U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

PETROGRAPHIC RECONNAISSANCE OF URANIFEROUS FRACTURES IN PRECAMBRIAN GNEISSES, LARAMIE RIVER VALLEY, LARIMER COUNTY, COLORADO

By
F. Allan Hills[1]

Open File Report 95-242

1995

[1]Denver, Colorado

TABLE OF CONTENTS

ABSTRACT

The valley of the Laramie River follows the north-trending Green Ridge fault past the Boston Peak fen, which owes its existence to a late Pleistocene landslide that blocks drainage at the north end of the fen. Lake sediments and peat that underlie the fen are anomalously rich in uranium (Zielinski and Otton, in press), and a previous study (Hills and others, in press) concluded that the source of uranium in the fen is most likely uraniferous veins in fractures related to the Green Ridge fault. The planned purpose of the present investigation was to examine and compare these veins with uranium-bearing veins elsewhere in the Front Range of Colorado. However, a reduction in funding for uranium studies caused this investigation to be terminated shortly after its inception, and this open-file report presents my preliminary petrographic information.

Bedrock in the catchment basin surrounding the fen consists of two-mica leucocratic granite gneiss and mafic gneiss of Proterozoic age. Locally, these gneisses are overlain by poorly lithified volcaniclastic sediment and tuff of Tertiary age, and by Pleistocene glacial till. The bedrock, where unaltered, the volcanic sediments, and the till are generally low in uranium and appear to have low potential as source rocks for the uranium in the fen.

The Green Ridge fault produced a north-trending zone almost a kilometer wide of subparallel shear and fracture zones in bedrock in the vicinity of the fen. In the fracture zones, the bedrock gneisses locally are stained hematite red. Chemical analyses of rock samples and a gamma spectrometric survey of the area (Hills and others, in press) indicate that some sheared and altered rocks, particularly those in the hematite-stained zones, are anomalously uraniferous (they contain as much as 119 ppm uranium in road cuts).

The rocks in the fracture zones commonly are pervasively epidotized and hematite impregnated. Hematite is found as dense, black to metallic fillings in a few fractures, but more commonly appears as a penetrative red stain, seen in thin section as discrete small grains. Most uranium in the fractured rock is in iron oxide minerals in the altered zones or in altered biotite and epidote.

The fractures and their alterations in the study area bear a resemblance to the important Schwartzwalder uranium deposit and, therefore, merit closer study. That they also appear to be the source of uranium in the Boston Peak fen raises the possibility that they may contain economically significant quantities of uranium.

INTRODUCTION

The Boston Peak fen lies on the east side of the Laramie River, about 1.5 km north of Chambers Lake. The fen occupies a depression that formed when a landslide blocked the drainage of a minor tributary to the Laramie River. Precambrian gneiss and granite surround the valley on the south, east, and west, and the landslide deposit, which consists mostly of volcanic debris of the Oligocene White River Formation and glacial till, blocks the topographically lower north end of the valley.

Lake sediments and peat that underlie the fen are enriched in uranium. Locally, they contain as much as 3200 ppm U by dry weight (Zielinski and Otton, written commun., 1993). The only apparent sources for the uranium are bedrock and till that underlie a small catchment basin, approximately 0.7 km^2, surrounding but mainly east of the fen. Elsewhere, the White River Formation has been a source rock for important uranium deposits (Zielinski, 1983; Dickinson, 1993). However, organic sediments are poor in uranium near the volcanic-sediment-rich landslide and near small streams draining the landslide and draining outcrops of the White River Formation. Greatest uranium enrichment is found in organic-rich sediment adjoining spring-fed pools along the east flank of the fen (Otton, written commun., 1993). Hills and others (in press) present evidence that these spring-fed pools drain fractures in bedrock on the hills east of the fen.

The Laramie River flows almost directly north from Chambers Lake (Fig. 1) through a nearly straight, U-shaped glacial valley, the orientation of which appears to be controlled by two major faults. McCallum and others (1983) show a high-angle reverse fault, the Green Ridge fault, tracing along the east side of the valley and a thrust fault, the

North Middle Mountain thrust, along the west side of the valley. The Green Ridge fault, which appears to pass directly beneath Boston Peak fen, and related fractures have been suggested as the source for uranium in the fen (Hills and others, in press).

BEDROCK OF THE CATCHMENT BASIN

Granite gneiss and a more mafic gneiss suite, composed of foliated granodiorite, quartz diorite, and amphibolite (Figure 1), underlie the catchment basin. W. A. Braddock (1989, written comm. with sketch map) mapped the geology of the area immediately around the fen and catchment basin. Braddock did not distinguish among compositionally different Precambrian rocks in the catchment basin, and Hills and others (in press) modified his map to show locations underlain predominantly by granite gneiss and predominantly by mafic gneiss.

Granite gneiss in the catchment basin is mostly very leucocratic and contains few dark minerals. It is most commonly fine- to medium-grained with a foliation manifested mainly in sheared and flattened quartz. Coarse-grained, pegmatitic granite appears as a common but volumetrically minor phase of the granite. Based on modal percentages (Table 1 and Hills and others, in press), the granite is classified (Streckeisen, 1976) as hololeucocratic, two-mica monzogranite and syenogranite. Locally, in fracture zones, leucocratic granite is stained a darker yellowish brown to hematite-red.

Thin sections indicate that the leucocratic granite consists of quartz, microcline, and oligoclase (An 15-25), with minor muscovite and biotite, and trace amounts of zircon, epidote, and opaque iron oxide. Muscovite is present in all of the granite samples examined. Minor chlorite, with limonite or hematite inclusions, is common and apparently formed by replacement of biotite. Sericite replaces plagioclase to some degree in most samples.

The mafic gneisses occur as discontinuous layers and as large enclaves in the leucocratic granite gneiss. Gneiss of granodioritic to tonalitic composition is most abundant; amphibolite is found as discontinuous layers and pods in the granodioritic to tonalitic gneiss. All of these rocks are strongly foliated and medium grained, with foliation formed by strongly preferred orientation of hornblende and by discontinuous compositional layers and streaks.

Thin sections indicate that the minerals of the mafic gneiss suite are quartz, andesine (An_{35}-An_{40}), minor microcline in streaks and veins, green hornblende, brown biotite, very minor iron oxide or sulfide minerals, apatite, zircon, rutile, titanite, and allanite. Alteration of primary minerals is common; well crystallized epidote is found dispersed and in small veins, chlorite and hematite or limonite replace some hornblende and most biotite, and plagioclase is sericitized locally. Magnetite is uncommon; some specimens contain no opaque minerals.

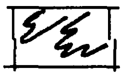
Examination of polished thin sections of the mafic rock suite by scanning electron microscope (SEM; assisted by Isabelle K. Brownfield) revealed an interesting suite of trace minerals found mainly as very fine grains. Iron and copper sulfides (pyrite, chalcopyrite, covellite) are present in some samples; ilmenite is present, but scarce; crystalline iron oxides were found in oxidized, hematite-red samples. Allanite and cerian perovskite(?) are present in numerous small grains; cerian perovskite(?) ($<3\mu m$) is chiefly in rutile, which is commonly corroded and mantled with titanite. Some zircon crystals contain 1-2 μm grains that consist mainly of uranium oxide, but have detectable lead. Presumably this is uraninite with radiogenic lead.

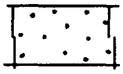
The pyrite, chalcopyrite, and covellite are associated with sericitized plagioclase, epidote, and hematite in irregularly shaped, one- to several-centimeter wide patchy areas in otherwise fresh mafic gneiss. The sulfide minerals commonly are rimmed by hematite, and small grains of hematite in the patchy areas may have formed by complete oxidation of small sulfide grains. The sulfide minerals were found in little-altered specimens collected near fractured and altered rock. They were not noted elsewhere, but they were only found during SEM examination of the specimens and were not looked for elsewhere. It is not

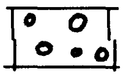
Figure 1. General geology of section 30 and part of section 31, T.8N., R.75W. [after W. A. Braddock, 1989, written comm. with sketch map; minor modifications] with sampling localities and an index map.

EXPLANATION:

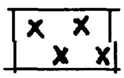
Quaternary

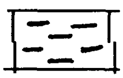
 Qls Landslide deposits

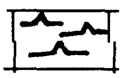
 Qal Alluvium

 Qg Till (includes some alluvium and colluvium)

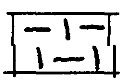
Tertiary

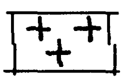
 Twt Rhyolite tuff of White River Formation (?)

 Twr White River Formation (?)

 Twa Andesite of White River Formation (?)

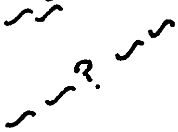
Middle Proterozoic

 Xg Leucocratic granite gneiss with inclusions and layers of mafic gneiss

 Xm Mafic gneiss intruded by leucocratic granite gneiss

Sampling locality

 Fracture zones of the Green Ridge fault



Inferred or extrapolated fracture zone

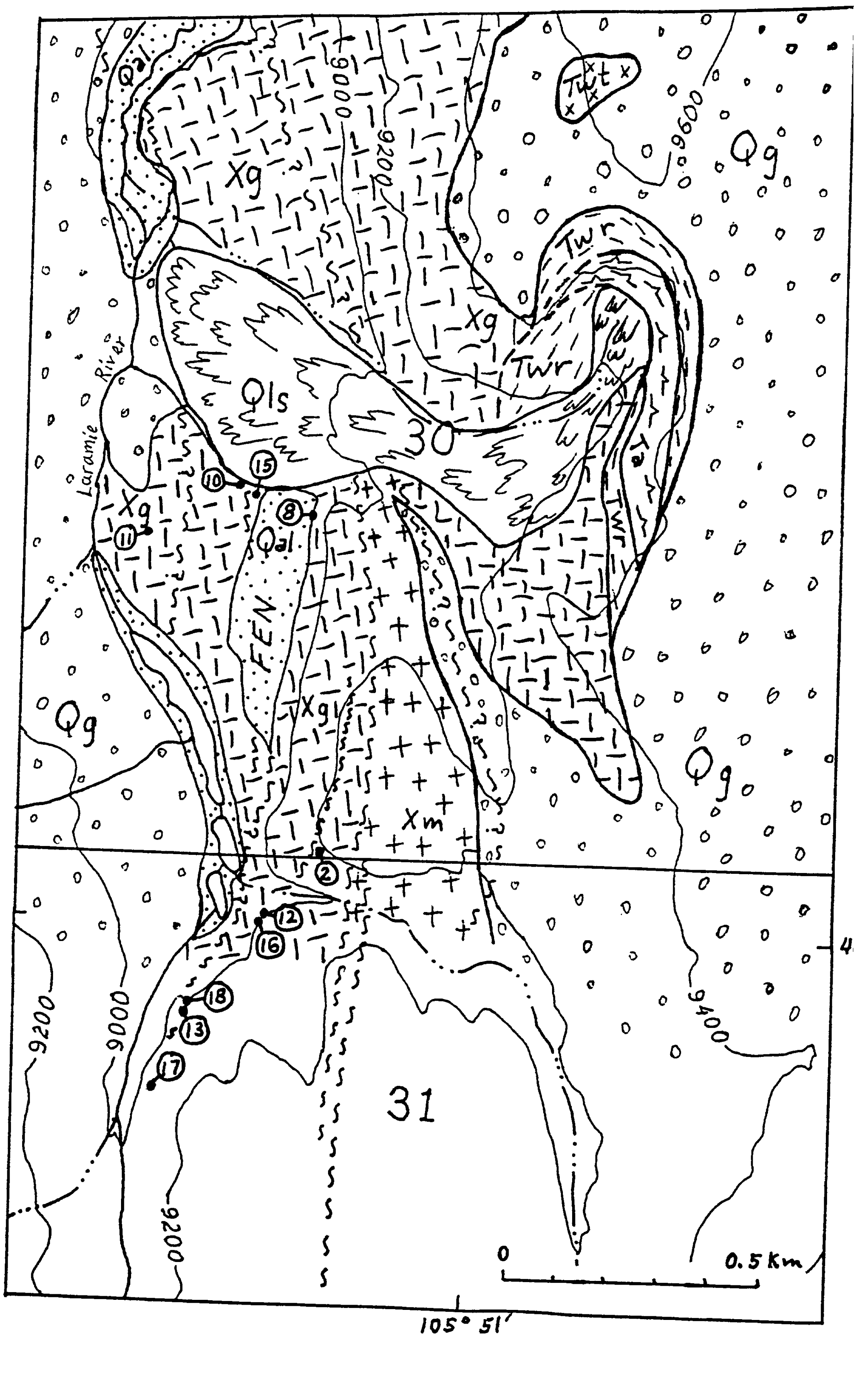

Qal
Xg
Twt
Qg
Twr
Qls
Laramie River
30
FEN
Xm
31
40°37'30"
105° 51'
0.5 Km
9000
9200
9400
9600

Table 1. Modal percentages of minerals in rocks in and surrounding the fracture zones, based on 1000 counts per thin section. (lg=leucocratic granite gneiss; mg= mafic gneiss; alt=epidotized and hematite stained; tr=trace; pl=plagioclase is moderately sericitized; p=present; --=not found by optical microscope but thin section was not examined by SEM. Sericitized feldspar was counted as feldspar if its progenitor could be identified. Modal compositions were not attempted on samples that are inhomogeneous in thin section; minerals identified in these samples are indicated by "p.")

	Sample Numbers					
	2	8	10	11	12C	13
	lg	lg	lg	lg	mg	alt
Quartz	36.9	34.5	27.5	30.3	14.1	tr
Microcline	46.1	36.7	38.1	47.0	13.9	p
Plagioclase	15.7	25.6	33.5	19.8	31.1	p
Hornblende	0.0	0.0	0.0	0.0	36.9	0.0
Biotite	0.9	0.0	0.0	1.3	1.7	0.0
Muscovite	0.3	0.9	0.2	0.7	0.0	0.0
Rutile	0.0	0.0	0.0	0.0	0.3	tr
Titanite	0.0	0.0	0.0	0.0	tr	p
Magnetite/Ilmenite	0.1	0.2	0.5	0.1	0.0	0.0
Hematite/Limonite	0.0	tr	tr	tr	tr	p
Sulfide (Fe, Cu)	0.0	0.0	0.0	0.0	0.2	0.0
Apatite	0.0	0.0	0.0	0.0	0.2	tr
Zircon	tr	tr	tr	tr	0.1	tr
Allanite	0.0	0.0	0.0	0.0	tr	tr
Epidote	0.0	tr	0.0	tr	0.7	p
Perovskite (?)	0.0	0.0	0.0	0.0	tr	0.0
Sericite, chlorite	pl	2.1	pl	0.8	0.8	tr

	Sample Numbers					
	15	16A	16B	17A	17B	18
	lg	mg	mg	mg	mg	alt
Quartz	17.7	0.9	4.8	4.8	2.5	p
Microcline	53.7	0.0	0.0	0.0	0.0	p
Plagioclase	27.7	37.7	28.0	51.3	29.9	p
Hornblende	0.0	58.9	65.1	42.0	63.4	p
Biotite	0.0	0.0	0.0	0.1	0.9	0.0
Muscovite	0.0	0.0	0.0	0.0	0.0	0.0
Rutile	0.0	0.0	0.0	0.0	0.0	0.0
Titanite	0.0	1.0	0.8	0.4	1.2	p
Magnetite/Ilmenite	0.5	0.0	0.0	0.0	0.0	p
Hematite/Limonite	tr	tr	0.0	tr	0.4	p
Sulfide (Fe, Cu)	0.0	0.2	tr	0.0	tr	0.0
Apatite	0.0	0.3	tr	0.2	0.1	p
Zircon	tr	0.1	0.2	0.3	0.3	p
Allanite	0.0	tr	--	--	--	--
Epidote	tr	0.9	1.1	0.9	1.3	p
Perovskite (?)	0.0	--	--	--	--	--
Sericite	0.4	p	p	p	p	p

known whether they are related to mineralizing fluids from the fracture zone.

CHARACTERISTICS OF FRACTURES AND FRACTURED BEDROCK

Exposures of bedrock along the east side of the valley from Chambers Lake northward through the vicinity of the fen and for several miles north of the fen are strongly fractured and sheared in a zone as much as a kilometer wide. As is typical of large faults, the Green Ridge fault consists of a set of more-or-less parallel fractures and crush zones that anastomose and locally splay off from the main fault zone. All of the fracture zones shown in figure 1 may be related to the Green Ridge fault. Within the kilometer-wide fault zone, most outcrops show some degree of fracturing and alteration. Outcrops of the most shattered rock consist of articulated blocks as little as ten centimeters in longest dimension. These outcrops may be cut by closely spaced, thin, steeply dipping, shear zones spaced tens of centimeters apart, but neither mylonite nor open-work breccias are important components of the exposed rock in the fault zone.

Some outcrops of the leucocratic granite have few fractures or have fractures that are recemented with silica so that the rock, which appears to be rather fresh and is very hard, is a ridge former. In other areas the same rock is highly sheared, fractured and stained hematite red; it crops out poorly if at all and is recognizable mainly by a rubble of red chips in the soil. Hematite staining and alteration also affects some of the mafic rocks. This is well displayed in road cuts between Chambers Lake and the fen (NW1/4 Sec. 31, T. 8 N., R. 75 W., Chambers Lake quadrangle). Hematite staining is penetrative as is oxidation and alteration of iron minerals, although feldspar remains unaltered in some specimens.

Locally, fractures contain as much as several millimeters of hematite. Hematite is black to metallic in fresher samples of bedrock, and powdery red in more altered or weathered samples. Fission-track studies, scintillometer surveys, and a gamma spectrometer survey show a good correlation between hematite and uranium, but no uranium minerals have been recognized in association with hematite (Hills and others, in press).

Uranium content of samples containing hematite as disseminated red coloration ranges from 6.1-119 ppm, and generally is greater than for any other samples analyzed. Also, the ratio of thorium to uranium (Th/U from 2.5 to $<<1$) is low as compared to the rock samples (Hills and others, in press). In the most uranium-rich samples the thorium to uranium ratio is much less than the range of 2 to 5 that is normal for igneous or metaigneous rocks. This suggests enrichment of uranium by throughgoing solutions in the fracture zone. Uranium was probably fixed by reduction by pre-existing sulfide minerals or by adsorption by alteration products such as iron and titanium oxides.

Fission-track maps showing uranium distribution in polished thin sections (see Zielinski and Rosholt, 1978) of the leucocratic granite gneiss indicate that uranium is in resistate minerals (zircon, thorite, allanite, and epidote), in altered biotite (chlorite and iron oxides in expanded cleavage planes), in hematite and limonite, and in fracture coatings. Fission-track maps of polished thin sections from the mafic gneiss suite show uranium in resistate and secondary minerals, especially titanite, zircon, epidote, and hematite or limonite. In sample 13, a highly altered, hematite-red rock with 113 ppm U, uranium is in secondary epidote and iron oxides.

Several generations of alteration and vein formation are recognized. Because their relationships are based on preliminary field work and examination of few thin sections, these relationships must be viewed as possibly incomplete and possibly not generally applicable. However, the sequence of alteration and vein formation appears to be:

(1) Pervasive epidotization of the country rock at some localities in the fracture zone. Plagioclase is replaced by epidote, sericite, and minor calcite; microcline is sericitized and locally replaced by adularia.

(2) Penetrative hematite alteration in zones a few millimeters thick to centimeters thick adjacent to fractures. Hematite occurs partly as metallic grains as much as 1-2

mm across, but more abundantly as red grains a fraction of a millimeter across.
(3) Veins filled with quartz, plagioclase, and microcline.
(4) Veins filled with epidote crystals oriented perpendicular to fracture faces, and appearing fibrous.

The relative timing of events (1) and (2) are not well established.

INTERPRETATION

This study does not unambiguously identify the source rock for uranium in the fen. However, hematite-red rocks of the shear zones are the most uraniferous rocks found, and alpha spectrometric analyses (Hills and others, in press) of isotope activity ratios indicate relatively recent loss of a significant amount of uranium from two samples of these rocks. They are, therefore, likely sources of uranium in the fen deposits.

This incomplete study does not permit close comparison of the uraniferous fractures in this study with better known uranium occurrences along the Front Range. However, based on the scant information available, there appear to be similarities with the Schwartzwalder uranium deposit. Wallace and Whelan (1986) describe several stages of hydrothermal alteration and vein mineralization in the Schwartzwalder deposit that include:

(1) Carbonate-sericite alteration that forms a bleached halo around the mineralized veins. This zone contains only minor epidote, but that may be a result of the wall-rock composition
(2) Hematite-adularia alteration that appears similar to that found in the present study.

Iron and copper sulfides are minor components in more than one of their stages of alteration and mineralization.

These apparent similarities between our study area and the Schwartzwalder uranium deposit suggests that the fracture zone of the Green Ridge fault merits a more detailed study. Coupled with the presence of a surficial uranium deposit in the Boston Peak fen, these similarities raise the possibility that the fractures may contain significant uranium deposits.

REFERENCES CITED

Camp, W. K., 1979, Structure and stratigraphy of the Laramie River valley, Larimer County, Colorado: Colorado State University, Fort Collins, Colorado, M.S. Thesis, 225 p.

Dickinson, K. A., 1993, Favorable areas for uranium in the Oligocene White River beds of southwestern South Dakota, southeastern Wyoming, and northwestern Nebraska: U.S. Geological Survey Open File Report 93-624, 7 pp, 1 map.

Griswold, Mark L., 1980, Petrology and structure of the southwest portion of the Precambrian Rawah batholith, north-central Colorado: Colorado State University, M.S. thesis, 248 p. typescript.

Hills, F. A., Owen, D. E., and Zielinski, R. A., in press, Bedrock sources of uranium for the Boston Peak fen, Larimer County, Colorado, U.S. Geological Survey Bulletin.

McCallum, M. E., Camp, W. K., and Griswold, M. L., 1983, Generalized tectonic map of the Medicine Bow Mountains and Laramie River valley, Larimer and Jackson Counties, Colorado: U.S. Geological Survey Open-File Report 83-579, Approx. 1:62,500.

Streckeisen, A.L., 1976, To each plutonic rock its proper name: Earth Science Reviews, v. 12, p. 1-33.

Wallace, A. R., and Whelan, J. F., 1986, The Schwartzwalder uranium deposit, III: Alteration, vein mineralization, light stable isotopes, and genesis of the deposit: Economic Geology, v. 81, p. 872-888.

Zielinski, R. A., 1983, Tuffaceous sediments as source rocks for uranium, a case study of the White River Formation, Wyoming: Journal of Geochemical Exploration, Elsivier, Amsterdam, v. 18, p. 285-306.
Zielinski, R. A., and Rosholt, J. N., Jr., 1978, Uranium in waters and aquifer rocks at the Nevada Test Site, Nye County, Nevada: U.S. Geological Survey Journal of Research, v. 6, n. 4, p. 489-498.
Zielinski, R. A., and Otton. J. K., in press, Chemistry and mineralogy of sediments of the Boston Peak fen: U.S. Geological Survey Bulletin.