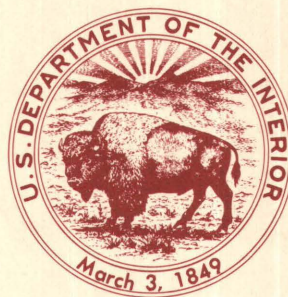


Uranium and Diagenesis in Evaporitic Lacustrine
Mudstone of the Oligocene White River Group,
Dawes County, Nebraska

U.S. GEOLOGICAL SURVEY BULLETIN 1956



AVAILABILITY OF BOOKS AND MAPS OF THE U.S. GEOLOGICAL SURVEY

Instructions on ordering publications of the U.S. Geological Survey, along with prices of the last offerings, are given in the current-year issues of the monthly catalog "New Publications of the U.S. Geological Survey." Prices of available U.S. Geological Survey publications released prior to the current year are listed in the most recent annual "Price and Availability List." Publications that are listed in various U.S. Geological Survey catalogs (see back inside cover) but not listed in the most recent annual "Price and Availability List" are no longer available.

Prices of reports released to the open files are given in the listing "U.S. Geological Survey Open-File Reports," updated monthly, which is for sale in microfiche from the U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225. Reports released through the NTIS may be obtained by writing to the National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22161; please include NTIS report number with inquiry.

Order U.S. Geological Survey publications **by mail or over the counter** from the offices given below.

BY MAIL

Books

Professional Papers, Bulletins, Water-Supply Papers, Techniques of Water-Resources Investigations, Circulars, publications of general interest (such as leaflets, pamphlets, booklets), single copies of Earthquakes & Volcanoes, Preliminary Determination of Epicenters, and some miscellaneous reports, including some of the foregoing series that have gone out of print at the Superintendent of Documents, are obtainable by mail from

**U.S. Geological Survey, Books and Open-File Reports
Federal Center, Box 25425
Denver, CO 80225**

Subscriptions to periodicals (Earthquakes & Volcanoes and Preliminary Determination of Epicenters) can be obtained **ONLY** from the

**Superintendent of Documents
Government Printing Office
Washington, D.C. 20402**

(Check or money order must be payable to Superintendent of Documents.)

Maps

For maps, address mail orders to

**U.S. Geological Survey, Map Distribution
Federal Center, Box 25286
Denver, CO 80225**

Residents of Alaska may order maps from

**Alaska Distribution Section, U.S. Geological Survey,
New Federal Building - Box 12
101 Twelfth Ave., Fairbanks, AK 99701**

OVER THE COUNTER

Books

Books of the U.S. Geological Survey are available over the counter at the following Geological Survey Public Inquiries Offices, all of which are authorized agents of the Superintendent of Documents:

- **WASHINGTON, D.C.**--Main Interior Bldg., 2600 corridor, 18th and C Sts., NW.
- **DENVER, Colorado**--Federal Bldg., Rm. 169, 1961 Stout St.
- **LOS ANGELES, California**--Federal Bldg., Rm. 7638, 300 N. Los Angeles St.
- **MENLO PARK, California**--Bldg. 3 (Stop 533), Rm. 3128, 345 Middlefield Rd.
- **RESTON, Virginia**--503 National Center, Rm. 1C402, 12201 Sunrise Valley Dr.
- **SALT LAKE CITY, Utah**--Federal Bldg., Rm. 8105, 125 South State St.
- **SAN FRANCISCO, California**--Customhouse, Rm. 504, 555 Battery St.
- **SPOKANE, Washington**--U.S. Courthouse, Rm. 678, West 920 Riverside Ave..
- **ANCHORAGE, Alaska**--Rm. 101, 4230 University Dr.
- **ANCHORAGE, Alaska**--Federal Bldg, Rm. E-146, 701 C St.

Maps

Maps may be purchased over the counter at the U.S. Geological Survey offices where books are sold (all addresses in above list) and at the following Geological Survey offices:

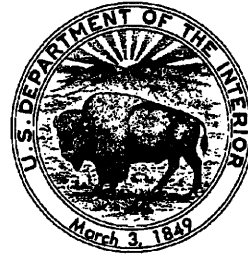
- **ROLLA, Missouri**--1400 Independence Rd.
- **DENVER, Colorado**--Map Distribution, Bldg. 810, Federal Center
- **FAIRBANKS, Alaska**--New Federal Bldg., 101 Twelfth Ave.

Uranium and Diagenesis in Evaporitic Lacustrine Mudstone of the Oligocene White River Group, Dawes County, Nebraska

By KENDELL A. DICKINSON

U.S. GEOLOGICAL SURVEY BULLETIN 1956

U.S. DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary



U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

Any use of trade, product, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Government.

UNITED STATES GOVERNMENT PRINTING OFFICE: 1991

For sale by the
Books and Open-File Reports Section
U.S. Geological Survey
Federal Center
Box 25425
Denver, CO 80225

Library of Congress Cataloging-in-Publication Data

Dickinson, Kendell A., 1931–
Uranium and diagenesis in evaporitic lacustrine mudstone of the Oligocene
White River Group, Dawes County, Nebraska / by Kendell A. Dickinson.
p. cm. — (U.S. Geological Survey bulletin ; 1956)
Includes bibliographical references.
Supt. of Docs. no.: I 19.3:1956
1. Uranium ores—Nebraska—Dawes County. 2. Geology,
Stratigraphic—Oligocene. 3. Geology—Nebraska—Dawes
County. 4. Diagenesis—Nebraska—Dawes County. 5. White River
Group. I. Title. II. Series.
QE75.B9 no. 1956
[QE390.2.U7]
557.3 s—dc20
[553.4'932'0978293]

90-14109
CIP

CONTENTS

Abstract	1
Introduction	1
Acknowledgments	1
Methods	2
Geology	3
Chadron Formation	3
Brule Formation	4
Facies and depositional environments	6
Mineralogy	7
Statistical analysis	7
Diagenesis	8
Uranium	12
Summary	15
References cited	16
Appendix. Chemical and mineralogic data for samples of the White River Group, Dawes County, Nebr.	19

FIGURES

1. Geologic map of study area showing sample localities	2
2. Chart of stratigraphy of the White River Group near Chadron, northwestern Nebraska	3
3. Generalized stratigraphic section of the White River Group at Trunk Butte	3
4. Photograph of the Chadron and Brule Formations at Trunk Butte	4
5. Generalized stratigraphic section of the White River Group at Noddings ridge	5
6. Scanning electron micrograph of rounded clay clast in upper purplish white layer at Noddings ridge	6
7. Photomicrograph of pelletal mudstone of the Orella Member at Trunk Butte	6
8. Generalized stratigraphic section of playa facies of the Orella Member near Isinglass Buttes	7
9. Photograph of bedded granular gypsum in evaporite facies of the Orella Member at Noddings ridge	7
10. Photograph of mudcrack impressions in shallow-water lacustrine limestone at Trunk Butte	8
11. Photomicrographs of a thin section of limestone from the uppermost limestone bed in the Orella Member, south end of Noddings ridge	9
12. Scanning electron micrographs of volcanic ash altered to montmorillonite in channel facies of Orella Member at Noddings ridge	13
13. Scanning electron micrograph of detrital clay from upper purplish white layer at Noddings ridge	13
14. Scatterplots showing relation between illite and smectite X-ray diffraction data	14

15. Photomicrograph showing fibrous gypsum and chalcedony in vein in the Orella Member at Noddings ridge **15**
16. Photomicrograph of thin section of fibrous gypsum **15**
17. Photomicrograph of thin section of calcareous mudstone from Noddings ridge area **16**
18. Scanning electron micrographs of siliceous veins in limestone in uppermost part of the Orella Member **17**
19. Scanning electron micrograph of air-fall volcanic ash (upper Whitney ash) from Round Top area **18**

TABLES

1. Location of X-ray diffractogram peaks measured for the White River Group samples **2**
2. Correlation coefficient matrix of \log_{10} -transformed data **10**
3. Varimax factor analysis for five factors: rotated factor loadings **12**

Uranium and Diagenesis in Evaporitic Lacustrine Mudstone of the Oligocene White River Group, Dawes County, Nebraska

By Kendell A. Dickinson

Abstract

The Oligocene White River Group consists of the Chadron and the overlying Brule Formations in northwestern Nebraska. The Chadron Formation consists of alluvial and colluvial vitric mudstone beds, but in addition contains white persistent layers (purplish-white layers) that probably resulted from soil formation on vitric parent material. West of the current study area a basal sandstone facies of the Chadron is host rock for the Crow Butte uranium deposit. The Brule, which consists mostly of pedogenically altered alluvial and fluvial vitric mudstone deposits, contains a uraniferous lacustrine facies northwest of Chadron, Nebraska.

Detrital minerals in rocks of the White River Group include quartz, feldspar, volcanic glass, smectite, and illite. Chemical precipitate minerals in the lacustrine facies are calcite, dolomite, and gypsum. Authigenic minerals include calcite, dolomite, gypsum, smectite, opal, chalcedony, together with oxidized uranium minerals.

An R-mode factor analysis and a correlation coefficient matrix were calculated for a chemical and mineralogical data base from White River samples. A five-factor grouping is summarized as follows: Factor 1 contained a large group of variables with negative factor loadings that are believed to represent a predominantly detrital suite. This group contained Al, Fe, K, Ti, Na, Li, feldspar, smectite, Ba, Cu, Mg, and illite. Included in the same factor but opposite in sign are opal, Ca, and U. Uranium and silica were probably released during alteration of the ash. The silica apparently formed opal and eventually chalcedony. Factor 2 included gypsum, Sr, and dolomite representing the evaporitic facies of the lacustrine beds. Quartz and SiO₂ make up factor 3. Factor 4 contained Mg and V, and factor 5 contained P.

Although vitric material in the mudstones partially altered to smectite, most of the clay material is believed to be detrital because it is included in factor 1 with the group of minerals and elements interpreted to be detrital and because most of the clay has a detrital texture. The purplish-white

layers are high in smectite relative to illite, perhaps resulting from pedogenic diagenesis.

INTRODUCTION

A uranium occurrence is present in a playa facies of the Brule Formation about 12 mi northeast of Chadron, Nebr. The Brule together with the underlying Chadron Formation constitutes part of the Oligocene White River Group. The group primarily comprises a nonmarine clastic sequence deposited by fluvial and pedogenic processes, but it also contains lacustrine beds. The objectives of the present report are to study the stratigraphic and diagenetic setting of the uranium deposit at Noddings ridge, which was first reported by Dunham (1955), about 12 mi northeast of Chadron, Nebr. Noddings ridge is an informal name applied to the topographic ridge that extends southward from the White River through secs. 3, 10, and 15, T. 34 N., R. 47 W.

Uranium is produced at an in-situ leaching pilot plant from the Crow Butte deposit in the basal Chadron Formation near Crawford, in western Dawes County, Nebr., about 20 mi west of Chadron, Nebr. (Collings and Knode, 1984; Gjelsteen and Collings, 1988). The Crow Butte deposit is west of the areas studied in this report.

Samples of the White River Group were collected from three areas: Trunk Butte, Isinglass Buttes, and Noddings ridge (fig. 1). A chemical-mineralogical data base was assembled from these samples.

ACKNOWLEDGMENTS

Help for this report was received from several people and is gratefully acknowledged. Gary Skipp prepared oriented clay mineral mounts for the X-ray diffraction studies and operated the XRD machine. James Nishi helped with the scanning electron microscope. The chemical

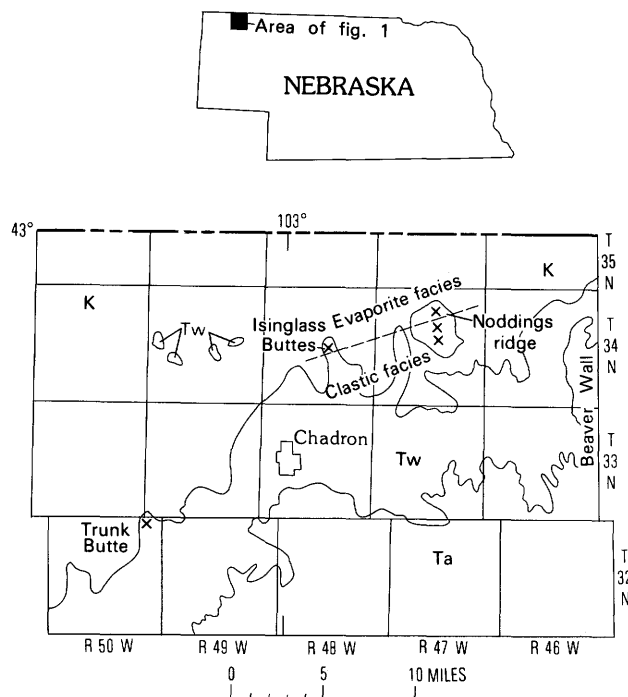


Figure 1. Geologic map of study area showing sample localities (x), Arikaree Group (Ta), White River Group (Tw), and Cretaceous (K). Geology from Burchett (1986).

analyses were done in the analytical laboratories of the U.S. Geological Survey at Denver, Colo. D.M. McKown supervised the radiochemical analyses; J.E. Taggart supervised the X-ray spectroscopy; and D.E. Detra and L.R. Layman supervised optical spectroscopy.

METHODS

The data used for this report are given in an appendix (p. 19), which comprises analyses of 16 elements and 8 minerals for 46 samples. Uranium and thorium contents were determined by the delayed-neutron method (Millard, 1976). Oxides were determined by X-ray fluorescence, and other elemental values were determined by inductively coupled plasma spectroscopy (ICP) (Crock and others, 1983). Mineralogical determinations were by X-ray diffraction of whole-rock cell mounts and oriented clay mineral mounts (XRD). Two sets of XRD data for smectite and illite are included in the appendix. One set, for the factor analysis and correlation coefficient matrix, was measured from the whole-rock X-ray diffractograms also used for dolomite, calcite, feldspar, quartz, opal, and gypsum. These data values are the areas in square inches of the appropriate XRD peaks (table 1). The whole-rock XRD data was obtained under conditions made as uniform as possible for all the XRD runs. The same mount preparation procedures, the same instrument, and the same instrument settings were used for all samples, and all the runs were

Table 1. Location of X-ray diffractogram peaks (Cu, K α radiation) measured for the White River Group samples (Dickinson, 1988)

Mineral	X-ray diffraction peak (degrees 2 θ)	Crystallographic indices
Dolomite	31.0	104
Calcite	29.4	104
Feldspar	26.9–27.9	002
Quartz	26.7	101
Opal (C–T) ¹	21.6	111
Gypsum	11.7	020
Illite ²	8.8	001
Smectite	5.9	001

¹Opal that displays a cristobalite-tridymite pattern (Jones and Segnit, 1971).

²The term "illite" is used for all minerals that contribute to the 10 Å (angstrom) XRD peak. It probably represents a mixture of fine-grained mica and illite.

made continuously from start to finish insofar as the length of the work day allowed. The second set of XRD data for smectite and illite was obtained from oriented glycolated mounts of the <2 μ m (micrometer) clay size. The values for this data are the number of counts from each XRD peak. The data base used here is the same as was used by Dickinson (1988) except that vanadium was substituted for LOI (loss on ignition) and the oriented clay mount data was included. Because of the close correlation between elements determined by ICP and XRF, only SiO₂ from the XRF data was included in the present statistical analysis.

Correlation coefficient matrices and R-mode factor analyses (Harmon, 1960) were calculated from the data base using commercially available software (Number Cruncher Statistical System, Hintze, 1987) and a personal computer. Three-fourths of the lower detection limit was substituted for ICP values reported as less-than values. For calculations made on log transformations of original values of XRD data, 0.00001 was substituted for zero because the log of zero is infinity. The factor analyses were performed to reduce the number of variables to be interpreted by grouping them into related sets. Correlation coefficients were also calculated and scatter diagrams were prepared for both sets of smectite and illite data.

Individual statistics were performed on untransformed units for the chemical data (Dickinson, 1988). Factor analysis and correlation coefficients were calculated for both untransformed units and for log-transformed data. Only the results for the log-transformed data are presented here because the communality (the proportion that could be accounted for by the factor analysis) is higher for uranium.

In general only minor differences were found between analysis of the original data (Dickinson, 1988) and the log-transformed data presented here.

The results of these studies suggest many interesting relationships, and the data can be interpreted to reflect sedimentologic and diagenetic processes. Some of the results, however, seem to defy interpretation, which may reflect lack of randomness in sample collection, too few samples, or various degrees of departure from normality of data distribution.

GEOLOGY

The Chadron and Brule Formations, which constitute the Oligocene White River Group, consist mostly of colluvial and alluvial claystone, and mudstone (figs. 2–5). Some lacustrine gypsum and limestone are also present. Paleosols were developed on some of the flood-plain surfaces (Schultz and others, 1955). The ultimate detrital source for the White River Group was rocks in the mountains far to the west. These rocks included volcanic material from the same sources that provided material for air-fall beds found at various stratigraphic intervals in the group in the study area. The Chadron unconformably overlies the Cretaceous Pierre

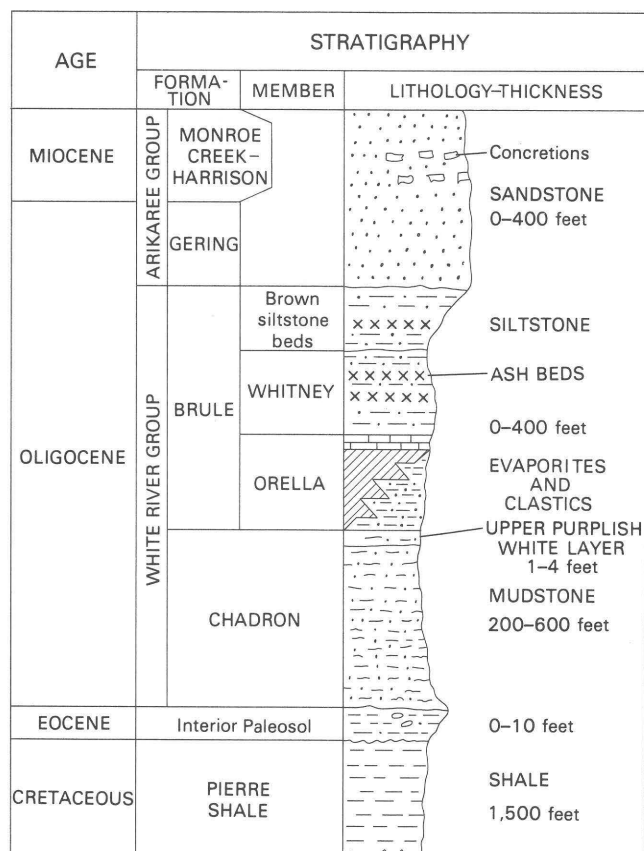


Figure 2. Stratigraphy of the White River Group near Chadron, northwestern Nebraska.

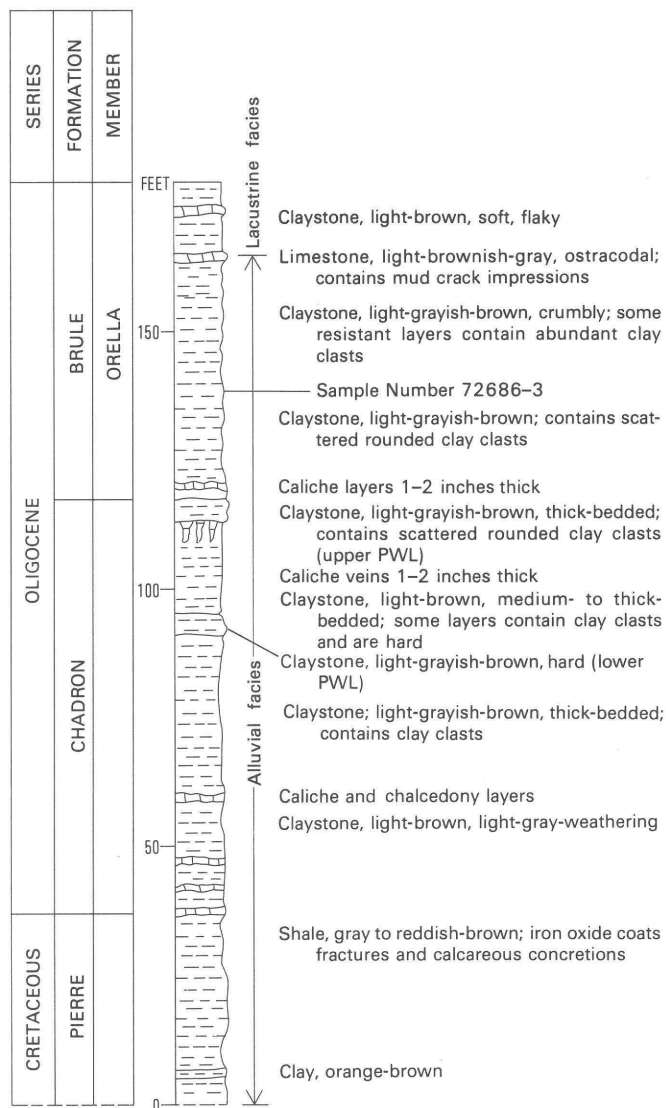


Figure 3. Generalized stratigraphic section of the White River Group at Trunk Butte.

Shale, although in some areas they are separated by an Eocene paleosol, the Interior Paleosol, or by younger Cretaceous sedimentary rocks. The Brule, above the Chadron, is in turn overlain by the Miocene Gering Formation of the Arikaree Group.

Chadron Formation

In northwestern Nebraska the Chadron Formation consists mostly of light-gray, green, and nearly white claystone and mudstone. It contains prominent beds known as “purplish-white beds” (Schultz and Stout, 1955). The top of the upper “purplish-white bed” is used as the top of the Chadron in this report as was done by Vondra (1958). The Chadron contains a basal sandstone facies that was

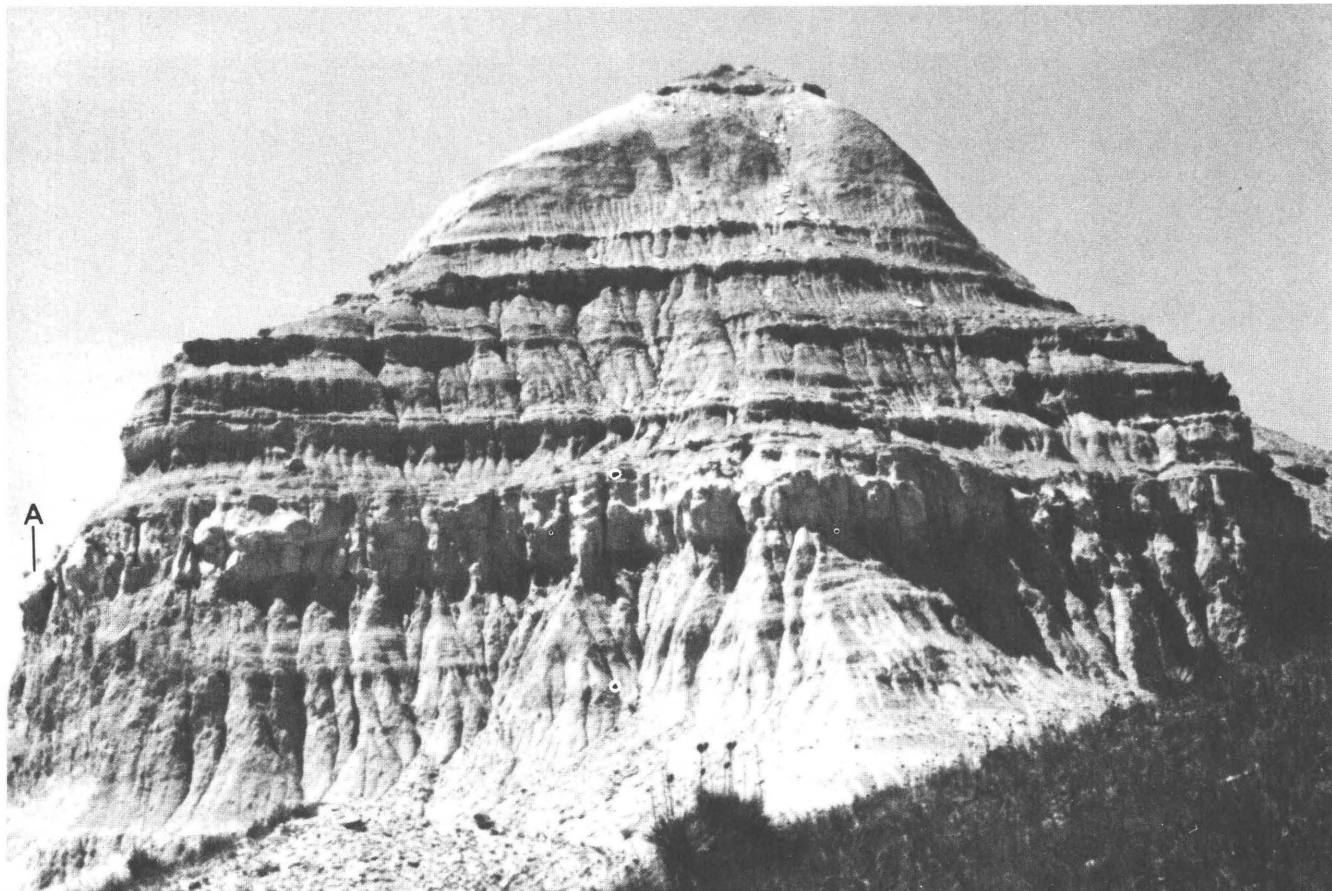


Figure 4. The Chadron and Brule Formations at Trunk Butte. The contact between the Chadron (below) and the Brule (above) is top of the prominent bed (A), which is the upper purplish white layer (PWL). Stratigraphic thickness from top of the upper PWL to top of the limestone bed (dark layer at top) is 45 feet.

deposited in channels scoured into the Pierre Shale. This facies consists of arkosic, vitric conglomeratic sandstone. It is the host rock for the Crow Butte uranium deposit (Gjelsteen and Collings, 1988), but it does not extend into the present study area and so is not shown in figure 2.

Purplish-white layers (PWL) are widespread resistant white beds of altered calcareous mudstone 1–3 ft thick in the Chadron Formation (fig. 4). They apparently formed from soil development on alluvial or fluvial sediment. They have been used as a correlation tool but they are difficult to tell apart. Mudstones overlying the purplish-white layers typically contain subhorizontal caliche veins, whereas those in underlying beds are vertical or nearly vertical. This suggests that during caliche formation in the upper mudstones, the purplish-white layers were barriers to vertical ground-water circulation. Pellets (rounded clay clasts) are common in but not restricted to the purplish-white layers (fig. 6). Along Noddings ridge the upper(?) purplish-white layer changes from pelletal mudstone on the south through an ashy facies to gypsiferous dolomite on the north. The gypsiferous dolomite underlies the thickest part of the evaporitic facies in the overlying Brule Formation and may have been altered diagenetically to gypsum and dolomite by

brines percolating downward from the overlying playa lake (figs. 1, 5). Schultz and Stout (1955), however, reported gypsum crusts in PWL's along the margins of the paleo-valleys. The purplish-white samples studied in this report contain abundant smectite and a dearth of illite relative to the other samples, as will be discussed in the section, "Diagenesis."

Brule Formation

In northwestern Nebraska the Brule Formation contains the Orella and Whitney Members in ascending order. An additional informal member called the brown siltstone was recognized above the Whitney by Swinehart and others (1985). The brown siltstone and the Whitney are soft siltstone and fine-grained sandstone that are partly eolian in origin. The Orella consists mostly of light-pink to brown pelletal mudstone (fig. 7), but in the area of this study it contains a playa facies characterized by gypsum, dolomite, and limestone of lacustrine origin (figs. 8, 9, 10). Swinehart and others (1985) described a regional

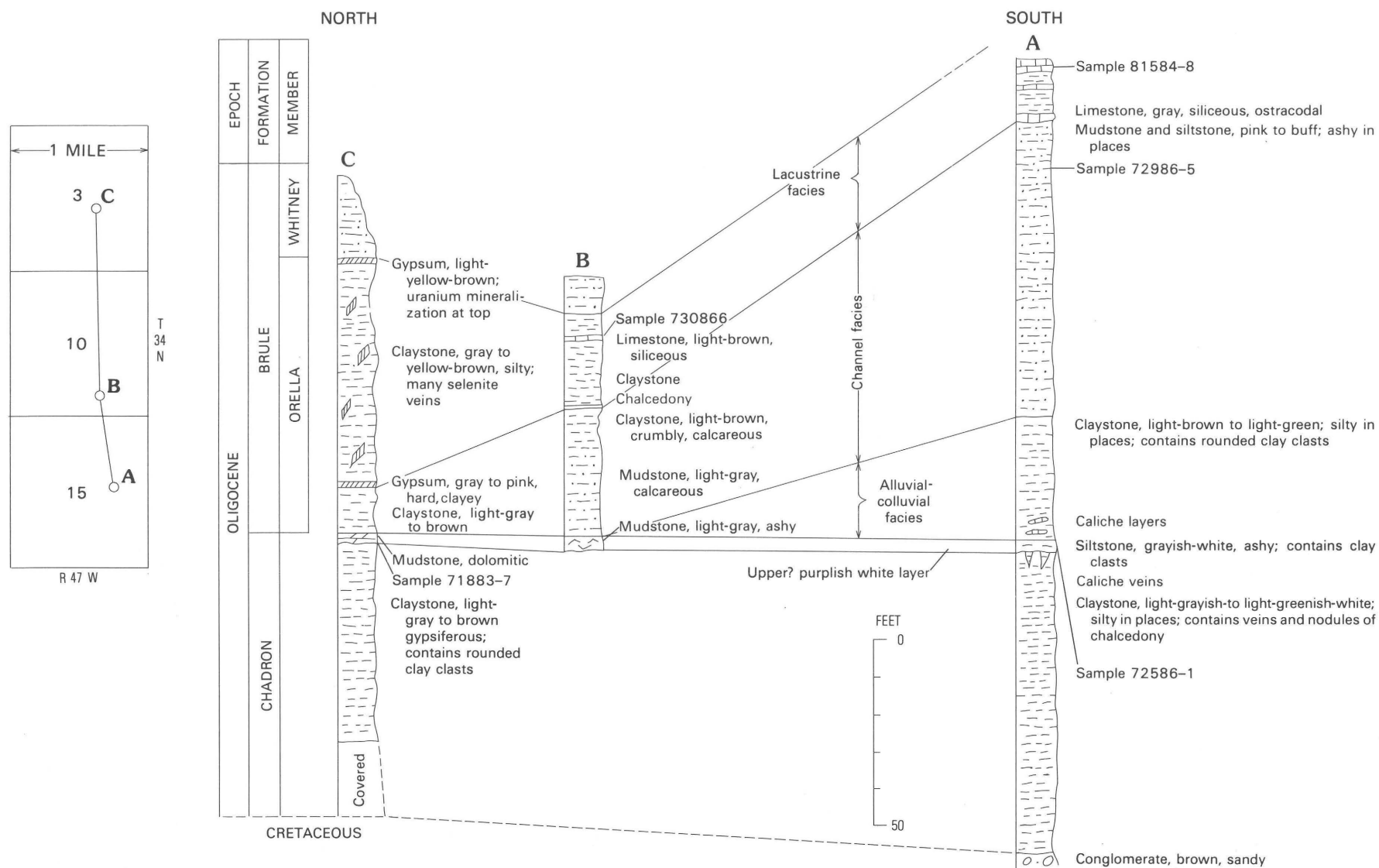


Figure 5. Generalized stratigraphic section of the White River Group at Noddings ridge.

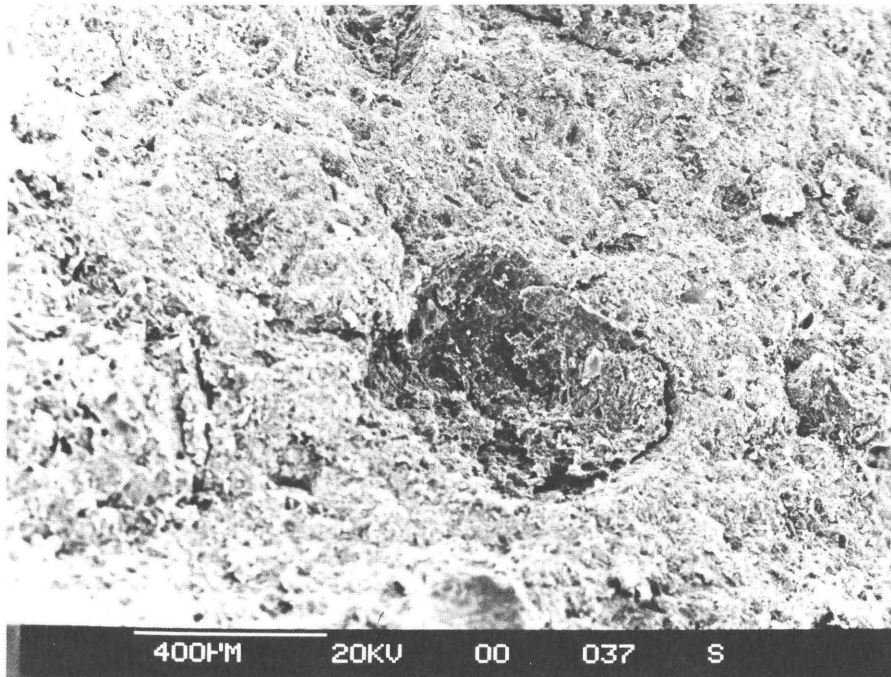


Figure 6. Scanning electron micrograph of rounded clay clast in upper purplish white layer (PWL) at Noddings ridge (sample 72586-1, locality on fig. 5).

unconformity within the Brule. Of the samples for this study, most were collected from the Orella Member of the Brule Formation (Dickinson, 1988, p. 29).

Facies and Depositional Environments

Dunham (1955) described two facies, a gypsum facies and a clastic facies, in the Orella Member in the vicinity of the uranium deposit at Noddings ridge. In this report, which covers a somewhat wider area, the Orella Member is generally divided into lacustrine and alluvial facies. The lacustrine facies contains a gypsum-dolomite subfacies, which is mostly gypsum (fig. 9), and a widespread, but thin, limestone subfacies (fig. 10). The alluvial facies can be generally divided into channel and flood-plain subfacies (figs. 3, 5). Most of the flood-plain rocks have been altered by pedogenesis. The gypsum-dolomite subfacies represents deposition from the more concentrated brines in the center of the lake basin, and the limestone from more dilute water at higher lake levels. The ancient lake was more widespread during later, fresher water phases. The shallow-water lacustrine limestone representing the fresher water phase (fig. 10) extends from Noddings ridge to Trunk Butte, a distance of about 15 mi. Erosion has removed much of the original playa deposit northwest of Isinglass Buttes and Noddings ridge.

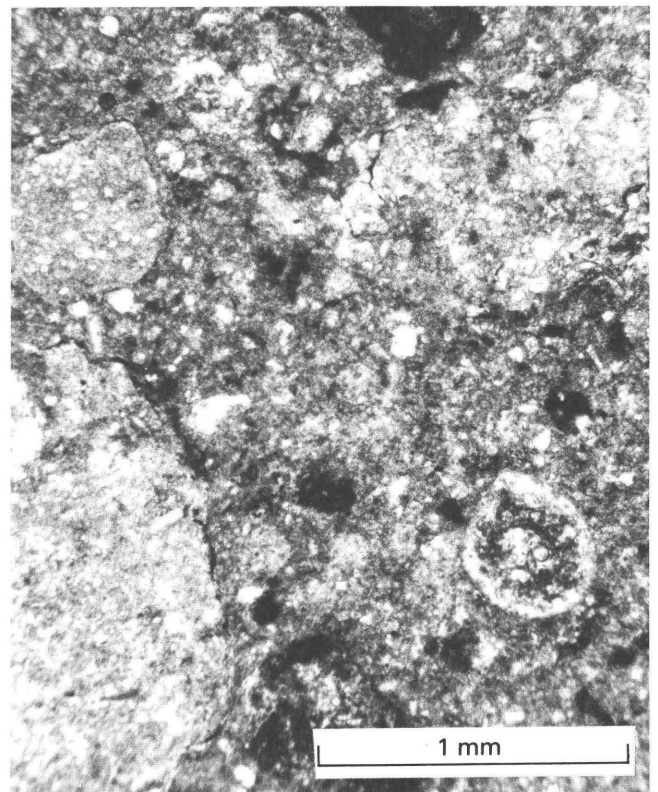


Figure 7. Photomicrograph of pelletal mudstone of the Orella Member at Trunk Butte (sample 72683-3). Plane-polarized light.

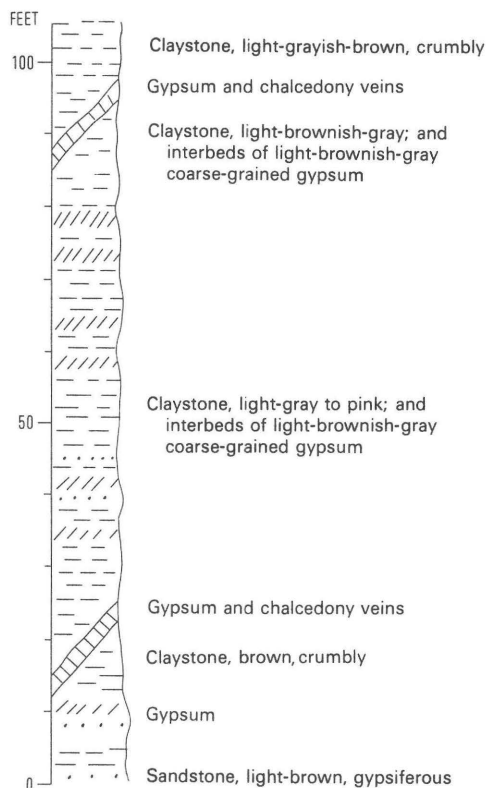


Figure 8. Generalized stratigraphic section of playa facies of the Orella Member near Isinglass Buttes.



Figure 9. Bedded granular gypsum in evaporite facies of the Orella Member at Noddings ridge.

Mineralogy

The mineral components of the White River Group can be classified as detritals, orthochemical precipitates, or diagenetic minerals. The detrital minerals, which predominate in the clastic rocks, are mainly quartz, feldspar, illite, and smectite. The chemical precipitate minerals, which predominate in the lacustrine rocks, are gypsum, calcite, and dolomite. Much of the calcite, however, is of pedogenic (caliche) origin. The predominant diagenetic minerals are calcite, gypsum, opal, and chalcedony.

STATISTICAL ANALYSIS

A correlation coefficient matrix and a R-mode factor analysis based on original units of the data base were presented by Dickinson (1988). A correlation coefficient matrix (table 2) and a five-factor model (table 3) presented herein were calculated from a log-transformed data base. The communality (proportion of total variance explained by the model for each variable) is higher for uranium here than for the original model (Dickinson, 1988). The interpretations of the factor analysis are based on primary factor

loadings for each variable, ignoring the fact that secondary loadings (where factor loadings are less than the highest for a given variable) may also be important in explaining the distributions.

Factor one.—Factor one contains both positive and negative groups of loadings. The variables with negative factor loadings in order of decreasing factor score are Al, K, Fe, Ti, Na, Li, feldspar, smectite, Ba, Cu, Mg, and illite. The association of these elements and minerals is believed to be controlled by their distribution in the source sediments. Volcanic glass was not measured, but any fluviually reworked glass would correlate with the detrital group. Opal, Ca, and U are the three most strongly loaded positive elements in factor one. The association of these elements with factor one, but opposite in sign to the preceding group, suggests that they are related to the detrital minerals as alteration products or as constituents of alteration products.

Silica and uranium were apparently derived from alteration of the volcanic ash. The silica probably formed opal and ultimately chalcedony. The explanation for Ca is



Figure 10. Mudcrack impressions in shallow-water lacustrine limestone at Trunk Butte.

more complex. Its source is the stream and ground water and its manner of deposition is varied.

Factor two.—Factor two contains only gypsum, strontium, and dolomite as negative elements and calcite and manganese as positive elements. The occurrence of gypsum and dolomite represents the evaporitic phase of the playa lake. Strontium remained in solution until the gypsum was deposited and apparently substituted for Ca in the gypsum structure because of their similar charge and size ($\text{Ca}^{+2}=0.99 \text{ \AA}$, $\text{Sr}^{+2}=1.12 \text{ \AA}$).

Factor three.—Factor three loads primarily on quartz and SiO_2 . The relation between the two is obvious, but parts of both the quartz and the SiO_2 are detrital and parts are authigenic. The SiO_2 also has fairly high factor loadings in factors one and two reflecting its occurrence in other silicates.

Factor four.—Factor four exhibits high negative loadings for Mg, V, Cu, and Mn. This association is not easily explained. The secondary loading for Mg, however, associates it with the detrital group, factor one, but it is weakly loaded in factor two which contains dolomite.

Factor five.—In factor five phosphorus loads at one pole and illite at the other. Phosphorus is generally related to biological activity, which was high during the more evaporative stages of the lake. The negative loading of illite probably represents the detrital fraction, which is diluted in this facies by the lacustrine chemical deposits. Its secondary factor loading is with the detrital fraction in factor one.

In summary, factor one represents detrital materials and their alteration products; factors two, three, and four represent introduced materials or alteration products from detrital materials. Factor two represents playa lake facies. Factor four is enigmatic. Factor five may in part reflect biological activity.

DIAGENESIS

Diagenesis in the lacustrine beds and related mudstones consisted mostly of dissolution and reprecipitation of siliceous minerals, carbonates, and sulfates. Some clay mineral alteration also occurred. The diagenetic minerals in the White River lacustrine and pedogenic sedimentary rocks include smectite, calcite, opal, chalcedony, and gypsum. No clinoptilolite or kaolinite was found. According to Stanley and Benson (1979), diagenetic alteration of Tertiary sandstones in the high plains has not been strong, and unaltered volcanic shards and feldspar still persist in the sediment. Their paragenesis in the sandstone is calcite, first, then smectite, kaolinite, and a silica-phase mineral. Clinoptilolite is rare in Tertiary high plains sandstones (Stanley and Benson, 1979). Paragenesis in the fine-grained fluvial and lacustrine rocks of this study is difficult to determine using present methods, because the diagenetic minerals, except for opal and chalcedony, have also been supplied to the sediment both as detrital minerals and as precipitates. In addition, the order of formation of some diagenetic minerals alternated. For example, figure 11 shows that calcite was followed by chalcedony in one fossil cavity and that calcite followed chalcedony in another cavity in the same sample. Another example is that fibrous gypsum and a chalcedony alternated in some of the vein fillings. These examples are presumably results of the fluctuation of the pore-water chemistry.

The only clay minerals in the samples are smectite and illite. Of the two, smectite is more abundant and more widespread. In the correlation coefficient matrix the two are related ($r=+0.39$, table 2), probably because of their predominantly detrital origin. Small amounts of authigenic smectite formed on shards in some of the mudstones (fig. 12). Smectite formed chiefly as an alteration product of the volcanic ash (Zielinski, 1983; also fig. 12). Much of the alteration probably took place in the sediment source area, and diagenetically produced smectite was transported in streams to depositional areas where it became a detrital sediment (fig. 13). Some of the alteration could have

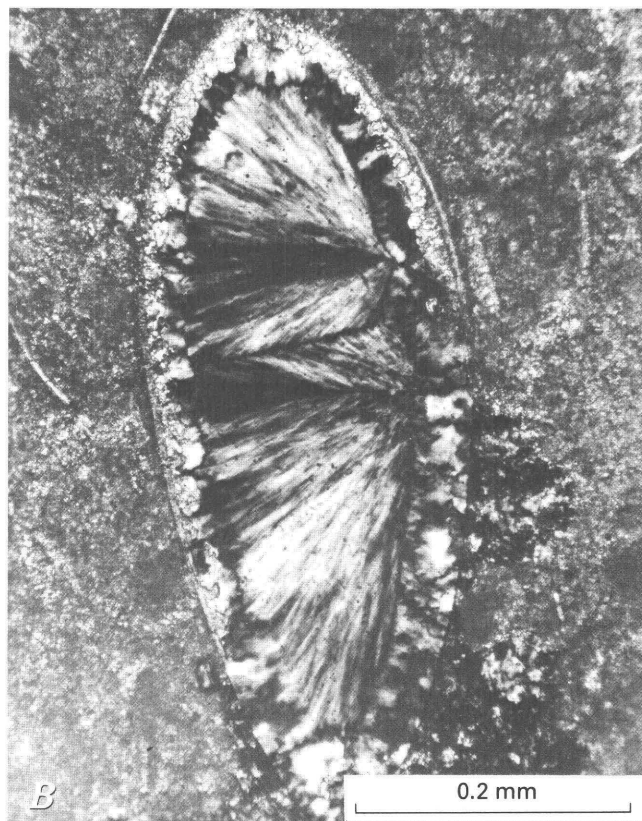
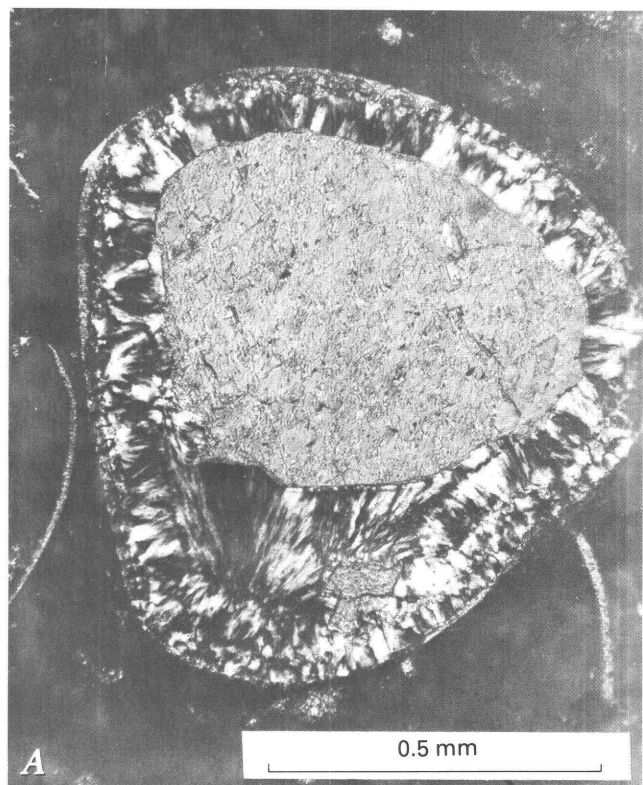


Figure 11. Photomicrographs of a thin section of limestone under crossed polarizers from the uppermost limestone bed in the Orella Member, south end of Noddings ridge (sample 81584–8, fig. 5). *A*, Fossil cavity with early deposition of chalcedony (outer layer) and later calcite in the center. *B*, Cavity in ostracode carapace is lined with early calcite, and later chalcedony filled the center and replaced parts of the earlier calcite and the limestone matrix.

occurred diagenetically after the volcanic ash was transported, via water or air, to the depositional site (fig. 8). The combination of the strong loading of smectite with detrital variables (factor 1, table 3) and the detrital texture of most of the clay in the mudstone suggests, however, that most of the smectite was deposited in a fluvial environment.

Illite is the other common mineral in the clay mineral suite of the samples (Dickinson, 1988); it is less abundant than smectite, but like smectite is associated (although somewhat less strongly) with the detrital group of elements and minerals. If the relative amounts of smectite and illite are compared from the oriented clay-mount XRD data (as opposed to the whole-rock data), they are negatively associated ($r = -0.26$, significant at 90 percent confidence level for normal populations; fig. 14). This latter statistic may suggest that smectite formed from the illite (Borchardt, 1977, p. 306, 309; Fanning and Keramidas, 1977, p. 206). Authigenic illite was not recognized in the samples studied in this report. Little or no interlayered smectite-illite, which would have suggested an intermediate stage, was found. The illite could be a detrital product of the Mesozoic and older crystalline source areas to the west. In PWL's the clay is predominantly smectite (fig. 14); illite originally in these beds may have been altered to smectite. Such alteration

would explain the weaker correlation between illite and the detrital group of chemicals and minerals (table 3).

The major carbonate mineral in the study area rocks is calcite. Its major occurrences are in the limestone subfacies as an orthochemical precipitate and in the alluvial mudstone facies as diagenetic caliche and cement deposited during pedogenesis. A sparry variety also was deposited in minor amounts as cavity filling in the limestone (fig. 11). Dolomite is interbedded with gypsum and closely associated with it in the statistical analysis (tables 2, 3).

Gypsum is present only in the lacustrine facies, where it occurs in two forms, in fibrous veins and in granular beds (figs. 9, 15). The vein-filling gypsum is authigenic and alternates with chalcedony in some of the veins. Judging from the coarse grain size, the gypsum appears to be recrystallized.

Diagenetic silica phases in the rocks of the study area are opal and chalcedony (figs. 16–17). Opal is widespread in the limestone subfacies and in some of the calcareous mudstones, but is absent from the gypsum-dolomite subfacies. The absence of opal in the gypsum-dolomite subfacies probably results from a higher Mg^{+} content, which has been shown to hasten the alteration from opal to microcrystalline quartz (Leeder, 1982; Kastner and others,

Table 2. Correlation coefficient matrix of log₁₀-transformed data

	U	Al	Ca	Fe	K	Mg
U	1.00					
Al	-0.42	1.00				
Ca	0.26	-0.67	1.00			
Fe	-0.49	0.96	-0.67	1.00		
K	-0.43	0.97	-0.65	0.93	1.00	
Mg	-0.29	0.52	-0.24	0.59	0.54	1.00
Na	-0.36	0.95	-0.65	0.88	0.93	0.50
Mn	0.29	0.01	0.31	-0.07	-0.02	0.25
P	-0.05	0.31	-0.00	0.27	0.27	0.23
Ti	-0.47	0.94	-0.68	0.98	0.91	0.58
Ba	-0.30	0.70	-0.43	0.66	0.67	0.35
Cu	-0.25	0.64	-0.58	0.69	0.62	0.52
Li	-0.51	0.89	-0.62	0.95	0.88	0.66
Sr	-0.00	-0.40	0.33	-0.28	-0.33	-0.04
SiO ₂	0.04	0.60	-0.66	0.54	0.56	-0.05
V	0.13	0.40	-0.37	0.34	0.37	0.39
Dolomite	-0.04	-0.36	0.34	-0.28	-0.25	0.22
Calcite	0.20	0.05	0.23	-0.07	-0.03	-0.29
Feldspar	-0.35	0.72	-0.63	0.74	0.72	0.55
Quartz	-0.00	0.16	-0.37	0.25	0.15	0.08
Opal	0.49	-0.51	0.35	-0.50	-0.58	-0.45
Gypsum	-0.06	-0.35	0.28	-0.27	-0.25	0.12
Illite	-0.32	0.43	-0.46	0.50	0.39	0.27
Smectite	-0.40	0.69	-0.46	0.60	0.67	0.11

	Li	Sr	SiO ₂	V	Dolomite	Calcite
U						
Al						
Ca						
Fe						
K						
Mg						
Na						
Mn						
P						
Ti						
Ba						
Cu						
Li	1.00					
Sr	-0.23	1.00				
SiO ₂	0.46	-0.51	1.00			
V	0.36	-0.46	0.43	1.00		
Dolomite	-0.20	0.80	-0.54	-0.35	1.00	
Calcite	-0.13	-0.67	0.27	0.24	-0.72	1.00
Feldspar	0.71	-0.13	0.34	0.28	-0.02	-0.23
Quartz	0.26	0.11	0.42	0.24	0.11	-0.26
Opal	-0.47	-0.28	0.08	0.05	-0.28	0.44
Gypsum	-0.21	0.84	-0.52	-0.40	0.93	-0.79
Illite	0.45	-0.14	0.29	0.22	-0.14	-0.16
Smectite	0.51	-0.07	0.34	0.16	-0.17	-0.05

Table 2. Correlation coefficient matrix of log₁₀-transformed data—Continued

	Na	Mn	P	Ti	Ba	Cu
U						
Al						
Ca						
Fe						
K						
Mg						
Na	1.00					
Mn	0.18	1.00				
P	0.36	0.42	1.00			
Ti	0.86	-0.08	0.21	1.00		
Ba	0.73	0.29	0.25	0.67	1.00	
Cu	0.61	0.02	0.21	0.69	0.53	1.00
Li	0.81	-0.05	0.22	0.92	0.66	0.73
Sr	-0.56	-0.59	-0.38	-0.29	-0.52	-0.30
SiO ₂	0.60	0.01	0.21	0.53	0.50	0.39
V	0.43	0.32	0.32	0.40	0.45	0.51
Dolomite	-0.46	-0.40	-0.31	-0.26	-0.50	0.20
Calcite	0.19	0.67	0.39	-0.10	0.29	-0.07
Feldspar	0.72	-0.20	0.10	0.72	0.39	0.47
Quartz	0.06	-0.34	-0.06	0.23	0.04	0.29
Opal	-0.45	0.33	-0.01	-0.48	-0.27	-0.21
Gypsum	-0.48	-0.58	-0.33	-0.24	-0.52	-0.24
Illite	0.38	-0.23	-0.05	0.54	0.28	0.33
Smectite	0.60	-0.36	-0.01	0.59	0.37	0.28

	Feldspar	Quartz	Opal	Gypsum	Illite	Smectite
U						
Al						
Ca						
Fe						
K						
Mg						
Na						
Mn						
P						
Ti						
Ba						
Cu						
Li						
Sr						
SiO ₂						
V						
Dolomite						
Calcite						
Feldspar	1.00					
Quartz	0.34	1.00				
Opal	-0.59	0.06	1.00			
Gypsum	-0.03	0.14	-0.31	1.00		
Illite	0.47	0.19	-0.28	-0.05	1.00	
Smectite	0.58	0.20	-0.61	-0.08	0.39	1.00

Table 3. Varimax factor analysis for five factors: rotated factor loadings

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Comm.
U	0.61	0.12	-0.36	-0.06	0.30	0.61
Al	-0.93	-0.16	0.24	-0.13	0.03	0.97
Ca	0.62	-0.16	0.49	0.24	0.35	0.78
Fe	-0.91	0.14	-0.17	-0.22	-0.08	0.94
K	-0.93	0.15	-0.14	-0.14	0.06	0.94
Mg	-0.52	-0.23	0.10	-0.77	0.08	0.94
Na	-0.87	0.39	-0.09	-0.17	0.07	0.95
Mn	0.19	0.60	0.29	-0.50	0.40	0.89
P	-0.23	0.31	0.00	-0.24	0.64	0.62
Ti	-0.88	0.13	-0.18	-0.26	-0.14	0.92
Ba	-0.61	0.49	-0.01	-0.25	-0.03	0.67
Cu	-0.54	0.14	-0.31	-0.52	-0.16	0.69
Li	-0.86	0.07	-0.15	-0.35	-0.12	0.89
Sr	0.17	-0.88	0.05	0.19	-0.01	0.84
SiO ₂	-0.40	0.51	-0.65	0.09	-0.30	0.85
V	-0.20	0.36	-0.43	-0.54	0.12	0.65
Dolomite	0.15	-0.93	0.08	-0.10	0.06	0.91
Calcite	0.14	0.85	0.13	0.08	0.31	0.87
Feldspar	-0.78	-0.12	-0.24	-0.14	-0.05	0.71
Quartz	-0.11	-0.22	-0.82	-0.05	-0.07	0.75
Opal	0.75	0.43	-0.23	-0.09	-0.05	0.82
Gypsum	0.12	-0.95	0.04	0.40	-0.03	0.93
Illite	-0.44	0.06	-0.12	-0.15	-0.62	0.61
Smectite	-0.78	0.00	-0.13	0.39	-0.03	0.77

1977). Opal exhibits a poorly ordered cristobalite-tridymite (C-T) XRD pattern (Jones and Segnit, 1971) in most of the samples. Lepispheres of opal result from diagenetic alteration of volcanic ash (fig. 19). In the ash, opal probably formed from excess silica released in the formation of smectite, and opal is a precursor of chalcedony. The distribution of chalcedony is difficult to characterize in this study because of the reliance on XRD, with which one does not differentiate between the authigenic quartz, chalcedony, and the detrital quartz. Some of the silica may have passed through an organic phase where it was incorporated in diatom frustules in the lacustrine environment, but no evidence for the existence of diatoms was found. The character of the detrital clays based on X-ray analysis is, however, closely similar to that of the authigenic clays found in the ash beds, and it is likely that the clays were mostly derived from authigenesis of volcanic ash in the sediment source area.

URANIUM

The Noddings ridge uranium deposit, which as presently known is below commercial size, was described in detail by Dunham (1955). He found enrichment as high as

0.43 percent U₃O₈ in a lacustrine gypsum facies of the Orella Member at that locality (fig. 1). Dunham identified three oxidized uranium minerals: carnotite [K₂O(VO₂)V₂O₅·2H₂O], sabugulite [HAl(VO₂)₄(PO₄)₄·16H₂O], and autunite [Ca(VO₂)P₂O₈·8H₂O]. The uranium deposit was probably originally syngenetic [Evaporative precipitates (Class 220), Mickle and Mathews (1978)], but subsequent diagenesis enriched the deposit locally.

The statistical analysis of the data base presented here, which did not contain uranium-enriched samples, fails to show a strong correlation between uranium and any element or mineral, but uranium is most closely allied with calcium, and opal. Opal and limestone, a major source of calcium, occur together in the fresh-water subfacies of the lacustrine deposits and may link the uranium with the deposition in the lake. In the factor analysis uranium occurs with the detritals but is opposite in sign. This association suggests that the uranium formed from alteration of the detrital materials. It also suggests that the uranium was derived from detritally deposited volcanic ash, considering that the primary source of the uranium is believed to be volcanic material (Zielinski, 1983), which makes up a significant proportion of some of the sedimentary beds, not only in the vicinity of the occurrence, but also for hundreds

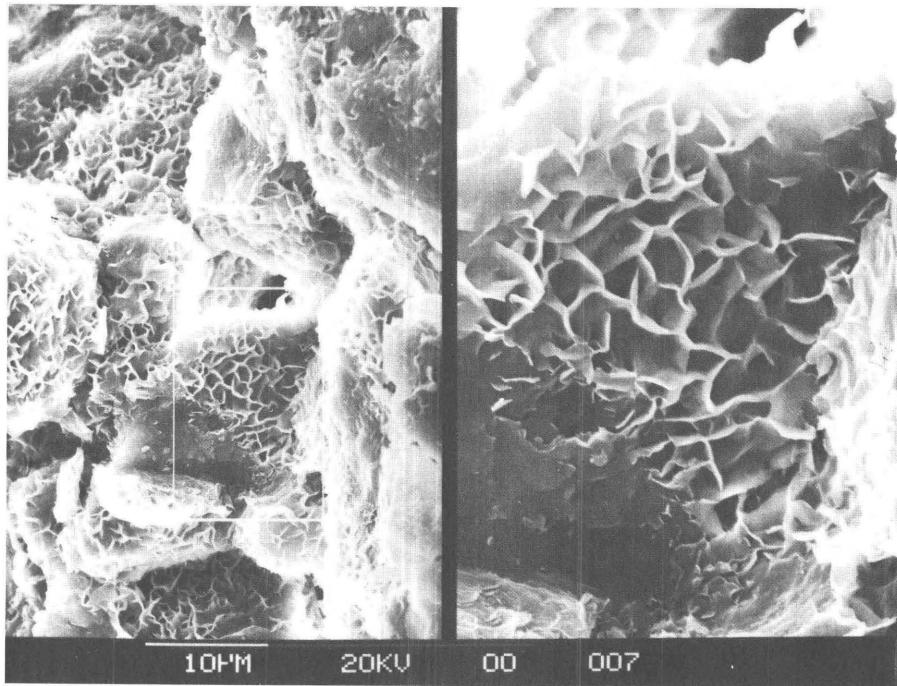


Figure 12. Scanning electron micrographs of volcanic ash altered to montmorillonite in channel facies of Orella Member at Noddings ridge. Bar scale is for left view, outlined portion in left view is magnified three times in right view (sample 72986-5, fig. 5).

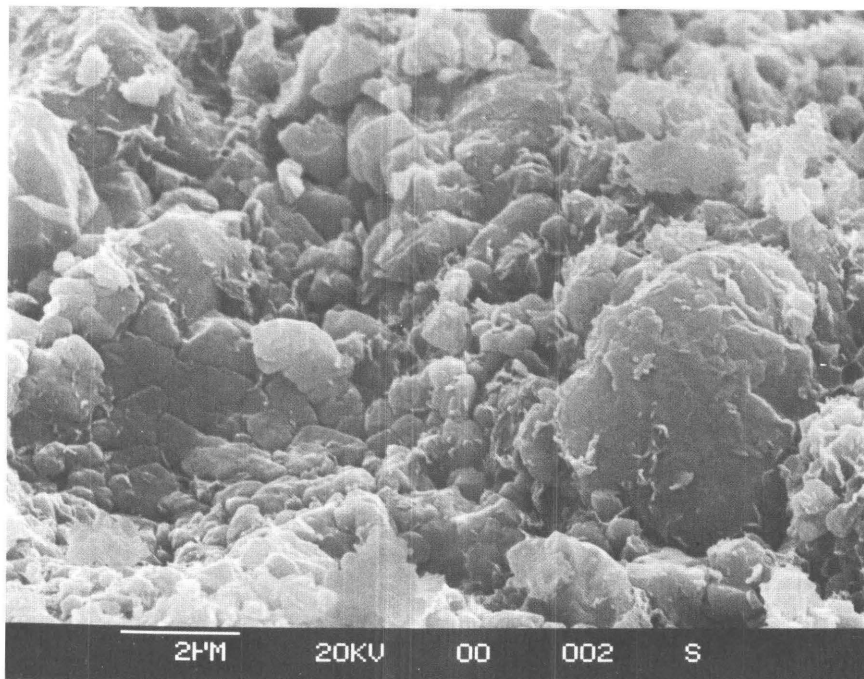


Figure 13. Scanning electron micrograph of detrital clay in upper purplish white layer from Noddings ridge (sample 72586-1, fig. 5).

of miles to the west. Crystalline rocks of the mountains to the west probably also contributed part of the uranium (Gjelsteen and Collings, 1988). Oxidized uranium dissolved in stream and ground water made its way eastward and entered the playa lake during deposition of the Brule

Formation. The uranium was deposited with gypsum from the most dense brine when the solubility product was exceeded through evaporation or by chemical reduction. Dunham (1955) asserted that the uranium minerals were associated with carbonaceous material, which indicates

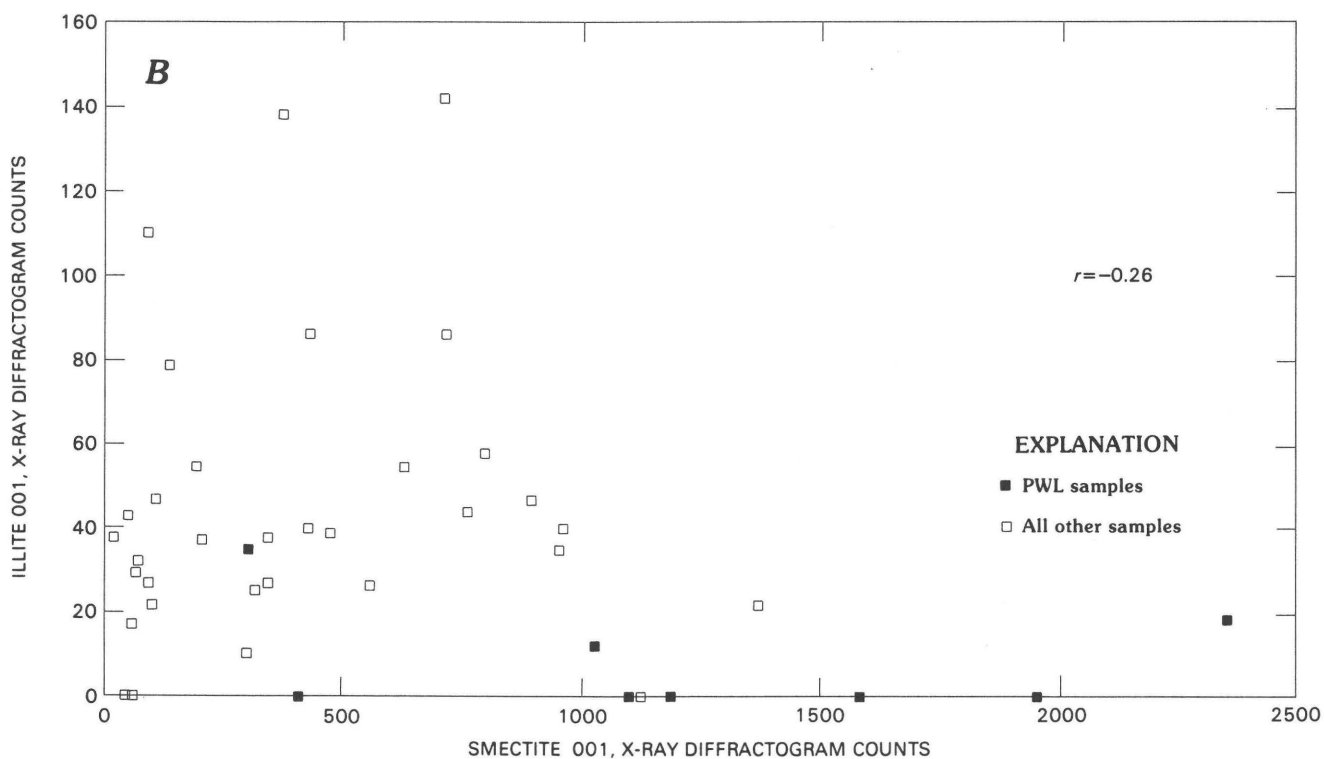
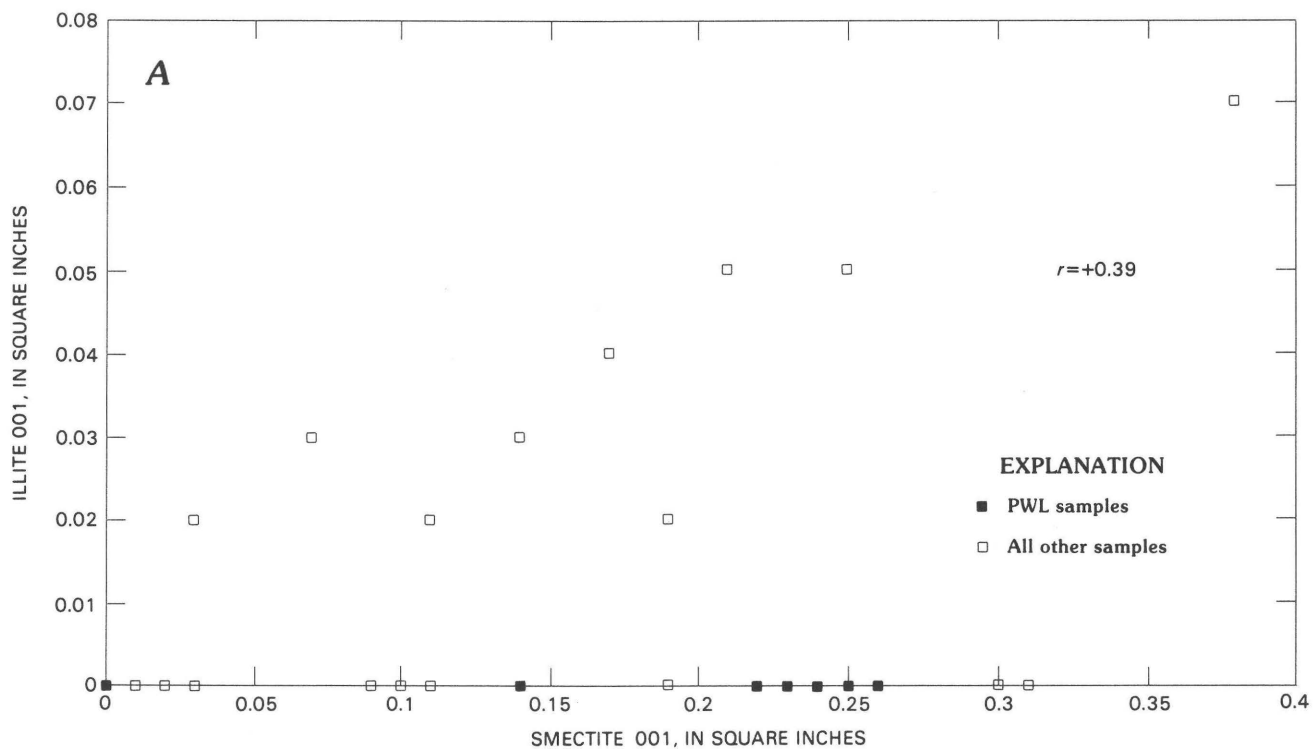


Figure 14. Scatterplots showing relation between illite and smectite X-ray diffraction data from purplish-white layers (PWL) and other samples. *A*, From whole-rock XRD data (based on areas in square inches of basal XRD peaks); *B*, From oriented $<2\ \mu\text{m}$ glycolated claymount data (based on XRD counts).

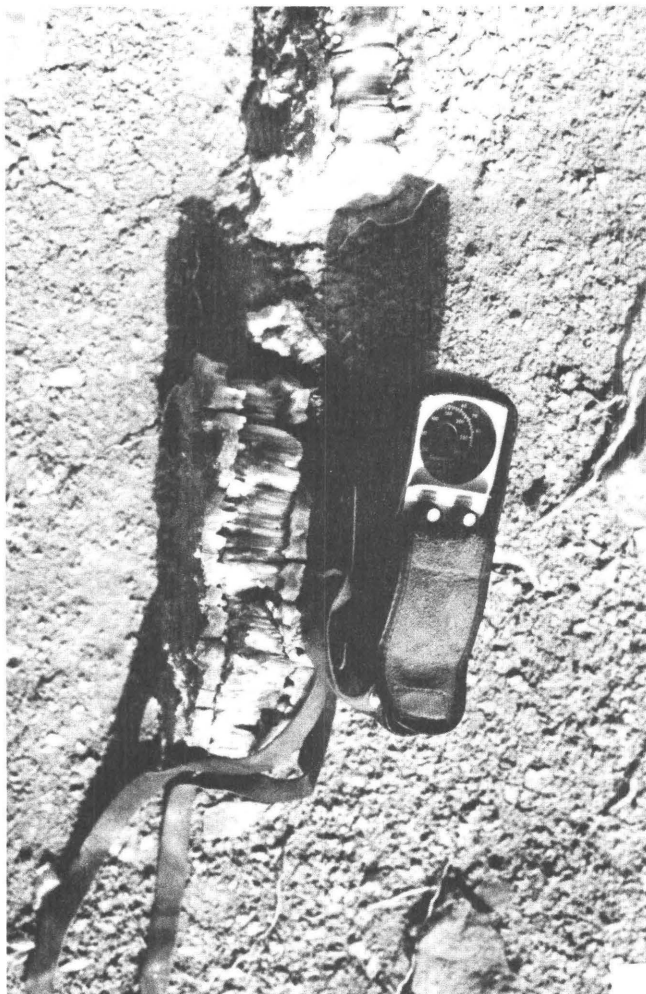


Figure 15. Vein in the Orella Member at Noddings ridge. The center is fibrous gypsum, and marginal layers are chalcedony. Scintillometer is 2.5 in. wide.

precipitation by reduction. Little evidence for carbonaceous material was noted in these rocks, but in either case, the uranium minerals were later altered (and concentrated?) during diagenesis.

Despite Dunham's (1955) reported occurrence of the uranium-vanadium mineral carnotite in the lacustrine facies, a valid correlation between uranium and vanadium could not be established using the data presented in this report (table 2). This lack of correlation, however, does not reflect an association that would probably have occurred in a data set containing only enriched samples. Among the chemical elements, vanadium is most closely allied with copper ($r = +0.51$, table 2), and among the minerals it is most closely related to feldspar ($r = +0.28$, table 2). The significance of its relation to copper is not understood, but its association with feldspar suggests a detrital link.

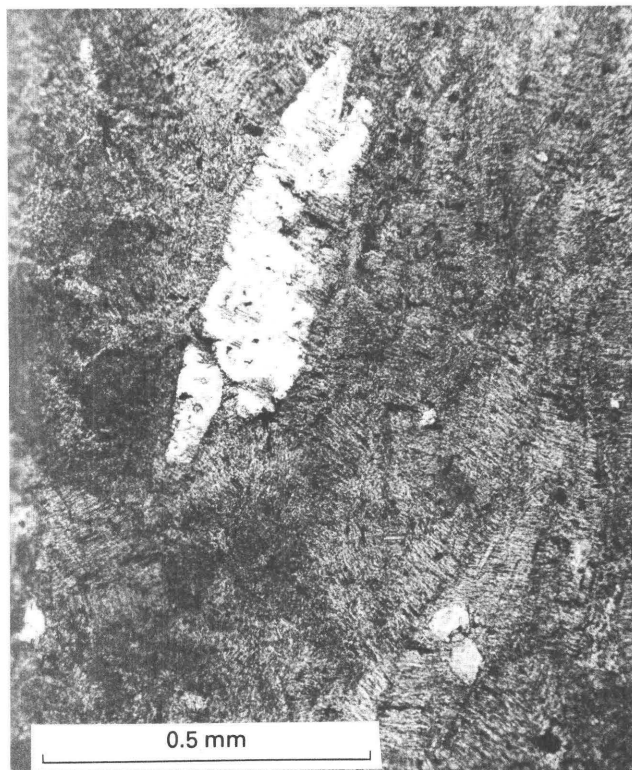


Figure 16. Photomicrograph of thin section of fibrous gypsum (sample 72183-7, fig. 5) with one prismatic crystal replaced by chalcedony. Plane-polarized light.

SUMMARY

1. The diagenetic minerals in the White River Group are mainly smectite, gypsum, opal, calcite, dolomite, quartz, and uranium minerals.

2. Electron micrographs of the White River mudstone and clay show both authigenic and detrital types, but statistical comparison of the clays to detrital minerals and chemical elements related to them indicate that the clays are predominantly of detrital origin.

3. Purplish-white layers in the Chadron Formation lack illite relative to smectite, suggesting that illite was destroyed or altered to smectite, probably during pedogenesis.

4. Enriched uranium at the Noddings ridge deposit is associated with the most evaporitic phases of the lacustrine deposition, but has been oxidized and does not correlate with any of the variables related to the lacustrine evaporitic stage.

5. In the White River Group in the Dawes County, Nebr., area, uranium is correlated with opal, which occurs primarily in the lacustrine limestone subfacies. This uranium has not been enriched.

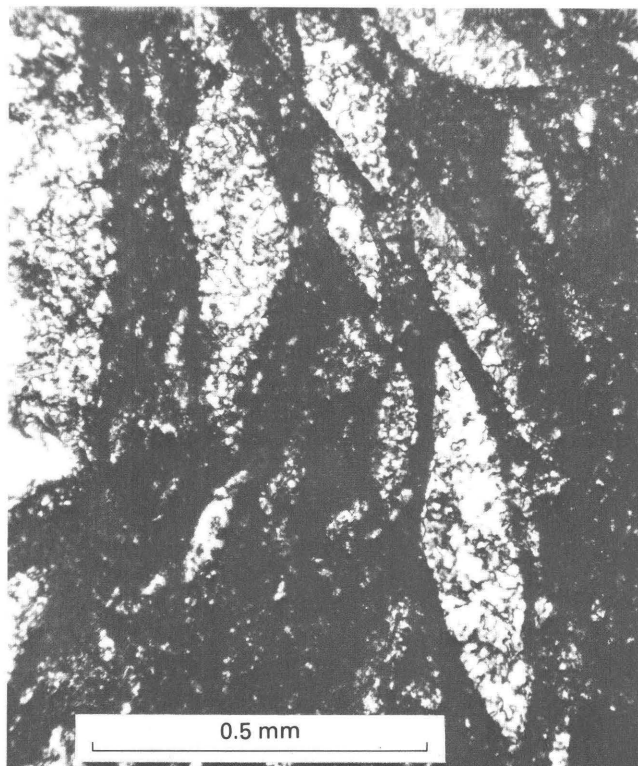


Figure 17. Photomicrograph of thin section of calcareous mudstone from the Chadron Formation(?) about 2 mi southeast of the south end of Noddings ridge, in which interstitial prismatic gypsum crystals have been replaced by opal (sample 81484-1). Plane-polarized light. Sample locality is near center of sec. 24, T. 34 N., R. 47 W.

REFERENCES CITED

- Borchardt, G.A., 1977, Smectite and other smectite minerals, chapter 9 in Dixon, J.B., and Weed, S.B., eds., *Minerals in soil environments*: Madison, Wis., Soil Science Society of America, p. 293–330.
- Burchett, R.R., 1986, *Geologic bedrock map of Nebraska*: Nebraska Geological Survey, scale 1:1,000,000.
- Collings, S.P., and Knode, R.H., 1984, *Geology and discovery of the Crow Butte uranium deposit*, Dawes County, Nebraska: American Institute of Mining Engineers, *Practical Hydromet'83*, 7th Annual Symposium on Uranium and Precious Metals, p. 5–14.
- Crock, J.G., Lichte, F.E., and Briggs, P.H., 1983, Determination of elements in National Bureau of Standards' geological reference materials SRM 278 obsidian and SRM 688 basalt by inductively coupled argon plasma–atomic emission spectrometry: *Geostandards Newsletter*, v. 7, no. 2, p. 335–340.
- Dickinson, K.A., 1988, A preliminary statistical analysis of some chemical and mineralogic data from lacustrine beds in the Oligocene White River Group in Dawes County, Nebraska: U.S. Geological Survey Open-File Report 88–449, 35 p.
- Dunham, R.J., 1955, Uranium minerals in the Oligocene gypsum near Chadron, Dawes County, Nebraska: U.S. Atomic Energy Commission, *Trace Elements Investigations Report* 525, 31 p.
- Fanning, D.S., and Keramidas, V.Z., 1977, Micas, chapter 7 in Dixon, J.B., and Weed, S.B., eds., *Minerals in soil environments*: Madison, Wis., Soil Science Society of America, p. 195–258.
- Gjelsteen, T.W., and Collings, S.P., 1988, Relationship between ground water flow and uranium mineralization in the Chadron Formation, northwest Nebraska: *Wyoming Geological Association Guidebook*, Thirty-ninth Field Conference, p. 271–284.
- Harmon, H.H., 1960, *Modern factor analysis*: Chicago, Ill., University of Chicago Press, 2nd revised ed., 471 p.
- Hintze, J.L., 1987, *Number Cruncher Statistical System*, version 5.01, reference manual: Kaysville, Utah, Jerry L. Hintze, 286 p.
- Jones, J.B., and Segnit, E.R., 1971, The nature of opal, 1—Nomenclature and constituent phases: *Journal of the Geological Society of Australia*, v. 18(1), p. 57–68.
- Kastner, M., Keene, J.B., and Gieskes, M., 1977, Diagenesis of siliceous oozes, 1—Chemical controls on the rate of opal-A to opal-CT transformation—An experimental study: *Geochimica et Cosmochimica Acta*, v. 41, p. 1041–1054.
- Leeder, M.R., 1982, *Sedimentology, process and product*: London, Allen and Unwin, 344 p.
- Mickle, D.G., and Mathews, G.W., 1978, *Geologic characteristics of environments favorable for uranium deposits*: Bendix Field Engineering Corporation, GJBX–67(78), 250 p.
- Millard, D.J., Jr., 1976, Determinations of uranium and thorium in USGS Standard rocks by the delayed-neutron technique: U.S. Geological Survey Professional Paper 840, p. 61–65.
- Schultz, C.B., and Stout, T.M., 1955, Classification of Oligocene sediments in Nebraska: *University of Nebraska State Museum Bulletin*, v. 4, no. 2, p. 17–52.
- Schultz, C.B., Tanner, L.G., and Harvey, Cyril, 1955, Paleosols of the Oligocene of Nebraska: *University of Nebraska State Museum Bulletin*, v. 4, no. 1, 15 p.
- Stanley, K.O., and Benson, L.V., 1979, Early diagenesis of high plains Tertiary vitric and arkosic sandstone, Wyoming and Nebraska: *Society of Economic Paleontologists and Mineralogists Special Publication* 26, p. 401–423.
- Swinehart, J.B., Souders, V.L., DeGraw, H.M., and Diffendal, R.F., Jr., 1985, Cenozoic paleogeography of Western Nebraska, in Flores, R.M., and Kaplan, S.S., eds., *Cenozoic paleogeography of West-Central United States*: Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, 1985, p. 209–229.
- Vondra, C.F., 1958, *The stratigraphy of the Chadron Formation in northwestern Nebraska*: Lincoln, Nebr., University of Nebraska M.S. thesis, 138 p.
- Zielinski, R.A., 1983, Tuffaceous sediments as source rocks for uranium—A case study of the White River Formation, Wyoming: *Journal of Geochemical Exploration*, v. 18, p. 285–306.

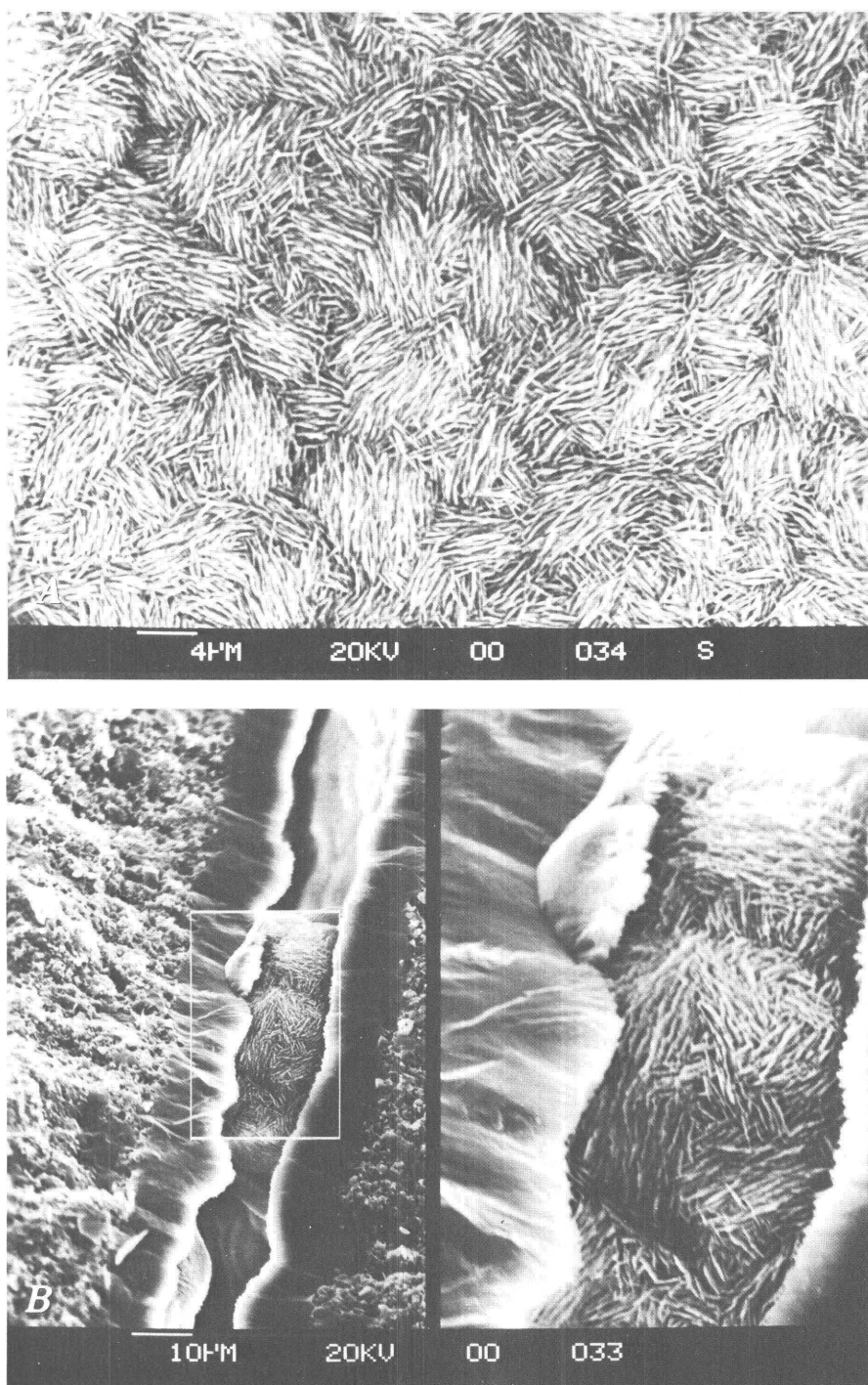


Figure 18. Scanning electron micrographs of siliceous veins in limestone from uppermost part of the Orella (sample 730866, fig. 5). *A*, Texture of opal or chalcedony surface. *B*, Opal or chalcedony in fracture. Bar scale is for left view; outlined portion in left view is magnified three times in right view.

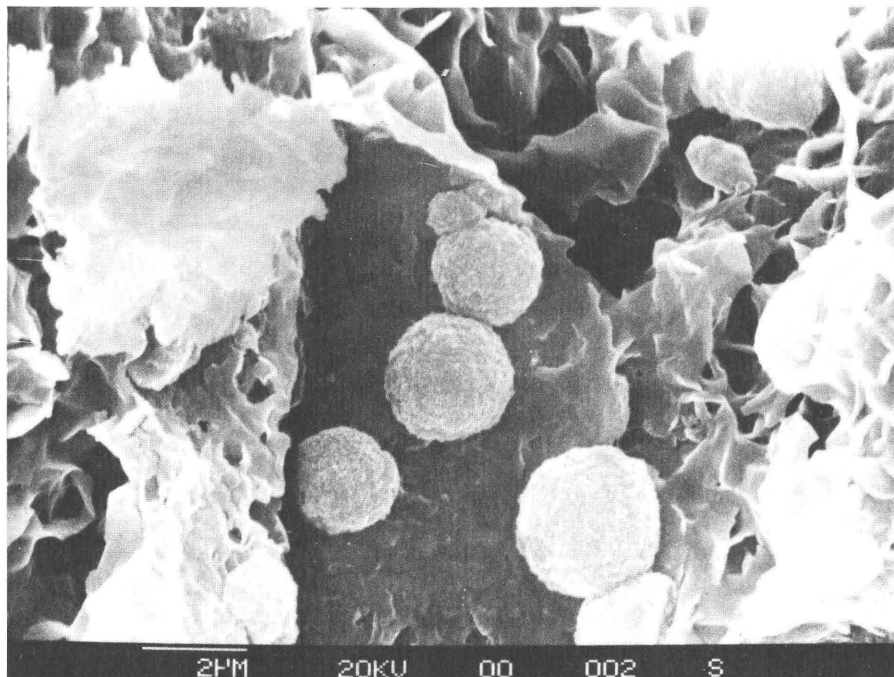


Figure 19. Scanning electron micrograph of air-fall volcanic ash (upper Whitney ash) from Round Top area, about 10 mi west of study area. Reticulated material is authigenic smectite; circular crystalline clusters are opal lepispheres (sample 82885-2).

Appendix. Chemical and Mineralogic Data for Samples of the White River Group, Dawes County, Nebr.

Chemicals are given in ppm (parts per million) or percent as indicated at the top of each column. Minerals are given as XRD peak areas in square inches except for the first set of smectite and illite data, the oriented-mount data, which is given in XRD counts. Asterisks are used where estimated values are substituted for less-than values.

Lab No.	Field No.	Formation	Locality	
D-260774	F71683-3	Brule	S29-R48W-T34N	Isinglass Buttes.
D-260775	F71683-4	Brule	S29-R48W-T34N	Do.
D-260776	F71683-5	Brule	S29-R48W-T34N	Do.
D-260777	F71683-6	Brule	S29-R48W-T34N	Do.
D-260778	F71883-1	Brule	S15-R48W-T34N	Do.
D-260779	F71883-3	Brule	S15-R48W-T34N	Do.
D-260780	F71883-5	Brule	S15-R48W-T34N	Do.
D-260781	F71883-7	Brule	S15-R48W-T34N	Do.
D-260782	F71883-9	Brule	S15-R48W-T34N	Do.
D-260783	F71883-11	Brule	S15-R48W-T34N	Do.
D-260784	F71983-3	Brule	S23-R48W-T34N	Do.
D-260785	F72183-7	Chadron	S3-R47W-T34N	Noddings ridge.
D-260786	F72183-8	Brule	S3-R47W-T34N	Do.
D-260787	F72183-9	Brule	S3-R47W-T34N	Do.
D-260788	F72183-10	Brule	S3-R47W-T34N	Do.
D-260789	F81584-4	Brule	S3-R47W-T34N	Do.
D-260790	F81584-5	Brule	S3-R47W-T34N	Do.
D-260791	F81584-6	Brule	S3-R47W-T34N	Do.
D-260792	F81584-7	Brule	S3-R47W-T34N	Do.
D-260793	F81584-8	Brule	S3-R47W-T34N	Do.
D-278830	F72586-1	Brule	S3-R47W-T34N	Do.
D-278831	F72586-2	Brule	S3-R47W-T34N	Do.
D-278832	F72586-3	Brule	S3-R47W-T34N	Do.
D-278833	F72586-4	Brule	S3-R47W-T34N	Do.
D-278834	F72586-5	Brule	S3-R47W-T34N	Do.
D-278835	F72586-6	Brule	S3-R47W-T34N	Do.
D-278836	F72686-1	Chadron	S36-R50W-T33N	Trunk Butte.
D-278837	F72686-2	Chadron	S36-R50W-T33N	Do.
D-278838	F72686-3	Brule	S36-R50W-T33N	Do.
D-278839	F72686-4	Brule	S36-R50W-T33N	Do.
D-278840	F72686-5	Brule	S36-R50W-T33N	Do.
D-278843	F72886-1	Chadron	S36-R50W-T33N	Do.
D-278844	F72886-2	Chadron	S36-R50W-T33N	Do.
D-279945	F72886-3	Chadron	S36-R50W-T33N	Do.
D-278855	F72886-4	Brule	S36-R50W-T33N	Do.
D-278856	F72886-5	Brule	S36-R50W-T33N	Do.
D-278857	F72886-6	Brule	S36-R50W-T33N	Do.
D-278846	F72886-7	Brule	S36-R50W-T33N	Do.
D-278847	F72886-8	Chadron	S36-R50W-T33N	Do.
D-278848	F72886-9	Chadron	S36-R50W-T33N	Do.
D-278849	F72986-1	Chadron	S15-R47W-T34N	Noddings ridge.
D-278850	F72986-2	Chadron	S15-R47W-T34N	Do.
D-278851	F72986-3	Brule	S15-R47W-T34N	Do.
D-278852	F72986-12	Brule	S10-R47W-T34N	Do.
D-278853	F72986-13	Chadron	S10-R47W-T34N	Do.
D-278854	F72986-14	Chadron	S10-R47W-T34N	Do.

Field No.	Lithology
F71683-3	Limestone, gray, siliceous
F71683-4	Limestone, gray, pure
F71683-5	Clay, pink, pelletal
F71683-6	Sandstone, lt. yellow to gray
F71883-1	Gypsum, lt. brown to gray
F71883-3	Gypsum, lt. yellow to brown
F71883-5	Clay, pink to lt. gray
F71883-7	Gypsum, lt. brown, crystalline
F71883-9	Gypsum, gray, crystalline
F71883-11	Gypsum, gray, crumbly, clayey
F71883-3	Mudstone, gray, noncalcareous
F72183-7	Dolomite, gray, hard (PWL)
F72183-8	Gypsum, gray, hard, clayey
F72183-9	Mudstone, lt. yellow brown
F72183-10	Gypsum, lt. brown, thin-bedded
F81584-4	Siltstone, lt. gray, laminated
F81584-5	Sandstone, lt. brown, fine
F81584-6	Mudstone, lt. yellow-brown
F81584-7	Limestone, lt. brown
F81584-8	Limestone, lt. brown-gray
F72586-1	Mudstone, white, pelletal
F72586-2	Limestone, white, sandy
F72586-3	Mudstone, white, pelletal
F72586-4	Limestone, white to lt. gray
F72586-5	Limestone, white, Mn on fract.
F72586-6	Limestone, white, ashy
F72686-1	Mudstone, buff, pelletal
F72686-2	Mudstone, buff, pelletal
F72686-3	Mudstone, buff, thin-bedded
F72686-4	Limestone, lt. brown, siliceous
F72686-5	Limestone, lt. brown, laminated
F72886-1	Mudstone, white (PWL)
F72886-2	Mudstone, white (PWL)
F72886-3	Mudstone, white (PWL)
F72886-4	Mudstone, brown, pelletal
F72886-5	Mudstone, lt. gray (blue ash)
F72886-6	Mudstone, brown, massive
F72886-7	Mudstone, lt. gray (PWL)
F72886-8	Mudstone, lt. gray, calcareous
F72886-9	Mudstone, lt. gray, calichified
F72986-1	Mudstone, white, pelletal (PWL)
F72986-2	Mudstone, white, pelletal (PWL)
F72986-3	Mudstone, white, crumbly
F72986-12	Mudstone, gray, pelletal (PWL)
F72986-13	Chalcedony, replaced limestone
F72986-14	Mudstone, white (PWL)

Field No.	Uranium (ppm)	Aluminum (pct)	Calcium (pct)	Iron (pct)	Potassium (pct)	Magnesium (pct)	Sodium (pct)
F71683-3	32	0.33	15	0.10	0.15	0.13	0.05
F71683-4	22	2.1	26	.73	.61	.69	.23
F71683-5	15	2.6	24	.74	.46	.89	.16
F71683-6	47	.59	34	.21	.20	.39	.08
F71883-1	5.8	1.4	18	.66	.67	5.1	.16
F71883-3	4.1	.65	21	.33	.45	1.5	.05
F71883-5	19	.45	23	.18	.25	9.0	.11
F71883-7	6.7	.90	20	.41	.39	.41	.07
F71883-9	.94	.60	23	.26	.32	.21	.03
F71883-11	4.6	1.6	19	.80	.89	.55	.08
F71983-3	5.5	7.3	1.4	2.6	1.9	1.8	.96
F72183-7	7.5	3.5	13	1.4	1.4	5.9	.60
F72183-8	8.8	.70	23	.29	.27	.19	.06
F72183-9	3.5	4.8	11	1.3	1.2	1.2	.65
F72183-10	41	.31	13	.12	.12	.09	.02
F81584-4	5.1	6.8	3.2	2.8	1.9	1.5	.95
F81584-5	4.3	5.3	4.5	2.0	1.8	.67	1.2
F81584-6	5.9	7.0	1.5	3.3	2.2	1.5	.77
F81584-7	11	1.8	19	.89	.68	.67	.21
F81584-8	9.6	.30	24	.13	.10	.29	.05
F72586-1	2.6	3.8	22	1.3	1.1	.89	.50
F72586-2	10	2.4	19	1.2	.94	.82	.23
F72586-3	6.3	5.5	13	1.2	2.0	1.2	.77
F72586-4	8.3	.37	27	.15	.15	.35	.05
F72586-5	2.9	.25	40	.13	.07	.38	.05
F72586-6	9.1	5.0	14	.39	2.7	.42	1.3
F72686-1	3.9	6.6	5.4	2.2	2.1	.95	1.4
F72686-2	7.0	5.6	8.5	1.3	2.0	.60	1.5
F72686-3	7.1	2.1	14	.72	.45	.48	.36
F72686-4	16	.79	16	.32	.27	.26	.16
F72686-5	5.9	.58	33	.22	.22	.36	.17
F72886-1	4.2	6.0	11	1.8	1.7	.98	1.0
F72886-2	6.2	6.6	3.7	1.6	2.2	.81	1.5
F72886-3	7.3	6.7	3.6	2.0	2.3	.87	1.6
F72886-4	2.4	6.5	8.4	2.5	1.8	1.3	1.0
F72886-5	4.1	7.6	5.6	1.8	1.7	1.1	1.7
F72886-6	3.2	6.9	1.3	2.9	2.2	1.2	1.1
F72886-7	5.2	6.9	1.7	1.9	2.0	.99	1.4
F72886-8	8.1	6.4	3.3	1.9	2.0	.99	1.3
F72886-9	4.6	7.7	1.0	2.8	2.3	1.3	1.2
F72986-1	3.5	7.7	1.3	2.6	2.2	1.3	1.1
F72986-2	6.0	5.7	8.5	1.3	2.1	.79	1.2
F72986-3	3.7	6.2	7.3	1.9	1.8	1.1	1.1
F72986-12	7.7	6.3	5.1	1.4	2.7	.60	1.7
F72986-13	15	.41	2.4	.12	.16	.09	.06
F72986-14	6.4	5.0	9.1	.84	1.5	.80	.85
Average	9.27	3.80	13.5	1.21	1.23	1.17	.669
Std. Dev.	9.29	2.73	9.85	.915	.853	1.57	.565

Field No.	Manganese (ppm)	Phosph. (pct)	Titanium (pct)	Barium (ppm)	Copper (ppm)	Lithium (ppm)	Strontium (ppm)
F71683-3	2,100	0.06	0.01	55	2.0	2.0	160
F71683-4	2,900	.34	.08	410	8.0	12	550
F71683-5	2,000	.04	.08	110	9.0	12	420
F71683-6	2,800	.03	.03	95	4.0	4.0	410
F71883-1	1,200	.04	.07	140	13	19	1,500
F71883-3	330	.03	.03	67	4.0	7.0	2,200
F71883-5	3,000	.08	.02	82	15	9.0	1,200
F71883-7	63	.01	.04	65	5.0	14	4,100
F71883-9	39	.05	.03	59	2.0	7.0	1,900
F71883-11	120	.03	.08	76	7.0	21	2,600
F71983-3	150	.08	.31	630	19	47	310
F72183-7	3,300	.05	.15	350	7.0	32	430
F72183-8	45	.01	.03	54	4.0	5.0	1,900
F72183-9	93	.05	.18	210	7.0	22	620
F72183-10	71	.01	.01	41	.75*	3.0	7,100
F81584-4	420	.07	.29	610	21	49	410
F81584-5	630	.08	.27	790	11.0	22	350
F81584-6	340	.04	.36	560	22.0	45	340
F81584-7	1,300	.05	.10	220	3.0	23	390
F81584-8	940	.04	.01	130	1.0	4.0	340
F72586-1	3,200	.11	.13	3,300	15.0	28	420
F72586-2	1,300	.05	.11	360	12	31	400
F72586-3	1,300	.06	.12	5,100	12	43	340
F72586-4	1,400	.05	.02	170	13	6.0	290
F72586-5	2,300	.03	.01	130	.75*	4.0	340
F72586-6	1,900	.02	.06	750	6.0	10	150
F72686-1	690	.03	.27	790	15	29	390
F72686-2	1,100	.26	.09	370	6.0	17	280
F72686-3	1,300	.37	.06	140	27	18	280
F72686-4	1,200	.03	.03	1,900	7.0	9.0	320
F72686-5	2,300	.03	.02	79	2.0	6.0	400
F72886-1	1,100	.08	.15	460	16	39	380
F72886-2	590	.02	.15	380	35	27	260
F72886-3	630	.07	.13	340	8.0	33	280
F72886-4	990	.06	.20	430	20	53	340
F72886-5	920	.08	.34	830	7.0	15	350
F72886-6	270	.08	.29	750	30	50	570
F72886-7	360	.02	.16	340	15	31	280
F72886-8	450	.37	.11	350	56	33	300
F72886-9	310	.01	.29	660	23	54	340
F72986-1	340	.02	.31	590	22	62	340
F72986-2	1,500	.07	.10	650	9.0	22	280
F72986-3	1,200	.07	.15	330	14	35	320
F72986-12	1,100	.19	.13	360	8.0	21	260
F72986-13	380	.03	.02	110	10	4.0	210
F72986-14	1,600	.28	.08	190	1.0	15	320
Average	1,120	.080	.124	535	12.1	22.9	775
Std. Dev.	911	.092	.102	868	10.4	16.1	1,210

Field No.	SiO ₂ (pct)	Al ₂ O ₃ (pct)	Fe ₂ O ₃ (pct)	MgO (pct)	CaO (pct)	Na ₂ O (pct)	K ₂ O (pct)
F71683-3	64	0.73	0.08	0.26	19	0.11	0.15
F71683-4	28	3.9	.95	1.2	35	.35	.68
F71683-5	31	4.8	.95	1.4	33	.25	.51
F71683-6	14	1.1	.21	.69	47	.11	.21
F71883-1	21	2.5	.85	8.1	24	.22	.72
F71883-3	13	1.1	.39	2.3	29	.11	.51
F71883-5	3.7	.78	.19	16	31	.20	.26
F71883-7	19	17	.50	.65	26	.11	.44
F71883-9	7.5	.98	.28	.40	31	.11	.33
F71883-11	20	2.7	.96	.82	25	.15	.94
F71983-3	64	14	3.6	3.0	1.8	1.4	2.4
F72183-7	30	6.2	1.9	10	18	.78	1.5
F72183-8	8.6	1.2	.31	.35	30	.11	.28
F72183-9	40	8.8	1.7	1.9	14	.89	1.5
F72183-10	48	.64	.13	.18	17	.11	.13
F81584-4	62	13	3.8	2.5	4.3	1.3	2.4
F81584-5	68	10	2.7	1.1	5.9	1.7	2.2
F81584-6	63	14	4.7	2.6	2.0	1.1	2.8
F81584-7	47	3.3	1.1	1.1	25	.29	.74
F81584-8	42	.63	.12	.51	31	.11	.10
F72586-1	29	6.4	1.7	1.4	30	.62	1.2
F72586-2	43	4.1	1.6	1.3	25	.35	1.0
F72586-3	44	9.3	1.7	1.9	17	.91	2.2
F72586-4	33	.74	.13	.59	36	.11	.15
F72586-5	2.9	.47	.10	.67	54	.11	.08
F72586-6	47	8.6	.49	.70	19	1.5	3.1
F72686-1	59	12	3.2	1.6	7.3	1.6	2.5
F72686-2	56	9.4	1.8	1.0	12	1.8	2.4
F72686-3	56	3.7	.93	.77	18	.40	.48
F72686-4	59	1.6	.36	.43	20	.11	.28
F72686-5	19	1.0	.22	.61	44	.21	.20
F72886-1	48	10	2.6	1.6	15	1.1	2.0
F72886-2	63	12	2.3	1.3	5.0	1.9	2.7
F72886-3	62	12	2.7	1.4	4.9	1.9	2.8
F72886-4	51	11	3.6	2.0	11	1.2	2.1
F72886-5	54	14	2.6	1.8	7.6	2.2	2.0
F72886-6	65	12	4.1	1.9	1.7	1.4	2.6
F72886-7	66	12	2.7	1.7	2.2	1.8	2.4
F72886-8	62	12	2.9	1.6	4.5	1.4	2.6
F72886-9	63	14	3.9	2.1	1.3	1.5	2.8
F72986-1	64	14	3.7	2.2	1.6	1.4	2.6
F72986-2	56	9.8	1.7	1.3	11	1.4	2.4
F72986-3	55	11	2.6	1.8	9.7	1.4	2.0
F72986-12	61	11	2.0	.98	6.8	2.1	3.3
F72986-13	90	1.5	.09	.02	3.1	.11	.16
F72986-14	57	8.6	1.1	1.3	12	.95	1.7
Average	44.7	6.84	1.66	1.94	18.0	.844	1.44
Std. Dev.	20.6	4.92	1.32	2.76	13.2	.680	1.04

Field No.	TiO ₂	P ₂ O ₅	MnO	V	Smectite 001 peak	Illite 001 peak
	(pct)	(pct)	(ppm)	(ppm)	(counts)	(counts)
F71683-3	0.01	0.13	0.26	16	92	27
F71683-4	.12	.74	.37	29	320	25
F71683-5	.11	.11	.25	29	0.0	0.0
F71683-6	.01	.07	.34	37	0.0	0.0
F71883-1	.09	.10	.14	27	380	140
F71883-3	.02	.07	.02	21	0.0	0.0
F71883-5	.01	.17	.36	40	68	29
F71883-7	.04	.04	.01	18	440	86
F71883-9	.01	.11	.01	20	190	55
F71883-11	.10	.07	.01	18	140	79
F71983-3	.56	.19	.01	8.7	630	55
F71183-7	.24	.12	.44	27	77	29
F72183-8	.02	.04	.04	20	720	140
F72183-9	.30	.11	.01	14	800	58
F72183-10	.01	.04	.01	12	350	38
F81584-4	.50	.17	.05	9.9	480	39
F81584-5	.49	.21	.08	6.7	760	44
F81584-6	.63	.10	.04	9.4	430	40
F81584-7	.13	.11	.16	22	57	17
F81584-8	.01	.09	.10	25	57	0.0
F72586-1	.21	.23	.40	28	44	0.0
F72586-2	.18	.12	.16	24	71	32
F72586-3	.22	.13	.16	21	350	27
F72586-4	.01	.11	.16	29	21	38
F72586-5	.01	.07	.27	42	100	22
F72586-6	.09	.04	.25	19	560	26
F72686-1	.47	.06	.08	13	200	37
F72686-2	.16	.55	.14	15	950	35
F72686-3	.09	.74	.16	19	720	86
F72686-4	.03	.06	.13	18	50	43
F72686-5	.01	.06	.27	35	110	47
F72886-1	.30	.18	.14	18	410	0.0
F72886-2	.26	.04	.07	11	1,000	12
F72886-3	.23	.14	.08	11	1,200	0.0
F72886-4	.41	.14	.12	17	2,400	18
F72886-5	.63	.21	.12	15	1,100	0.0
F72886-6	.56	.19	.03	9.5	92	110
F72886-7	.27	.04	.04	11	2,000	0.0
F72886-8	.26	.87	.05	11	300	10
F72886-9	.52	.04	.03	11	960	40
F72986-1	.56	.04	.04	10	900	47
F72986-2	.19	.15	.19	15	1,600	0.0
F72986-3	.30	.16	.16	15	1,400	22
F72986-12	.22	.39	.14	11	300	35
F72986-13	.01	.05	.04	4.0	0.0	0.0
F72986-14	.12	.58	.20	16	1,100	0.0
Average	.213	.177	.138	18.6	518	34.5
Std. Dev.	.194	.197	.114	8.78	543	34.2

Field No.	Dolo. (in. ²)	Calc. (in. ²)	Feld. (in. ²)	Quar. (in. ²)	Opal (in. ²)	Gyp. (in. ²)	Ill. (in. ²)	Smectite (in. ²)
F71683-3	0.0	1.1	0.0	1.1	0.39	0.0	0.0	0.0
F71683-4	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0
F71683-5	0.0	1.1	0.0	.50	.31	0.0	0.0	.19
F71683-6	0.0	1.5	0.0	.06	.15	0.0	0.0	0.0
F71883-1	1.1	0.0	.03	.34	0.0	.61	0.0	0.0
F71883-3	.51	0.0	0.0	.21	0.0	1.2	0.0	0.0
F71883-5	1.4	0.0	.03	.07	0.0	.26	0.0	0.0
F71883-7	.39	0.0	.06	.30	0.0	.89	0.0	.02
F71883-9	.35	0.0	0.0	.08	0.0	1.2	0.0	.03
F71883-11	.32	0.0	0.0	.22	0.0	1.2	0.0	.01
F71983-3	0.0	0.0	.23	.75	0.0	.02	0.0	.03
F72183-7	1.2	0.0	.08	.26	0.0	.19	0.0	0.0
F72183-8	.94	0.0	.06	.10	0.0	1.1	0.0	.30
F72183-9	.20	0.0	.46	.58	0.0	.75	.05	.21
F72183-10	.26	0.0	0.0	1.5	0.0	1.0	0.0	.01
F81584-4	0.0	.1	.27	.58	0.0	0.0	.07	.38
F81584-5	0.0	.3	1.00	.23	0.0	0.0	.03	.14
F81584-6	0.0	0.0	.20	.48	0.0	0.0	.05	.25
F81584-7	0.0	1.0	.07	.32	.39	0.0	0.0	0.0
F81584-8	0.0	1.1	0.0	.73	.33	0.0	0.0	0.0
F72586-1	0.0	1.1	0.0	.22	0.0	0.0	0.0	.10
F72586-2	0.0	.96	0.0	.22	.26	0.0	0.0	0.0
F72586-3	0.0	.79	.07	.11	0.00	0.0	0.0	.23
F72586-4	0.0	1.4	0.0	.53	.23	0.0	0.0	0.0
F72586-5	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0
F72586-6	0.0	1.00	0.0	0.0	0.0	0.0	0.0	.09
F72686-1	0.0	.30	.18	.23	0.0	0.0	.03	.07
F72686-2	0.0	.60	.40	.18	0.0	0.0	0.0	.11
F72686-3	0.0	.74	0.0	.10	1.3	0.0	0.0	0.0
F72686-4	0.0	.96	0.0	.99	.46	0.0	0.0	0.0
F72686-5	0.0	1.2	0.0	0.0	.21	0.0	0.0	0.0
F72886-1	0.0	.61	.13	.24	0.0	0.0	0.0	.25
F72886-2	0.0	.23	.16	.26	0.0	0.0	0.0	.26
F72886-3	0.0	.17	.17	.15	0.0	0.0	0.0	.14
F72886-4	0.0	.54	.33	.29	0.0	0.0	.02	.19
F72886-5	0.0	.42	.06	.05	0.0	0.0	0.0	.31
F72886-6	0.0	0.0	.20	.53	0.0	0.0	0.0	0.0
F72886-7	0.0	.05	.12	.17	0.0	0.0	0.0	.24
F72886-8	0.0	.08	.08	.21	0.0	0.0	0.0	.26
F72886-9	0.0	0.0	.26	.45	0.0	0.0	.04	.17
F72986-1	0.0	0.0	.21	.50	0.0	0.0	0.0	.25
F72986-2	0.0	.64	.07	.17	0.0	0.0	0.0	.23
F72986-3	0.0	.29	.14	.22	0.0	0.0	.02	.11
F72986-12	0.0	.51	.15	.30	0.0	0.0	0.0	.24
F72986-13	0.0	.16	0.0	1.8	.65	0.0	0.0	0.0
F72986-14	0.0	.55	.03	.08	0.0	0.0	0.0	.22
Average	.145	.478	.114	.355	.101	.183	.007	.110
Std. Dev.	.340	.479	.174	.365	.232	.386	.016	.115

SELECTED SERIES OF U.S. GEOLOGICAL SURVEY PUBLICATIONS

Periodicals

Earthquakes & Volcanoes (issued bimonthly).

Preliminary Determination of Epicenters (issued monthly).

Technical Books and Reports

Professional Papers are mainly comprehensive scientific reports of wide and lasting interest and importance to professional scientists and engineers. Included are reports on the results of resource studies and of topographic, hydrologic, and geologic investigations. They also include collections of related papers addressing different aspects of a single scientific topic.

Bulletins contain significant data and interpretations that are of lasting scientific interest but are generally more limited in scope or geographic coverage than Professional Papers. They include the results of resource studies and of geologic and topographic investigations; as well as collections of short papers related to a specific topic.

Water-Supply Papers are comprehensive reports that present significant interpretive results of hydrologic investigations of wide interest to professional geologists, hydrologists, and engineers. The series covers investigations in all phases of hydrology, including hydrogeology, availability of water, quality of water, and use of water.

Circulars present administrative information or important scientific information of wide popular interest in a format designed for distribution at no cost to the public. Information is usually of short-term interest.

Water-Resources Investigations Reports are papers of an interpretive nature made available to the public outside the formal USGS publications series. Copies are reproduced on request unlike formal USGS publications, and they are also available for public inspection at depositories indicated in USGS catalogs.

Open-File Reports include unpublished manuscript reports, maps, and other material that are made available for public consultation at depositories. They are a nonpermanent form of publication that may be cited in other publications as sources of information.

Maps

Geologic Quadrangle Maps are multicolor geologic maps on topographic bases in 7 1/2- or 15-minute quadrangle formats (scales mainly 1:24,000 or 1:62,500) showing bedrock, surficial, or engineering geology. Maps generally include brief texts; some maps include structure and columnar sections only.

Geophysical Investigations Maps are on topographic or planimetric bases at various scales; they show results of surveys using geophysical techniques, such as gravity, magnetic, seismic, or radioactivity, which reflect subsurface structures that are of economic or geologic significance. Many maps include correlations with the geology.

Miscellaneous Investigations Series Maps are on planimetric or topographic bases of regular and irregular areas at various scales; they present a wide variety of format and subject matter. The series also includes 7 1/2-minute quadrangle photogeologic maps on planimetric bases which show geology as interpreted from aerial photographs. Series also includes maps of Mars and the Moon.

Coal Investigations Maps are geologic maps on topographic or planimetric bases at various scales showing bedrock or surficial geology, stratigraphy, and structural relations in certain coal-resource areas.

Oil and Gas Investigations Charts show stratigraphic information for certain oil and gas fields and other areas having petroleum potential.

Miscellaneous Field Studies Maps are multicolor or black-and-white maps on topographic or planimetric bases on quadrangle or irregular areas at various scales. Pre-1971 maps show bedrock geology in relation to specific mining or mineral-deposit problems; post-1971 maps are primarily black-and-white maps on various subjects such as environmental studies or wilderness mineral investigations.

Hydrologic Investigations Atlases are multicolored or black-and-white maps on topographic or planimetric bases presenting a wide range of geohydrologic data of both regular and irregular areas; principal scale is 1:24,000 and regional studies are at 1:250,000 scale or smaller.

Catalogs

Permanent catalogs, as well as some others, giving comprehensive listings of U.S. Geological Survey publications are available under the conditions indicated below from the U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225. (See latest Price and Availability List.)

"**Publications of the Geological Survey, 1879- 1961**" may be purchased by mail and over the counter in paperback book form and as a set of microfiche.

"**Publications of the Geological Survey, 1962- 1970**" may be purchased by mail and over the counter in paperback book form and as a set of microfiche.

"**Publications of the U.S. Geological Survey, 1971- 1981**" may be purchased by mail and over the counter in paperback book form (two volumes, publications listing and index) and as a set of microfiche.

Supplements for 1982, 1983, 1984, 1985, 1986, and for subsequent years since the last permanent catalog may be purchased by mail and over the counter in paperback book form.

State catalogs, "List of U.S. Geological Survey Geologic and Water-Supply Reports and Maps For (State)," may be purchased by mail and over the counter in paperback booklet form only.

"**Price and Availability List of U.S. Geological Survey Publications**," issued annually, is available free of charge in paperback booklet form only.

Selected copies of a monthly catalog "New Publications of the U.S. Geological Survey" available free of charge by mail or may be obtained over the counter in paperback booklet form only. Those wishing a free subscription to the monthly catalog "New Publications of the U.S. Geological Survey" should write to the U.S. Geological Survey, 582 National Center, Reston, VA 22092.

Note.--Prices of Government publications listed in older catalogs, announcements, and publications may be incorrect. Therefore, the prices charged may differ from the prices in catalogs, announcements, and publications.

