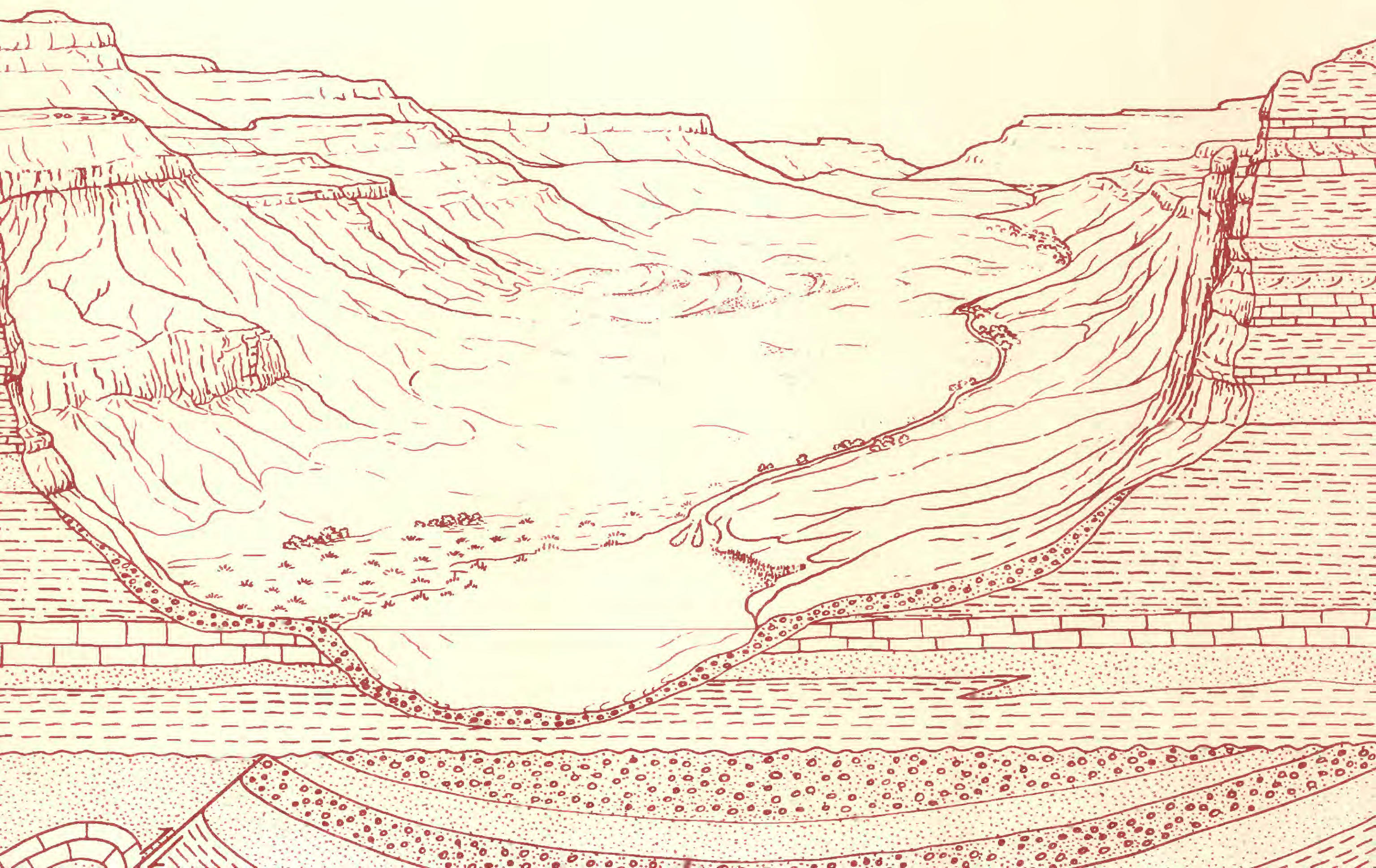
Upper Devonian to Upper Mississippian Strata of the Antler Foreland in the Leppy Hills, Easternmost Northern Nevada

U.S. GEOLOGICAL SURVEY BULLETIN 1988–G



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 may be listed in various U.S. Geological Survey catalogs **(see back inside cover)** but not listed in the most recent annual "Price and Availability List" may no longer be available.

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 listed 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, Map Distribution
Box 25286, MS 306, Federal Center
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, DC 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
Box 25286, Bldg. 810, Federal Center
Denver, CO 80225

Residents of Alaska may order maps from

U.S. Geological Survey, Earth Science Information Center
101 Twelfth Ave., Box 12
Fairbanks, AK 99701

OVER THE COUNTER

Books and Maps

Books and maps of the U.S. Geological Survey are available over the counter at the following U.S. Geological Survey offices, all of which are authorized agents of the Superintendent of Documents.

- **ANCHORAGE, Alaska**–Rm. 101, 4230 University Dr.
- **LAKEWOOD, Colorado**–Federal Center, Bldg. 810
- **MENLO PARK, California**–Bldg. 3, Rm. 3128, 345 Middlefield Rd.
- **RESTON, Virginia**–USGS National Center, Rm. 1C402, 12201 Sunrise Valley Dr.
- **SALT LAKE CITY, Utah**–Federal Bldg., Rm. 8105, 125 South State St.
- **SPOKANE, Washington**–U.S. Post Office Bldg., Rm. 135, West 904 Riverside Ave.
- **WASHINGTON, D.C.**–Main Interior Bldg., Rm. 2650, 18th and C Sts., NW.

Maps Only

Maps may be purchased over the counter at the following U.S. Geological Survey offices:

- **FAIRBANKS, Alaska**–New Federal Bldg, 101 Twelfth Ave.
- **ROLLA, Missouri**–1400 Independence Rd.
- **STENNIS SPACE CENTER, Mississippi**–Bldg. 3101

Upper Devonian to Upper Mississippian Strata of the Antler Foreland in the Leppy Hills, Easternmost Northern Nevada

By K.M. Nichols *and* N.J. Silberling

EVOLUTION OF SEDIMENTARY BASINS—EASTERN GREAT BASIN
Harry E. Cook and Christopher J. Potter, Project Coordinators

U.S. GEOLOGICAL SURVEY BULLETIN 1988–G

A multidisciplinary approach to research studies of sedimentary rocks and their constituents and the evolution of sedimentary basins, both ancient and modern

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1993

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

Robert M. Hirsch, Acting Director

For sale by
USGS Map Distribution
Box 25286, Building 810
Denver Federal Center
Denver, CO 80225

Library of Congress Cataloging-in-Publication Data

Nichols, K.M. (Kathryn Marion), 1946–
Upper Devonian to Upper Mississippian strata of the Antler foreland in the Leppy Hills, easternmost northern Nevada / by K.M. Nichols and N.J. Silberling.
p. cm. — (Evolution of sedimentary basins—Eastern Great Basin ; ch. G) (U.S. Geological Survey bulletin ; 1988)
Includes bibliographical references.
Supt. of Docs. no.: I 19.3:1988–G
1. Geology, Stratigraphic—Devonian. 2. Geology, Stratigraphic—Mississippian. 3. Geology—Nevada—Leppy Hills Region.
I. Silberling, N.J. (Norman John), 1928– . II. Title. III. Series. IV. Series: U.S. Geological Survey bulletin ; 1988.
QE75.B9 no. 2023–G
[QE665]
557.3 s—dc20 93–10960
[551.7′4′09793] CIP

CONTENTS

Abstract G1
Introduction 1
Stratigraphy 2
  Pilot Shale 2
  Joana Limestone 5
  Needle Siltstone Member of the Chainman Shale 9
Structure 10
Paleotectonic Implications 11
References Cited 13

FIGURES

1–3. Maps showing:
  1. Location of Leppy Hills area G2
  2. Location of Leppy Hills and other localities referred to in text 3
  3. Topography of part of Leppy Hills area and locations of sections A and B 4
4. Photographs of section A, upper A–1 Canyon 5
5, 6. Columnar sections:
  5. Section A 6
  6. Section B 7
7. Photograph of characteristic outcrop of dolomitic siltstone of Pilot Shale 7
8. Photomicrographs of dolomitic siltstone of Pilot Shale 8
9–15. Photographs of:
  9. Limestone bed displaying Bouma-sequence layering, Pilot Shale 8
  10. Limestone bed displaying Bouma-sequence layering, Pilot Shale 8
  11. Carbonate-cemented siltstone showing plane-bed lamination, Pilot Shale 9
  12. Dolomitic siltstone showing possible hummocky cross stratification, Pilot Shale 9
  13. Local angular discordance at faulted contact between Joana Limestone and Pilot Shale 9
  14. Concordant but faulted contact between Joana Limestone and Pilot Shale 10
  15. Nodular cherty limestone, basal part of Joana Limestone 10
16. Photomicrograph of bioclastic wackestone, lower unit of Joana Limestone 10
17. Photograph showing crinoid-rich stringers in peloidal packstone, middle unit of Joana Limestone 11
18. Photomicrographs of peloidal bioclastic packstone, middle unit of Joana Limestone 11
19, 20. Photographs of:
  19. Oncolites near top of Joana Limestone 12
  20. Solution-compacted bioclastic wackestone near top of Joana Limestone 12
21. Photomicrograph of solution-compacted limestone in uppermost part of Joana Limestone 12
22. Photograph of contact between Joana Limestone and Needle Siltstone Member of the Chainman Shale 12

Upper Devonian to Upper Mississippian Strata of the Antler Foreland in the Leppy Hills, Easternmost Northern Nevada

By K.M. Nichols *and* N.J. Silberling

ABSTRACT

Upper Devonian to Upper Mississippian strata in the Leppy Hills, easternmost northern Nevada, represent, in ascending order, rock units whose formal names, albeit somewhat misleading, are the Guilmette Formation, Pilot Shale, Joana Limestone, and Needle Siltstone Member of the Chainman Shale. In the Leppy Hills study area, both the upper and lower contacts of the Pilot Shale are bedding-subparallel, attenuational faults; other such faults may be present within the Pilot and also could be present between the Needle Siltstone Member and higher parts of the Chainman Shale.

The Pilot Shale in the study area closely resembles the lower part of the Pilot elsewhere in the eastern Great Basin and is mostly laminated, secondarily dolomitic siltstone that includes a distinctive interval of intercalated Bouma-sequence limestone. Strata of the Pilot Shale can be interpreted as storm deposits formed on the ramp of a restricted intrashelf subsident area.

The Joana Limestone in the Leppy Hills study area is anomalously thin and probably correlates with only the basal part of the Joana, as this name is applied, in ranges farther to the south. In the Leppy Hills the Joana is disconformably overlain by dolomitic siltstone of the Needle Siltstone Member whose character reflects sedimentation during the Delle phosphatic event.

The relatively weak lithic expression of the onset of the Delle phosphatic event in the Leppy Hills study area, and the evidently greater age of the uppermost part of the Joana Limestone here, as compared with sections in west-central Utah, is of significance for interpreting the flexural-loading paleotectonics of the Antler foreland. In the Leppy Hills study area a distinct disconformity separates the Needle Siltstone Member, the base of which corresponds to the advent of the Delle phosphatic event, from the Joana Limestone. Mississippian strata in this area may therefore record deposition on the previously hypothesized Antler foreland bulge. The existence of such a feature has been called upon to explain the peculiar anoxic nature of strata formed farther to the east, in the backbulge region of the foreland, under the influence of the Delle phosphatic event.

INTRODUCTION

The Upper Devonian to Upper Mississippian section in the Leppy Hills, just north of the town of Wendover on the Nevada-Utah State line (fig. 1), provides a strategically located reference point for regional interpretation of the depositional history of the Antler foreland in the eastern Great Basin. Exposures of these rocks are the northernmost of the succession that is characteristic of the Antler foreland for several hundred kilometers to the south in easternmost Nevada and westernmost Utah. This succession includes, in ascending order, the Pilot Shale, limestones collectively referred to the Joana Limestone, and the Needle Siltstone Member forming the basal part of the Chainman Shale.[1] Although the Pilot through Needle succession in the Leppy Hills is incomplete owing to bedding-subparallel, attenuational faulting, as described later, the contact of the Needle Siltstone Member with the underlying Joana Limestone is disconformable, preserving a weak, but incontrovertible record of the onset of the Delle phosphatic event (Silberling and Nichols, 1990, 1991), the effects of which are best represented at localities in west-central Utah such as the Lakeside Mountains (fig. 2) (Sandberg and Gutschick, 1984; Nichols and Silberling, 1990). This disconformable contact provides a datum that allows the unusually thin Joana Limestone in the Leppy Hills to be contrasted with the much thicker sections of Lower Mississippian pre-Delle phosphatic

[1]Note that although the term "shale" is used as part of the regional name for both the Pilot Shale and the Chainman Shale, this lithic identification is not descriptive of the specific parts of these units discussed in this report.

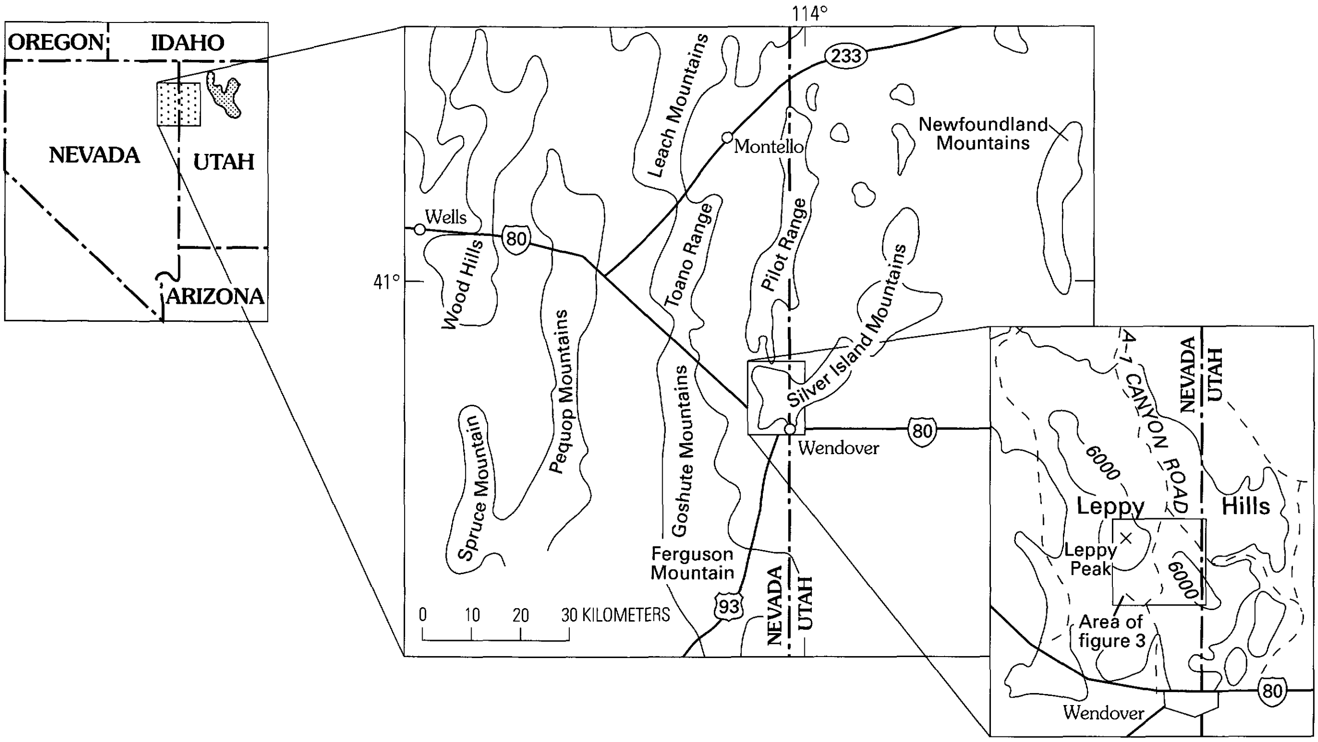


Figure 1. Index map of northeastern Nevada and northwestern Utah showing the location of the Leppy Hills area. Modified from Schneyer (1984).

event limestone farther to the south and east in Nevada and Utah. Consequently, the Leppy Hills section has an important bearing on regional paleogeography and the applicability of flexural-loading models to explain the shifting pattern of uplift and subsidence in the late Paleozoic Antler foreland.

STRATIGRAPHY

Parts of the Pilot Shale, Joana Limestone, and Needle Siltstone Member and younger members of the Chainman Shale are fairly well exposed near the head of A-1 Canyon in the Leppy Hills. Much of the section was measured twice on adjacent minor spurs on the west side of the canyon in order to place the discontinuous exposures in the same stratigraphic context. The northern and southern of these parallel sections are designated respectively sections A and B; their locations are shown on figure 3, and the nature of the exposures at section A is shown in figure 4.

PILOT SHALE

The areal distribution of the rocks assigned to the Pilot Shale in the study area is shown on the map of the Leppy Hills by Schneyer (1990), who interpreted the contact between the Pilot and underlying Guilmette Formation in the headwaters of A-1 Canyon as a bedding-subparallel, attenuational fault marked by a zone of brecciation and silicification. Although the amount of missing section is unknown, the youngest limestone beds of the Guilmette here are thin-parted, mottled, pelletal-skeletal packstone containing abundant open-marine bioclasts such as echinoderm ossicles. These limestones lithically resemble those, in sections farther to the south in easternmost Nevada and westernmost Utah, that either constitute a distinctive rock unit forming the uppermost part of the Guilmette or are recognized as a separate formation—the West Range Limestone—intervening between the Guilmette and Pilot. Because of this and because of the nature of the older part of the Pilot in A-1 Canyon, as described later, the thickness of omitted strata is probably not great.

The upper contact of the Pilot Shale with the overlying Joana Limestone is also a bedding-subparallel fault, as shown by the omission of at least a few meters of the basal part of the Joana along strike between sections A and B (figs. 5, 6). The amount of the Pilot cut out on this fault is unknown. The several-meter difference in thickness of the limestone-rich and higher parts of the Pilot between sections A and B, which are only about 200 m apart, could be attributed to attenuation on this fault or others within poorly exposed parts of the Pilot section, or it could simply reflect the imprecision in section

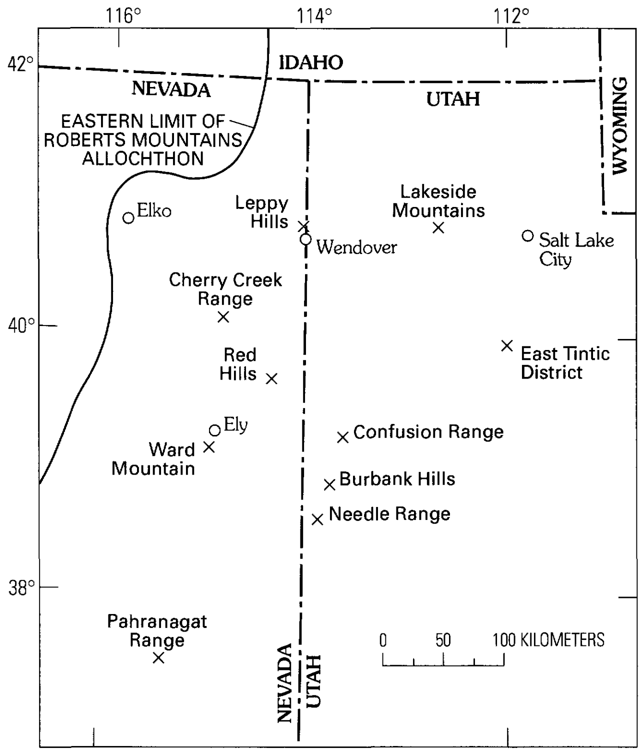


Figure 2. Map of eastern Nevada and western Utah showing the location of the Leppy Hills and other localities referred to in text (marked by X's). The eastern limit of the Roberts Mountains allochthon is controlled by its original eastward thrust emplacement onto the continental margin during Antler orogenesis as well as by subsequent contractional and extensional tectonism.

measuring. The minimum thickness of the Pilot in upper A–1 Canyon is about 130 m.

Most of the Pilot Shale in A–1 Canyon is generally recessive, dolomitic siltstone to very fine grained sandstone having conspicuously planar lamination and parting (fig. 7). These rocks are black on fresh surfaces and mostly weather grayish orange to yellowish orange, less commonly very pale orange or pale red. In less fissile parts of the section, the matrix of subhedral secondary dolomite crystals in places supports detrital quartz grains, and at least some laminae are silty dolostone (fig. 8). The laminated siltstone is variably calcitic owing either to incomplete replacement by dolomite of original lime-mud matrix or to dedolomitization. More fissile parts of the clastic section are shaly and have less carbonate cement. In addition to quartz, trace amounts of white mica and plagioclase are present among the detrital terrigenous-clastic grains.

The principal lithic variation within the succession of laminated siltstone is the occurrence of discrete limestone interbeds through an interval about 30 m thick that is best exposed in the lower part of section B (fig. 6). These limestone beds are about 10–40 cm thick, are for the most part intercalated in the resident dolomitic siltstone (although some limestone beds are composite), and display the internal Bouma sequences T_bA, AB, ABC, and ABCE (fig. 9) (Poole, 1974, fig. 7b). The thickest and most coarse grained limestone beds are among the stratigraphically highest. In these, the T_bA layer forms most of the bed and is bipartite, consisting of a poorly sorted, coarsely intraclastic lower part overlain abruptly by distinctly finer grained, but graded, quartz-sandy limestone (for example, fig. 10). One such bed contains in its lower part individual tabular clasts, as long as 18 cm, of various types of limestone including bioclastic wackestone and distinctly laminated packstone. These clasts are in a matrix of smaller intraclasts and sandy limestone containing coarse quartz grains. The composition of the intraclasts suggests their origin by the rip-up of related, previously deposited limestone beds, although the coarse, well-rounded quartz sand and bioclasts are exotic to the local Pilot section.

Above the part of the Pilot in A–1 Canyon characterized by limestone interbeds is 40–45 m of the Pilot Shale that, although only partly exposed, is apparently wholly composed of more or less carbonate-cemented siltstone resembling the siltstones beneath the limestone. These siltstone beds exhibit the same characteristic even lamination (fig. 11), although some are distinctly more shaly and fissile. About 3 m below the top of the Pilot in section A, low-angle truncation of the siltstone laminae is suggestive of hummocky cross stratification (fig. 12).

Neither body fossils nor feeding tracks were observed in the siltstone of the Pilot Shale in A–1 Canyon, suggesting relatively oxygen deficient conditions during sedimentation. In keeping with this inference, the pervasive secondary dolomitization of the original carbonate cement or matrix of the siltstone may have been induced by a reducing diagenetic environment.

In comparison with other sections of the Pilot Shale in the eastern Great Basin, the Pilot Shale in the Leppy Hills probably represents the relatively older part of the Pilot. Discrete limestone beds having well-defined Bouma-sequence layers are characteristic of the lower part of the Pilot in, for example, the Cherry Creek, Confusion, and Pahranagat Ranges (fig. 2). Conodonts from the T_bE layer of one of these limestone beds in section B in A–1 Canyon, about 10 m above the limestone bed illustrated by figure 9 and located stratigraphically on figure 6, are reported by R.G. Stamm (U.S. Geological Survey, written commun., 1991) to be palmatolepids of early Frasnian to middle Famennian age, thus supporting this lithic correlation.

Rocks of the Pilot Shale elsewhere in the eastern Great Basin that are lithically similar to those in the Leppy Hills are commonly interpreted to be deep-marine, turbiditic deposits (for example, Sandberg and others, 1989, p. 198), but the implication of sediment transport and deposition by gravity-driven flows is open to question. The general character and stratigraphic context of

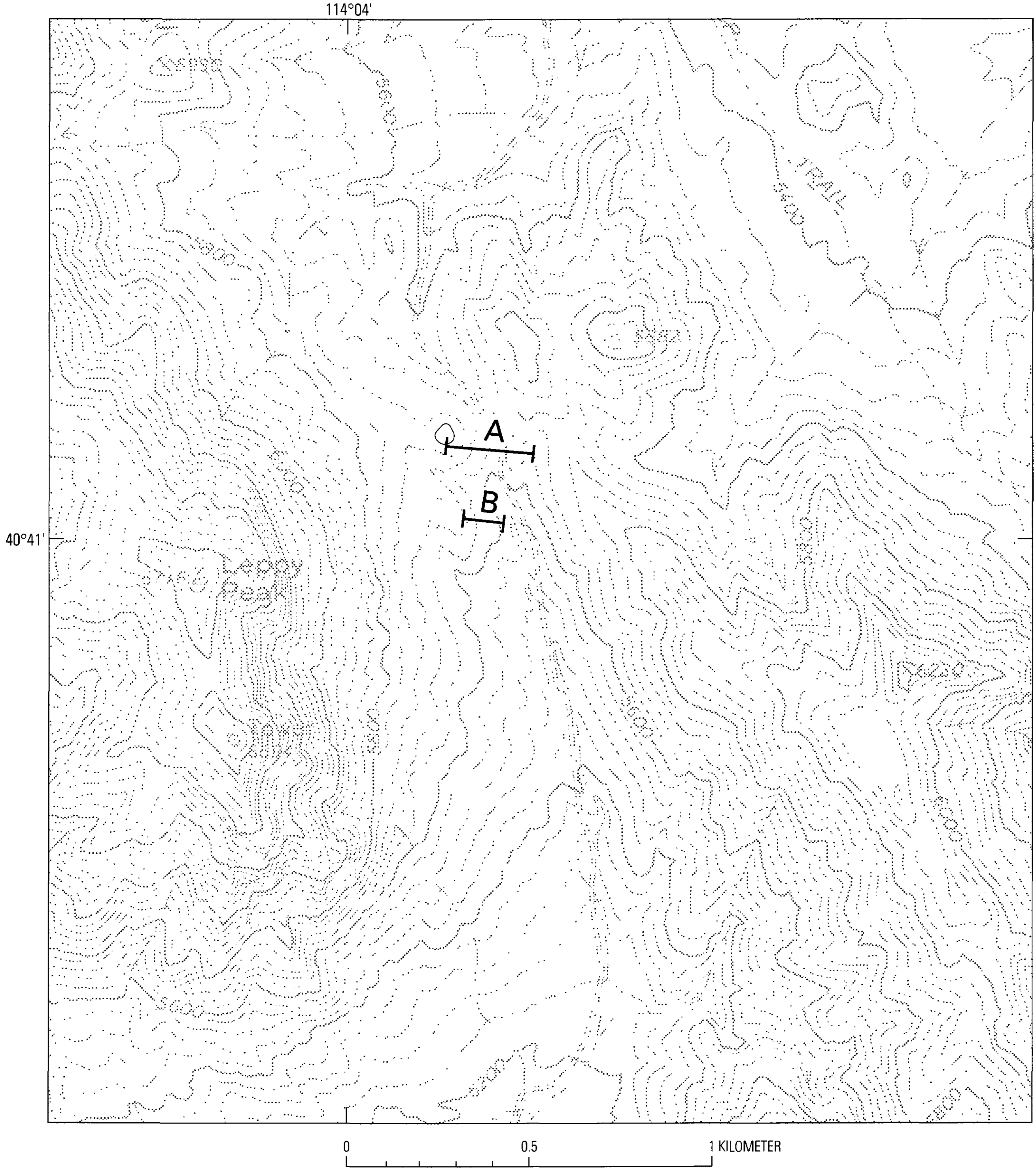


Figure 3. Topographic map of the part of the Leppy Hills showing the area of the upper part of A–1 Canyon in the Leppy Hills, northeastern Nevada. The locations of sections A and B (figs. 5 and 6, respectively) are also shown. Base is the Leppy Peak 1:24,000-scale quadrangle (contour interval 20 and 40 ft).

the secondarily dolomitic, fine-grained clastic rocks of the Pilot Shale do not suggest deposition in a slope or deep basin environment, and gravity-flow structures such as slump folds are absent in these deposits. The rare turbiditelike Bouma-sequence limestone beds in the Pilot of easternmost Nevada and westernmost Utah are regarded by us as primarily storm deposits or tempestites. Although the transport of their finer grained constituents

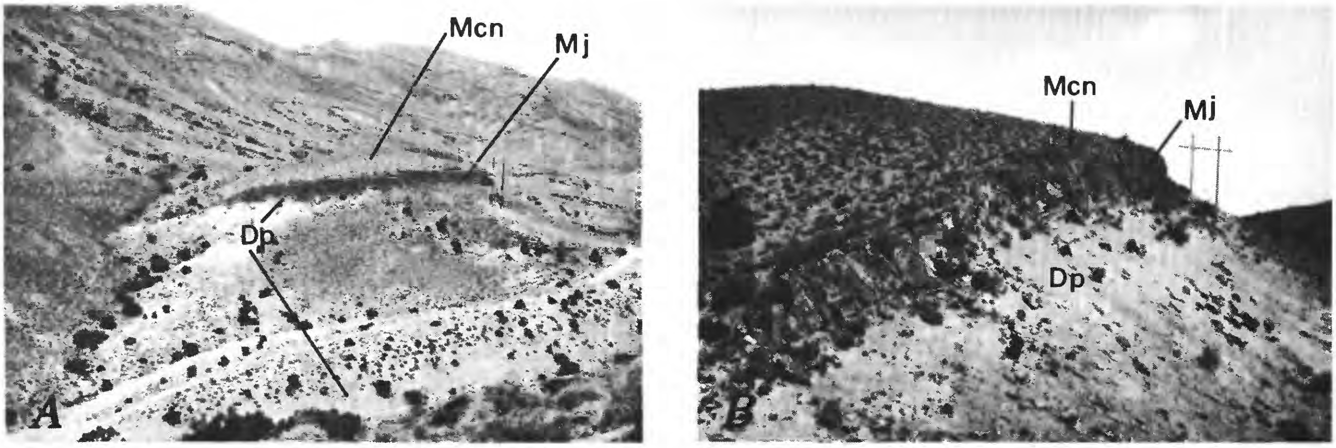


Figure 4. Photographs showing section A in upper A–1 Canyon, northeastern Nevada. Location of section A is shown in figure 3. Dp, Upper Devonian part of Pilot Shale; Mj, Lower Mississippian Joana Limestone; Mcn, Mississippian Needle Siltstone Member of the Chainman Shale (the Needle is recognized as including Lower and Upper Mississippian rocks where it is reported in other areas, Poole and Sandberg, 1991). Cliffy exposures of unit Mj are about 5 m high. *A*, View looking northwest across upper A–1 Canyon toward section A. Note power-line pole at right center. *B*, View looking north along strike across upper part of section A toward the power-line pole shown in *A*.

may have had some component of turbidity-current flow in addition to storm-generated combined flow, we believe that storm activity was initially responsible for putting this sediment into suspension. Water depths during Pilot deposition need only to have been sufficiently deep to maintain a reducing environment, and in the absence of slope deposits these conditions could be met at shallow depths, for example, in a paralic system.

JOANA LIMESTONE

The relatively thin unit of limestone intervening between siltstone of the Pilot Shale and siltstone of the Needle Siltstone Member of the Chainman Shale in A–1 Canyon is referred to the Joana Limestone following Schneyer (1990). The thickness of the Joana ranges from 5 to 7 m in the exposures in upper A–1 Canyon because of the local truncation of section on an attenuational fault at its base. Mild disruption of layering in siltstone of the Pilot immediately below this fault is apparent where this part of the section is well exposed in section A (figs. 13, 14).

Three lithic units comprise the Joana Limestone in sections A and B: (1) a lower unit of nodular, distinctly bedded, cherty packstone and wackestone, (2) a middle unit of massive, peloidal, crinoidal packstone and grainstone, and (3) an upper unit of oncolitic bioclastic wackestone and subordinate packstone.

As much as 3.5 m of the lower unit of nodular limestone is locally preserved above the fault at the base of the Joana Limestone. Rocks of this unit are distinctly mottled or nodular in thin to medium beds that are separated by irregular partings of fine-grained siliciclastic impurities that form the locus of blebs and stringers of dark-colored secondary chert (figs. 13–15). In thin section (fig. 16), the limestone of this interval is composed of irregularly intermixed patches of finely bioclastic packstone and wackestone. As much as several meters of similar limestone characteristically is present in the basal parts of Lower Mississippian limestone units elsewhere in eastern Nevada and western Utah where these units disconformably overlie fine-grained clastic rocks of the Pilot Shale. For this reason, we believe that at most only a few meters of the lower unit of the Joana is cut out by faulting in the vicinity of sections A and B.

The main, middle unit of the Joana Limestone consists of about 4 m of massively bedded peloidal and crinoidal packstone and grainstone mixed together in irregular patches and stringers (figs. 17, 18). Calcite veinlets in these rocks fill a complicated network of fractures and small-scale faults, and the limestone itself is greatly solution compacted and stylolitized.

The upper unit of the Joana Limestone is 0.5–1.0 m thick. It is gradational with the middle unit but is characterized by scattered oncolites in beds of massive wackestone (fig. 19). The uppermost few tens of centimeters of limestone, as observed both megascopically and in thin section, are extensively dissolved and solution compacted (figs. 20, 21) beneath the rocks of the Needle Siltstone Member of the Chainman Shale, the base of which manifests the onset of the Delle phosphatic event. For just a few meters along strike at section A, the solution-compacted limestone at the top of the Joana is completely exposed and is irregularly replaced by 10–20 cm of massive black chert, at the top of which is a discontinuous

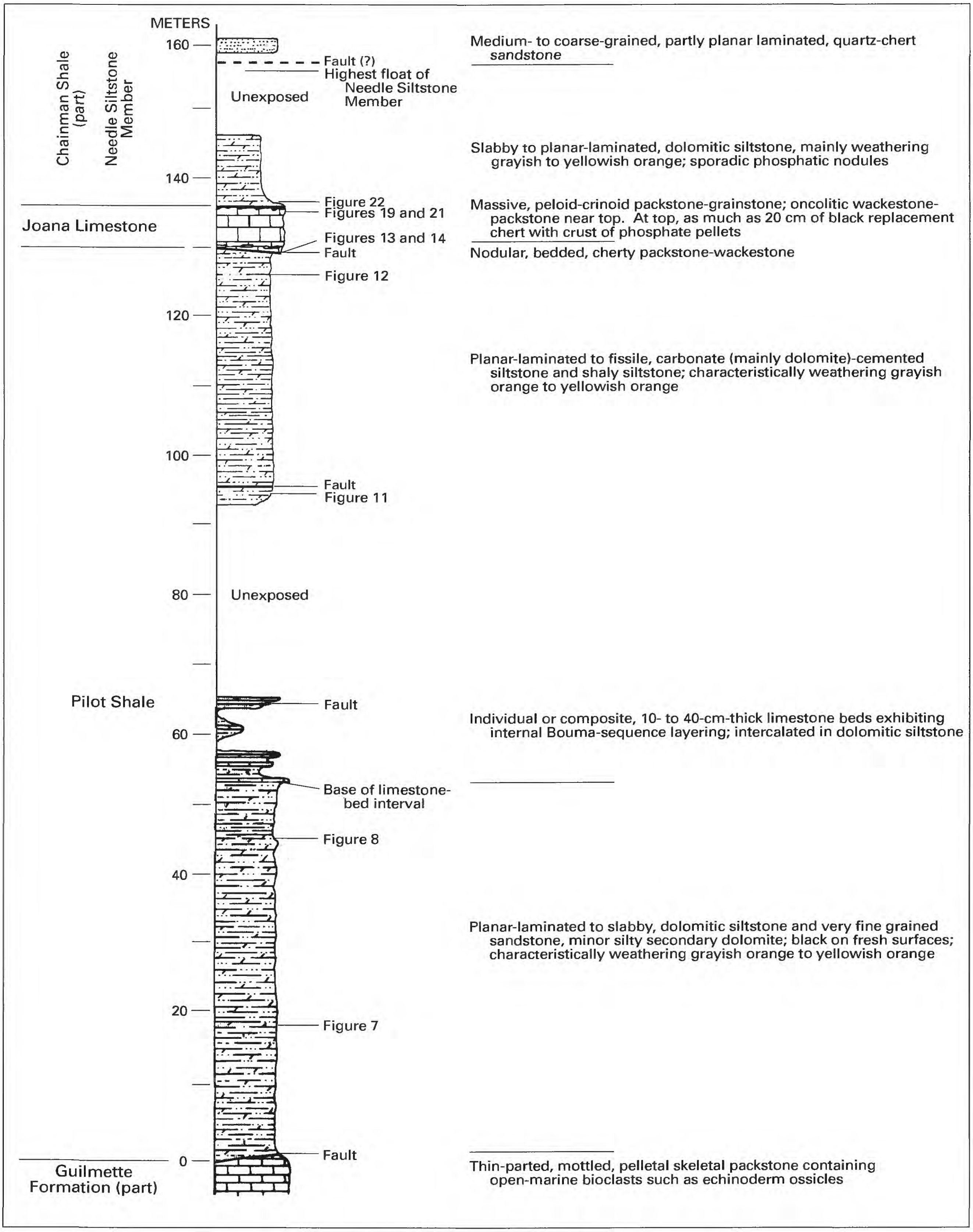


Figure 5. Columnar section of section A. Location of study section is shown in figure 3.

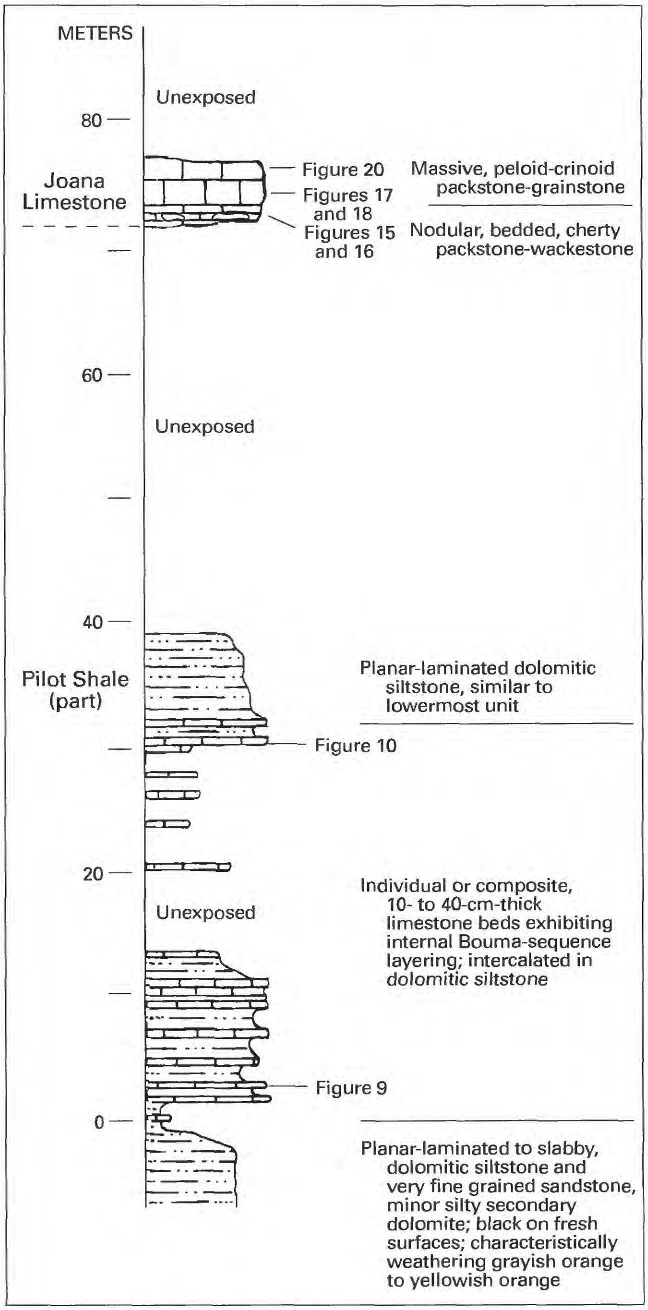


Figure 6. Columnar section of section B. Location of study section is shown in figure 3.

layer of phosphate peloids as much as a centimeter thick (fig. 22). Laminated dolomitic siltstone of the Needle Siltstone Member crops out within 20 cm above the layer of phosphate peloids. The progressively intense solution compaction toward the top of the Joana Limestone, the replacement of limestone by chert, and the appearance of pelletal phosphate grains are all characteristic diagenetic effects of the onset of the Delle phosphatic event on preexisting carbonate rocks (Nichols and Silberling, 1990; Silberling and Nichols, 1991).

Figure 7. Characteristic outcrop of dolomitic siltstone of the Pilot Shale. Strata are thinly laminated, platy weathering, and grayish orange to yellowish orange. Section A, 20 m above (faulted) base, upper A–1 Canyon, northeastern Nevada. Location of section is shown in figure 3. Hammer handle about 40 cm long.

The three depositional units forming the unusually thin section of the Joana Limestone in A–1 Canyon represent a single shallowing-upward cycle. Forming the basal part of this cycle is bedded, subtidal, offshore ramp limestone of the lower unit overlain by massive peloid-crinoid shoal deposits of the middle unit that in turn grade up into oncolitic peritidal limestone in the upper unit. Accepting that the faulted remnant of the lower unit is representative of the rocks originally forming the basal part of the limestone section, the Joana of A–1 Canyon resembles the basal parts of the formation in the few reasonably complete, nearby sections to the south. For example, in the Red Hills (fig. 2) two successive upward-shoaling cycles comprising limestone similar in character to that of the Joana in the Leppy Hills form the initial Joana deposits of the Kinderhookian transgression over the disconformably underlying Pilot Shale. On the basis of conodonts from its uppermost beds, the Joana in A–1 Canyon was assigned a late Kinderhookian age by Newman (1980), and the age of our collections from the middle and upper units of the section was similarly interpreted by R.G. Stamm (U.S. Geological Survey, written commun., 1991), primarily on the basis of conodonts of the genus *Patrognathus*. Thus, both lithic and conodont-based-paleontologic correlations indicate that the Joana at A–1 Canyon represents only the lowermost part of the Joana in terms of the much thicker Joana sections that are present farther to the south in easternmost Nevada and westernmost Utah and that span the upper Kinderhookian and the lower Osagean.

Assignment of the Lower Mississippian limestone beds in the Leppy Hills to the Joana Limestone (see Schneyer, 1990) can be justified only in the sense that all carbonate rocks of this general age that intervene between the Pilot Shale and Chainman Shale in easternmost

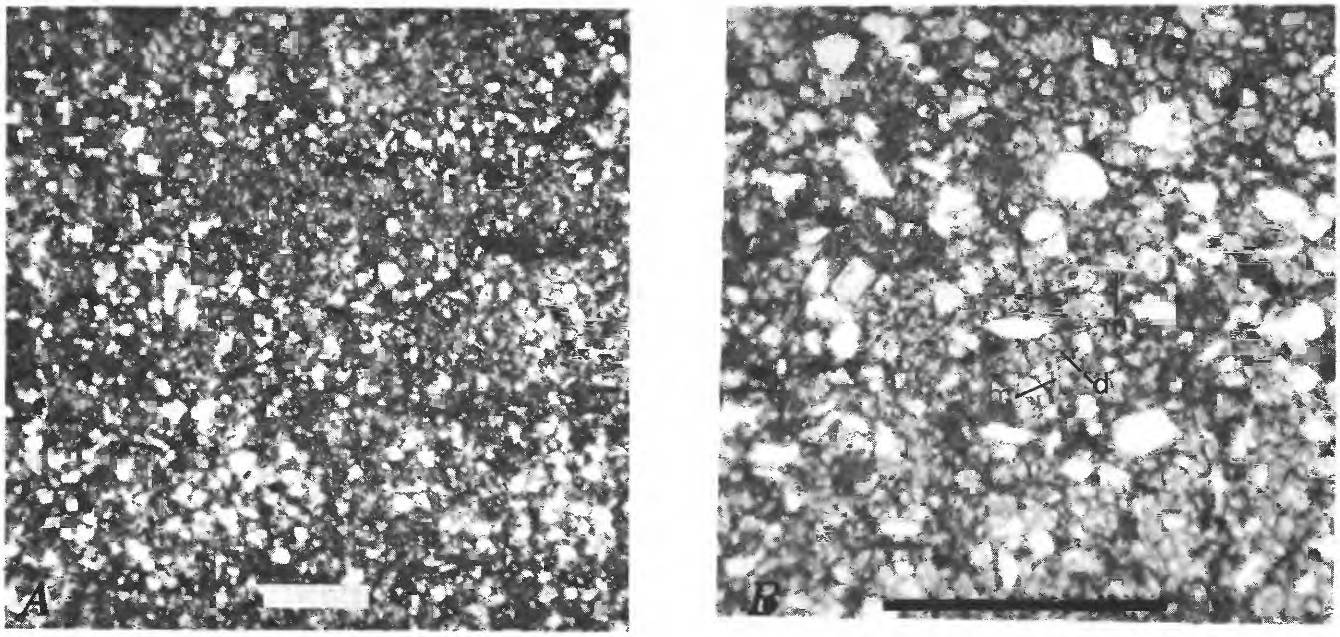


Figure 8. Photomicrographs of dolomitic siltstone of the Pilot Shale. Section A, 45 m above base, upper A–1 Canyon, northeastern Nevada. Location of section is shown on figure 3. Note dolomite euhedra (d) and mica flakes (m) in center of *B*. Bar scales, 0.5 mm.

Figure 9. Isolated limestone bed in the Pilot Shale displaying Bouma sequence ABCE and grading from coarsely quartz-sandy limestone at base to lime mudstone at top. T_bC foresets dip approximately due south. Section B, 3 m above base, upper part of A–1 Canyon, northeastern Nevada. Location of section is shown in figure 3. Pencil for scale.

Figure 10. Upper part of an isolated limestone bed in the Pilot Shale displaying Bouma sequence AB. Note poor sorting of limestone intraclasts forming base of the T_bA layer and their abrupt contact with the massive, graded packstone forming the upper part of this layer. Section B, 32 m above base, upper part of A–1 Canyon, northeastern Nevada. Location of section is shown in figure 3. Pencil for scale.

Nevada and adjacent Utah are customarily so referred. Few, if any, of the lithically diverse carbonate-rock units that regionally comprise the various sections presently referred to the Joana can be demonstrated to have genetic counterparts in the typical reference section of the Joana at Ward Mountain south of Ely, Nevada (fig. 2). Rocks currently called the Joana Limestone in the Confusion Range, Burbank Hills, and Needle Range in westernmost Utah (fig. 2), all formerly termed the Midridge Limestone by Bacon (1948) and Ogden (1951), have more in common in terms of their included carbonate units and sequence stratigraphy with the Fitchville Formation and Gardison Limestone of the East Tintic district in west-central Utah (fig. 2) than with the typical Joana of the Ely district in Nevada. Resolution of this nomenclatural problem is beyond the scope of this paper, but for paleotectonic interpretation it is important that the Fitchville in Utah either includes a complete stratigraphic sequence or is in

Figure 11. Carbonate-cemented (by dolomite and by calcite formed by dedolomitization?) siltstone of the Pilot Shale showing ubiquitous plane-bed lamination; black on fresh surfaces, weathering to very pale orange. Section A, 96 m above base, upper A–1 Canyon, northeastern Nevada. Location of section is shown in figure 3. Pencil for scale.

Figure 12. Dolomitic siltstone of the Pilot Shale showing bedding lamination suggestive of hummocky cross stratification. Section A, 3 m below (faulted) top of Pilot Shale, upper A–1 Canyon, northeastern Nevada. Location of section is shown in figure 3. Pencil for scale.

Figure 13. Local angular discordance resulting from disruption beneath the faulted contact between the Joana Limestone and underlying siltstone of the Pilot Shale. Section A, upper A–1 Canyon, northeastern Nevada. Location of section is shown in figure 3. Hammer handle is about 40 cm long.

itself a complete cycle. The overlying Gardison forms only the lower part of the ensuing sequence in which deposits of the Delle phosphatic event, such as the Needle Siltstone Member of the Chainman Shale, represent the transgressive systems tract (Silberling and Nichols, 1992). The limestone assigned to the Joana in the Leppy Hills belongs to the same regional stratigraphic sequence as the Fitchville and the lower parts of the various sections customarily referred to the Joana elsewhere in eastern Nevada and westernmost Utah.

NEEDLE SILTSTONE MEMBER OF THE CHAINMAN SHALE

In the Leppy Hills, the rocks assigned to the Joana Limestone by Schneyer (1990) are disconformably overlain by a minimum of 19 m of dolomitic siltstone in section A (fig. 5). These siliciclastic rocks are very similar to those forming most of the typical Needle Siltstone Member of the Chainman Shale in the Needle Range (fig. 2) and the Needle elsewhere in western Utah and eastern Nevada. Like the siltstone strata of the older Pilot Shale, these rocks are planar-laminated to irregularly platy, secondarily dolomitic siltstone that mostly weathers yellowish orange to grayish orange. Unlike siltstone strata of the Pilot, siltstone strata of the Needle have abundant bedding-parallel feeding tracks on some surfaces, and phosphate nodules as large as a few centimeters are

Figure 14. Concordant but faulted contact between limestone of the Joana Limestone and underlying siltstone of the Pilot Shale about 5 m to the south along strike from view in figure 12. Hammer handle is about 40 cm long.

sporadically enclosed in the siltstone. Dolomitic siltstone, such as in the Needle, is characteristic of deposition during the Delle phosphatic event, even though layered phosphate in the Leppy Hills is restricted to the thin crust of phosphate peloids capping the diagenetically altered uppermost part of the Joana Limestone in section A. Intervals of ostracode lime mudstone (Silberling and Nichols, 1991) or dense, featureless, micritic limestone that are a subordinate, but conspicuous, characteristic of the Delle phosphatic event elsewhere in Utah and eastern Nevada are not present in A–1 Canyon.

In section A, above the Needle Siltstone Member but separated from it by a covered interval equivalent to about 10 m of section, medium- to coarse-grained, partly planar laminated, quartzitic chert sandstone crops out on the tip of the small hill atop which both fairly continuous exposures and section A end. A fault omitting a significant thickness of section here could intervene between the Needle and the chert-quartz sandstone representing a higher part of the Chainman Shale.

Figure 15. Thin-bedded, nodular, cherty limestone having irregular, calcareous fine-grained siliciclastic partings between bed. Section B, upper A–1 Canyon, northeastern Nevada. Location of section is shown in figure 3. Characteristic of unit as much as 3.5 m thick forming basal part of the Joana Limestone. Pencil for scale.

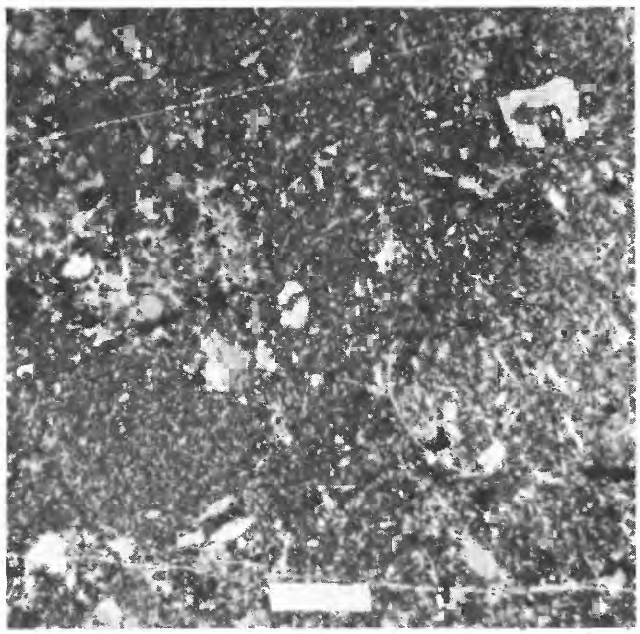


Figure 16. Photomicrograph of bioclastic wackestone in the lower unit of the Joana Limestone. Section B, upper A–1 Canyon, northeastern Nevada. Location of section is shown in figure 3. Bar scale, 0.5 mm.

STRUCTURE

The structure of A–1 Canyon and the Leppy Hills area, as described by Schneyer (1984), is dominated by

Figure 17. Fresh outcrop face of the middle unit of the Joana Limestone showing crinoid-rich stringers in peloidal packstone, 3.5 m above local base of the Joana. Section B, upper A–1 Canyon, northeastern Nevada. Location of section is shown in figure 3. Pencil for scale.

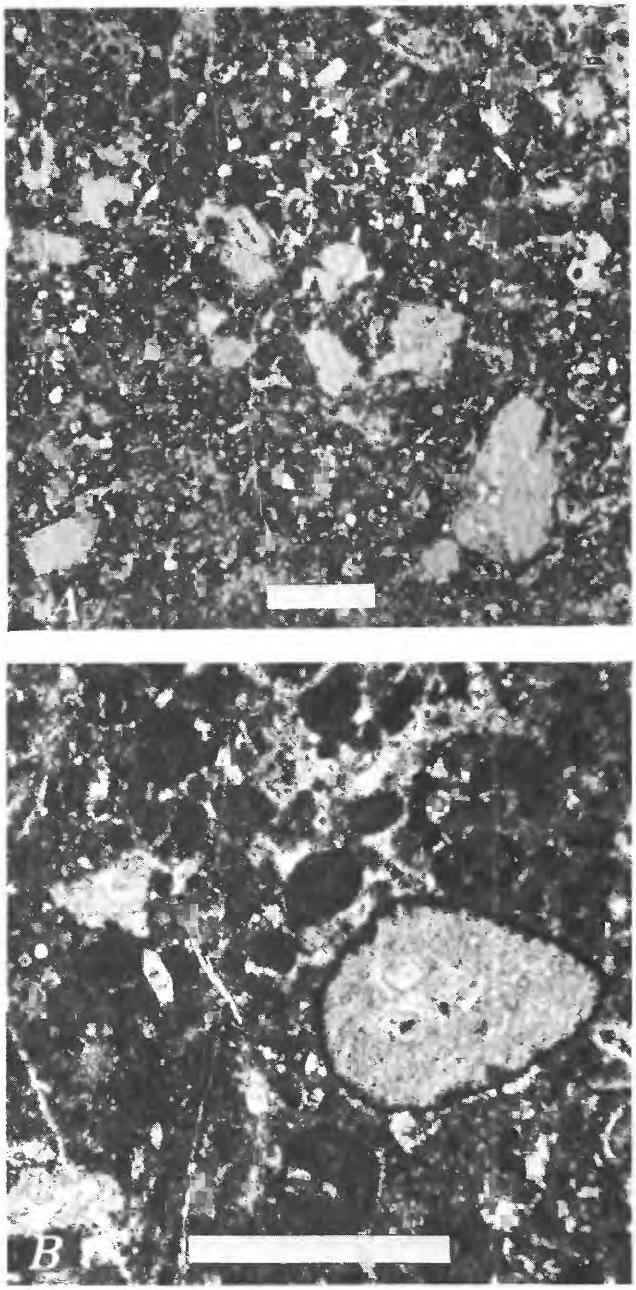


Figure 18. Photomicrographs of peloidal, bioclastic packstone from the middle unit of the Joana Limestone, 3.5 m above local base of the Joana. Section B, upper A–1 Canyon, northeastern Nevada. Location of section is shown in figure 3. Highly micritized rim of conspicuous crinoid columnal (center right, photomicrograph *B*) suggests that some peloids may be totally micritized bioclasts. Bar scales, 0.5 mm.

extensional faulting of Cenozoic age. Throughout the area "* * * the Chainman Shale and older units are thinned primarily by faulting [so that] all paleogeographic reconstructions based upon variations in formation thickness are uncertain" (Schneyer, 1984, p. 93). In the local area of sections A and B in upper A–1 Canyon, the style of observed faulting is the cutting out of section along bedding-subparallel faults that commonly form the contacts between units of contrasting competency (as, for example, between the Guilmette Formation and Pilot Shale, and the Pilot Shale and Joana Limestone). These faults are thought by us to be generally minor normal faults that formed in response to dominolike tilting of the slablike stratigraphic units above a master low-angle detachment, which in this case would be rooted to the east. This style of omissional faulting is observed throughout the eastern Great Basin in this same part of the upper Paleozoic stratigraphic section.

PALEOTECTONIC IMPLICATIONS

Despite the prevalence of attenuational faulting in the study area, as described previously, the Joana Limestone is in depositional contact with the overlying Needle Siltstone Member of the Chainman Shale; fault omission of

Figure 19. Oncolites 0.5 m below the top of the Joana Limestone. Section A, upper A–1 Canyon, northeastern Nevada. Location of section is shown in figure 3. Pencil for scale.

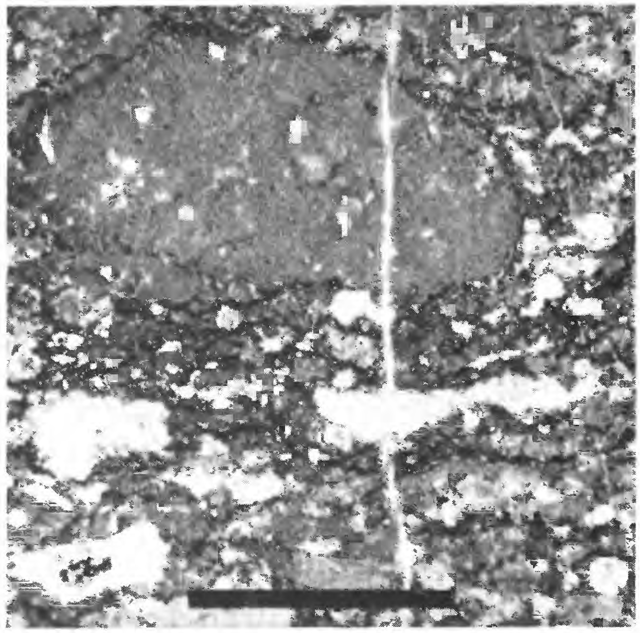


Figure 21. Photomicrograph of stylolitized and solution-compacted limestone in the uppermost part of the Joana Limestone. Section A, upper A–1 Canyon, northeastern Nevada. Location of section is shown in figure 3. Bar scale, 0.5 mm.

Figure 20. Solution-compacted bioclastic wackestone or packstone near the top of the Joana Limestone. Section B, upper A–1 Canyon, northeastern Nevada. Location of section is shown in figure 3. Pencil for scale.

Figure 22. Contact between the Joana Limestone and overlying Needle Siltstone Member of the Chainman Shale. Section A, upper A–1 Canyon, northeastern Nevada. Location of section is shown in figure 3. Pencil in lower center of photograph points to the contact between replacement chert and underlying solution-compacted Joana Limestone; pencil in upper center points to the thin layer of phosphate pellets atop the chert; and hammer point is resting on small outcrop of dolomitic siltstone of the Needle Siltstone Member.

strata at the base of the Joana is minor. Thus, only a relatively very thin Joana section, representing just an erosional remnant of what regionally would be its late Kinderhookian basal part, is disconformably preserved beneath the Needle, the older age limit for which from regional correlations is middle Osagean or younger. Moreover, aside from the return to oxygen-deficient depositional conditions indicated by the phosphate-nodule-bearing, dolomitic siltstone of the Needle, the expression of the Delle phosphatic event is relatively weak in the basal part of the Needle in the Leppy Hills in comparison to that in sections farther to the east and southeast in Utah (for example, in the Lakeside Mountains and East Tintic district, fig. 2). In these latter sections, deposits as thick as tens of meters that formed during the early phases of the Delle phosphatic event are characterized by multiple layers of peloidal and other forms of phosphate, dissolution and chert replacement of limestone intercalated in dolomitic siltstone and phosphatic mudstone, preservation of pelagic fossils such as radiolarians in replacement-chert beds and dissolution remnants of limestone, and deposition of other distinctive limestone units indicative of peculiar water chemistry (Nichols and Silberling, 1990). The Delle phosphatic event has been attributed by us (Silberling and Nichols, 1991) to restriction of the inner shelf by the development of a sill in the form of a foreland bulge in response to tectonic loading of the outboard continental margin during a late stage of Antler orogenesis. The Lower and Upper Mississippian rocks of the Leppy Hills may document deposition on the continentward flank of this hypothetical foreland bulge and the effects of subtle uplift in the forebulge area contemporaneous with relative depression of the broad, generally flat region farther to the east and south. The Gardison Limestone and the laterally equivalent upper part of the type Joana Limestone were deposited across this region to the east and south of the Leppy Hills during the early part of Osagean time but were onlapped by the Needle Siltstone Member and its lateral equivalents toward the positive area on which the Needle of the Leppy Hills was deposited. The Joana Limestone of the Leppy Hills, belonging to an earlier sequence cycle, originally may have been significantly thicker prior to being eroded below the sequence cycle that regionally includes the Gardison, the upper part of the Joana, and fine-grained clastic rocks of the Delle phosphatic event such as the Needle Siltstone Member of the Chainman Shale.

REFERENCES CITED

Bacon, C.S., 1948, Geology of the Confusion Range, west-central Utah: Geological Society of America Bulletin, v. 59, p. 1027–1052.

Newman, G.J., 1980, Conodonts and biostratigraphy of the Lower Mississippian in western Utah and eastern Nevada: Brigham Young University Geology Studies 27, p. 103–121.

Nichols, K.M., and Silberling, N.J., 1990, Delle Phosphatic Member—An anomalous phosphatic interval in the Mississippian (Osagean-Meramecian) shelfal sequence of central Utah: Geology, v. 18, p. 46–49.

Ogden, L.M., 1951, Mississippian and Pennsylvanian stratigraphy, Confusion Range, west-central Utah: American Association Petroleum Geologists Bulletin, v. 35, p. 62–82.

Poole, F.G., 1974, Flysch deposits of the Antler foreland basin, western United States, *in* Dickinson, W.R., ed., Tectonics and sedimentation: Society of Economic Paleontologists and Mineralogists Special Publication 22, p. 58–82.

Poole, F.G., and Sandberg, C.A., 1991, Mississippian paleogeography and conodont biostratigraphy of the western United States, *in* Cooper, J.D., and Stevens, C.H., eds., Paleozoic paleogeography of the western United States–II: Society of Economic Paleontologists and Mineralogists, Pacific Section, v. 67, p. 107–136.

Sandberg, C.A., and Gutschick, R.C., 1984, Distribution, microfauna, and source-rock potential of Mississippian Delle Phosphatic Member of Woodman Formation and equivalents, Utah and adjacent states, *in* Woodward, Jane, Meissner, F.F., and Clayton, J.L., eds., Hydrocarbon source rocks of the greater Rocky Mountain region: Rocky Mountain Association of Geologists, p. 135–178.

Sandberg, C.A., Poole, F.G., and Johnson, J.G., 1989, Upper Devonian of the western United States, *in* McMillan, N.J., Embry, A.F., and Glass, D.J., eds., Devonian of the world: Canadian Society of Petroleum Geologists Memoir 14, v. 1, Regional Syntheses, p. 183–220.

Schneyer, J.D., 1984, Structural and stratigraphic complexities within an extensional terrain—Examples from the Leppy Hills area, southern Silver Island Mountains, near Wendover, Utah, *in* Kerns, G.J., and Kerns, R.L., eds., Geology of northwest Utah, southern Idaho and northeast Nevada: Utah Geological Association Publication 13, p. 93–116.

———1990, Geologic map of the Leppy Peak quadrangle and adjacent area, Elko County, Nevada, and Tooele County, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I–1938, scale 1:24,000.

Silberling, N.J., and Nichols, K.M., 1990, Tectonic implications of wide-spread anoxia on the Mississippian shelf, western and northern Utah: Geological Society of America Abstracts with Programs, v. 22, p. 83–84.

———1991, Petrology and regional significance of the Mississippian Delle Phosphatic Member, Lakeside Mountains, northwestern Utah, *in* Cooper, J.D., and Stevens, C.H., eds., Paleozoic paleogeography of the western United States–II: Society of Economic Paleontologists and Mineralogists, Pacific Section, v. 67, p. 425–438.

———1992, Depositional cycles of the Upper Devonian–Lower Mississippian limestone succession in the southern Lakeside Mountains, *in* Wilson, J.R., ed., Field guide to geologic excursions in Utah and adjacent areas of Nevada, Idaho, and Wyoming: Utah Geological Survey Miscellaneous Publication 92-3, p. 131–145.

Published in the Central Region, Denver, Colorado
Manuscript approved for publication March 22, 1993
Edited by Judith Stoeser
Graphics prepared by Gayle Dumonceaux and Norma Maes
Type composed by Shelly A. Fields

☆U.S. GOVERNMENT PRINTING OFFICE: 1993-774-049/66064

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 hydrology, 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 maybe 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. The 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; the 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 USGS Map Distribution, Box 25286, Building 810, Denver Federal Center, 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 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" is 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.

U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849