UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Metalliferous Oil Shales in Central Montana and Northeastern Nevada

By

George A. Desborough, Forrest G. Poole,
and Gregory N. Green

Open-File Report 81-121
1981

This report is preliminary and has not been edited for conformity with U.S. Geological Survey editorial standards.

CONTENTS

	Page
Abstract	1
Introduction	2
Central Montana	2
Metals, syncrude oil, and water in shales of Heath Formation in Fergus and Golden Valley Counties, Montana	6
Problems in resource assessment of black shales in Heath Formation of Big Snowy trough, central Montana	9
Northeastern Nevada	11
Acknowledgments	12
References cited	13

ILLUSTRATIONS

Page

Figure 1. Metalliferous oil shales in central Montana and northeastern Nevada..... 4

2. Generalized map of central Montana region; patterned area shows distribution of Heath oil shale with highest potential (modified from Harris, 1972)..... 5

TABLES

Table 1. Data for black-shale samples of Mississippian Heath Formation, Fergus and Golden Valley Counties, central Montana..... 7

2. Modified Fischer oil-assay results for four black-shale samples of Heath Formation, Fergus and Golden Valley Counties, Montana..... 8

3. Estimated gross values of contained metals and extractable syncrude oil based on analytical data in tables 1 and 2..... 10

Metalliferous Oil Shales in Central Montana and Northeastern Nevada

By

George A. Desborough, Forrest G. Poole,

and Gregory N. Green

ABSTRACT

Metalliferous oil shales in the Heath Formation of Late Mississippian age underlie more than 2,700 mi^2 (7020 km^2) in central Montana. The area of occurrence constitutes an east-west-trending Upper Mississippian depositional and structural trough as much as 200 mi (322 km) long and about 10 to 20 mi (16 to 32 km) wide. Present distribution of the Heath Formation is due partly to late Paleozoic and Mesozoic tectonics and erosion. The oil shales have been known for many years, but their metal content has been only recently recognized. Metals of high potential (values are expressed in weight percent) include vanadium (as much as 0.8 V_2O_5), molybdenum (as much as 0.09), nickel (as much as 0.11), zinc (as much as 0.69), and selenium (as much as 0.012); the highest metal values are present in strata that also have the highest yields of syncrude oil. Our estimates of shale-oil resources in the Heath Formation in central Montana exceed 180 billion barrels of syncrude oil based on a minimum thickness of 160 ft (48 m) of shale with an estimated oil yield of 10 gallons per ton of rock. A similar metalliferous oil shale in the Woodruff Formation of Devonian age in southwestern Elko County, Nev., contains significant amounts of vanadium. The average organic-carbon content of the Nevada rocks is apparently too low to constitute a commercial source of syncrude oil at this time, but it has been considered as a possible source of vanadium (320 million pounds) in the last decade. Both of these deposits are major potential sources of future metal and energy resources.

INTRODUCTION

This report presents preliminary results of recent investigations of Paleozoic marine metalliferous shales in Montana and Nevada and is intended to point out major sedimentary mineral resources that potentially can be recovered in connection with future energy and metal needs. Many of the areas are amenable to openpit or other large-scale mining methods or to possible in situ or modified in situ production technologies for the extraction of syncrude oil and contained metals. Commercial extraction of syncrude oil and associated resources (including rock water) has not been accomplished on a large scale in the United States to date, but it is currently under intensive study, particularly as applied to lacustrine oil shales of the Eocene Green River Formation in Colorado and Utah. The major potential energy and metal resources in the Montana and Nevada areas identified herein would seem to merit comparable commercial efforts.

Some of the area of known and inferred occurrences of metalliferous oil shales in both central Montana and northeastern Nevada are on Federal land, and development of the metal and energy resources will be subject to Governmental leasing procedures.

Paleozoic marine metalliferous oil shales are known in several areas of the world but had not been publicly documented in the Western United States prior to 1979 (Desborough and others, 1979; Poole and Desborough, 1980). Detailed field and laboratory studies are in progress and the results will be reported later.

CENTRAL MONTANA

The large metalliferous oil-shale deposits in the Upper Mississippian Heath Formation in central Montana were examined and sampled as part of a mineral and energy resource study of Paleozoic black shales during the 1980

field season (figs. 1, 2). This report summarizes our field observations, subsequent analytical data, and a review of published reports and an unpublished doctoral thesis by W. L. Harris (1972). Harris' stratigraphic data and interpretations are the best available, and supersede those in earlier reports. Harris reported that some black shales of the Heath Formation were oil shales based mainly on a statement by Perry and Sloss (1943, p. 1297) that some Heath shales have an oil yield of more than 15 gallons per ton of rock. Harris (p. 103), however, overstated their potential oil yield by a factor of 42; "15 barrels of petroleum per ton" should read 15 gallons of petroleum per ton. Miller (1953) and Cox (1973) reported that many black shales of the Heath Formation in Fergus County were oil shales based on distillate collected from shale heated in a closed retort and condenser apparatus. They obtained maximum oil yields of 22-26 gallons per ton of shale from some thin organic-rich layers.

Gardner (1950, 1959) mapped the geology of large areas in the Lewistown-Big Snowy Mountains-Little Snowy Mountains region. At that time, however, his definition of the Heath Formation was different than it is now, and the only base maps available were relatively inaccurate planimetric maps. Thus, some of his formation contacts and stratigraphic nomenclature are somewhat outdated. The measured stratigraphic sections of Easton (1962) and a subsequent report of Maughan and Roberts (1967) are too general and were of limited value in our study of the black metalliferous oil shales of the Heath Formation. Smith and Gilmour (1979, p. 19) cited Harris' 1972 thesis as the most thorough document on the Heath Formation.

Owing to the absence of subsurface core samples, the present report draws freely on the stratigraphic work of Harris and on the studies of Smith and Gilmour to supplement our own observations and analytical data. Our estimates

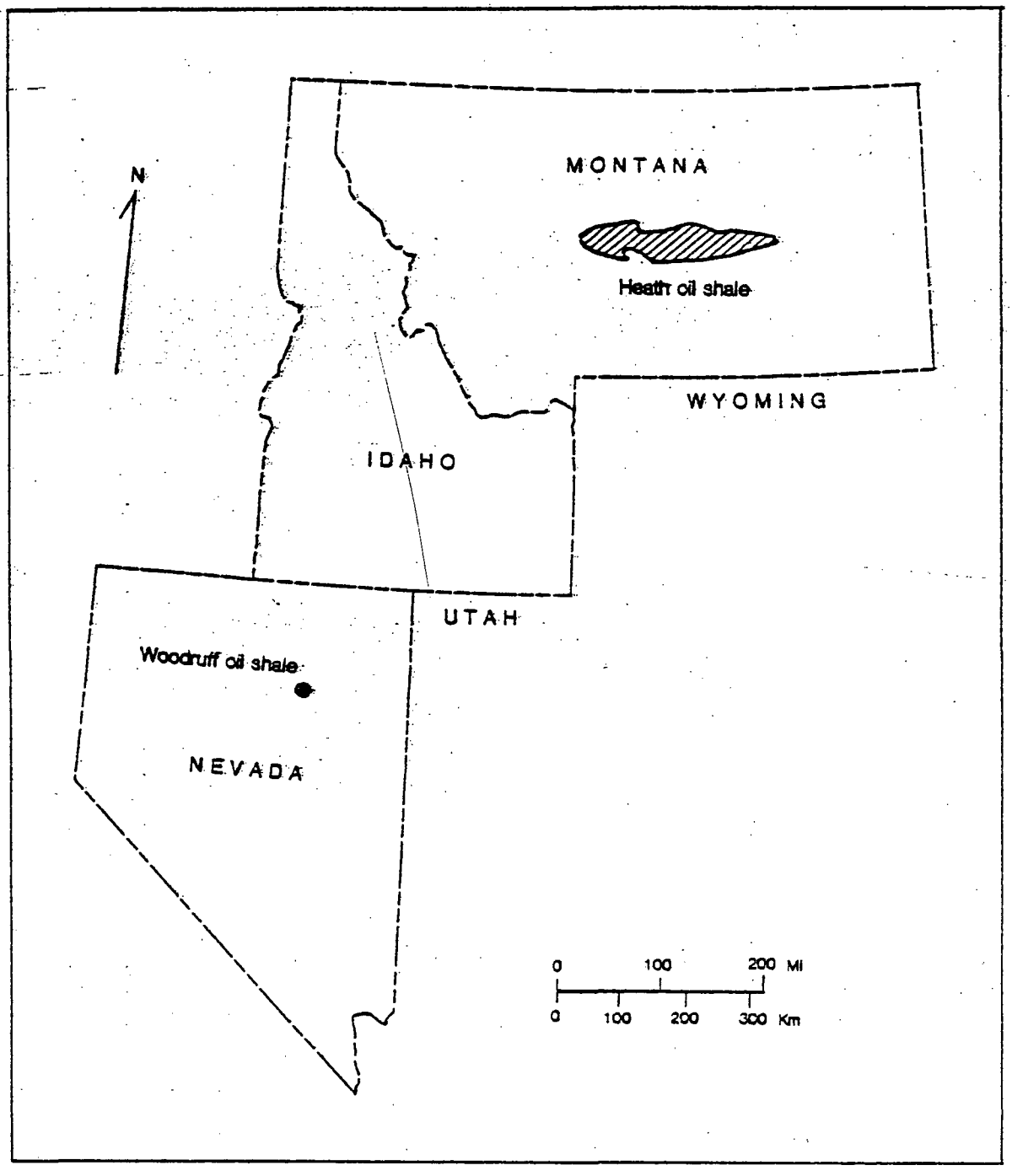

Figure 1.--Metalliferous oil shales in central Montana and northeastern Nevada.

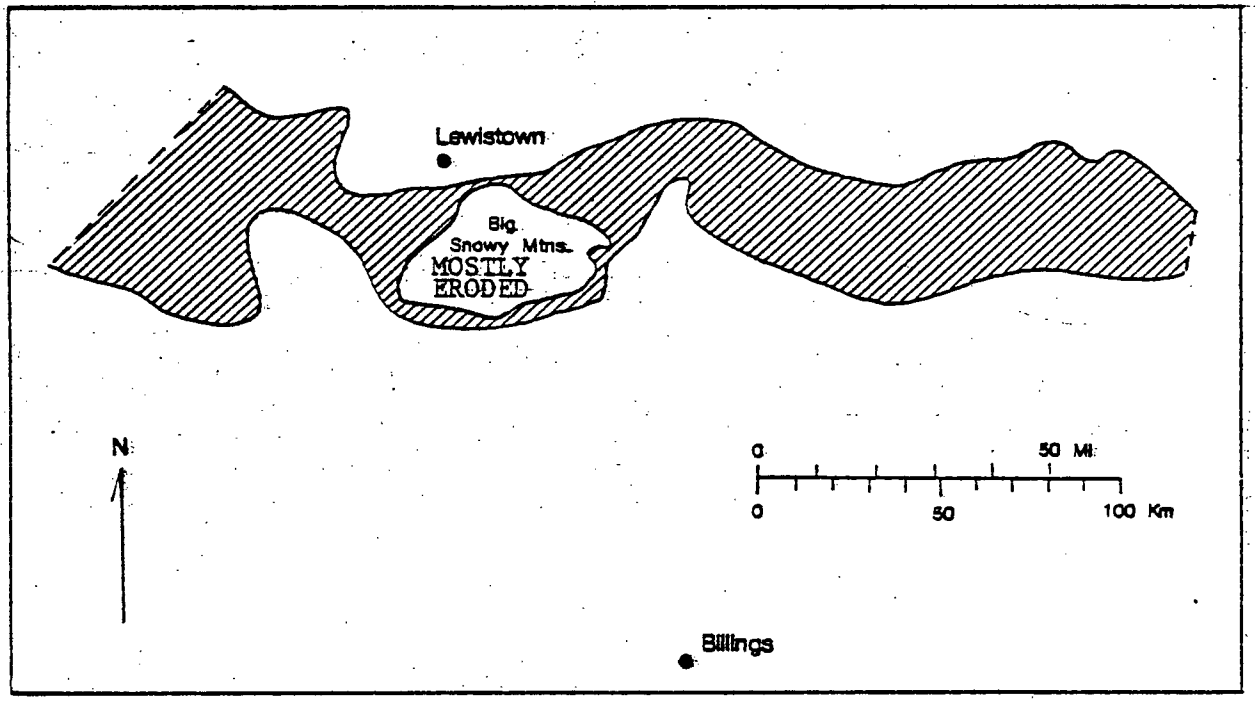

Figure 2.—Generalized map of central Montana region; patterned area shows distribution of Heath oil shale with highest potential (modified from Harris, 1972).

of metal and energy resources in the deposits are highly conservative and may be increased by 10 to 20 times through additional studies.

Our calculated syncrude oil resource potential of 1.8×10^{11} barrels for the Heath Formation in central Montana is based on thickness, lithofacies, and distribution data shown on plate 11 of Harris (1972), and on modified Fischer oil-assay analyses of four representative outcrop samples (table 2) collected recently from the central part of the Big Snowy trough southeast of Lewistown, Mont. The black-shale facies of the Heath Formation herein evaluated for oil and metal resources consists of more than 80 percent shale (<20 percent limestone) with a thickness of 160 to 240 ft (48 to 73 m) that is distributed through more than 75 townships (2,700 mi^2 or 7020 km^2) in an east-west-trending basin as much as 200 mi (322 km) long and about 10 to 20 mi (16 to 32 km) wide (fig. 2). In our shale-oil resource calculations, we used a minimum thickness of 160 ft of shale with an estimated oil yield of 10 gallons-per-short ton of rock (table 2) and a bulk-rock density of 2 g/cm^3 (0.45 m^3 or 16 ft^3 of rock equals 1 short ton).

Our results of nondestructive (X-ray fluorescence) analyses for contained metals in the Heath oil shales (table 1) are considered reliable to within ±10 percent of the amount present (Desborough and others, 1980).

METALS, SYNCRUDE OIL, AND WATER IN SHALES OF HEATH FORMATION IN FERGUS AND GOLDEN VALLEY COUNTIES, MONTANA

Concentration data for vanadium, nickel, zinc, selenium, and molybdenum and Fischer assay oil yield are given in table 1 for four fresh representative outcrop samples. The elements were analyzed by nondestructive, energy-dispersive X-ray methods. Preliminary organic geochemical data indicate that the organic matter in fresh unoxidized samples is immature to mature. Oil-yield values were obtained from modified Fischer oil-assay methods by the Colorado School

Table 1.--Data for black-shale samples of Mississippian Heath Formation, Fergus and Golden Valley Counties, central Montana

[Elemental analyses by Gregory N. Green; oil-yield analyses by Colorado School of Mines Research Institute]

Sample No.	Location	Concentration of selected elements (in weight percent)					Fischer-assay oil yield (gallons per ton)
		V_2O_5	Ni	Zn	Se	Mo	
80FP-100S	SW 1/4 sec. 5, T. 13 N., R. 21 E.	0.4	0.03	0.14	0.0045	0.025	10.1
80FP-110S	SE 1/4 sec. 26 (unsurveyed), T. 11 N., R. 20 E.	.1	.009	.06	.0014	.030	4.95
80FP-114S	N. 1/2 sec. 19 (unsurveyed), T. 12 N., R. 23 E.	.8	.11	.69	.012	.09	13.2
80FP-119S	NE 1/4 sec. 6, T. 12 N., R. 20 E.	.03	.006	.04	.003	.01	9.89

Table 2.--Modified Fischer oil-assay results for four black-shale samples of Heath Formation, Fergus and Golden Valley Counties, Montana

[Analyzed by Colorado School of Mines Research Institute]

Sample No.	Oil (gallons/ton*)	Water (gallons/ton*)	Specific gravity of oil	Gas + loss (weight percent)
80FP-100S	10.1	18.2	0.962	3.96
80FP-110S	4.95	5.25	.910	1.30
80FP-114S	13.2	18.5	.957	6.22
80FP-119S	9.89	10.1	.954	1.46

*Gallons-per-short ton = 4.17 liters-per-metric ton.

of Mines Research Institute, and these are presented in table 2. The oil-yield values seem to be about 20 percent too low compared to preliminary data we have collected on organic-carbon content and pyrolysis-assay products. Other samples of the Heath Formation yielded less oil, and it is not known if the shales contained more oil originally and lost some due to weathering and (or) to thermal degradation.

Translation of potential commodity gross values based on our analytical data is given in table 3 for two Heath Formation shale samples from Montana, and the gross value of the relatively metal-free lacustrine Eocene Green River Formation oil shale from Colorado is given for comparison. Dollar values for the metals in table 3 are based on quotations in a recent Engineering and Mining Journal (November 1980, p. 21). No dollar value could be assigned to water yields from our samples (table 2), but the importance of this commodity in the Western United States is recognized. If any part of the "gas + loss" fraction is methane, the dollar values given are more conservative than implied.

PROBLEMS IN RESOURCE ASSESSMENT OF BLACK SHALES IN HEATH FORMATION OF BIG SNOWY TROUGH, CENTRAL MONTANA

1. The nonresistant weathering character of the black shales results in concealed or poor exposures.
2. The incompetent nature of water-saturated black shales results in extensive landslides in areas of moderate to high local relief.
3. The Heath Formation was gently folded in many areas before Tyler sediments were deposited. Deltaic and fluviatile channels that formed during early Tyler time locally cut into the upper Heath Formation. Thus, erosion of the upper Heath Formation prior to deposition of overlying sediments of

Table 3.--Estimated gross values of contained metals and extractable syncrude oil based on analytical data in tables 1 and 2

Potential commodity	Contained amount per ton	Gross value per unit	Gross value per ton
Oil shale from Heath Formation (sample 80FP-114S) in southern Fergus County, Montana			
Syncrude oil	13 gal	$30/bbl	$ 9.30
V_2O_5	16 lbs	$3.05/lb	48.80
Ni	2 lbs	$3.00/lb	6.00
Zn	13 lbs	$0.35/lb	4.55
Se	0.24 lbs	$10.00/lb	2.40
Mo	1.8 lbs	$9.00/lb	16.20
Total			$87.25
Oil shale from Heath Formation (sample 80FP-100S) in southern Fergus County, Montana			
Syncrude oil	10 gal	$30/bbl	7.15
V_2O_5	8 lbs	$3.05/lb	24.40
Total			$31.55
Oil shale from Mahogany zone in Green River Formation of northwestern Colorado			
Syncrude oil	30 gal	$30/bbl	21.45
Byproducts--- ammonia and sulfur			?
Total			$21.45

the Tyler Formation precludes confident local correlation or regional projection of black-shale units in the Heath Formation.

4. Near structural domes, some oil shales in the Heath Formation appear to have been thermally degraded. These domes probably formed above igneous intrusions that provided a heat source. West of the Big Snowy Mountains large dikes and sills of Tertiary age intrude shales of the Heath Formation (Vine, 1956, p. 424). These intrusives probably "overcooked" the organic matter in the adjacent oil shales whereby the black shale should yield little or no oil on pyrolysis. Vine mapped many of these igneous intrusions in the Stanford-Hobson area of central Montana, and this type of local thermal alteration must be considered in assessment of shale-oil resources in central Montana.
5. Lateral changes in lithofacies from limestone to black shale in the Heath Formation are significant in resource evaluation. Therefore, detailed sedimentary facies maps must be prepared as part of a resource assessment of the Heath Formation.

In addition, core drilling will be an essential component for accurate resource assessment of metalliferous oil shales in the Heath Formation of central Montana to gain information on thickness, lithology, lateral continuity, and thermal history.

NORTHEASTERN NEVADA

Brooks and Potter (1974) reported on extraction methods for vanadium from weathered and carbonaceous shale (Woodruff Formation of Devonian age), respectively, in "sec. 34, T. 32 N., R. 53 E., and sec. 4, T. 31 N., R. 52 E., Elko County," Nevada (fig. 1). Brooks and Potter reported values of 10 weight percent of organic carbon for the unweathered dolomitic shale, but they made no mention of the fact that the rock was a low-grade oil shale. They reported

that as much as 20 million tons of shale averaging 0.8 percent V_2O_5 is amenable to openpit mining under an overburden-to-shale ratio of 2. Further delineation of these resources requires additional geologic mapping and exploration by drilling, as well as by other methods of resource evaluation. The complex tectonic setting of the Woodruff Formation vanadium deposit prohibits confident projection or extrapolation of grade and tonnages at this locality. Fischer oil assay of a large fresh outcrop sample (76FP-132S) yielded 13.9 gallons of oil per ton of rock. Data on vanadium content are given by Brooks and Potter. Concentrations of oil and metals in this metalliferous oil-shale deposit were presented in 1980 (Poole and Desborough).

ACKNOWLEDGMENTS

We have benefited from the advice and encouragement of David Lindsey, Russell Tysdal, and Richard Taylor of the U.S. Geological Survey. We also thank Tom Elliott for permission to collect samples on N Bar Ranch property in Fergus County, Mont.

REFERENCES CITED

Brooks, P. T., and Potter, G. M., 1974, Recovering vanadium from dolomitic Nevada shale: U.S. Bureau of Mines Report of Investigations No. 7932, 20 p.

Cox, W. E., 1973, Fergus County research project; evaluation of Heath-Tyler oil shales with laboratory analyses by J. W. Blumer: Montana Bureau of Mines and Geology Open-File Report No. 15, 83 p.

Desborough, G. A., Poole, F. G., Hose, R. K., and Radtke, A. S., 1979, Metals in Devonian kerogenous marine strata at Gibellini and Bisoni properties in southern Fish Creek Range, Eureka County, Nevada: U.S. Geological Survey Open-File Report 79-530, 31 p.

Desborough, G. A., Poole, F. G., Maughan, E. K., Groves, H. L., and Green, G. N., 1980, Quantitative analysis versus semiquantitative optical-emission spectrographic analysis of chromium, nickel, zinc, vanadium, and molybdenum in organic-rich Paleozoic marine strata, Western United States: U.S. Geological Survey Open-File Report 80-1271, 27 p.

Easton, W. H., 1962, Carboniferous formations and faunas of central Montana: U.S. Geological Survey Professional Paper 348, 126 p.

Gardner, L. S., 1950, Geology of the Button Butte-Forest Grove area, Fergus County, Montana: U.S. Geological Survey Oil and Gas Investigations Preliminary Map 106.

_____1959, Geology of the Lewistown area, Fergus County, Montana: U.S. Geological Survey Oil and Gas Investigations Map OM-199.

Harris, W. L., 1972, Upper Mississippian and Pennsylvanian sediments of central Montana: Missoula, Mont., University of Montana, Ph. D. Dissertation, 252 p.

Maughan, E. K., and Roberts, A. E., 1967, Big Snowy and Amsden Groups and the Mississippian-Pennsylvanian boundary in Montana: U.S. Geological Survey Professional Paper 554-B, p. B1-B27.

Miller, R. N., 1953, Oil shales in Montana: Butte, Mont., Montana College of Mineral Science and Technology, B.S. thesis, 78 p.

Perry, E. S., and Sloss, L. L., 1943, Big Snowy Group; lithology and correlation in the northern Great Plains: American Association of Petroleum Geologists Bulletin, v. 27, no. 10, p. 1287-1304.

Poole, F. G., and Desborough, G. A., 1980, Oil and metals in Ordovician and Devonian kerogenous marine strata of central Nevada [abs.]: American Association of Petroleum Geologists Bulletin, v. 64, no. 5, p. 767.

Smith, D. L., and Gilmour, E. H., 1979, The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States--Montana: U.S. Geological Survey Professional Paper 1110-X, p. X1-X32.

Vine, J. D., 1956, Geology of the Stanford-Hobson area, central Montana: U.S. Geological Survey Bulletin 1027-J, p. J405-J470.