with the greenstone at Flanders Bay.

Reexamination of the area at the head of Flanders Bay (by Gilman) has disclosed what is believed to be an unconformity between the greenstone and the conglomerates, and suggests an alternative interpretation to Metzger's; namely that the conglomerates are in fact part of the Bar Harbor Formation, and that the unconformity at Flanders Bay is perhaps the same as that observed on Spectacle Island.

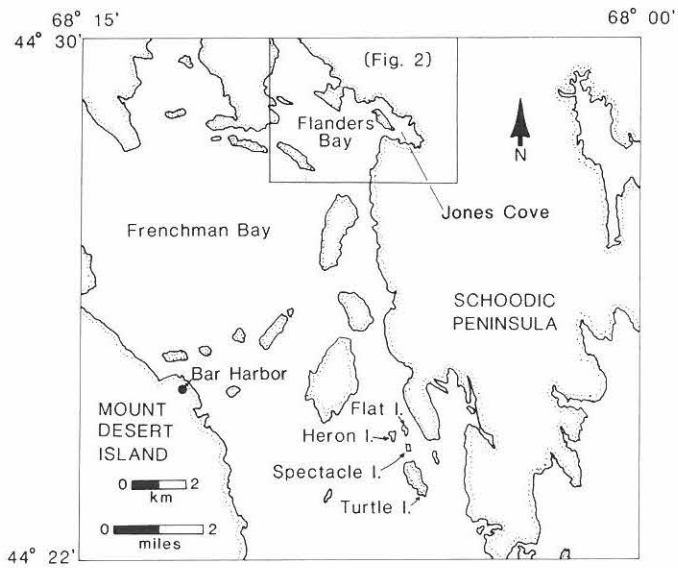

Figure 1. Location map for the Frenchman Bay area, Maine.

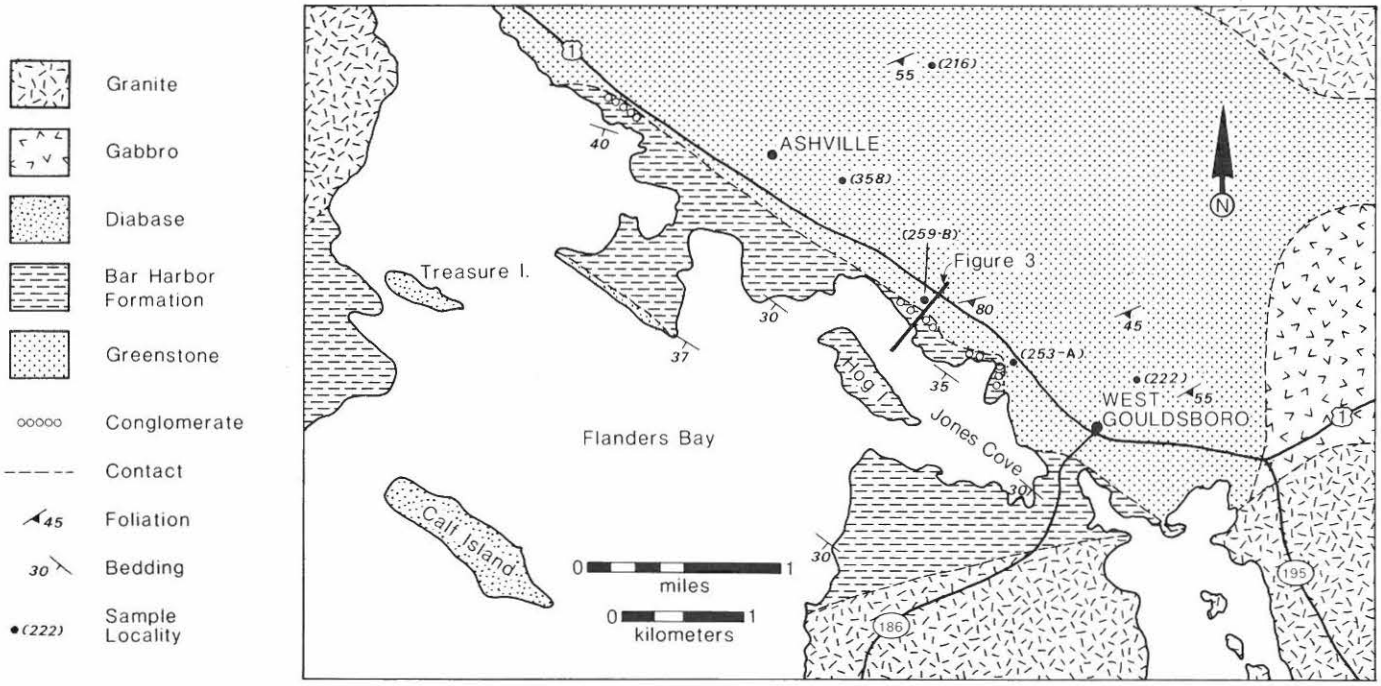

Figure 2. Geologic map of the Flanders Bay area; in part modified from Metzger, 1979. Numbers in parentheses are analyzed samples in Table 1.

DESCRIPTION OF THE UNCONFORMITY AT FLANDERS BAY

The unconformity is exposed at several locations between the shore and U.S. Route 1 west of West Gouldsboro (Fig. 2). It is usually marked by an abrupt change in slope a few hundred meters south of the highway where limited moss-covered exposures can be found in the woods (Fig. 3). It appears to be a planar but irregular surface that strikes northwestward and dips toward the southwest.

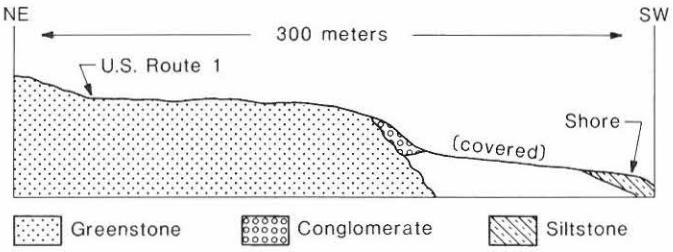

Figure 3. Cross section of the unconformity at Flanders Bay (not drawn to scale; see Fig. 2 for location).

Greenstone below the unconformity is characterized by abundant epidote veins and a faint but persistent foliation that strikes N70°E and dips 45-70 degrees to the south. Similar rocks crop out extensively north of the highway before they are truncated by granite and gabbro. In thin section the greenstone consists of a fine-grained assemblage of plagioclase and actinolite in which mats and "feathers" of actinolite usually obscure the plagioclase grain boundaries. A few sections show plagioclase phenocrysts. Primary mafic minerals have been completely replaced by actinolite and minor amounts of epidote. Some samples show a weak compositional layering, but none show a clear metamorphic foliation. The rock appears to have undergone a weak thermal metamorphism from the intrusion of granite and gabbro that lie to the north and east (Fig. 2).

Epidote veins and the foliation of the greenstone are abruptly truncated by the overlying sedimentary rocks which, in some instances, is a pebbly siltstone rather than a conglomerate. Bedding in these associated siltstones parallels the attitude of the contact, but the conglomerate itself appears to be non-bedded. The conglomerate consists of well-rounded clasts, usually less than 6 cm in diameter but locally as large as 30 cm, that typically "float" in a matrix of dark gray mudstone and siltstone. Clasts include light- and dark-colored volcanic rocks and quartz. Seven oversized thin sections were made from samples of the conglomerate. Of about fifty pebbles over 1.0 cm in diameter, the vast majority were felsites, a few of which showed porphyritic, pilotaxitic, or flow-banded textures; the remainder were polycrystalline quartz. No pebbles of plutonic igneous rocks or greenstone were noted in thin section.

Two exposures, one about a mile west of West Gouldsboro, the other just south of U.S. Route 1 west of Ashville (Fig. 2), exhibit gently dipping siltstone and quartz-pebble conglomerate, respectively, assumed to overlie the greenstone. These exposures emphasize the lithologic and structural diversity of the sedimentary rocks lying directly above the greenstone.

Exposures of the conglomerate are only a few meters thick and adjacent siltstone outcrops of the Bar Harbor Formation are commonly found within 100 meters to the south. Therefore, the conglomerate is much thinner than the conglomerates on and near Spectacle Island. This, plus the lack of greenstone clasts led Metzger (1979) to conclude that the conglomerate is not a basal unit of the Bar Harbor Formation, but rather an intraformational conglomerate in the greenstone. However, additional mapping has not disclosed greenstone exposures to the south between the conglomerate and siltstones of the Bar Harbor Formation along the shore, nor conglomerate exposures north of U.S. Route 1. Consequently, Gilman (1984) considered the conglomerate to be within the Bar Harbor Formation.

DISCUSSION

One of Metzger's (1979) arguments for not including the Flanders Bay conglomerates within the Bar Harbor Formation was the lack of clasts of the underlying greenstone such as are found on Spectacle Island and neighboring islands (see also Gates, in press). In this sense it is not the "typical" basal conglomerate in which clasts of the underlying lithologies are abundant. Moreover, the Flanders Bay conglomerates do not have massive boulder beds as described by Metzger on Turtle, Flat, and Heron Islands, nor are the Flanders Bay conglomerates as thick. But these differences need not imply that the conglomerates at Flanders Bay are not Bar Harbor Formation equivalents. If the Flanders Bay conglomerates are related to other polymict conglomerates along the coast as described by Gates (in press), his proposed origin of the conglomerates, which for some involves a debris flow process, would account for the local variability in both thickness and lithology observed at different locations, and also for the lack of locally derived clasts in a conglomerate such as at Flanders Bay.

Clast lithologies of the conglomerate clearly reflect a lithologically diverse source area. The texturally mature nature of clasts is best explained by abrasive rounding of detritus during transport in a high-gradient fluvial system prior to final deposition from debris flows. Additionally, rapid transport would enhance the preservation potential of unstable volcanic detritus. The origin of the mud matrix of the conglomerates is problematic when considered in the context of transport of the clasts. It is certainly conceivable that the well-rounded clasts mixed with offshore or slope mud during downslope gravity transport to form debris flows. According to Metzger (1979) the conglomerates on and near Spectacle Island are interlayered with sandstones and siltstones that accumulated from turbidity currents.

Sedimentologic characteristics of rocks of the Bar Harbor Formation (Metzger, 1979) suggest that the paleogeography of the source terrane was characterized by areas of moderate to high relief surrounded by flat fluvial plains and shallow basins in which sediment derived from the complex volcanic-plutonic terrane was variably reworked (Fig. 4). Periodically, downslope

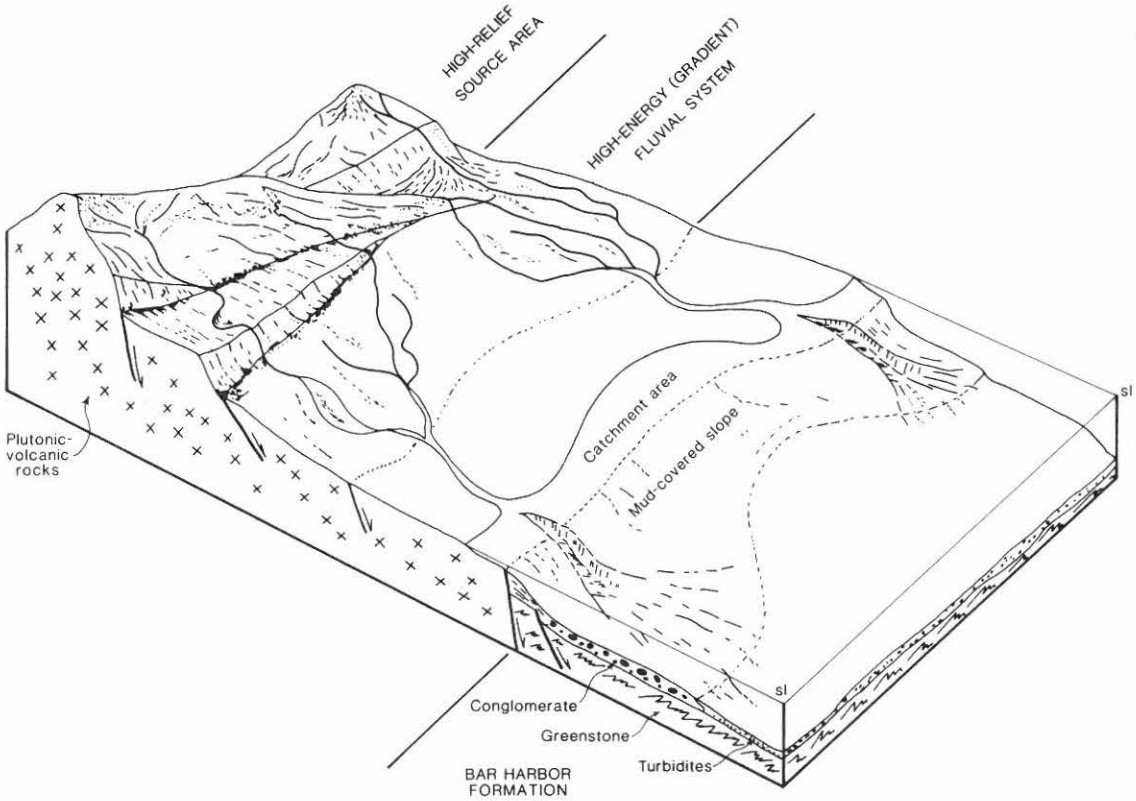

Figure 4. Schematic paleogeography and depositional environments for the Bar Harbor Formation.

gravity flows comprised of a mixture of well-rounded volcanic and/or plutonic clasts were generated. This sediment mixed with slope mud deposited farther offshore to form the debris flows (Fig. 4). Fine-grained sandstone and siltstone turbidites accumulated between periods of conglomerate deposition (Metzger, 1979). Accumulation of these deposits may reflect sediment bypassing of shallow water catchment basins in which gravel-sized detritus preferentially accumulated only to be released at a later time to form the conglomerate beds.

The interpretation that the Flanders Bay conglomerate represents Bar Harbor Formation resting unconformably on the greenstone also eliminates the need for an inferred fault postulated by Metzger (1979) with which he separates the conglomerate from the Bar Harbor Formation siltstones along the shore. The fact that there is laminated siltstone associated with the pebble conglomerate that looks much like the siltstone of the Bar Harbor Formation along the shore, and that there are no known exposures of greenstone between the conglomerate and the exposed siltstones of the Bar Harbor Formation adds support to this alternative interpretation.

GREENSTONE CORRELATION

Another question raised in the Flanders Bay area concerns the correlation of the greenstone. Chapman (1957, 1970, 1974, and pers. commun., 1985) considers the greenstone to be atypical Cranberry Island Series. This is a group of mostly rhyolites and tuffs with minor basaltic members found on the Cranberry Islands and on the southern end of Mount Desert Island on the west side of Frenchman Bay. However, Brookins et al. (1973) report a Rb-Sr age of 387 ± 9 Ma (converts to 375 Ma using $\lambda = 1.42 \times 10^{-11}$/yr) for the Cranberry Island Series and Metzger et al. (1982) obtained a Rb-Sr age of 408 ± 27 Ma for tuffs within the Bar Harbor Formation at Ireson Hill on Mount Desert Island. Thus while the Bar Harbor Formation is clearly younger than the greenstone at Spectacle Island and Flanders Bay, the correlation of the greenstone with the Cranberry Island Series as proposed by Chapman needs further study.

Metzger (1979) proposed that the greenstone is a hitherto unrecognized unit in the regional stratigraphy. The unit is older than the Bar Harbor Formation, and hence he believes older than the Cranberry Island Series, but younger than the highly tectonized Ellsworth Schist (Precambrian-Ordovician) that is exposed at the north end of Frenchman Bay and on Mount Desert Island. Given the wide range in ages between the units of the coastal volcanic belt as shown by Gates (in press), it may be that the greenstone is correlative with one of the older suites in the coastal volcanic belt. Chemical analyses of five samples of the greenstone from Flanders Bay were obtained in order to better describe the unit and to compare it to volcanic rocks from the Machias-Eastport area (Gates and Moench, 1981). Tables 1 and 2 show that the Flanders Bay greenstone is consider ably higher in SiO_2 than the Silurian basic lavas of the Machias-Eastport area, but is closer to those of the "older Devonian" Eastport Formation; both being basaltic andesites on the basis of SiO_2 content. However, other major oxides, notably CaO and Na_2O, are substantially different between these two suites.

Figure 5 compares elemental abundances and ratios of the least mobile elements (Ti, Zr, Y; Smith and Smith, 1976; Pearce and Cann, 1971) of the Flanders Bay greenstone to basic volcanics of the Machias-Eastport area. Although immobile element discriminant diagrams are most commonly used to determine the tectonic environment of eruption of orogenic basalts (e.g., Pearce, 1980, among others) they are employed here simply as a comparative rather than interpretive tool. The discriminant plots show that the Flanders Bay greenstone plots closer to the Silurian volcanics than to the "older Devonian" ones.

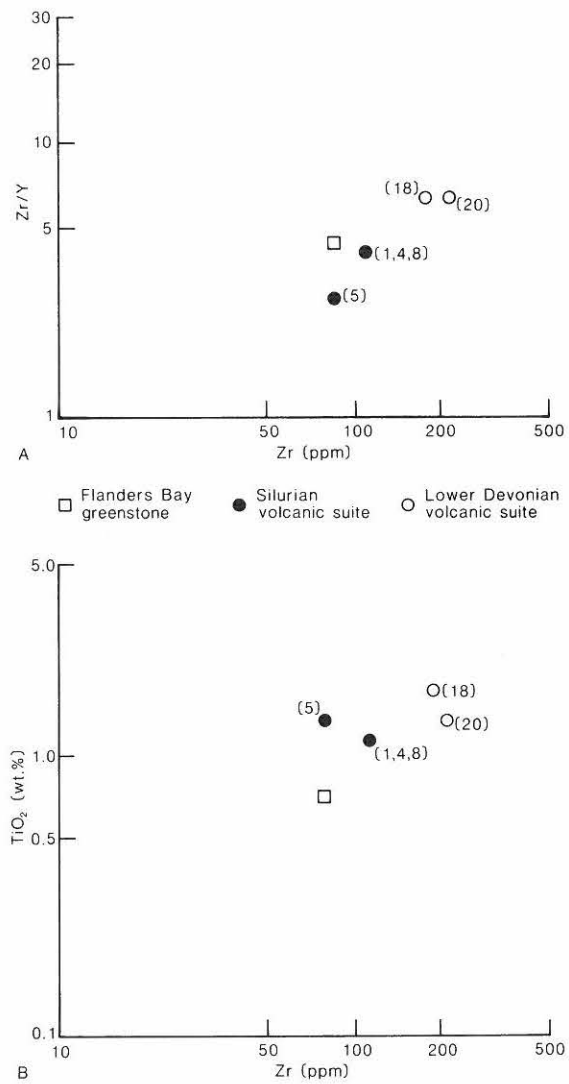

Figure 5 a,b. Abundances of Ti, Zr, and Y for greenstone from Flanders Bay compared to Silurian and Lower Devonian volcanic suites from the Machias-Eastport area (numbers in parentheses are samples from Gates and Moench, 1981). (a) Zr/Y vs. Zr (b) TiO_2 vs. Zr.

CONCLUSIONS

1. In light of new field data, the conglomerates exposed at the head of Flanders Bay are reinterpreted to be part of the Bar Harbor Formation that lies with angular unconformity above the weakly foliated greenstone, rather than as an intraformational conglomerate within the greenstone as proposed earlier by Metzger (1979).

2. The well rounded clasts, mostly of volcanic rocks and quartz supported by a fine siltstone matrix, along with the association of laminated siltstones, suggest a debris flow process of sedimentation in which coarse gravels were mixed with silt and mud prior to final deposition. Such a process has been proposed for other conglomerates along the coast (Gilman, 1966; Gates, in press).

3. Chemical analyses of the greenstone from Flanders Bay do not match closely any of the analyses for the basalts and basaltic andesites from the Machias-Eastport area.

TABLE 1. CHEMICAL ANALYSES OF FLANDERS BAY GREENSTONES RECALCULATED WITHOUT VOLATILES

Sample #	358	259-B	216	222	253-A
SiO_2 (wt.%)	58.1	53.8	55.3	54.2	54.5
Al_2O_3	14.8	15.5	14.9	15.2	16.2
Fe_2O_3 (total Fe)	9.2	11.6	10.7	9.4	10.7
MgO	4.7	4.6	5.7	6.8	5.4
CaO	9.6	10.4	9.1	9.9	9.7
Na_2O	1.6	2.6	2.5	2.5	2.0
K_2O	0.8	0.2	0.6	0.9	0.4
TiO_2	0.7	0.8	0.8	0.6	0.7
P_2O_5	0.10	0.12	0.10	0.08	0.11
MnO	0.17	0.25	0.18	0.16	0.20
Cr (ppm)	30	70	60	180	110
Sr	110	120	80	130	250
Y	20	20	20	20	20
Zr	80	100	100	60	80
Nb	20	30	20	30	20

XRF analyses by X-RAY ASSAY LTD., Don Mills, Ontario, Canada

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TABLE 2. MAJOR OXIDE ANALYSES IN WEIGHT PERCENT OF VOLCANIC ROCKS IN THE MACHIAS-EASTPORT AREA, MAINE RECALCULATED WITHOUT VOLATILES

Assemblage	Silurian						Older Devonian					
Formation	Dennys		Edmunds		Leighton		Eastport					
Sample No.	1	2	3	4	5	6	16	17	18	19	20	21
Laboratory No.	D160 372W	W176 692	W176 691	W176 689	W176 686	W178 301	W176 671	D160 375W	W176 674	W176 673	W176 672	W176 679
Rock Class	Flow	Flow	Flow	Flow	Flow	Flow	Tuff	Flow	Flow	Flow	Flow	Flow
Phenocrysts	N	N	P	C,O	N	P,C	N	P	P	P,C	P,C	P
SiO_2	51.4	49.7	52.8	51.0	48.3	53.4	56.6	49.8	52.0	53.1	54.9	56.6
Al_2O_3	17.2	17.4	16.2	17.3	17.5	16.8	16.0	19.7	17.7	15.2	16.8	15.7
FeO ($FeO+0.9\ Fe_2O_3$)	8.8	10.7	9.4	9.7	10.6	8.1	9.2	11.1	10.0	11.6	9.5	11.9
MgO	8.0	8.5	6.5	6.9	8.3	6.2	7.0	3.1	5.3	4.3	3.8	2.9
CaO	9.5	6.7	7.7	9.5	10.9	9.8	4.7	8.9	7.4	6.3	8.0	5.2
Na_2O	2.2	3.2	4.6	3.2	2.2	3.0	3.1	3.7	3.4	4.9	3.2	4.2
K_2O	1.0	1.3	.86	.58	.16	.48	1.2	.67	1.6	.34	1.5	.43
TiO_2	1.3	1.7	1.3	1.3	1.5	1.4	1.5	1.9	1.8	2.8	1.4	2.0
P_2O_5	.26	.23	.16	.20	.16	.39	.24	.30	.29	.48	.36	.77
MnO	.17	.22	.16	.23	.16	.10	.17	.26	.21	.24	.15	.25

(modified from Gates and Moench, 1981)

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