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THE JOHN BLUE CANYON SILICA SAND DEPOSIT, BIG HORN COUNTY, WYOMING

by

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Abstract

The Tensleep Sandstone contains a silica sand deposit in the John Blue Canyon area eleven miles northeast of Lovell, Big Horn County, Wyoming. Based on surface studies, there is an estimated 186,382,000 short tons of indicated, marginal reserves of silica sand in this deposit. The silica sand averages 87.3 percent SiO_2 and occurs at an average depth of 174 feet below the surface. An estimated additional 106 million short tons of inferred, marginal reserves of silica sand are possibly present east of the studied area. The silica sand unit is 20 feet thick and may be amenable to mining using a borehole mining technique. It may be possible to improve the grade of the sand to 96 percent or greater SiO_2 by using water to remove impurities such as calcium carbonate, clay, and gypsum. Additional studies, including core drilling, are necessary to verify the amounts of silica sand estimated in this study as well as the washability of the sand.

The sand, which is very fine to fine grained, is potentially usable as a source for fused silica and other silica products, including the manufacture of certain types of glass. Other mineral raw materials that are used in the production of silica products, include soda ash, limestone, and feldspar. These materials are accessible nearby (**Figure 1**). Railroad and highway routes are located within six miles of the resource area, and other supportive services are also available in the Lovell and northern Big Horn County area.

Introduction

This report describes a field investigation of the geology and resources of silica sand exposed in John Blue Canyon and present in the subsurface of adjacent areas on the southwestern flank of Little Mountain, northeast of Lovell, Wyoming. The investigation provides a preliminary estimate of the grade of the silica sand and the tonnages present in the area. Supporting background information is provided on silica and silicon definitions, uses, and production.

John Blue Canyon was named for a hermit who lived near a perennial spring at the mouth of the canyon. The John Blue Canyon silica sand deposit is located in the canyon area in the foothills of the Bighorn Mountains, about 11 miles northeast of Lovell, Big Horn County, Wyoming, in sections 13, 14, 15, 23, and 24, T57N, R94W, and sections 18 and 19, T57N, R93W (**Figure 1** and **Plate 1**). The elevation of the study area is between 3,800 and 5,200 feet above mean sea level. Outdoor work is possible most of the year, except during winter snowstorms and summer thunderstorms. Sagebrush covers the area at lower elevations, while mixed juniper and sagebrush cover the area at the higher elevations.

The silica sand deposit is located 5 miles north of U.S. Highway 14A and 6 miles from the Burlington Northern Railroad's siding at Kane. A graded dirt road from U.S. 14A leads north to the mouth of John Blue Canyon. An unpaved road up John Blue Canyon provides access to Little Mountain and Natural Trap Cave. The John Blue Canyon road, and other unpaved roads throughout the study area are best traveled with four-wheel-drive vehicles. Most of the John Blue Canyon road passes over red shales of the Amsden and Phosphoria Formations; these shales turn to gumbo during wet conditions.

The John Blue Canyon deposit is a 20-foot-thick, very friable, fine-grained high silica sandstone unit that comprises the entire Tensleep Sandstone in this area. Outcrop samples from the deposit average

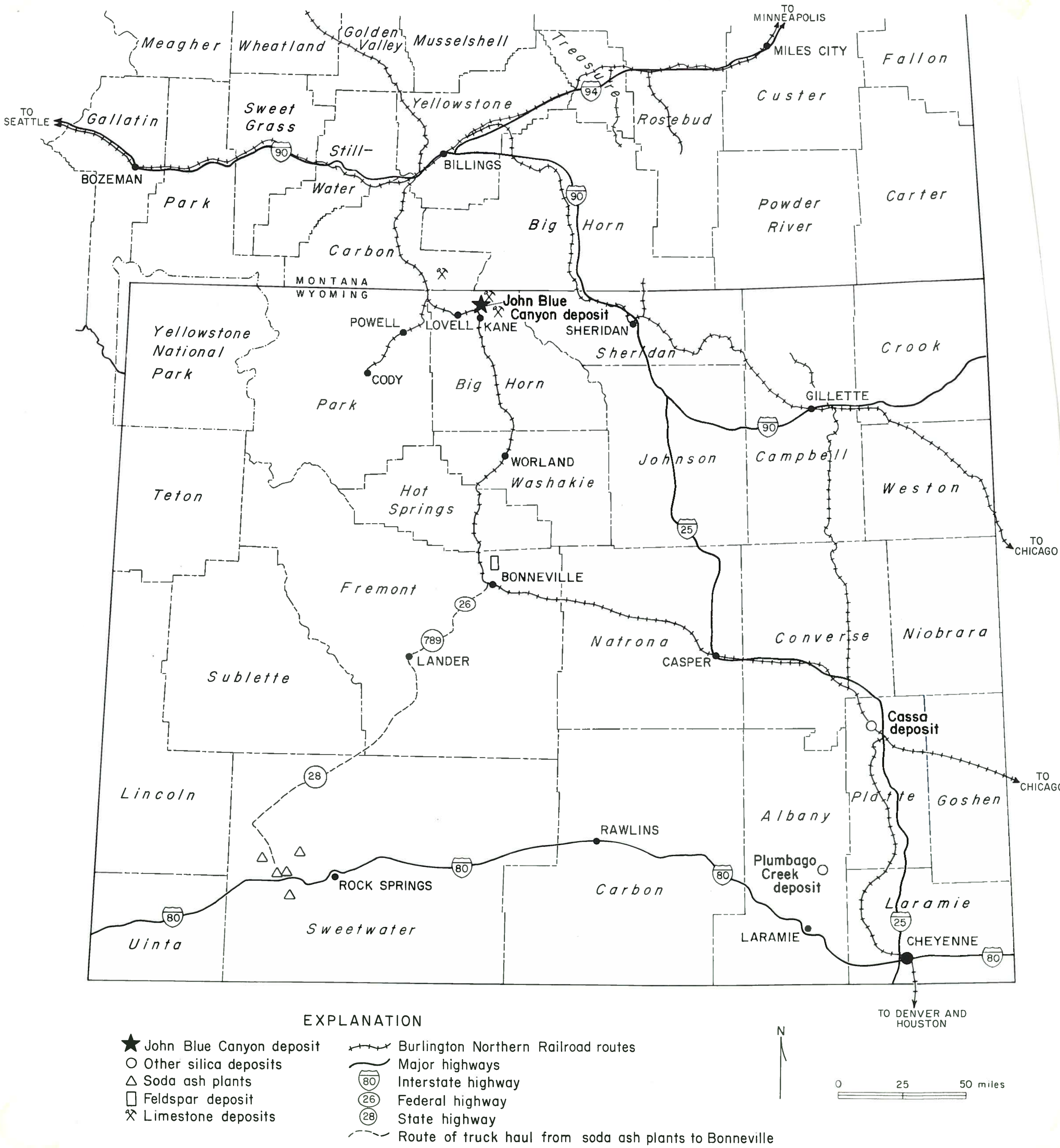


Figure 1. Index map showing transportation routes and the location of the John Blue Canyon silica sand deposit, Big Horn County, Wyoming.

87.3 percent silica (SiO_2), and vary from 73.0 to 96.8 percent silica. It may be possible to remove impurities (calcium carbonate, clay, and gypsum) in the silica sand by washing, but no washability studies were conducted. The high silica sandstone is thought to be present beneath younger units throughout the study area. Although three core holes were attempted, the silica sand was too friable for recovery by a conventional core drill. Hence this study is based upon detailed surface studies only. It is possible that a specialized drilling program could successfully recover core from this deposit. Such a program is necessary to verify and refine the calculations of the amount and grade of the deposit as presented in this report.

The silica sand in the John Blue Canyon deposit is apparently suitable for the manufacture of fused silica, glass, or other industrial uses such as metallurgical flux, abrasives, fillers in ceramics, and as an ore for making silicon metal. The material in the deposit is too fine for use as hydraulic fracturing sand.

Acknowledgments

The Town of Lovell obtained funds for this project, including the mapping, sampling, sample analyses, and the attempted core drilling, from the Wyoming Department of Commerce, Division of Economic and Community Development (DECD) through a planning-only grant. Mr. John T. Nickle, Mayor of the Town of Lovell, and Mr. Bill Space, Town Manager of Lovell, were especially helpful in obtaining the funding for this study. Information from this project was given to the Geological Survey of Wyoming by the Town of Lovell and the DECD. The Geological Survey of Wyoming provided technical assistance for the geologic portion of the study. The authors also appreciate the advice and assistance of Mr. Norman "Dutch" Hoffman, Dr. John Welch, Mrs. Jane Welch, and others. The authors thank Mr. Jon K. King of the Geological Survey of Wyoming and Mr. Michael A. Linkous of U.S. Borax and Chemical Co., for their technical review of this report.

Silica, silica sand, glass sand, silicon, and silicones

Silica (SiO_2) is the primary ingredient in the manufacture of all types of glass and related products (**Tables 1, 2,** and **3**). Silica also has a variety of other industrial uses (**Table 4**). Quartz is the most common silica-rich mineral. Important sources of quartz are recent and ancient quartzose sands and sandstones and ancient pegmatitic quartz veins.

Silica sand is classified as a type of industrial sand (Bolen, 1992). Bates and Jackson (1987) define silica sand as "an industrial term for a sand or an easily disaggregated sandstone that has a high percentage of quartz." This report uses that definition of silica sand. Glass sand is silica sand that is used as the primary source of silica in the manufacture of all types of glass (Huntley and Snow, 1986).

Silicon is a metal produced by smelting silica. Silicon metal is the feedstock for production of ferrosilicon alloys that are used in transportation equipment, particularly automobiles.

These alloys have high tensile strengths and are very resistant to corrosion. Silicon metal is also used in chemicals, machinery (particularly items requiring resistance to corrosion and abrasion), construction products such as ferrosilicon-alloy beams, and other products such as electrical semiconductors. New

Table 1. Types of glass products (after Bentzen, 1979).

Flat Glass	**Other specialty glasses**
Sheet	Tableware
Float	Lead crystal
Rolled	Fused silica
Glass Containers	Heat resistant (borosilicate)
Colorless	Light bulbs (high-sodium)
Colored	Tubing
Glass Fibers	Electronics
Reinforcement filaments	Scientific and laboratory glassware
Insulation	Optical glass
Optical fibers	Bullet-proof glass
Fused silica fibers	

Table 2. Typical proportion of ingredients for flat glass (after Huntley and Snow, 1986). (Total does not add up to 100% because of independent rounding.)

Ingredient	% of total batch
Silica sand	60.13
High calcium limestone	4.39
Dolomitic limestone	15.15
Soda ash	19.42
Salt cake or gypsum	0.48
Rouge (iron colorant)	0.42
	99.99

Table 3. Specifications for crystal glass (tableware) (Anchor Hocking Glass Company, 1981).

Chemical component	Specifications
SiO_2	98.0% ± 1.0%
Fe_2O_3	0.020% maximum
Al_2O_3	0.05% ± 0.05%
CaO + MgO	1.0% ± 0.5%
Loss on Ignition	1.0% ± 0.5%
Cr_2O_3	5 ppm maximum
Other coloring agents:	none allowed (examples include cobalt, copper, manganese and nickel)
Physical component	**Specifications**
Retained on 20 mesh screen	0.1% maximum
Retained on 30 mesh screen	5.0% maximum
Retained on 40 mesh screen	20.0% maximum
Passing 100 mesh screen	25.0% maximum
Refractory particles after fusion:	maximum on 40 mesh screen: 2 particles per pound maximum on 60 mesh screen: 20 particles per pound

Table 4. Tonnages of silica rock or silica sand used for industrial purposes in the United States in 1985 and 1988 (after Teipordei, 1987; and Bolen, 1990).

End Use	1985	1988
Glass	10,293,000	12,141,000
Foundry	5,143,000	7,610,000
Abrasives	1,681,000	2,113,000
Hydraulic fracturing	2,102,000	1,299,000
Chemicals	378,000	655,000
Roofing granules	403,000	575,000
Filtration	345,000	407,000
Traction	292,000	305,000
Ceramics	150,000	280,000
Fillers	158,000	142,000
Metallurgical	188,000	N/A[1]
Coal Washing	18,000	N/A[1]
Other	2,446,000	809,000
Total	23,597,000	26,336,000

[1] Data not available; figures withheld by U.S. Bureau of Mines and not included in the total.

applications of silicon-based materials include their use in electronics, photovoltaic chemicals, other metal alloys, and metal matrix composites (Gambogi, 1990).

Silicones, which are chemical polymers consisting of hydrocarbon chains with silicon and oxygen, are produced from silicon metal. These polymers are used in lubricants, sealants, and insulators (Gambogi, 1990; Neuharth, 1989).

Uses of silica sand

Silica sand with a purity of at least 95 percent SiO_2 is the primary ingredient in the manufacture of glass and related products, such as fused silica and synthetic quartz crystals. Many varieties of glass are manufactured for a variety of applications (**Table 1**). Optical glass, fiber optical glass, synthetic quartz crystals, and lasers require the purest silica feedstock. Other types of glass require high purity material sources (**Tables 2** and **3**). Colored glass can be produced from a much lower purity silica feedstock. Early settlers in Wyoming, for example, used river or dune sands to produce glass for containers. Although their product was usually brown or dark green, it was adequate for their purposes. Fused silica can be manufactured from fine grained source material. The manufacture of other types of glassware may require medium-grained sand sources.

Glass is also being tested as a medium to isolate radioactive waste (Harker and Flintoff, 1984; Ondracer and Toscano, 1984) and toxic waste. New kinds of glass are continually being tested for waste isolation purposes. As yet, exact specifications for this purpose have not been proposed. The preferred glass for waste isolation at present is a borosilicate type similar to high-durability fiberglass. This use may increase in the future as technology for the isolation and storage of radioactive or toxic waste develops.

Domestic silica production

Silica sand, silica rock, or high silica industrial sand is produced in thirty-eight states, but not in Wyoming. Most of this production is from industrial areas of the Midwest, Gulf Coast states, Middle Atlantic states, and the West Coast (see **Appendices A** and **B**). Most domestic glass sand production is from quartz-rich sandstone. The largest producer in the United States is Unimin Corporation. The second largest producer is U.S. Silica Company, a subsidiary of RTZ Ltd. (Bolen, 1992).

Geology

Introduction

Rocks exposed in the vicinity of John Blue Canyon include the Madison Limestone, Amsden Formation, Tensleep Sandstone, Phosphoria Formation, and the undivided Dinwoody Formation and Chugwater Group. The Phosphoria Formation has been mapped and informally subdivided into two district units, an upper limestone unit and a lower red shale and gypsum unit. The upper part of the undivided Dinwoody and Chugwater Formations is only present south of the mouth of John Blue Canyon.

The John Blue Canyon silica sand deposit comprises the entire thickness of the Tensleep Sandstone, which is unusually thin in the area. Here the Tensleep Sandstone is only 20 feet thick, while 10 miles south in the Five Springs Creek area it is about 40 feet thick. The Tensleep is from 80 to 100 feet thick in the subsurface some 10 miles downdip (west) from the study area (A.J. Ver Ploeg, personal communication, 1992).

The outcrops of the above formations and the silica sand unit are shown on the geologic map (**Plate 1**). In the study area, two roughly northwest-trending monoclines with more steeply dipping strata are separated by a homocline. A cross section perpendicular to the strike of these structures on the southwest flank of Little Mountain shows these formations and the silica sand unit in the subsurface (**Plate 1**). Minor structural complications found in the study area include block slides and breccia pipes.

Seventy-five percent of the exposures in the study area occur as a dip slope on a limestone bed in the upper part of the Phosphoria Formation. The limestone dip slope is deeply incised by canyons such as John Blue Canyon. In these canyons, the Phosphoria Formation, Tensleep Sandstone, Amsden Formation, and Madison Limestone are exposed in descending order (**Figure 2**). See **Appendix C** for an explanation of lithologic symbols on **Figures 2** through **7.** The lower Phosphoria, Tensleep, and Amsden exposures in the canyons form steep slopes at the angle of repose and are covered with large blocks and other debris from overlying limestones in the Phosphoria Formation. The Madison Limestone forms vertical walls in the deeper parts of John Blue Canyon and a dip slope north of the study area (**Plate 1**). Northeast of the center of section 13, T57N, R94W and in section 19, T57N, R93W, the Phosphoria, Tensleep, and the Amsden are exposed in a series of hogback ridges and strike valleys. Southwest of the mouth of the canyons, the resistant limestone is covered at lower elevations by red shales and siltstones of the undivided Triassic Dinwoody Formation and the Chugwater Group (**Plate 1**).

Stratigraphy

The rock units mapped in the study area include, from oldest to youngest: the Mississippian Madison Limestone, the Mississippian-Pennsylvanian Amsden Formation, the Pennsylvanian Tensleep Sandstone (the silica sand unit), and the Phosphoria Formation (**Figure 2**).

In this report, the Phosphoria Formation includes all rocks between the Tensleep Sandstone and the base of the Chugwater and Dinwoody Formations. This correlates with nomenclature to the north in Montana where this interval is also designated the Phosphoria Formation (Balster, 1980).

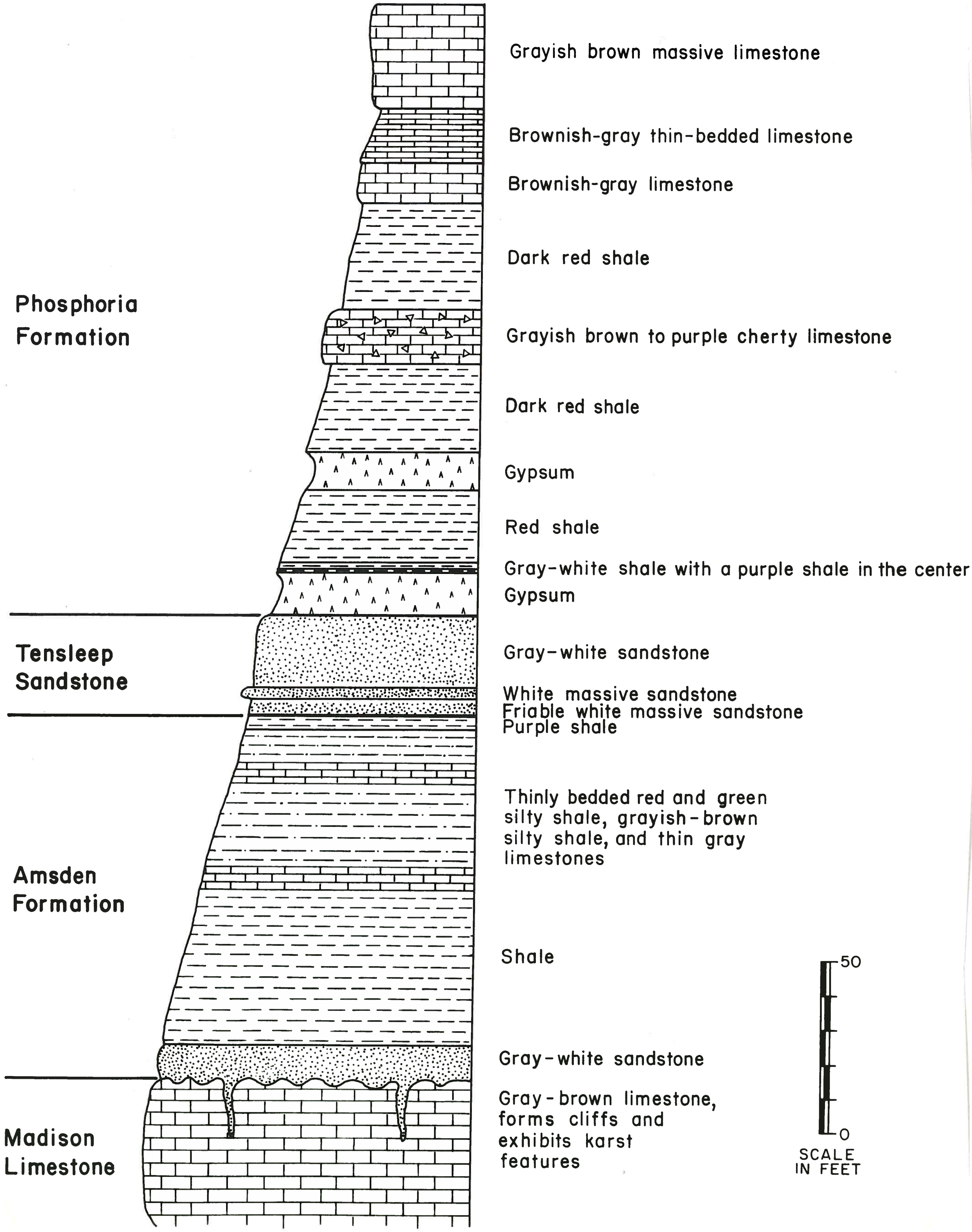


Figure 2. Generalized stratigraphic section of the Amsden Formation, Tensleep Sandstone, and Phosphoria Formation, John Blue Canyon, Wyoming (Measured Section No. 1 on Plate 1).

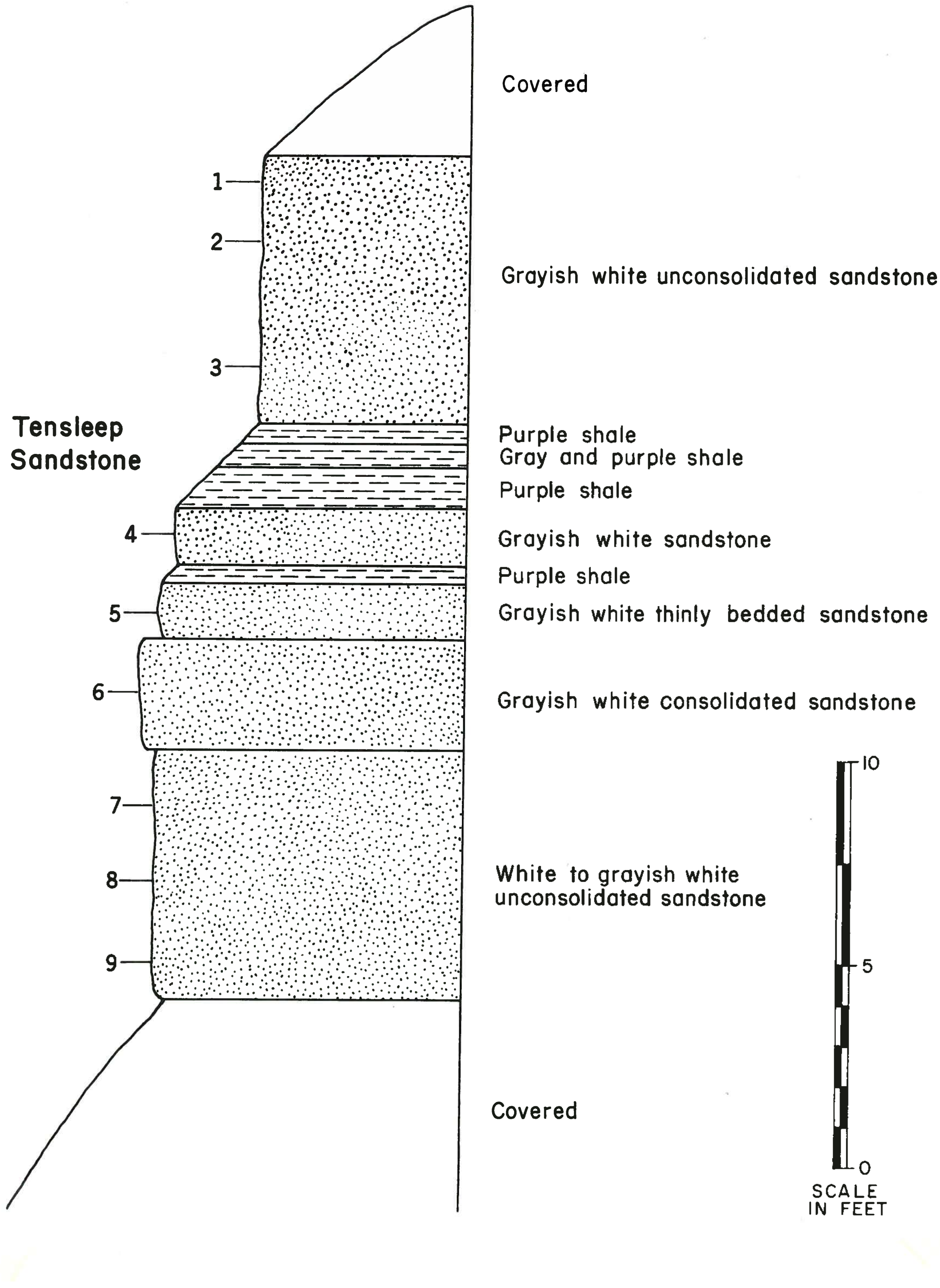


Figure 3. Measured Section No. 2 of the silica sand deposit (located on Plate 1).

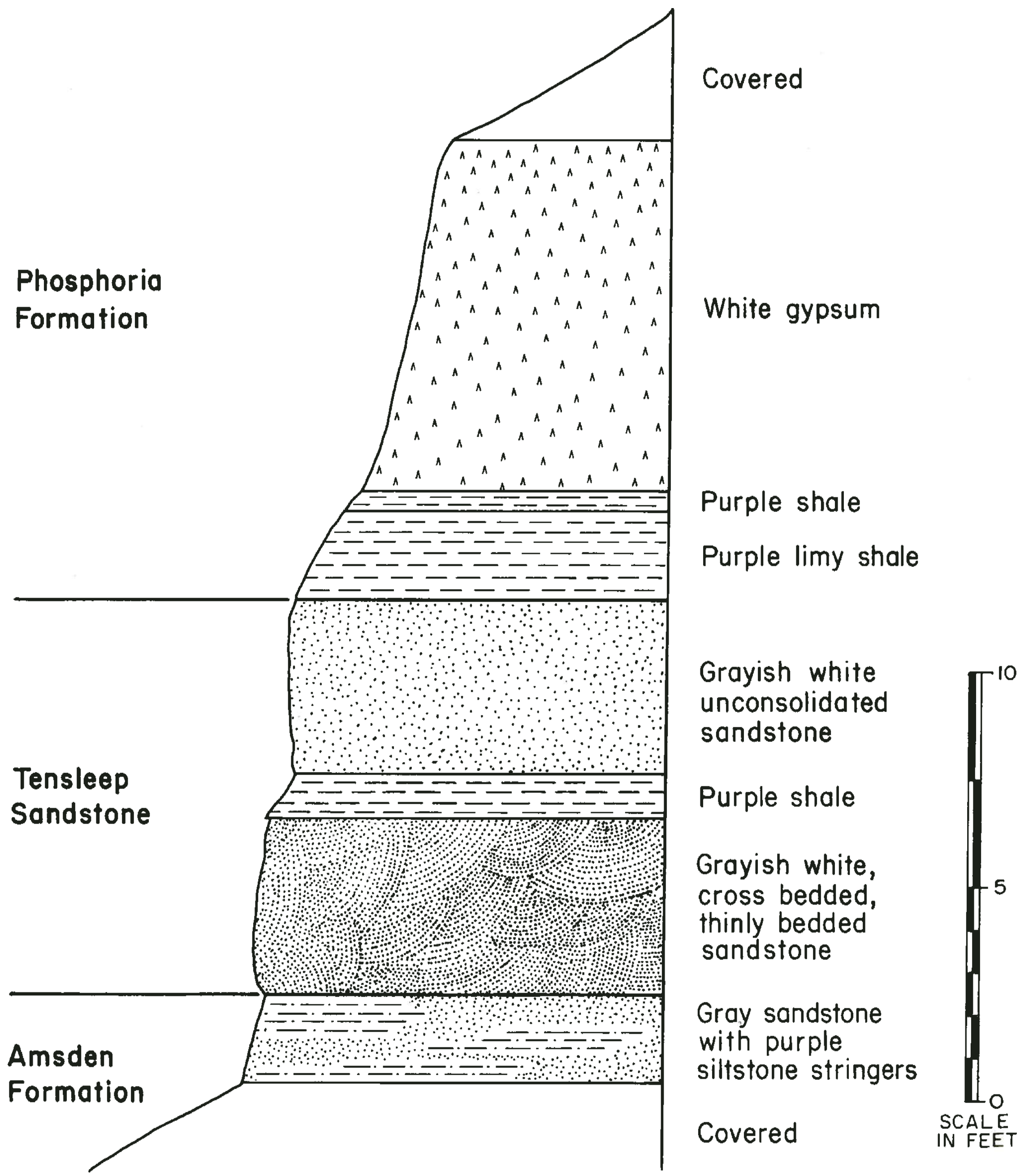


Figure 4. Measured Section No. 3 of the silica sand deposit (located on Plate 1).

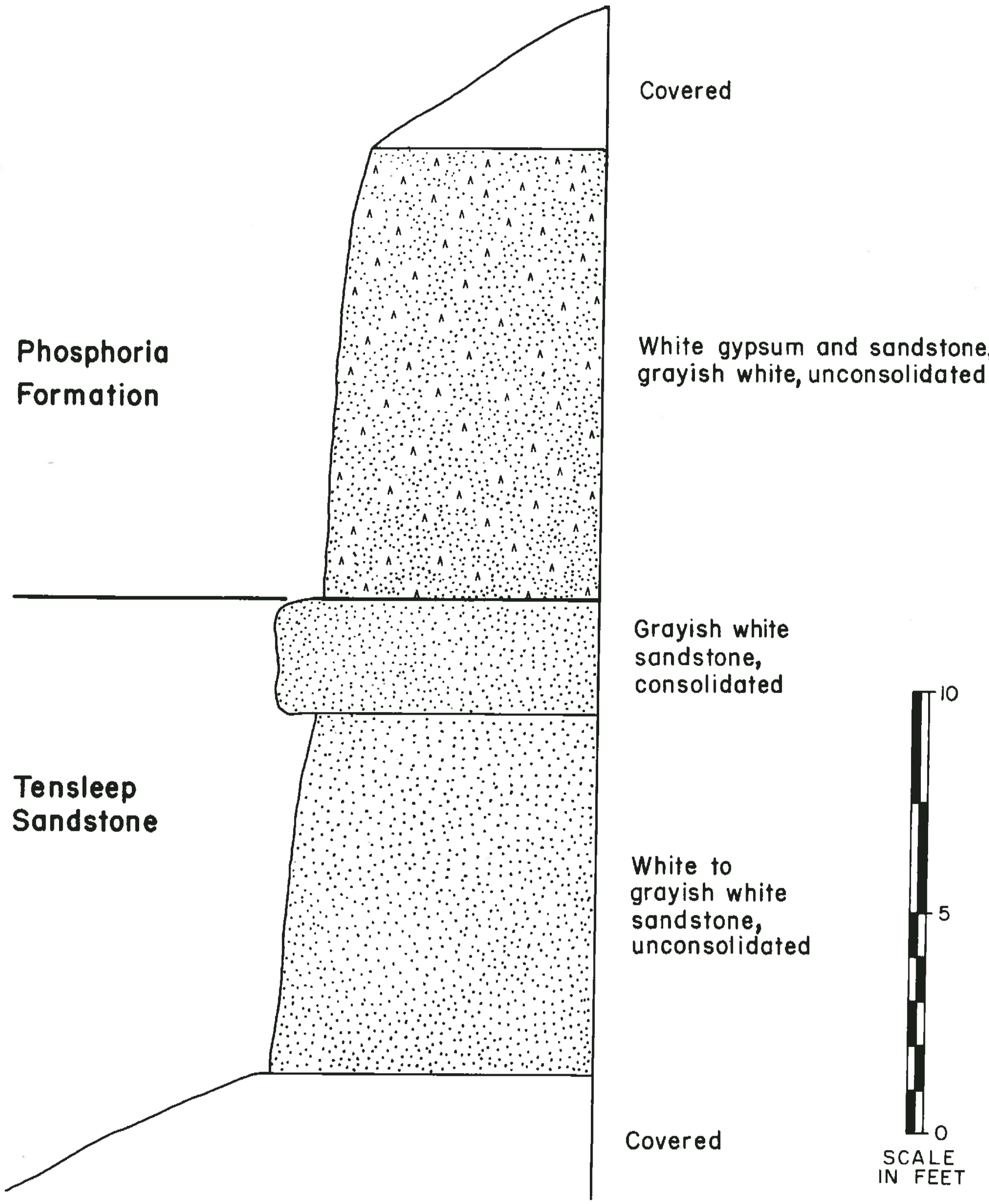


Figure 5. Measured Section No. 4 of the silica sand deposit (located on Plate 1).

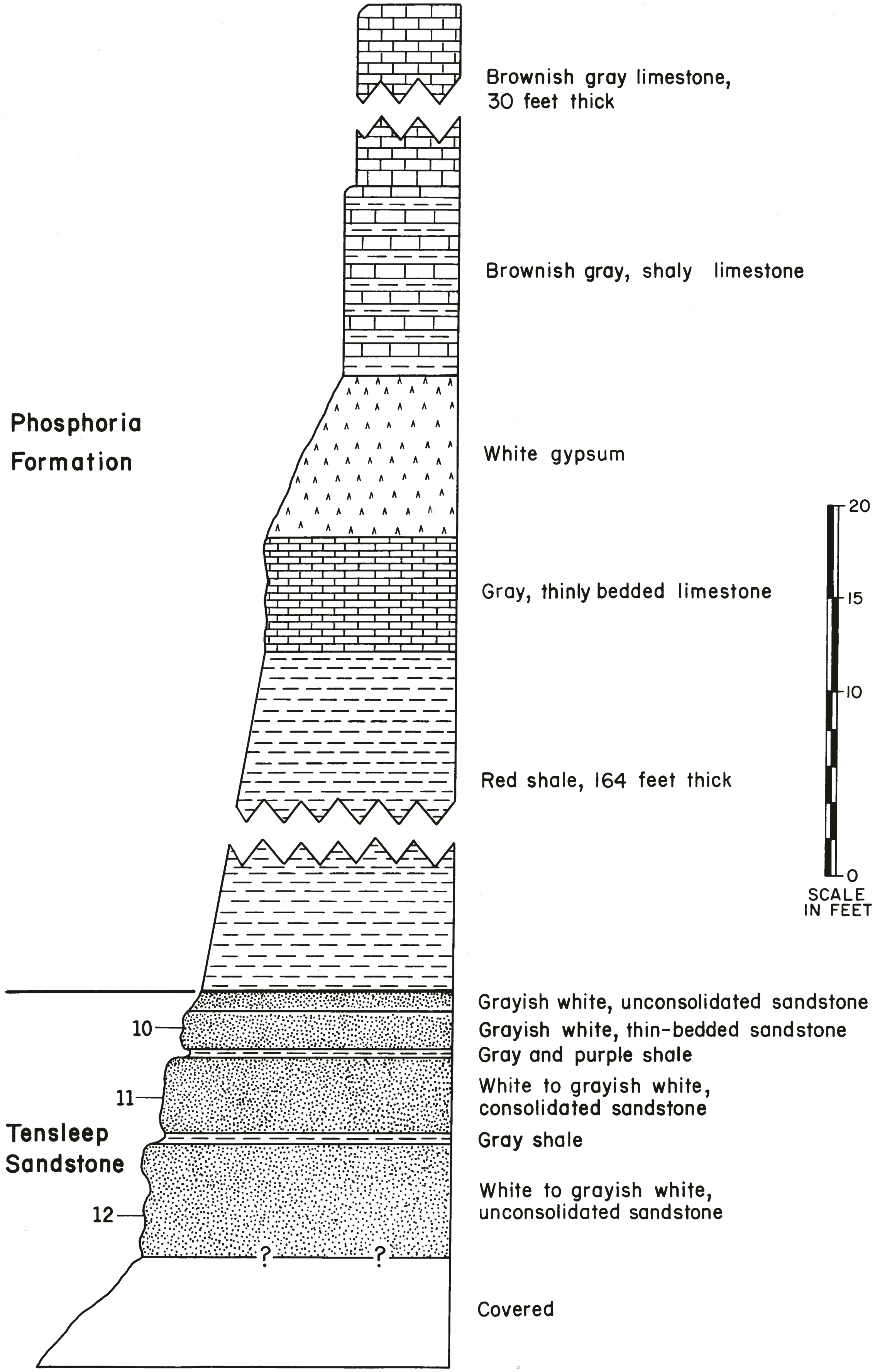


Figure 6. Measured Section No. 5 of the silica sand deposit (located on Plate 1).

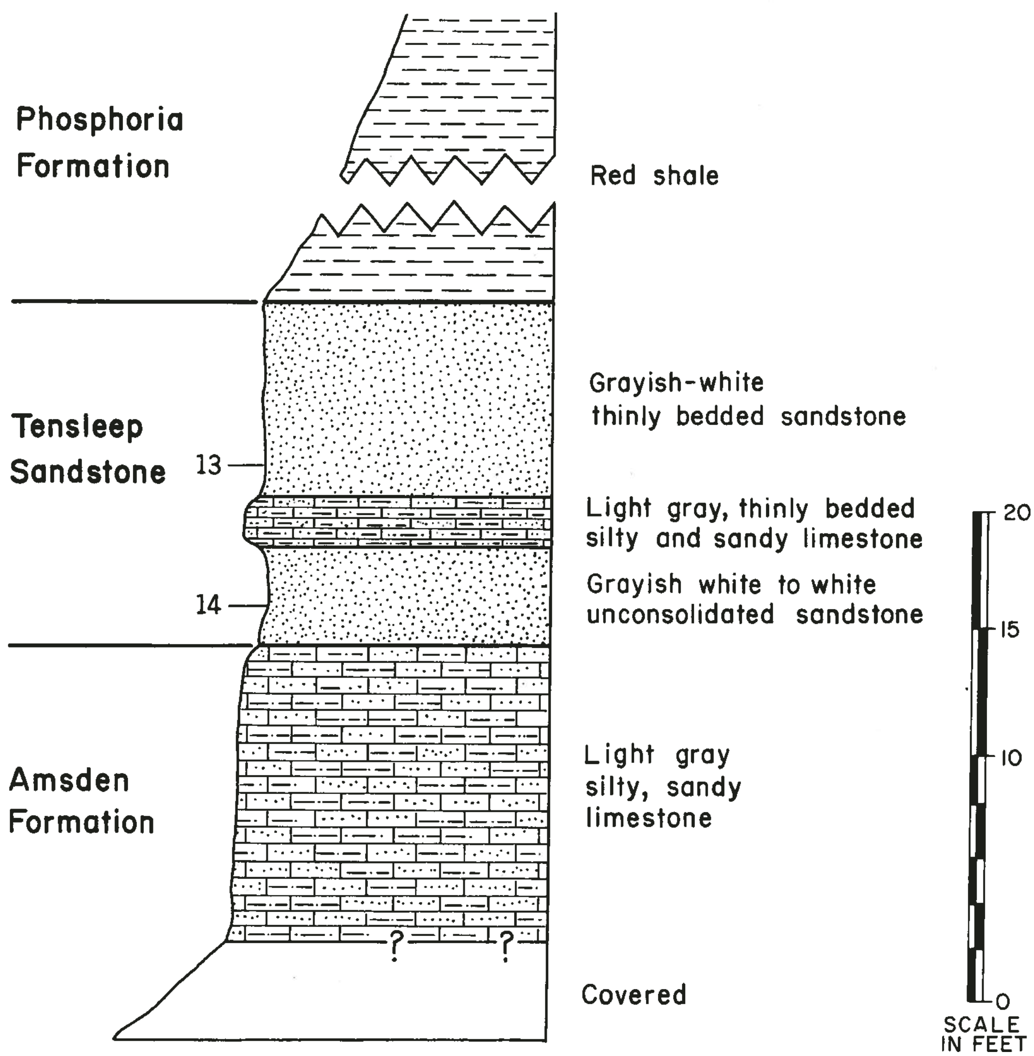


Figure 7. Measured Section No. 6 of the silica sand deposit (located on Plate 1).

Madison Limestone. The Madison Limestone (Mississippian) underlies the Amsden Formation and is the oldest unit exposed in the study area. It forms a narrow, vertical-walled canyon where it is exposed in the deepest parts of John Blue Canyon and forms a dip slope on the monocline in the northeastern halves of section 13, T57N, R94W and section 19, T57N, R93W (**Plate 1**). The formation was first described by Peale (1893) and named for exposures along the Madison River near Three Forks, Montana.

In John Blue Canyon, only the upper 30 feet of the Madison Limestone are exposed. The Madison Limestone here consists of massive to thick-bedded, buff limestone that weathers to a gray to dark gray color. Chert nodules are present, but sparse.

On Little Mountain and its flanks, the contact between the Madison Limestone and the overlying Amsden Formation is an erosional unconformity characterized by the development of paleokarst features in the upper part of the Madison. On Little Mountain and in the adjacent Pryor Mountains of Montana, paleokarst features commonly contain uranium mineralization. Collapse of caves and other paleokarst features after the deposition of at least part of the Amsden Formation and younger units has resulted in the disruption of bedding or the formation of breccia in the overlying rocks. This disruption is discussed below in the section on **Structure**.

Amsden Formation. The Amsden Formation is exposed in the lower walls of John Blue Canyon in sections 23 and 24, T57N, R94W and forms steep slopes often covered by large blocks of the resistant limestone unit of the Phosphoria Formation (**Plate 1**). It was first described by Darton (1904) on the east flank of the Bighorn Mountains and was named after Amsden Creek, a branch of the Tongue River west of Dayton, Wyoming.

In John Blue Canyon, the Amsden Formation consists of about 95 feet of interbedded green and red shale, grayish brown silty shale, and thin-bedded limestone, capped by a purple shale (**Figure 2**). In this area, a sandstone bed about 10 feet thick separates the Amsden Formation from the underlying Madison Limestone. This sandstone is probably the Darwin Sandstone, an informal designation for the lowest sandstone unit in the Amsden Formation.

Tensleep Sandstone. The silica sand unit is the entire thickness of the Tensleep Sandstone in the John Blue Canyon area. This unit is found 114 feet beneath the uppermost red shale of the Phosphoria Formation. The Tensleep Sandstone was named and described by Darton (1904) from exposures in Tensleep Canyon on the west flank of the Bighorn Mountains in Washakie County, Wyoming. It is much thinner in the study area than elsewhere in the Bighorn Mountains. This area may represent the northern edge of the sand dune facies characteristic of most of the Tensleep Sandstone on the eastern flank of the Bighorn Basin.

The Tensleep Sandstone (or silica sand unit) is about 20 feet thick, and in most exposures, can be subdivided into three distinctive subunits (**Figures 3** through **7**). The upper subunit is a 4- to 10-foot thick, white to gray-white, thin-bedded, very friable sandstone. It is a very fine grained sandstone, with subangular to subrounded grains. Gypsum sometimes forms the matrix in this subunit, particularly near the top. The middle subunit is 1 to 6 feet thick and is lithologically similar to the upper subunit. The middle subunit, however, is better cemented than the upper unit, sometimes with calcium carbonate. Thin purple shales, 0.5 to 6 inches thick, are occasionally present (**Figures 3, 4,** and **6**). The lower subunit is about

6 feet thick and is otherwise identical to the upper subunit, except that gypsum is not present. Both the upper and lower subunits weather into loose sand.

The Tensleep sandstone is poorly exposed in the John Blue Canyon area. It is usually covered by debris from overlying units. The best exposures are in John Blue Canyon road cuts, in the strike valley in the northeastern part of the mapped area, and locally along the walls of John Blue and nearby canyons (**Plate 1**).

The Tensleep Sandstone rests with local angular unconformity on the Amsden Formation. Slightly folded beds of the Amsden are truncated by the plane of the lowest sandstone of the Tensleep Sandstone.

Phosphoria Formation. The Phosphoria Formation was first named and described by Richards and Mansfield (1912) for exposures in Phosphoria Gulch, north of Montpelier, Idaho. In the study area, the Phosphoria Formation consists of a lower unit composed of about 114 feet of red, gray-white, and purple silty shales, variably-colored cherty limestone, and gypsum and an upper 60-foot thick limestone unit that caps the formation. The capping limestone appears to rest unconformably, but with no angular discordance, on the uppermost red shale unit.

Red shales and interbedded gypsum are found in the lower part of the Phosphoria Formation. Gypsum beds are visible in the nearly vertical canyon walls, but are covered by red silt and debris on the gentler slopes. The gypsum can often be distinguished by its characteristic popcorn to frothy surface weathering appearance. The best exposures of the gypsum are in the saddle between the hogback just west of the center of section 13, T57N, R94W. Here, massive gypsum is exposed at the surface.

In the study area, a resistant limestone of the Phosphoria Formation forms dip slopes and hogback ridges. Where cut by transverse canyons, this limestone forms vertical walls at the top of the canyons. It is overlain by red siltstones and shales of the undivided Dinwoody Formation and Chugwater Group in SW section 23, T57N, R94W (**Plate 1**). In the walls of John Blue Canyon, this limestone is light yellowish gray. It consists of an upper, cherty, massive limestone unit (more than 30 feet thick), 15 feet of thin bedded, gray limestone in the middle, and a basal 12-foot thick unit of massive limestone (**Figure 2**).

Structure

Three major structures and two minor structures are present in the study area (**Plate 1**). Northeast of a line drawn diagonally through the center of sections 11 and 13, T57N, R94W and section 19, T57N, R93W, the strata dip about 35° southwest along a monocline. Southwest of this line, the strata dip from 4° to 7° southwest on the homocline that is the dominant structural feature in the area. The homocline is characterized geomorphically by an extensive low-angle dip slope on the resistant limestone in the Phosphoria Formation. Another monocline is present southwest of a line drawn from the southwestern corner of section 14, T57N, R94W to the center of section 24, T57N, R93W. Dips along this monocline are about 20° southwest. No major faults were noted in the study area.

A smaller scale structural feature in the area is a large displaced block of the Phosphoria Formation exposed at the head of John Blue Canyon. This block has been displaced downward and possibly southwestward (**Plate 1**). This feature appears to be a block slide, with the slide plane on a gypsum bed in the Phosphoria Formation. The silica sand deposit lies below the block and is unaffected by the slide. Another small block slide is located in SW SW section 14, T57N, R94W (**Plate 1).**

A brecciated zone was encountered in Drill Hole No. 2 (SE SE NE, section 13, T57N, R94W) (**Plate 1**). In this hole, 136 feet of undisturbed Phosphoria Formation rocks were drilled. At 138.5 feet, just below a 2.5-foot-thick limestone, a breccia consisting of broken fragments of red and purple siltstones and claystones from the Phosphoria Formation was encountered. This breccia was probably formed by the collapse of paleokarst features in the underlying Madison Limestone. These breccia zones may extend upward through the Amsden Formation, the Tensleep Sandstone, and the lower Phosphoria Formation to the base of the resistant limestone that caps the Phosphoria Formation.

Silica sand reserves

The resource and reserve terminology used in this report is that defined by the U.S. Bureau of Mines and the U.S. Geological Survey (1980).

The Tensleep Sandstone constitutes an indicated, marginal reserve of silica sand in the John Blue Canyon study area. Where it crops out, this sandstone is 5 to 22 feet thick, and averages 20 feet in thickness. The silica sand is exposed in John Blue Canyon and in an unnamed canyon in the southwest corner of section 14, T57N, R94W (**Plate 1**). The silica resource area underlies about 2,250 acres and encompasses the southwestern half of section 13; all but NE NE section 14; the northeastern third of section 15; NE, section 23; all of section 24, T57N, R94W; and the southwestern half of section 19, T57N, R93W (**Plate 1**). In this area, about 320 acres of the resource have been removed by erosion (such as in John Blue Canyon), which leaves an area of 1,930 acres that still contains silica resources. Assuming that the sand averages 20 feet thick over the entire area and weighs 2.19 short tons per cubic yard, the indicated marginal reserves of silica sand are about 186,382,000 short tons. An additional inferred, marginal reserve of 106 million short tons of silica sand is probably present beneath the more steeply dipping monocline southwest of the resource area described above, including the area under section 25, T57N, R94W (**Plate 1).**

An average grade of 87.3 percent SiO_2 was determined by chemical analyses of 15 surface samples of the silica sand (**Table 5**). **Table 5** also shows the for percentages of elemental impurities in the samples. The locations of these samples are plotted on the geologic map (**Plate 1**) and are shown on the lithologic columns (**Figures 3**, **6**, and **7**).

Economic factors

Other mineral raw materials used in the manufacture of glass are all found relatively close to the John Blue Canyon silica sand deposit. Large quantities of soda ash are used in the production of most types of glass. Ninety percent of all domestic soda ash is produced by five companies that operate mines and processing plants west of Green River, Wyoming, about 300 miles from Lovell. A portion of the produced soda ash is trucked to Bonneville, Wyoming, 130 miles south of Lovell, where it is loaded into railroad cars. Some of this soda ash is then shipped on the Burlington Northern Railroad line that passes within 6 miles of John Blue Canyon (**Figure 1**).

Table 5. Whole-rock chemical analyses of surface samples from the John Blue Canyon silica sand deposit (values in weight percent). (Totals may not equal 100% because of analytical procedures).

Sample Number[1]	SiO_2	Al_2O_3	Fe_2O_3	Cr_2O_3	K_2O	Na_2O	CaO	MgO	MnO	BaO	TiO_2	P_2O_5	S	LOI[2]	Total
Tensleep Sandstone - silica sand (Measured Section 2, Figure 3).															
1	94.00	1.30	0.18	<0.01	0.92	0.06	0.45	0.37	<0.01	0.01	0.08	0.12	0.03	0.49	98.01
2	94.80	0.99	0.18	<0.01	0.61	0.03	0.85	0.39	<0.01	0.01	0.06	0.30	0.02	1.20	99.44
3	92.60	1.80	0.31	<0.01	1.25	0.02	0.81	0.38	<0.01	0.03	0.17	0.13	<0.02	1.02	98.52
4	81.60	1.76	0.32	<0.01	1.18	0.04	4.44	3.16	0.01	0.01	0.10	0.29	<0.02	6.80	99.71
5	54.80	2.46	0.43	<0.01	1.71	0.04	11.50	8.40	0.03	0.02	0.13	0.21	0.02	18.45	98.20
6	89.20	2.09	0.79	<0.01	0.88	0.01	1.03	1.19	<0.01	0.01	0.09	0.02	0.30	3.04	98.65
7	93.40	0.95	0.16	<0.01	0.63	<0.01	0.94	0.50	<0.01	0.01	0.07	0.11	0.02	1.32	98.11
8	95.70	1.32	0.22	<0.01	0.96	0.05	0.17	0.47	<0.01	0.02	0.10	0.12	<0.02	0.60	99.73
9	88.20	1.08	0.13	<0.01	0.80	<0.01	3.17	1.44	<0.01	0.01	0.05	0.06	0.02	3.96	98.92
Tensleep Sandstone - silica sand (Measured Section 5, Figure 6).															
10	82.30	0.87	0.12	<0.01	0.56	0.02	9.61	0.41	<0.01	0.01	0.06	0.20	<0.02	6.94	101.10
11	94.70	0.72	0.10	<0.01	0.47	0.01	1.34	0.28	<0.01	<0.01	0.05	0.15	0.03	1.21	99.06
12	96.80	0.50	0.07	<0.01	0.24	0.01	0.60	0.14	<0.01	<0.01	0.05	0.20	<0.02	0.69	99.30
Tensleep Sandstone - limy sandstone (Measured Section 6, Figure 7).															
13	73.00	0.70	0.09	<0.01	0.52	0.02	13.60	0.12	0.02	<0.01	0.05	0.20	0.04	10.19	98.55
Tensleep Sandstone - silica sand (Measured Section 6, Figure 7).															
14	88.90	1.27	0.15	<0.01	0.95	0.03	3.86	0.16	<0.01	0.01	0.08	0.10	0.02	3.06	98.59
Tensleep Sandstone - silica sand outcrop (NE1/4 SW1/4 SE1/4 Sec. 13, T57N, R94W, Plate 1.)															
15	89.80	0.87	0.13	<0.01	0.59	0.01	3.92	0.19	<0.01	<0.01	0.08	0.20	<0.02	3.06	98.85

[1] Sample numbers are those shown on Plate 1.
[2] LOI = loss on ignition.

Limestone and feldspar are other ingredients used in the manufacture of glass. Limestone is available in the Madison Limestone just north of John Blue Canyon, or at many other locations nearby (Harris and Meyer, 1986). The Madison Limestone is presently quarried on the west flank of the Pryor Mountains, Montana, just north of the Wyoming border (**Figure 1**) and shipped by rail to Billings, Montana, and Scottsbluff and Mitchell, Nebraska, where it is used in the refining of sugar beets into sugar. Feldspar deposits are found just north of Bonneville (**Figure 1**) (Harris and others, 1985). Feldspar is often used to strengthen certain types of glass.

The closeness of the John Blue Canyon silica sand deposit to paved, all-weather roads and to rail transportation (**Figure 1**) decreases the transportation costs of both raw materials and finished products. The John Blue Canyon deposit is six miles by road from the Burlington Northern Railroad's siding at Kane, five miles from paved U. S. Highway 14A, and eleven miles from the nearest town, Lovell. There are potential sites for glass manufacturing plants along the Burlington Northern Railroad line from Kane to Lovell. Other industrial plants are already located in the area, including bentonite plants near Lovell and a gypsum plant south of Lovell. Lovell also has a sugar beet refining plant. Power is available from local suppliers.

The deposit is located 1,500 feet higher in elevation than the area around Kane and Lovell. Some sort of gravity-operated belt or tram system may be feasible to transport silica sand from the deposit to a plant site.

The 174 feet of overburden over most of the silica deposit makes extraction by conventional, surface mining methods uneconomical or marginal at best. Because the sand is poorly consolidated, it might be economically feasible to recover this sand by borehole mining. This method, however, has not been tried for the recovery of silica sand. Loest (1979), and Savanick (1979) do describe tests of this method in mining a uranium-rich sandstone and other minerals.

In these tests, vertical holes were drilled into sandstone. A specialized tool containing a high-pressure, rotating nozzle and openings for recovery of material was placed in the hole. Water under high pressure was sprayed from the rotating nozzle into the sandstone unit. The stream of water loosened the sand and formed a slurry which was pumped to the surface. At the surface, a recovery plant separated the sand from the fine impurities and water (**Figure 8).**

Summary

In the area of John Blue Canyon there is an estimated 186 million tons of silica sand, averaging 87.3 percent silica, present in the Tensleep Sandstone. Under present economic conditions, this deposit is classified as an indicated, marginal reserve. Should certain economic conditions improve, or if a low-cost mining method be developed, the deposit could be upgraded in classification to an indicated reserve. Additional drilling is needed to define the measured reserves in this deposit (U.S. Bureau of Mines and the U.S. Geological Survey, 1980).

Because this silica sand deposit is overlain by 174 feet of overburden, it is not economically recoverable by conventional surface or underground mining techniques. It may require a hydraulic

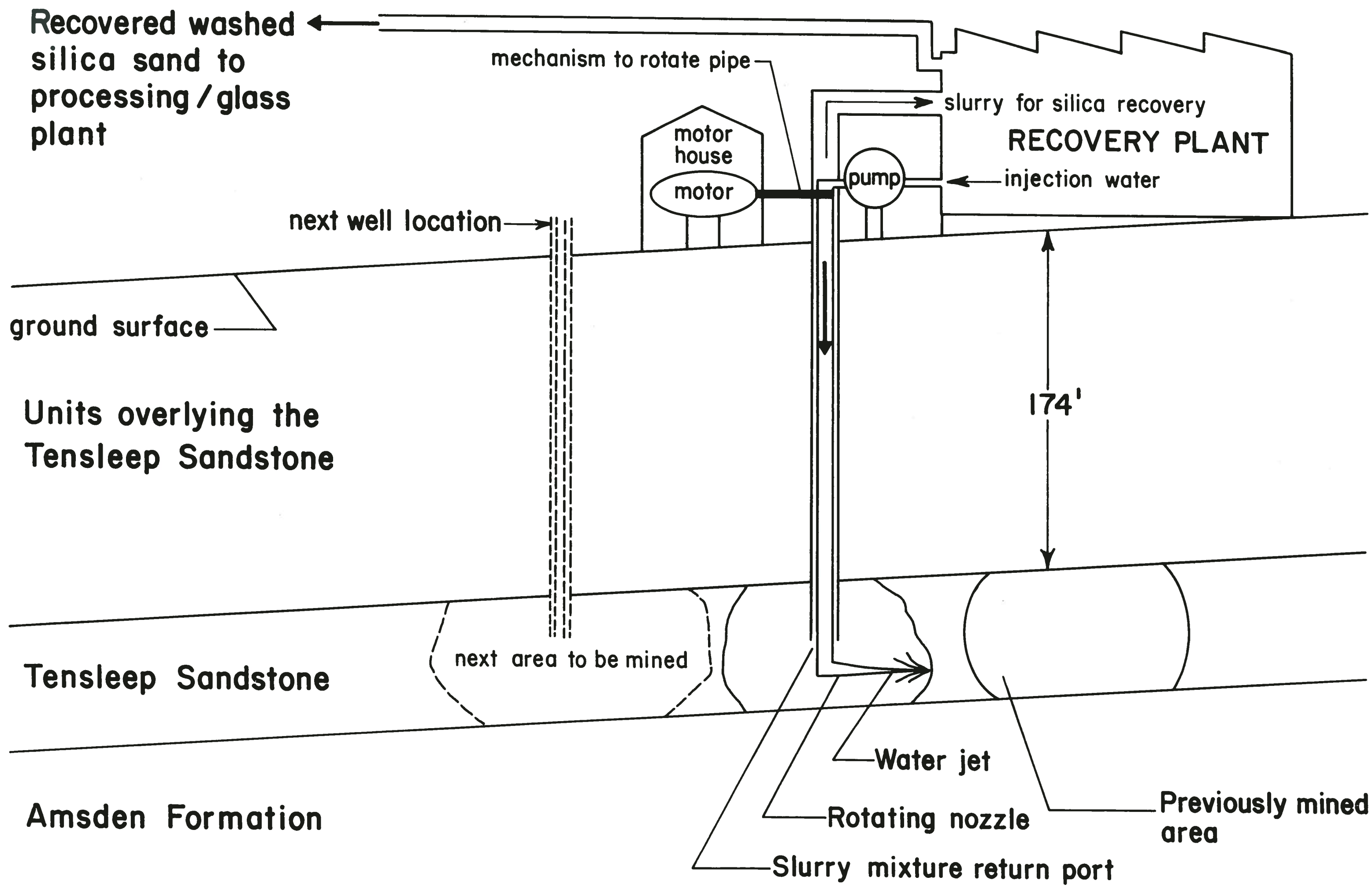


Figure 8. Schematic diagram of a borehole mining method.

borehole mining method to economically recover this silica sand. Transportation of the mined silica sand from a recovery site at John Blue Canyon to a manufacturing plant site involves a drop of 1,500 feet in elevation. Innovative transportation methods including a tramway or a conveyor system may be feasible.

Due to the fineness of the raw material, the John Blue Canyon silica sand deposit may lend itself particularly to the manufacture of fused silica products. Also, the silica sand may possibly be beneficiated by washing with water to meet specifications for glass sand. The presence of nearby resources of limestone, feldspar, and soda ash enhance the economic favorability for nearby production of glass or fused silica products. Existing transportation routes may facilitate shipping finished glass products.

References Cited

Anchor Hocking Glass Company, 1981, Sand — crystal glass (tableware): Anchor Hocking Technical Services Standard 208-700-005-02, 1 p.

Balster, C.A., 1980, Stratigraphic nomenclature chart for Montana and adjacent areas, third edition: Montana Bureau of Mines and Geology, 1 sheet.

Bates, R.L., and Jackson, J.A., editors, 1987, Glossary of geology, third edition: American Geological Institute, Alexandria, Virginia, 788 p.

Bentzen, E.H., III, 1979, Production and processing problems of western glass sands: Colorado Geological Survey Resource Series 8, p. 63-74.

Bolen, W.P., 1990, Industrial sand and gravel: U.S. Bureau of Mines Minerals Yearbook 1988, v. 1, p. 833 - 843.

Bolen, W.P., 1992, Directory of industrial sand and gravel producers in the United States in 1991: U.S. Bureau of Mines Mineral Industry Surveys, 8 p.

Darton, N.H., 1904, Comparison of the stratigraphy of the Black Hills., Bighorn Mountains, and Rocky Mountain Front Range: Geological Society of America Bulletin 15, p. 379-448.

Gambogi, Joseph, 1990, Silicon: U.S. Bureau of Mines Minerals Yearbook 1988, v. 1, p. 845-853.

Harker, A.B., and Flintoff, J.F., 1984, Polyphase ceramic and glass-ceramic forms for immobilizing ICCP high-level nuclear waste, *in* McVay, G.L., editor, Scientific basis for nuclear waste management III: Elsevier, New York, p. 513-520.

Harris, R.E., Hausel, W.D., and Meyer, J.E., 1985, Metallic and industrial minerals map of Wyoming: Geological Survey of Wyoming Map Series 14, scale 1:500,000.

Harris, R.E., and Meyer, J.E., 1986, Construction materials map of Wyoming: Geological Survey of Wyoming Map Series 21, scale 1:500,000.

Huntley, F.D., and Snow, R.R., 1986, Mineral raw materials for flat glass manufacturing: Society of Mining Engineers Preprint 86-40, 8 p.

Loest, K.W., 1979, Development of an in situ operation—Nine Mile Lake: Proceedings third annual uranium seminar, American Institute of Mining, Metallurgical, and Petroleum Engineers, Casper, Wyoming, p. 75-77.

Neuharth, C.R., 1989, Silicon: U.S. Bureau of Mines Mineral Commodity Summaries, 1989, p. 144-142.

Ondracer, G., and Toscano, E.H., 1984, In-can hot pressing of borosilicate glass for the immobilization of high- and medium-level wastes, in McVay, G.L., editor, Scientific basis for nuclear waste management III: Elsevier, New York, p. 591-596.

Peale, A.C., 1893, The Paleozoic section in the vicinity of Three Forks, Montana: U.S. Geological Survey Bulletin 110, p. 33-39.

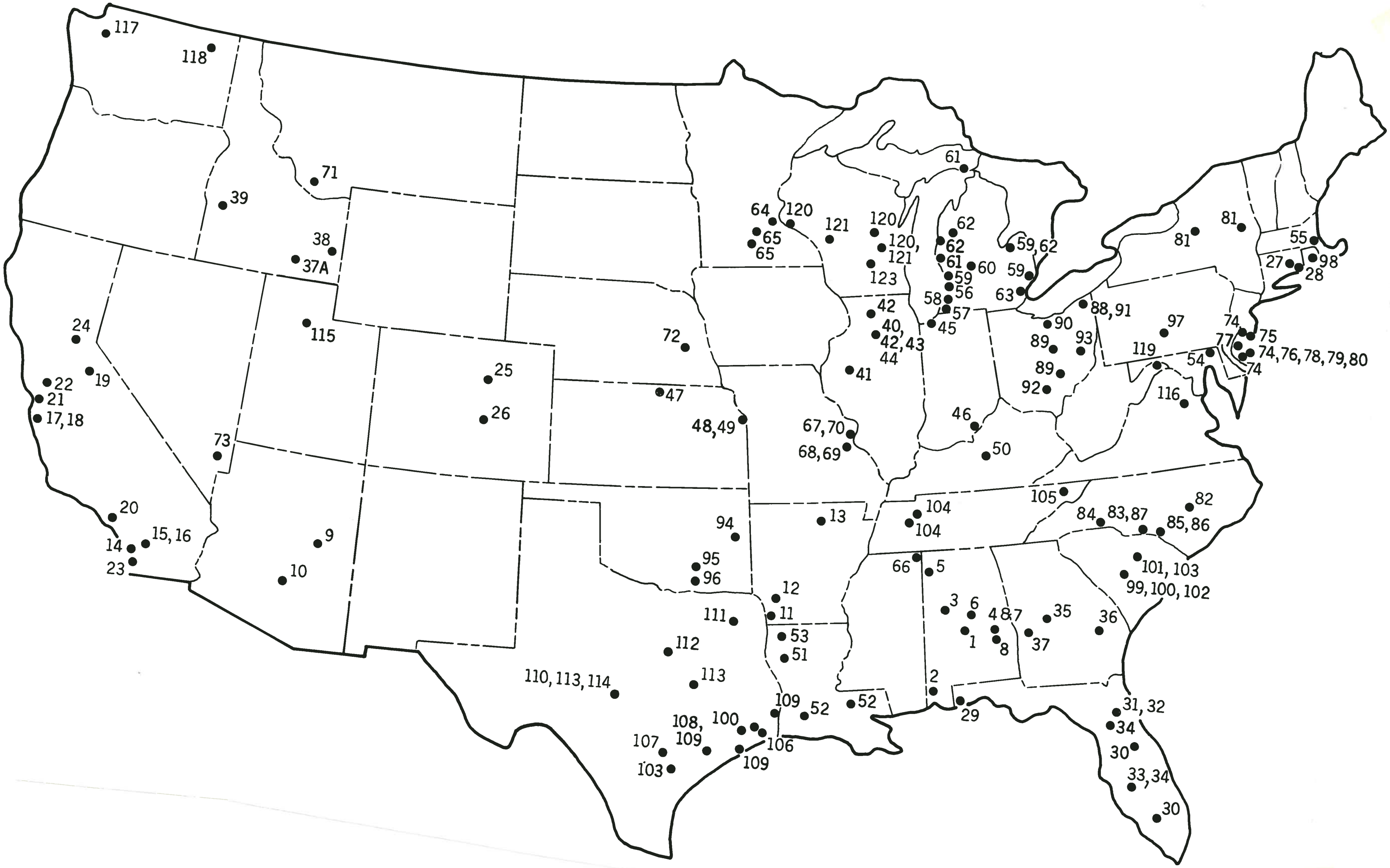
Richards, R.W., and Mansfield, G.R., 1912, The Bannock overthrust, a major fault in southeastern Idaho and northeastern Utah: Journal of Geology, v. 20, p. 681-709.

Savanick, G.A., 1979, Borehole (slurry) mining of coal and uraniferous sandstone: Proceedings third annual uranium seminar, American Institute of Mining, Metallurgical, and Petroleum Engineers, Casper, Wyoming, p. 115-125

Teipordei, V.V., 1987, Sand and gravel: U.S. Bureau of Mines Minerals Yearbook 1985, v. 1, p. 821-835.

U.S. Bureau of Mines and the U.S. Geological Survey, 1980, Principles of a resource/reserve classification for minerals: U.S. Geological Survey Circular 831, 5 p.

White, J.B., 1983, Trends in the flat glass industry: Collected Papers from the 44th Annual Conference on Glass Problems, University of Illinois at Urbana-Champaign, p. 7-9.



Appendix A. Geographic locations of glass sand, hydraulic fracturing sand, and silica rock producers in the United States in 1991 (Bolen, 1992).

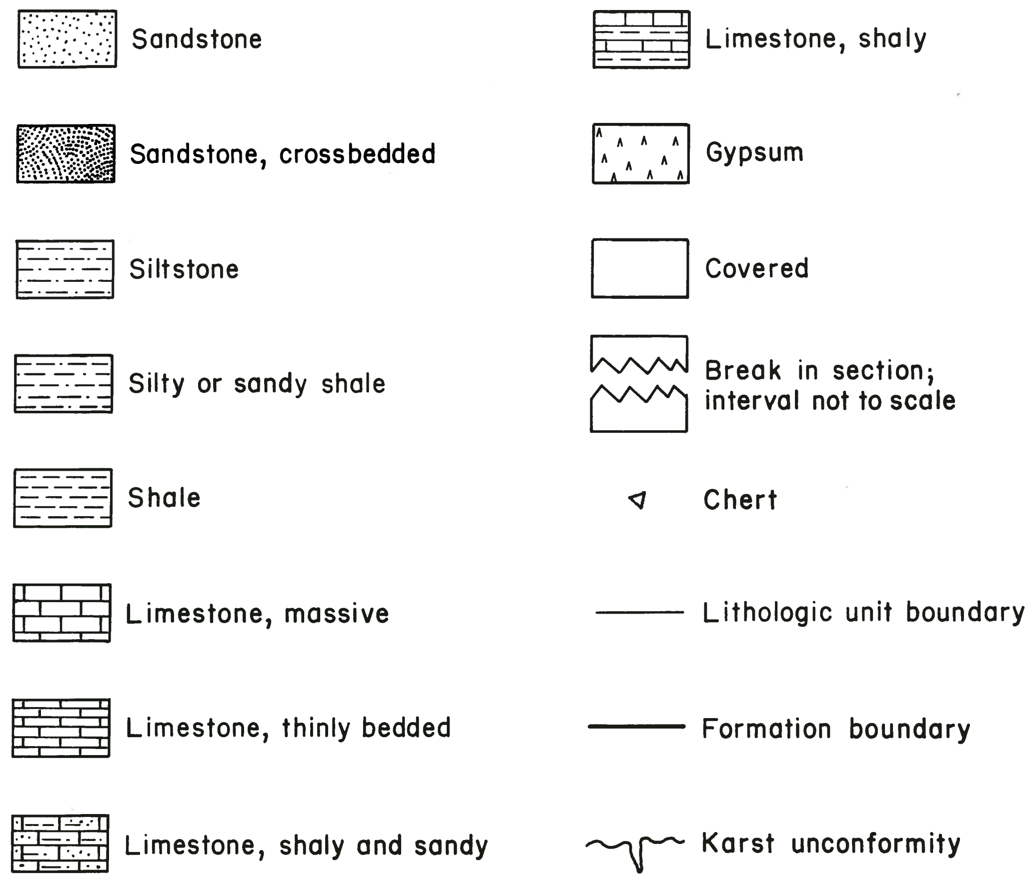
Appendix B. List of glass sand, hydraulic fracturing sand, and silica rock producers in the United States in 1991 (after Bolen, 1992).

Number on Appendix A map	State and producer	Number of Active Operations
	Alabama	
1	Cosby-Carmichael, Inc.	1
2	Dravo Basic Materials Company, Inc.	1
3	The Morie Company, Inc.	1
4	R and S Materials, Inc.	1
5	Spruce Pine Sand and Gravel Company	1
6	Superior Products, Inc.	1
7	Tuskegee Sand and Gravel, Inc.	1
8	U.S. Silica Company	1
	Arizona	
9	Arizona Silica Sand Company	
10	Inspiration Consolidated Copper Company	1
	Arkansas	
11	Gifford-Hill and Company, Inc.	1
12	Ideal Basic Industries, Inc.	1
13	Unimin Corporation	1
	California	
14	California Silica Products Company	1
15	Corona Industrial Sand Company	1
16	Gifford-Hill and Company, Inc.	1
17	Lone Star Industries, Inc.	1
18	Monterey Sand Company, Inc.	2
19	Owens-Illinois, Inc.	1
20	P.W. Gillibrand Company	1
21	Santa Cruz Aggregates Company	1
22	Unimin Corporation	1
23	U.S. Silica Company	1
24	Yuba Silica, Inc.	1
	Colorado	
25	Cherry Creek Sand Specialties Company	1
26	Colorado Silica Sand, Inc.	1
	Connecticut	
27	The Feldspar Corporation	1
28	U.S. Silica Company	1
	Florida	
29	Clark Sand Company, Inc.	1
30	E.R. Jahna Industries, Inc.	2
31	The Feldspar Corporation	1
32	Florida Rock Industries, Inc.	1
33	Gall Silica Mining Company, Inc.	1
34	Standard Sand and Silica Company	3

Number on Appendix A map	State and producer	Number of Active Operations
	Georgia	
35	Atlanta Sand and Supply	1
36	Montgomery Sand Company	1
37	The Morie Company, Inc.	1
	Idaho	
37A	FMC Corporation	1
38	Monsanto Industrial Chemicals Company	1
39	Unimin Corporation	1
	Illinois	
40	Manley Brothers of Indiana, Inc.	1
41	Manito Investment Company	1
42	Unimin Corporation	3
43	U.S. Silica Company	1
44	Wedron Silica Company	1
	Indiana	
45	Crisman Sand Company, Inc.	1
46	U.S. Silica Company	1
	Kansas	
47	Alsop Sand Company, Inc.	1
48	Kaw Valley Sand and Gravel, Inc.	1
49	List and Clark Construction Company	1
	Kentucky	
50	Green River Silica Company	1
	Louisiana	
51	Cobb Industrial Corporation	1
52	Southern Silica of Louisiana	2
53	U.S. Silica Company	1
	Maryland	
54	Harford Sands, Inc.	1
	Massachusetts	
55	WHIBCO, Inc.	1
	Michigan	
56	Cheyenne Sand Corporation	2
57	Evans Mining Corporation	2
58	Manley Brothers of Indiana, Inc.	2
59	Nugent Sand Company, Inc.	3
60	Pierson Sand and Gravel, Inc.	1
61	Sand Products Corporation	2
62	Sargent Sand Company	3
63	U.S. Silica Company	1

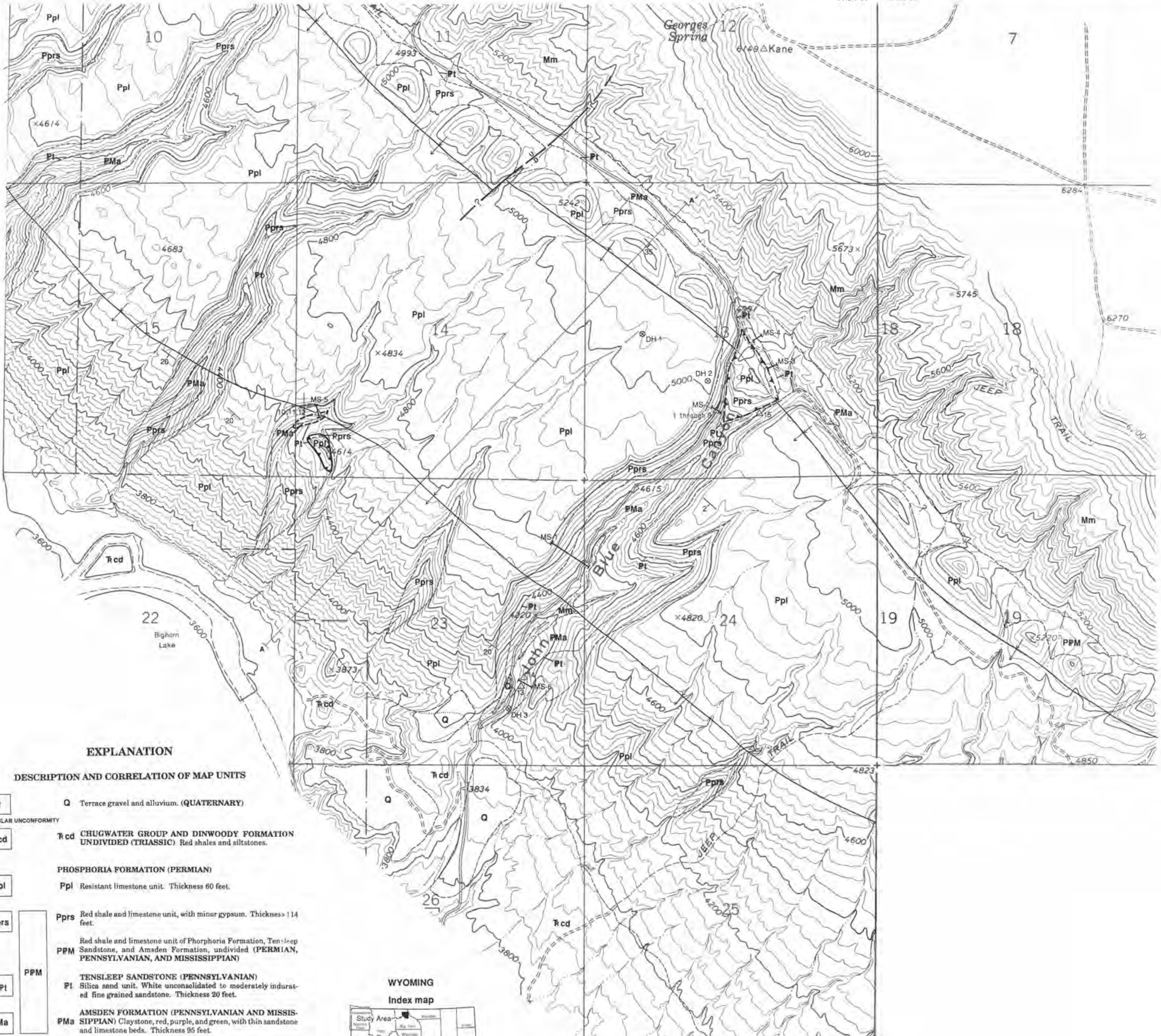
Number on Appendix A map	State and producer	Number of Active Operations
	Minnesota	
64	Twin Cities Silica, Ltd.	1
65	Unimin Corporation	2
	Mississippi	
66	Tri- Sands, Inc.	1
	Missouri	
67	All Purpose Sand Company	1
68	Bussen Quarries, Inc.	1
69	Unimin Corporation	1
70	U.S. Silica Company	1
	Montana	
71	Rhone-Poulenc Basic Chemicals Company	1
	Nebraska	
72	Western Sand and Gravel Company	1
	Nevada	
73	Simplot Silica Products	1
	New Jersey	
74	The Morie Company, Inc.	4
75	N.J. Pulverizing Company	1
76	Ricci Brothers Sand Company, Inc.	1
77	South State, Inc.	1
78	Unimin Corporation	1
79	U.S. Silica Company	1
80	WHIBCO, Inc.	2
	New York	
81	WHIBCO, Inc.	2
	North Carolina	
82	Becker Minerals, Inc.	1
83	Lessees of B.V. Hedrick Gravel and Sand Company	1
84	KMG Minerals, Inc.	1
85	Southern Products and Silica Company, Inc.	1
86	Unimin Corporation	1
87	W.R. Bonsal Company, Inc.	1
	Ohio	
88	Best Sand Corporation	1
89	Central Silica Company	2
90	Keener Sand and Clay Company	1
91	R.W. Sidley, Inc.	1
92	Southern Silica, Inc.	1
93	U.S. Silica Company	1

Number on Appendix A map	State and producer	Number of Active Operations
	Oklahoma	
94	APAC Arkansas, Inc.	1
95	Unimin Corporation	1
96	U.S. Silica Company	2
	Pennsylvania	
97	U.S. Silica Company	1
	Rhode Island	
98	Holliston Sand Company, Inc.	1
	South Carolina	
99	Columbia Silica Sand Company	1
100	Foster Dixiana Corporation	1
101	Unimin Corporation	1
102	U.S. Silica Company	1
103	WHIBCO, Inc.	1
	Tennessee	
104	The Morie Company, Inc.	2
105	Short Mountain Silica Company	1
	Texas	
106	Barry and Barry Sand Company, Inc.	1
107	Palo Alto Silica Sand, Company	1
108	Pioneer Concrete of Texas, Inc.	2
109	Specialty Sand Company	3
110	Texas Mining Company	1
111	Tyler Sand Company	1
112	Unimin Corporation	1
113	U.S. Silica Company	3
114	Vulcan Materials Company	1
	Utah	
115	Salt Lake Valley Sand and Gravel Company	1
	Virginia	
116	Unimin Corporation	1
	Washington	
117	L-Bar Products, Inc.	1
118	Lane Mountain Silica Company	1
	West Virginia	
119	U.S. Silica Company	1
	Wisconsin	
120	A.F. Gelhar Company, Inc.	2
121	Badger Mining Corporation	3
122	Bay City Silica Company	1
123	Unimin Corporation	1



Appendix C. Explanation of lithologic symbols used in measured sections

Open File Report, 92-3: Plate 1
John Blue Canyon Silica Sand Deposit



EXPLANATION

DESCRIPTION AND CORRELATION OF MAP UNITS

QUATERNARY

Q Terrace gravel and alluvium. (**QUATERNARY**)

ANGULAR UNCONFORMITY

TRIASSIC

Ꮂcd **CHUGWATER GROUP AND DINWOODY FORMATION UNDIVIDED (TRIASSIC)** Red shales and siltstones.

PERMIAN

PHOSPHORIA FORMATION (PERMIAN)

Ppl Resistant limestone unit. Thickness 60 feet.

Pprs Red shale and limestone unit, with minor gypsum. Thickness 114 feet.

PPM Red shale and limestone unit of Phorphoria Formation, Tensleep Sandstone, and Amsden Formation, undivided (**PERMIAN, PENNSYLVANIAN, AND MISSISSIPPIAN**)

PENNSYLVANIAN

Pt **TENSLEEP SANDSTONE (PENNSYLVANIAN)** Silica sand unit. White unconsolidated to moderately indurated fine grained sandstone. Thickness 20 feet.

MISSISSIPPIAN

PMa **AMSDEN FORMATION (PENNSYLVANIAN AND MISSISSIPPIAN)** Claystone, red, purple, and green, with thin sandstone and limestone beds. Thickness 95 feet.

KARST UNCONFORMITY

Mm **MADISON LIMESTONE (MISSISSIPPIAN)** Limestone, buff, gray weathering, thick to massive bedded. Only upper 30 feet exposed in map area.

SYMBOLS USED ON MAP

CONTACT - Dashed where approximately located, dotted where inferred.

LOW ANGLE FAULT - Dashed where approximately located. Teeth on upper plate of fault.

NORMAL FAULT - Relative movement between fault blocks shown.

MONOCLINAL AXIS - Dotted beneath displaced blocks on upper plate of low angle fault.

35 STRIKE AND DIP OF BEDS

DH 2 DRILL HOLE LOCATION AND HOLE NUMBER

8 SAMPLE LOCATION - Number refers to sample numbers on Table 5.

MS-3 MEASURED SECTION

A — A' LINE OF CROSS SECTION

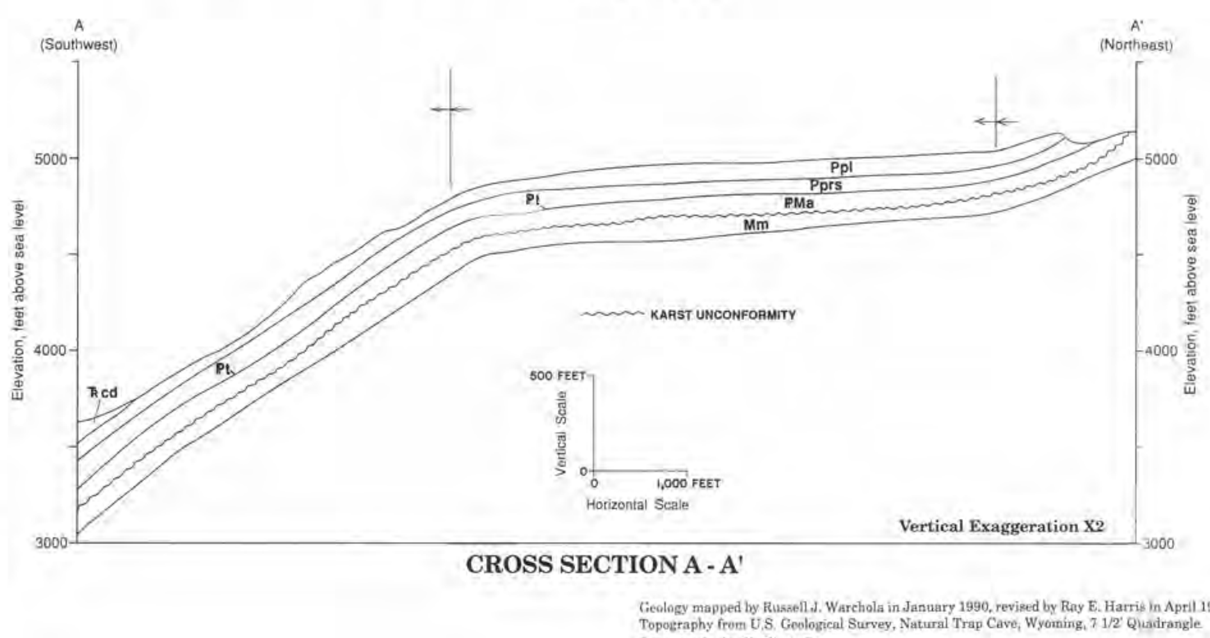
WYOMING
Index map

North

Scale

0 — 1 Mile
0 — 5,000 Feet
0 — 1 — 2 Kilometers

Contour interval 40 feet



CROSS SECTION A - A'

Geology mapped by Russell J. Warchola in January 1990, revised by Ray E. Harris in April 1990.
Topography from U.S. Geological Survey, Natural Trap Cave, Wyoming, 7 1/2' Quadrangle.
Cartography by Phyllis A. Ranz.

GEOLOGIC MAP OF THE JOHN BLUE CANYON SILICA SAND DEPOSIT, BIG HORN COUNTY, WYOMING

by
Ray E. Harris and Russell J. Warchola
1992