THE GEOLOGICAL SURVEY OF WYOMING
Gary B. Glass, State Geologist

THE PLUMBAGO CREEK SILICA SAND DEPOSIT, ALBANY COUNTY, WYOMING

by
Ray E. Harris

Report of Investigations No. 40
1988

Laramie, Wyoming

First printing of 400 copies by Cheyenne Newspapers, Cheyenne, Wyoming.

This and other publications available from: The Geological Survey of Wyoming
P.O. Box 3008, University Station
Laramie, Wyoming 82071

Cover: Festoon-crossbedded Casper Formation sandstone, Plumbago Creek silica sand deposit.

THE GEOLOGICAL SURVEY OF WYOMING
Gary B. Glass, State Geologist

Report of Investigations No. 40

THE PLUMBAGO CREEK SILICA SAND DEPOSIT, ALBANY COUNTY, WYOMING

by
Ray E. Harris

Laramie, Wyoming
1988

Contents

Illustrations

Figures

Tables

Introduction

Silica (SiO_2) is the primary ingredient in the manufacture of glass and related products. It is also produced for a variety of industrial uses. Quartz is the most common naturally occurring silica mineral. The primary sources of silica are ancient and recent quartzose sandstone or sand deposits and pegmatitic quartz.

This report describes the geology and silica resources of a deposit of sandstone exposed in sec. 36, T.20N., R.73W., about 30 miles north of Laramie, Wyoming, in Albany County, adjacent to State Highway 34 (**Figure 1**). The deposit contains friable, easily beneficiated sandstone, averaging 77.4 percent SiO_2. Almost 100 percent of the sand grains are the mineral quartz. Feldspar grains were rare in most observed samples. The remainder of the sandstone consists of matrix calcite and minor clay. The sandstone is classified as a calcareous orthoquartzite (Pettijohn, 1949).

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 term is used to describe the material in the Plumbago Creek deposit. It can be purified to about 95 percent SiO_2 by washing. It may be less expensive to mine and purify than higher grade, but less easily processed deposits.

Silica sand deposits like the one at Plumbago Creek are uncommon west of the Mississippi River. This deposit could supply Rocky Mountain, Great Basin, and possibly West Coast glass markets. Also, new technologies and transportation considerations may make it possible to establish production to serve a worldwide market. The availability of a large silica sand resource in the area could form the basis for the construction of a glass plant in the area. The nearby presence of other raw materials needed for the manufacture of glass (limestone and feldspar) and the closeness of soda ash production (200 miles by direct rail transport) also contribute to the economic viability of this deposit (**Figure 1**).

Funding for the drilling program and sample analyses was obtained by the Albany County Commissioners from the Wyoming Economic Development and Stabilization Board (EDSB) through a planning-only grant. This grant was given to provide a preliminary estimate of the amount and grade of the silica sand resource. Information from this drilling project and analytical results were given to the Geological Survey of Wyoming by the Albany County Commissioners and EDSB. The Geological Survey also provided technical advice for the drilling program.

Geology

The Plumbago Creek silica sand deposit is in the Permian-Pennsylvanian Casper Formation exposed in sec. 36, T.20N., R.73W. (**Figure 2**). The Casper Formation was named and described by Darton (1908) from exposures on Casper Mountain south of Casper, Wyoming. It is a sequence of Pennsylvanian and Permian carbonate rock, sandstone, and shale exposed on the flanks of the Laramie Mountains and some adjacent areas in Wyoming (Condra and Reed, 1935; Knight, 1929). The Casper Formation is in part equivalent to the Tensleep Sandstone to the northwest, the Minnelusa and Hartville Formations to the northeast, the

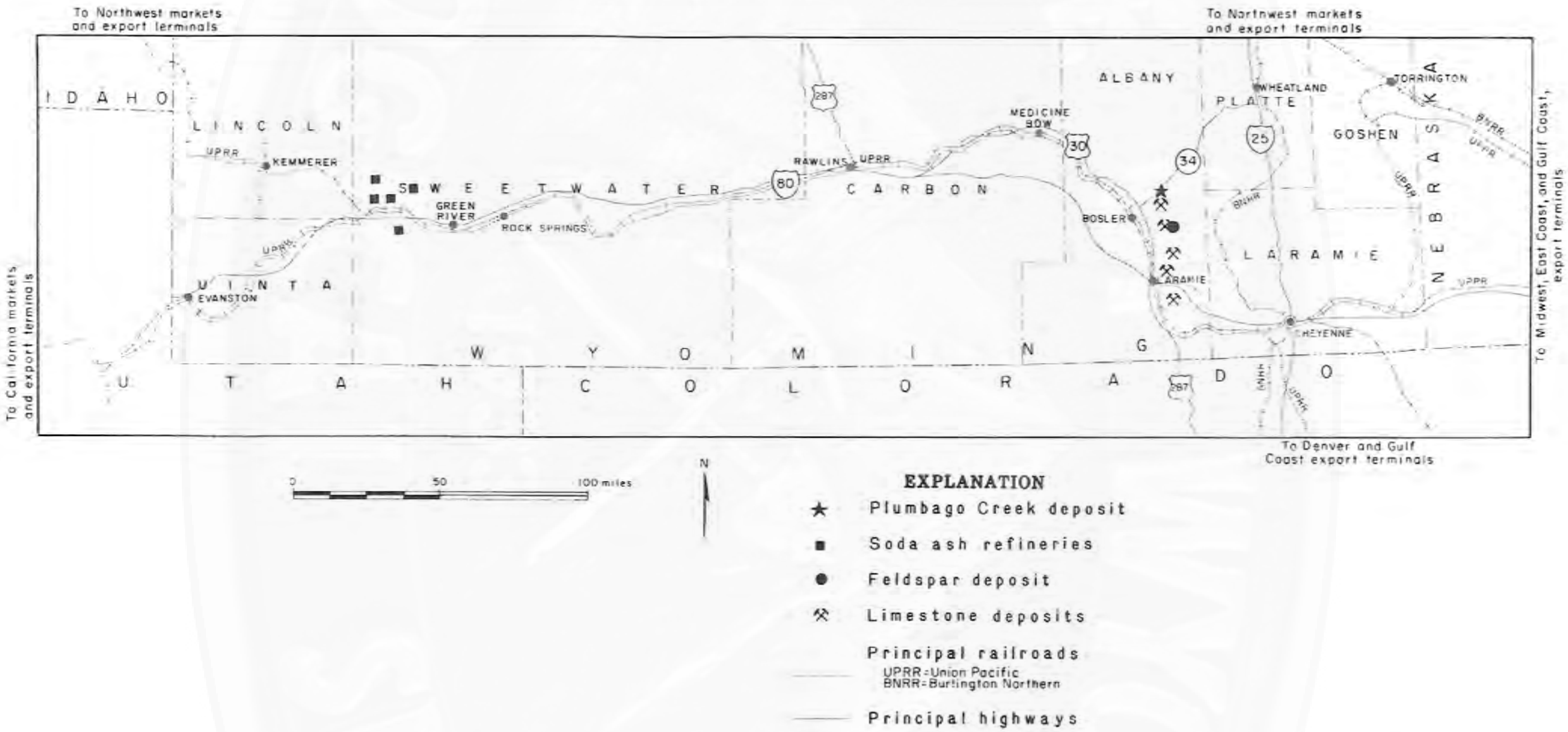


Figure 1. Regional map showing location of Plumbago Creek silica sand deposit; nearby trona, feldspar, and limestone deposits; and transportation routes.

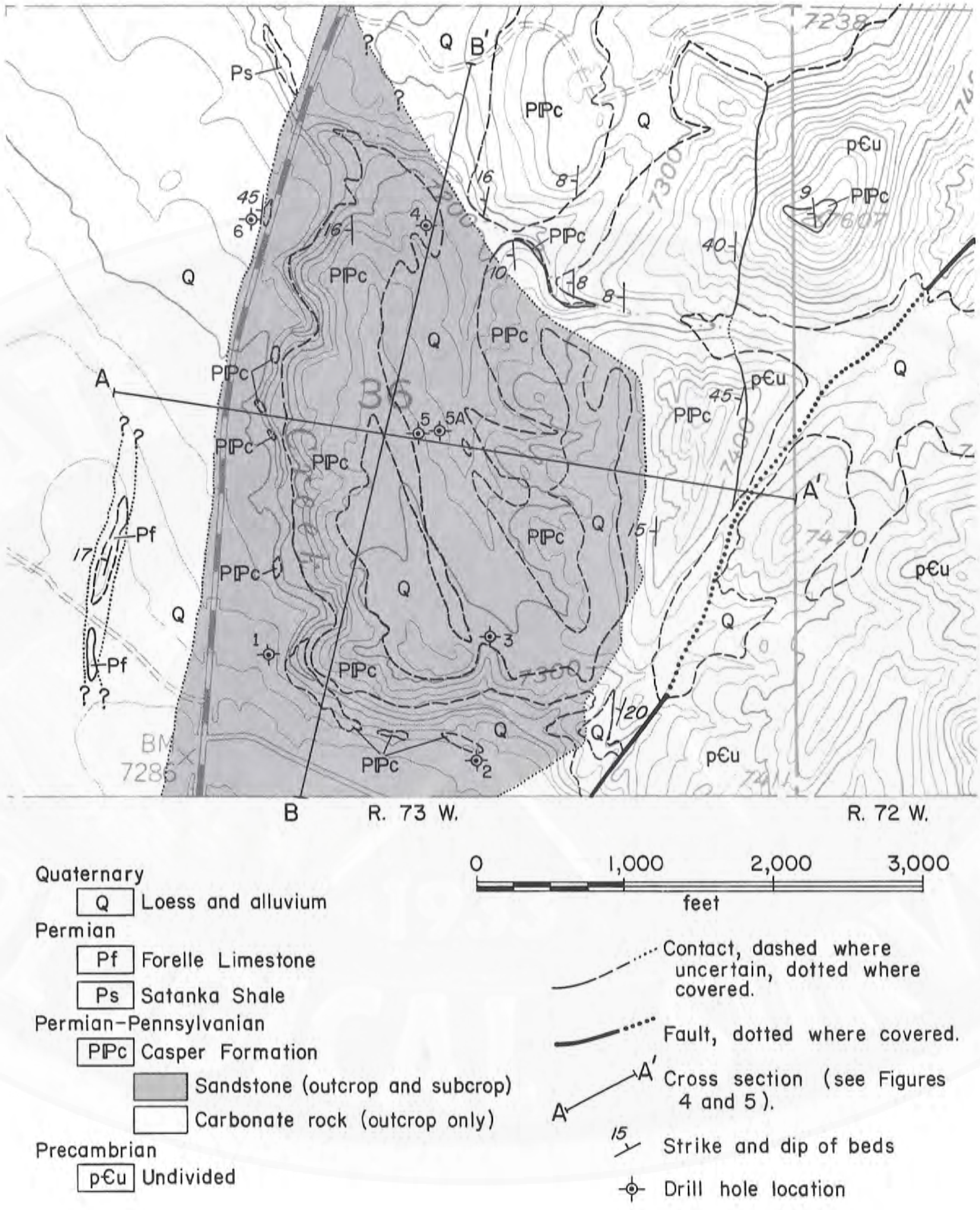


Figure 2. Geologic map of the Plumbago Creek silica sand deposit.

Fountain Formation to the south and southwest, and the Ingleside and Fountain Formations in Colorado.

A fairly complete section of the lower part of the Casper Formation is exposed in sec. 36 along Plumbago Creek (**Figure 3**). This section is depicted on cross sections A-A' and B-B' (**Figures 4** and 5). The basal Casper Formation overlies Precambrian rocks. The top of the formation is not exposed in sec. 36 or adjoining sections, but it was encountered in drill hole 6 (located on **Figure 2**). It is overlain by red siltstones and fine-grained silty sandstones of the Permian Satanka Formation. About 65 percent of the Plumbago Creek silica sand deposit is covered by windblown soil (loess) or alluvium of Quaternary age. One drill hole (5A, **Figure** 2) was abandoned because surficial sediments were greater than 20 feet thick (which exceeded the length of available surface casing). West of Highway 34, Permian and younger rocks are almost entirely covered by loess.

The Casper Formation varies from 352 feet to 1,218 feet thick along the west flank of the Laramie Mountains (Tudor, 1952). The Casper Formation north of Plumbago Creek, in the south-central and southwest parts of sec. 36, including the silica sand deposit, is estimated from drilling and surface exposures to be about 480 feet thick. In an earlier study of the Plumbago Creek area, Harrison (1938) measured 460.5 feet of Casper Formation, which consisted primarily of carbonate units. His section was said to be located in sec. 31, T.20N., R.72W. This location is apparently an error. Mapping by the author (**Figure 2**) and by Bochensky (1982) shows that no Casper Formation is present in sec. 31 or immediately east of sec. 36, T.20N., R.73W.

In the Plumbago Creek area, the Casper Formation dips westward from the west flank of the Laramie Mountains. Dips range from 45°W in limestones at the base of the Casper Formation at the east edge of the sandstone, to 8° to 10°W in the center, to 45°W at the west edge of the outcrop area (**Figure 2**). No faults were observed within the sandstone sequence in sec. 36. It is possible that a fault exists between drill hole 6 and the Casper Formation sandstone outcrop 50 feet to the east. However, the angle of the beds recovered from drill hole 6 suggests that the dip at this location is at least 45°. Therefore, no fault is shown on either the geologic map (**Figure 2**) or cross section A-A' (**Figure** 4). The Forelle Limestone (Permian) exposed in NW1/4SW1/4 sec. 36 dips west at 17°W (**Figure 2**).

Figure 3. Exposure of the silica sand deposit along Plumbago Creek.

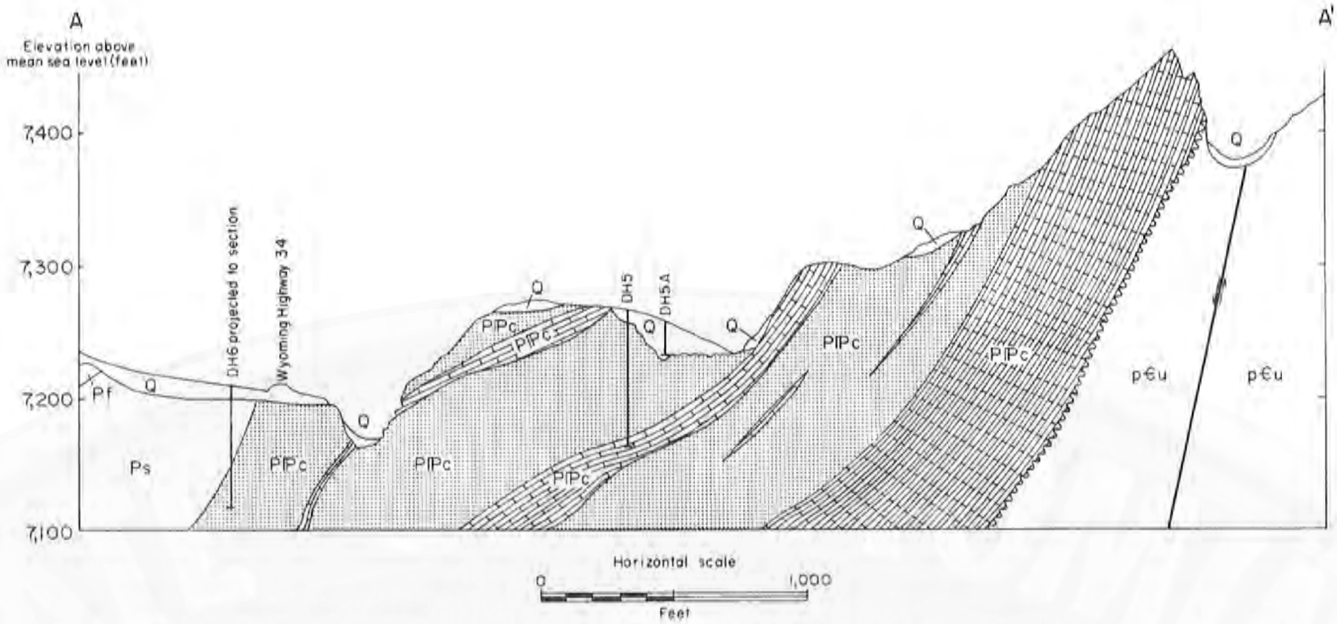


Figure 4. East-west cross section, Plumbago Creek silica sandstone deposit (view to north).

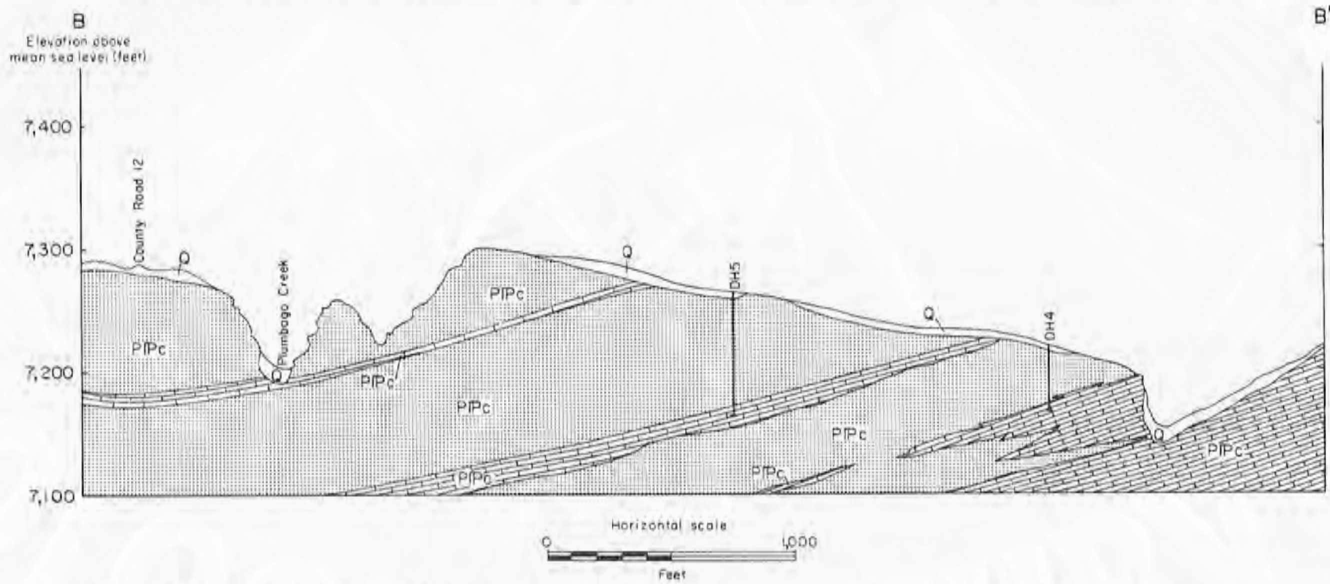


Figure 5. North-south cross section, Plumbago Creek silica sandstone deposit (view west).

Explanation

Q	Quaternary loess and alluvium
Pf	Permian Forelle Limestone
Ps	Permian Satanka Shale
PIPc	Permian-Pennsylvanian Casper Formation
PIPc	Sandstone (silica sand)
PIPc	Carbonate rock
pЄu	Precambrian rocks, undivided
DH5	Drill hole location
	Fault, arrows indicate relative movement
	Unconformity

Love and Christiansen (1985) show a normal fault truncating the Casper Formation in SE1/4 sec. 36, T.20N., R.73W., with no Paleozoic rocks north of the fault in sec. 36. This is apparently an error because Paleozoic rocks do crop out north of the fault. Mapping by the author (**Figure 2**) and by Bochensky (1982) shows a fault truncating the lower limestone of the Casper Formation in SW1/4SE1/4 sec. 36, T.20N., R.73W. but the silica sand deposit is not affected by this fault.

The silica sand deposit is well exposed along the north bank of Plumbago Creek in sec. 36 (**Figure 3**). It is friable, light yellow, and exhibits festoon crossbedding characteristic of wind-deposited sand dunes (**Cover photo**). A reddish coloration due to interstitial iron oxides is characteristic of the upper part of the middle sandstone. The basal zone of the sandstone is light yellow or light red, fine grained, friable, planar crossbedded, and thin bedded (**Figure 6**). Similar sandstone bodies are occasionally found interbedded with dune sandstones. Thin, yellow, sandy, interdunal lacustrine(?) carbonate rocks and interbeds of gray marine carbonates (**Figure 7**) are also present. These carbonates consist of limestone and dolomitic limestone. High-calcium limestones occur at the base of the Casper Formation.

The silica sand deposit formed during the Pennsylvanian as windblown sand dunes. Carbonate interbeds (**Figures 4** and **5**) may represent marine encroachments over the dune field, which formed on a coast near a paleoshoreline. The thin-bedded planar-crossbedded sandstones are typical of nearshore marine sand deposits. They represent a transition between the marine carbonate rocks deposited in deeper offshore waters and the subaerial dunes, and were deposited during marine encroachment into the nearshore dune field.

In the north half of sec. 36, the silica sand interfingers with marine carbonates of the Casper Formation (**Figure 5**). South of sec. 36, the same relationship may be present, however, this area is covered by loess deposits. The silica sand deposit extends west of Highway 34 beneath Permian and younger rocks (**Figure 4**).

Six holes were drilled into the silica sand deposit in sec. 36 (locations on **Figure 2**). Because no holes were over 120 feet deep, drilling did not penetrate the entire formation at any location. Lithologies penetrated by the six holes are shown in the columnar sections (**Appendix A**). The two cross sections (**Figures 4** and **5**) were constructed using the geologic map (**Figure 2**) and information from the drill cores.

Silica sand resources

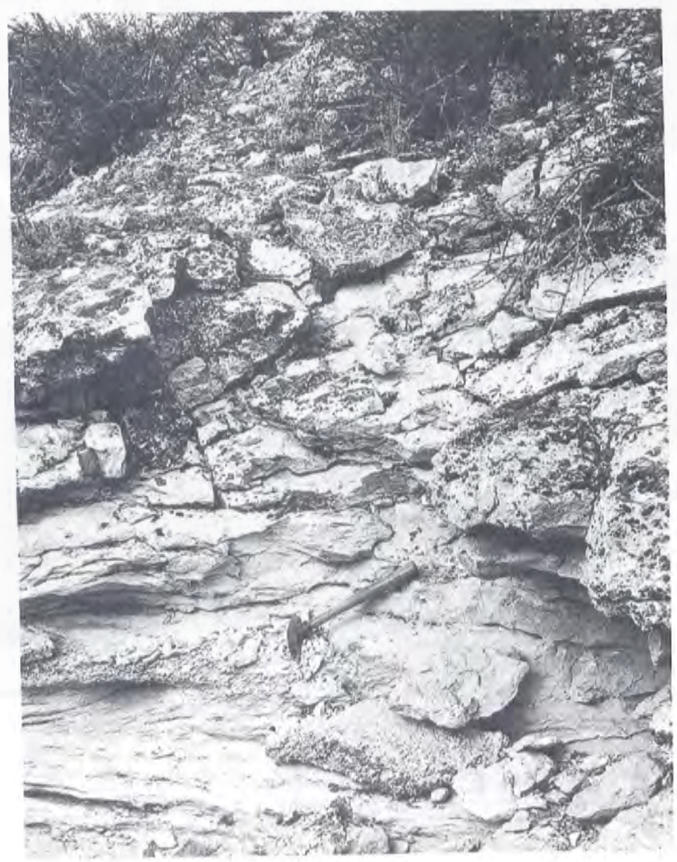
Quantity

In the study area, the silica sand is present in three beds overlying the lower marine limestone of the Casper Formation. These silica sands are separated by two carbonate units that may be continuous across the area (**Figures 4** and **5**). Estimates of the resource present in this deposit (east of Highway 34) are based on estimates of the thickness of the sandstone units, determined from surface mapping and drilling, and the areal extent of the deposit, measured from the geologic map (**Figure 2**). For the purposes of resource estimation, the two carbonate units were assumed to be continuous and the silica sand was divided into three units. These units are not designated on the map (**Figure 2**), but they can be seen on the cross sections (**Figures 4** and **5**).

The stratigraphically lowest sandstone averages 55 feet thick, underlies an area of 800,000 square yards, and

Figure 6. Exposure of basal Casper Formation fluvial sandstone, Plumbago Creek area (notebook for scale).

Figure 7. Upper carbonate bed showing gradational contact with the silica sand deposit, Plumbago Creek area (hammer for scale).



contains an estimated 29,800,000 tons of silica sand. The middle silica sand is approximately 80 feet thick, underlies an area of 630,000 square yards, and contains an estimated 16,400,000 tons of silica sand. The upper sandstone is approximately 120 feet thick, underlies an area of 450,000 square yards, and contains an estimated 18,000,000 tons of silica sand. Collectively, there are an estimated 64,200,000 tons of silica sand in the deposit.

Additional silica sands are probably present west of Highway 34. These have not been tested by drilling. If the average thickness of sandstone is relatively uniform locally, as estimated east of Highway 34, the amount of silica sand west of Highway 34 is at least as great as that east of the highway.

Quality

Two hundred samples of core from the Plumbago Creek area were analyzed for eleven elements (**Appendix B**). Based on this information, it is estimated the deposit averages 77.4 percent SiO_2. The most abundant impurities are calcite (calcium carbonate), feldspar, and a clay mineral. Calcium carbonate ($CaCO_3$) makes up 10 to 25 percent of the sandstones.

The impurities are easy to remove. Three core samples of yellow, white, and red sandstone (samples 3-79, 4-24, and 5-19, respectively, **Table 1**) were each agitated in water in a household blender for 30 seconds. The solution consisting of water and fine-grained material was then poured off and the remaining sand analyzed for four major oxides (silica, calcium oxide, aluminum oxide, and iron oxide). The results (**Table 1**) show silica values much greater than the original samples, approaching or exceeding 95 percent. Longer washing times or repeated washing cycles may upgrade the material even further.

Because calcium carbonate is usually added to silica during the glass manufacturing process, the Plumbago Creek silica sand may be usable as a raw material source of silica and calcium carbonate with no separation necessary. Tests should be done to determine if this is feasible.

Iron oxide (Fe_2O_3) values averaged less than 0.5 percent (**Appendix B**). Since steel crushers and pulverizers were used, some iron was introduced into the whole-rock analyses through the sample preparation process. Samples of the washed silica sands (**Table 1**) were processed with ceramic equipment, and these show iron oxide values generally lower than 0.1 percent. A sample of the red silica sand that was washed (sample 5-19, **Table 1**) had a total iron oxide content of less than 0.2 percent.

Uses of silica sand

Silica sand, processed to a grade of 95 percent or greater SiO_2, is the primary ingredient in the manufacture of glass and related products (fiberglass, synthetic quartz crystals, etc.). There are many varieties of glass with various uses. Glass classifications are shown in **Table 2**. High quality glass such as optical glass, fiber optical glass, and silica used to grow quartz crystals requires the purest silica sand. Colored glass (brown container glass etc.) requires a lower grade silica sand. **Table 3** provides a list of specifications for some of the glass products listed in **Table 2**.

Industrial sand is a classification of sand based on both physical and chemical properties. Silica sand is classified as a type of industrial sand (U.S. Bureau of Mines, 1986). The sand from

Table 1. Silica, calcium carbonate (CaO + LOI), aluminum oxide, and iron oxide analyses of selected washed and unwashed core samples, Plumbago Creek silica sand deposit (values in weight percent).

Sample number[1]	SiO_2	CaO	Al_2O_3	Fe_2O_3	LOI[2]
3-79	79.80	6.70	1.73	0.41	7.50
3-79 washed	93.51	1.65	0.72	0.08	1.40
4-24	81.30	4.84	1.23	0.20	6.90
4-24 washed	96.67	0.73	0.70	0.09	0.60
5-19	74.50	8.96	2.57	0.66	7.50
5-19 washed	93.17	1.17	1.50	0.18	1.70

[1] Sample number is hole number and depth. See Appendix A2, A3, and A4 for lithology and stratigraphic location. [2] Loss on ignition.

the Plumbago deposit may also be used for non-silica sand industrial purposes. These uses include foundry sand, silicon metal, metallurgical flux, abrasives, and hydraulic fracturing sand (**Table 4**). The highest priced industrial sands are used as fillers in ceramics and for hydraulic fracturing (Tepordei, 1987).

Other kinds of glass are being used to isolate radioactive waste (Harker and Flintoff, 1984; Ondracer and Toscano, 1984). For this kind of glass, color is not important. Therefore the presence of impurities (for example, iron) that produce colored glass do not detract from the usefulness of the sand. There are currently no exact specifications developed for this purpose since new types of glass are continually being tested. As of this writing, the preferred glass is a borosilicate type similar to the high-durability fiberglasses shown in **Table 3.** This use may increase in the future as technology for the isolation and storage of high-level radioactive waste develops.

Table 2. Classification of glass products, (after Bentzen, 1979).

Flat glass
- Sheet
- Float (most flat glass production)
- Rolled (seldom used now)

Glass containers
- Colorless
- Colored

Glass fibers
- Reinforcement filaments
- Insulation
- Optical fibers (fiber optics)
- Fused silica fibers

Other specialty glasses
- Tableware
- Lead crystal
- Fused silica
- Heat resistant (borosilicate) glass
- Light bulbs (high-sodium)
- Tubing
- Electronics
- Scientific and laboratory glassware
- Optical glass
- Bullet-proof glass
- Other specialty glasses

Domestic silica sand production

Silica sand is produced in thirty-one states (**Appendix C**). Most of this production is near the industrial areas of the Midwest, Middle Atlantic states, or West Coast. The largest producer of silica sand in the United States is U.S. Silica, owned by the British firm RTZ. The next largest, Unimin, is also partly foreign owned (Harben, 1987). Most of the resources are in consolidated sandstone.

The Plumbago Creek deposit is located in an area far from current silica sand production. Convenient transportation may make it possible to ship finished or partly finished products from a glass plant near the deposit to all parts of the United States or worldwide.

Table 3. Approximate compositions of selected glasses (after McLellan and Shand, 1984).

Glass designation	Use	Oxide constituents, in weight percent											
		SiO_2	Al_2O_3	B_2O_3	Na_2O	K_2O	CaO	MgO	TiO_2	ZnO	BaO	PbO	Others
Fiberglass	Low alkali lime-alumina borosilicate	55.0	14.5	7.0	0.5		21.8	0.5	0.5				0.2 Fluorine
	Soda-lime borosilicate	65.0	4.0	5.5	8.0	0.5	14.0	3.0					
	Soft soda-lime borosilicate	61.0	4.0	7.0	14.5	1.0	9.0	3.5					
	High durability lime-free soda borosilicate I	59.5	5.0	8.0	15.0				8.0				0.5 Fluorine 4.0 ZrO_2
	High durability lime-free soda	58.5	6.0	10.5	10.5	3.0	2.0			4.0	5.0		0.5 Fluorine
	High-magnesia	64.5	24.5		0.5			10.5					
Lime glasses	Light bulbs	73	1		17		5	4					
	Tempered ovenware	75	1.5		14		9.5						
	Ophthalmic lenses	68	2		8	9.5	8.5		0.5	3.5			
	Containers	66-75	0.7-7[1]		12-16	0.1-3	6-12	0.1-5			0-0.5		
	Float	73-74	0.2-0.3		13.5-15	0.2	8.7-8.9	3.6-3.8					0.07-0.13 Fe_2O_3 0.2-0.3 SO_3
	Sheet	71-73	0.5-1.5		12-15		8-10	1.5-3.5					
Barium glasses	Color TV panels	65	2		7	9	2	1			2	2	10 SrO, F^-
	Ophthalmic biofocal segments	50.5		4	11.5		5		2.5	7.5	16		3 ZrO_2
	Optical dense barium crowns	36	4	10						9	41		
Lead glasses	Neon tubing	63	1		8	6						22	
	Electronic parts	56	2		4	9						29	
	Color TV funnels	54	2		6	8	3	2				23	
	Ophthalmic biofocal segments	35	2			7.5			3.5			51	1 ZrO_2
	Optical dense flints	32			1	2						65	
	Solder sealing	3	11	12								74	
Borosilicate glasses	Chemical apparatus	81	2	13	4								
	Tungsten sealing	74	1	15	4							6	
	Kovar sealing	64	8	19	2	3					3		1 Li_2O, F^-
	Pharmaceuticals	72	6	11	7	1	1				2		
	Optical boro-silicate brown	69.5		11.5	9	7					3		
Aluminosilicate glasses	Combustion tubes	62	17	5	1		8	7					
	Resistor substrates	57	16	4			10	7			6		
	Fiberglass	64.5	24.5		0.5			10.5					

[1] Most container glasses have less than 2.3 percent Al_2O_3.

Table 4. Industrial uses of silica sand in 1985 (after Tepordei, 1987).

End use	Quantity (short tons)	Percent of total
Glass	10,293,000	43.6
Foundry	5,143,000	21.8
Hydraulic fracturing	2,102,000	8.9
Abrasives	1,681,000	7.1
Roofing granules	403,000	1.7
Chemicals	378,000	1.6
Filtration	345,000	1.5
Traction	292,000	1.2
Metallurgical	188,000	0.8
Fillers	158,000	0.7
Ceramics	150,000	0.6
Coal washing	18,000	0.1
Other	2,446,000	10.4
Total	23,597,000	100.0

Other economic factors

In addition to the quality and quantity of the Plumbago silica sand resource, the nearby location of other materials used in the manufacture of glass and convenient transportation routes enhance the suitability of this deposit for development. Large quantities of soda ash are also used in glass production. Ninety-five percent of domestic soda ash is produced 200 miles west of the Plumbago Creek deposit near Green River, Wyoming. Direct shipment to the Laramie area is available on the Union Pacific Railroad (**Figure 1**).

Calcium carbonate and feldspar are present within the Plumbago silica sand in amounts that may be suitable for glass production. High-calcium limestones are also present in the Casper Formation at the base of the silica sand deposit in sec. 36 and to the south and north. A sample from a Casper Formation limestone exposed in an aggregate quarry in NW1/4SE1/4NW1/4 sec. 1, T.19N., R.73W., one quarter mile south of the Plumbago Creek silica sand deposit (**Figure 1**), was analyzed and found to be 100 percent calcium carbonate. Feldspar is present in large amounts in the Laramie anorthosite complex, which underlies an area of about 290 square miles immediately east of Plumbago Creek silica sand deposit. A deposit of feldspar also exists at Twin Buttes, ten miles south of the silica sand deposit (Hausel, 1981) (**Figure 1**).

A Union Pacific Railroad siding at Bosler, Wyoming, is 11 miles by paved road from the silica sand deposit. Wyoming Highway 34 is adjacent to the deposit, as is Albany County Road 12 (graded). The deposit is 11 miles from

U.S. Highway 30 and 29 miles from Laramie, Wyoming. The closeness of the Plumbago Creek silica sand deposit to paved all-weather roads and to rail transportation (**Figure 1**) decreases transportation costs of both raw materials and finished products. East Coast, Gulf Coast, Pacific Coast, and Midwestern markets as well as export terminals may be reached by direct rail shipment (**Figure 1**).

Summary

This report is the result of surface mapping and of 570 feet of drilling. To refine the Plumbago Creek silica sand resource and grade estimates, additional tests must be done, especially close-spaced drilling. Additional studies are needed to determine mining costs and product suitability.

The present study indicates that this deposit contains a large resource of good quality silica sand, easily mined and beneficiated, which may be processed to meet specifications for many types of silica and industrial sand, or material for isolation of radioactive waste. It may be an excellent source of silica for a new local or regional glass industry or for sale to existing plants in the western United States.

In addition, limestone and feldspar resources in the area enhance the economic factors favoring the local production of glass. The nearness of domestic soda ash production and interstate and local transportation routes may also decrease the cost of producing and marketing the glass.

References

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.

Bochensky, Paul, 1982, Contact metamorphism effects of the Laramie anorthosite complex at Morton Pass, Wyoming: M.S. thesis, University of Wyoming, Laramie, Wyoming, 58 p.

Condra, G.E., and Reed, E.C., 1935, The Permo-Pennsylvanian section of the Hartville area of Wyoming: Nebraska Geological Survey Bulletin 9, 46 p.

Darton, N.H., 1908, Paleozoic and Mesozoic of central Wyoming: Geological Society of America Bulletin, v. 19, p. 403-470.

Dickson, Ted, 1984, North American silica sand: Industrial Minerals, no. 197, p. 39-45.

Engineering and Mining Journal, 1987, International directory of mining and mineral processing operations 1987-1988: Engineering and Mining Journal, New York, 623 p.

Goldman, H.B., and Reining, Don, 1983, Sand and gravel, *in* Lefond, S.J., editor, Industrial minerals and rocks, 5th edition: American Institute of Mining, Metallurgical, and Petroleum Engineers, Baltimore, Maryland, p. 1151-1166.

Harben, Peter, 1987, U.S. industrial minerals - survival of the fittest: Mining Magazine, v. 156, no. 11, p. 437.

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 VII: Elsevier, New York, p. 513-520.

Harrison, J.W., 1938, Pennsylvanian stratigraphy of the Laramie Range of southeastern Wyoming: M.A. thesis, University of Wyoming, Laramie, Wyoming, 85 p.

Hausel, W.D., 1981, Updated report on the Twin Buttes feldspar-limestone-flagstone property, Albany County, Wyoming: Geological Survey of Wyoming Mineral Report 81-1 (unpublished), 5 p.

Knight, S.H., 1929, The Fountain and Casper Formations of the Laramie Basin, Wyoming: University of Wyoming Publications in Science, Geology, v. 1, no. 1, 80 p.

Love, J.D., and Christiansen, A.C., 1985, Geologic map of Wyoming: U.S. Geological Survey, scale 1:500,000.

McLellan, G.W., and Shand, E.B., 1984, Glass engineering handbook: McGraw Hill, p. 1-10 and 20-24.

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 VII: nuclear waste management VII: Elsevier, New York, p. 591-596.

Pettijohn, F.J., 1949, Sedimentary rocks: Harper and Brothers, New York, 526 p.

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

Tudor, M.S., 1952, Geology of the west-central flank of the Laramie Range, Albany County, Wyoming: M.A. thesis, University of Wyoming, Laramie, Wyoming, 51 p.

United States Bureau of Mines, 1986, Directory of industrial sand and gravel producers in the United States in 1985: Division of Industrial Minerals, U.S. Bureau of Mines Annual Advance Summary Supplement, 7 p.

Appendices

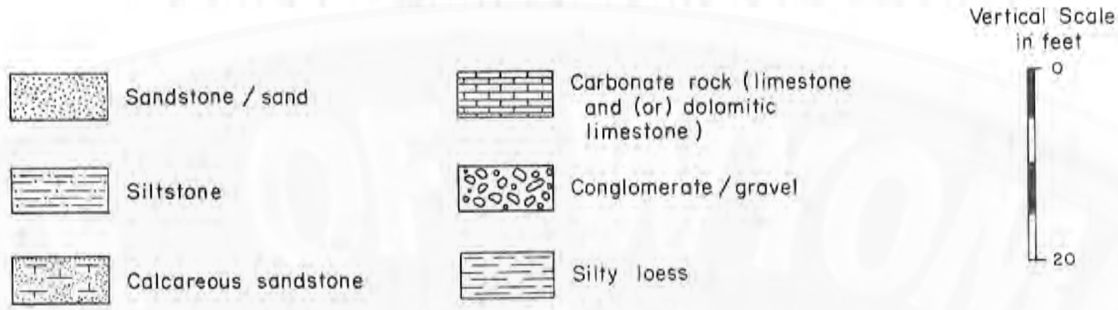
Appendix A. Lithologies in drill holes.

Appendix B. Whole-rock chemical analyses of cores.

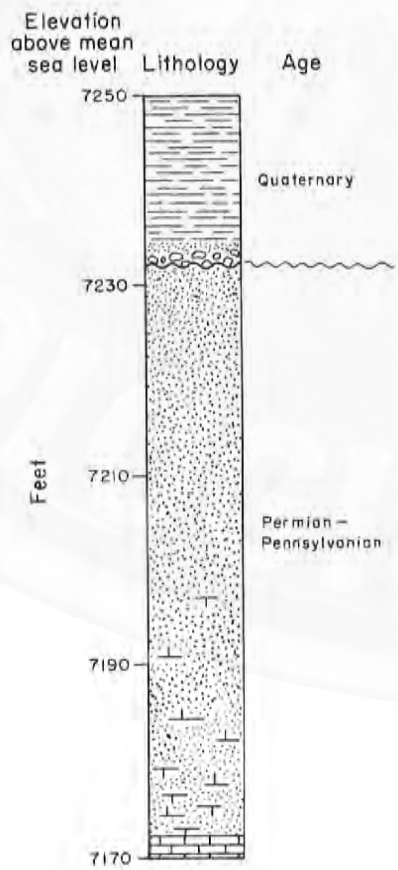
Appendix C. United States silica sand and other silica production.

Appendix A

EXPLANATION OF LITHOLOGIC SYMBOLS USED IN APPENDIX A(1-6)



AI. Lithologies in drill hole 1.



DESCRIPTION

Surficial deposits

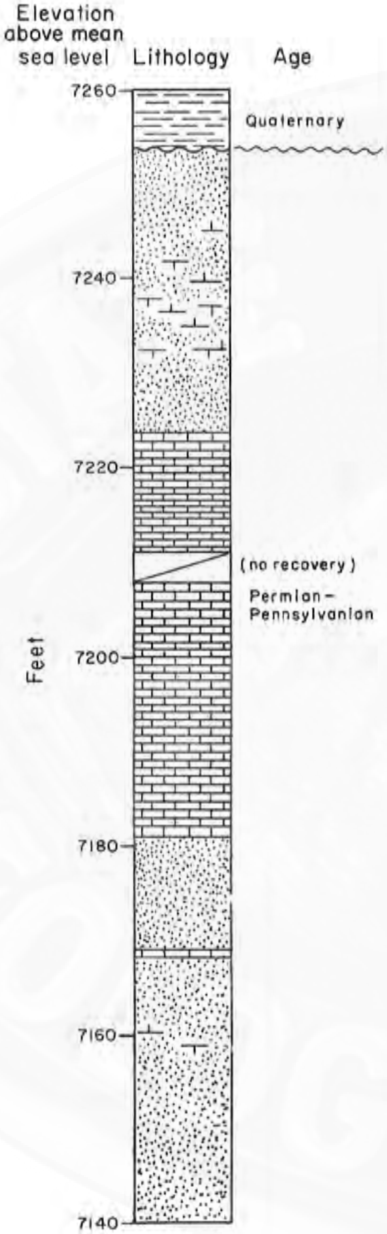
Brown silty loess, sand and gravel at base.

Casper Formation

61 feet of yellow to light yellow, festoon-crossbedded, quartz-rich sandstone (silica sand), becoming more calcareous at base; dips 16°W.

Pale yellowish gray dense limestone.

A2. Lithologies in drill hole 2.



DESCRIPTION

Surficial deposits
Brown silty loess.

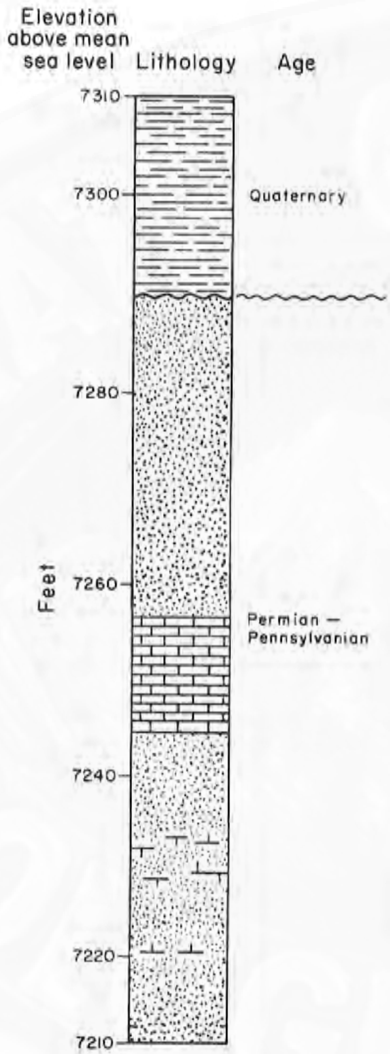
Casper Formation

30 feet of yellow to light yellow, crossbedded, quartz-rich sandstone (silica sand) with numerous hard, yellow, fine-grained, calcareous, quartz-rich sandstone (silica sand) interbeds, dips 8°W.

Gray to yellow, dense, hard, dolomitic limestone.

40 feet of light yellow, fine- to medium-grained, crossbedded sandstone; one-foot-thick, yellow, dense carbonate interbed and a few fine-grained, calcareous sandstone interbeds.

A3. Lithologies in drill hole 3.



DESCRIPTION

Surficial deposits
Brown silty loess.

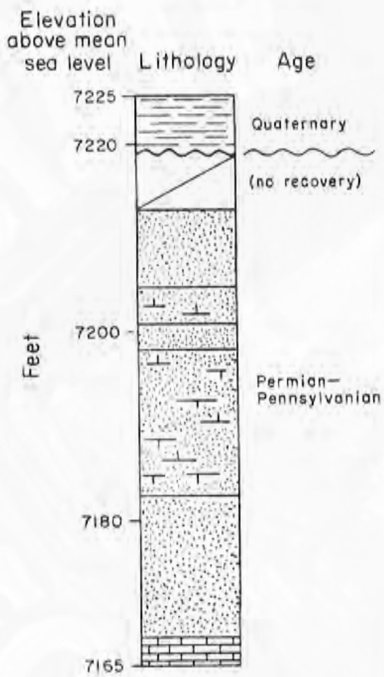
Casper Formation

34 feet of light yellow to yellow, medium-grained to fine-grained, festoon-crossbedded, quartz-rich sandstone (silica sand); dips 8°W.

Gray, hard, massive limestone.

33 feet of yellow to light yellow, festoon-crossbedded, quartz-rich sandstone (silica sand): yellow, hard, calcareous, quartz-rich sandstone (silica sand) interbeds.

A4. Lithologies in drill hole 4.



DESCRIPTION

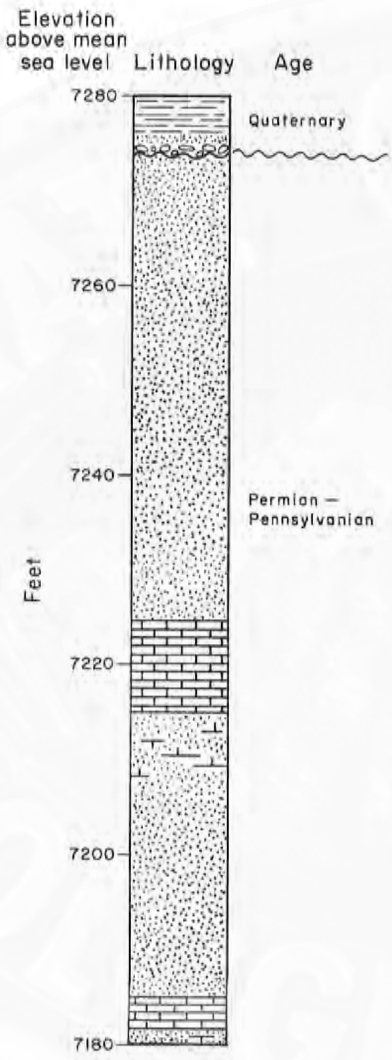
Surficial deposits
Brown silty loess.

Casper Formation

White quartz-rich sandstone (silica sand) in cuttings. Light yellow, crossbedded, quartz-rich sandstone (silica sand); interbeds of yellow, fine-grained, calcareous sandstone; dips 16°W.

Light brownish gray massive limestone.

A5. Lithologies in drill hole 5.



DESCRIPTION

Surficial deposits
Brown silty loess, sand and gravel at base.

Casper Formation

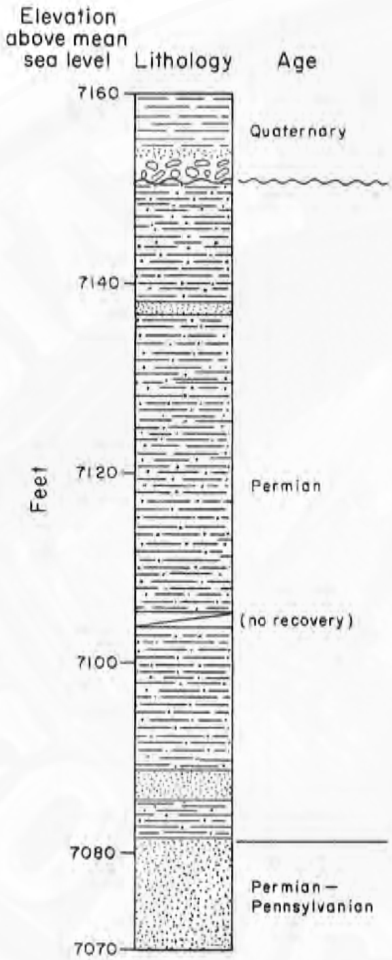
Red, festoon-crossbedded, medium-grained, quartz-rich sandstone (silica sand). Grades to yellow, festoon-crossbedded, quartz-rich sandstone (silica sand) below elevation 7,235 feet; dips about 10°W.

Carbonate interbed, yellow, dense, sandy, manganese dendrites common; becomes more sandy and grades into a quartz-rich sandstone (silica sand) unit at base.

Light yellow, festoon-crossbedded, quartz-rich sandstone (silica sand).

Dense, yellow, carbonate interbed.
Light yellow, calcareous, fine-grained sandstone.

A6. Lithologies in drill hole 6.



DESCRIPTION

Surficial deposits
Brown silty loess, sand and gravel at base.

Satanka Formation

Brick red siltstone, shaly siltstone, and fine-grained sandstone.

Casper Formation
White to light yellow, medium-grained, festoon-cross-bedded, quartz-rich sandstone (silica sand); dips 45°W.

Appendix B

B1. Whole-rock chemical analyses of core from drill hole 1, Plumbago Creek silica sand deposit (values in weight percent).

Sample number[1]	Al_2O_3	CaO	Fe_2O_3	K_2O	LOI[2]	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2	Total
22	2.94	2.01	0.75	1.44	2.00	0.15	<0.01	0.08	0.13	88.80	0.10	94.40
27	2.55	1.74	0.64	1.14	1.70	0.13	<0.01	0.07	0.23	90.00	0.08	98.28
30	2.17	6.47	0.44	0.99	5.10	0.11	0.01	0.05	0.20	83.30	0.07	98.91
39	2.31	8.54	0.47	0.81	9.60	2.43	0.02	0.09	0.29	75.00	0.07	99.63
42	2.48	12.45	0.43	1.08	12.40	2.30	0.02	0.10	0.13	66.80	0.15	98.34
48	2.95	10.19	0.55	1.29	8.50	0.24	0.02	0.08	0.26	75.70	0.14	99.92
55	2.88	11.40	0.41	1.31	10.10	0.67	0.01	0.08	0.33	72.20	0.14	99.53
58	2.51	12.20	0.40	0.78	10.70	0.62	0.02	0.07	0.28	72.10	0.08	99.76
64	2.87	7.59	0.45	1.32	9.90	3.12	<0.01	0.07	0.42	73.30	0.13	99.17
71	2.42	11.40	0.45	1.22	13.50	3.78	0.01	<0.01	0.22	65.30	0.11	98.41
77	2.55	17.30	0.31	1.25	15.80	1.93	0.02	0.05	0.22	59.20	0.17	98.80

[1] Sample number is also the depth from the surface. See Appendix A1 for lithology and stratigraphic location of each sample.

[2] Loss on ignition.

B2. Whole-rock chemical analyses of core from drill hole 2, Plumbago Creek silica sand deposit (values in weight percent).

Sample number[1]	Al_2O_3	CaO	Fe_2O_3	K_2O	LOI[2]	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2	Total
15	1.91	3.72	0.44	0.94	5.00	1.70	<0.01	0.04	0.30	84.90	0.06	99.01
16	2.21	5.82	0.40	1.07	6.10	0.84	<0.01	0.09	0.36	81.80	0.09	98.78
17	1.52	14.30	0.31	0.76	11.80	0.20	0.01	0.03	0.27	70.40	0.06	99.66
19	1.00	15.30	0.24	0.37	12.80	0.24	0.01	<0.01	0.39	69.20	0.03	99.58
20	1.74	6.10	0.45	0.84	5.30	0.21	<0.01	0.02	0.24	84.40	0.06	99.36
21	1.02	12.46	0.23	0.44	11.00	0.74	0.01	0.02	0.22	71.98	0.03	98.15
22	2.57	5.12	0.62	1.23	4.80	0.55	0.01	0.03	0.21	83.60	0.12	98.86
23	1.42	12.10	0.20	0.58	10.50	0.65	0.02	0.03	0.30	73.70	0.97	100.47
24	2.05	9.50	0.49	0.96	7.80	0.21	0.01	<0.01	0.08	77.90	0.09	99.09
25	2.02	9.40	0.50	1.02	7.40	0.21	0.02	0.02	0.19	78.30	0.09	99.17
26	2.20	6.10	0.54	1.07	6.10	1.02	0.01	0.04	0.20	82.10	0.08	99.46
27	2.45	4.20	0.68	1.16	4.70	0.96	<0.01	0.02	0.20	84.80	0.09	99.26
28	2.03	7.47	0.42	0.82	7.10	0.78	0.01	<0.01	0.25	81.20	0.08	100.16
29	2.12	4.32	0.41	0.87	5.20	1.51	0.01	<0.01	0.23	83.70	0.08	98.45
31	1.50	8.32	0.44	0.40	7.50	1.00	0.01	<0.01	0.26	79.00	0.04	98.47
32	1.09	5.48	0.44	0.18	7.30	2.65	0.01	<0.01	0.22	81.60	0.03	99.00
33	3.79	1.36	0.61	1.66	2.10	0.63	0.01	0.04	0.26	82.10	0.30	92.86
34	3.94	1.88	0.61	1.75	2.80	0.83	0.01	0.03	0.41	85.70	0.28	98.24
35	4.38	0.86	0.79	2.04	1.70	0.54	0.01	<0.03	0.22	87.00	0.28	97.82
36	4.28	0.35	0.77	1.82	1.10	0.33	0.01	0.04	0.38	89.10	0.24	98.42
37	0.29	32.80	0.11	<0.03	46.20	19.10	0.02	0.02	0.27	1.38	0.01	100.20
38	0.21	40.30	0.08	<0.03	44.80	11.80	0.04	<0.01	0.29	1.63	<0.01	99.15
39	0.16	41.30	0.10	<0.03	45.10	10.57	0.04	<0.01	0.26	0.63	<0.01	98.16
41	0.12	48.30	0.06	0.04	44.10	4.73	0.08	<0.01	0.40	0.59	<0.01	98.42
43	0.13	50.58	0.13	<0.03	41.00	2.90	0.06	<0.01	0.24	6.89	<0.01	101.93

Sample number[1]	Al_2O_3	CaO	Fe_2O_3	K_2O	LOI[2]	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2	Total
45	1.66	50.07	0.48	0.09	38.60	1.18	0.05	0.39	0.23	8.73	0.05	101.53
48	1.17	50.10	0.32	0.05	40.10	0.61	0.02	0.26	0.18	6.30	0.03	99.14
50	0.47	42.20	0.20	<0.03	44.00	9.44	0.04	<0.01	0.28	1.70	0.01	98.34
52	0.40	45.37	0.21	<0.03	43.10	7.55	0.04	0.05	0.23	3.28	0.01	100.24
57	0.25	40.03	0.12	<0.03	45.20	12.41	0.04	0.03	0.30	1.07	<0.01	99.45
59	0.18	38.01	0.10	<0.03	45.50	14.22	0.03	0.04	0.24	0.93	<0.01	99.25
60	0.14	41.40	0.07	<0.03	45.00	10.70	0.03	<0.01	0.26	0.58	<0.01	98.18
62	0.22	34.50	0.10	<0.03	45.80	16.80	0.03	0.04	0.27	1.20	<0.01	98.96
65	0.16	33.80	0.12	<0.03	46.10	16.96	0.02	0.02	0.27	0.67	<0.01	98.12
66	0.19	32.11	0.12	<0.03	46.20	18.27	0.02	0.03	0.32	0.87	<0.01	98.13
68	0.59	32.00	0.12	0.10	45.10	17.40	0.02	0.03	0.24	2.49	0.03	98.12
69	0.24	45.10	0.22	<0.03	43.90	7.00	0.06	<0.01	0.19	1.21	<0.01	97.92
71	0.43	49.06	0.24	<0.03	43.70	5.26	0.05	0.02	0.20	1.88	0.02	100.86
73	0.29	35.01	0.13	<0.03	45.90	16.24	0.04	<0.01	0.27	1.43	0.01	99.32
75	0.36	36.60	0.18	<0.03	45.30	14.68	0.04	0.02	0.21	2.11	0.02	99.52
76	0.32	31.68	0.16	<0.03	46.00	17.79	0.05	0.01	0.31	2.07	0.01	98.40
77	0.41	31.50	0.18	0.11	45.40	17.50	0.03	0.02	0.27	3.00	0.02	98.44
79	0.18	40.45	0.11	0.04	45.30	11.18	0.03	<0.01	0.32	0.97	<0.01	98.58
82	1.36	10.99	0.25	0.66	16.20	6.44	0.01	0.04	0.40	63.00	0.06	99.41
83	1.92	11.10	0.25	1.01	14.40	5.12	0.01	0.02	0.19	65.00	0.07	99.09
84	2.22	8.07	0.36	1.08	12.10	5.10	0.01	0.02	0.21	69.50	0.09	98.76
85	2.30	6.21	0.36	1.19	9.60	3.78	<0.01	<0.01	0.21	74.60	0.10	98.35
86	2.11	7.11	0.47	0.97	9.80	4.06	0.01	0.05	0.24	73.70	0.08	98.60
87	1.98	5.77	0.65	0.99	9.20	3.37	0.01	0.01	0.23	69.90	0.08	92.19
89	2.18	6.21	0.50	1.13	9.50	4.12	0.01	0.03	0.23	75.40	0.08	99.39
91	2.08	6.49	0.62	1.10	8.40	2.95	0.01	0.02	0.23	77.00	0.06	98.96
93	1.30	6.61	0.40	0.66	10.50	3.46	0.01	0.01	0.19	74.40	0.04	97.58
95	1.45	15.10	0.34	0.71	13.10	0.98	0.02	0.01	0.29	68.51	0.04	100.55
97	1.98	5.85	0.49	0.98	8.90	3.80	0.01	0.01	0.22	78.07	0.08	100.39
99	2.08	10.34	0.44	1.03	11.60	5.96	0.01	<0.01	0.10	66.81	0.12	98.49
101	1.83	9.29	0.41	0.96	9.30	1.80	0.01	0.01	0.21	76.41	0.05	100.28
103	2.38	5.47	0.54	1.26	8.60	3.47	0.01	<0.01	0.13	77.00	0.15	99.01
105	2.12	7.73	0.31	1.14	7.10	1.34	0.01	0.02	0.11	79.02	0.09	98.99
107	2.30	6.00	0.52	1.20	7.60	2.65	0.01	0.02	0.22	79.00	0.08	99.60
109	2.29	5.38	0.50	1.19	7.80	2.54	<0.01	0.02	0.21	78.10	0.09	98.12
111	2.24	7.81	0.40	1.16	9.60	2.90	0.01	0.13	0.22	74.40	0.09	98.96
113	2.66	7.30	0.59	1.23	8.70	3.75	0.01	0.05	0.38	74.80	0.07	99.54
115	1.46	8.96	0.37	0.75	12.20	4.44	0.01	0.02	0.26	70.40	0.05	98.92
116	2.14	8.26	0.57	1.03	13.10	5.11	0.01	0.03	0.26	67.30	0.13	97.94
117	2.06	9.90	0.50	1.07	15.50	6.21	0.01	0.02	0.24	63.30	0.13	98.94
119	2.04	9.68	0.48	1.01	14.30	5.71	0.01	<0.01	0.20	66.97	0.11	100.51
120	2.60	8.54	0.48	1.12	11.50	3.96	0.01	0.05	0.35	70.00	0.10	98.71

[1] Sample number is also the depth from the surface. See Appendix A2 for lithology and stratigraphic location of each sample.

[2] Loss on ignition.

B3. Whole-rock chemical analyses of core from drill hole 3, Plumbago Creek silica sand deposit (values in weight percent).

Sample number[1]	Al_2O_3	CaO	Fe_2O_3	K_2O	LOI[2]	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2	Total
21	0.34	29.70	0.37	<0.03	45.50	19.00	0.04	0.01	0.31	2.74	0.01	98.02
25	2.10	7.50	0.29	1.05	7.40	1.25	0.01	0.15	0.26	80.10	0.09	100.20
29	2.20	5.00	0.35	1.06	5.20	0.95	0.01	0.03	0.40	84.40	0.07	99.67
33	2.57	4.66	0.48	1.29	5.10	1.19	0.01	0.03	0.43	83.20	0.13	99.09
37	2.35	4.42	0.46	1.27	5.10	1.10	0.01	0.04	0.25	83.60	0.16	98.76
40	3.40	4.43	0.43	1.57	6.50	2.52	0.01	0.04	0.37	79.80	0.20	99.27
42	2.02	4.88	0.41	0.98	6.00	1.92	0.01	0.03	0.41	82.30	0.05	99.01
44	2.02	8.24	0.47	0.88	9.00	2.06	0.01	<0.01	0.42	76.90	0.06	100.06
48	2.56	5.95	0.40	1.31	9.30	3.97	0.01	<0.01	0.43	74.00	0.13	98.06
49	3.61	4.85	0.48	1.66	7.70	2.99	0.01	0.03	0.41	76.90	0.18	98.82
52	3.46	4.97	0.52	1.74	7.30	2.63	0.01	0.04	0.48	77.80	0.20	99.15
53	1.96	6.46	0.43	0.96	8.00	2.41	0.01	0.01	0.45	78.50	0.10	99.29
54	1.50	16.80	0.23	0.72	14.70	0.72	0.01	<0.01	0.40	64.20	0.08	99.36
55	0.28	31.30	0.09	<0.03	46.20	18.70	0.02	0.02	0.58	0.65	<0.01	97.84
57	0.22	30.90	0.31	<0.03	46.40	20.10	0.04	0.03	0.28	0.72	<0.01	99.00
59	0.29	30.70	0.37	<0.03	46.10	19.70	0.04	0.02	0.61	1.23	0.01	99.07
60	0.62	29.60	0.28	0.13	45.50	19.40	0.02	0.11	0.31	2.13	0.03	98.13
63	0.44	29.55	0.29	0.07	46.00	19.57	0.03	<0.01	0.31	1.72	0.02	98.00
66	0.45	30.20	0.30	0.17	44.50	20.80	0.05	<0.01	0.30	1.09	0.02	97.88
68	1.43	13.03	0.24	0.74	14.20	3.33	0.02	0.03	0.24	66.68	0.06	100.00
69	1.53	7.34	0.31	0.72	10.30	3.53	0.02	<0.01	0.24	75.30	0.07	99.36
70	2.32	11.00	0.46	1.04	16.10	6.89	0.02	0.06	0.49	61.70	0.12	100.20
72	1.78	9.51	0.35	0.83	14.10	5.88	0.02	0.01	0.51	66.10	0.10	99.19
73	1.91	9.53	0.34	0.86	14.30	6.26	0.02	<0.01	0.47	65.70	0.11	99.50
74	0.68	13.60	0.26	0.03	13.20	1.95	0.02	0.09	0.53	68.90	0.02	99.28
75	0.71	10.11	0.28	0.03	11.90	2.15	0.02	<0.01	0.44	72.90	0.02	98.56
76	1.73	8.00	0.29	0.87	9.30	2.27	0.02	0.30	0.28	75.90	0.09	99.05
77	1.38	8.38	0.33	0.69	9.10	2.19	<0.01	0.27	0.26	75.80	0.06	98.46
78	1.33	13.80	0.33	0.67	12.50	2.24	0.02	<0.01	0.23	70.60	0.06	101.78
79	1.73	6.70	0.41	0.94	7.50	1.95	0.02	0.25	0.25	79.80	0.06	99.61
80	0.87	13.26	0.16	0.40	11.80	1.00	0.02	0.37	0.25	70.58	0.03	98.74
81	1.04	9.66	0.28	0.50	9.60	1.63	0.02	0.22	0.23	75.60	0.04	98.82
82	0.63	17.00	0.18	0.26	14.30	0.45	0.03	0.23	0.27	65.50	0.02	98.87
83	1.66	8.13	0.41	0.91	8.60	1.69	0.02	0.33	0.22	77.60	0.07	99.64
84	2.12	8.11	0.24	1.18	8.10	1.33	0.01	0.23	0.25	77.00	0.10	98.67
85	1.93	7.66	0.25	0.96	7.70	1.12	0.01	0.24	0.22	78.50	0.09	98.68
86	1.82	7.23	0.23	0.94	7.40	1.43	0.01	0.24	0.18	79.70	0.07	99.25
87	1.95	5.44	0.44	1.01	6.60	1.44	0.01	<0.01	0.21	81.70	0.07	98.87
88	1.98	4.92	0.39	0.97	6.30	2.03	0.01	0.22	0.20	82.50	0.10	99.62
89	1.74	8.76	0.25	0.86	7.40	1.24	0.01	0.04	0.21	78.50	0.06	99.07
90	1.67	6.38	0.43	0.80	11.80	1.96	0.01	<0.01	0.18	75.70	0.08	99.01
91	2.51	5.00	0.51	1.05	6.80	0.66	0.01	<0.01	0.23	81.20	0.03	98.00
92	2.41	4.97	0.48	1.25	8.60	2.15	0.01	0.02	0.26	77.60	0.16	97.91
93	1.28	10.60	0.28	0.60	9.50	0.85	0.01	0.04	0.25	75.90	0.04	99.35
94	2.20	5.15	0.39	1.12	6.70	2.16	0.01	0.02	0.26	82.80	0.11	100.92
95	2.30	4.99	0.36	1.19	6.50	2.21	0.01	0.02	0.22	80.42	0.10	98.32
96	2.02	6.49	0.37	1.02	7.30	1.85	0.01	0.02	0.23	80.00	0.08	99.39
97	2.53	5.16	0.52	1.28	6.70	2.25	0.01	0.15	0.26	80.60	0.08	99.54
98	2.41	5.04	0.43	1.31	6.80	2.20	0.01	<0.01	0.24	82.50	0.15	101.09
99	2.30	5.30	0.44	1.24	6.80	2.08	0.01	<0.01	0.34	81.53	0.14	100.18
100	2.21	5.92	0.43	1.18	7.10	1.90	0.01	<0.01	0.30	81.01	0.16	100.22

[1] Sample number is also the depth from the surface. See Appendix A3 for lithology and stratigraphic location of each sample.

[2] Loss on ignition.

B4. Whole-rock chemical analyses of core from drill hole 4, Plumbago Creek silica sand deposit (values in weight percent).

Sample number[1]	Al_2O_3	CaO	Fe_2O_3	K_2O	LOI[2]	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2	Total
12	2.03	4.43	0.41	1.12	6.10	2.12	0.01	<0.01	0.29	82.13	0.09	98.73
13	1.82	6.37	0.41	0.96	7.70	2.07	0.01	<0.01	0.32	80.39	0.07	100.12
14	1.66	6.87	0.40	0.91	7.90	2.11	0.01	<0.01	0.19	79.56	0.08	99.69
15	1.34	7.92	0.30	0.71	8.50	2.09	0.01	<0.01	0.23	81.50	0.05	102.65
16	1.34	7.92	0.30	0.71	8.60	1.97	0.01	<0.01	0.23	79.60	0.05	100.73
17	1.46	7.70	0.30	0.72	7.60	1.93	0.01	<0.01	0.24	80.40	0.05	100.41
18	1.30	6.13	0.40	0.68	7.40	2.09	0.01	<0.01	0.29	80.80	0.04	99.14
19	1.13	8.13	0.30	0.61	9.10	2.24	0.01	<0.01	0.26	76.92	0.05	98.75
20	0.58	15.50	0.18	0.28	13.60	1.06	0.01	<0.01	0.20	68.10	0.02	99.53
24	1.23	4.84	0.20	0.64	6.90	2.56	0.01	<0.01	0.20	81.30	0.04	97.92
25	1.18	5.97	0.30	0.65	7.20	2.18	0.01	<0.01	0.20	81.40	0.04	99.13
26	0.98	7.32	0.21	0.53	8.50	2.35	0.01	<0.01	0.23	79.50	0.04	99.67
40	2.92	12.20	0.33	1.70	10.60	0.48	0.01	<0.01	0.24	70.80	0.18	99.46
42	2.49	12.80	0.30	1.35	10.60	0.29	0.01	<0.01	0.19	71.20	0.09	99.32
46	3.29	6.03	0.34	1.74	7.30	1.82	0.01	<0.01	0.33	78.40	0.15	99.41
48	3.56	6.16	0.35	1.64	6.90	2.12	0.01	<0.01	0.26	77.30	0.16	98.46
49	3.65	4.20	0.58	2.00	5.70	1.89	0.01	<0.01	0.28	80.50	0.16	98.97
50	3.45	4.16	0.54	1.90	5.50	1.97	0.01	<0.01	0.30	80.40	0.16	98.39
51	3.55	4.37	0.49	1.97	15.70	1.67	0.01	<0.01	0.30	70.50	0.17	98.73
52	3.81	4.52	0.69	2.10	6.20	2.01	0.01	<0.01	0.24	79.50	0.21	99.29
53	3.34	7.73	0.49	1.85	8.10	1.36	0.01	0.03	0.24	75.23	0.20	98.58
54	4.10	5.49	0.54	2.14	6.40	1.53	0.01	<0.01	0.26	78.10	0.32	98.89
55	4.23	2.06	0.57	2.31	4.40	1.41	0.01	<0.01	0.23	82.80	0.22	98.24
56	4.01	5.31	0.42	2.16	5.60	0.73	0.01	<0.01	0.27	79.50	0.19	98.20
57	0.32	37.00	0.52	<0.03	45.50	14.10	0.04	<0.01	0.33	0.78	0.19	98.78
60	0.88	28.80	0.58	0.26	45.80	19.10	0.03	<0.01	0.37	2.43	0.04	98.29

[1] Sample number is also the depth from the surface. See Appendix A4 for lithology and stratigraphic location of each sample.

[2] Loss on ignition.

B5. Whole-rock chemical analyses of core from drill hole 5, Plumbago Creek silica sand deposit (values in weight percent).

Sample number[1]	Al_2O_3	CaO	Fe_2O_3	K_2O	LOI[2]	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2	Total
15	2.64	6.83	0.45	1.33	10.10	3.93	0.01	<0.01	0.26	73.70	0.11	99.36
17	2.41	6.84	0.58	1.01	10.90	4.63	0.01	<0.01	0.24	72.53	0.08	99.23
19	2.57	8.96	0.66	1.30	7.50	3.52	0.02	<0.01	0.25	74.50	0.12	99.40
20	2.82	11.07	0.56	1.47	12.10	2.48	0.03	<0.01	0.23	69.47	0.12	100.35
24	2.89	8.07	0.76	1.45	11.40	4.17	0.02	<0.01	0.31	70.40	0.18	99.65
27	2.47	10.06	0.77	1.22	15.20	5.98	0.01	<0.01	0.27	64.01	0.16	100.15
30	3.00	7.50	0.90	1.45	12.20	5.01	0.01	<0.01	0.20	69.00	0.17	99.44
35	4.71	4.08	1.04	1.99	6.40	2.67	0.01	0.09	0.15	78.20	0.28	99.62
39	4.41	3.76	0.98	1.74	5.30	2.64	0.01	0.05	0.25	74.00	0.26	93.40
50	3.58	3.85	0.51	1.80	5.70	2.02	0.01	<0.01	0.23	81.40	0.18	99.28
55	1.62	28.70	0.32	0.74	45.70	19.90	0.03	<0.01	0.28	1.78	0.01	99.08
62	0.27	30.90	0.47	<0.03	45.70	20.60	0.03	<0.01	0.30	0.79	0.01	99.07
65	0.24	30.70	0.47	<0.03	45.10	19.50	0.03	<0.01	0.25	2.03	0.02	98.34
68	1.63	15.90	0.32	0.74	24.30	11.00	0.02	<0.01	0.19	46.20	<0.01	100.30
69	2.86	11.12	0.45	1.10	17.20	7.44	0.01	0.04	0.22	58.02	0.07	98.53
70	1.67	13.50	0.27	0.86	12.40	1.29	0.01	<0.01	0.17	69.40	0.12	99.69
71	2.31	8.84	0.34	1.19	8.50	1.07	0.01	<0.01	0.16	75.70	0.09	98.21
72	1.68	5.51	0.29	0.85	7.50	2.55	0.01	<0.01	0.20	80.50	0.09	99.18
73	1.96	3.46	0.35	1.01	5.30	2.04	0.01	<0.01	0.15	84.00	0.06	98.34
74	1.82	4.44	0.26	0.95	5.90	1.77	0.01	<0.01	0.16	83.60	0.08	98.99
75	1.74	5.39	0.44	0.70	6.10	1.57	0.01	<0.01	0.16	83.10	0.05	99.26
76	1.72	5.11	0.34	0.88	5.60	1.30	0.01	<0.01	0.15	84.20	0.04	99.35
77	1.71	5.02	0.43	0.51	5.00	0.83	0.01	<0.01	0.13	85.20	0.06	98.90
78	2.90	3.06	0.62	1.53	3.90	1.11	0.01	<0.01	0.19	85.50	0.03	98.85
79	2.16	3.22	0.65	1.06	3.80	0.87	0.01	<0.01	0.15	85.70	0.17	97.79
80	2.48	3.16	0.46	1.20	3.90	1.05	0.01	<0.01	0.16	86.30	0.08	98.80
81	2.24	3.63	0.38	1.02	5.30	1.25	0.01	<0.01	0.12	78.30	0.10	92.35
82	2.72	3.65	0.45	1.32	4.70	1.55	0.01	<0.01	0.15	84.40	0.12	99.07
83	2.13	4.58	0.42	1.14	5.10	1.08	0.01	<0.01	0.14	84.60	0.14	99.34
86	2.18	5.46	0.55	1.05	5.90	1.25	0.01	<0.01	0.14	83.10	0.09	99.73
88	4.12	3.63	0.60	1.61	6.40	2.52	0.01	<0.01	0.15	73.40	0.08	92.52
90	4.70	3.74	0.74	1.81	6.10	1.92	0.01	<0.01	0.18	79.50	0.24	98.94
91	4.26	4.02	0.51	2.16	6.40	2.50	0.01	<0.01	0.13	79.00	0.22	99.21
92	4.27	3.99	0.61	2.18	6.80	2.77	0.01	<0.01	0.12	77.71	0.24	98.70
93	3.69	5.25	0.53	0.55	8.00	3.24	0.01	<0.01	0.12	77.80	0.23	99.42
94	3.35	6.77	0.47	1.78	10.40	4.24	0.01	<0.01	0.11	73.31	0.21	100.65
95	0.24	31.40	0.13	0.09	46.40	19.33	0.02	<0.01	0.17	<0.01	0.21	97.99
96	0.35	31.40	0.08	0.08	45.90	18.60	0.02	<0.01	0.18	0.98	0.02	97.61
97	0.86	33.40	0.19	0.11	43.60	16.10	0.04	<0.01	0.19	4.24	0.04	98.77
99	2.45	17.11	0.55	0.74	24.90	9.95	0.02	0.07	0.24	43.56	0.11	99.70
100	1.62	11.20	0.25	0.77	17.20	7.09	0.01	<0.01	0.08	59.50	0.10	97.82

[1] Sample number is also the depth from the surface. See Appendix A5 for lithology and stratigraphic location of each sample.

[2] Loss on ignition.

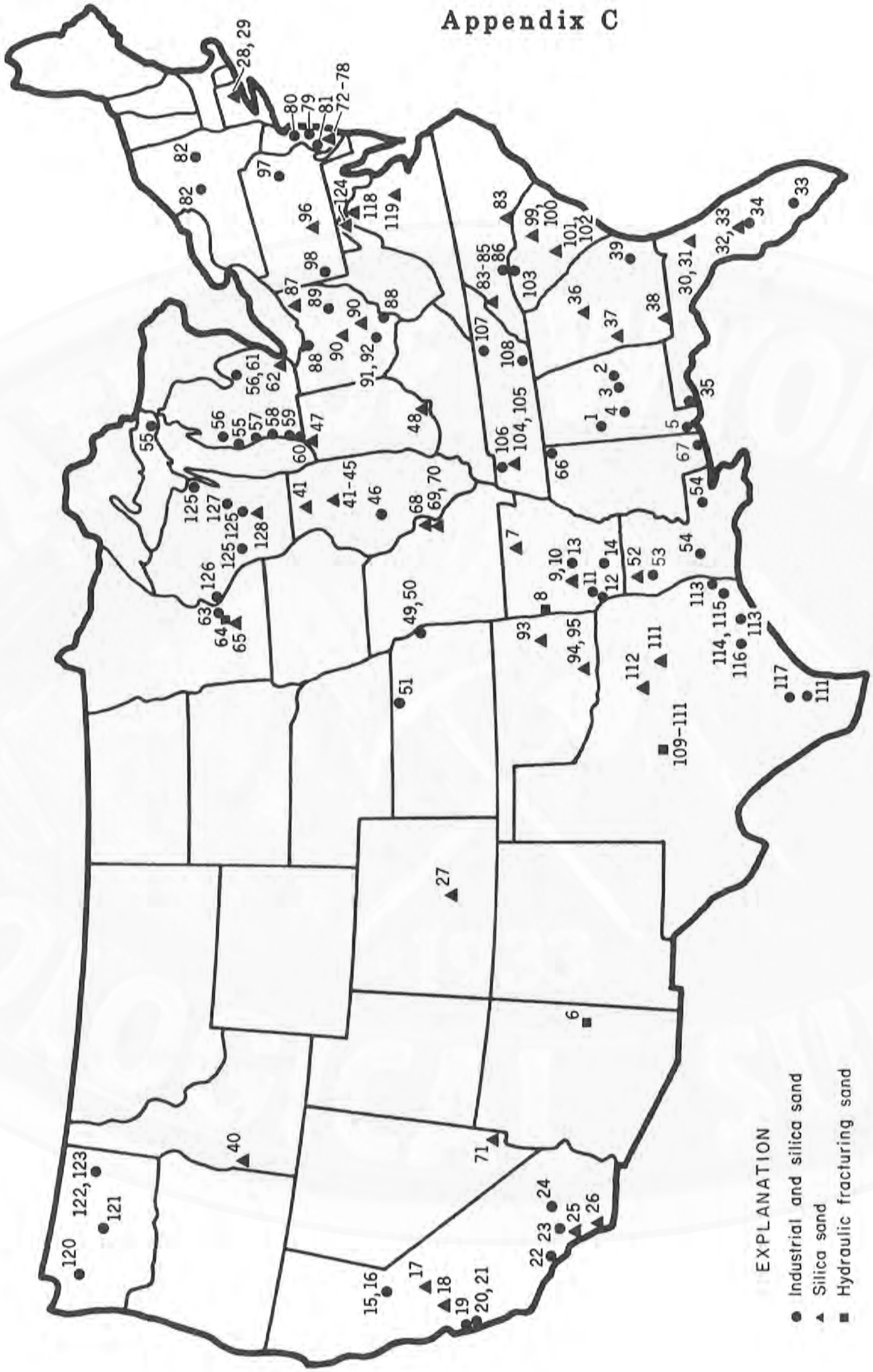
B6. Whole-rock chemical analyses of core from drill hole 6, Plumbago Creek silica sand deposit (values in weight percent).

Sample number[1]	Al_2O_3	CaO	Fe_2O_3	K_2O	LOI[2]	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2	Total
77	3.68	13.88	0.60	1.46	12.10	0.46	0.03	<0.01	0.13	67.81	0.38	100.53
80	8.09	6.33	1.37	2.82	11.90	4.70	0.02	<0.01	0.24	65.09	0.56	101.12
88	0.62	0.17	0.49	0.21	0.30	0.08	<0.01	<0.01	0.06	97.30	0.03	99.26
90	0.68	0.24	0.34	0.28	0.50	0.18	<0.01	<0.01	0.06	96.70	0.03	99.01

1 Sample number is also the depth from the surface. See Appendix A6 for lithology and stratigraphic location of each sample.

2 Loss on ignition.

Appendix C



Appendix C1. Location of United States silica sand and other silica production (including feldspar produced as a glass raw material and some industrial sand production that may be used for silica sand). Numbers refer to producers, Appendix C2.

Appendix C2. United States glass and hydraulic fracturing sand and silica production (including feldspar produced as a glass raw material). Modified from U.S. Bureau of Mines (1986), Engineering and Mining Journal (1987), Goldman and Reining (1983), Dickson, (1984), and U.S. Bureau of Mines Minerals Yearbooks 1982-1985 (for 1981-1984), v. I, Metals and minerals, and v. II, Area reports: domestic.

Numbers refer to map symbol (Appendix C1)	Major silica sand producers and products (if known)	Number of active operations
	Alabama (foundry, silicon, ferrosilicon)	
1	The Morie Company, Inc.	1
2	Warrior Sand and Gravel Company, Inc.	1
3	R & S Materials, Inc.	2
4	Cosby-Carmichael, Inc.	1
5	Dravo Basic Materials Company, Inc.	1
	Arizona	
6	Arizona Silica Sand Company (frac)	1
	Arkansas (foundry, glass, abrasives)	
7	Silica Products Company (glass)	1
8	Ashland Oil, Inc. (probably frac)	1
9	Coleman Crystal Inc. (LASCAS)	1
10	Geomex Mine Services Inc. (LASCAS)	1
11	Ideal Basic Industries, Inc.	1
12	Gifford-Hill and Company, Inc.	1
13	Arkansas White Rock, Inc.	1
14	Turner Trucking Company	1
	California (glass, other)	
15	Pacific Silica Company	1
16	Yuba Silica Inc. (silica flour)	1
17	Owens-Illinois, Inc. (glass)	1
18	Unimin Corporation (glass)	1
19	Santa Cruz Aggregates Company	1
20	Lone Star Industries, Inc.	1
21	Monterey Sand Company, Inc.	2
22	P.W. Gillibrand Company	1
23	Gifford-Hill and Company, Inc.	1
24	Calspar Inc. (feldspar and quartz)	1
25	Ogleby-Norton (California Silica Products Co.) (feldspar-quartz sand for glass)	1
26	U.S. Silica (feldspar-quartz sand for glass)	1
	Colorado	
27	Colorado Silica Sand, Inc. (glass)	1
	Connecticut	
28	U.S. Silica (glass)	1
29	The Feldspar Corporation (feldspar for glass)	2
	Florida (glass, foundry)	
30	The Feldspar Corporation (by-product sand for glass)	1
31	Florida Rock Industries	1
32	Standard Sand and Silica Company (glass)	6
33	E.R. Jahna Industries, Inc.	2
34	Gall Silica Mining Company, Inc.	1
35	Clark Sand Company, Inc.	1
	Georgia (glass, fused silica, other)	
36	The Feldspar Corporation (feldspar for glass)	2
37	The Morie Company, Inc. (glass)	1
38	Florida Crushed Stone Company (glass?)	1
39	Satilla Sand Company, Inc.	1
	Idaho	
40	Unimin Corporation (glass, other)	1
	Illinois (glass, foundry, frac)	
41	Unimin Corporation (glass, frac)	3

Numbers refer to map symbol (Appendix C1)	Major silica sand producers and products (if known)	Number of active operations
42	U.S. Silica (glass)	1
43	Wedron Silica Company (glass, foundry, frac)	1
44	Manley Brothers of Indiana, Inc. (glass)	1
45	Treco Sales Inc.	1
46	East Side Sand Company	1
	Indiana	
47	Unimin Corporation (glass)	1
48	Card Industrial Sand Corporation (glass, other)	1
	Kansas (fiberglass, abrasive, other)	
49	List and Clark Construction Company	1
50	HUB Materials, Inc.	1
51	Alsop Sand Company, Inc.	1
	Louisiana (glass, foundry)	
52	U.S. Silica (glass)	1
53	Cobb Industrial Corporation	1
54	Mid State Sand and Gravel Company, Inc.	2
	Michigan (foundry, glass, frac)	
55	Sand Products Corporation	2
56	Sargent Sand Company	3
57	Nugent Sand Company, Inc.	2
58	Construction Aggregates Corporation	2
59	Manley Brothers of Indiana, Inc.	2
60	Unimin Corporation	1
61	Great Lakes Minerals Company	1
62	U.S. Silica (glass)	1
	Minnesota (frac, glass, foundry)	
63	Twin City Silica, Ltd.	1
64	J.L. Shiely Company (frac)	1
65	Unimin Corporation (frac, glass)	2
	Mississippi (unknown)	
66	Tri-Sands, Inc.	1
67	Jet Sands, Inc.	1
	Missouri	
68	U.S. Silica (glass)	2
69	Unimin Corporation (glass)	1
70	Master Brothers Silica Sand Company	1
	Nevada	
71	J.R. Simplot Company (glass, other)	1
	New Jersey (glass, foundry, abrasive)	
72	The Morie Company, Inc. (glass)	4
73	Unimin Corporation (glass)	1
74	U.S. Silica (glass)	1
75	Warner Company	1
76	Owens-Illinois, Inc. (glass)	1
77	George F. Pettinos, Inc.	1
78	Whitehead Brothers Company (glass)	1
79	N.J. Pulverizing Company	1
80	South River Sand Company	1
81	Downer Silica Company	1
	New York (foundry, minor glass)	
82	Whitehead Brothers Company	2
	North Carolina	
83	Unimin Corporation (glass, high purity silica)	2
84	Indusmin Inc. (by-product silica)	1
85	The Feldspar Corporation (high purity silica)	1
86	KMG Minerals Inc. (by-product feldspar and silica)	1

Numbers refer to map symbol (Appendix C1)	Major silica sand producers and products (if known)	Number of active operations
	Ohio (foundry, glass, silica flour)	
87	Best Silica Sand Company (foundry, frac, glass)	2
88	Keener Sand and Clay Company	2
89	U.S. Silica	1
90	Ogleby-Norton (Central Silica Company) (glass, silica flour, foundry)	2
91	Southern Silica Corporation (glass)	1
92	The Parry Company	1
	Oklahoma (fiberglass, glass)	
93	Ashland Oil, Inc. (quartz-feldspar sand for frac, glass)	1
94	U.S. Silica (glass)	2
95	Mid-Continent Glass Sand Company (glass)	1
	Pennsylvania (glass, other)	
96	U.S. Silica (glass)	1
97	Alliance Sand Company	1
98	McCrady, Inc.	1
	South Carolina (fiberglass, glass, abrasive)	
99	Whitehead Brothers Company	1
100	Unimin Corporation (glass)	1
101	U.S. Silica (glass)	1
102	Columbia Silica Sand Company	1
103	Jobe Sand Company, Inc.	1
	Tennessee (glass, foundry, fused silica, other)	
104	The Morie Company, Inc. (glass?)	2
105	Tri-State Sand Company (glass?)	1
106	Murray Silica Sand Company	1
107	Caryville Sand Company	1
108	Vulcan Materials Company	1
	Texas (glass, frac, other)	
109	Ogleby-Norton (Texas Mining Company) (frac)	1
110	Vulcan Materials Company (frac)	1
111	U.S. Silica (frac, glass)	3
112	Unimin Corporation (glass)	1
113	Specialty Sand Company	2
114	Pioneer Concrete of Texas, Inc.	1
115	Barry and Barry Sand Company, Inc.	1
116	Ideal Basic Industries, Inc.	1
117	Palo Alto Silica Sand, Inc.	1
	Virginia	
118	Unimin Corporation (glass)	1
119	The Feldspar Corporation (aplite for glass)	1
	Washington (glass, ferrosilicon, other)	
120	Industrial Mineral Products, Inc.	1
121	Wenatchee Silica Products, Inc. (silicon and ferrosilicon)	1
122	Lane Mountain Silica Company (ferrosilicon?)	1
123	Northwest Alloys, Inc. (ferrosilicon)	1
	West Virginia	
124	U.S. Silica (glass)	1
	Wisconsin (foundry, glass, frac)	
125	Badger Mining Corporation (glass?)	3
126	Treco Sales Inc.	1
127	A.F. Gelhar Company, Inc.	2
128	Unimin Corporation (glass)	1

The Plumbago Creek Silica Sand Deposit, Albany County, Wyoming

STATE OF WYOMING GEOLOGICAL SURVEY 1933

Geology--Interpreting the past to provide for the future

RI 40