Geology of Microcrystalline Silica (Tripoli) Deposits, Southernmost Illinois

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Department of Energy and Natural Resources
ILLINOIS STATE GEOLOGICAL SURVEY

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Morris W. Leighton, Chief

Natural Resources Building
615 East Peabody Drive
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Cover photo (ca 1912) courtesy of Ms. Joan Bartosz, Aumsville, Oregon
Interior of a microcrystalline silica (tripoli) mine south of Jonesboro, Illinois. Notes on the photo read: "Ginney the oldest mine mule in southern Illinois, age 38 years old, worked in the silica mines 16 years. Died July 29, 1912, and buried." In the background are some workers with hand tools, a screening box, and the ore cart. To the right is Ginney's owner, John Bauscher, and to the left, a "company man."

Graphic Artists—J. Hannah and P. Carrillo
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ABSTRACT

Microcrystalline silica (tripoli) has been mined for more than 80 years from deposits in Alexander and Union Counties in southernmost Illinois. This mineral commodity is primarily used as a buffing and polishing compound and a filler and extender in plastics, paints, and rubber. Almost all deposits occur in the Lower Devonian Clear Creek Chert and are confined to the Elco district and the much smaller Wolf Lake district.

Outside these districts, the Clear Creek Chert consists of interbedded chert, limestone, and dolomite. Within these districts, however, all carbonate has been leached from this and other exposed formations, and silicification has produced a sequence of lithologies ranging from hard novaculitic chert to friable microcrystalline silica. Scanning electron microscopy shows that the hard chert consists of aggregates of subhedral quartz crystals, and the microcrystalline silica consists of euhedral quartz crystals generally 0.5 to 6 µm long.

Microcrystalline silica deposits are conformable to bedding, usually 4 to 7 meters (13–23 ft) thick and mainly in the upper third of the Clear Creek Chert. They are not, however, confined to a specific stratigraphic horizon. Layers of gray, plastic, kaolinitic clay a few centimeters thick are common in the Clear Creek Chert in the Elco district. The only laterally traceable beds in the Clear Creek Chert are the massive chert beds in the uppermost 10 meters (33 ft) of the formation. These beds are characterized by abundant fossils, small intraclasts, and laminations parallel to bedding. Flat-topped ridges have developed on top of these massive chert beds.

As a result of this research, it is proposed that a hydrothermal event played a significant role in the formation of these microcrystalline silica deposits. Preliminary microthermometric determinations on fluid inclusions in quartz crystal overgrowths indicate that silica was precipitated from low salinity fluids at temperatures of about 200°C. Depth of leaching of carbonate in the Elco district defines a saucer-shaped surface that is discordant to both bedding and Cretaceous or Tertiary erosion surfaces. Leaching of carbonate was accompanied by silicification of the Clear Creek Chert in the Elco district and probably also in the Wolf Lake district to the northwest. Prominent positive magnetic anomalies, which have been interpreted to be caused by mafic plutons in the Precambrian basement, coincide with both the Elco and Wolf Lake districts. It is proposed that groundwater flowing north from the Pascola Arch, which was uplifted in early Mesozoic (?) time, was heated by these plutons. Consequently, as it rose closer to the surface, it dissolved carbonates and deposited silica.

ACKNOWLEDGMENTS

The cooperation and assistance of many individuals and organizations made this investigation productive and enjoyable.

Lone Star Industries (Cape Girardeau, Missouri) permitted access to their open-pit silica mine west of Elco. Local landowners, without exception, gave permission to walk across their lands and showed genuine friendliness. U.S. Forest Service personnel in the Jonesboro and Harrisburg offices provided a wealth of helpful information on the area.

At the Illinois State Geological Survey (ISGS), the scientific and technical staff performed a variety of procedures efficiently and carefully: Duane M. Moore, x-ray diffraction (XRD) analysis; Donald J. Lowry, scanning electron microscopy (SEM); D. Scott Beaty, preparation of thin sections and XRD analysis; Joel M. Dexter, field photography; and Robert R. Frost and L. Ray Henderson, chemical analyses under the direction of Gary B. Dreher. Jianzhong (Stu) Xu assisted with the compilation of information on inactive mines.

Many others at the ISGS shared freely of their time, knowledge, and enthusiasm for scientific investigation. Joseph A. Devera provided much information on the stratigraphy of the area and offered us the opportunity for valuable discussion on Devonian stratigraphy and formation of microcrystalline silica deposits. Michael L. Sargent provided information on lower Paleozoic stratigraphy, and Leon R. Follmer contributed information on paleosols. Reviews by James C. Bradbury and Joseph A. Devera (ISGS), Mark L. Chatman (U.S. Bureau of Mines), and Fred N. Earll (Department of Geological Engineering, Montana College of Mineral Science and Technology) contributed to the improvement of this manuscript.

This investigation was completed while Richard B. Berg, visiting geologist from Montana, was participating in a 1-year exchange program between the geological surveys of Illinois and Montana. At the conclusion of the study, Dr. Berg returned to the Montana Bureau of Mines and Geology, Montana College of Mineral Science and Technology, Butte, Montana 59701.

INTRODUCTION

Mining of microcrystalline silica (tripoli) in southernmost Illinois began several years prior to 1907 (Ernest 1908). Host formations of these deposits include the Lower Devonian Clear Creek Chert, Grassy Knob Chert, and Bailey Limestone. This fine grained, friable, white rock is pulverized to produce material used in buffing and polishing compounds and as a filler or extender in a variety of commodities, including paints and plastics. Formation of these deposits resulted from the alteration of limestone, dolomite, and chert. Addition of hydrothermal silica to this sequence of sedimentary rocks was accompanied by leaching of all carbonates to produce these unusual deposits.

This report is divided into two major sections: the first generally covers microcrystalline silica deposits in southernmost Illinois, and the second specifically covers the geology of the area west of Elco.

PREVIOUS WORK

Lamar (1953) presented the most detailed description of all types of siliceous materials (microcrystalline silica, novaculite, and ganister) in southernmost Illinois. He described some of the deposits, provided information on the physical and chemical properties of selected samples, and discussed their origin.

Levine (1973) concentrated on the geology of microcrystalline silica deposits in the Clear Creek Chert within the Mill Creek 7.5-Minute Quadrangle. Observations presented by Levine on structural features and on the distribution of iron oxide staining within the deposits are particularly useful because he had the opportunity to examine approximately 60 mines and exploratory adits. A geologic map of much of the southern two-thirds of the Mill Creek 7.5-Minute Quadrangle is included in Levine's thesis, but maps of individual mines or deposits are not included.

J. Weller and Ekblaw (1940) published a preliminary geologic map (scale 1:62,500), which encompassed most of the area of microcrystalline silica deposits. It extended north from Olive Branch in Alexander County to 2 miles (3.2 km) north of the Union–Jackson county line. This geologic map shows the extent of the Lower Devonian Bailey Limestone, Grassy Knob Chert, Backbone Limestone, and Clear Creek Chert. Their discussion of these formations, as well as other formations not directly associated with the microcrystalline silica deposits in this area, are thorough and useful. Some additional stratigraphic information, as well as a discussion of silicification of these beds, is presented by J. Weller (1944). A geologic map by Pryor and Ross (1962) includes the southernmost 6 miles (10 km) of the area mapped by J. Weller and Ekblaw. Pryor and Ross offered an alternative stratigraphic interpretation for the area between Olive Branch and Tamms.

Much has been written on the Devonian formations of the central United States. Collinson et al. (1967) presented a regional discussion of Devonian formations in Illinois; Allen (1985) discussed the petrology, paleontology, and origin of the Clear Creek Chert; Rogers (1972) described Devonian stratigraphy in Illinois; and Biggs (1957), in his study of nodular cherts in Illinois, described specimens from Devonian formations of southernmost Illinois.

Several authors have reported on the properties of microcrystalline silica and its suitability for different applications. Chemical analyses of this material were reported by Bain (1907). Subsequent investigations focused on its use for sand-lime bricks (Ernest 1908, Williams 1909) and pottery (Parmelee 1932). More recent studies characterized the finest size fraction of microcrystalline silica (Leamnson et al. 1969, Thomas et al. 1970). Pickering et al. (1986) presented a good summary of the geology, petrography, mining, processing, and uses of this mineral commodity from southernmost Illinois.

PURPOSE

The main goal of this investigation was to provide information useful for the economic evaluation and development of microcrystalline silica (tripoli) deposits in southernmost Illinois. For this reason, an effort was made to understand and describe the relationship of the deposits to stratigraphic units and local structure. Additionally, it is hoped that the information in this report on the mineralogy and stratigraphy of this sequence of Devonian rocks will be useful to anyone investigating the geology of this area.

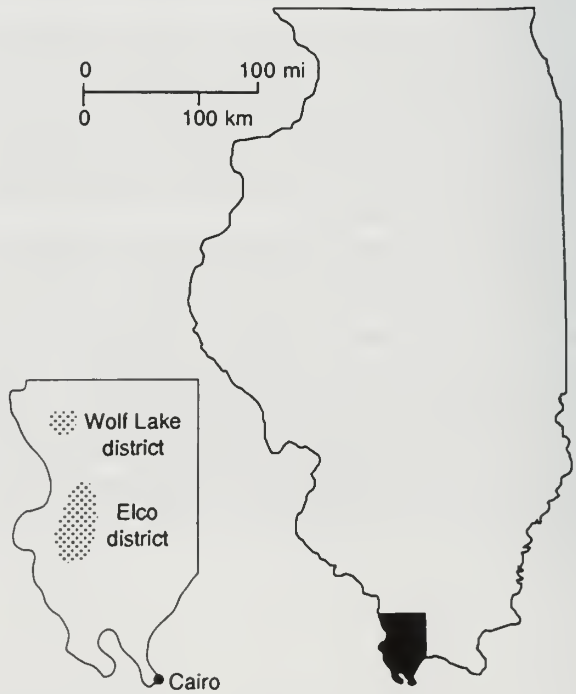


Figure 1 The Elco and Wolf Lake microcrystalline silica districts in Illinois.

PROCEDURES

Because of the relatively short time available for this study (1 year), it was decided that more could be gained by concentrating on the detailed examination of part of the Elco district (fig. 1). Consequently, a 6.5-km^2 (2.5-mi^2) area west of Elco in the heart of the microcrystalline silica district was selected for investigation (plate 1).

In this area, these deposits occur in the Lower Devonian Clear Creek Chert. Numerous inactive mines and exploratory adits afforded the opportunity to examine these beds. Although for reasons of liability, it was not possible to enter the underground workings, exposures at the portals of the workings were an important source of information. Exposures at the open-pit silica mine operated by Lone Star Industries provided the opportunity to make a detailed examination of a 32-meter (104-ft) section of the Clear Creek Chert. From October 1989 to May 1990, 70 days spent in the field were largely devoted to mapping the geology of the area west of Elco. Petrographic examination of 34 thin sections, x-ray diffraction (XRD) analysis of clay samples, and chemical analysis and scanning electron microscopy (SEM) of selected samples were all employed to characterize rocks from the area.

Metric units (followed by the British equivalent) are used throughout the report, except in those cases for which the original measurements were reported in British units.

MICROCRYSTALLINE SILICA (TRIPOLI)

DEFINITIONS

There has been some confusion over the usage of the terms tripoli, amorphous silica, and microcrystalline silica as they apply to the deposits in southernmost Illinois. The following definitions apply to terms used throughout this report.

Amorphous silica Some of the early literature used this term to describe the microcrystalline silica from southernmost Illinois. More recently, it has been replaced by the terms *tripoli* or *microcrystalline silica*. When methods for the identification of very fine grained crystalline quartz were not available, this material was thought to be amorphous. X-ray diffraction (XRD) analysis and scanning electron microscopy (SEM) have proved that it is crystalline quartz.

Chert "A hard, extremely dense or compact, dull to semivitreous, microcrystalline or cryptocrystalline sedimentary rock, consisting dominantly of interlocking crystals of quartz less than about 30 µm in diameter; it may contain amorphous silica or opal" (Bates and Jackson 1980, p. 108).

Ganister Lamar (1953, p. 27) described Illinois ganister as "a high-silica material, usually white, cream, light yellow or red, which is loosely consolidated and readily disintegrated into irregular particles an inch or less in size." Ganister is more generally defined as "a hard, fine grained quartzose sandstone or quartzite, used in the manufacture of silica brick" (Bates and Jackson 1980, p. 252).

Microcrystalline silica A friable rock consisting almost entirely of submicroscopic quartz crystals, most <2 µm in length. The rock is transformed into commercial microcrystalline silica products by disaggregating and sizing processes. The terms amorphous silica, tripoli, and microcrystalline silica have all been used to describe the material mined in southernmost Illinois. Both the rock and the commercial material derived from it are best described as microcrystalline silica.

Novaculite Novaculite has been used to describe hard chert (Holbrook 1917) that occurs in beds and, unlike much chert from this area, does not break readily into small fragments. It is gray to white, has a waxy or dull luster, and may be translucent on thin edges. Novaculite from the Hot Springs–Little Rock area of Arkansas differs from that of southern Illinois because textures indicate thermal metamorphism in the Arkansas material (Keller et al. 1977).

Quartz Microcrystalline silica, chert, ganister, novaculite, and tripoli are all quartz, one of a group of minerals composed of silicon dioxide (SiO_2).

Silica This general term has been applied to deposits of ganister, novaculite, and microcrystalline silica, all of which consist of alpha quartz, the most abundant member of the group of silicon dioxide minerals.

Tripoli The term tripoli was initially applied to deposits of diatomite (a material consisting of siliceous cell walls of diatoms) found near Tripoli in northern Libya. Because microcrystalline silica from Seneca, Missouri, resembled the Libyan diatomite, it was also called tripoli. Later other deposits of microcrystalline silica, such as those in southernmost Illinois, were also commonly called tripoli.

USES

Microcrystalline silica (tripoli) is an unusual rock that, because of unique characteristics, can be processed into a useful commodity. The most important properties of this rock, as typified by deposits in southernmost Illinois, are described below.

■ It is composed of quartz, a relatively hard mineral (7 on Mohs scale of mineral hardness) that does not react with most chemicals.

■ Except where stained by iron oxide, it is unusually white and can yield a product with GE brightness in the high 80s. GE brightness is a measure of the reflectivity of minerals used as fillers and extenders. Magnesium oxide has a GE brightness of 100.

■ Because it consists of submicroscopic quartz crystals, some of which are <1 µm in length, it is friable and can be disaggregated and sized by standard industrial procedures to make products of very small grain size. Not only can very fine grained material be prepared by disaggregating this rock into the constituent quartz crystals, but a material is produced in which the small grains are bounded mainly by natural crystal faces rather than irregular fracture surfaces. Natural fracture surfaces produce grains with sharp edges. Quartz crystal faces intersect at larger angles, thus a material composed of unfractured quartz has fewer sharp edges than that produced from fractured quartz.

The hardness, small grain size, and lack of sharp edges make microcrystalline silica suitable for buffing and polishing. Uniform sizing is very important in these applications; 99.5% of the particles of microcrystalline silica used in buffing and polishing compounds must be <10 µm in size (Bradbury and Ehrlinger 1983). The mildly abrasive properties of microcrystalline silica are used to advantage in toothpaste, industrial soaps, and fine polishes for lenses and lacquer surfaces.

Microcrystalline silica is widely used as an extender in paints. In this market, it competes with other white, fine grained minerals such as talc, calcium carbonate, and kaolin. Because of its greater hardness, microcrystalline silica has particular application in the formulation of paints to produce a durable surface that resists chemicals and abrasion. A disadvantage of using microcrystalline silica in paint is that its greater hardness causes increased wear of metal parts used in mixing and application equipment.

Microcrystalline silica is also used as a functional filler in plastics. It improves strength, opacity, and dielectric properties of the plastic. Because of the high dielectric characteristics of quartz, it is particularly desirable in plastics used in cable coverings. As with paints, various minerals are used in plastics. Some plastics are loaded with as much as 50% functional filler. Mineral fillers are frequently treated with a coupling agent that is an organic compound, which aids in forming a strong bond between the mineral particle and the resin. Surface modification enhances the properties of the functional filler but adds to the cost of the material.

The most recent published prices for microcrystalline silica sold by an Illinois producer are for 1983. Micronized grades ranged from $128 to $191 per ton F.O.B. Elco, Illinois (Harben 1983). The finest size grades are the most expensive. The coarser material (air-floated grades) ranged from $71 to $95 per ton.

DEPOSITS OF MICROCRYSTALLINE SILICA IN THE UNITED STATES

Microcrystalline silica (tripoli) and novaculite, shipped all across the United States and to many other countries, is produced from three districts in the midcontinent. The districts lie along the Missouri–Oklahoma border and in central Arkansas and southernmost Illinois.

Tripoli deposits of southwestern Missouri and extreme northeastern Oklahoma are flat-lying, 2 to 20 feet (0.6–6 m) thick, lens-shaped, and a few tens of feet to several acres in lateral extent. Occurring in Mississippian cherty limestone, they are thought to have been formed by the initial deposition of colloidal silica and alkaline salts; subsequent dissolution of alkaline salts concentrated the silica (Quirk and Bates 1978). The deposits are very fine grained, fibrous, microcrystalline silica that is cream to rose color, depending on iron oxide content. The history of mining these deposits reaches back to the first mining in 1869 at Seneca, Missouri.

Both novaculite and tripoli are mined in central Arkansas in the Ouachita Mountains. The Arkansas Novaculite is Late Devonian in age, except for the upper part, which is Mississippian in age (Steuart et al. 1983). Novaculite also occurs in the same formation in the western part of the Ouachita Mountains in Oklahoma. Novaculite from these deposits shows textural evidence of thermal metamorphism, visible only at high magnification using SEM (Keller et al. 1977).

Earliest mining of novaculite from these deposits was by Indians, who used it for making tools. Recently, the rock has been mined for whetstones. Mining for this use continues, mainly in the area northeast of Hot Springs, Arkansas. Novaculite from this district makes good whetstones because of its unusual porosity, caused by solution of a carbonate leaving rhombic cavities. The uniform texture and sharp edges on the quartz grains are important for this use (Steuart et al. 1983).

Tripoli is mined in the area of Hot Springs, Arkansas, from beds in the uppermost part of the Arkansas Novaculite. Deposits of tripoli in an area encompassing part of Tennessee, northwestern Alabama, and northeastern Mississippi have not been mined in recent years (Bradbury and Ehrlinger 1983). Deposits are also known from Texas and northwestern Georgia.

In northwestern Alabama, deposits in the Mississippian Fort Payne Chert, are attributed to subaerial weathering of the precursor chert (Rheams and Richter 1988). A color photograph of a cut in a typical tripoli deposit in northwestern Alabama (Rheams and Richter 1988) looks similar to exposures of the Clear Creek Chert in southernmost Illinois. In both deposits, the distribution of secondary iron minerals has produced a distinct banding of alternating light reddish brown and white beds. A scanning electron micrograph (SEM) of microcrystalline silica from northwestern Alabama exhibits texture similar to that of material from southernmost Illinois (Rheams and Richter 1988).

CHEMICAL AND PHYSICAL CHARACTERISTICS

Microcrystalline silica is simple mineralogically, consisting almost entirely of quartz (fig. 2). The chemical composition is close to that of pure quartz (table 1). The small concentration of iron oxide is from the secondary iron minerals present in much microcrystalline silica. The titanium dioxide is probably from detrital or diagenetic anatase, and the alumina is from clays. The calcium oxide may be explained by calcite inclusions in some of the larger (>100 µm) euhedral quartz crystals that are scattered throughout the microcrystalline silica. The magnesia may be from dolomite inclusions in these same crystals.

The distinguishing characteristic of microcrystalline silica, particularly that from beds in the Clear Creek Chert, is the small grain size and euhedral shape of most quartz crystals. Figure 3 shows crystals from several micrometers in length to less than 1 µm. Except where crystals have impinged on one another during growth, they show well developed crystal faces. Because this rock lacks an interlocking texture, it can be broken apart into the individual crystals during fine grinding (micronizing).

EXPLORATION, MINING, AND PROCESSING

Economically minable deposits of microcrystalline silica are relatively soft beds, which are seldom exposed, even on steep hill slopes. Thus, exploration sampling must penetrate overlying soils, variously developed in loess, colluvium, and associated weathered rock units. Before about 1960, this was accomplished by driving adits into the steep slopes on the sides of ridges. In the area mapped in detail west of Elco, most of the adits shown on plate 1 are exploratory adits only a few tens of meters long. Recently, core drilling and reverse circulation drilling have been used in exploration. The flat-topped ridges, which are underlain by the massive chert beds at the top of the Clear Creek Chert, provide good access from which to drill into the underlying Clear Creek Chert.

Production of microcrystalline silica in southernmost Illinois began before 1906. There were three mills in operation, including Illinois Silica's mill at Reynoldsville (Bain 1907). At least nine companies have operated mills for the production of microcrystalline silica from deposits in Alexander and Union Counties (figs. 4 and 5). Because of closure and consolidation, only two mills were operating in 1990: Illinois Minerals at Elco and

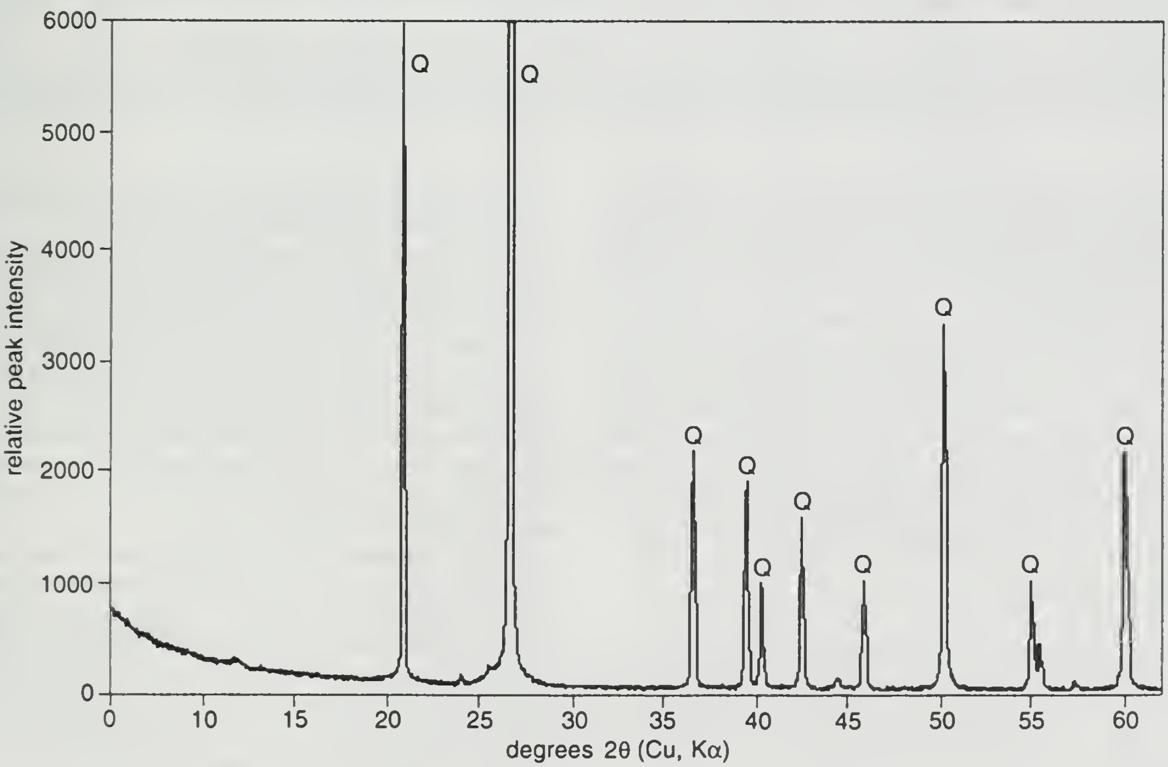


Figure 2 XRD trace of specimen TRB-514 of microcrystalline silica from the Clear Creek Chert exposed in the Jason mine (site 8, appendix A and fig. 5). The pulverized sample was prepared in a random orientation mount (Q = quartz). Analysis by D. M. Moore, Clay Minerals Unit, ISGS.

Table 1 Chemical analyses of microcrystalline silica from southernmost Illinois (reported in wt %).*

	TRB-510	TRB-511	TRB-513	TRB-514	TRB-517	TRB-518	7	8
SiO_2	89.40	84.51	89.43	98.95	99.64	98.26	99.31	99.5 ± 0.5
TiO_2	0.33	0.48	0.34	0.03	0.01	0.02	0.003	0.005
Al_2O_3	6.79	10.38	6.84	0.47	0.16	0.56	0.13	0.009
Fe_2O_3	0.20	0.25	0.23	0.04	0.04	0.06	0.04	0.025
MnO	0.004	0.005	0.004	0.002	0.002	0.004	0.002	
MgO	0.18	0.20	0.19	0.08	0.08	0.06	0.05	0.008
CaO	0.12	0.13	0.12	0.10	0.11	0.10	0.09	0.15
Na_2O	0.09	0.07	0.06	N.D.	N.D.	N.D.	0.05	
K_2O	0.49	0.56	0.50	0.08	0.05	0.08	0.01	
P_2O_5	0.05	0.05	0.02	0.01	0.03	0.03	0.006	
SrO	0.003	0.002	N.D.	N.D.	0.001	0.002	N.D.	
BaO	0.012	0.016	0.009	N.D.	N.D.	0.002	N.D.	
L.O.I.	2.52	3.67	2.47	0.43	0.28	1.12	0.47	
TOTAL	100.19	100.32	100.21	100.19	100.40	100.30	100.16	

TRB-510, 511, and 513 are samples of microcrystalline silica from the Bailey Limestone–Grassy Knob Chert transition zone exposed in the underground mine northeast of Olive Branch (site 119, app. A, fig. 10).
TRB-514 is a sample from a mined bed of microcrystalline silica (section 10, app. B) in the Clear Creek Chert exposed at the Jason mine (site 8, app. A, fig. 5).
TRB-517 and 518 are samples of microcrystalline silica in the Clear Creek Chert exposed on the south wall of the north pit at the Lone Star mine (site 65, app. A, plate 1). Section 4 in appendix B shows the stratigraphic position of sampled beds.
Sample 7 is silica of spectrographic purity analyzed by the same methods and at the same time as analyses of the first six samples.
Sample 8 is typical processed microcrystalline silica from southernmost Illinois (Pickering et al. 1986).

*Analyses of the TRB sample series were performed by R. R. Frost, Analytical Chemistry Section, ISGS. Samples were fused using a lithium tetraborate flux, then pulverized and pressed into pellets for analysis on a Rigaku 3371 wavelength dispersive x-ray fluorescence unit.

Tammsco at Tamms. Both companies are owned by Unimin Corporation, the largest silica sand producer in the United States, and they are operated as Unimin Specialty Minerals.

Until 1983, when Illinois Minerals Company began mining by open pit, all the microcrystalline silica from beds in the Clear Creek Chert was mined underground. Because beds are nearly horizontal, mining was by the room-and-pillar method with portals developed on the sides of the steep slopes. Early mines were wagon mines where the shot rock was loaded by hand. Holbrook (1917, p. 1138) gives a picturesque description of a typical underground silica mine in the early 1900s.

> For a mine, the underground scene is one of unusual beauty. The main roads in the mine are lighted with coal-oil wall lamps hanging from spikes that have been driven into the soft walls and reflecting the light on the walls, pillars, roof and floor, all of alabastine whiteness. Of added interest is the presence of mules and wagons underground, for the rooms are of sufficient size to allow the teams to go underground, drive directly to the face and load with about two and a half to three tons of mined silica. This is hauled to the grinding mills, often several miles distant.

In more recent years, haulageways have been driven sufficiently large to accommodate trucks that are loaded mechanically. Passageways are typically 4.6 to 6.1 meters (15–20 ft) high and 6.1 meters (20 ft) wide with pillars measuring 9 by 9 meters (30×30 ft) (Pickering et al. 1986). Ground support is not required in these mines. An arched roof stands well, except where thin clay layers between chert beds provide planes of weakness. Slope failure is not a problem in open pits; very steep slopes will stand for years.

In 1989, there were two active surface mines and one active underground mine. Illinois Minerals operated the Birk open-pit mine (site 107, fig. 5), and Tammsco mined microcrystalline silica at the Birk no. 2, an underground mine (site 109, fig. 5). Lone Star Industries operated an open-pit mine (site 65, plate 1) where they mined silica, some of it stained with iron oxide, for use in the manufacture of portland cement at their plant in Cape Girardeau, Missouri.

Processing of microcrystalline silica consists of drying the silica, reducing its size, and sizing it to produce

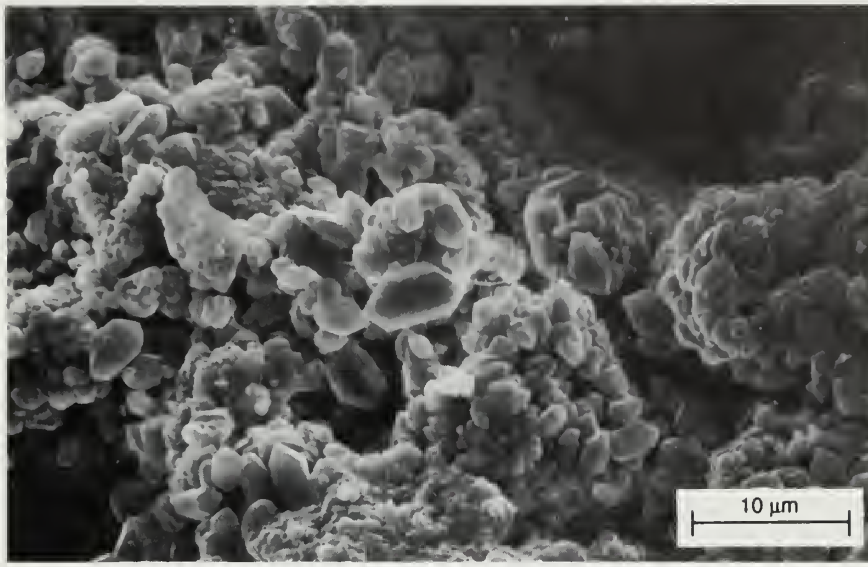


Figure 3 SEM micrograph of specimen TRB-67 of microcrystalline silica from the Clear Creek Chert exposed in the Jason mine. Micrograph by D. J. Lowry, SEM Laboratory, ISGS.

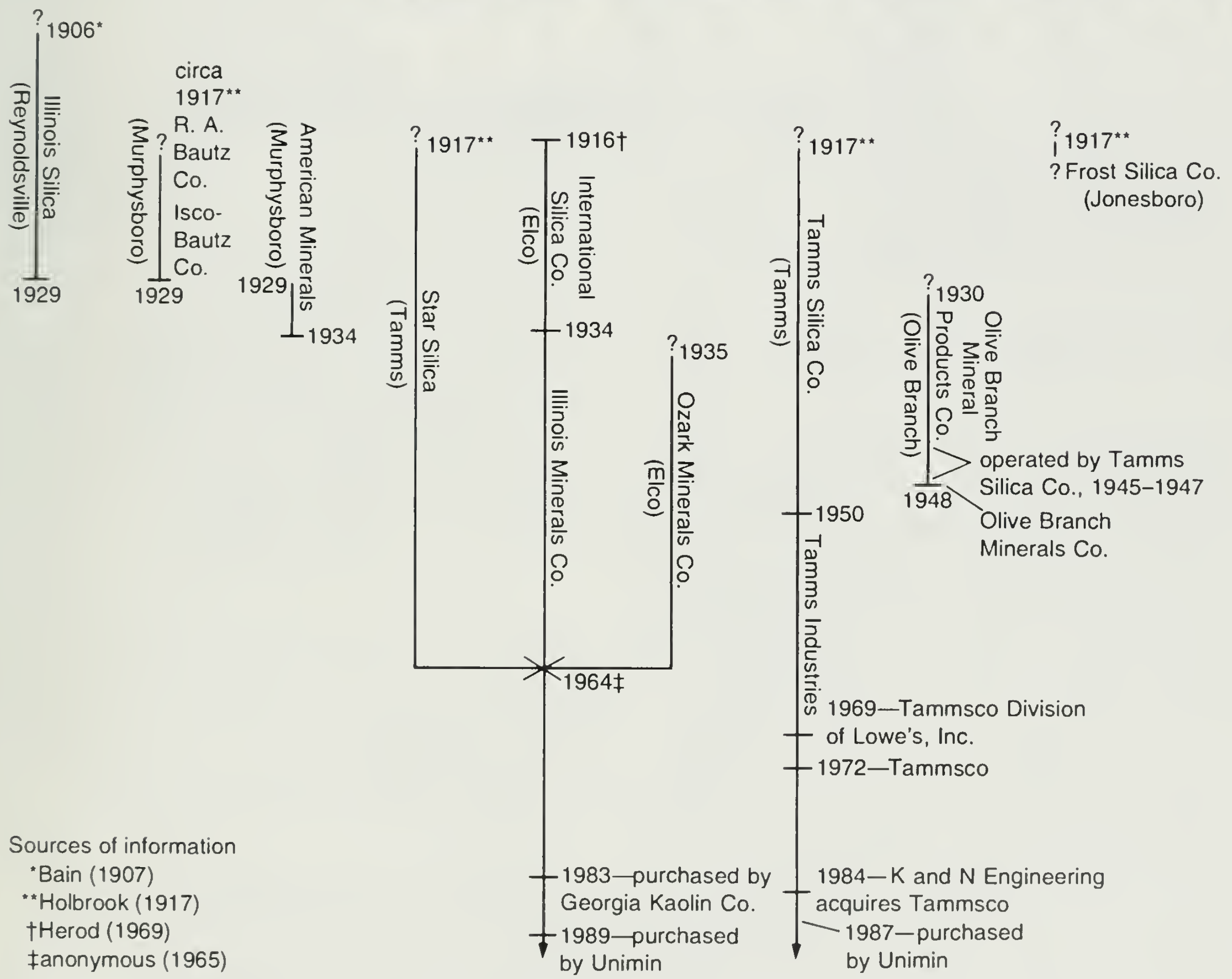


Figure 4 Microcrystalline silica producers in southernmost Illinois. Locations of mills in parentheses. Information was also obtained from two publications of the U.S. Bureau of Mines, *Mineral Resources of the United States, 1924–1931*, and *Minerals Yearbooks, 1932–1987*.

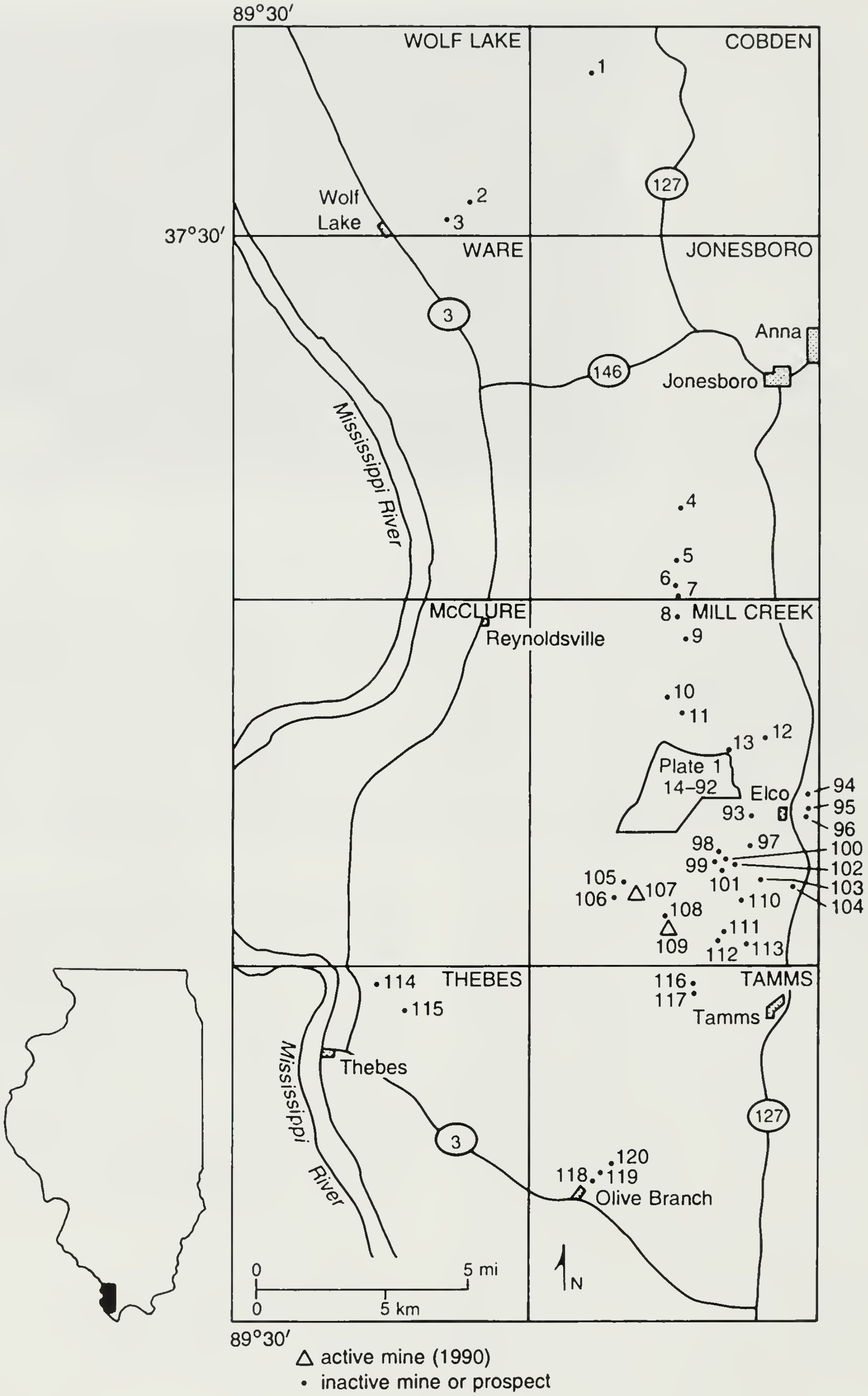


Figure 5 Sites of silica mines and prospects listed in appendix A. Plate 1 shows localities 14–92. Microcrystalline silica, ganister, and novaculitic chert mines are included. Boundaries of 7.5-minute quadrangles are shown.

various grades for different applications. Pickering et al. (1986) outlined the general procedure employed by Illinois Minerals Company at their Elco mill. Initially, crude ore is crushed to less than 1 cm in diameter in a hammer mill, then it is dried in a fluid bed dryer. Further size reduction is accomplished by a ceramic rod mill. Air classification is used to separate the coarse material from the finer material, which is then micronized in self-attrition mills. The finest product consists of greater than 50% <1.2 µm.

In the very competitive world of industrial mineral commodities, a consistently uniform product is a prerequisite to competing effectively. Uniformity is achieved through careful, automated monitoring and control of the processing of microcrystalline silica. The following description (Weigel 1927, p. 167) gives an interesting indication of the changes in quality-control techniques since the 1920s: "The silica is then graded into different sizes by eye and by testing between the teeth and roughly marked off into different grades."

REGIONAL STRATIGRAPHY

The microcrystalline silica deposits of Illinois are situated on the southwest flank of the Illinois Basin, where Devonian sedimentary rocks are exposed in a north-south-trending belt in Union and Alexander Counties. Mississippian formations are exposed to the east and northeast of the microcrystalline silica deposits. Ordovician and Silurian formations are exposed to the southwest and along the Mississippi River Valley to the west. Lower Devonian formations in southernmost Illinois consist of siliceous carbonates interbedded with chert (fig. 6). Silica has been introduced and carbonates leached in the area of the microcrystalline silica deposits; the result is a variable sequence of hard chert to friable microcrystalline silica layers and thin clay beds. The Devonian stratigraphy in this part of Alexander County is poorly understood because of the absence of distinctive mappable beds and scarcity of exposures.

Bailey Limestone

The Bailey Limestone, which consists mainly of siliceous argillaceous limestone and chert beds grading into nodular chert, is reported to be at least 200 feet (61 m) and perhaps as much as 350 feet (107 m) thick in southwestern Illinois (J. Weller and Ekblaw 1940). The lowest part of the Devonian System appears to occur within the Bailey Limestone; fossils of Silurian age have been found at the base of this formation (Collinson et al. 1967).

Beds of white microcrystalline silica are exposed in a long roadcut in the Bailey Limestone 2 miles (3.4 km) southeast of Thebes along Illinois route 3. This roadcut offers an opportunity to trace individual beds of unleached siliceous limestone into microcrystalline silica (fig. 7). Lamar (1953) traced a bed of limestone 6 inches (15 cm) thick for 350 feet (106 m) in this roadcut from unleached rock to a rock almost completely leached of

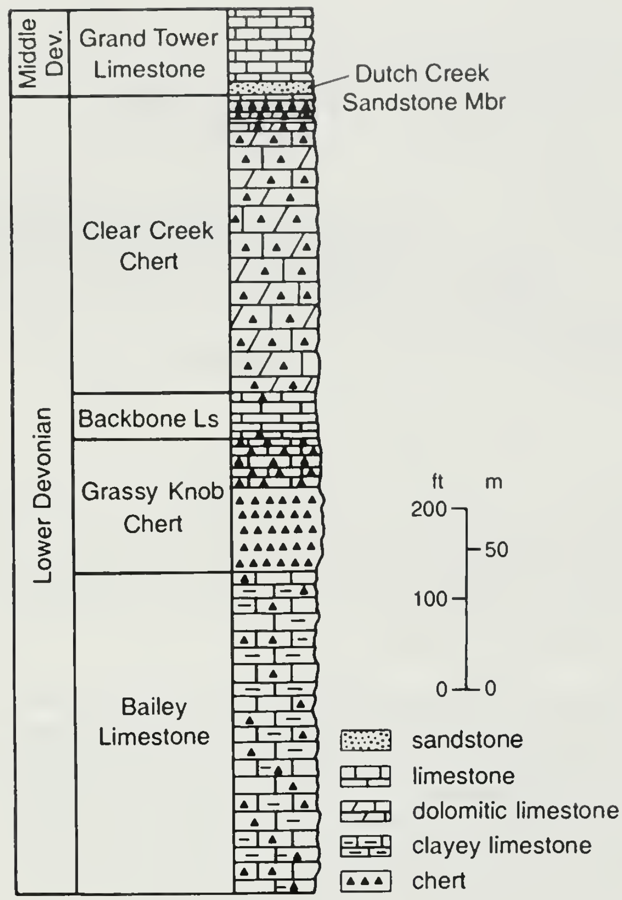


Figure 6 Generalized stratigraphic section for the Lower and part of the Middle Devonian formations of southwestern Illinois (modified from Collinson et al. 1967).

carbonate. The unleached siliceous limestone that he sampled contained 69.88% total carbonates (65.80% $CaCO_3$ and 4.08% $MgCO_3$), whereas the most highly leached portion of this bed contained only 0.28% total carbonate. The stratigraphic thickness between individual chert beds remains constant from areas of unleached siliceous limestone to an area where all of the carbonate has been removed (fig. 16, *in* J. Weller 1944). Both the distribution of leaching, as seen in this roadcut, and the fact that leached porous beds have not been compacted by lithostatic pressure indicate that leaching of carbonate occurred at shallow depth.

Figure 8 shows a sequence of interbedded chert, siliceous limestone, clay, and microcrystalline silica exposed in this same roadcut. Solution of the carbonate in this exposure has been selective, producing interbedded microcrystalline silica and siliceous limestone. Also, thinly bedded microcrystalline silica exposed at the northwest end of the roadcut is discordant with the general attitude of bedding, perhaps as a result of intrusion along a fault plane (fig. 7). Thinly bedded microcrystalline silica (fig. 9) is interbedded with brown to gray clay. On a moist, freshly broken surface of the thinly bedded microcrystalline silica, layers of differing

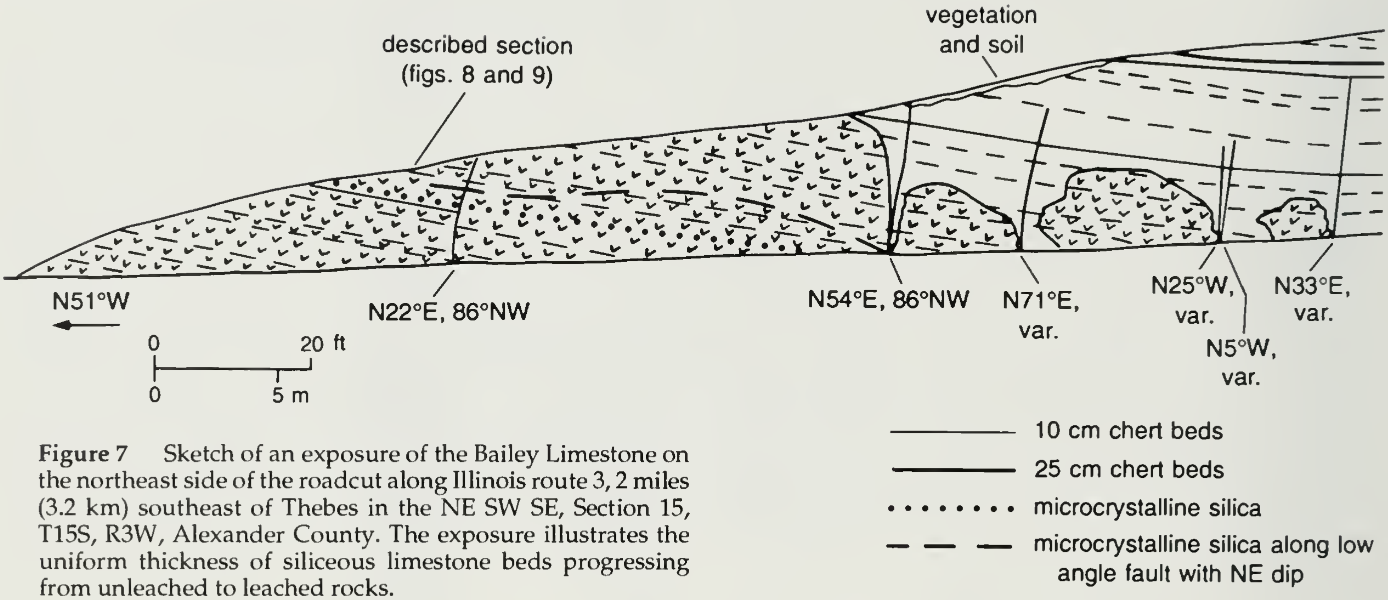


Figure 7 Sketch of an exposure of the Bailey Limestone on the northeast side of the roadcut along Illinois route 3, 2 miles (3.2 km) southeast of Thebes in the NE SW SE, Section 15, T15S, R3W, Alexander County. The exposure illustrates the uniform thickness of siliceous limestone beds progressing from unleached to leached rocks.

porosity several millimeters thick were recognizable. Textural differences causing these fine layers were not recognized, however, in thin section. Chert nodules from the leached portion of this roadcut have moderately soft microcrystalline silica rinds that are white, in contrast with the light gray chert. Most fracture surfaces are coated with hydrated iron oxide or hematite, which gives the entire roadcut a tan color.

Grassy Knob Chert

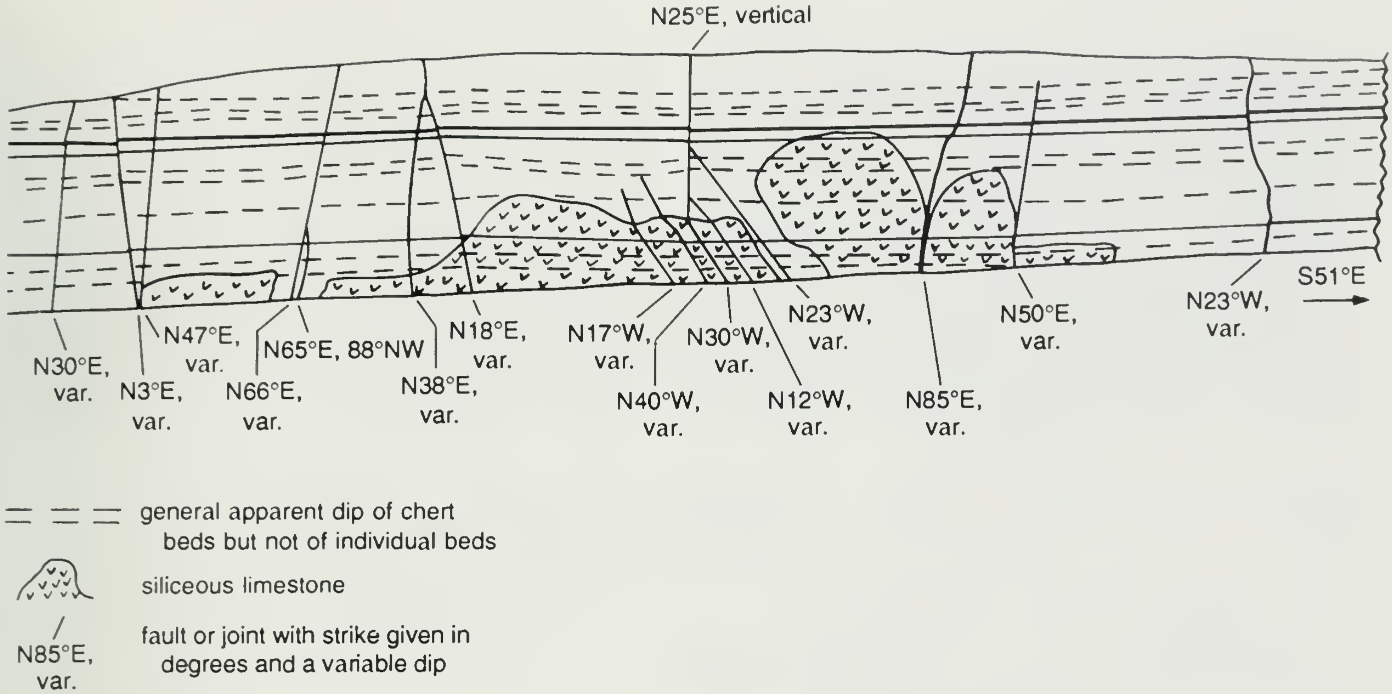
The Lower Devonian Grassy Knob Chert overlies the Bailey Limestone and consists almost completely of chert (J. Weller 1944). Thickness in this area is about 200 feet (61 m); thickness is about 300 feet (92 m) in the subsurface to the east (Willman et al. 1975). Pryor and Ross (1962) did not recognize the Grassy Knob Chert as separate from the Bailey Limestone at least as far north as the north boundary of their map, about 1 mile (1.2 km) north of Tamms. They assigned the 100 feet (31 m) of strata exposed in quarries northeast of Olive Branch (fig. 10) to the upper part of the Bailey Limestone. The interpretation by J. Weller and Ekblaw (1940) of these beds as part of the Grassy Knob Chert is preferred.

Massive chert beds exposed in the northeasternmost quarry from Olive Branch (site 120, fig. 10) resemble chert beds exposed near the base of the cut at the Jordan Novaculite quarry (site 113, fig. 5) northwest of Tamms. Both the underground mine and silica quarry nearest Olive Branch (sites 118 and 119, fig. 10) expose a sequence of beds with more fine grained friable material than are present in the northeasternmost quarry (site 120, fig. 10) or in the Jordan Novaculite quarry. A tentative correlation is that a transition zone between the lowermost Grassy Knob Chert and the uppermost Bailey Limestone is exposed in the underground mine and quarry nearest Olive Branch. This transition is overlain by Grassy Knob Chert exposed in the northeasternmost quarry at Olive Branch and also in the Jordan Novaculite quarry northwest of Tamms.

J. Weller and Ekblaw (1940) described the Grassy Knob Chert exposed in the bluffs above the Big Muddy River 25 kilometers (15 mi) northwest of Jonesboro. They stated that the middle third of this formation is massive chert, which is in part a well cemented breccia. Lamar (1953) also described a chert breccia in the middle part of the Grassy Knob Chert.

The massive chert beds, exposed in the roadcut on the county road 3.8 kilometers (2.3 mi) west of Tamms in the NW NE NE, Section 10, T15S, R2W, are probably in the middle part of the Grassy Knob Chert. Chert beds are pockmarked with irregular cavities in this roadcut. Some cavities are coated with chalcedony and lined with quartz crystals. Fractures a few centimeters long are filled with gray quartz. Similar to chert in the Clear Creek Chert, the chert breccia from this exposure contains many rhombic cavities 30 to 100 μm long, presumably the result of solution of dolomite crystals. These same beds of massive chert are exposed on the northwest-trending ridge along the east side of Sandy Creek in the SW SW, Section 28, T14S, R2W.

The transition zone between the Grassy Knob Chert and Bailey Limestone exposed in the inactive silica mines northeast of Olive Branch contains nodular chert surrounded by microcrystalline silica (figs. 11 and 12). The individual chert nodules are surrounded by a rind of moderately soft microcrystalline silica. Cavities within a chert bed exposed in the quarry nearest Olive Branch (site 118, fig. 10) are lined with quartz crystals. Similar nodular chert beds are exposed in the nearby underground mine (site 119, fig. 10).



Material from these deposits differs in chemical composition and grain shape from that of material in the Clear Creek Chert. Samples collected from the underground mine contain 6.8 to 10.4 weight percent Al_2O_3; whereas samples of microcrystalline silica from the Clear Creek Chert contain less than 0.6 weight percent Al_2O_3 (table 1). XRD analysis of a sample from the quarry nearest Olive Branch showed kaolinite to be the major clay mineral and illite to be much lower in concentration. An SEM micrograph shows that the microcrystalline silica from this deposit consists of slightly rounded, tabular grains (fig. 13).

Clear Creek Chert

The Clear Creek Chert is also of Lower Devonian age; in the area southwest of Jonesboro, it overlies the Grassy Knob Chert. Because of the way the strata have been altered and the absence of the normally intervening Backbone Limestone, they are difficult to distinguish. The Backbone Limestone is a distinctive formation consisting of sparry calcite with abundant crinoid fragments. North of Jonesboro, this limestone is present and facilitates mapping; however, it has not been found in the area southwest of Jonesboro. Either the Backbone Limestone is represented by an unrecognized siliceous facies to the south, or more likely, it has been completely dissolved by extensive leaching of all carbonate from this stratigraphic interval.

In the area where the Backbone Limestone is absent, the contact between the Grassy Knob Chert and overlying Clear Creek Chert is not easily identifiable. J. Weller (1944) suggested that the contact between these two formations is exposed in the large Jordan Novaculite quarry 1.8 mile (2.8 km) northwest of Tamms (site 113, fig. 5). A 200-foot (61-m) section is exposed in this inactive quarry. J. Weller based this inference on the occurrence of loose blocks of chalcedonic chert containing fossils similar to those found in the lower part of the Backbone Limestone to the north. Two-thirds of the way up the quarry face is a massive chert bed that is 3 to 7 meters (10–23 ft) thick and has some irregular cavities up to a few tens of centimeters across. This chert bed shows the same brecciated texture as the chert exposed in the roadcut 2.3 miles (3.8 km) west of Tamms. It may be the middle massive chert of the Grassy Knob Chert. If this interpretation is correct, the silicified remnant of the Backbone Limestone should be exposed near the top of the quarry face.

J. Weller and Ekblaw (1940) estimated the thickness of the Clear Creek Chert in southwesternmost Illinois to be at least 300 feet (90 m) and perhaps much thicker. For the area west of Elco, a thickness of 350 feet (107 m) was estimated. (See the section, "Geology of the Area West of Elco," in this report.) J. Weller and Ekblaw observed that the Clear Creek Chert is much more fossiliferous than the Grassy Knob Chert and that, with the exception of the uppermost chert beds, it lacks the massive chert beds found in the Grassy Knob Chert. Chert with a brecciated texture similar to that described from the Grassy Knob was not observed in the Clear Creek Chert in the Elco area. Rogers (1972) observed that the Clear Creek Chert contains alternating layers of distinct but laterally consistent lithologies. By contrast, limestone is absent in the study area west of Elco, where lateral continuity of chert beds, with the exception of the uppermost beds, could not be demonstrated (a detailed discussion is given in the section, "Geology of the Area West of Elco"). North of an east-west line running through Jonesboro, however, the formation contains siliceous limestone (Lamar 1953).

Acid-insoluble residues recovered from cuttings of limestone from the Hileman no. 1 well in the NW SE SW, Section 21, T13S, R1W, Union County, were examined. The upper 45 feet (14 m) of the Clear Creek Chert was penetrated by this well, and it contains an average of 48 weight percent acid-insoluble material (table 2). This residue consists largely of euhedral quartz crystals and fragments of chert, and less abundant rounded quartz grains and pyrite. The euhedral quartz crystals contain calcite inclusions and gas-filled cavities similar to crystals separated from clay beds in the Clear Creek Chert west of Elco. By comparison, a sample of limestone contains 7.7 weight percent acid-insoluble material that consists of rounded quartz grains and less abundant amounts of euhedral quartz crystals, clay, and silt. This sample was collected from an exposure described by Allen (1985) in the SE NW NW, Section 27, T11S, R2W, located 7 miles (11 km) northwest of Jonesboro. The uppermost 14 feet (4 m) of the Clear Creek Chert is exposed here below beds of the Dutch Creek Sandstone Member of the Grand Tower Limestone. At this exposure, the Clear Creek Chert consists mainly of gray, finely crystalline limestone, containing three thin chert beds in the upper half and 3.3 feet (1 m) of light gray chert near the base.

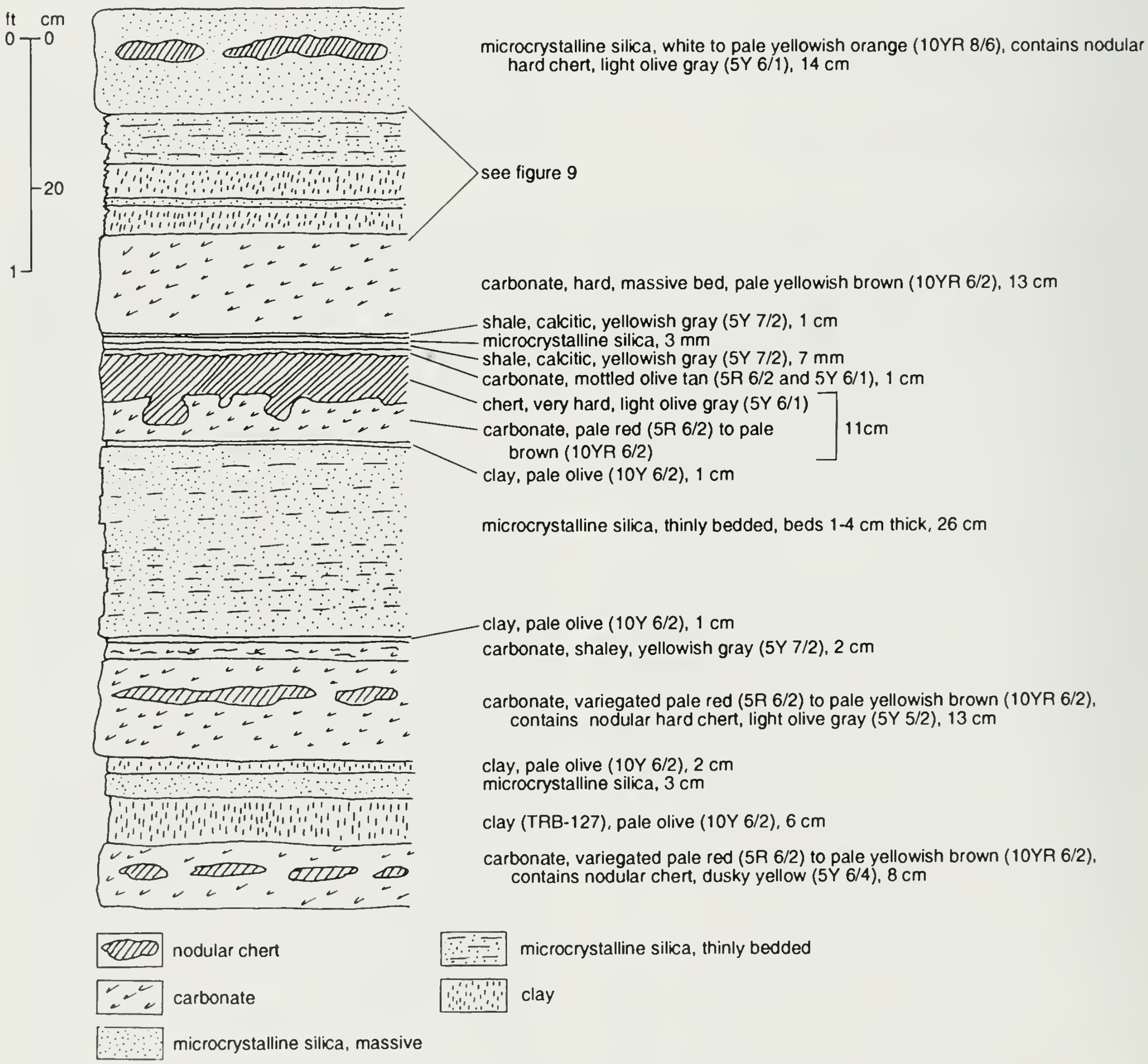


Figure 8 Described section of interbedded chert, siliceous limestone, clay, and soft microcrystalline silica in the Bailey Limestone exposed in the roadcut shown in figure 7. Color designations are according to the Rock-Color Chart (1963).

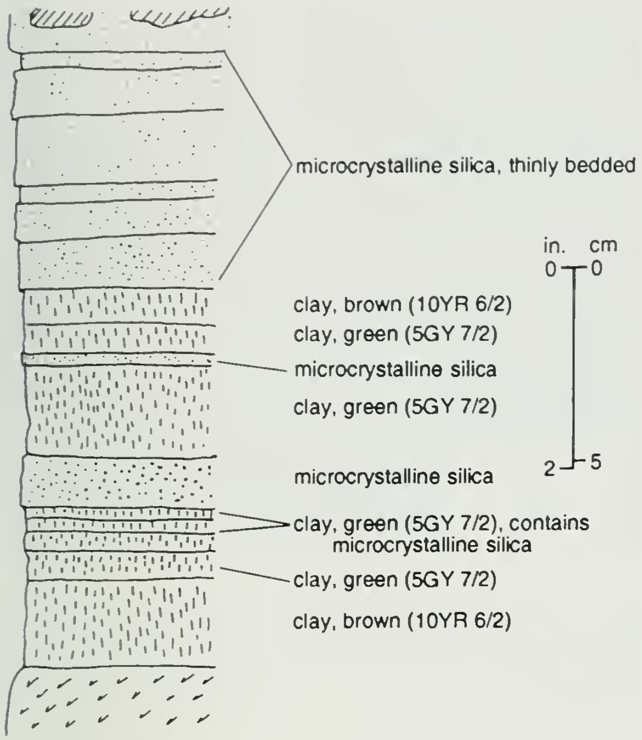


Figure 9 Detail of a part of the described section (fig. 8) of the Bailey Limestone from the roadcut shown in figure 7. Explanation of symbols appears on figure 8.

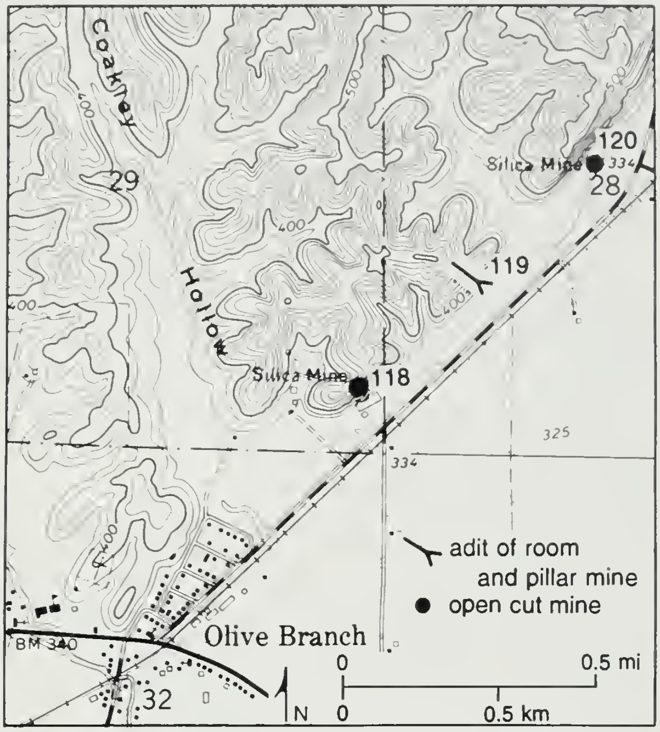


Figure 10 Sites of inactive silica mines northeast of Olive Branch (Secs. 28 and 29, T15S, R2W, Alexander County) plotted on the Tamms 7.5-Minute Quadrangle.

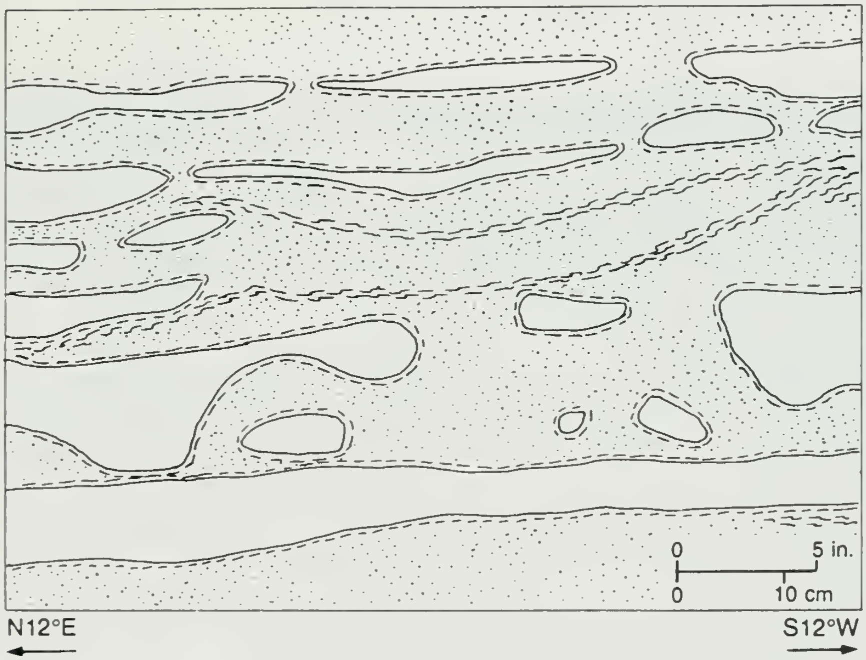


Figure 11 Sketch of an exposure in the transition zone between the Bailey Limestone and Grassy Knob Chert in an inactive silica mine 1 km (0.6 mi) northeast of Olive Branch (site 118, appendix A and fig. 10).

Table 2 HCl-insoluble residue from cuttings of Clear Creek Chert recovered from the Hileman no. 1 well in the NW SE SW, Sec. 21, T13S, R1W, Union County, Illinois.

Sample* interval (ft)	Wt % acid insoluble <125 µm	>125 µm	Total	Major constituents >125 µm fraction
925–935	3	21	24	Abundant euhedral quartz crystals and minor chert
935–940	2	61	63	Euhedral quartz crystals, rounded quartz grains, and chert
940–950	1	56	57	Abundant euhedral quartz crystals and chert
950–960	4	39	43	Euhedral quartz crystals, rounded quartz grains, chert, and pyrite
960–965	5	41	46	Mainly pyrite
965–970	7	68	75	Mainly pyrite
Weighted average	3	45	48	

*Sample set 25992 in the ISGS Samples Library.

Dutch Creek Sandstone Member of the Grand Tower Limestone

The Dutch Creek Sandstone is the lowest member of the Grand Tower Limestone. It is the only member present in the study area (plate 1) or discussed in the text. It overlies the Clear Creek Chert and is estimated to be only 5 feet (1.5 m) thick in the area west of Elco (J. Weller and Ekblaw 1940). This Middle Devonian unit, which unconformably overlies the Clear Creek Chert in southernmost Illinois, is described in more detail in the section, "Geology of the Area West of Elco."

Tuscaloosa (?) Formation

The Tuscaloosa (?) Formation in the study area is a chert gravel that is partly silica-cemented and contains predominantly rounded chert clasts derived from the Clear Creek Chert. It unconformably overlies the Clear Creek Chert and the Dutch Creek Sandstone Member of the Grand Tower Limestone in the area west of Elco. This gravel, which is only preserved in a few sites on ridge tops, could have been deposited some time during or after the uplift of the Pascola Arch. It may be as young as the rearrangement of drainage networks that accompanied the formation of the Mississippi Embayent (Marcher and Sterns 1962, Kolata et al. 1981).

REGIONAL STRUCTURE

The microcrystalline silica mining districts in southernmost Illinois are situated on the southwest margin of the Illinois Basin, an interior cratonic basin bounded on

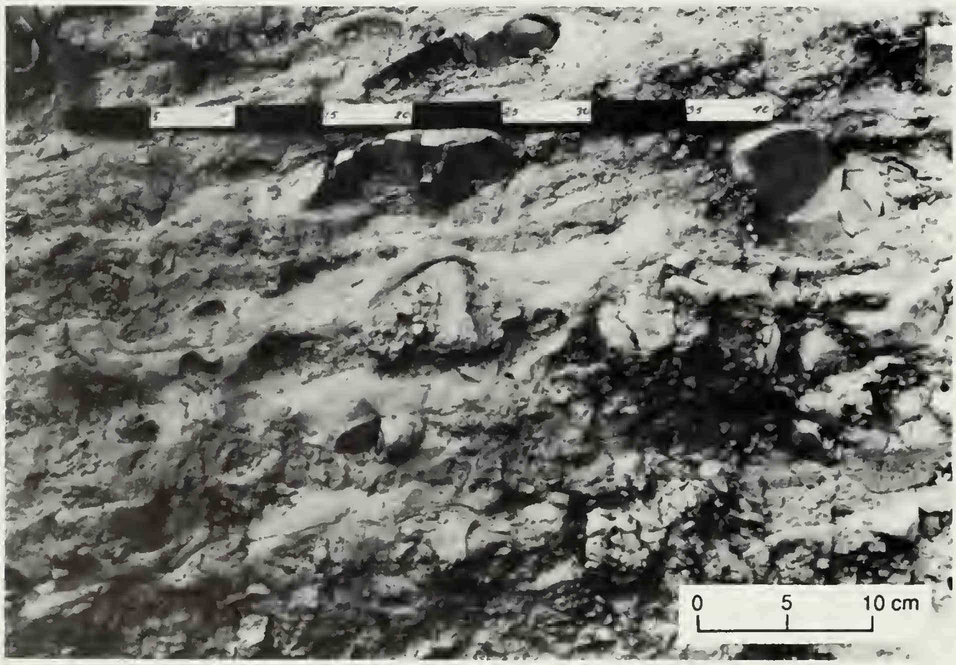


Figure 12 Nodular chert surrounded by microcrystalline silica in the transition zone between the Bailey Limestone and Grassy Knob Chert. The exposure is in an inactive silica mine 1 km (0.6 mi) northeast of Olive Branch (site 118, appendix A, fig. 10). Photo by R. B. Berg.

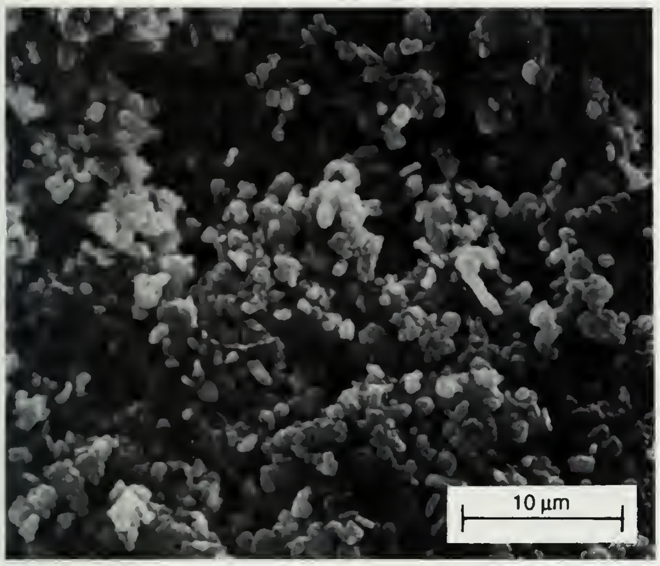


Figure 13 SEM micrograph of specimen TRB-41 of microcrystalline silica from the transition zone between the Bailey Limestone and Grassy Knob Chert in an inactive silica mine 1 km (0.6 mi) northeast of Olive Branch (site 118, appendix A, fig. 10). Micrograph by D. J. Lowry, SEM Laboratory, ISGS.

the west by the Ozark Dome and on the south by the Pascola Arch (fig. 14a). The deepest part of this basin lies within the Rough Creek Graben in Kentucky. In the Rough Creek Graben, sedimentary rocks ranging in age from Cambrian through Pennsylvanian account for a cumulative thickness of at least 22,000 feet (6,700 m). The depth to the Precambrian basement in the study area ranges from 6,500 feet (2000 m) on the west to 12,500 feet (3,800 m) on the east (M. L. Sargent, ISGS, personal communication 1991). Kolata and Nelson (1991) suggested that the Pascola Arch did not develop and complete the formation of the Illinois Basin until after the Permian or during early Mesozoic time. Following extensive erosion of the Pascola Arch, regional subsidence and extension of the Mississippi Embayment into southernmost Illinois occurred during Late Cretaceous time.

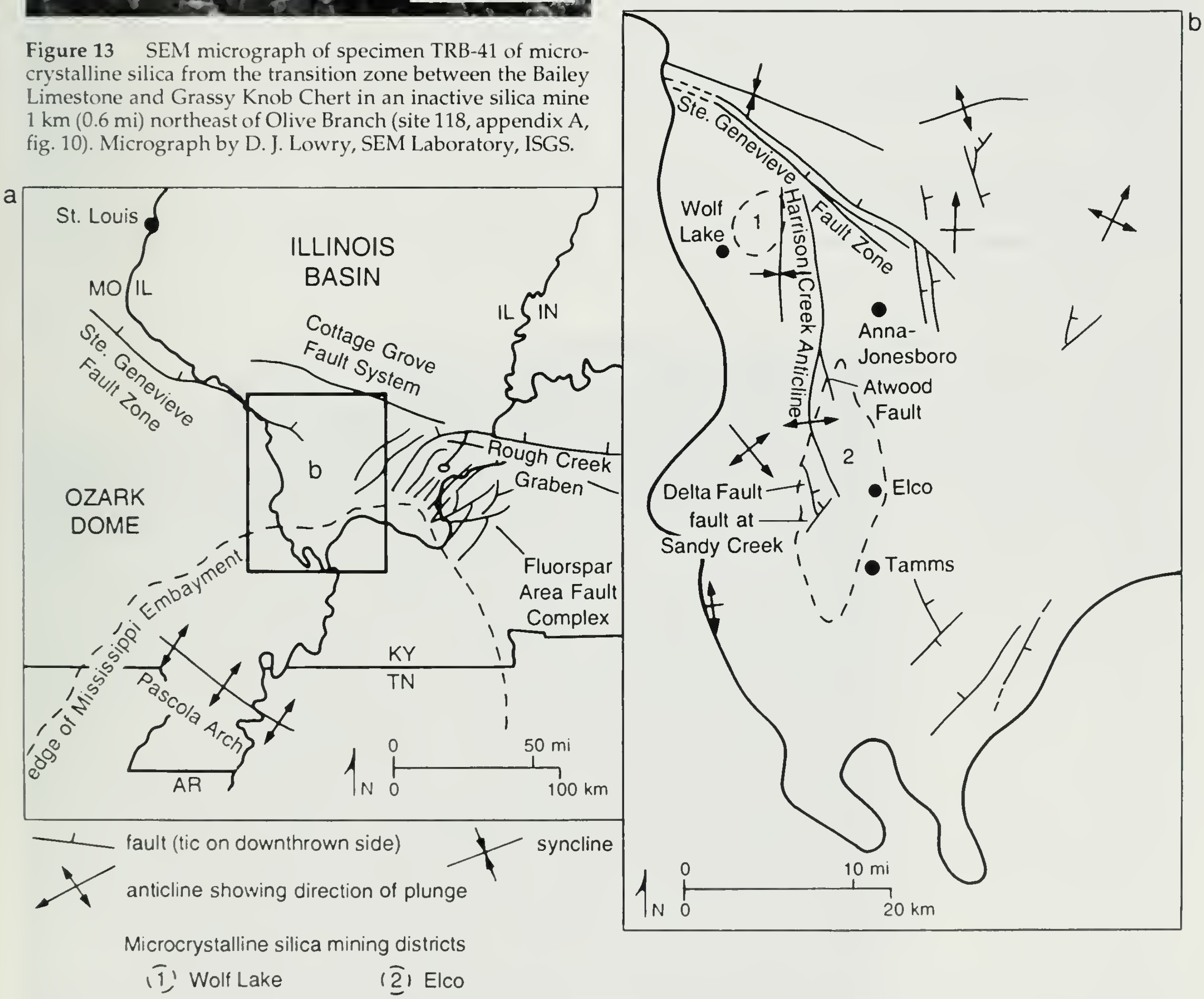


Figure 14 Tectonic setting of the microcrystalline silica districts: (a) modified from figure 1 in Nelson and Lumm (1985); and (b) modified from plate 1 in J. Treworgy (1981). Possible fault in the valley of Sandy Creek taken from plate 2 in Levine (1973).

The silica mining districts are close to areas of numerous faults (fig. 14b). The northwest-trending Ste. Genevieve Fault Zone consists of high-angle faults along which the north side moved up during late Middle Devonian time (Nelson and Lumm 1985). During latest Mississippian and early Pennsylvanian time, movement along this fault zone was reversed with uplift of the Ozark Dome on the south. This structure was described as the Rattlesnake Ferry Monocline by J. Weller and Ekblaw (1940). Pryor and Ross (1962) reported at least four high-angle, probably normal faults south of Thebes, Illinois. Structures in the study area are described in the section, "Geology of the Area West of Elco."

Northeast-striking, high-angle faults characterize an area of structural complexity in southeasternmost Illinois, extending into Kentucky. Movement on these faults is thought to have been mainly post-Early Permian and pre-Late Cretaceous (Baxter and Bradbury 1989). Mineralization within the Illinois–Kentucky Fluorspar district, which lies within this area of northeast-trending faults, is post-Pennsylvanian but probably not younger than the Cretaceous (Richardson et al. 1988).

The Mississippi Embayment of the Gulf Coastal Plain extended northward into Illinois as a result of downwarping that began during the Late Cretaceous time and continued into the Tertiary. The limits of the area of Cretaceous and Tertiary sedimentation can only be inferred by the northernmost erosional edge of these sediments. The Tuscaloosa (?) chert–pebble conglomerate unconformably overlying Paleozoic formations west of Elco presumably was deposited in a tributary drainage to the earliest form of the Mississippi Embayment. In southernmost Illinois, the margin of the Mississippi Embayment generally follows the northern limit of fluvial–deltaic fine sand and clay deposits of the Late Cretaceous McNairy Formation on the north side of the Cache Valley.

MINES AND PROSPECTS

Information from published sources and geological field notes in the files of the Illinois State Geological Survey (ISGS) is summarized in appendix A. Sites of mines and prospects are shown on figures 5 and 10 and plate 1. The mines listed are largely inactive underground mines, all with workings at entry level; there are no shaft mines. Many exploratory adits are included from the study area west of Elco. Some of the inactive underground mines are dangerous to enter. Roof fall is common, particularly where clay seams and fractures provide planes of weakness. Where the chert is fractured, fall from the rib is also common.

Cobden 7.5-Minute Quadrangle

There is only one known silica mine in the Cobden Quadrangle (site 1, appendix A and fig. 5). It is an inactive open-cut mine on the east slope of Bald Knob. Here, a massive chert bed in the uppermost Clear Creek Chert overlies about 5 meters (16 ft) of white microcrystalline silica that contains some chert nodules.

Wolf Lake 7.5-Minute Quadrangle

There are two inactive underground silica mines known in the Wolf Lake Quadrangle. Both are in the Clear Creek Chert near the south boundary of the quadrangle (sites 2 and 3, appendix A and fig. 5). These mines are almost 14 kilometers (8.7 mi) northwest of the closest known mine in the Elco district. Although J. Weller and Ekblaw (1940) mapped the Backbone Limestone between the Grassy Knob and Clear Creek Chert up Silica Hollow (presumably the hollow where the Wolf Lake silica mine is situated), they described it to be a crinoidal and bryozoan-bearing chert, rather than limestone. It has the same fossil assemblage as that occurring in the limestone several kilometers to the north. All limestone in this area has either been silicified or dissolved, like that of the microcrystalline silica mining district west of Elco.

The largest of these two mines was referred to as the Wolf Lake Silica mine (site 3, appendix A, fig. 5) operated in 1917 by R.A. Bautz & Company (Holbrook 1917). Later the company became Isco–Bautz (Parmelee and Schroyer 1918–1920). Crude silica from this mine was hauled by rail to their mill at Murphysboro where the material was wet ground, dried, and sized (Weigel 1927). At least some of this product was destined for use in ceramics.

The following observations are summarized from field notes dated June 30, 1927, in the ISGS files. At that time, this mine was inactive and fire had destroyed a grinding mill near the mine. In 1990, the foundation of a mill was visible a short distance below the adit of the Wolf Lake Silica mine. This was probably the mill described in the 1927 field notes, which reported that the deposit consists of soft, very white silica containing thin and slightly iron-stained chert beds. Fifteen feet (4.5 m) of microcrystalline silica in the lower part of the exposure had been mined. It is overlain by about 20 feet (6 m) of less pure silica that had been exposed in developing the mine. Schroyer (ca 1918) reported that the mine consisted of four separate tunnels driven 150 feet (46 m) or more, and the silica was mined by the room-and-pillar method. The small mill near the mine was to be replaced by the larger mill at Murphysboro to increase production from 10 to 100 tons per day. He also reported that some silica was taken from a small mine (site 2, appendix A and fig. 5), referred to as the Butcher mine by Parmelee and Schroyer (1918-1920).

Jonesboro 7.5-Minute Quadrangle

Little information is available on the inactive silica mines in the Jonesboro Quadrangle. All known mines are in the southern part of the quadrangle and in the Clear Creek Chert where it is exposed on the east flank of the Harrison Creek Anticline (fig. 14b). Here, along the high-angle, northwest-trending Atwood Fault, the Clear Creek Chert is juxtaposed against the Grassy Knob Chert, which lies to the southwest (plate 1, *in* J. Weller and Ekblaw 1940). Parmelee and Schroyer (1918–1920) mentioned three silica mines in the NE, Section 15, T13S, R2W. The mines supplied silica to the Southern Illinois Manufacturing Company mill in Jonesboro.

Mill Creek 7.5-Minute Quadrangle

Most of the known microcrystalline silica deposits of southernmost Illinois are within the Mill Creek Quadrangle, where there are more than 100 prospects and mines. Many of the sites given in appendix A, particularly for the area of detailed mapping west of Elco (plate 1), are exploratory adits. In the rest of the quadrangle, which was not mapped during this investigation, only those mines cited in published or unpublished reports or made known by local individuals are shown. Thus, the distribution of prospects and mines shown in figure 5 does not necessarily indicate the actual distribution of mining activities or of potentially commercial deposits of microcrystalline silica. All known microcrystalline silica mines and prospects in this quadrangle are in the Clear Creek Chert. Abandoned ganister mines are also present in this quadrangle. All known ganister deposits are in the Mississippian-age Fort Payne Formation ("Hartline" chert).

Lone Star Industries operates an open-pit mine (site 65, appendix A; plate 1) where they mine silica for use in the manufacture of portland cement at their Cape Girardeau plant. The small concentration of iron oxide in this deposit is acceptable because it is also an ingredient of portland cement, but it would make this rock unsuitable for use in the filler or extender markets.

Production from this mine includes softer varieties of bedded chert in addition to microcrystalline silica. In the southern part of the mine, loess and hard chert beds that overlie the deposit must first be stripped as the mine advances into the ridge (fig. 15). A 32-meter (105-ft) section of the upper Clear Creek Chert is exposed (figs. 16, 17) in the north part of the mine. Steeply dipping faults exposed in this northern pit generally show apparent displacement of less than 1 meter (3 ft).

Microcrystalline silica used as a functional filler, extender, and abrasive is mined at two localities in the southern part of this quadrangle. The Illinois Minerals Company operated the Birk open-pit mine in which unusually white microcrystalline silica occurs just below the upper massive chert beds in the Clear Creek Chert (site 107, appendix A). This deposit was mined underground prior to being mined from an open pit. Silica from this mine was trucked to the company's plant at Elco for processing.

Tammsco operated the Birk no. 2 mine (site 109, appendix A), an underground mine also in the Clear Creek Chert. It is situated about 1.5 kilometers (2 mi) southeast of the Birk open pit. Tammsco hauled silica mined from this deposit to their plant at Tamms.

Figure 15 West wall of the south pit at the Lone Star mine in the Clear Creek Chert (site 65, appendix A and plate 1). The photo shows where loess and massive chert beds have been stripped to expose the microcrystalline silica. The silica is mined for use in portland cement. Photo by J. M. Dexter, ISGS.

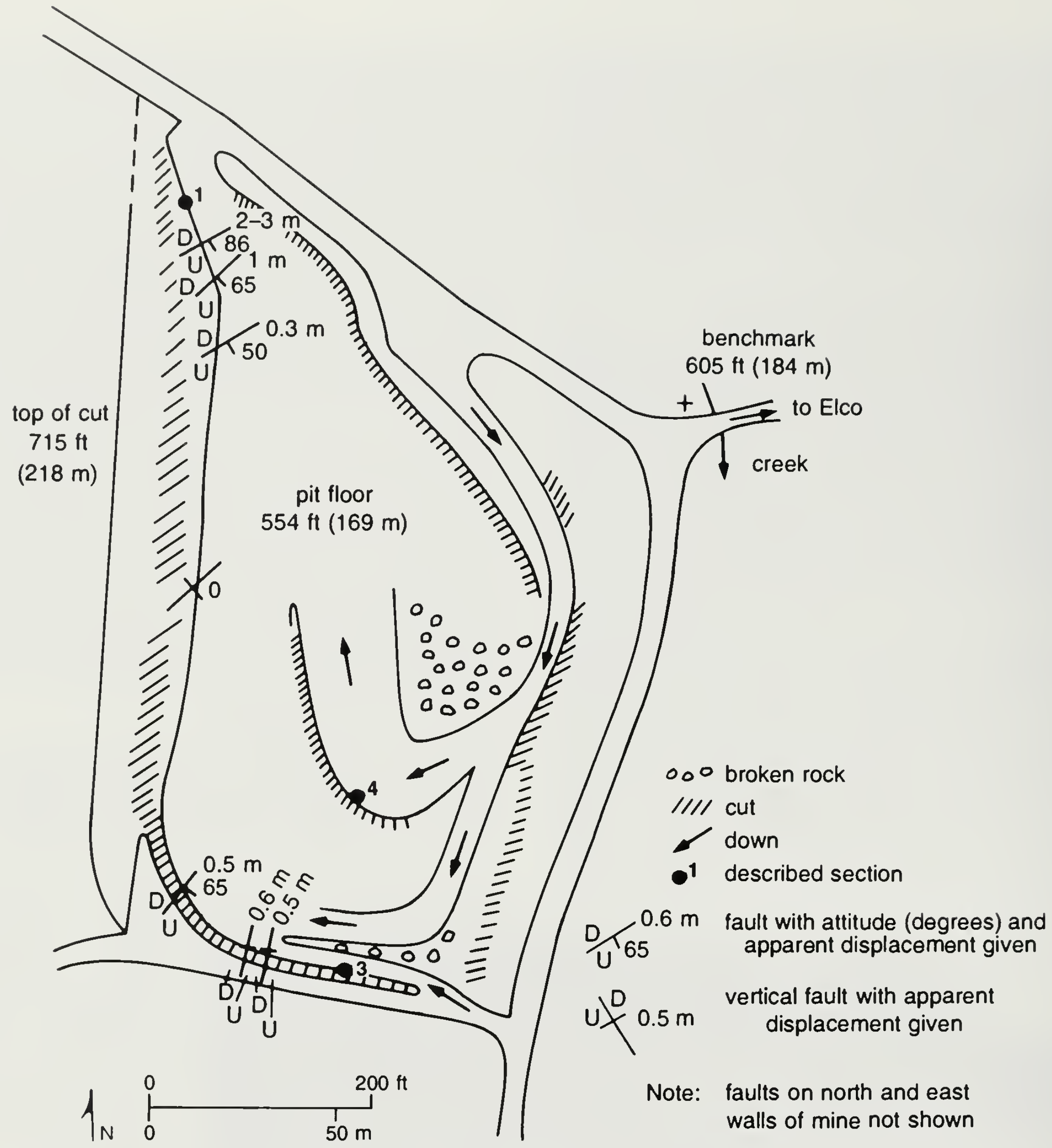


Figure 16 Tape and compass map of the north pit at the Lone Star mine shows faults and locations of described sections (R. B. Berg, December 1989). See figure 25 for section 1 and appendix B for sections 3 and 4.

In October 1989, Illinois Minerals was acquired by Unimin, which also owns Tammsco. Since then, Unimin has reorganized both operations into a division of the corporation, Unimin Specialty Minerals, Inc.

The following surface and underground mines described in this quadrangle are inactive. Some underground mines must have been inactive for more than 50 years. Underground mines were not examined during this investigation, thus information on these mines is sketchy and generally limited to observations from field notes and unpublished reports in ISGS files.

The Jason mine (site 8, appendix A) was operated by Illinois Minerals until 1987, when it was reclaimed (fig. 18). Prior to mining in an open cut, an underground room-and-pillar mine had been operated for many years. Four entries to these underground workings are still visible at this mine. The visible interval of microcrystalline silica mined underground here is approximately 4 to 5 meters (13–16 ft) thick and overlain by beds of hard chert to friable microcrystalline silica (see section 10, appendix B). Apparent dip of bedding in exposures in the cut ranges between 5° and 15° southeast, and most faults strike northeast (fig. 19). Faults dip greater than 45°, and most are close to vertical. Displacement is slight, generally measured in tens of centimeters, and it is not sufficient to cause problems in following the ore-body of microcrystalline silica.

The mined interval of microcrystalline silica, as exposed in the bottom of the cut, is almost completely free of iron stain; however, it is covered with brown clay

Figure 17 West wall of the north pit at the Lone Star mine shows loess on top of the ridge and several small faults in the Clear Creek Chert. The distance from the top of the ridge to the pit floor is 161 feet (49 m). The black patches are dead vegetation. The location of the described section (fig. 25) is shown by a dashed line. Photo by J. M. Dexter, ISGS.

and silt washed down from overlying loess. The uppermost massive chert beds in the Clear Creek Chert are not exposed at the mine, but float of this chert is found on the ridges around the mine. It is reasonable to expect that these ridges developed on the massive chert beds are underlain by more microcrystalline silica.

The Halliman Silica mine (site 9, appendix A) was active on July 11, 1927, when the following observations were recorded. Very white silica was being mined. A clay seam 1/16 to 1 inch (1.8–25 mm) thick separated it from about 7 feet (2.1 m) of overlying iron-stained silica containing much chert. Iron staining is particularly strong on fracture surfaces in the chert. Because bedding dips 12° to 15° southeast, in the same direction as the slope of the hill, the minable thickness increases from about 5 feet (1.5 m) near the portal to

Figure 18 Clear Creek Chert exposed in the Jason mine (site 8, appendix A and fig. 5). In this view to the southeast, the interval of microcrystalline silica that was mined underground is almost hidden by talus. Grass covers the reclaimed pit (fig. 19) and the hillside above the highwall. Photo by R. B. Berg.

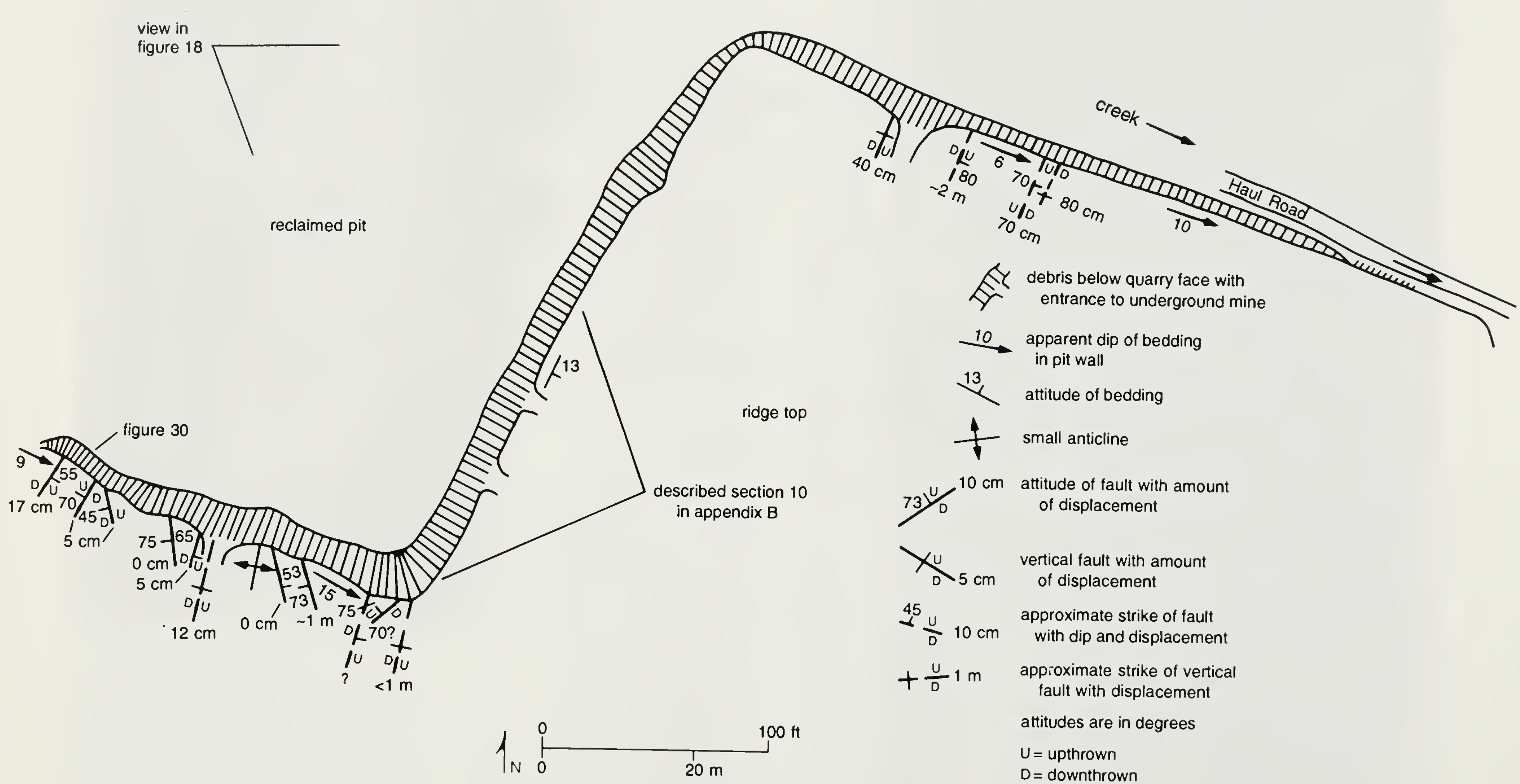


Figure 19 Tape and compass map of the reclaimed Jason mine (site 8, appendix A and fig. 5) (June 1990).

about 12 feet (3.7 m) back within the mine. The microcrystalline silica body continues southeast below the gully, but slumping and other difficulties caused this part of the mine to be abandoned.

The Allen and Miller mine (site 10, appendix A) was examined on May 31, 1931, when the following observations were noted. This room-and-pillar mine was the source of microcrystalline silica for the American Mineral Corporation mill at Murphysboro; the deposit is in the Clear Creek Chert. The entry is 118 feet (36 m) below the top of the ridge and about 75 feet (23 m) above the level of the main creek to the north. A 11 foot (4-m) face was being worked 350 feet (107 m) back from the entry. Although this deposit is unusually free of iron oxide discoloration, where yellow and pink stains occur, they appear to be more pronounced below surficial valleys. The discoloration, which was thought to be secondary, occurs in three modes: (1) adjacent to small fractures that usually contain a thin filling of highly plastic clay; (2) associated with horizontal beds of fresh to slightly decomposed chert; and (3) in ramifying bands or sheets that apparently represent irregular groundwater channels. Roots found about 10 feet (3 m) back from the portal have seemingly followed clay seams from the surface. A flow sheet for the mill at Murphysboro shows two main circuits, a dry-grinding circuit followed by an air separator and a wet-grinding circuit followed by a cone classifier. Wet grinding produced the finest products, some consisting of material of which 100% would pass through a 325-mesh sieve.

The notes for the Western Firebrick Company ganister mine (site 12, appendix A) were recorded on July 8, 1927. The following observations were noted. About 12 feet (3.7 m) of ganister has been mined, using the room-and-pillar method, from the "Hartline" chert (Mississippian Fort Payne Formation). The lowest 5 feet (1.5 m) of the interval is very white. In an exposure next to the portal, the upper iron-stained zone extends down to a very hard chert bed. In this zone, iron-stained beds are 3 to 8 inches (8–20 cm) thick, and they contain chert beds 1/8 inch (3 mm) thick. No chert beds occur in the beds of white ganister.

The ganister mine of Hagler, Wisely, Carter, and Steele (site 13, appendix A), later known as the Southern Illinois Minerals Company, was examined by J. E. Lamar in May 1941. He concluded that the ganister, overlain by chert–pebble conglomerate (Cretaceous?) and underlain by green shale of the Springville Shale (Mississippian age), is probably in the "Hartline" chert (Fort Payne Formation). Lamar noted that a new entry a little west of the old Goodman mine had been driven 25 feet (7.6 m), and slightly yellow ganister was being mined from a 12-foot (3.7-m) face. In both this and the Goodman mine, rectangular blocks of relatively solid chert surrounded by ganister were encountered. They were thought to be joint-controlled blocks that, for some reason, were not as thoroughly altered as the surrounding ganister.

An earlier visit to the adjacent Goodman ganister mine on July 21, 1927, resulted in the following observations. This room-and-pillar mine, about 100 feet (31 m) from the top of the ridge, is worked from two entries about 15 feet (5 m) apart. Intensely iron-stained ganister overlies the mined interval consisting of 14 feet (4 m) of white to very light yellow and locally pink ganister. A chert bed at least 9 inches (23 cm) thick is exposed close to the mine floor. Distribution of color is irregular in this mine and does not conform to bedding.

When the Allan Silica mine (site 86, appendix A) was visited on July 11, 1927, it was leased to the Illinois Silica Company. It was producing 30 to 35 tons of microcrystalline silica per day. Active mining was about 500 feet (153 m) from the portal of this room-and-pillar mine. Because of poor roof conditions at the entry, only a 6-foot (2-m) thickness of what was described as moist, very white silica was mined. As mining progressed farther under the ridge, the minable thickness of silica increased to 14 feet (4 m). Unusable chert beds 6 inches (15 cm) thick are exposed at 7 feet (2 m) and 14 feet (4 m) above the floor of the mine. Several normal faults, with the south side downthrown, show 4 to 6 inches (10–15 cm) of displacement. Iron-stained bands occur throughout the deposit and in cherty beds above a clay seam, as well as along fractures. Staining is most prominent near the surface at the entry and stained zones dip about 5° south.

The ganister mine of the Western Fire Brick Company (site 95, appendix A) is an adit 60 feet (18.5 m) long driven on a decline in which a thickness of up to 15 feet (4.6 m) is mined (Schroyer ca 1918). The ganister is white or pale buff. Iron staining follows bedding and also occurs along a few vertical surfaces. Gravel in discolored clayey ganister indicates a dike filling that was 2 feet (0.6 m) thick or more, and that cut off the workings at the west side. A test pit dug 32 feet (10 m) deep near the portal of the adit was said to have encountered ganister of poorer quality at depth (Schroyer ca 1918). This mine is probably in the Fort Payne Formation. Mined rock was hauled 3/4 mile (1 km) by wagon to the Mobile and Ohio Railroad at Elco.

Schroyer (ca 1918) briefly described the J. W. Joynt ganister mine (site 96, appendix A). Ganister from the "Hartline" chert (Fort Payne Formation) was mined here for the manufacture of silica brick and fire brick at the Western Firebrick Company plant in Granite City, Illinois. He observed vertical seams of gravel that indicated open fracture fillings. Bedding dips back into the mine at about 5°, and beds are slightly contorted.

A large novaculitic chert quarry northwest of Tamms (Jordan Novaculite quarry, site 113, appendix A) was opened perhaps more than 100 years ago and first operated by the Mobile and Ohio Railroad (Savage 1908). The Novaculite Paving Company (Schroyer ca 1918), the Novaculite Gravel Company (Lamar 1953), and most recently the Markgraf Materials Company operated this quarry.

Novaculite from this quarry was used as ballast for railroads and waterbound macadam for roads. It was also ground and fired to make paving bricks (Lamar 1953, Schroyer ca 1918). Markgraf Materials Company produced a special skid-resistant aggregate that was used in the surface layer of asphalt cement highways. J. E. Lamar, in field notes recorded on July 20, 1927, described the quarry as having a maximum height of 150 feet (46 m) and two main faces, one 500 feet (153 m) long and the other 700 feet (213 m) long. The chert is highly fractured, cut by open and incipient joints. The deposit is relatively uniformly iron stained to a light yellowish brown to gray and contains some thin clay beds. J. Weller and Ekblaw (1940) proposed that the contact between the Clear Creek Chert and underlying Grassy Knob Chert is exposed high in this quarry.

Thebes 7.5-Minute Quadrangle

Lamar (1953) showed an area of microcrystalline silica northeast of Thebes and mentioned that small amounts of silica were mined in this area. The inferred location of a silica mine and a mine from which clay and probably silica were mined are shown on figure 5 (sites 114 and 115, appendix A). Both of these mines are thought to be in the Bailey Limestone.

Tamms 7.5-Minute Quadrangle

All silica mines in this quadrangle are either in the lower Grassy Knob Chert or in the transition zone between the lower Grassy Knob Chert and upper Bailey Limestone. Two mines west of Tamms (sites 116 and 117, appendix A) were not examined, and little information about them is available. Three mines northeast of Olive Branch along the edge of the Cache Valley were examined (sites 118, 119, and 120, appendix A and fig. 10). The mines, two open-cut and an underground mine, provide excellent exposures.

Pryor and Ross (1962) mapped the bedrock in this area as Bailey Limestone, whereas J. Weller and Ekblaw (1940) suggested that these deposits are either in the Grassy Knob Chert close to its contact with the underlying Bailey Limestone or in the uppermost Bailey Limestone. On the basis largely of J. Weller and Ekblaw's description of these formations, it is suggested that the two mines closest to Olive Branch (sites 118 and 119, appendix A and fig. 10) are in the transition zone between the Grassy Knob Chert and the underlying Bailey Limestone. The mine northeast of these (site 120, appendix A and fig. 10) is in the lowest Grassy Knob Chert.

The clayey microcrystalline silica and hard chert in the Olive Branch area differ markedly from the interbedded hard chert and microcrystalline silica characteristic of the Clear Creek Chert in the Elco area to the north. Northeast of Olive Branch, chert nodules and discontinuous hard chert beds, generally less than 30 centimeters (12 in.) thick, are surrounded by soft siliceous material. In many instances, the hard chert nodule or bed is surrounded by a white rind of soft chert less than 1 centimeter (<0.4 in.) thick (figs. 11 and 12). Some individual beds of chert can be traced for 10 meters (33 ft), but most are discontinuous and can only be traced for 1 to 2 meters (3–7 ft).

Many of the chert nodules that appear to occur in layers are either remnants of continuous chert beds that have been partly altered to clayey microcrystalline silica or, more likely, simply beds of nodular chert. Some chert nodules are multilobed and have rounded protuberances that extend upward or downward. A hard chert bed in the mine nearest Olive Branch contains small veinlets of white quartz a few millimeters thick and small cavities lined with quartz crystals. Around some chert nodules, a crude onion-skin texture is also developed, apparently as a result of compaction around the nodules after solution of carbonate from the rock. An SEM micrograph of a specimen from this mine (fig. 13) shows some alignment of tabular quartz crystals, perhaps caused by compaction.

Small structures are more abundant in these three mines than they are farther north in the Clear Creek Chert. The structures are best seen in the inactive underground mine (fig. 20). A northeast-trending graben about 5 meters (16 ft) across with a displacement estimated to be 5 meters (16 ft) is exposed here. Numerous small brecciated zones, most nearly vertical but with displacement of generally less than 20 centimeters (<8 in.), are also exposed. The brecciated zones are not continuous vertically for more than 1 to 2 meters (3–7 ft) and, in some instances, grade into small bedding-plane faults. These faults, which do not seem continuous, may represent small adjustments in response to solution of carbonates. Numerous small open folds with heights less than 1 meter (3 ft) are also visible. In addition to the small folds indicated on this map, there are many small flexures shown by the change in attitude of bedding as seen by variation in apparent dip on vertical exposures. Nearly vertical joints are prominent, many with east-southeast or north-northeast strike. This mine was excavated with the floor essentially level but with the rooms varying in height. It is estimated that the roof in the southernmost room is 11 meters (36 ft) above the floor and the roof in the southwesternmost room is 12 meters (40 ft) high. There has been roof fall through most of this mine, and waste rock has been shoved into mined areas (fig. 21).

RESOURCES

Microcrystalline silica has been mined from deposits in the Bailey Limestone (east of Thebes), the Grassy Knob Chert (Olive Branch area), and the Clear Creek Chert. There are many more deposits, however, in the Clear Creek Chert than in the other two formations combined. Although the Clear Creek Chert occupies a large area extending from west of Tamms on the south almost to Jackson County on the north, known deposits are confined to two areas: the large Elco district and the

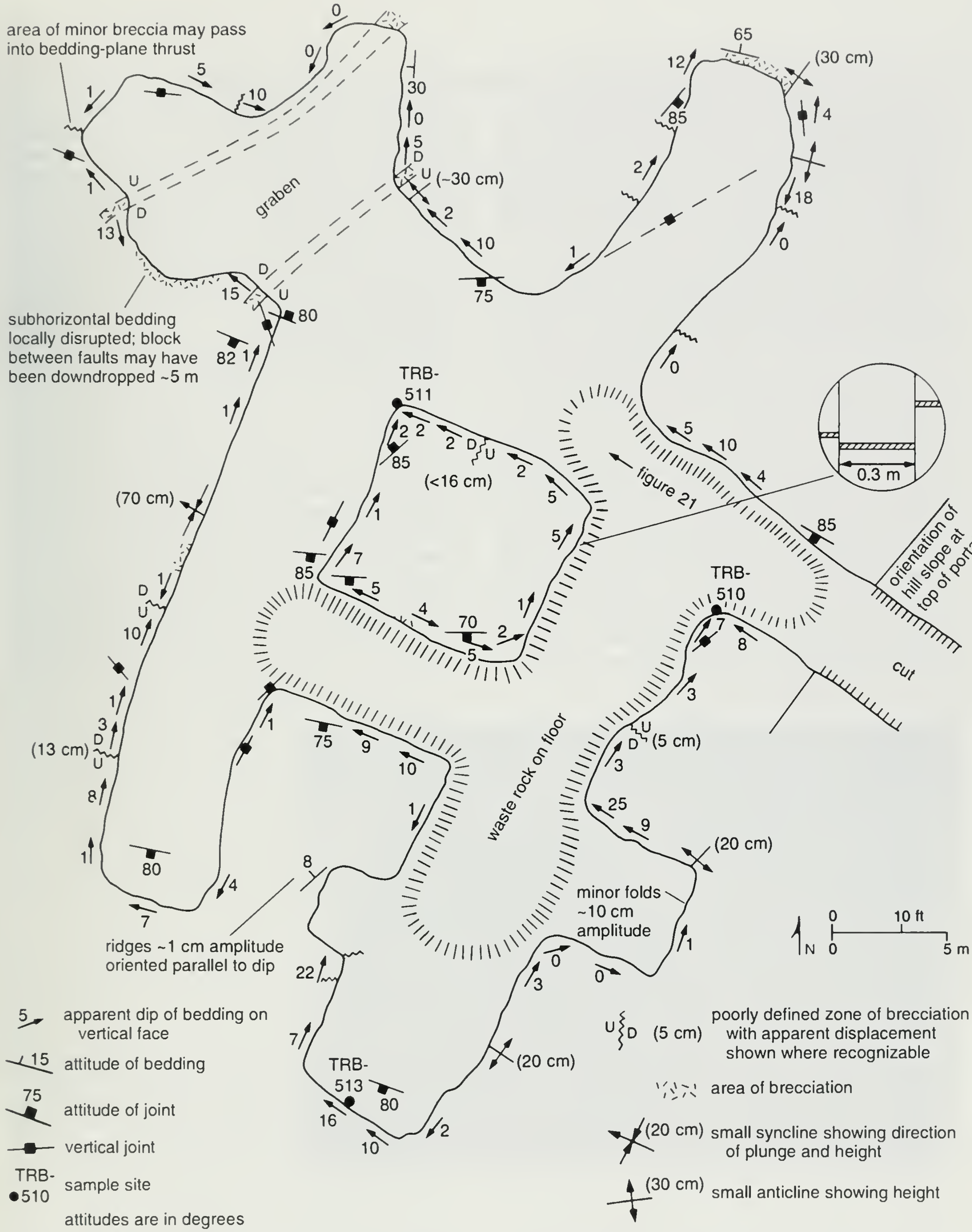


Figure 20 Tape and compass map of an inactive underground microcrystalline silica mine northeast of Olive Branch (site 119, fig. 10) in the transition zone between the Bailey Limestone and the Grassy Knob Chert (May 1990).

much smaller Wolf Lake district. In both districts, the Clear Creek Chert is characterized by massive and distinctive chert beds near its contact with the overlying Dutch Creek Sandstone Member of the Grand Tower Limestone. These chert beds occur just below the uplands and ridges in the Clear Creek outcrop area. The occurrence of these massive chert beds is seemingly confined to those areas where carbonates have been dissolved from the Devonian formations and where microcrystalline silica deposits occur.

There is no individual stratigraphic horizon at which microcrystalline silica characteristically occurs within the Clear Creek Chert. Deposits appear to be discontinuous and do not show a clear relationship to structural trends. Rather they are confined to the area of introduction of silica and removal of carbonates. (See the section, "Formation of Microcrystalline Silica Deposits," in this report.)

An estimate of the depth of leaching of carbonates, gained from examining cuttings from water wells, indicates that the maximum depth of carbonate removal is situated approximately 7 kilometers (4 mi) southwest of Elco. This area offers the best possibility for finding deposits of microcrystalline silica at depth. The upper constraint on the occurrence of microcrystalline silica deposits is the massive chert beds at the top of the Clear Creek Chert, and the lower limit is the depth of silicification and carbonate leaching. Similar constraints probably apply to the occurrence of microcrystalline silica deposits in the Wolf Lake district.

Color is extremely important for microcrystalline silica used in the filler and extender markets. Only material essentially free from iron staining is acceptable. As Lamar (1953) and others have observed, iron staining is generally most intense near the surface. Although discoloration follows some beds to depth and is controlled by faults in some exposures, generally the farther from surface weathering, the greater the possibility of encountering white material. Thus, the area southwest of Elco, in which deposits may extend to the greatest depth, should offer the greatest possibility for discovery of large bodies of commercial-grade microcrystalline silica.

The material mined northeast of Olive Branch near the contact between the Grassy Knob Chert and Bailey Limestone, or from the transition zone between these two formations, is significantly different from the microcrystalline silica mined from deposits in the Clear Creek Chert. This material contains a significant amount of kaolinite. Three samples of microcrystalline silica from the underground mine (site 119, appendix A and fig. 10) contain 6.79 to 10.38 weight percent Al_2O_3 as compared with less than 0.56 weight percent Al_2O_3 for samples from the Clear Creek Chert (table 1). Also the particles of quartz are tabular to irregular rather than the euhedral and subhedral quartz crystals typical of microcrystalline silica from the Clear Creek Chert (compare fig. 13 with fig. 3). The kaolinitic microcrystalline silica from the Olive Branch area cannot be mined free of chert nodules, which would have to be separated during processing.

Figure 21 Inactive underground silica mine northeast of Olive Branch (site 119, fig. 10). The haulageway is about 5 meters (16 ft) wide. Figure 20 shows the location of the photo (taken by J. M. Dexter).

GEOLOGY OF THE AREA WEST OF ELCO

The Clear Creek Chert is the major bedrock formation exposed in the area west of Elco (plate 1). Exposures of this formation were described in detail in an effort to identify beds that could be correlated. With the exception of the uppermost chert beds, however, beds within the Clear Creek Chert could not be correlated between exposures. Flat-topped, loess-covered ridges are underlain by these massive chert beds, which crop out at several localities. Natural exposures of the underlying beds in the Clear Creek Chert are limited to gullies and streams. Exposures at the portals of more than 70 mines and prospects offer an opportunity to examine short sections, usually less than 4 meters (12 ft) in height.

STRATIGRAPHY

Clear Creek Chert

The Lower Devonian Clear Creek Chert is exposed in a north-trending belt. The belt is 50 kilometers (31 mi) long, extending from west of Tamms in Alexander County to northwesternmost Union County (plate 1, *in* J. Weller and Ekblaw 1940). The Clear Creek Chert is underlain by the Lower Devonian Backbone Limestone in the northern area of its exposure (northwest of Jonesboro). In the rest of the area, the Backbone Limestone, if present, is represented entirely by chert beds.

The Dutch Creek Sandstone Member of the Middle Devonian Grand Tower Limestone overlies the Clear Creek Chert. The thickness of the Clear Creek Chert in southernmost Illinois is estimated to be considerably greater than 300 feet (100 m) (J. Weller and Ekblaw 1940). Presumably the thickness of this formation is less in the area of microcrystalline silica deposits because of the extensive leaching of carbonates. Only a rough estimate of the thickness can be made for this formation west of Elco because of sparse exposures and the difficulty of differentiating between the lower Clear Creek Chert and the upper Grassy Knob Chert.

The best estimate of thickness of the Clear Creek Chert in the area west of Elco can be made from the water well drilled in 1934 for C.C.C. Camp Delta. This well is situated in the NE SW, Section 20, T14S, R2W, in a valley approximately 280 feet (85 m) below the uppermost chert bed in the Clear Creek Chert. Examination of cuttings from this well in the sample repository at the ISGS shows that, to a depth of 140 feet (50 m), most of the material is buff, medium hard chert with some microcrystalline silica. Well cuttings typically contain a disproportionate concentration of the harder chert, however, as compared with the friable microcrystalline silica.

The interval from 140 to 150 feet (43–46 m) contains gray mottled chert with some quartz veinlets and small quartz crystals in cavities. Below this interval is a mixture of medium hard chert and some mottled gray chert. The mottled gray chert with quartz veinlets resembles chert exposed in the roadcut west of Tamms in the NE NE, Section 10, T15S, R2W, and also east of county highway 3 in the SW, Section 28, T14S, R2W. The massive chert bed exposed at these localities is in the Grassy Knob Chert (plate 1, *in* J. Weller and Ekblaw 1940) and must be the extremely massive chert in the middle of this formation described by these authors. The Grassy Knob Chert is about 200 feet (60 m) thick (Willman et al. 1975). Thus, the top of the massive middle chert beds in the Grassy Knob Chert is about 70 feet (21 m) below the base of the Clear Creek Chert. All these observations, combined with examination of cuttings from the Camp Delta well, formed the basis for estimating a thickness of 350 feet (107 m) for the Clear Creek Chert at this site.

Uppermost Chert Beds The only beds that could be consistently recognized and mapped in the Clear Creek Chert in this area are those of the uppermost massive chert beds. These beds are limited to the upper 20 to 30 meters (66–98 ft) of this formation and are directly overlain by the Dutch Creek Sandstone Member of the Grand Tower Limestone. Because of their resistance to erosion, these chert beds have controlled the topography in this area; for example, they underlie all the flat-topped ridges examined in the study area (plate 1), as well as in the surrounding areas in the Mill Creek 7.5-Minute Quadrangle. The massive chert beds are overlain by the ubiquitous loess that caps all ridges. In most places, these beds are not exposed in outcrop; however, their presence is indicated by large loose slabs of gray-weathering chert, many more than 1 meter (3 ft) in length and lying high on the hillsides just below the loess caps.

The best natural exposures of these massive chert beds are on the west-facing slope along the ridge connecting Bass Hill and Dago Hill in the SE SW, Section 3, T14S, R2W. Two intervals of massive chert beds are exposed along the west side of Bass Hill. The uppermost interval, close to the top of the ridge, is best exposed on the west slope, where the interval is approximately 4 meters (13 ft) thick (figs. 22 and 23). A lower interval of massive chert beds about 2.3 meters (7.5 ft) thick is exposed about 8 meters (26 ft) below the base of the uppermost bed. Between these two intervals exposures are sparse. Float is abundant, however, consisting of medium hard chert fragments and iron-stained, granular, medium hard to soft chert rubble. Approximately 30 meters (98 ft) below the lower chert beds, a prospect adit has been driven about 11 meters (36 ft) into a 3- to 4-meter (10–13 ft) thick interval of white friable microcrystalline silica mixed with a little soft white chert and medium hard chert (site 14, plate 1). The Bass Hill area is the only area where the two intervals of massive chert beds in the uppermost Clear Creek Chert are sufficiently well exposed to describe and determine the thickness of intervening beds.

Some of these uppermost chert beds of the Clear Creek Chert are also exposed (section 9, appendix B) in

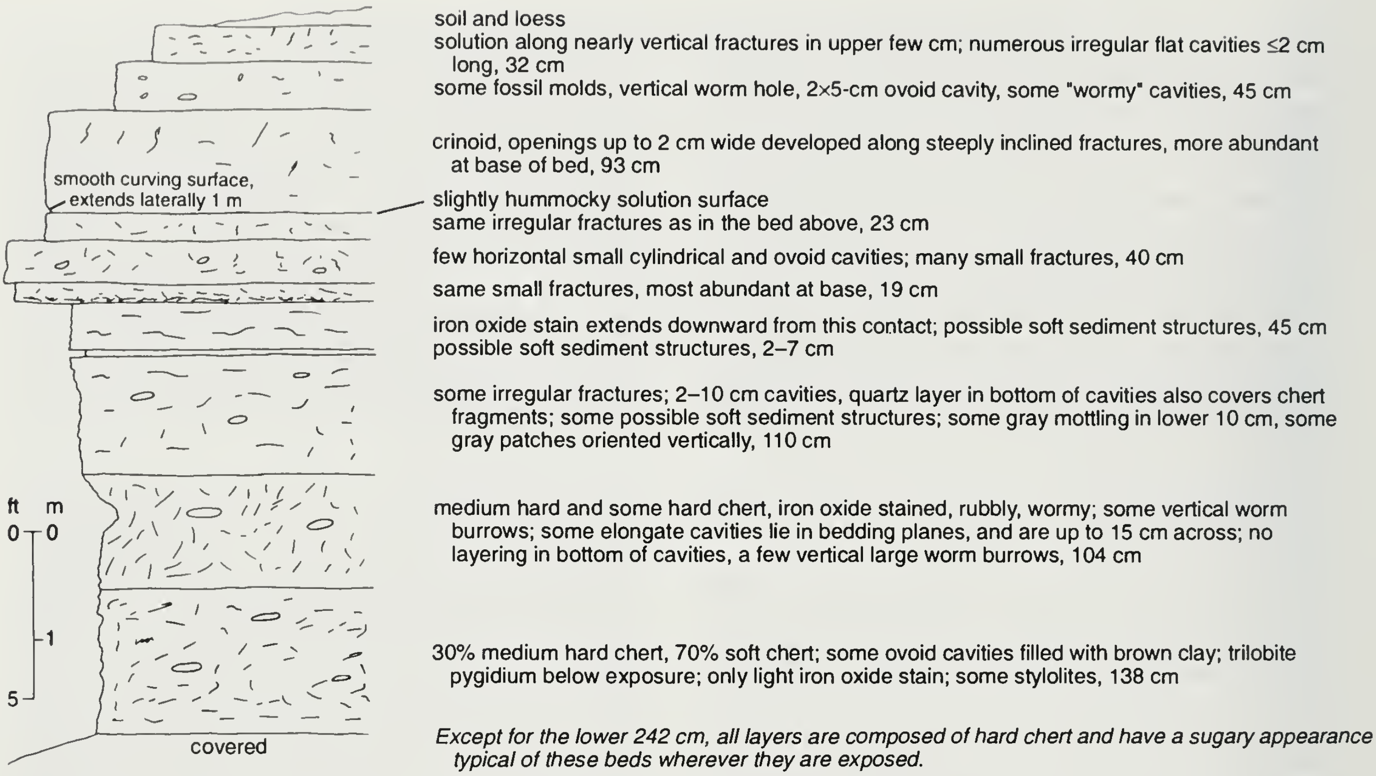


Figure 22 Exposure of the uppermost interval of chert beds in the Clear Creek Chert on the west side of Dago Hill (NE SE SW, Sec. 3, T14S, R2W, Alexander County).

an area of subsidence above a large inactive underground silica mine, near the highest point on the ridge (site 39, appendix A and plate 1). On the ridge north of Magazine Hollow, these chert beds are exposed in another area of subsidence above an inactive underground silica mine (site 27, appendix A and plate 1). Uppermost chert beds are also exposed (sections 1 and 2, appendix B; site 65, appendix A and plate 1) in the southern cut of the Lone Star mine.

Aside from the outcrops and distinctive large blocks of float characteristic of these chert beds, the beds can be recognized by several distinctive features in smaller pieces of float. They are the most fossiliferous of any chert beds seen in the Devonian section in this area. A 5-minute examination of float fragments will usually yield several brachiopods. Crinoid fragments are less abundant, and trilobite fragments are found only rarely. These beds are very light gray (N8) to pinkish gray (5YR8/1) on a freshly broken surface, and some have an alabaster-like appearance. The rock breaks with a subconchoidal to irregular fracture. Quartz crystals (≤1 mm long) line some fossil molds and coat fractures, and cause fragments of chert from these beds to sparkle in the sun. These small quartz crystals are much more abundant in these chert beds than they are in any of the other chert beds in the Clear Creek Chert, with the exception of a flinty chert (novaculite) exposed at the Jason mine. (See the following section, "Hard Chert.")

Another feature recognizable in small fragments of the uppermost chert beds is the fine-scale layering that can be seen on weathered surfaces by alternating light and medium gray layers 1 to 2 millimeters thick. Commonly, these layers are parallel across the distance of a fragment of float or an outcrop, but some show planar crossbedding. Fine layering in hard chert is restricted to these upper massive beds, and it is limited to a few percent of the outcrops.

Individual chert beds in the uppermost part of the Clear Creek Chert range from 20 centimeters to a little more than 1 meter (8 in. to 3.3 ft) thick. These are the thickest beds of hard chert seen in this formation. Hummocky surfaces with 5 to 10 centimeters (2–4 in.) of local relief separate some of the massive beds and appear to have formed by solution along bedding planes. The predominant lithology is hard massive chert. There are also less abundant, hard, flinty chert (novaculite) beds and a few softer beds consisting of a mixture of medium hard chert, soft chert, and friable microcrystalline silica. The most distinctive beds are made up of alabaster-like chert containing small structures that are, in some instances, irregular blebs less than 1 millimeter to several centimeters across of medium hard chert in a gray, hard quartz matrix resembling a breccia. The chert exposed in the Lone Star mine has an abundance of structures shown by medium hard chert layers in irregular masses, some resembling boudins (fig. 24). Intricate and enigmatic structures are shown by some of these features.

Almost all the chert beds in this sequence in the upper part of the Clear Creek Chert contain cavities. Irregular cylindrical cavities from about 0.5 to 1 centimeter (0.2–0.4 in.) in diameter and oriented perpendicular to bedding are interpreted to be worm burrows. The burrows were produced in soft sediment and preserved by being filled with material that was more calcitic than the surrounding sediment and preferentially leached to form the cavity.

Other elongate cavities 1 to 10 centimeters (0.4–4 in.) long are parallel to bedding planes. The most abundant cavities are irregular to ovoid and range up to a few tens of centimeters across. These cavities have smooth interiors, some of which bear a striking resemblance to solution caverns in limestone. The most reasonable explanation for their formation is solution of carbonate (calcite or dolomite masses). For example, one cavity is a few centimeters across and partially filled with angular fragments of chert. The fragments are coated with quartz druse, very similar to roof fall that has been coated with flowstone in a limestone cavern.

Some beds of hard chert contain numerous fractures with many different orientations. These fractures are typically coated with hematite or limonite and cemented by silica. Slight rotation of individual blocks has produced small wedge-shaped cavities along some of the fractures.

Gray clay layers up to several centimeters thick occur conformably between some of these chert beds; and where clay has been injected into fractures, it forms clastic dikes. Reddish brown clay coats many of the fractures and partially or completely fills irregular cavities in the uppermost chert beds. These clays have the same characteristics as clay skins in the B_t horizon of a normal soil profile, but instead of coating peds, the clay coats fractures and fills voids in the chert beds. Clay in the cavities exhibits extremely fine, horizontal laminations. These clays are best seen in fresh exposures of the uppermost chert beds, as in the south pit of the Lone Star mine. On natural exposures, the clay has largely been washed out of the cavities , but it can be seen in exceptional exposures such as the one at Dago Hill.

Section Below Uppermost Chert Beds Beds in the Clear Creek Chert below the uppermost massive chert beds are poorly exposed; natural exposures are limited to small areas in some steep tributary gulches and along creeks. These natural exposures are, in most instances, limited to less than 2 meters (7 ft) of stratigraphic section and thus permit only glimpses of this formation. The steep hillsides in the area only have some scattering of float, and it is all chert fragments. Because microcrystalline silica completely disaggregates, none is visible in the float. No distinctive features that could be associated with the presence of ore-grade bodies of microcrystalline silica were discovered in the float.

Examination of this lithology was mainly confined to the best available exposures, specifically at the portals of underground mines and in surface mines. In particular, the Lone Star mine (site 65, appendix 1 and plate 1) and the inactive Jason mine (site 8, appendix A and fig. 5) provided excellent exposures. Although the Jason mine is 5 kilometers (3 mi) north of the area mapped in detail, descriptions are included here because the mine provides excellent exposures of the Clear Creek Chert in this area of sparse outcrops.

The thickest, most continuously exposed section of the Clear Creek Chert is about 44 meters (144 ft)

Figure 23 Upper part of the section shown in figure 22. Rule is 1 meter long. Photo by J. M. Dexter, ISGS.

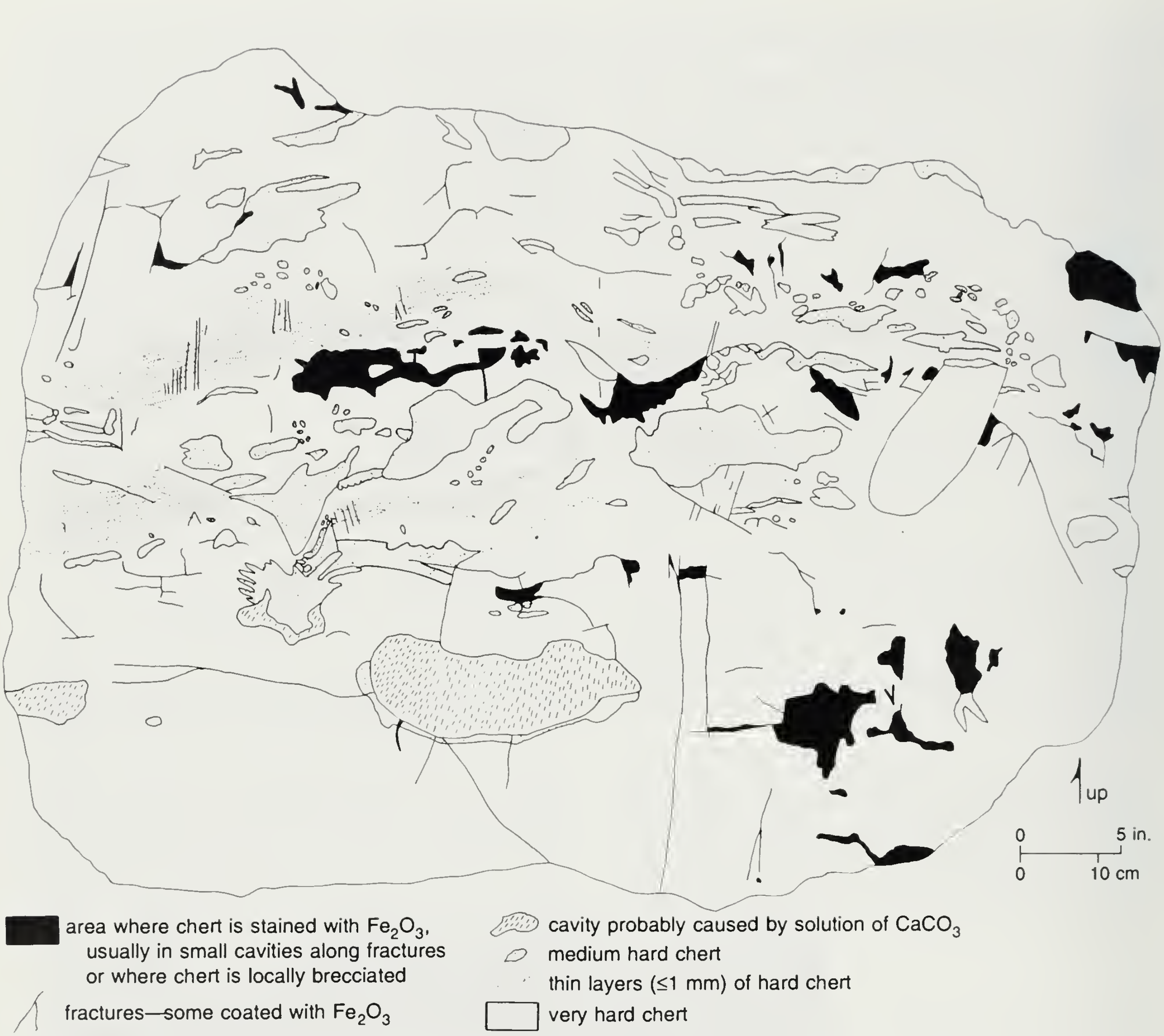


Figure 24 Tracing of small-scale, soft sediment-like and other structures from a photograph of a vertical fracture surface in a chert bed exposed near the top of the Clear Creek Chert at the Lone Star mine.

in height. It forms the west wall of the north pit of the Lone Star mine (fig. 17). The top of this section is very close to the base of the uppermost chert beds and probably within 15 meters (49 ft) of the upper contact of the formation. The lower 31.8 meters (104 ft) of this section is described in figure 25.

The exposed section at the Jason mine is much shorter, estimated to be 16 meters (52 ft) high. Only the lower 6 meters (20 ft) of this section could be reached for detailed examination (section 10, appendix B). Float of the massive uppermost chert beds found on the ridge above the Jason mine indicates that the section exposed at the Jason mine, like that at the Lone Star mine, is in the upper part of the Clear Creek Chert. In the study area west of Elco, only what is inferred to be the upper half of the Clear Creek Chert is exposed. The mines from which microcrystalline silica has or is being mined in the Mill Creek 7.5-Minute Quadrangle appear to be within the upper half of the Clear Creek Chert.

The main purpose of describing the exposed sections in detail was to identify beds, or sequences of beds, that could be correlated throughout the study area. This process facilitated the recognition of localities favorable for the occurrence of deposits of microcrystalline silica. Although prominent chert beds are persistent in individual exposures, and "appear" as though they could be traced laterally, no distinctive beds other than the uppermost massive chert beds could be correlated from one exposure to another with certainty. The gray, plastic clay layers could be important for correlation

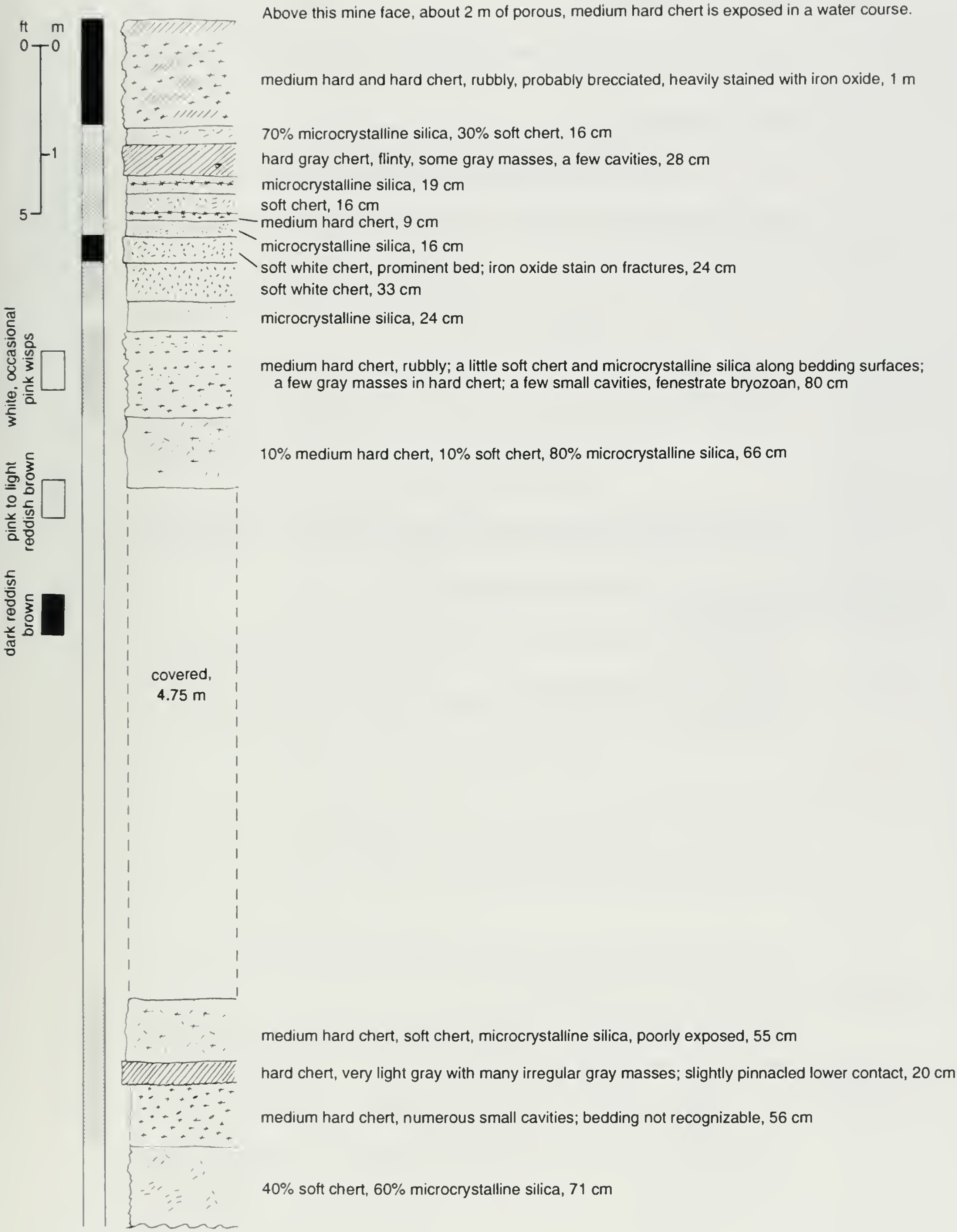
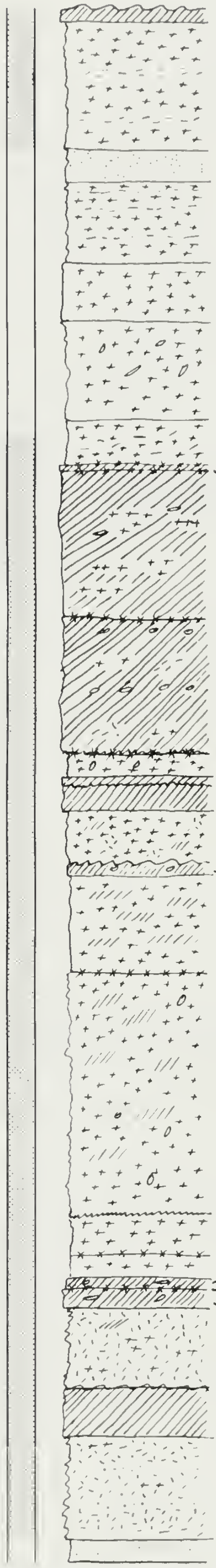


Figure 25 Section of Clear Creek Chert exposed at the northwest corner of the Lone Star mine (section 1, fig. 16).



hard chert, a few gray masses, 11 cm

medium hard chert, some small irregular cavities; a little soft chert along bedding surfaces, 90 cm

microcrystalline silica, 23 cm

medium hard chert with soft white chert along some bedding surfaces, 55 cm

medium hard chert, almost hard chert, more massive than above unit; some vertical cylindrical cavities, 43 cm

medium hard chert, many small irregular cavities; bedding not recognizable, 70 cm

80% medium hard chert, 20% soft chert, 32 cm

hard chert, 5 cm

70% hard chert, 30% medium hard chert, numerous small cavities; mainly subhorizontal, 104 cm

hard chert, gray masses locally dissolved, leaving cavities along bedding; stylolites along some bedding surfaces; minor medium hard chert and soft chert, 96 cm

medium hard chert, a few small cylindrical cavities, 18 cm

hard chert, 8 cm

hard chert, 17 cm

10% hard chert, 60% medium hard chert, 30% soft chert, some ovoid cavities; solution along bedding, 38 cm

hard chert, flinty, a few ovoid cavities, 10 cm

40% hard chert, 60% medium hard chert, some gray masses, some ovoid and cylindrical cavities, 68 cm

20% hard chert, 80% medium hard chert, some ovoid cavities, 175 cm

medium hard chert, hard gray chert in upper 2 cm, includes a tan and maroon clay layer <1 cm thick (TRB-157), 46 cm

hard chert, a few cylindrical cavities, 9 cm

clay (TRB-154)

hard chert, prominent bed, a few gray masses and cylindrical cavities, 11 cm

5% hard chert, 15% medium hard chert, 80% soft chert, soft chert along bedding in upper few cm; local development of stylolites, 58 cm

hard chert, gray masses, a few cylindrical cavities near upper and lower contacts; local stylolites, 37 cm

5% medium hard chert, 85% soft chert, 10% microcrystalline silica occurring along wavy bedding surfaces, 75 cm

microcrystalline silica, 17 cm

Figure 25 *(continued)*

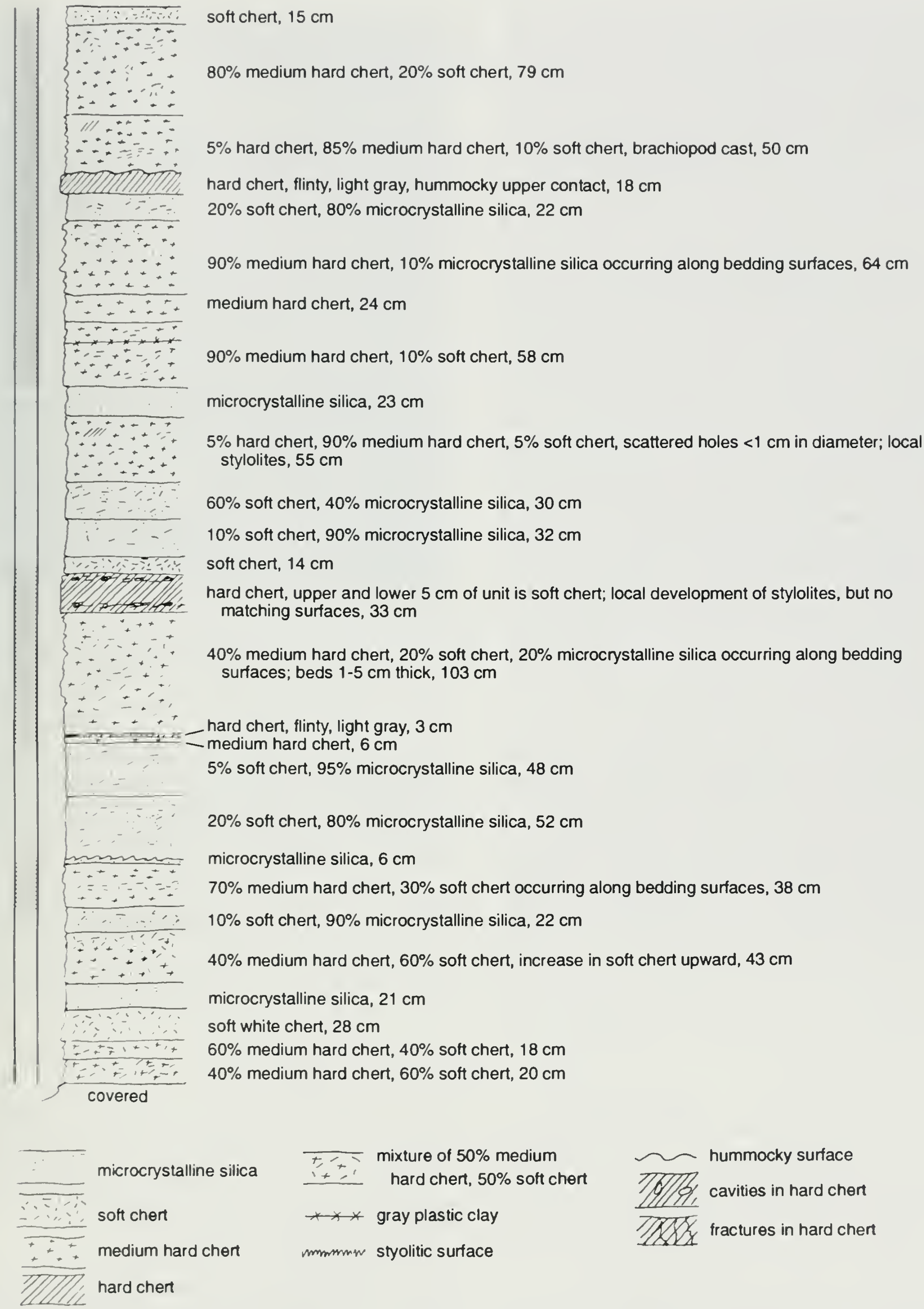


Figure 25 *(continued)*

within this area. Because they have been locally squeezed out, however, they are not always laterally traceable for more than a few meters. Some feature not recognizable in outcrop or hand specimen might provide the key for correlation of these beds. Although trace elements could possibly provide a means of correlating beds that are not distinctive lithologically, this seems to be unlikely within this sequence of largely monomineralic rocks that have probably been subjected to both hydrothermal activity and extensive leaching.

Distinctive thin layers of gray, plastic clay are abundant in the Clear Creek Chert. Although the clay mineralogy has been affected by postdepositional events, hydrothermal activity, and weathering, it was thought that the nonclay fraction might prove distinctive. If these layers were altered bentonites, this fraction might contain plagioclase, K-feldspar, and quartz, in addition to the common igneous accessory minerals. This fraction instead consists of aggregates of microcrystalline silica and euhedral quartz crystals, clearly not phenocrystic material. The mineralogy of this fraction is discussed in more detail in the section, "Clay Layers."

For descriptive purposes, the lithologies in the Clear Creek Chert are divided into the categories of hard chert, medium hard chert, soft chert, and microcrystalline silica. Most beds within the described sections contain a mixture of these rock types and are shown in the described sections as such. The abundances of the different lithologies in individual beds were estimated in the field.

Hard chert Because of their durability, hard chert beds stand out in relief relative to the softer, more easily eroded beds in the walls of open-cut mines. Most of the beds of hard chert are less than 30 centimeters (12 in.) thick, and many are approximately 10 centimeters (4 in.) thick. On a fresh surface, the hard chert ranges from very light gray (N8) to medium light gray (N6). Where exposed in cuts, these beds are usually light reddish brown because hematite and hydrated iron oxides stain fracture surfaces. Fracture surfaces are subconchoidal to irregular. Fifteen percent of the described section at the Lone Star mine is hard chert, but only 3% of the section at the Jason mine is of this lithology (fig. 25 and section 10 in appendix B).

Cavities are abundant in hard chert. Some cylindrical vertical cavities less than 1 centimeter (<0.4 in.) in diameter may be preserved worm burrows. In addition to the vertical, generally irregular, cylindrical cavities, there are other randomly oriented cylindrical cavities as much as several centimeters long. Some beds contain many irregular cavities that are as much as several centimeters across and have bulbous forms frequently filled with reddish brown clay. Fossils are only rarely recognizable in hand specimens of this chert.

The hardest chert bed seen in the Clear Creek Chert is exposed near the top of the cut at the Jason mine and is estimated to be approximately 0.6 meter (2 ft) thick. This chert breaks with a subconchoidal fracture. It contains irregular cavities up to 2 centimeters (0.8 in.) across and lined with chalcedony, which is in turn covered with drusy quartz.

Some beds of very light gray hard chert contain irregular light gray (N7) to light olive gray (5Y6/1) mottles that were removed to various degrees by weathering. A cavernous chert with a worm-eaten appearance is the result. Removal of these darker portions of the chert has progressed from bedding planes into the chert bed. In many instances, the interior of such a chert bed does not show evidence of removal of material, but cavities are present near its upper and lower surface (fig. 26). Further removal of quartz results in very spongy chert that has more than 50% pore volume and lacks sufficient strength to support the overlying beds. In some instances, this chert has collapsed, producing a granular material. This variety of "wormy" chert is most abundant just below the uppermost chert beds and in the lowest part of the section exposed in the Lone Star mine.

Medium hard chert The distinction made between hard chert and medium hard chert in the field is based largely on the ease with which the rock breaks. The medium hard chert breaks much more easily than the hard chert, but it still breaks into hard fragments with no tendency to be friable. This chert cannot be scratched with a knife or steel needle, and the attempt leaves a streak of steel on the chert. It does not form the beds that stand out in relief on a pit wall, as does hard chert, nor is it as heavily stained by secondary iron minerals. Numerous beds contain a mixture of medium hard chert and soft chert in varying proportions. Beds of medium hard or soft chert, or a mixture of the two, are generally thicker than hard chert beds. Many are 0.5 to 1 meter (1.5–3 ft) thick.

Soft chert Soft chert is the next category in the continuum from hard chert to friable microcrystalline silica. It is somewhat friable and easily broken into small fragments with a hammer. Because it is slightly friable, it can be gouged with a knife or steel needle.

Microcrystalline silica Microcrystalline silica is a distinctive rock type because of the ease with which it can be disaggregated into its constituent microscopic quartz crystals. This property is the reason for its economic importance. When dry, this rock can be easily disaggregated by hand. Because of its high porosity, it is very lightweight. Levine (1973) reported bulk densities of 1.24 and 1.17 gm/cc for two samples of very friable microcrystalline silica.

Intervals of microcrystalline silica are much thicker than the beds of the various types of chert in the Clear Creek Chert. Whereas various chert beds are less than 1 meter (3 ft) thick, beds of microcrystalline silica are

Figure 26 Specimen of hard chert shows evidence of solution having progressed from bedding planes into the chert. The specimen is from the Clear Creek Chert exposed in the north pit of the Lone Star mine. Scale bar is 2 centimeters (0.8 in.). Photo by J. M. Dexter, ISGS.

commonly thicker. The average intervals of commercial microcrystalline silica range from 8 to 40 feet (2.4–12.2 m) thick (Levine 1973). Most microcrystalline silica intervals contain a few fragments of medium hard and hard chert. The purer intervals of microcrystalline silica are sought after in mining.

A distinct variety of slabby microcrystalline silica is exposed at a few localities (e.g., the Jason mine). This rock is characterized by its ability to break into slabs only a few centimeters thick, in contrast to typical microcrystalline silica, which breaks into irregularly shaped but relatively equidimensional fragments.

The stratigraphic distribution of adit levels below the uppermost chert beds of the Clear Creek Chert is concentrated in the range of 15 to 95 feet (5–29 m). Only rarely were adits found more than 120 feet (37 m) below the uppermost chert beds. This is essentially the same interval of rock as is exposed in Lone Star's north pit (figs. 17 and 25), where a commercial thickness of microcrystalline silica is not present. Generally, more adits are found closer to the uppermost chert beds than are found farther down the section (fig. 27). The entry levels of inactive mines in the northern part of the area of plate 1 are closer to the uppermost massive chert beds in the Clear Creek Chert than are those in the southern part of this area. There is no obvious explanation for this difference. Although the histograms (fig. 27) are admittedly only a crude indication of the stratigraphic position, they indicate that the microcrystalline silica deposits are not confined to a specific stratigraphic horizon. Because entry levels are limited by the lowest elevation of creeks, however, no entry levels could be more than 200 feet (61 m) below the uppermost chert beds. Information is not available on lower levels of mine workings, and these may extend below creek elevation.

Thin Section Petrography Petrographic examination of four thin sections taken from the uppermost massive chert beds shows that the chert consists mainly of microcrystalline quartz, 1 to 10 μm in size. Small areas and crude veinlets consist of coarser grained quartz crystals, as much as 20 μm in length. Scattered individual crystals are 20 to 80 μm in maximum dimension and show evidence of euhedral form. Grain boundaries of these larger crystals appear irregular because they are overlapped in thin section by finer grained crystals, but careful examination shows the presence

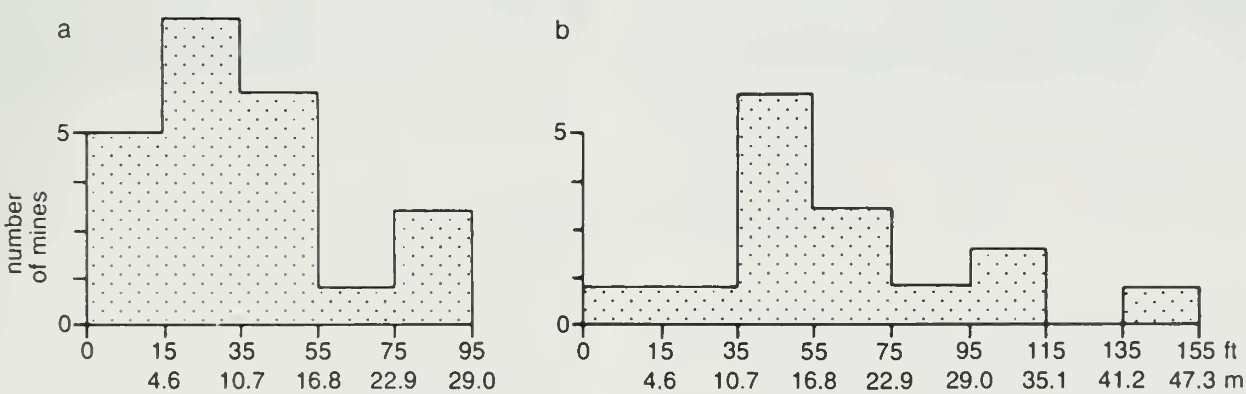


Figure 27 Histograms of the vertical distance between the bottom of the uppermost chert beds in the Clear Creek Chert and entry levels of inactive mines: (a) represents mines to the north of cross section B–B′ on plate 1 (23 mines, average distance of 10 m [34 ft]); and (b) represents mines to the south (15 mines, average distance of 19 m [61 ft]).

of some crystal faces. Calcite inclusions, fluid-vapor inclusions, and some vapor-filled inclusions are present in the rims of these crystals. They are not as abundant as similar inclusions found in euhedral quartz crystals that are 80 to 120 μm long and occur in clay layers in the Clear Creek Chert.

Some chert specimens show fine layering that is easily recognizable in hand specimen but not recognizable in thin section. One chert specimen from the exposure above the area of subsidence at site 39 (appendix A and plate 1) has an alabaster-like luster and shows discontinuous wavy layers 0.3 to 0.5 millimeter apart. Some layers are marked by a concentration of larger euhedral quartz crystals of random orientation. A few flakes of muscovite as much as 100 μm long were observed. One specimen of the finely layered chert contains local concentrations of pelmatazoan fragments. It also contains areas of fine grained calcite interspersed with the microcrystalline quartz. Also occurring in some cavities in this specimen is calcite, most likely deposited by groundwater long after leaching of these beds occurred.

Individual beds of hard chert have most characteristics in common with the uppermost massive chert beds in the Clear Creek Chert. Irregular patches and crude veinlets of coarser grained (up to 20 μm) quartz crystals, are scattered throughout the matrix of microcrystalline quartz. Masses of coarser grained crystals are as much as 150 μm across. Rare 2- to 3-millimeter cavities have been filled with inclusion-free quartz crystals as much as 0.5 millimeter long. There are also numerous quartz crystals about 50 μm long throughout the microcrystalline chert. Silicified fossil fragments, mainly pelmatazoans 0.1 to 0.8 millimeter long, are abundant in some chert specimens. Many of these fragments are surrounded by quartz crystals that are coarser than normal.

Rhombohedral cavities are found in all chert specimens, but they are particularly abundant in some specimens of hard chert. They are mainly 40 to 120 μm across and have sharp, straight sides. Presumably, these cavities have been left by the solution of authigenic dolomite rhombs.

Smaller (2–50 μm) cubic cavities were found in all specimens of hard chert, including specimens from the Bailey Limestone exposed in the roadcut southeast of Thebes, the Grassy Knob Chert exposed in the roadcut west of Tamms, and the Clear Creek Chert exposed in the Lone Star mine. Unlike the sharp rhombic cavities, some of these cavities have rounded corners and edges, and they have slightly irregular dimpled surfaces.

The precursor of these cavities was obviously an isometric mineral that grew in cubes. The most likely possibilities are fluorite, halite, or pyrite. In none of these specimens could even the smallest remnant of the mineral responsible for these cubic molds be found. Some molds preserve evidence of intergrown individual crystals indicative of a penetration twin characteristic of fluorite or pyrite.

It is unlikely that these cavities were left by solution of halite. Although some occur within a millimeter of cavities lined with quartz crystals, no quartz crystals have been observed lining them. Therefore, whatever mineral was responsible for these rhombohedral and cubic cavities must have dissolved after quartz was deposited in the larger vugs. Otherwise, some quartz crystals would also line these smaller cavities. Because halite is highly soluble, it was unlikely to still be present in the chert bed as water permeating the rock was depositing quartz in an adjacent cavity.

There are also irregular cavities of about the same size range as the cubic cavities. These have dimpled surfaces and somewhat resemble kneaded dough in shape, but give no clue as to the mineral that was dissolved.

The main difference seen in thin section between microcrystalline silica and the several varieties of chert is the much greater porosity of the microcrystalline silica. The predominantly intercrystalline porosity of the microcrystalline silica is from 10% to 30%, as estimated from thin sections. The type of porosity is interconnected, giving the rock permeability. In contrast, the varieties of chert have negligible permeability due to the lack of interconnected pores. Their porosity is limited to isolated molds of crystals of dolomite and a cubic mineral, and of irregular masses of an unidentified material. As is also true with hard chert, specimens of friable microcrystalline silica contain a few scattered larger quartz crystals, rhomboid cavities, cubic cavities, irregular cavities, and fossil fragments. Generally, the grain size in the friable microcrystalline silica is more uniform than in the chert.

Scanning Electron Microscopy Examination using the scanning electron microscope (SEM) provided more useful information on samples of microcrystalline silica and chert than was obtained by petrographic examination of thin sections. Much of the material is simply too fine grained for resolution by optical microscopy.

Significant textural differences can be observed between examples of hard chert, medium hard chert, and microcrystalline silica (figs. 28 and 29). Also, on the basis of only a few observations, it appears that there is a textural difference between microcrystalline silica in the samples from the Grassy Knob Chert to Bailey Limestone transition zone and the samples taken from the Clear Creek Chert. Further examination of different lithologies from all three formations would most likely reveal additional significant differences.

A layer of very hard chert in the Clear Creek Chert is exposed in the Jason mine and consists of extremely fine grained cryptocrystalline quartz (fig. 28a). Unlike all the other specimens examined by SEM, only a few individual quartz crystals can be recognized at a magnification of 2160× because the chert is too fine grained. In hand specimen, this very light gray (N8) chert is hard and flinty, breaking with a conchoidal fracture.

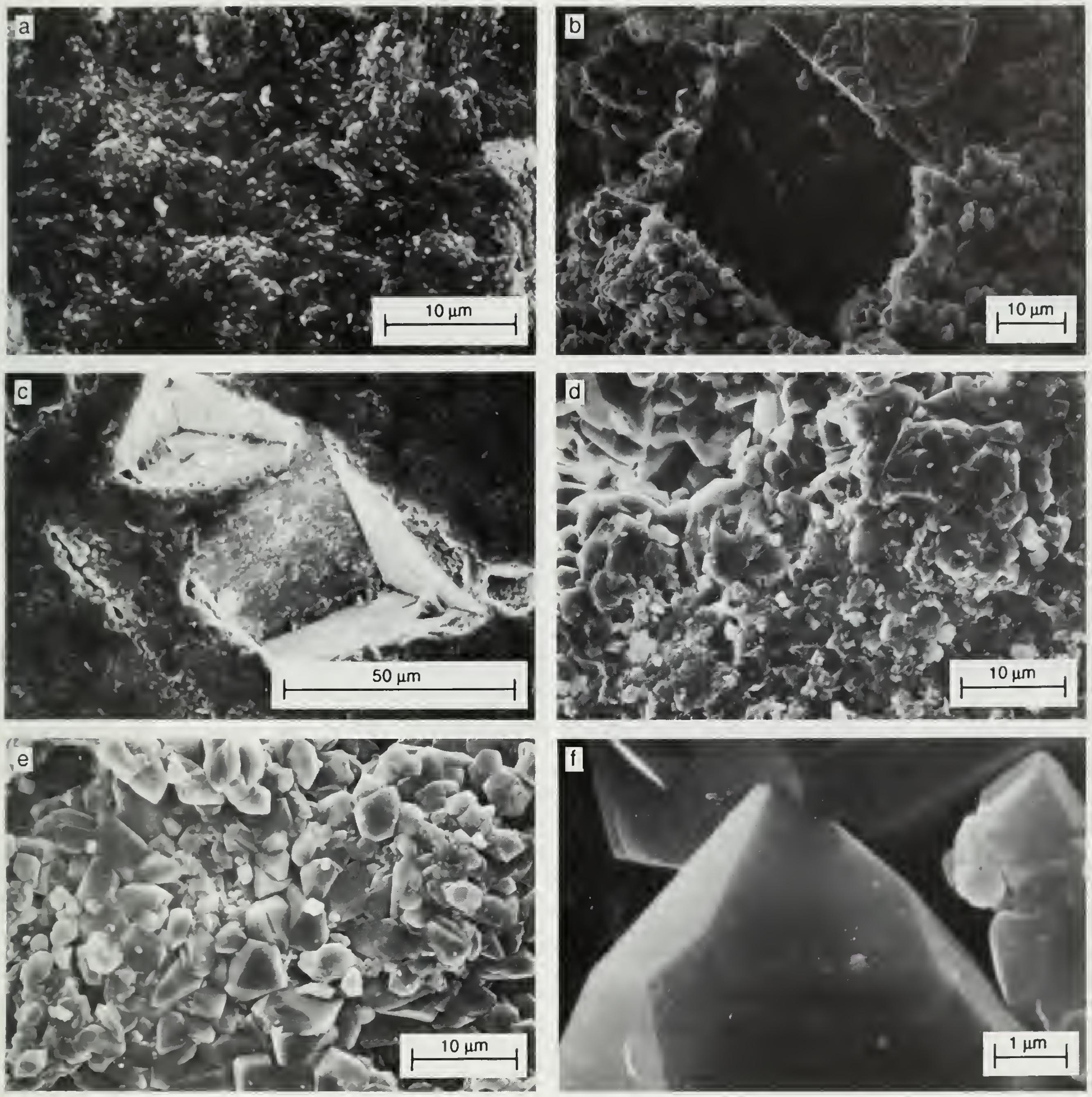


Figure 28 SEM micrographs of specimens from the Clear Creek Chert. The specimens were coated with gold and palladium and exposed at a beam voltage of 15 kv with an Amray SEM. Micrographs by D. J. Lowry, SEM Laboratory, ISGS.

a) Sample from the very hard chert bed exposed at the Jason mine (TRB-57).
b) Sample of rhombohedral mold surrounded by microcrystalline silica from the microcrystalline silica bed mine underground at the Jason mine (TRB-67).
c) Cubic molds in the very hard chert bed exposed at the Jason mine (TRB-57).
d) Sample from a massive chert bed in the uppermost part of the Clear Creek Chert exposed in the south pit of the Lone Star mine (TRB-92).
e) Sample from the bedding surface of a medium hard chert bed exposed in the north pit of the Lone Star mine (TRB-134).
f) Interpenetration of euhedral quartz crystals in the same specimen of medium hard chert shown in fig. 28e (TRB-134).

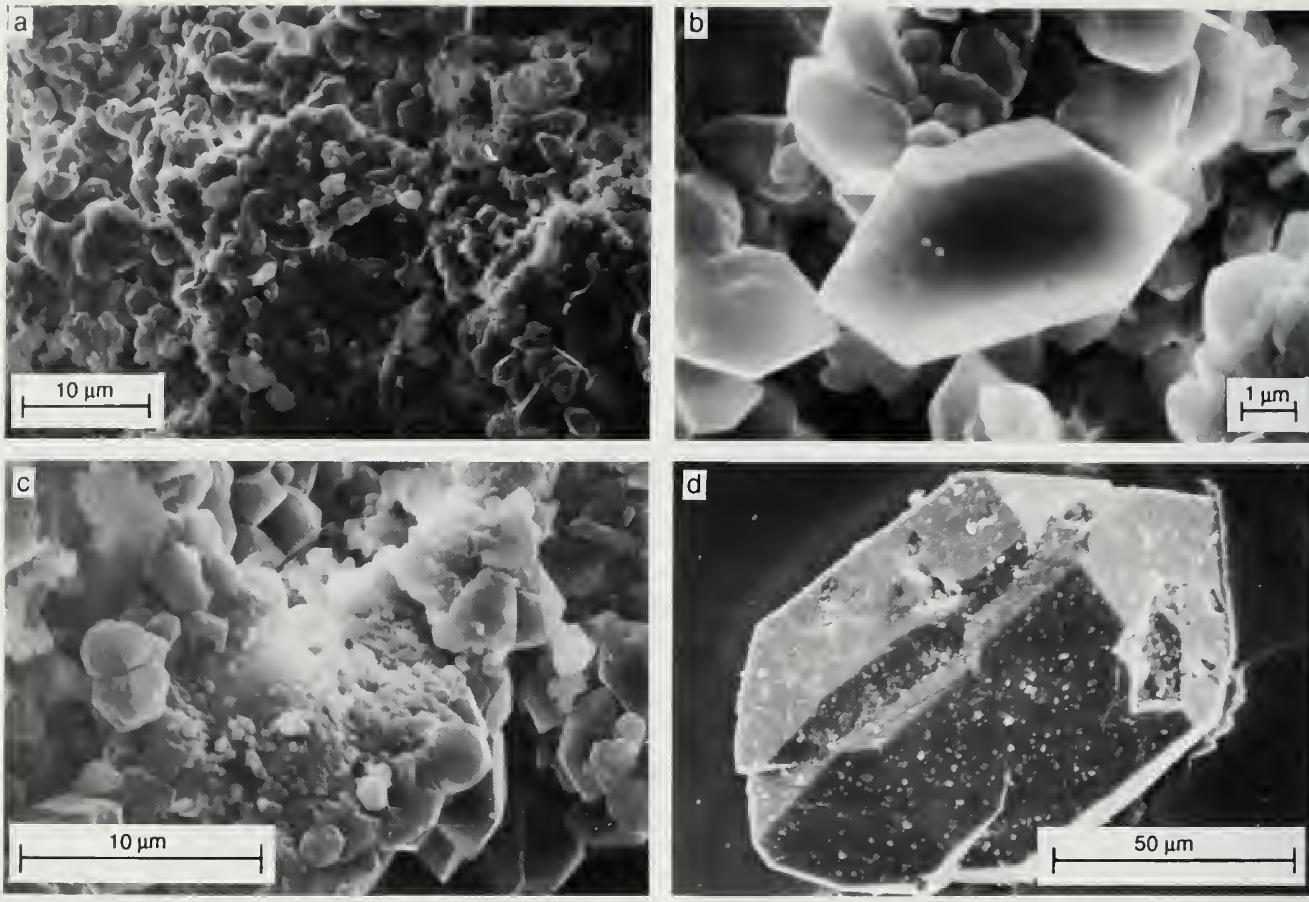


Figure 29 SEM micrographs of specimens from the Clear Creek Chert:
a) slabby microcrystalline silica exposed at the portal of an inactive mine (site 53, appendix A and plate 1) (TRB-166);
b) microcrystalline silica from the Jason mine (TRB-67);
c) microcrystalline silica from a roadcut (site 15, appendix A and plate 1) (TRB-502);
d) euhedral quartz crystal separated from a clay layer exposed in the same cut (site 15, appendix A and plate 1) (TRB-410); the crystal is twinned according to the Dauphine law.

Both chert and microcrystalline silica contain numerous rhombohedral cavities (fig. 28b) and also cubic cavities (fig. 28c) that are in the range of 30 to 100 µm in maximum dimension. The rhombic features are interpreted to be molds of dolomite crystals.

A specimen of hard chert from one of the uppermost chert beds in the Clear Creek Chert shows two textural variations (fig. 28d). The coarser grained texture is exemplified by the closely packed arrangement of subhedral and euhedral quartz crystals 5 to 15 µm long, as shown in the upper left hand corner of the SEM micrograph. The other texture seen in this micrograph is caused by much smaller crystals, some less than 1 µm, with a scarcity of crystal faces. Medium hard, white chert from the section below the uppermost beds of chert consists mainly of slightly interpenetrating subhedral to euhedral quartz crystals (fig. 28e–f).

A specimen of the slabby variety of microcrystalline silica consists of a mixture of anhedral quartz several micrometers in size and masses of euhedral quartz crystals somewhat larger in size, around 5 µm (fig. 29a). A specimen of microcrystalline silica from the interval mined at the Jason mine consists of quartz crystals from 1 to 6 µm in length (figs. 3, 29b). Even some of the smallest quartz crystals, <1 µm long in this specimen, show crystal faces. Another specimen of microcrystalline silica, also from the Clear Creek Chert, shows an area of extremely fine grained material, presumably quartz, surrounded by larger subhedral quartz crystals (fig. 29c).

Texture and Hardness SEM micrographs show distinct textural variations that can be correlated with the hardness or degree of cohesiveness of the specimen. The hardest chert encountered in the Clear Creek Chert consists of very fine grained micro- to cryptocrystalline quartz. The next hardest chert of the specimens examined by SEM shows very fine grained quartz mixed with coarser grained material consisting of intergrown subhedral quartz crystals. In the medium hard chert, interpenetrating quartz crystals generally show development of crystal faces. This rock also contains some masses of very fine grained quartz. Friable microcrystalline silica is easily pulverized because it consists mainly of individual euhedral quartz crystals. This abundance of euhedral, only slightly intergrown, crystals and large void space permit the easy micronizing of this material.

Clay Layers • *Mineralogy* Concordant layers of gray, plastic clay are found throughout the Clear Creek Chert in the area west of Elco. These clay layers vary in thickness, but they are always less than 10 centimeters (4 in.) and usually approximately 2 centimeters (0.8 in.) thick. They pinch out entirely in many instances.

In addition to forming concordant layers, this clay has been intruded along steeply inclined faults and some fractures where it is often thicker than it is in the layers (fig. 30). In a compilation of all the described sections of the Clear Creek Chert, exclusive of the uppermost massive chert beds, there are 31 clay layers; however, it is not possible to correlate them between described sections. Each layer has an average thickness of 2 centimeters (0.8 in.), and their total thickness accounts for less than 1% of the described sections of 78.7 meters (258 ft). Clay layers are found in all of the lithologies of the Clear Creek Chert. Color ranges from very light gray (N8) to yellowish gray (5Y8/1), and some of the clay layers are stained red by hematite along veinlets.

The ovoid cavities, 5 to 20 centimeters (2–8 in.) long, in the harder chert beds contain clay ranging in color from moderate brown (5YR4/4) to moderate orange pink (5YR8/4). The clay generally shows fine scale, horizontal color banding parallel to the bottom of the cavity. Brown clay also fills fractures in the harder chert beds, but it is rarely found in the beds of friable microcrystalline silica. Waxy orange masses recovered from the brown clay by wet sieving contain hematite (identified by XRD analysis).

XRD analyses of the <2 μm fraction of gray clay samples show kaolinite to be the dominant mineral. Typical XRD traces are shown in figure 31. Lesser amounts of illite and expandable material appear in some samples (table 3). Randomly interlayered kaolinite/smectite is the dominant clay mineral in one reddish brown clay sample (TRB 61). These analyses show similar mineralogy for both the brown and red clays.

Nonclay fraction The >44 μm fraction was separated by wet sieving samples from clay layers in the Clear Creek Chert as well as from two clayey layers in the Bailey Limestone. The most abundant constituent of this size fraction is masses of extremely fine grained microcrystalline silica, too small to be recognized with the petrographic microscope. Doubly terminated euhedral quartz crystals generally constitute less than 10% of this size fraction (table 4 and fig. 32). Waxy masses, which were orange to brown when viewed under the petrographic microscope using transmitted light, were identified by XRD analysis to be a mixture of hematite

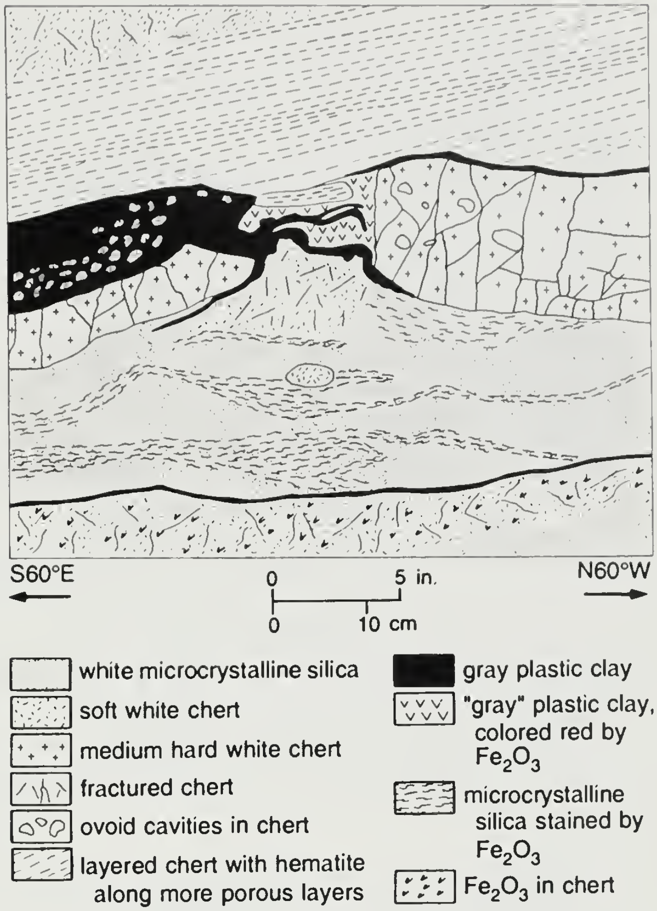


Figure 30 Exposure of Clear Creek Chert in the south wall of the Jason mine shows intrusion of gray clay along fractures (see fig. 19 for location of exposure).

and clay. Angular quartz grains are a minor constituent of some separates, as are subrounded to rounded quartz grains 0.1 to 0.3 millimeter in maximum dimension, many with frosted surfaces.

Euhedral quartz crystals from the gray clay occur in a relatively narrow size range. Many range between 80 and 120 μm in length. Some are as large as 160 μm, and some are as small as a few micrometers long, similar to those found in the microcrystalline silica beds. Although not common, a few quartz crystals are twinned according to the Japan and the Dauphine laws (fig. 29d). Crystals show no evidence of surface etching. Some crystals have small clusters of hematite grains adhering to the surface. Indentations on the faces of most crystals are attributed to interference from other quartz crystals during growth.

Quartz crystals found in these clay layers are similar in morphology and nature of inclusions to the larger quartz crystals found in beds of microcrystalline silica and chert. It was easier to separate these crystals from clay layers than from chert or microcrystalline silica layers, thus crystals from clay layers were studied in detail. Cores of some of these crystals are rounded,

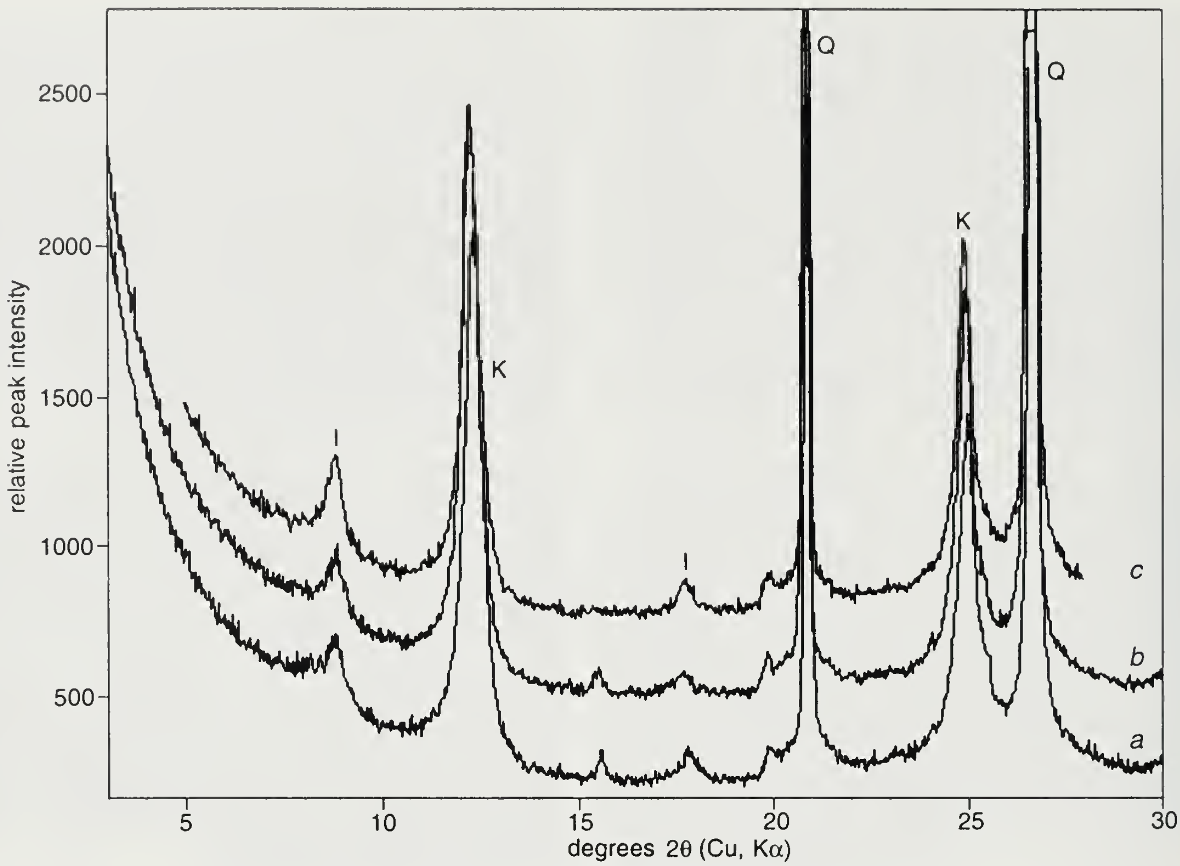


Figure 31 XRD traces of the <2μm fraction of sample TRB-60 of gray clay from the Clear Creek Chert (see fig. 41 for a description of the stratigraphic section, including this bed). All mounts were prepared by pipetting suspension onto a glass disk, and samples were run on a Scintag automated x-ray diffractometer. Trace *a* is of an air-dried mount, *b* of a mount glycolated by exposure to ethylene glycol vapor for more than 64 hours at 60°C, and *c* from a mount heated at 350°C for 1 hour. I = illite, K = kaolinite, and Q = quartz. The peak at about 15.5° 2θ is from an unidentified phase. Analyses by D. M. Moore, Clay Minerals Unit, ISGS.

Table 3 XRD analyses of clay samples from the Clear Creek Chert; the size fraction analysed is <2 μm equivalent spherical diameter.*

Sample	Location	Description	Mineralogy
TRB-23	NE SW, Sec. 16, T14S, R2W	Natural exposure along Sexton Creek; brown clay from cavity in chert bed.	Major kaolinite; about two parts in ten illite and less than one part in ten expandable clay minerals.
TRB-60	site 15, appendix A, plate 1, fig. 41	Specimen from gray clay layer (1 cm thick) exposed in a cut (figs. 40 and 41).	Major kaolinite; one part in ten illite and no expandable clay minerals (fig. 31).
TRB-61	site 15, appendix A, plate 1, fig. 41	Reddish brown clay from cavities in chert bed exposed in a cut (figs. 40 and 41).	Dominant clay is interlayered kaolinite/smectite; subordinate illite and minor expandable clay minerals.
TRB-66	site 8, appendix A, fig. 5	Gray clay mass from southwest face of Jason mine.	Major kaolinite; less than one part in ten illite and expandable clay minerals.
TRB-73	site 8, appendix A, fig. 5	Gray clay bed (2 cm thick) in mined bed of microcrystalline silica at Jason mine (see section 10 in appendix B).	Kaolinite eight to nine parts in ten; balance of sample is illite and expandable clay minerals.

*Analyses made and interpreted by D. M. Moore, ISGS.

but many appear to be smaller euhedral quartz crystals. These cores are defined by the planar arrangement of small (1–20 µm), round calcite grains, identified by XRD analysis. Cores can also be recognized by the arrangement of very small (<4 µm) fluid inclusions along planes. Examination of the cores of these quartz crystals by luminoscope failed to show any evidence of cathodoluminescence (T. S. Hayes, USGS, personal communication 1990). Detrital quartz of igneous or metamorphic origin typically exhibits cathodoluminescence because of Ti^{4+} or Fe^{3+} in trace concentrations, whereas authigenic quartz is purer and does not luminesce under these conditions. In addition to containing calcite inclusions, these quartz crystals contain rhombohedral and cubic molds like those observed in chert and microcrystalline silica. Rare, small dolomite rhombs occur in these crystals (see section, "Fluid Inclusions in Quartz Crystals," in this report).

Origin of clay layers The gray clay that formed conformable layers and filled fractures in the Clear Creek Chert was either introduced into this formation after leaching, or it is indigenous. Field relationships and mineralogy indicate an indigenous origin. The clay layers are probably residual, remaining after solution of carbonate from impure carbonate beds, as suggested by J. Weller (1944). The occurrence of gray clay in conformable layers is difficult to explain by introduction from an external source. The hydrostatic pressure would have to be sufficient to inject a clay suspension between chert beds—an unlikely possibility. If the clay were introduced, it should be confined to cavities and fractures; but this is not the case. Much of the reddish brown clay found in fractures and cavities in chert beds near the surface is associated with iron staining and probably related to pre-Wisconsinan periods of soil formation. At least

Table 4 Mineralogy of the >44 µm fraction of clay samples separated by wet sieving. All samples are gray clay, except where red or brown clay is noted.

Sample	Location	Formation	Microcrystalline quartz masses*	Angular quartz grains	Rounded detrital quartz grains	Euhedral quartz	Reddish brown masses	Opaque grains	Carbonate aggregates
TRB-9	Roadcut southeast of Thebes, see fig. 7, clay from unidentified bed	Bailey Limestone	M	t			t		
TRB-23	Exposure along Sexton Creek next to site 48 on plate 1, clay from cavity in chert	Clear Creek Chert (brown clay)	M		t	t		m	
TRB-60	Plate 1, site 15, see fig. 41, clay bed	Clear Creek Chert	m		t	M		t	
TRB-61	Plate 1, site 15, see fig. 41, clay from ovoid cavity in chert	Clear Creek Chert (red clay)	m	M		M	M		
TRB-112	Plate 1, site 62, clay bed	Clear Creek Chert	m		m	M			
TRB-120	Appendix B, Section 8	Clear Creek Chert	M		M	m	t		
TRB-124	Exposure in Sexton Creek, clay bed, NW NE NE Sec. 16, T14S, R2W	Clear Creek Chert	M			m	t	t	
TRB-127	Roadcut southeast of Thebes, see fig. 8	Bailey Limestone	M	t					M
TRB-135	Plate 1, site 65, north pit (fig. 16), clay from unidentified bed in east face	Clear Creek Chert	M		t	m	m	t	
TRB-139	Figure 10, site 118, clay bed	Grassy Knob Chert or Bailey Limestone	M	m					
TRB-152	Plate 1, site 65, appendix B, Section 1	Clear Creek Chert	m	M		M			
TRB-154	Plate 1, site 65, see fig. 25	Clear Creek Chert	M		t	m			
TRB-157	Plate 1, site 65, see fig. 25	Clear Creek Chert (brown clay)	m		m	m	M		

M = major constituent; m = minor constituent; t = trace constituent

* Samples 152, 154, and 157 contain chert rather than the masses of friable microcrystalline silica seen in the other separates.

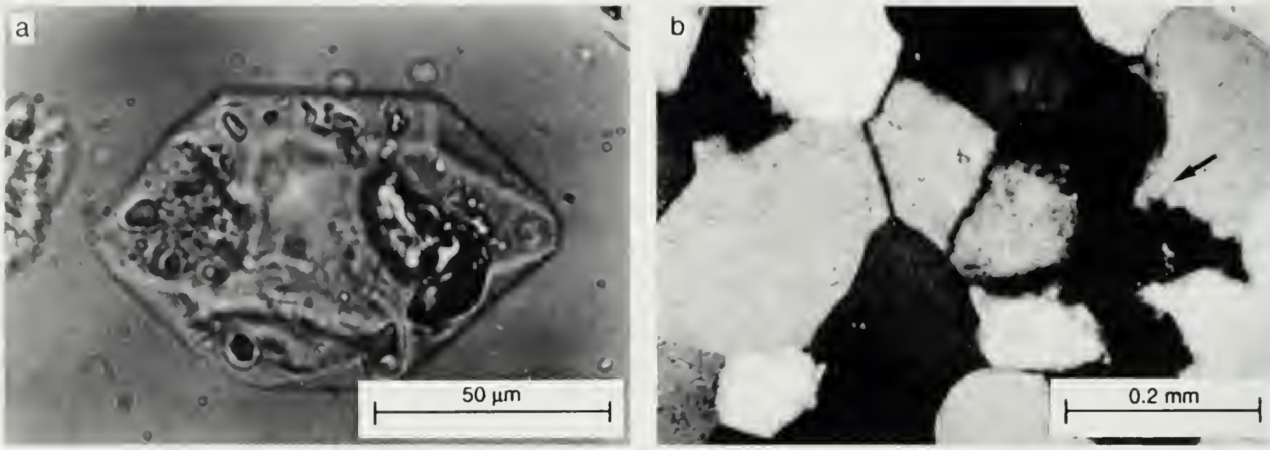


Figure 32 (a) Photomicrograph of euhedral quartz crystal from the clay layer (sample TRB-60) in the Clear Creek Chert exposed in the cut described in figure 41. Large inclusion to the right is vapor-filled, and the smaller inclusions are calcite. (b) Photomicrograph (under crossed polars) of a sample from the Dutch Creek Sandstone Member of the Grand Tower Limestone from the SE NW NE, Section 11, T14S, R2W, Alexander County. The faint outline of a subrounded detrital quartz grain is indicated by an arrow (upper right).

some of the reddish brown clay is simply gray clay that has been colored by the introduction of hydrated iron oxide and hematite.

If the gray clay layers represent primary sedimentary clay beds, a mechanism is required for the introduction of large quantities of clay into the Devonian sea at irregularly spaced intervals. The most likely possibility would be volcanic ash that settled into the Devonian sea, was altered to smectite, and later underwent diagenetic change to form a metabentonite such as the Tioga Bentonite Bed in the Grand Tower Limestone (Willman et al. 1975). Intensive weathering of a metabentonite could have formed a clay mineral suite consisting mainly of kaolinite with minor illite.

There are two major objections to this hypothesis. The first is that metabentonite beds have not been reported from the Clear Creek Chert. Given the abundance of clay layers in the exposures of Clear Creek Chert examined in the study area west of Elco, metabentonite beds would certainly have been recognized elsewhere on electric logs. The second objection is that examination of material coarser than 5.5 µm separated from the clay bed (sample TRB-60) exposed at site 15 (appendix A and plate 1) failed to show the presence of phenocrystic material. If these clay beds are altered bentonites, it is likely that some relict igneous minerals would be recognized.

Lamar (1953) briefly mentioned the most likely explanation: removal of carbonates by solution left "soft clayey" layers. The amount of carbonate originally present in these beds is not known and can only be inferred on the basis of what is known of the Clear Creek Chert outside of the Elco district where carbonates account for a major part of this formation.

Dutch Creek Sandstone Member of the Grand Tower Limestone

This unit overlies the Clear Creek Chert and is overlain by a chert–pebble conglomerate of uncertain age. The only exposure of the Dutch Creek Sandstone Member within the area shown on plate 1 is near the head of a gulch in the ridge north of Magazine Hollow in the SE NW NE, Section 11, T14S, R2W. The chert–pebble conglomerate is exposed higher and farther east on the same hillside. At this locality, 1.5 meters (5 ft) of massive Dutch Creek Sandstone is exposed. The actual thickness of this formation is probably not more than a few times the thickness of this exposed bed. At other localities, the Dutch Creek Sandstone Member was mapped by the presence of large blocks of this distinctive sandstone. These blocks are as much as 1 meter (3 ft) across and have, in many instances, moved down steep gullies to an intermittent creek valley. Small remnants of this formation are left on some flat ridges underlain by the uppermost chert beds in the Clear Creek Chert. The sandstone is characterized by a case-hardened, brown-weathering rind that is several centimeters thick and covers the pinkish gray (5YR8/1) interior. Some blocks contain abundant brachiopod and other fossil casts and molds. The Dutch Creek Sandstone Member is a mature, partially silica-cemented, orthoquartzite consisting of rounded quartz grains that are 0.15 to 0.25 millimeter in maximum dimension (fig. 32b).

Chert–Pebble Conglomerate

Within the area mapped (plate 1), the only exposures (fig. 33) of chert–pebble conglomerate are on the south-facing slope near the east boundary of the SE NE NE, Section 11, T14S, R2W. In addition to these outcrops there are numerous large blocks, some more than 1 meter (3 ft) across. They are composed of very strongly silica-cemented conglomerate and have moved downslope. The maximum exposed thickness of chert–pebble conglomerate is about 1.7 meters (5.6 ft). As shown in fig. 33, local dip is about 10° east. The conglomerate is overlain by about 8 meters (26 ft) of loess on the ridge top. The area underlain by chert–pebble conglomerate in the east half of Section 10, T14S, R2W, was mapped on the basis of concentrations of rounded chert pebbles on both sides of the loess-covered ridge.

This poorly sorted conglomerate has a bimodal size distribution and consists mainly of light gray (N8) to very light gray (N7) subangular to subrounded chert pebbles. Brachiopod fossils are found in some of the chert pebbles, and there are rare pebbles of orthoquartzite derived from the underlying Dutch Creek Sandstone. With the exception of a few darker gray chert pebbles, most of the chert pebbles are light gray, typical of the Clear Creek Chert. Some pebbles contain white (N9) weathering rinds as much as several millimeters thick. This conglomerate is clast supported with smaller angular to subangular chert granules and sand grains (0.5–1.0 mm) partially filling voids between pebbles. Sand grains are subrounded quartz grains typical of the Dutch Creek Sandstone. Some blocks of conglomerate float consist almost entirely of sandstone composed of these grains. Approximately 25% of the conglomerate observed in outcrop is strongly cemented by quartz. In some instances, chalcedony completely fills the intraclast voids. Hydrated iron oxide partially fills the voids in some layers.

A concentration of float of a sandy, silica-cemented siltstone occurs in the gully just west of the exposures of chert–pebble conglomerate. The siltstone is indicative of a lens of finer grained sediment within the conglomerate. This hard rock is pinkish gray (5YR8/1) to very light gray (N8). It consists of detrital subrounded to angular quartz and less abundant chert grains, 0.1 to 0.5 millimeter, in a very fine grained matrix of microcrystalline quartz. In some of the quartz grains, outlines of subrounded cores are recognizable in thin section. These quartz grains were undoubtedly derived from the Dutch Creek Sandstone Member of the Grand Tower Limestone and the chert grains derived from chert beds in the underlying Clear Creek Chert. The fine grained quartz composing the matrix was also derived from the Clear Creek Chert, as were the scattered euhedral quartz crystals with calcite inclusions. Secondary silicification, in some instances filling interstices between quartz grains, has produced a hard siliceous rock. Root casts up to 3 millimeters in diameter and extending at least 11 cm are locally abundant. Some specimens of this sandy siltstone contain numerous casts of fragments of wood or plant stems 3 to 10 millimeters long.

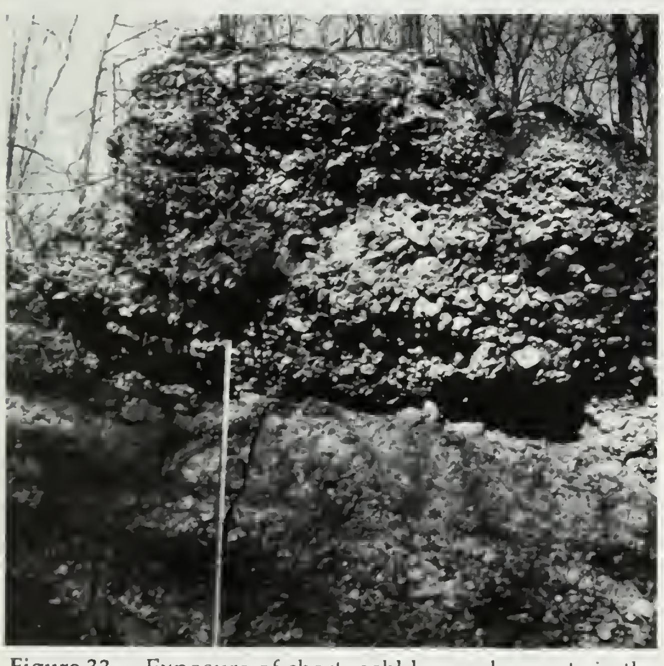


Figure 33 Exposure of chert–pebble conglomerate in the SE NE NE, Section 11, T14S, R2W, Alexander County. Rule is 1 meter long. Photo by J. M. Dexter, ISGS.

A concentration of float of the chert–pebble conglomerate cemented with hydrated iron oxide appears to occur near or at the base of the conglomerate where the conglomerate overlies the previously described exposure of Dutch Creek Sandstone. The concentration of hydrated iron oxide in the lower part of the chert–pebble conglomerate and the common occurrence of a weathering rind in the Dutch Creek Sandstone indicate downward movement of iron oxide in a weathering environment. The iron enrichment near or at the lower contact of the chert–pebble conglomerate is similar to exposures of the Little Bear Soil in Alexander and Pulaski County, Illinois (Pryor and Ross 1962). The Little Bear Soil was defined by Mellen (1937) as an iron-enriched residual soil that developed on Paleozoic rocks overlain by Cretaceous or Tertiary sediments. It occurs in Kentucky and south to central and eastern Alabama and western Georgia. Pulverulent silica and tripoli also occur in formations below the Little Bear Soil in areas where it is exposed in Alabama, Tennessee, and Mississippi (Mellen 1937).

The origin of the chert–pebble conglomerate seems reasonably clear. It unconformably overlies the Dutch Creek Sandstone Member of the Grand Tower Limestone and the Clear Creek Chert. Most chert clasts are probably from the Clear Creek Chert, and sand grains are probably from the Dutch Creek Sandstone. It is hypothesized that this conglomerate was deposited by streams developed on an erosion surface that formed mainly on the top of massive chert beds of the uppermost Clear Creek Chert. Poor sorting indicates a fluvial environment, but moderate rounding of chert pebbles indicates lengthy transport. The position of the chert gravel on ridge tops indicates that if the gravel was deposited on a broad erosion surface, it has been highly dissected, or if the gravel was deposited in valleys, erosion has inverted the topography. No direct field evidence indicates the age of the chert–pebble conglomerate. It is younger than the Dutch Creek Sandstone (Middle Devonian) because it overlies this unit and contains a few sandstone pebbles from the Dutch Creek Sandstone. Pryor and Ross (1962) interpreted the isolated chert gravels in southernmost Illinois as remnants of the Cretaceous Tuscaloosa Formation (Smith and Johnson 1887) found in Kentucky, Tennessee, and Alabama adjacent to and within the Mississippi Embayment.

Loess

All ridges and flat areas are covered with about 8 meters (26 ft) of loess, which is windblown silt and clay derived from glacial meltwater deposits in the Mississippi and Ohio River Valleys during the Wisconsinan glacial stage. In addition to capping the ridges, the loess has been washed down the steep slopes and deposited as colluvium. Pre-Wisconsinan loesses are not exposed in the study area, but they were probably present, intensely weathered, and then extensively eroded before deposition of the present Wisconsinan loess. No effort was made to map the extent of loess during this investigation of silica deposits.

Usually the contact between loess and bedrock is shown by a change in slope. The first bedrock float on the side of a loess-capped ridge is usually encountered where the slope steepens, often in an area of green moss. On some slopes piping has developed in the loess.

STRUCTURE

Devonian bedrock west of Elco is characterized by low-angle dipping beds and many high-angle faults, most with a displacement of less than 2 meters (7 ft). The major structure is the Harrison Creek Anticline (fig. 14b), which extends southeastward into the area from its northernmost extent near Bald Knob, 27 kilometers (17 mi) northwest of this area (J. Weller and Ekblaw 1940). West of Elco, the anticline is asymmetric and dips up to 10° on the east limb (plate 1, cross section B–B′). The crest is a broad area of essentially horizontal beds, which dip gently to the west on the west limb of the anticline outside the area mapped. The configuration of this structure is shown by the elevations of the contact between the Clear Creek Chert and the overlying Dutch Creek Sandstone Member of the Grand Tower Limestone (plate 1).

Along a northeast-trending ridge in the E 1/2, Section 10, T14S, R2W, the uppermost chert beds of the Clear Creek Chert are 40 to 60 feet (12–18 m) lower than they are on the flat-topped ridge to the southeast. The beds are also 80 to 100 feet (24–30 m) lower than they are on the ridge at Bass Hill (plate 1, cross section A–A′). The lower elevation of these chert beds along this ridge is best explained by a relatively shallow northeast-trending syncline superimposed on the broader anticline. The drainage pattern and surface geology do not show evidence of this area being a northeast-trending graben. A small monocline exposed at site 21 (appendix A and plate 1) trends N35°E, possibly parallel to the syncline axis.

Two major faults have been mapped in this part of Alexander County. The northwest-trending Delta Fault lies 1 kilometer (0.6 mi) west of the area mapped here (fig. 14b). Movement along this fault displaced the Clear Creek Chert downward on the northeast to juxtapose it against Grassy Knob Chert to the southwest (plate 1, *in* J. Weller and Ekblaw 1940).

East of this fault, another fault follows Sandy Creek and trends N30°E (Levine 1973). The northwest side is downthrown, and the Clear Creek Chert is exposed on both sides. Levine postulated a fault here because of the straight pattern of Sandy Creek for 4.5 kilometers (2.8 mi) and changes in the dip of the bedrock from south or southwest on the west side of the valley to northeast on the east side. There is no continuation of this valley or any topographic break in slope indicative of a fault along the trend of Sandy Creek to the northeast. In the NW, Section 15, T14S, R2W, the elevation of the upper massive chert beds in the Clear Creek Chert on the west side of the Sandy Creek Valley is approximately the same as the elevation of these beds on the east side of the valley. Even if there is a fault in this valley, it has not caused significant stratigraphic displacement. West of the Lone Star mine, the uppermost chert beds are at an elevation of 700 feet (213 m). Across the valley to the east in the E 1/2, Section 15, T14S, R2W, they are at an elevation of 720 feet (220 m).

The entire area is intersected by many high-angle faults that have displacements of less than 2 meters (7 ft), as judged from the abundance of faults exposed in mines. A plot of the strike of 16 faults shows two maxima, west of north and northeast (fig. 34). Although most of these faults were observed within 1 kilometer (0.6 mi) of the possible fault in Sandy Creek, its trend of N30°E is not a dominant orientation of the exposed faults. An example of a small normal fault exposed along Sexton Creek is shown in figure 35. Other faults, also with small displacements, are well

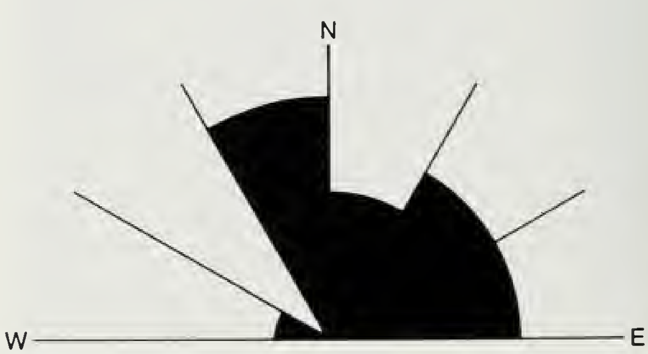


Figure 34 Rose diagram shows strike of 16 high-angle faults in the area west of Elco.

exposed in the highwall of the north pit of the Lone Star mine (fig. 16, 17).

Although most of the faults are high-angle faults with either reverse or normal movement, other faults indicate lateral movement, as shown at the portal of the mine at site 72 (appendix A and plate 1; fig. 36). The cause of these numerous faults is probably not tectonic. More likely, they occurred in response to collapse caused by a decrease in volume in the Clear Creek Chert caused by solution of carbonates.

The irregular nature of some of these faults is suggestive of a subsidence phenomenon. Furthermore, it does not seem reasonable to assume that reduction in volume occurred so uniformly over this area that there was no cause for adjustment. Although there are no major faults within the mapped area, the few possible determinations of the attitude of bedding show fairly abrupt changes in dip over short distances, an indication that there are probably many unexposed faults. Given these conditions and the general lack of correlatable beds in the Clear Creek Chert, it becomes difficult, if not impossible, to project the position of a minable microcrystalline silica interval from one mine or exposure to another.

FEATURES INDICATIVE OF SOLUTION IN THE CLEAR CREEK CHERT

Exposures of chert beds in the Clear Creek Chert show features indicative of solution along bedding surfaces. These features can be characterized as follows:

- very irregular jagged surface that lies parallel to bedding and has open solution cavities as much as 3 cm high, usually coated with hydrated iron oxide (fig. 37). This feature may continue along the bedding for 3 or 4 meters (10–13 ft). The concentration of hydrated iron oxide along this surface and the lack of hydrated iron oxide in the surrounding chert indicate a local source of iron, perhaps pyrite, along this bedding plane.
- stylolitic surfaces that range from fluted stylolites more than 2 cm high to a pinnacled surface with less than 1 cm relief (fig. 38). In some cases, the "worm-eaten" chert shows the beginning of stylolitic development along bedding surfaces. Stylolitic surfaces are lightly coated with hydrated iron oxide.
- hummocky surface with less than 2 cm of relief and typically a white porous layer 1 millimeter or less thick. An SEM micrograph of such a surface shows no evidence of solution of quartz crystals (fig. 28e).

The first impression in examining these features is that they resulted from the solution of chert as groundwater moved along bedding planes. Stylolites have been described from the Caballos Novaculite of west Texas, where Cox and Whitford-Stark (1987) concluded, on the basis of textural relationships, that stylolites developed after the formation of this novaculite.

SEM examination of specimens of microcrystalline silica and chert from the Clear Creek Chert shows, however, no evidence of solution. There is no pitting of

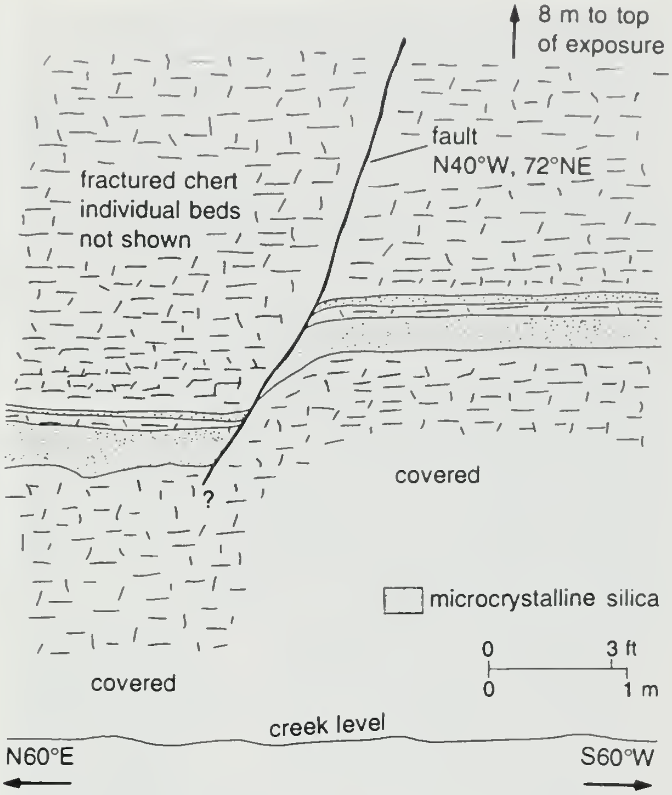


Figure 35 Sketch of a small fault in the Clear Creek Chert along the east side of Sexton Creek in the NE SW, Section 16, T14S, R2W, Alexander County.

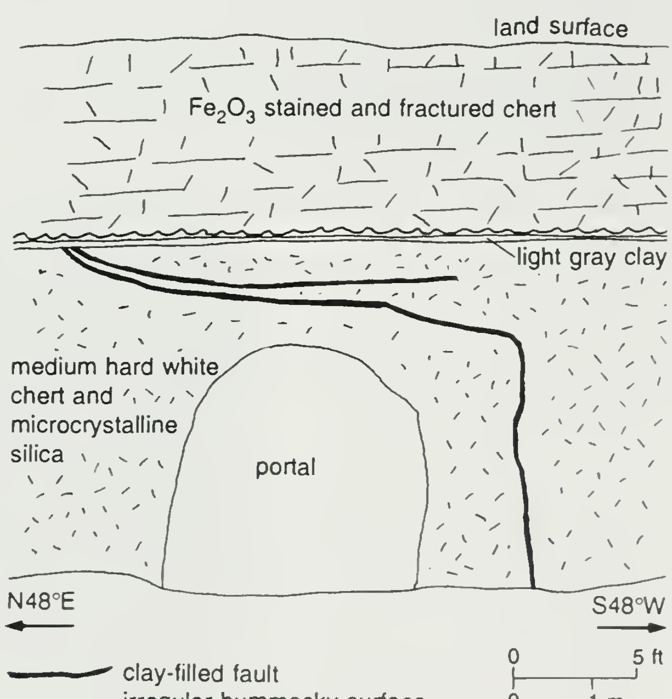


Figure 36 Clay-filled faults at the portal of an inactive mine in the Clear Creek Chert at site 72 (appendix A and plate 1).

Figure 37 Exposure of chert beds in the Clear Creek Chert showing evidence of solution along bedding surfaces. The exposure is on the east side of the north pit at the Lone Star mine (site 65, appendix A and plate 1). Rule is 1 meter long. Photo by J. M. Dexter, ISGS.

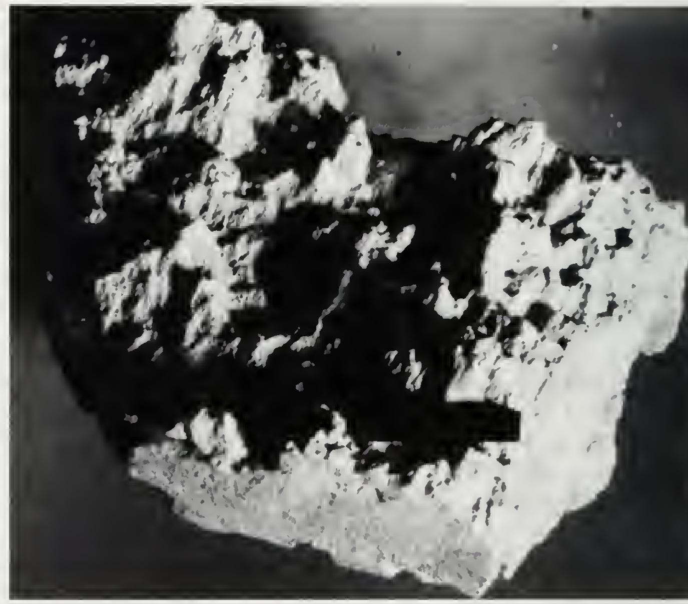


Figure 38 Stylolitic surface in hard chert from the Clear Creek Chert exposed near the floor of the north pit of the Lone Star mine (site 65, appendix A and plate 1). Scale bar is 2 centimeters (0.8 in.). Photo by J. M. Dexter, ISGS.

the quartz crystals and no rounding of terminations of quartz crystals, as has been cited in evidence of solution of quartz in the Arkansas tripoli (Keller 1978). If solution of quartz from the Clear Creek Chert had been sufficient to form stylolites and related features, the evidence would certainly be apparent in the examination of samples by SEM. Lamar (1953) discussed the origin of stylolites that he had observed in the Grassy Knob Chert and concluded that they were formed in limestone beds and then preserved when silica replaced limestone and formed the chert beds. The same origin is suggested for the stylolites and related solution features described in the Clear Creek Chert.

IRON STAINING OF CLEAR CREEK CHERT

The most noticeable feature in all exposures of Clear Creek chert beds is the reddish brown to yellowish brown coloration caused by hematite and other hydrated iron oxides (especially on fracture surfaces and bedding planes). Were it not for selective staining of the beds of harder chert in exposures in the Lone Star and Jason mines, recognition and tracing of chert beds would be very difficult (figs. 17, 18). The coloration caused by iron oxide should not be confused with the light brown coating of silt and clay washed down from overlying loess onto pit walls. The distribution of iron oxide in deposits of microcrystalline silica is of major economic importance because iron-stained material is unsuitable for most markets.

Usually the upper several meters of rock exposed at the portals of underground silica mines is heavily stained with iron oxide. The break between the iron-stained rock and white rock is sharp and parallel to bedding. In some places, unstained beds occur within the strongly stained beds (fig. 39). In many exposures, iron-stained beds also occur within the white beds below the main interval of iron staining. The abundance of these iron-stained beds diminishes with depth. Levine (1973, p. 28) made a similar observation after examining many underground mines. He concluded that "generally, the deeper into a ridge one proceeds, the less colored the material. The occurrence of color, however, is extremely unpredictable and there are many exceptions to the above observations." Lamar (1953) also observed that the whitest deposits of novaculite are found low in ridges and hills below the zone of pronounced iron staining.

Below this near-surface zone of intense iron staining, the iron staining is sporadic and lithologically controlled in many instances. There is a pronounced correlation in some exposures between intensity of coloration and permeability of the beds. Figures 40 and 41 show the distribution of iron oxide, intensity of staining, and lithologies in an exposure of the Clear Creek Chert. The permeable, highly fractured, hard chert beds are the most intensely stained. The porous, but less permeable, microcrystalline silica beds are white. A possible explanation is that as iron-bearing water percolates down from the surface, the relatively large

Figure 39 Portal of an inactive silica mine at site 100 (appendix A and figure 5). The photo shows the abrupt change in the amount of discoloration caused by iron oxide. Note the thin unstained bed, as indicated by the arrow, in the upper part of exposure. Photo By J. M. Masters, ISGS.

voids along fractures in the chert beds are alternately saturated and drained. This process provides an oxidizing environment that favors precipitation of iron oxides. In contrast, the microcrystalline beds, because of lower permeability, may remain saturated with water during both wet and dry intervals. The saturation maintains a reducing environment in which iron oxides are not precipitated.

Although typically unstained, some of the thicker beds of microcrystalline silica contain local areas, usually conformable to bedding or near the surface, that are stained. No relationship was observed between the conformable clay layers and iron staining to indicate that these layers acted as barriers to iron transport.

The high-angle faults, such as those exposed in the wall at the Lone Star mine, show no indication of having controlled iron oxide precipitation, but they typically displace the alternating white and reddish brown beds (fig. 17). Levine (1973) offered an example, however, from an underground mine where a clay-filled fracture had clearly controlled iron staining. The microcrystalline silica on one side of the fracture was heavily iron stained, whereas the silica on the other side was not stained to the same extent.

The source of the iron oxides and most of the reddish brown clay near the surface in the Clear Creek Chert must be predominantly external to this formation. The local concentration of hematite and hydrated iron oxides in the overlying chert–pebble conglomerate may be related to iron staining in the Clear Creek Chert. Also, the occurrence of concretionary ferruginous material in float at the contact between the conglomerate and uppermost chert beds indicates the availability of iron. This iron oxide must have been deposited during the interval encompassing the development of an erosion surface on the top of the chert beds and deposition of the conglomerate. If hematite

Figure 40 Exposure of the Clear Creek Chert described in detail in figure 41 (site 15, appendix A and plate 1). Black line shows the position of the 3 meter (9.8 ft) described section. Disruption of beds to the right is from collapse caused by volume decrease resulting from solution of carbonates from underlying beds. Photo by J. M. Dexter, ISGS.

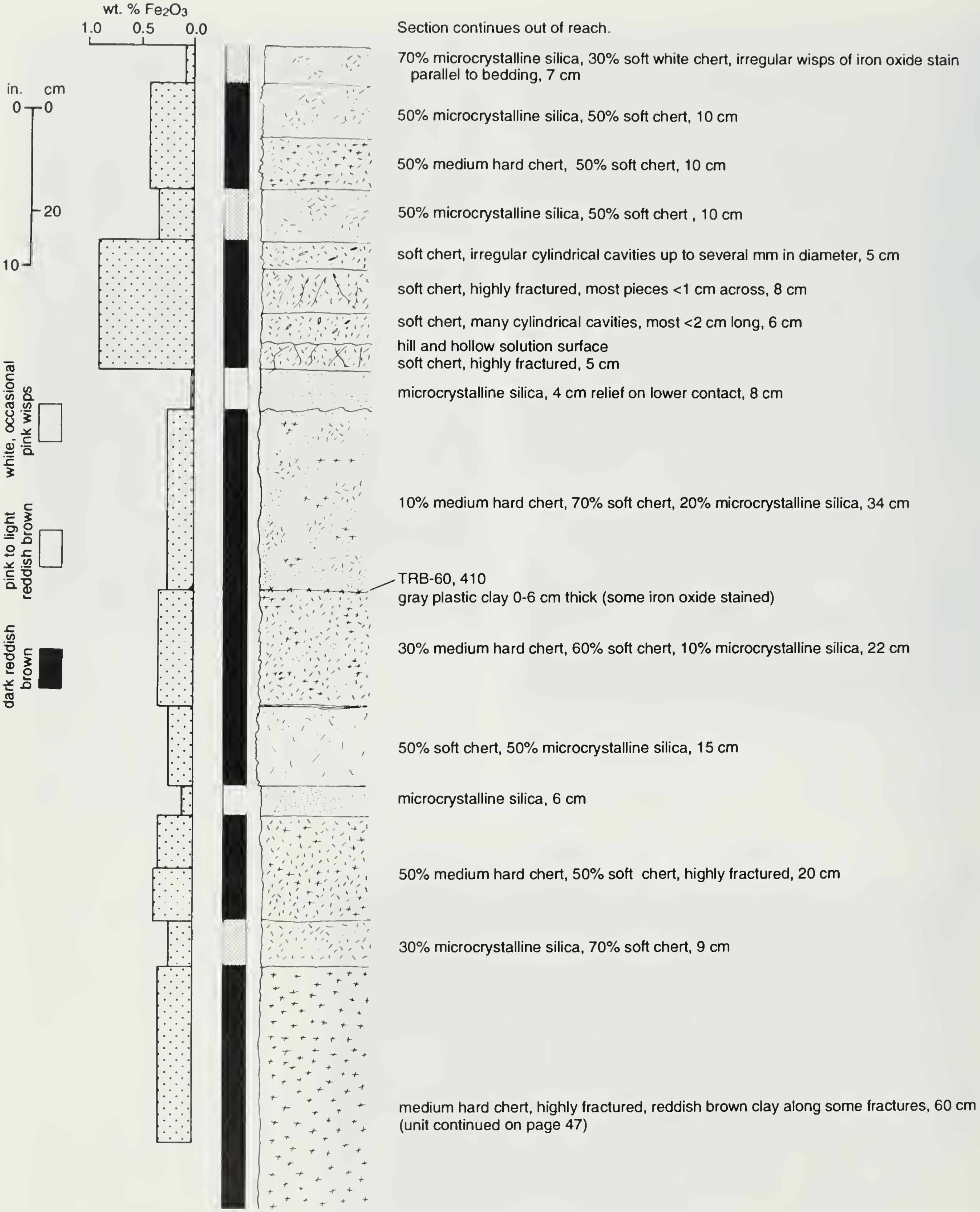


Figure 41 Description of Clear Creek Chert exposed in the cut shown in figure 40 (site 15, appendix A and plate 1). The Fe_2O_3 analyses were performed by x-ray fluorescence and reported on a dry basis (R. R. Frost, Analytical Chemistry Section, ISGS).

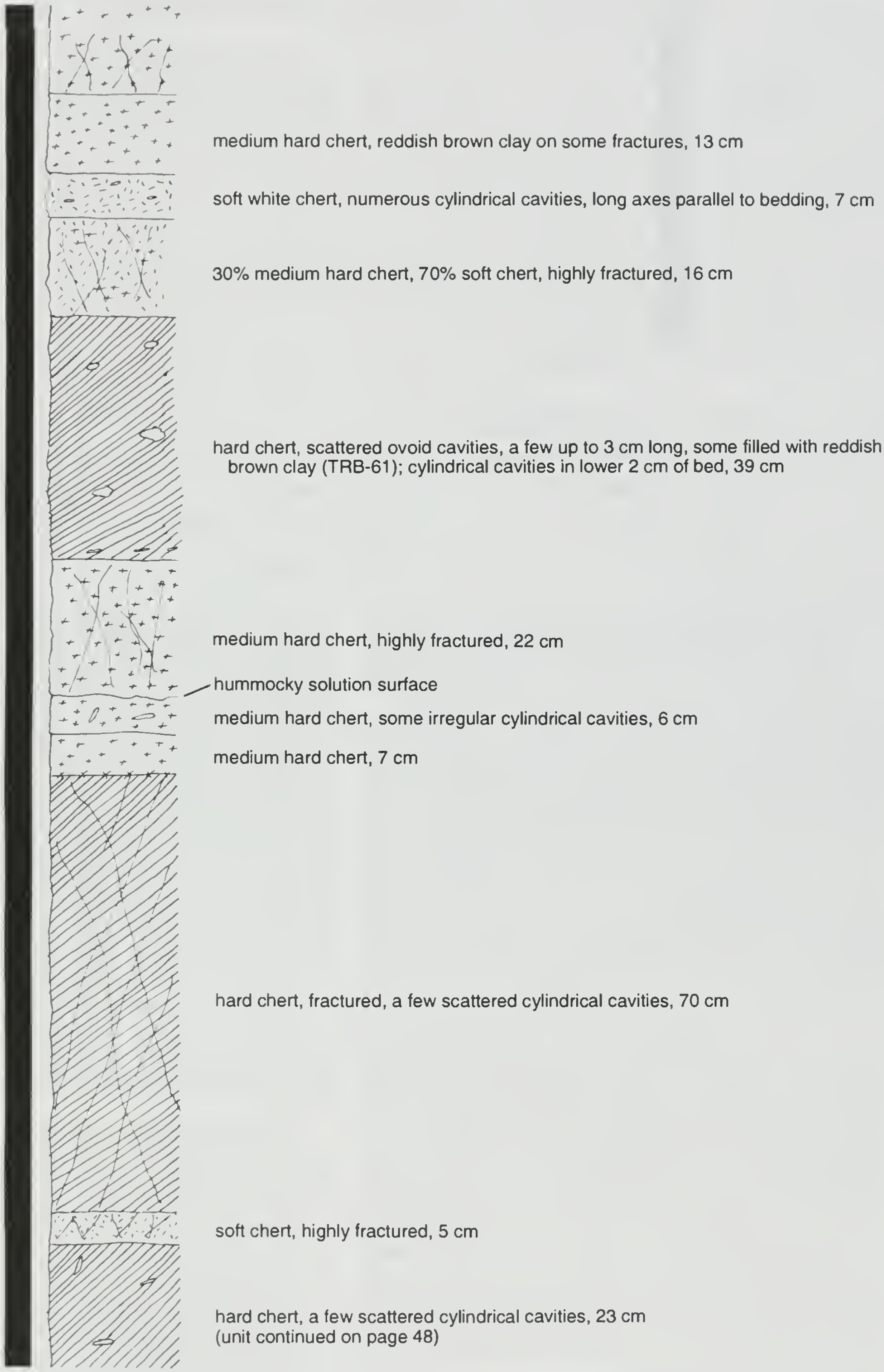


Figure 41 *(continued)*

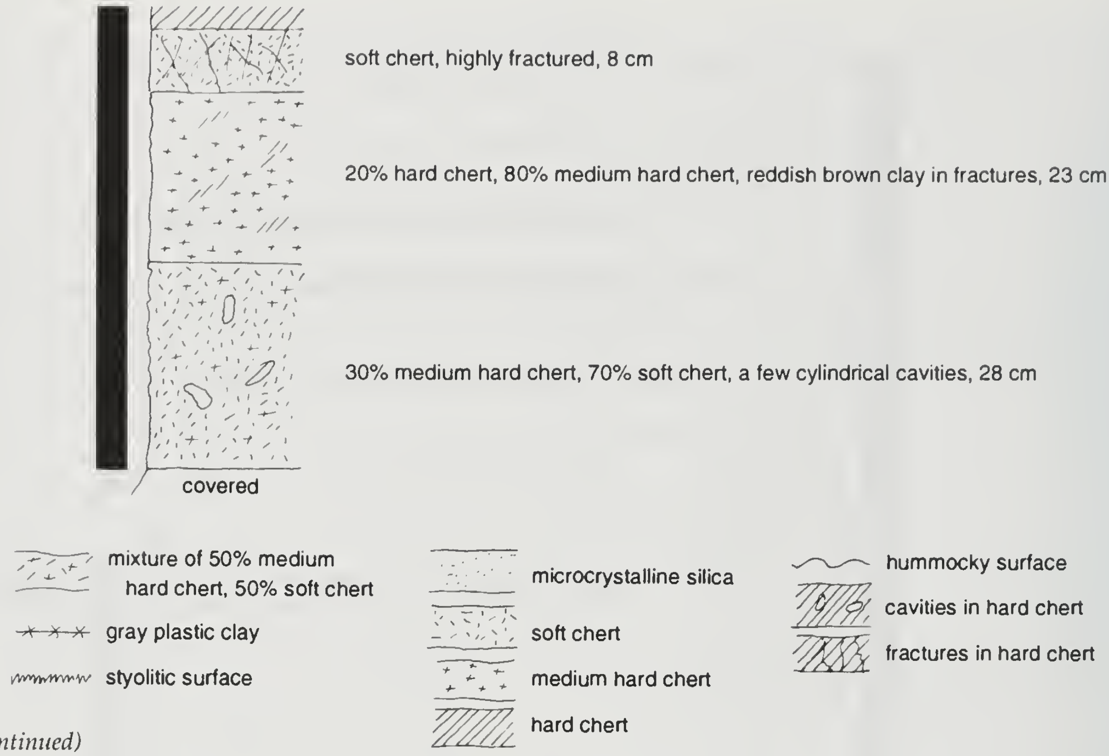


Figure 41 *(continued)*

and hydrated iron oxides were deposited at this contact, soil-forming processes could have remobilized and transported them downward, reprecipitating iron oxides on fracture surfaces in the underlying beds.

The increase in hematite, hydrated iron oxide, and reddish brown clay in the Clear Creek Chert close to the present surface indicates that these materials moved downward into the cherty residuum and bedrock from a surface relatively close to the present erosion surface. The nature of the occurrence of these materials in the cherty residuum and in fractures and cavities in chert beds near the surface is typical of the Bt soil zone, a zone of clay enrichment, in mature soils. The soils in the Wisconsinan loess overlying the Clear Creek today (fig. 15) are not sufficiently developed to account for much of the hydrated iron oxide and reddish brown clay in the chert. Highly mature paleosols have been seen, however, in pre-Wisconsinan loesses elsewhere in southernmost Illinois. These paleosols have Bt zones developed to the degree seen in the caprock chert in the Lone Star south pit (L. R. Follmer, ISGS, personal communication, 1991). It thus appears likely that these deeply weathered pre-Wisconsinan loesses were present and that they were the source of at least a significant part of the hematite, hydrated iron oxide, and reddish brown clay in the caprock chert. A period of erosion probably preceded the deposition of Wisconsinan loess in much of southernmost Illinois. The older loesses and at least some residuum in most upland areas were removed, and only their compound Bt zones were left in the chert as evidence of their presence.

Small masses of hydrated iron oxides a few millimeters across occur rarely in the white chert and microcrystalline silica. Chemical analysis of one of these masses showed, in addition to more than 37% Fe, small concentrations of Cu, Zn, and As. This composition of hematite and hydrated iron oxides in an otherwise white rock indicates that the original mineral was pyrite. Samples, particularly of hard chert, were examined carefully for an iron-bearing sulfide, but none was found. The abundant cubic molds in some chert and microcrystalline silica are not iron stained, but the molds could indicate the prior occurrence of pyrite.

FLUID INCLUSIONS IN QUARTZ CRYSTALS

Microthermometric determinations were made on a small number of fluid inclusions in euhedral quartz crystals in an effort to obtain temperature and salinity information for the conditions of crystal growth. The clearly preliminary results are presented here to identify an interesting and potentially productive line of research.

Euhedral quartz crystals were separated from a sample of a clay layer 1 to 2 centimeters (0.4–0.8 in.) thick. The clay was from the Clear Creek Chert exposed in the cut shown and described in figures 40 and 41. The sample was dispersed using a Waring blender, then the 44 to 90 μm fraction was separated by wet sieving. This fraction, which contains the greatest concentration of euhedral quartz crystals, was mounted between two cover slips for microscopic examination and microthermometric determinations. Araldite (Ciba–Geigy) rapid setting epoxy was used as the mounting medium. Mounts were made by mixing a small sample of the separated quartz crystals with the epoxy on a microscope cover slip. The mixture was then covered with another cover slip, and as many air bubbles as possible were squeezed out.

Fluid inclusions containing a vapor bubble were recognized in quartz crystals separated from several clay layers. Because they are most abundant in the clay layer from the locality described above, however, all microthermometric determinations were made on inclusions in quartz crystals from this layer. Similar euhedral quartz crystals containing fluid inclusions occur in the uppermost massive chert beds and microcrystalline silica deposits in the Clear Creek Chert. Euhedral quartz crystals recovered from limestone in the Clear Creek Chert encountered in the Hileman no. 1 well (table 2) also contain fluid inclusions. In addition to euhedral quartz crystals, separates from clay layers contain fragments of microcrystalline quartz. The petrography of these euhedral quartz crystals is described in the section, "Clay Layers."

Fluid inclusions in these quartz crystals show large variation in the relative size of the vapor bubble. Smaller inclusions are 5 to 10 µm in maximum dimension, and the vapor is estimated to constitute less than 10% of the volume of the cavity. The vapor phase in larger inclusions occupies more than 50% of the volume. In addition to the liquid and vapor-filled inclusions, many larger (10–20 µm) irregular inclusions are concentrated in the outer margin of the quartz crystals and completely filled with a vapor. It is likely that these have been opened and are now filled with air. Inclusions containing both vapor and liquid are rare. Typically, the cavities now filled with liquid and vapor are subrounded; none was found with a negative crystal morphology. No evidence of "necking down" or "necking off" of fluid inclusions was recognized. All evidence indicates that they are primary in the sense that they were formed by trapping fluids during the growth of the outer zone of these crystals.

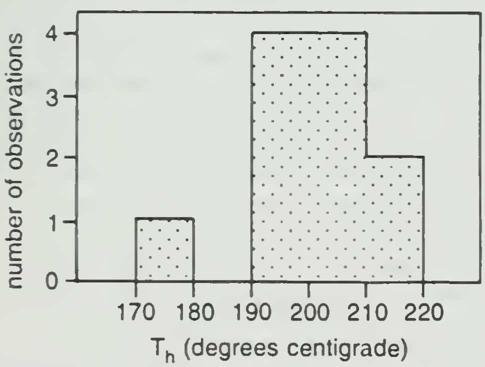


Figure 42 Histogram of homogenization temperatures (T_h) determined on fluid inclusions in euhedral quartz crystals separated from a clay layer in the Clear Creek Chert (TRB-60). (See table 5 for determinations and figure 41 for stratigraphic position of the bed.)

The variable vapor to liquid ratio observed in these inclusions can be explained by either leaking or trapping of both gas and liquid from a heterogeneous system (Roedder 1984, p. 256). The presence of healed fractures, along which leakage occurred since trapping, cannot be ruled out. No microfractures were recognized during microscopic examination of these quartz crystals; however, microfractures must have been present to permit the dissolution of dolomite, as shown by the rare rhombohedral cavities. Also, the cubic cavities required the dissolution of some unknown mineral, probably fluorite or pyrite. Although the cubic mineral and dolomite were dissolved from these crystals, the abundant calcite grains were not. This indicates that dissolution occurred before calcite growth, which preceded or was contemporaneous with quartz overgrowth.

The observed range in vapor to liquid ratios, and thus the variation in temperature of homogenization, is likely to have been caused by the growth of these quartz crystals in a heterogeneous system. If the quartz crystal trapped different mixtures of liquid and vapor phases during its growth, a range of vapor–liquid ratios would be preserved upon cooling. This process would result in a large range of homogenization temperatures. Trapping of excess vapor would result in a higher temperature of homogenization, as compared with an inclusion that trapped liquid only at the temperature of formation.

Temperatures of homogenization of fluid inclusions were determined using a USGS-type, gas flow, heating/freezing system in the Geology Department of Southern Illinois University at Carbondale. Salinities were estimated by using this same apparatus to measure freezing-point depression. The results of these preliminary determinations are given in table 5 and shown graphically in figure 42. Multiple determinations on individual inclusions showed a variability of less than 1°C, usually within several tenths of 1°. These determinations were made on small (2–6 µm) inclusions that had a fairly constant liquid–vapor ratio and occur in arrays within individual crystals.

Although fluid inclusions are relatively abundant in these crystals, those that meet the above criteria are rare. More than 7,000 individual quartz crystals were examined with the petrographic microscope to find the few crystals on which the reported determinations were made. In addition to the determinations of freezing-point depression reported here, five other determinations were made on inclusions with large vapor bubbles for which no freezing-point depression was detected. Two tentative conclusions can be drawn from these preliminary data: the growth of the outer part of these quartz crystals occurred at low salinity and at temperatures clearly well above 100°C, perhaps about 200°C.

A comparison between these results and results from studies of the Illinois Basin and surrounding areas shows interesting differences. Cobb (1981), in his study on the geology and geochemistry of sphalerite in coal from the Illinois Basin, showed a range in homogenization temperature from 88° to 104°C (specimens from six localities). Direct analysis of water from fluid inclusions in these specimens showed a range in salinity (mainly NaCl) from 11.1 to 21.3 weight percent (Cobb 1981). Slightly lower temperatures and similar salinities were reported by Shaffer (1981) for inclusions in sphalerite from a Silurian reef in Carroll County, Indiana. Most reported homogenization temperatures were between 80° and 88°C, and salinity ranged from 15.5% to 22%.

Homogenization temperatures of 85°C for calcite and 109°C for dolomite from the Burlington Limestone (mid-Mississippian) indicate temperatures of diagenesis for this formation on the west margin of the Illinois Basin (Smith et al. 1984). Mean bulk salinities are 19.4 weight percent for the inclusions in calcite and 20.0 weight percent for those in dolomite.

Detailed studies have been conducted of the fluid inclusions in fluorite, quartz, sphalerite, calcite, and barite from the Cave-in-Rock fluorspar district in Illinois (Richardson and Pinckney 1984, Richardson et al. 1988). The studies report 145° ± 5°C for main stage and a generally lower temperature of 125° ± 25°C for late stage mineralization. The main stage fluids were more saline (19 ± 1 equivalent weight percent NaCl) than the late stage fluids (1–9 equivalent weight percent NaCl). Considerably higher homogenization temperatures (160.1–266.5°C) were observed for milky growth bands in quartz crystals from this same district (Richardson and Pinckney 1984). Salinities of inclusions within these growth bands range between 20 and 20.5 equivalent weight percent NaCl.

The preliminary data reported here indicate that fluids responsible for the deposition of the outer part of the quartz crystals from the Clear Creek Chert must have been hotter and less saline than those typically trapped in minerals of the Illinois Basin. These data also indicate that this phase of quartz crystallization falls within the much wider range of temperature and salinity conditions reported for the mineralization of the Cave-in-Rock fluorspar district. However, no genetic relationship is implied.

FORMATION OF MICROCRYSTALLINE SILICA DEPOSITS

Understanding the origin of microcrystalline silica deposits is important for the evaluation of this mineral resource. Microcrystalline silica is an unusual rock that consists of very small (some <1 μm long) euhedral quartz crystals (fig. 3). In addition, deposits are confined to a relatively small area of unusually siliceous Lower Devonian formations. The geometries of microcrystalline silica deposits depend on the extent to which their formation was controlled by stratigraphy, structure, or a source of heat for hydrothermal fluids. J. Weller (1944) stated that although time and cause of alteration are unknown, silicification or a similar process affected the Lower Devonian rocks in this area.

Information on the Clear Creek Chert outside of the study area west of Elco is from J. Weller (1944) and J. Weller and Ekblaw (1940). The bedrock geologic map produced by Weller and Ekblaw encompasses all known microcrystalline silica deposits from the Olive Branch deposits north to the deposits east of Wolf Lake in Union County (fig. 5).

The most extensive bedrock formation in this area is the Clear Creek Chert, the host for most microcrystalline silica deposits. Although most of the following discussion on silicification and leaching of carbonate is concerned with the Clear Creek Chert, it also applies to the underlying Backbone Limestone, Grassy Knob Chert, Bailey Limestone, and also perhaps to the early Mississippian Fort Payne Chert.

SILICIFICATION

The most obvious lateral change in the Clear Creek Chert is the absence of limestone in the area of silica production. South of Illinois state highway 146, extending west from Jonesboro, this formation consists of gradations from chert to microcrystalline silica with thin clay beds. North of the highway, this formation consists mainly of novaculitic chert interbedded with very siliceous limestone (J. Weller and Ekblaw 1940).

For instance, the uppermost 4.3 meters (14 ft) of Clear Creek Chert exposed below the Dutch Creek Sandstone Member of the Grand Tower Limestone in the SE NW NW, Section 27, T11S, R2W (11 km [7 mi] northwest of Jonesboro), consists of 3.1 meters (10.2 ft) of limestone with two thin chert beds overlying 1 meter (3.3 ft) of light gray chert (Allen 1985). A water well drilled in the SW SE NW of this same section encountered 200 feet (61 m) of limestone below 10 feet (3 m) of sandstone, which is probably the Dutch Creek Sandstone. This information is from the drilling log; no samples from this well were available for study. The driller did not record encountering the hard, massive chert beds found at the top of the Clear Creek Chert both to the south in the Elco district and northwest in the Wolf Lake district. This raises the possibility that these chert beds are only locally present.

Another example of siliceous limestone in the Clear Creek Chert is the previously described Hileman no. 1 well in the NW SE SW, Section 21, T13S, R1W, 10 kilometers (6 mi) southeast of Anna (table 2). Using well samples as the basis of his description, Rogers (1972) described this formation as alternating layers of fine grained, finely siliceous or dolomitic limestone, calcareous dolomite, and bedded dolomitic chert.

Obviously, the Clear Creek Chert is lithologically different inside the silica districts than it is outside these districts. The difference has two possible explanations:

(1) a fairly abrupt facies change occurs, or (2) carbonates were removed and silica introduced.

J. Weller (1944) and Lamar (1953) presented the following evidence for local silicification of the Clear Creek Chert, rather than a facies change. Stylolites in the Clear Creek Chert and Grassy Knob Chert developed in limestone and were subsequently replaced by silica. Lamar presented convincing evidence that stylolites in the Grassy Knob Chert (some at a limestone–chert interface where the limestone is above the stylolite, and others with the chert above the stylolite) formed in a precursor limestone and were preserved during silicification. The same mechanism is thought to be responsible for the preservation of stylolitic surfaces between chert beds in the Clear Creek Chert in the study area.

J. Weller (1944) observed that a similar fossil assemblage occurs in the uppermost limestone beds of the Clear Creek Chert and stratigraphically equivalent chert beds, and thus indicates a similar sedimentary environment. Some fossils in the limestone beds have been silicified, and those in the chert beds are preserved as molds and casts. Weller thought it unlikely that organisms that secrete calcareous shells would live in an environment in which silica was deposited to the almost, if not total, exclusion of carbonate. This evidence together with what appears to be a restricted lateral extent of these uppermost chert beds is suggestive of their formation by silicification.

Lamar (1953) provided further evidence of the addition of silica to the Grassy Knob Chert. The massive chert beds in the middle part of this formation, as exposed west of Tamms, are composed of chert breccia in a microcrystalline silica matrix. Lamar noted that some rounded quartz grains in the matrix have quartz overgrowths and the texture of this rock is that of a silicified limestone breccia.

Evidence of the nature of the initial sedimentary rocks must first be considered when considering the events leading to the formation of the microcrystalline silica deposits. Allen (1985) conducted a detailed study of the paleontology and petrology of the Clear Creek Chert. He concluded that this formation was deposited in a broad basin in which the water was generally oxygenated and of normal salinity. The water was probably between tens of meters and 100 meters deep. Uniform sedimentation over a wide area would be characteristic of this stable-shelf environment in which lime mud, abraded echinoderm fragments, and some calcareous megafossils (such as brachiopods, echinoderms, and tentaculids) were deposited. Radiolarians and sponge spicules were a source of silica in the sediment. Allen considered rivers draining into the Devonian sea from the surrounding area to have carried dissolved silica into this basin. During the initial stages of diagenesis, some calcite was replaced by silica gel, according to Allen's interpretation, which further indicated that carbonate was replaced by silica during two periods: one early in diagenesis preceding dolomitization, and another later during an epigenetic phase.

A study of hydrogen and oxygen isotopic ratios of cherts included analysis of a sample of microcrystalline silica from the Clear Creek Chert and a sample of chert from the Bailey Limestone (Knauth and Epstein 1976). The specimen of microcrystalline silica was collected from an inactive underground mine west of Elco in the SE, Section 10, T14S, R2W, and the sample of chert from the Bailey Limestone was collected from the roadcut in the NE SW SE, Section 15, T15S, R3W, southeast of Thebes (Knauth 1973). The specimen of microcrystalline silica from the Clear Creek Chert has a $\delta^{18}O$ value of 32.0 and δD of –56, and chert from the Bailey Limestone has a $\delta^{18}O$ value of 30.1 and δD of –37. Knauth and Epstein plotted δD versus $\delta^{18}O$. They found that the Clear Creek Chert and Bailey Limestone samples plot within the field defined by upper Paleozoic cherts and along a line representing the assumed isotopic compositions of quartz in equilibrium with ocean water. Temperature of crystallization of chert estimated from these isotopic ratios is 22°C for the Clear Creek Chert and 33°C for chert from the Bailey Limestone.

These data substantiate Allen's hypothesis that silica was deposited early in the diagenetic evolution of these rocks and was in isotopic equilibrium with reasonable temperatures for sea water. Biggs (1957), in his study of chert nodules from Paleozoic formations in Illinois, included specimens from the Bailey Limestone and Clear Creek Chert; he concluded that these nodules formed during diagenesis from the accretion of quartz that had been syngenetically deposited.

There is a discrepancy between the temperatures indicated by these isotopic ratios and preliminary determinations from fluid inclusions in quartz overgrowths presented in this report (table 5). Further investigation using both methods may provide an estimate of the relative importance of diagenetic versus epigenetic processes.

DISTRIBUTION AND LEACHING OF CARBONATES

Removal of carbonates by leaching was a necessary step in the formation of commercial deposits of microcrystalline silica. Figure 43 shows the inferred elevation of the surface above which all carbonate has been leached from the bedrock. For comparison, figure 44 shows the distribution of silica mines and prospects. Cuttings from five wells were examined for the presence of carbonates (table 6) and, together with the location of outcrops containing limestone, form the basis for the generalized map of figure 43. Although control points for this surface are few, it is clear that the area of deepest leaching of carbonate is centered west of Elco where there are many microcrystalline silica prospects and mines. In the Olive Branch area to

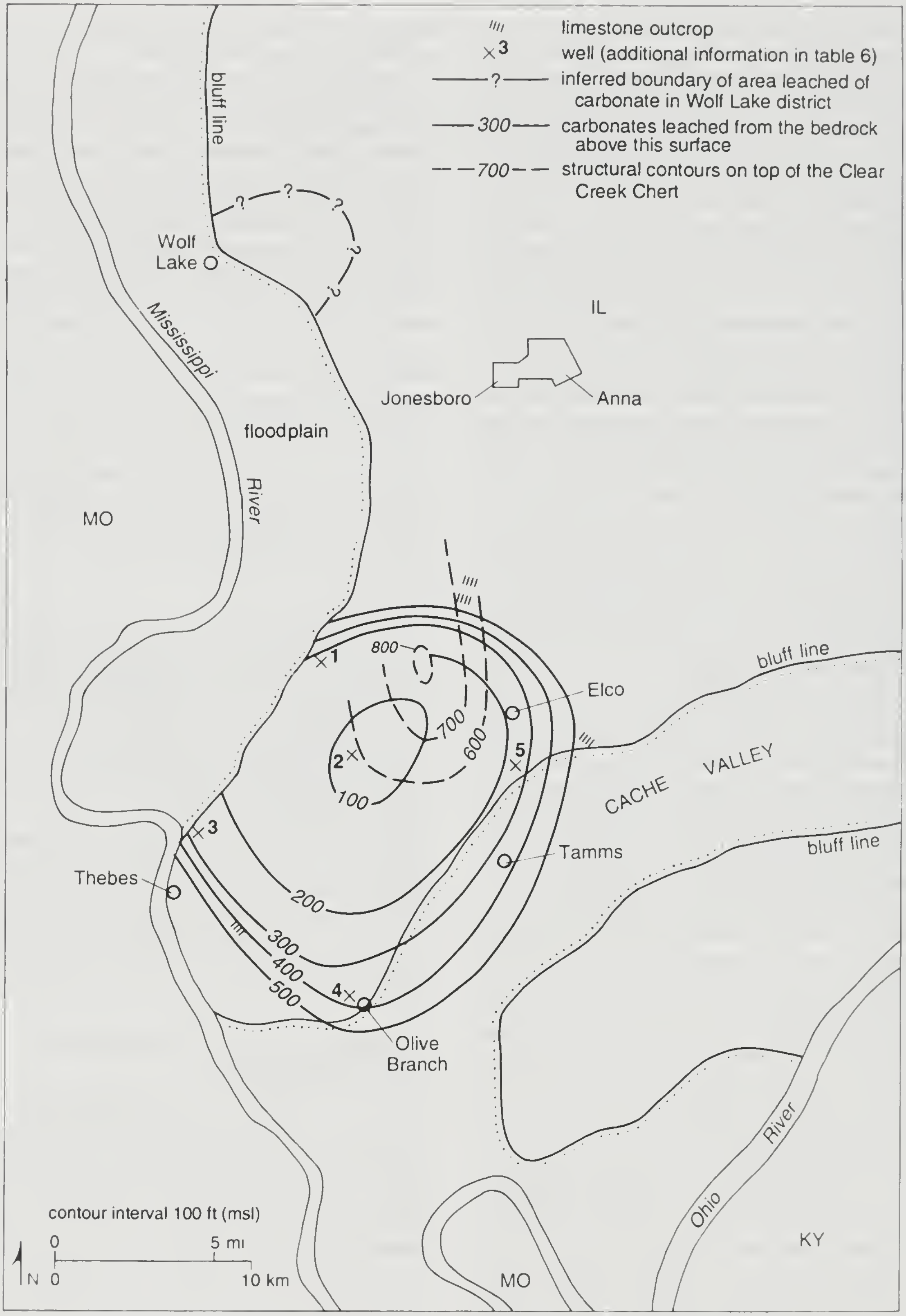


Figure 43 The top of the Clear Creek Chert in relation to the elevation (msl) of the first occurrence of carbonates in the bedrock. Location of the limestone outcrop southeast of Elco is from S. Weller and Krey (1939), and exposures northwest of Elco are from J. Weller and Ekblaw (1940). Inferred boundary of the carbonate-leached area is based on J. Weller and Ekblaw (1940) and Joseph A. Devera (ISGS, personal communication 1990).

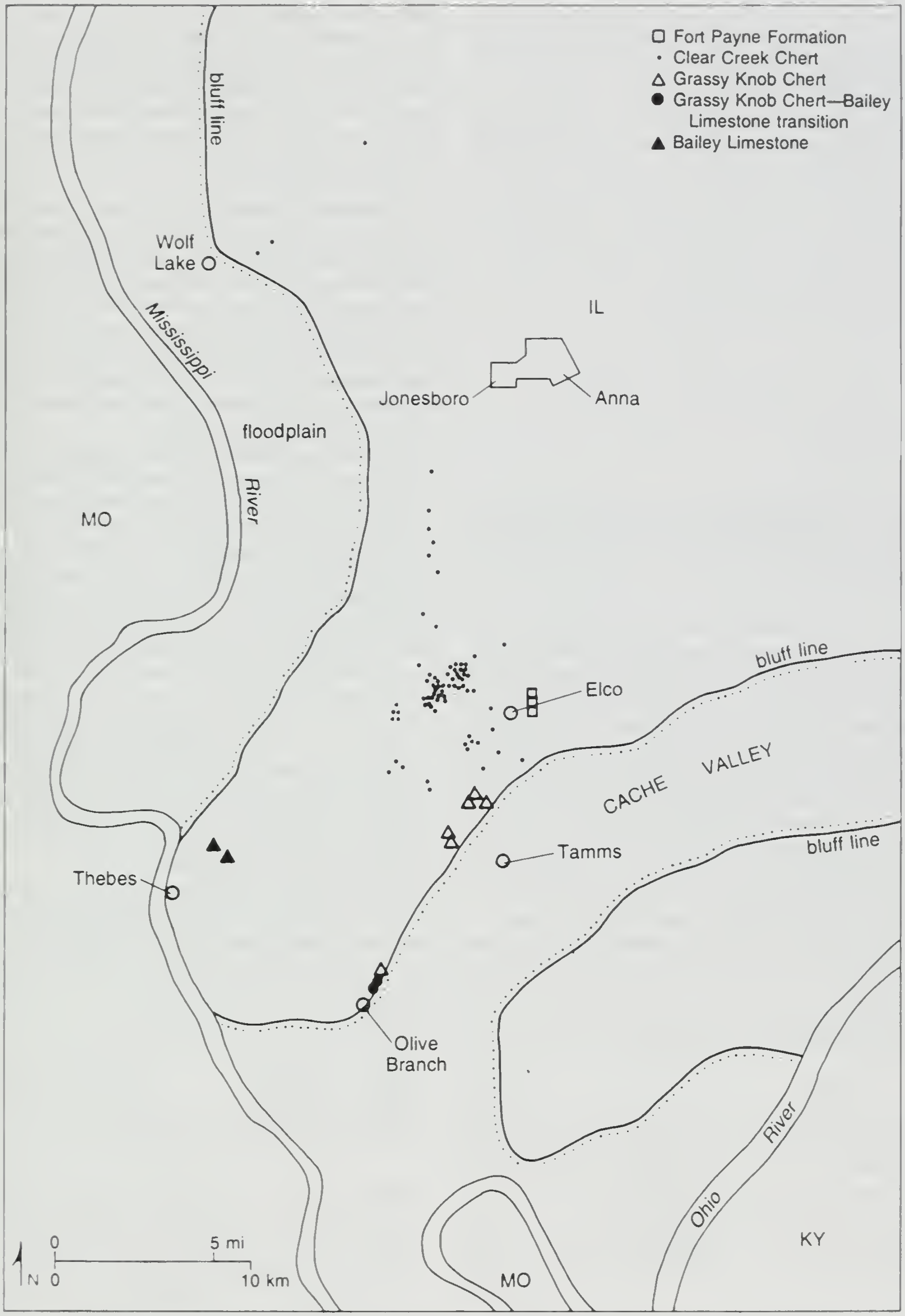


Figure 44 Rock formations exposed in silica mines and prospects in southernmost Illinois.

Table 5 Microthermometric determinations of fluid inclusions in euhedral quartz crystals separated from sample TRB-60, a clay layer in the Clear Creek Chert (see figs. 40 and 41 for location information).

Crystal	T_h (°C)	T_m(°C)	Equivalent wt % NaCl
A	206	−0.8	1.4
A	214	−0.7	1.2
A	201	−1.7 ± 0.5	2.9
A	196	−0.7	1.2
A	193		
B	202		
C	176		
C	192		
E	194		
F	202		
F	217		

T_h = temperature of homogenization; T_m = temperature of melting of ice. Equivalent wt % NaCl estimated from T_m using Roedder (1984, table 8–2). All crystals listed contained other fluid inclusions too small for determinations.

the south, a water well indicated a limestone at 20 feet (6.1 m) below surficial material. Limestone is exposed in a roadcut 7 kilometers (4.3 mi) northwest. Siliceous limestone of the Bailey Limestone is present in this roadcut below rock from which calcite has been dissolved (fig. 7). No data were available for the area in the floodplain of the Mississippi River north of Thebes. Northwest of Elco, limestone outcrops provide a limit on the maximum depth to which calcite was leached from these rocks. The water well drilled at C.C.C. Camp Delta (well 2 on fig. 43) to a depth of 405 feet (123 m) did not penetrate carbonate beds. The depth to limestone in this area can only be guessed.

J. Weller and Ekblaw (1940) provided evidence that leaching of carbonate, perhaps accompanied by silicification, also occurred in the Wolf Lake area. The Backbone Limestone lies between the Grassy Knob Chert and overlying Clear Creek Chert. Northeast of Wolf Lake, it is a crinoidal crystalline limestone. To the south, in the vicinity of microcrystalline silica deposits, Weller and Ekblaw observed that this formation changes character, and its presence was recognized by crinoid-bearing chert

An extended period of deep weathering has been suggested as a possible means for complete removal of carbonate from these rocks (J. Weller and Ekblaw 1940). The massive chert beds in the uppermost Clear Creek Chert would have provided an ideal protective carapace for the less durable underlying beds. The earliest that such leaching could have occurred is after lithification of sediments of the Clear Creek Chert and before deposition of the Dutch Creek Sandstone Member of the Grand Tower Limestone.

J. Weller and Ekblaw (1940) suggested that a slight unconformity is present between the Clear Creek Chert and the overlying Dutch Creek Sandstone. If leaching of carbonate is related to this time interval, there should be a spatial relationship over a wide area between depth of leaching and this contact. Figure 43 shows the discordance of these two surfaces. Structure contours on the top of the Clear Creek Chert northwest of Elco cross the contours on the surface separating leached from unleached rocks. If leaching is related to the Clear Creek Chert–Dutch Creek Sandstone unconformity, extensive leaching of the Clear Creek Chert should not be limited laterally but should be widespread along the contact. Neither in the Hileman no. 1 well 9 kilometers (5.6 mi) northeast of Elco nor in the exposure northwest of Anna, as described by Allen (1985), is there evidence of solution of limestone in the uppermost Clear Creek Chert.

The discordance between the upper contact of the Clear Creek Chert and the depth to unleached limestone is critical in evaluating the possibility that leaching occurred during Mesozoic or Tertiary periods of

Table 6 Drill hole data used to contour the surface above which carbonate has been leached from the bedrock (fig. 43). Wells are located in Alexander County, Illinois.

Well	Driller, owner	Location	ISGS sample set	Total depth (ft)	Depth to bedrock (ft)	Depth to carbonate and comments from examination of cuttings
1	Schneider Drlg. C. Pearce	NW NE SW, Sec. 6, T14S, R2W	15762	385	50	Tan chert to 180 ft; no carbonate; limestone below 180 ft.
2	E. M. Gould C.C.C. Camp Delta	NE SW, Sec. 20, T14S, R2W	1416	405	55	Entirely in chert; lower part probably Grassy Knob Chert.
3	E. M. Gould Gale School	SW SE SW, Sec. 33, T14S, R3W	2329	112	16	20–45 ft sandstone with weak or no reaction with 10% HCl; below 45 ft, sandstone with calcite cement; limestone at 100 ft.
4	Schneider Drlg. Clyde Vick	SE NE NW, Sec. 32, T15S, R2W	15758	85	20	Chert and tan limestone at 20–25 ft.
5	H. B. Stalcup Newell	SE SE SW, Sec. 19, T14S, R1W	27739	390	85	Chert to 90 ft; no carbonate; limestone below 90 ft.

tectonic activity related to formation of the Pascola Arch or the Mississippi Embayment. The chert–pebble conglomerate, whether of Mesozoic or Tertiary age, was deposited fluvially on the unconformity in the uppermost massive chert beds of the Clear Creek Chert and Dutch Creek Sandstone Member of the Grand Tower Limestone. Groundwater percolating downward through these deposits could have dissolved carbonates from the underlying beds. J. Weller and Ekblaw (1940) and J. Weller (1944) suggested a similar, but younger environment. They cited the development of a peneplain on the Clear Creek Chert, Dutch Creek Sandstone, and Cretaceous (?) gravels. This peneplain, sloping to the south, is now dissected. It is recognizable by flat ridges at elevations of about 500 feet (150 m) just north of Olive Branch, about 800 feet (240 m) west of Elco, and about 850 feet (260 m) near the Union–Jackson county line. However, the configuration of the surface above which carbonate was removed is discordant with the unconformity or the peneplain, and does not support the hypothesis of groundwater leaching (fig. 43). The surface representing the maximum depth of complete removal of carbonate is a broad, roughly circular depression. The surface is not a plain that gently rises to the north from the Olive Branch area, as would be expected if leaching was related to a peneplain sloping to the south or an unconformity developed on the upper chert beds in the Clear Creek Chert and the Dutch Creek Sandstone.

HYDROTHERMAL MODEL

The discrete configuration of the surface above which carbonate had been leached from the bedrock requires a process not directly related to an erosion surface, whether Tertiary, Mesozoic, or Devonian. Another mechanism must be responsible. J. Weller (1944, p. 101) stated that, if his conclusions were correct, chertification of the Devonian and subsequent removal of carbonate from this section were "accomplished by totally unrelated processes that were active at different times." It is an unlikely coincidence that these Lower Devonian formations were silicified and then leached of carbonate in two separate events, perhaps separated by hundreds of millions of years but seemingly occurring within the same area, and perhaps centered within a few kilometers of each other. The following discussion provides a hypothesis that eliminates the need for two separate unrelated processes.

As previously discussed, there is evidence on a regional basis that the Clear Creek Chert has been silicified in the area of exposure in southernmost Illinois, roughly coincidental with the Elco microcrystalline silica district. Silicification of the Backbone Limestone is indicated in the Wolf Lake microcrystalline silica district. On a microscopic scale, there is also evidence for epigenetic silica deposition, perhaps the result of the same process responsible for silicification of the Clear Creek Chert. Rogers (1972) observed quartz overgrowths on silt-size terrigenous detrital grains in the Clear Creek Chert, and Lamar (1953) described similar overgrowths on rounded quartz grains in the Grassy Knob Chert. Specimens of all varieties of siliceous rocks from the Clear Creek Chert in the area west of Elco contain sparse, large (>100 µm) euhedral quartz crystals that contain calcite inclusions, two-phase fluid inclusions, and vapor-filled cavities. Similar euhedral quartz crystals were recovered from the acid insoluble residue of limestone beds within the Clear Creek Chert and from clay beds in the Clear Creek Chert exposed west of Elco. As discussed in the section, "Fluid Inclusions in Quartz Crystals," preliminary data indicate deposition of silica from water of low salinity at temperatures of about 200°C (table 5, fig. 42).

The low salinity of trapped water, much less saline than present sea water, and temperatures much above any reasonable temperature of a sea, indicate that these overgrowths were deposited from a hydrothermal system. The timing or extent of this system is not known. The large variation in vapor–liquid ratio of the larger inclusions is indicative of a heterogeneous system such as that produced along the water boiling curve. It is hypothesized that these overgrowths formed from hydrothermal solutions in a boiling environment at shallow depth. If the hydrothermal system was characterized by decreasing pH, decreased solubility of silica would cause precipitation of quartz, accompanied by increased solution of calcite. Calcite inclusions surrounding the cores of these grains are interpreted as relict calcite that the quartz overgrowth protected from further solution. Some dolomite rhombs are preserved in these quartz crystals, but rhombic molds as well as cubic molds indicate solution of minerals.

Hydrothermal introduction of silica with contemporaneous solution of carbonates explains the limited extent of the leached zone. For the same reason, deposits of microcrystalline silica are not laterally continuous in one stratigraphic bed, as they would be if controlled by primary deposition in a sedimentary basin. An objection to the hydrothermal interpretation may be raised, however, by referring to the lateral continuity of chert beds across at least one exposure at the Lone Star mine. Addition of silica may have been controlled by the initial lithology of the Clear Creek Chert. There is no evidence of silicification moving outward from faults or along faults. It is most likely that the numerous faults with small offset formed in response to the volume decrease that accompanied removal of carbonate. The faults were thus contemporaneous with the introduction of silica and did not control the formation of microcrystalline silica deposits.

Both the Elco and the much smaller Wolf Lake microcrystalline silica districts are spatially associated with prominent positive magnetic anomalies (figs. 44 and 45). Heigold (1976) interpreted these anomalies to be caused by basic intrusives in the Precambrian basement

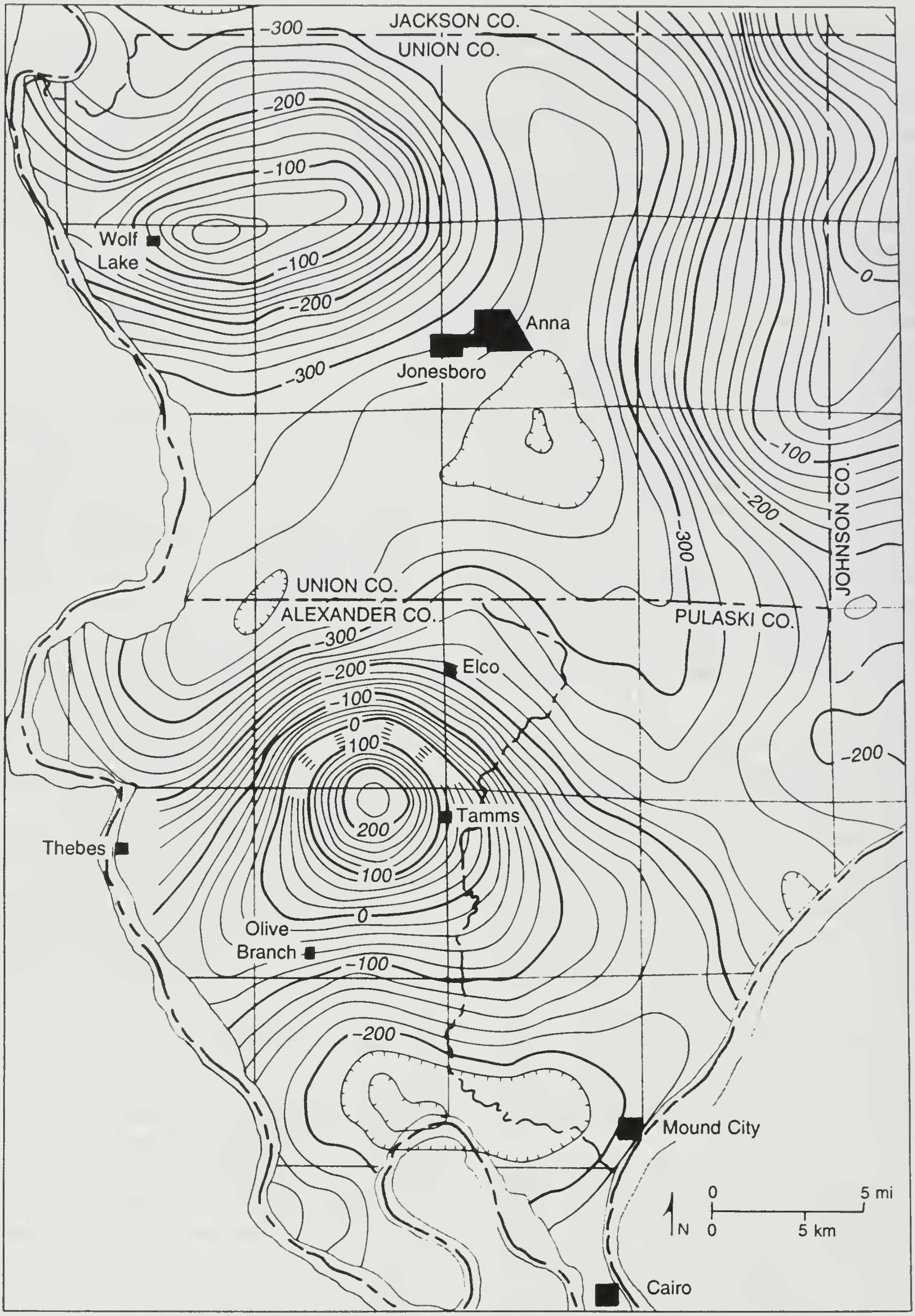


Figure 45 Residual total magnetic intensity map with contour interval of 20 gammas for southernmost Illinois (modified from plate 1 *in* Heigold 1976).

at a depth of 4.4 kilometers (14,400 ft) and 3.9 kilometers (12,800 ft) below sea level for the "Elco" and Wolf Lake anomalies respectively. The center of the "Elco" anomaly lies a few miles southwest of Elco (fig. 45). A Bouguer gravity map of Illinois (McGinnis et al. 1976) shows a strong positive gravity anomaly in approximately the same location as the "Elco" magnetic anomaly and a weaker positive gravity anomaly at the Wolf Lake magnetic anomaly. A model developed for the gravity anomaly in the Elco district, referred to as the Cache anomaly, indicates a pluton with an uppermost extent of 8.0 kilometers (5 mi) below sea level (McGinnis et al. 1976). They did not provide a model for the less pronounced, positive gravity anomaly near Wolf Lake.

A hydrothermal model best explains the spatial coincidence of these two positive magnetic anomalies, positive gravity anomalies, concentration of microcrystalline silica deposits, area of leaching of carbonate from Lower Devonian formations, and introduction of silica. The deposition of silica at elevated temperatures, as indicated by preliminary determinations on fluid inclusions from the Elco district, also supports this model. Leaching of carbonates and deposition of silica, or perhaps simply replacement of carbonates by silica, were controlled by a hydrothermal process approximately centered on the positive magnetic anomalies. If these anomalies are caused by mafic plutons in the upper Precambrian basement, then local heat sources are available for hydrothermal activity.

The relationship between the Wolf Lake microcrystalline silica district and a positive magnetic anomaly is strengthened by the occurrence of limestone in the intervening area between this district and the Elco district to the south. Massive chert beds, similar to those exposed at the top of the Clear Creek Chert in the Elco district, occur 6 to 12 meters (20–40 ft) above the portals of the Butcher and Wolf Lake mines (sites 2 and 3, appendix A and fig. 5). North of these mines, J. A. Devera (ISGS, personal communication 1990) observed large blocks of chert below a flat-topped ridge with an elevation of 700 feet (213 m) in Sections 35 and 36, T11S, R3W. The association of a flat-topped ridge, evidently underlain by massive chert beds, is similar to that characteristic of the Elco district. Topographic maps of the area between the Elco and Wolf Lake districts show a lack of flat-topped ridges, an indication that in this area the uppermost massive chert beds in the Clear Creek Chert are not present.

Bald Knob, located about 7 kilometers (4 mi) northeast of the silica mines in the Wolf Lake district, is a prominent topographic feature at an elevation of 1,020 feet (311 m). It is underlain by Clear Creek Chert, and massive chert is found as large boulders on the slopes of this knob (J. Weller and Ekblaw 1940). A chert bed similar to that in the uppermost chert sequence in the Clear Creek Chert of the Elco district is exposed above a deposit of microcrystalline silica in an inactive open-cut silica mine on Bald Knob (site 1, fig. 5). The abundance of unusually massive chert forming a knob close to an area of known silica deposits associated with a positive magnetic anomaly are all indicative of deposition by hydrothermal activity. Detailed study of the Wolf Lake district and Bald Knob in particular would be worthwhile in evaluating the hydrothermal model for these deposits.

Upward movement of groundwater heated by plutons in the basement can explain both silicification and leaching of carbonate in the microcrystalline silica districts. Because data from deep wells are lacking, the depth to Precambrian basement can only be estimated to be between 6,500 and 12,500 feet (2.0 and 3.8 km) (M. L. Sargent, ISGS, personal communication 1991). Bethke (1986) and Bethke et al. (1991) modeled both the flow of groundwater driven northward out of the Illinois Basin by compaction of sediments and the gravity-driven flow of groundwater moving northward from the Pascola Arch. From these models, they concluded that flow northward from the Pascola Arch was a more likely mechanism for movement and deposition of metallic minerals in the Upper Mississippi Valley deposits than was compaction-generated flow out of the Illinois Basin. Compaction-driven flow would be slower than gravity-driven flow from an uplift. According to Bethke's models, water driven by compaction of sediments would cool below the temperatures estimated for formation of the Upper Mississippi Valley deposits by conduction of heat to the surrounding rocks. The faster, gravity-driven flow would maintain the water temperature required for the formation of these deposits.

Bethke's model may be applied to the formation of microcrystalline silica deposits in southernmost Illinois. Groundwater flowing northward from the Pascola Arch was heated by cooling mafic plutons in the basement. As this water rose toward the surface, cooling caused deposition of silica and replacement of calcite by silica in the microcrystalline silica districts. A critical question to be answered is the importance of hydrothermal activity in the formation of these deposits in relation to the importance of silica precipitated in the sedimentary environment.

The last stage of precipitation of silica in the Clear Creek Chert was most active in the upper 20 meters (66 ft) of this formation, where many fossil molds are lined with drusy quartz. The uppermost massive chert beds, locally brecciated, are cemented by quartz; some cavities in these beds are lined with a quartz druse. The very hard chert bed exposed in the Jason mine contains cavities coated with chalcedony that is in turn coated with drusy quartz. The drusy quartz differs from the euhedral quartz crystals in lacking inclusions recognizable with the petrographic microscope. It is thought that this inclusion-free quartz was the last quartz to be deposited. The drusy quartz is most abundant in the upper part of the Clear Creek Chert, where it may have precipitated slowly from groundwater at low temperatures. The quartz cementing the chert–pebble conglomerate is also free of fluid inclusions or vapor-filled cavities and may have been deposited by the same process. It is interesting that rhombic and cubic molds in the chert and microcrystalline silica are not lined with drusy quartz. If the solution from which the drusy quartz was deposited permeated the entire upper part of the Clear Creek Chert, it should also have deposited quartz in the cavities.

Formation of microcrystalline silica deposits in southernmost Illinois cannot be explained simply by weathering. If the deposits were formed by weathering, the accompanying removal of carbonates from these formations would generally be concordant with either an unconformity or the present topographic surface. This relationship was not observed. The spatial coincidence of microcrystalline silica deposits with positive gravity and magnetic anomalies suggests a genetic relationship: specifically, that plutons of unknown age in the Precambrian basement provided a source of heat for the development of hydrothermal systems responsible for the local silicification of these Devonian formations. Therefore, the silicification in the Elco and Wolf Lake microcrystalline silica mining districts is best explained by a hydrothermal model.

SUGGESTIONS FOR FURTHER RESEARCH

The hydrothermal hypothesis explains most of the features observed in the microcrystalline silica district, but it is only a working hypothesis. Some avenues of research that would be particularly important to understanding the bedrock geology and paleohydrologic systems of this area are listed below.

- Map the bedrock geology; focus on the Lower Devonian stratigraphy and extent of uppermost chert beds in the Clear Creek Chert.
- Examine the acid-insoluble residue from carbonate beds in the Clear Creek Chert to determine whether microcrystalline silica deposits could have formed by the removal of carbonate from the formation, but without the addition of silica.
- Investigate the stable isotopes (oxygen and hydrogen) of cherts and euhedral quartz to place constraints on the environment of deposition of the silica.
- Examine in detail the chert–pebble conglomerate, particularly the distribution of the quartz cement to determine whether it has a bearing on the formation of microcrystalline silica deposits.
- Conduct microthermometric determinations of fluid inclusions in quartz crystals in the microcrystalline silica deposits; also study the fluid inclusions observed in the quartz cement in the Dutch Creek Sandstone Member.
- Examine the acid-insoluble residues recovered from wells penetrating the Devonian formations to determine the areal extent of quartz grains with euhedral overgrowths.
- Drill two core holes, one in the microcrystalline silica district and one adjacent to the district, to provide reference sections of altered rocks for comparison with unaltered rocks.

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APPENDIX A
Silica mines and prospects

APPENDIX B
Described sections of the Clear Creek Chert

Appendix A

Site	Location* 1/4 1/4 1/4 Sec. T. R.	County	Mine name, owner /operator**	Major products	Development
Cobden 7.5-Minute Quadrangle					
1	NW SE SE 17 11S 2W	Union		Microcrystalline silica	Open cut
Wolf Lake 7.5-Minute Quadrangle					
2	SE SE 35 11S 3W	Union	Butcher mine (3) Isco-Bautz Co. (1)	Microcrystalline silica	
3	NW NE 2 12S 3W	Union	Wolf Lake Silica mine Isco-Bautz Co. (2)	Microcrystalline silica for refractory brick	Four separate tunnels. One is driven back 150 ft (46 m), leaving huge cylindrical pillars for roof support (1).
Jonesboro 7.5-Minute Quadrangle					
4	SE NE NE 10 13S 2W	Union		Microcrystalline silica	
5	NE 15 13S 2W	Union		Microcrystalline silica	
6	SW SE SE 15 13S 2W	Union		Microcrystalline silica	
7	NE SE NE 22 13S 2W	Union		Microcrystalline silica	
Mill Creek 7.5-Minute Quadrangle					
8	SE NW SE 22 13S 2W	Union	Jason mine, Illinois Minerals Co.	Microcrystalline silica	Pit about 50 m (160 ft) by 90 m (300 ft)
9	SE NE NE 27 13S 2W	Union	Halliman Silica mine (1)	Microcrystalline silica	
10	NW NW SE 34 13S 2W	Union	Allen & Miller mine	Microcrystalline silica mainly for paint filler (1)	
11	SE SE SE 34 13S 2W	Union			

* Location plotted on figure 5 or plate 1.

** In many instances, this information is of historic interest only because the listed company operated the mine 40 or more years ago. Numbers in parentheses refer to the source of information (last column).

† The periods of activity at most abandoned sites are unknown, but many have been inactive for more than 40 years, as judged from the high degree of natural reclamation.

Silica mines and prospects

Site	Status†	Formation	Comments	Source
Cobden 7.5-Minute Quadrangle				
1	Inactive	Clear Creek Chert	About 5 m (16 ft) of microcrystalline silica with some chert exposed.	
Wolf Lake 7.5-Minute Quadrangle				
2	Inactive in 1918; adit room and pillar mine (1)	Clear Creek Chert (2)	Not examined.	1) Schroyer ca 1918 2) Weller and Ekblaw 1940 3) Parmelee and Schroyer 1918–1920
3	Inactive adit room and pillar mine	Clear Creek Chert (3)	See " Mines and Prospects" Section.	1) ISGS Ind. Min. field notes, 6/30/27 2) Schroyer ca 1918 3) Weller and Ekblaw 1940
Jonesboro 7.5-Minute Quadrangle				
4	Inactive adit room and pillar mine	Clear Creek Chert (1)	Not examined. Location from Joe Newcomb, U.S.F.S. Jonesboro.	1) Weller and Ekblaw 1940
5	Inactive adit room and pillar mine	Clear Creek Chert (1)	Not examined. Three mines in this 1/4 section are noted as having supplied silica to the Southern Illinois Mfg. Co., Jonesboro (2). Locations of two mines in this area were plotted by Lamar on a copy of plate 1 (1).	1) Weller and Ekblaw 1940 2) Parmelee and Schroyer 1918–1920
6	Inactive adit room and pillar mine	Clear Creek Chert (1)	Not examined. Location from Joe Newcomb, U.S.F.S. Jonesboro.	1) Weller and Ekblaw 1940
7	Inactive adit room and pillar mine	Clear Creek Chert (1)	Not examined. Location from Joe Newcomb, U.S.F.S. Jonesboro.	1) Weller and Ekblaw 1940
Mill Creek 7.5-Minute Quadrangle				
8	Reclaimed	Clear Creek Chert (2)	Operated as an open pit until about 1987. Pit exposed old underground workings (extent unknown). These may be workings that supplied silica to the Southern Illinois Mfg. Co., Jonesboro (1). See "Mines and Prospects" section.	1) Parmelee and Schroyer 1918-1920 2) Weller and Ekblaw 1940
9	Inactive adit room and pillar mine	Clear Creek Chert (3)	Not examined. These workings and perhaps others in the N 1/2 of the same section may have supplied silica to the Southern Illinois Mfg. Co., Jonesboro (2). See "Mines and Prospects" section.	1) ISGS Ind. Min. field notes, 7/11/27 2) Parmelee and Schroyer 1918-1920 3) Weller and Ekblaw 1940
10	Inactive adit room and pillar mine	Clear Creek Chert (2)	Not examined. See "Mines and Prospects" section.	1) ISGS Ind. Min. field notes, 5/25/31 2) Weller and Ekblaw 1940)
11	Inactive	Clear Creek Chert (1)	Not examined.	Shown on Mill Creek 7.5-Minute Quadrangle (1947, photorevised 1978) 1) Weller and Ekblaw 1940

Site	Location 1/4 1/4 1/4 Sec. T. R.	County	Mine name, owner /operator	Major products	Development
Mill Creek *(cont.)*					
12	SW SE NE 1 14S 2W	Alexander	Western Firebrick Co. mine, shipped to mill at Granite City	Ganister for refractories, silica brick, etc.	Worked back to 150 ft (46 m) in 1918 (1)
13	NW SW SW 1 14S 2W	Alexander	Hagler, Wisely, Carter & Steele mine Southern Illinois Minerals Co., and old Goodman mine (1)	Ganister for refractories, silica brick, etc.	
14	SW SE SW 3 14S 2W	Alexander			Adit goes in about 11 m (36 ft)
15	NE NW NW 11 14S 2W	Alexander			
16	SW SE NE 10 14S 2W	Alexander		Microcrystalline silica	
17	SE SW NE 10 14S 2W	Alexander		Microcrystalline silica	
18	SE NW SE 10 14S 2W	Alexander			Adit goes in about 13 m (43 ft)
19	SW NE SE 10 14S 2W	Alexander			Adit goes in about 4 m (13 ft)
20	SW NE SE 10 14S 2W	Alexander			Adit goes in about 20 m (66 ft)
21	SE NE SE 10 14S 2W	Alexander			
22	NE NE SE 10 14S 2W	Alexander		Microcrystalline silica	Adit goes in about 17 m (56 ft)
23	NE NE SE 10 14S 2W	Alexander		Microcrystalline silica	Adit goes in ≥16 m (≥52 ft)
24	NE SW NW 11 14S 2W	Alexander		Microcrystalline silica	Adit ≥10 m (≥33 ft) long
25	NW SE NW 11 14S 2W	Alexander		Microcrystalline silica	
26	NE SW NW 11 14S 2W	Alexander		Microcrystalline silica	

(continued)

Site	Status	Formation	Comments	Source
Mill Creek *(cont.)*				
12	Inactive adit room and pillar mine	"Hartline" or Fort Payne Chert (2)	Owner-Manager Edward Bryden, Tamms, about 70 cars shipped (1).	1) Schroyer c. 1918 2) Lamar 1953
13	Inactive adit room and pillar mine	"Hartline" or Fort Payne (2)	Not examined. See "Mines and Prospects" section.	1) ISGS-Ind. Min. field notes, 7/21/27 and 5/41 2) Lamar 1953
14	Prospect adit	Clear Creek Chert	Entry bearing N5°E. At entry there is 3–4 m (10-13 ft) of white microcrystalline silica, soft white chert, and some medium hard chert, overlain by 2 m (7 ft) of iron-stained, more cherty material than below. Portal 30 m (98 ft) below top of upper chert bed.	
15	Prospect cut	Clear Creek Chert	See figures 40 and 41.	
16	Inactive adit mine (probably)	Clear Creek Chert	Entry bearing S30°W. Small fault at portal N2°W, 75°SW. Much gray clay at portal. More than 2 m (7 ft) of white microcrystalline silica in mine.	
17	Inactive adit mine, caved at portal	Clear Creek Chert	White SiO_2 screenings next to road. Microcrystalline silica, chert and several clay beds exposed. Some beds Fe_2O_3-stained.	
18	Prospect adit	Clear Creek Chert	Entry bearing N60°W. Some light pink beds, many reddish brown, some gray clay beds. Bedding N35°E, 3°NW.	
19	Prospect adit	Clear Creek Chert	Bedding N65°E, 4°NW.	
20	Prospect adit	Clear Creek Chert	Entry bearing N10°W. Fe_2O_3-stained silica.	
21	Prospect cut or caved adit	Clear Creek Chert	Two gray clay beds about 5 cm (2 in.) thick. Small monocline 0.5 m (1.5 ft) high exposed in cut.	
22	Inactive mine or prospect adit	Clear Creek Chert	Slabby soft white chert at portal. Tan silica at portal. About 6 m (20 ft) white microcrystalline silica mined.	
23	Inactive small adit mine	Clear Creek Chert	Entry bearing N70°E. Room to left. Lower 1 m (about 3 ft) white microcrystalline silica.	
24	Prospect adit	Clear Creek Chert	Entry bearing S85°W. Interlayered white and red silica, about 20% white with two beds of gray clay 1–2 cm thick (0.3–0.7 in.). Bedding horizontal.	
25	Inactive adit room and pillar mine	Clear Creek Chert	Entry bearing S15°E. Pillar visible. Three meters (10 ft) >90% very white microcrystalline silica. A couple of red streaks. Usually red rock above white.	
26	Inactive adit room and pillar mine	Clear Creek Chert	Mine parallels slope from inside entry for about 50 m (about 164 ft). Vertical fault N65°W. SW side down 30 cm (1 ft).	

Site	Location 1/4 1/4 1/4 Sec. T. R.	County	Mine name, owner /operator	Major products	Development
Mill Creek *(cont.)*					
27	SW NE NW 11 14S 2W	Alexander		Microcrystalline silica	
28	NW NW NE 11 14S 2W	Alexander		Microcrystalline silica	
29	NE SW NW 11 14S 2W	Alexander			Adit goes in 12 m (39 ft)
30	SW NW NE 11 14S 2W	Alexander		Microcrystalline silica	
31	NW SW NE 11 14S 2W	Alexander		Microcrystalline silica	
32	NE SW NE 11 14S 2W	Alexander			
33	SE NW NE 11 14S 2W	Alexander			
34	SE NW NE 11 14S 2W	Alexander		Microcrystalline silica	
35	SW NE NE 11 14S 2W	Alexander		Microcrystalline silica	
36	NE SW NE 11 14S 2W	Alexander			
37	NW SW NE 11 14S 2W	Alexander		Microcrystalline silica	
38	NW SW NE 11 14S 2W	Alexander		Microcrystalline silica	

(continued)

Site	Status	Formation	Comments	Source
Mill Creek *(cont.)*				
27	Inactive adit room and pillar mine	Clear Creek Chert	Sudsidence at surface has obscured portal. Massive chert bed exposed on highest point on ridge at edge of subsidence.	
28	Inactive adit room and pillar mine	Clear Creek Chert	Bedding N45°W, 7°NE. Three meters (10 ft) or more of white microcrystalline silica in mine. Fe_2O_3-stained silica above this.	
29	Prospect adit	Clear Creek Chert	Entry bearing N35°W. All silica Fe_2O_3-stained. Bedding approximately horizontal.	
30	Inactive adit room and pillar mine	Clear Creek Chert	Bedding N50°W, 9°NE. About 5 m (16 ft) of white microcrystalline silica exposed.	
31	Inactive adit room and pillar mine	Clear Creek Chert	Entry bearing N75°W. At least one cross-cut in mine. Lower 2 m (7 ft) exposed in mine is white microcrystalline silica. Otherwise Fe_2O_3-stained except for a few white beds. Bedding N10°E, 9°NW.	
32	Prospect cut or completely caved adit	Clear Creek Chert	Bedding N40°W, 9°NE.	
33	Prospect adit	Clear Creek Chert	Entry bearing N25°W. About 2 m (7 ft) of rubbly chert exposed at portal. No well defined zone of white microcrystalline silica. Bedding horizontal.	
34	Inactive adit room and pillar mine	Clear Creek Chert	Air moving out of portal. Probably part of a large mine complex under this ridge with other openings.	
35	Inactive adit room and pillar mine	Clear Creek Chert	Entry bearing N55°E, gentle decline follows bedding at 8°NE. Amplitude of valleys in bedding about 1 cm (0.3 in.). Local downdip movement on a very few small faults. About 2.5 m (8 ft) of 90% white microcrystalline silica inside portal.	
36	Prospect adit	Clear Creek Chert	Entry bearing S5°W. A few white layers of microcrystalline silica <10 cm (about 1/3 ft) thick, mainly Fe_2O_3-stained. Bedding N25°E, 10°SE.	
37	Inactive adit mine or prospect adit	Clear Creek Chert	Entry bearing S30°W. About 2 m (6.5 ft) of white microcrystalline silica, Fe_2O_3-stained above this. Bedding N15°E, 10°SE.	
38	Inactive adit room and pillar mine	Clear Creek Chert	Entry bearing S5°W. About 4 m (13 ft) of 90% white microcrystalline silica. Circular area of subsidence on ridge above this mine. Bedding N5°W, 10°NE.	

Site	Location 1/4 1/4 1/4 Sec. T. R.	County	Mine name, owner /operator	Major products	Development
Mill Creek *(cont.)*					
39	SW NE 11 14S 2W	Alexander		Microcrystalline silica	
40	SW SE NE 11 14S 2W	Alexander		Microcrystalline silica	
41	SW NW NE 16 14S 2W	Alexander			
42	NW SW NE 16 14S 2W	Alexander			
43	SW SW NE 16 14S 2W	Alexander			
44	SE SW NE 16 14S 2W	Alexander			
45	SW SW NE 16 14S 2W	Alexander		Microcrystalline silica	
46	NW NW SE 16 14S 2W	Alexander			

(continued)

Site	Status	Formation	Comments	Source
Mill Creek *(cont.)*				
39	Inactive room and pillar mine with three entries	Clear Creek Chert	Main entry as shown on topographic map at end of road is now completely obscured by caving. Adits shown to west probably enter the same workings, which judging from amount of subsidence, must have been a large mine. As much as 200 vertical ft (61 m) of microcrystalline silica is said to have been mined from three levels of a mine in this section (1). The uppermost chert interval is exposed in area of subsidence.	1) Levine 1973, p. 14
40	Inactive adit room and pillar mine	Clear Creek Chert	Entry bearing N5°W. About 3.5 m (11 ft) of >90% white microcrystalline silica. Clay seams at portal have caused slabby roof fall. Joint N8°E, vertical. Base of chert interval that marks the top of the Clear Creek Chert is about 3 m (10 ft) above top of white microcrystalline silica. Bedding N10°E, 6°SE.	
41	Prospect pit	Clear Creek Chert	Cut in side of hill. Microcrystalline silica and soft white chert. Contains 30 cm (1 ft) of microcrystalline silica with blocky fracture and fissility, which splits into layers <1 cm (<0.3 in.) thick. Upper 1 m (3 ft) of cut below soil is Fe_2O_3-stained.	
42	Prospect adit	Clear Creek Chert	At portal 2 m (7 ft) of hard white chert is exposed. Below this 4 m (13 ft) of softer chert, some with Fe_2O_3-stain, is exposed in workings. Quartz-lined cavities in chert. Some brecciation, recemented by gray silica. Some sugary silica with fine-scale structures.	
43	Prospect adit	Clear Creek Chert	Probable prospect adit, cannot see in because of rubble at portal. About 2 m (7 ft) of soft white chert exposed. Bedding horizontal.	
44	Prospect pit	Clear Creek Chert		
45	Inactive adit room and pillar mine	Clear Creek Chert	Probably a mine, 5 m (16 ft) of white, soft leached chert exposed at portal and in mine. White microcrystalline silica extends nearly to grass roots but with some Fe_2O_3 splotches and wisps at portal. Upper 0.6 m (2 ft) hidden by roots and Fe_2O_3-stained.	
46	Prospect adit	Clear Creek Chert	Entry bearing N20°E. Because of rock fall at portal, cannot see how far in it goes. Two gray clay beds at portal. About 30% of 3 m (10 ft) section is hard chert. Loose blocks indicate that one chert bed is >49 cm (1.6 ft) thick.	

Site	Location 1/4 1/4 1/4 Sec. T. R.	County	Mine name, owner /operator	Major products	Development
Mill Creek *(cont.)*					
47	NW NW SE 16 14S 2W	Alexander			
48	NE NE SW 16 14S 2W	Alexander			
49	NE NE SW 16 14S 2W	Alexander			Adit goes in about 16 m (52 ft)
50	NW NW SE 16 14S 2W	Alexander			
51	NW NW SE 16 14S 2W	Alexander			Adit goes in about 15 m (49 ft) and down about 2 m (7 ft)
52	NW NW SE 16 14S 2W	Alexander			
53	NW NW SE 16 14S 2W	Alexander		Microcrystalline silica	
54	NE NW SE 16 14S 2W	Alexander			Adit goes in about 13 m (43 ft)
55	NE SE SE 16 14S 2W	Alexander			
56	SE NE SE 16 14S 2W	Alexander			

(continued)

Site	Status	Formation	Comments	Source
Mill Creek *(cont.)*				
47	Prospect adit	Clear Creek Chert	Entry bearing N10°E, cannot see whether it is a prospect or mine. Some clay seams at portal. About 1.3 m (4 ft) of Fe_2O_3-stained, rubbly hard chert and usual mixture of other varieties at portal. About 2 m (7 ft) of white soft microcrystalline silica exposed below Fe_2O_3-stained material. Some quartz-lined cavities in chert.	
48	Prospect or natural exposure	Clear Creek Chert	Main exposure in bank along Sexton Creek, but some indication of prospect excavation. About 12 m (39 ft) of interbedded chert and microcrystalline silica.	
49	Prospect adit	Clear Creek Chert	Entry bearing S20°W. Fe_2O_3-stained silica extends in about 5 m (16 ft). Mixture of varieties of chert and microcrystalline silica. Bedding about N53°W, 5°SW, somewhat irregular.	
50	Prospect adit	Clear Creek Chert	Caved at portal. About 2 m (7 ft) of rubbly, Fe_2O_3-stained mixture of chert types at portal: medium hard chert, soft chert, and microcrystalline silica. No distinctive chert beds.	
51	Prospect adit	Clear Creek Chert	Entry bearing S0°E. Much hard chert at portal. Bedding not clearly recognizable, may be close to horizontal.	
52	Prospect adit	Clear Creek Chert	Almost completely caved at portal, caused by clay along inclined surfaces. Bedding not recognizable at portal. Heavy Fe_2O_3-stain. Some hard chert, generally rubbly.	
53	Inactive adit room and pillar mine	Clear Creek Chert	Entry bearing S35°E, horizontal. At portal about 3.5 m (11 ft) exposure consisting of white interbedded hard chert (rare), medium hard chert and slabby soft chert (most common), and microcrystalline silica. About 1 m (3 ft) of similar Fe_2O_3-stained rock above this. Bedding essentially horizontal.	
54	Prospect adit	Clear Creek Chert	Entry bearing S55°E. Upper 3 m (10 ft) of Fe_2O_3-stained chert. Lower 2 m (7 ft) interlayered white and Fe_2O_3-stained, leached chert. Bedding horizontal, judging from position of chert float on opposite hillside.	
55	Prospect adit	Clear Creek Chert	Entry bearing S60°W. Four meters (13 ft) of red, rubbly chert above 2 m (7 ft) of white microcrystalline silica. Fracture filled with gray clay and oriented N20°E, 80°SE.	
56	Prospect adit	Clear Creek Chert	Entry bearing N40°E. Mixture of hard white chert, medium hard chert, soft chert and some microcrystalline silica at sill of adit. All silica Fe_2O_3-stained. Bedding about horizontal.	

Site	Location 1/4 1/4 1/4 Sec. T. R.	County	Mine name, owner /operator	Major products	Development
Mill Creek *(cont.)*					
57	NW NE SE 16 14S 2W	Alexander		Microcrystalline silica	
58	NE NE SE 16 14S 2W	Alexander		Microcrystalline silica	
59	NE NE SE 16 14S 2W	Alexander		Microcrystalline silica	
60	SE SE NE 16 14S 2W	Alexander		Microcrystalline silica	Adit goes in at least 18 m (59 ft)
61	SE SE NE 16 14S 2W	Alexander		Microcrystalline silica	
62	NW SW NW 15 14S 2W	Alexander			Adit goes in about 20 m (66 ft)
63	SW NW NW 15 14S 2W	Alexander			Adit goes in about 20 m (66 ft)
64	SE NW NW 15 14S 2W	Alexander		Microcrystalline silica	
65	NE NW 15 14S 2W	Alexander	Lone Star mine, Lone Star Industries	Microcrystalline silica	
66	SE SE NE 15 14S 2W	Alexander			
67	NE SW NE 15 14S 2W	Alexander		Microcrystalline silica	Adit goes in about 10 m (33 ft)
68	NE SW NE 15 14S 2W	Alexander			
69	NW SE NE 15 14S 2W	Alexander		Microcrystalline silica	Adit goes in at least 35 m (115 ft)

(continued)

Site	Status	Formation	Comments	Source
Mill Creek *(cont.)*				
57	Inactive adit room and pillar mine	Clear Creek Chert	Entry bearing N50°E. About 3 m (10 ft) white microcrystalline silica overlain by 3 m (10 ft) red rubbly chert. Color change is abrupt. Clay-filled fracture oriented N35°E, 70°SE at portal.	
58	Inactive adit room and pillar mine	Clear Creek Chert	Entry bearing S25°W, opens into rooms within 6 m (20 ft) of portal. Exposure of 5 m (16 ft) of white microcrystalline silica, overlain by red chert beds at portal. Approximate bedding N60°W, 8°SW.	
59	Inactive adit room and pillar mine	Clear Creek Chert	Entry bearing N60°W, with ≥2 m (7 ft) of white microcrystalline silica exposed in mine below Fe_2O_3-stained rock.	
60	Inactive adit mine or prospect adit	Clear Creek Chert	Entry bearing N40°E. Mainly Fe_2O_3-stained medium hard chert, soft chert with a little microcrystalline silica at portal. Bedding N40°E, 6°SE.	
61	Inactive adit room and pillar mine	Clear Creek Chert	Entry bearing N9°E, with ≥4 m (13 ft) of white microcrystalline silica exposed. Fault has clearly controlled Fe_2O_3-staining.	
62	Prospect adit	Clear Creek Chert	Entry bearing N70°W.	
63	Prospect adit	Clear Creek Chert	Entry bearing S60°W, with 2 m (7 ft) of white and brown banded white microcrystalline silica, soft white chert and medium hard white chert exposed. Thickest white bed about 50 cm (1.6 ft).	
64	Inactive adit room and pillar mine	Clear Creek Chert	Entry bearing N80°W. Thickest bed of white microcrystalline silica 60 cm (2 ft).	
65	Active quarry	Clear Creek Chert	See figures 15, 16, 17, and discussion in text. Source of silica for Lone Star's Cape Girardeau cement plant.	
66	Prospect adit	Clear Creek Chert	Adit goes under Opossum Trot Trail.	
67	Prospect adit	Clear Creek Chert	Entry bearing N48°W. Adit goes in about 10 m (33 ft) then collapsed. Red clay layer above portal underlain by about 4.5 m (15 ft) of interbedded medium hard chert and wormy chert with numerous thin gray clay beds. Below these beds, 1 m (3 ft) of interbedded medium hard chert, soft chert, and microcrystalline silica with light Fe_2O_3-stain. Bedding N48°W, 13°NE.	
68	Prospect adit	Clear Creek Chert	Completely caved. Located on slope east of creek.	
69	Inactive adit room and pillar mine	Clear Creek Chert	Entry bearing S65°E. Exposure of 4 m (13 ft) of white microcrystalline silica with minor Fe_2O_3-stain above this. Bedding N65°W, 10°NE. Fault at portal N10°E, vertical (variable), NW side up 10 cm (0.3 ft).	

Site	Location 1/4 1/4 1/4 Sec. T. R.	County	Mine name, owner /operator	Major products	Development
Mill Creek *(cont.)*					
70	SE NW NE 15 14S 2W	Alexander		Microcrystalline silica	Adit goes in >20 m (>66 ft)
71	NE NW NE 15 14S 2W	Alexander			Adit goes in about 7 m (23 ft)
72	NE NW NE 15 14S 2W	Alexander		Microcrystalline silica	
73	NW NE NE 15 14S 2W	Alexander			Adit goes in at least 20 m (66 ft)
74	NW NE NE 15 14S 2W	Alexander			Adit goes in at least 20 m (66 ft)
75	SE NE NE 15 14S 2W	Alexander			Adit goes in at least 12 m (39 ft)
76	SE NE NE 15 14S 2W	Alexander			Adit goes in about 15 m (49 ft)
77	SW NW NW 14 14S 2W	Alexander		Microcrystalline silica	
78	NW NW NW 14 14S 2W	Alexander			Collapsed area extends into hill about 8 m (26 ft)

(continued)

Site	Status	Formation	Comments	Source
Mill Creek *(cont.)*				
70	Inactive adit room and pillar mine	Clear Creek Chert	Entry bearing N18°W, with 3 m (10 ft) of white microcrystalline silica with a few tan stringers, overlain by about 1 m (3 ft) of white and red interbedded chert and microcrystalline silica. Bedding horizontal.	
71	Prospect adit	Clear Creek Chert	Gray clay in beds and intruded along small fault or joint N20°W, vertical. Red coloration along fractures in gray clay. Mainly Fe_2O_3-stained. Small caved prospect cut up stream 20 m (66 ft) on south side of creek.	
72	Inactive adit room and pillar mine	Clear Creek Chert	Entry bearing S70°E. Pillars visible from portal. Contains 4 m (13 ft) of >90% white microcrystalline silica. Small fault N55°W, 73°SW. Bedding horizontal.	
73	Prospect adit	Clear Creek Chert	Entry bearing S70°E. Soft chert at portal. Some wormy chert. Stylolitic partings in chert, Fe_2O_3 along these partings. About 3 m (10 ft) exposed in adit of which about 2/3 is white microcrystalline silica. Irregular mass of gray clay at portal.	
74	Prospect adit	Clear Creek Chert	Entry bearing N5°E. Old "gopher hole," a one-man mine or prospect above adit. Mainly Fe_2O_3-stained microcrystalline silica in adit, with some white microcrystalline silica. Vertical fracture trends N25°E.	
75	Prospect adit	Clear Creek Chert	Entry bearing S12°W. Entire exposure Fe_2O_3-stained. Prominent joint set N30°E, vertical. Gray clay has intruded some fractures. Minor fault with <10 cm (0.3 ft) displacement, N18°W, 50°NE. Bedding horizontal.	
76	Prospect adit	Clear Creek Chert	Entry bearing N60°E. About 1/3 white microcrystalline silica in layers 1 m (3 ft) thick. Fault N10°W, 60°NE, NE side down 5 cm (0.2 ft). Bedding N25°W, 5°NE.	
77	Inactive adit room and pillar mine	Clear Creek Chert	Entry bearing S60°W. Fault N85°E, vertical, NW side down about 1.5 m (5 ft) on basis of red-stained beds. Exposure of 3.5 m (12 ft) of mainly white microcrystalline silica. Bedding N45°E, 4°SE.	
78	Caved prospect adit or cut	Clear Creek Chert	Fault N85°W, 83°SW. SW side down about 1.5 m (5 ft) on basis of red-white contact. A few cm of Fe_2O_3-staining just above a gray clay bed. At least 11 gray clay beds, all <2 cm (1 in.) thick. Upper 2 m (7 ft) reddish brown, underlain by 3 m (10 ft) mainly white microcrystalline silica with some reddish brown layers.	

Site	Location 1/4 1/4 1/4 Sec. T. R.	County	Mine name, owner /operator	Major products	Development
Mill Creek *(cont.)*					
79	NE NW NW 14 14S 2W	Alexander		Microcrystalline silica	
80	NE NW NW 14 14S 2W	Alexander		Microcrystalline silica	
81	SE NW NW 14 14S 2W	Alexander		Microcrystalline silica	
82	NE SW NW 14 14S 2W	Alexander			Adit goes in >50 ft (15 m)
83	SE NE SE 10 14S 2W	Alexander		Microcrystalline silica	Adit goes in at least 15 m (49 ft)
84	NE SE SE 10 14S 2W	Alexander			Adit goes in at least 13 m (43 ft)
85	NW SW SW 11 14S 2W	Alexander		Microcrystalline silica	
86	NE SW SW 11 14S 2W	Alexander	Allan Silica mine (1), Illinois Silica Co. (1)	Microcrystalline silica	Operating 500 ft (152 m) from entry (1)
87	SW NE SW 11 14S 2W	Alexander		Microcrystalline silica	
88	NW SE SW 11 14S 2W	Alexander	Tamms Silica Co. 1911	Microcrystalline silica	
89	SE NE SW 11 14S 2W	Alexander		Microcrystalline silica	
90	SW NW SE 11 14S 2W	Alexander		Microcrystalline silica	
91	NE SE SE 11 14S 2W	Alexander		Microcrystalline silica	

Site	Status	Formation	Comments	Source
Mill Creek *(cont.)*				
79	Inactive adit room and pillar mine	Clear Creek Chert	Entry bearing N60°W. Large dump of white microcrystalline silica by haulage road. Pillars visible in mine. About 3 m (10 ft) of mainly white microcrystalline silica exposed. A few brown layers. Bedding about horizontal (1° dip). Another adit below this entry, trend of adit N35°W. Sill of lower portal 8 m (26 ft) below top of upper portal.	
80	Inactive adit room and pillar mine	Clear Creek Chert	Entry bearing N30°W. Breeze blowing out of portal, probably connects with entry to southwest (site 79). About 3 m (10 ft) of white microcrystalline silica exposed.	
81	Inactive adit room and pillar mine	Clear Creek Chert	Entry bearing N72°W. About 5 m (16 ft) of tan to white microcrystalline silica exposed. Fault N50°E, 70°NW, SE side down about 1.5 m (5 ft). Must have been a screening plant here as indicated by dumps of white chert fragments.	
82	Prospect adit	Clear Creek Chert	Not examined.	Levine 1973, plate 1
83	Inactive adit room and pillar mine	Clear Creek Chert	Entry bearing S35°E. Exposure of 6 m (20 ft) of Fe_2O_3-stained microcrystalline silica. Bedding N40°E, 3°SE.	
84	Prospect adit (may have been a mine)	Clear Creek Chert	Entry bearing S65°E. Exposure of 4 m (13 ft) reddish brown microcrystalline silica with some white microcrystalline silica. Bedding N0°W, 10°W.	
85	Caved adit	Clear Creek Chert	Caved at portal. Only red-stained, rubbly microcrystalline silica exposed at head of slump. White silica on entry road below.	
86	Inactive adit room and pillar mine	Clear Creek Chert	Entry bearing S40°E. About 4 m (13 ft) of white microcrystalline silica exposed at portal, overlain by 1.5 m (5 ft) of red-stained silica. See "Mines and Prospects" section.	1) ISGS Ind. Min. field notes, 7/11/27
87	Inactive caved adit mine	Clear Creek Chert	Completely caved at portal. Much white silica on road to portal.	
88	Inactive adit room and pillar mine	Clear Creek Chert	This may not be a portal but where a mine caved to surface. Just southwest of here is a definite area of subsidence. About 3 m (10 ft) 90% white microcrystalline silica exposed.	
89	Inactive adit room and pillar mine	Clear Creek Chert	Entry bearing S60°E. About 4 m (13 ft) of white microcrystalline silica overlain by 2 m (7 ft) of Fe_2O_3-stained silica. Old road to mine.	
90	Inactive adit room and pillar mine	Clear Creek Chert	Dumps of white silica below what is probably an adit that caved long ago.	
91	Inactive adit room and pillar mine	Clear Creek Chert	Entry bearing N12°W, with 6 m (20 ft) of almost white microcrystalline silica exposed.	

Site	Location 1/4 1/4 1/4 Sec. T. R.	County	Mine name, owner /operator	Major products	Development
Mill Creek *(cont.)*					
92	NE SE SE 11 14S 2W	Alexander		Microcrystalline silica	
93	NW SW NE 13 14S 2W	Alexander			Adit goes in <50 ft (15 m)
94	SE 7 14S 1W	Alexander	George Hartline	Ganister for silica brick, fire-brick	
95	NE 18 14S 1W	Alexander	Western Fire Brick Co. (1)	Ganister for refractory brick	Worked back 60 ft (18 m), 15 ft (5 m) high (1)
96	NE 18 14S 1W	Alexander	J. W. Joynt (1)	Ganister for silica brick, fire-brick	
97	SW SW SE 13 14S 2W	Alexander			
98	SE NE NE 23 14S 2W	Alexander		Microcrystalline silica	
99	SW SE NE 23 14S 2W	Alexander			
100	SE SE NE 23 14S 2W	Alexander		Microcrystalline silica	
101	SE SE NE 23 14S 2W	Alexander		Microcrystalline silica	
102	SE SW NW 24 14S 2W	Alexander		Microcrystalline silica	
103	NW SE SE 24 14S 2W	Alexander		Microcrystalline silica	
104	SW SW SE 19 14S 1W	Alexander		Chert (novaculite gravel)	
105	NW SW SE 21 14S 2W	Alexander			
106	SE NE NW 28 14S 2W	Alexander		Chert (?)	
107	SE NE NE 28 14S 2W	Alexander	Birk open pit, Unimin Specialty Minerals, Elco, IL	Microcrystalline silica	

(continued)

Site	Status	Formation	Comments	Source
Mill Creek *(cont.)*				
92	Inactive open cut mine	Clear Creek Chert	About 12 m (38 ft) of Fe_2O_3-stained chert chert and microcrystalline silica is exposed in E-W trending face. Below this is about 2.5 m (8 ft) of white microcrystalline silica that is underlain by hard chert beds.	
93	Prospect adit	Clear Creek Chert	Not examined.	Levine 1973, plate 1
94	Inactive adit mine	lower Mississippian Fort Payne Formation (2)	Not examined. Located north of site 95. Locations noted by Lamar on a copy of plate 1 (2) but workings may have also been in Sec. 18 (1).	1) Schroyer ca 1918 2) Weller and Ekblaw 1940
95	Inactive adit room and pillar mine active in 1918 (1)	lower Mississippian Fort Payne Formation (2)	Not examined. About 14 cars shipped. Location in irreg. sec. 3,300 ft E (1,006 m), and 800 ft S (244 m) of NW corner (1947 Mill Creek, 7.5-min. quad.) See "Mines and Prospects" section.	1) Schroyer ca 1918 2) Weller and Ekblaw 1940
96	Inactive adit mine	lower Mississippian Fort Payne Formation (2)	Not examined. Location near site 95 and is from locations plotted by Lamar on plate 1 (2). See "Mines and "Prospects" section.	1) Schroyer ca 1918 2) Weller and Ekblaw 1940
97	Prospect adit	Clear Creek Chert	Not examined.	Levine 1973, plate 1
98	Inactive adit mine or prospect (map not clear).	Clear Creek Chert	Not examined.	Levine 1973, plate 1
99	Prospect adit ?	Clear Creek Chert	Not examined.	Levine 1973, plate 1
100	Inactive adit room and pillar mine	Clear Creek Chert	This mine has entries on both sides of ridge (see fig. 39) and may be connected with sites 97 and 98. Microcrystalline silica mined from under this narrow ridge crest.	
101	Inactive adit room and pillar mine	Clear Creek Chert	Not examined.	Levine 1973, plate 1
102	Inactive adit room and pillar mine	Clear Creek Chert	Float indicates massive uppermost chert beds in Clear Creek Chert cap ridge above mine. Subsidence on ridge above this mine.	
103	Inactive adit room and pillar mine (map not clear)	Clear Creek Chert	Not examined.	Levine 1973, plate 1
104	Inactive	Clear Creek Chert or Grassy Knob Chert		Lamar 1953
105	Inactive adit or prospect	Clear Creek Chert	Seen from highway.	
106	Inactive quarry	Clear Creek Chert	Probably an aggregate quarry. Cut about 12 m (about 39 ft) high. No white microcrystalline silica beds.	
107	Active surface mine	Clear Creek Chert	Source of high quality microcrystalline silica. See "Mines and Prospects" section. Processing plants at Elco and Tamms.	

Site	Location 1/4 1/4 1/4 Sec. T. R.	County	Mine name, owner /operator	Major products	Development
Mill Creek *(cont.)*					
108	SW NW SE 27 14S 2W	Alexander		Microcrystalline silica	
109	NE SW SE 27 14S 2W	Alexander	Birk No. 2, Unimin Specialty Minerals, Elco, IL	Microcrystalline silica	
110	NW 25 14S 2W	Alexander	Star Silica Co. (1)	Microcrystalline silica	
111	NE NE NE 35 14S 2W	Alexander	Novaculite Paving Co. (1)	Microcrystalline silica or ganister	
112	SE NE NE 35 14S 2W	Alexander	Novaculite Paving Co. (1)	Microcrystalline silica or ganister	
113	SE NE NW 36 14S 2W	Alexander	Jordan Novaculite Quarry, Markgraf Materials Co.	Chert and maybe ganister	Quarry estimated to be 200 ft (61 m) high, 800 ft (244 m) wide and extends 1000 ft (305 m) into the bluff
Thebes 7.5-Minute Quadrangle					
114	E NE 4 15S 3W	Alexander	International Silica Co. (1)	Clay and maybe microcrystalline silica (?)	
115	SW SE 4 15S 3W	Alexander		Microcrystalline silica	
Tamms 7.5-Minute Quadrangle					
116	NW 2 15S 2W	Alexander	Tamms Silica Co. (1)	Microcrystalline silica	
117	NW 2 15S 2W	Alexander	Alexander Silica Co. (1)	Microcrystalline silica	

(continued)

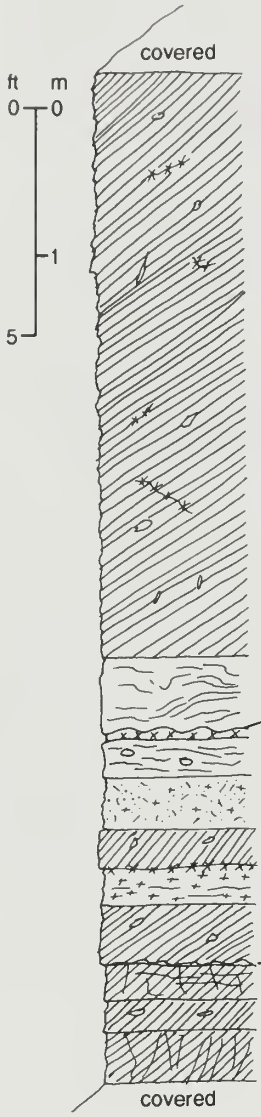
Site	Status	Formation	Comments	Source
Mill Creek *(cont.)*				
108	Inactive adit room and pillar mine	Clear Creek Chert	Not examined. Shown by symbol on USFS version of Mill Creek 7.5-min. quad.	
109	Active adit room and pillar mine	Clear Creek Chert	Source of high quality microcrystalline silica. See "Mines and Prospects" section. Processing plants at Tamms and Elco.	
110	Inactive adit room and pillar mine	Probably Clear Creek Chert	Not examined. There was a working face of 21 ft (6.4 m) of white silica with a few traces of harder beds, and the full thickness had not yet been penetrated (1).	1) Parmelee and Schroyer 1918–1920
111	Inactive adit room and pillar mine	Clear Creek Chert or Grassy Knob Chert	Not examined. Location from Jonesboro 15-min. quad. Field notes (1) mention what must be sites 111 and 112. One was abandoned because of poor roof and the other because of too much Fe_2O_3-stain.	1) ISGS Ind. Min. Field notes, 7/20/27
112	Inactive adit room and pillar mine	Clear Creek Chert or Grassy Knob Chert	Not examined. Location from Jonesboro 15-min. quad. Field notes (1) mention what must be sites 111 and 112. One was abandoned because of poor roof and the other because of too much Fe_2O_3-stain.	1) ISGS Ind. Min. Field notes, 7/20/27
113	Inactive quarry	Grassy Knob Chert with possibly some Clear Creek Chert near top of quarry	In recent years material mined from this deposit was mainly used for road gravel and skid-resistant aggregate. It was most likely originally used for railroad ballast (1). Novaculite Gravel Co. also worked the quarry in the bluff 2000 ft (600 m) to the south (2). See "Mines and Prospects" section.	1) Savage 1908 2) Lamar 1973
Thebes 7.5-Minute Quadrangle				
114	Inactive since about 1933, room and pillar adit mine	Bailey Limestone	Not examined. Adit driven into south bluff of Sandy Creek (2), mined 5–8 ft (1.5–2.4 m) bed of clay. Test results on clay reported by Lamar (1).	1) Lamar 1948 2) Cook 1979
115	Inactive	Bailey Limestone	Not examined. Lamar reported (1953, p. 15) "small amounts of silica were once mined from the Bailey Formation near Thebes, but little else is known about the silica possibilities of the formation." Location inferred from Lamar 1953, fig. 2.	Lamar 1953
Tamms 7.5-Minute Quadrangle				
116	Inactive mine	Grassy Knob (2) (Upper) Chert	Not examined. It is probably one of two mines plotted by Lamar on a copy of plate 1 (2).	1) Parmelee and Schroyer 1918–1920 2) Weller and Ekblaw 1940
117	Inactive mine	Grassy Knob (2) (Upper) Chert	Not examined. It is probably one of two mines plotted by Lamar on a copy of plate 1 (2).	1) Parmelee and Schroyer 1918–1920 2) Weller and Ekblaw 1940

Site	Location 1/4 1/4 1/4 Sec. T. R.	County	Mine name, owner /operator	Major products	Development
Tamms *(cont.)*					
118	SE SE SE 29 15S 2W	Alexander	Olive Branch Minerals Co. (1)	Crushed chert (3,4), microcrystalline silica and clay (1)	
119	SE NW SW 28 15S 2W	Alexander	Olive Branch Minerals Co. (1)	Microcrystalline silica and clay (1,2)	
120	SE SE NW 28 15S 2W	Alexander	Egyptian Gravel or Egyptian Novaculite Co. (?) (1). Also operated at site 118.	Crushed chert (3) and microcrystalline silica (?)	

(continued)

Site	Status	Formation	Comments	Source
Tamms *(cont.)*				
118	Inactive quarry	Grassy Knob Chert (2) or transition zone with Bailey Limestone	Abundant white but firm microcrystalline silica with soft white chert beds and thin beds and nodules of medium to hard, light gray chert. Foundation for mill is overgrown by brush. Quarry visible from road.	1) Lamar 1948 2) Weller and Ekblaw 1940 3) ISGS Ind. Min. field notes 8/9/27 4) Lamar 1973
119	Inactive adit and pillar mine	Grassy Knob Chert or transition zone with Bailey Limestone	Some roof fall, about average for these underground mines. Small folds and faults. See "Mines and Prospects" section. Incorrectly shown as a shaft mine on 1967 Tamms 7.5-min. quad. Current landowner Henry Shoemaker.	1) Lamar 1948 2) ISGS Ind. Min. field notes 8/9/27
120	Inactive quarry	Grassy Knob Chert (2)	Abundant hard chert beds with microcrystalline silica rinds. Foundations for crusher partly overgrown by brush. Current landowner Henry Shoemaker.	1) Parmelee and Schroyer 1918–1920 2) Weller and Ekblaw 1940 3) ISGS Ind. Min. field notes 8/9/27

APPENDIX B



hard chert, flinty, iron oxide stained, generally highly fractured, gray clay in cavities and along irregular fractures, some ovoid cavities, some cylindrical cavities a few mm in diameter; bedding not recognizable in lower 3 m, 4 m

hard chert, sugary, small scale wavy soft sediment-like structures, 52 cm

relief up to 6 cm on this surface

gray plastic clay (TRB-152), 0-3 cm

hard chert, light gray, flinty, some small scale wavy soft sediment-like structures, a few small cavities, 23 cm

medium hard chert, soft chert, microcrystalline silica, gray clay, mixed in variable proportions, 35 cm

hard chert, flinty, gray, some irregular cavities, moderately fractured, 28 cm

medium hard chert, some small brachiopods, some irregular lamellar structures, 23 cm

hard chert, light gray, flinty, some ovoid cavities a few cm across, 42 cm

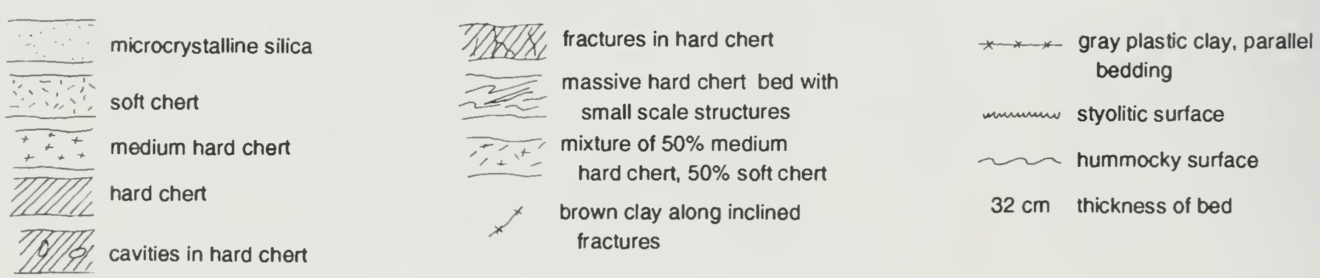
up to 5 cm relief on this surface

hard chert, highly fractured, flinty, a few small scale wavy soft sediment-like structures, 22 cm

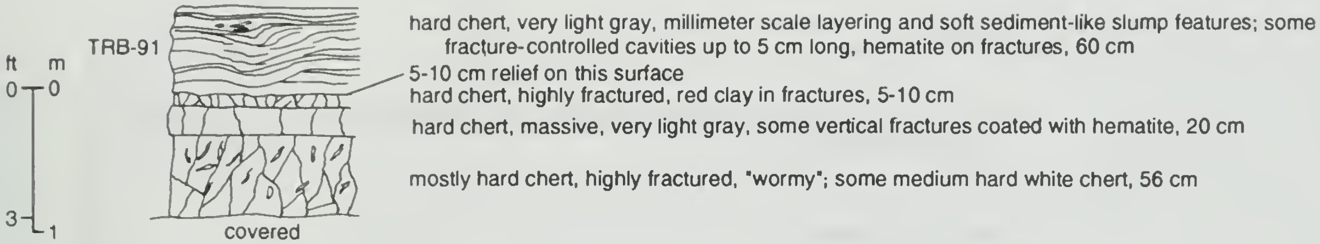
hard chert, flinty, gray, a few ovoid cavities, 20 cm

hard chert, light gray, flinty, highly fractured, 38 cm

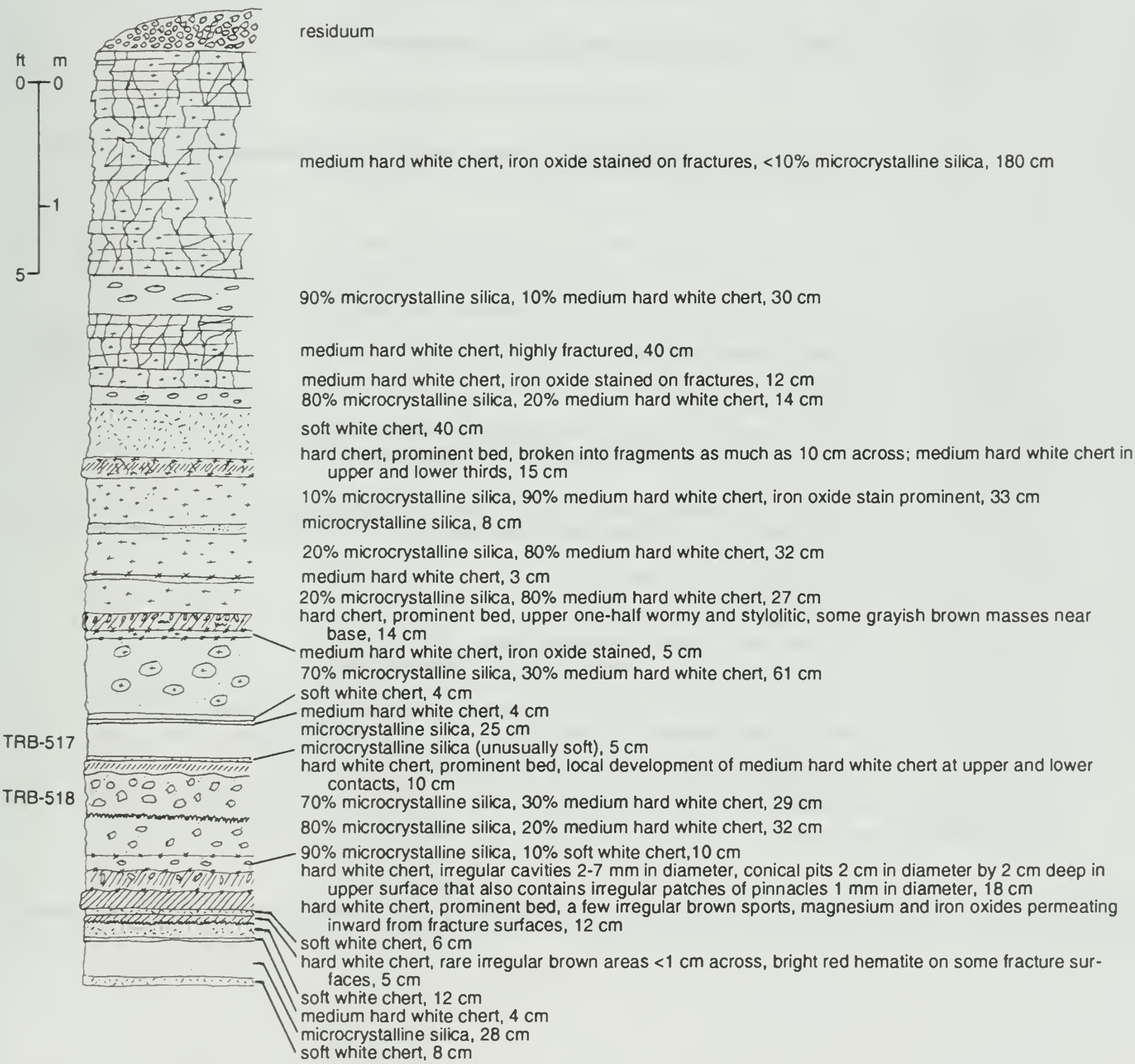
explanation for Sections 1 through 10



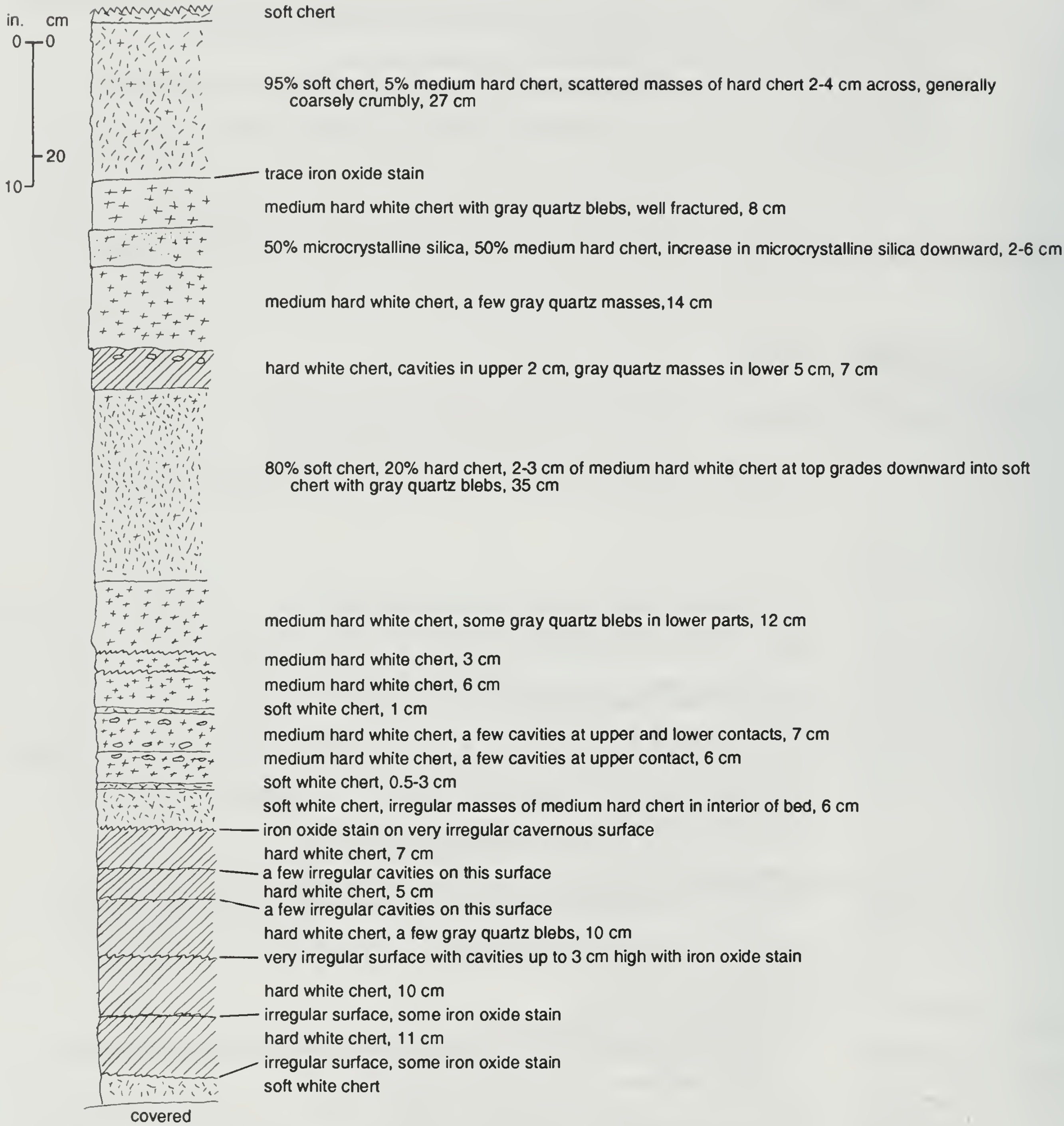
Section 1 Uppermost chert beds in the Clear Creek Chert exposed in the south cut of the Lone Star mine (site 65, appendix A and plate 1).



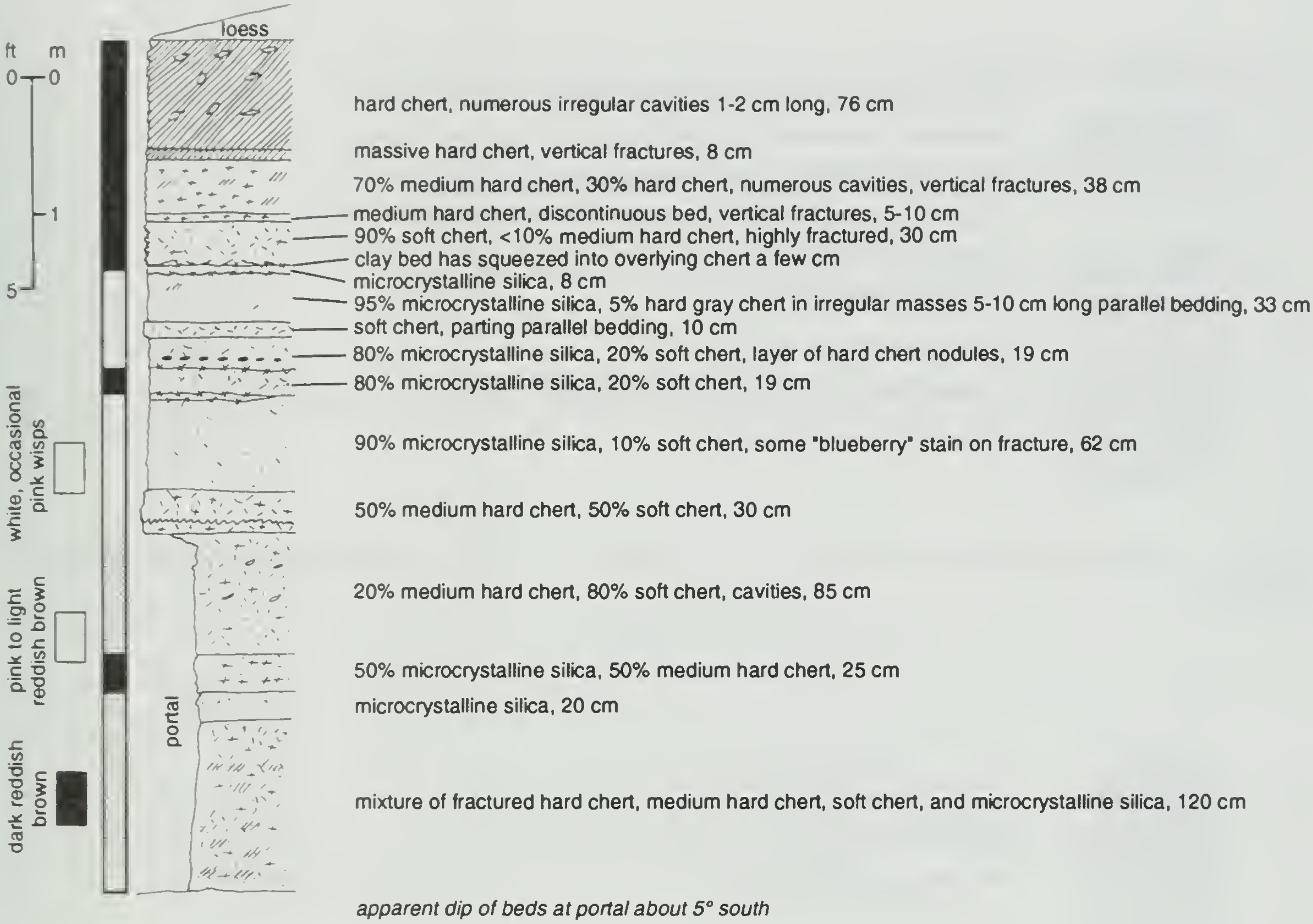
Section 2 Lower part of the sequence of uppermost chert beds in the Clear Creek Chert exposed in the south cut of the Lone Star mine (site 65, appendix A and plate 1).



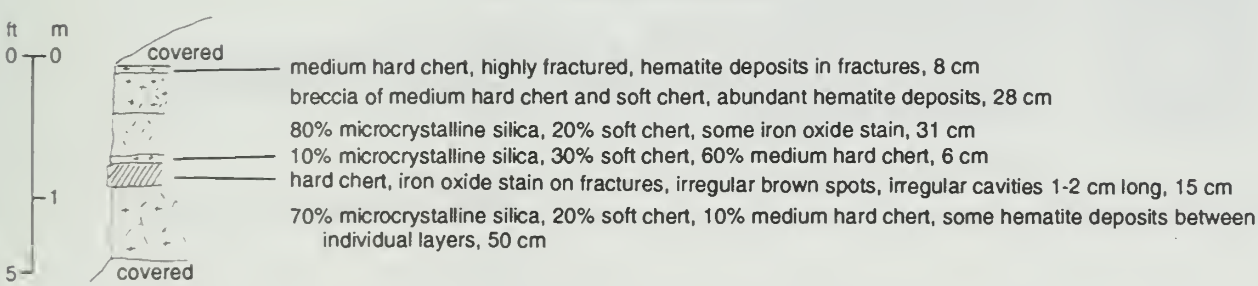
Section 3 Clear Creek Chert exposed on the south wall of the north pit (fig. 16) at the Lone Star mine (site 65, appendix A and plate 1).



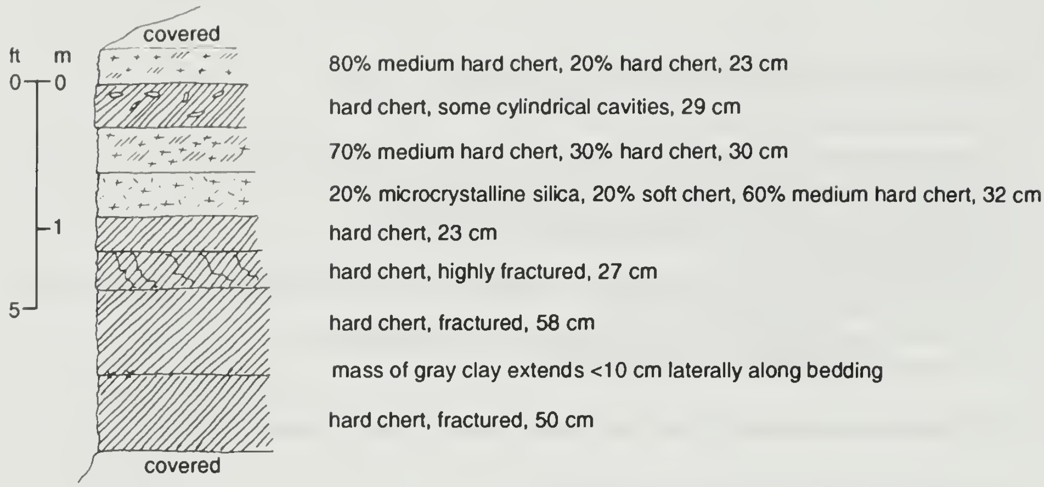
Section 4 Clear Creek Chert exposed in the bottom of a cut in the north pit (fig. 16) of the Lone Star mine (site 65, appendix A and plate 1).



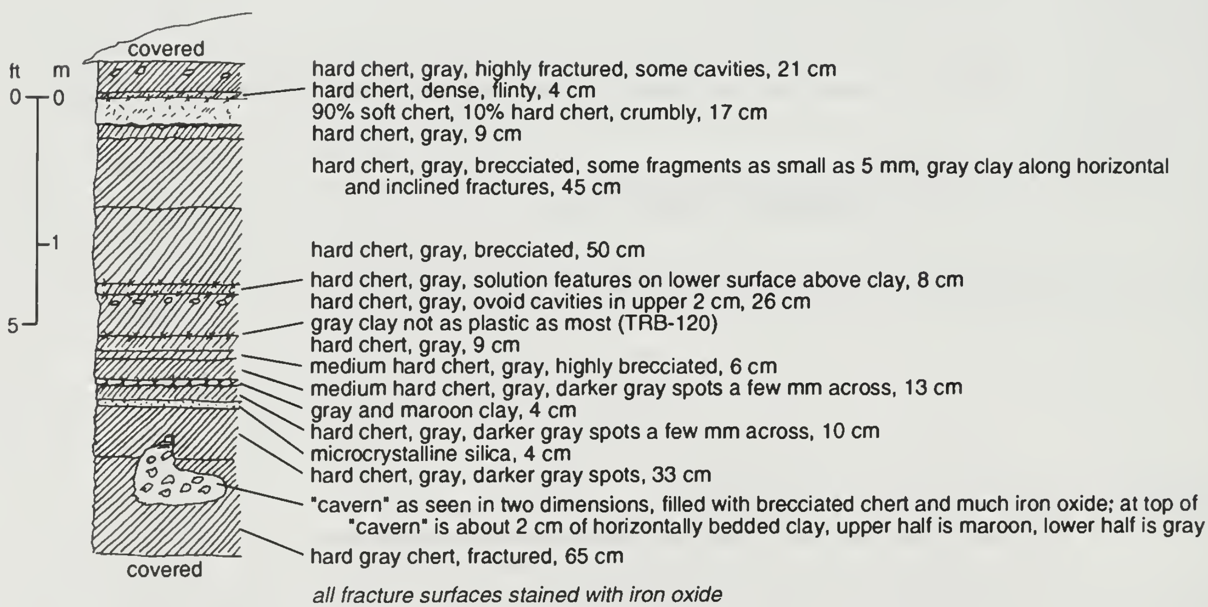
Section 5 Clear Creek Chert exposed at the portal of an adit mine (site 61, appendix A and plate 1).



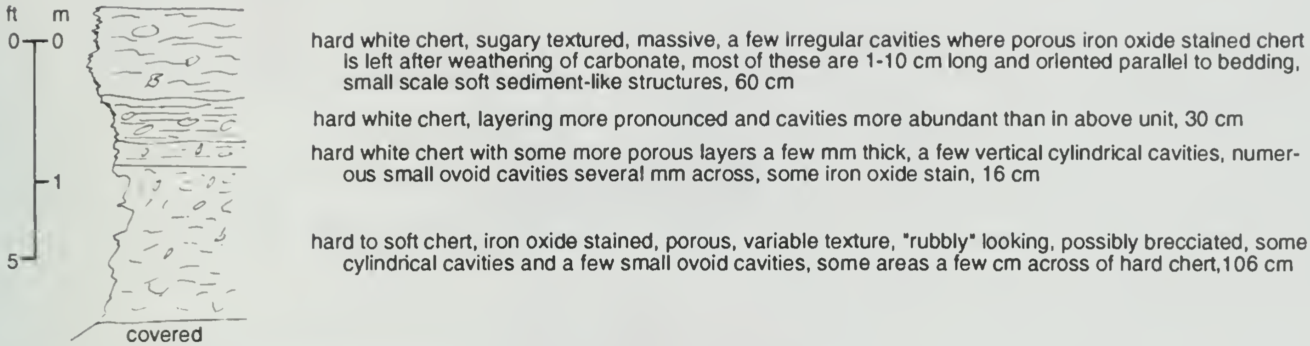
Section 6 Small exposure of Clear Creek Chert in a prospect cut in the SE NW NW, Section 15, T14S, R2W (near site 64, plate 1).



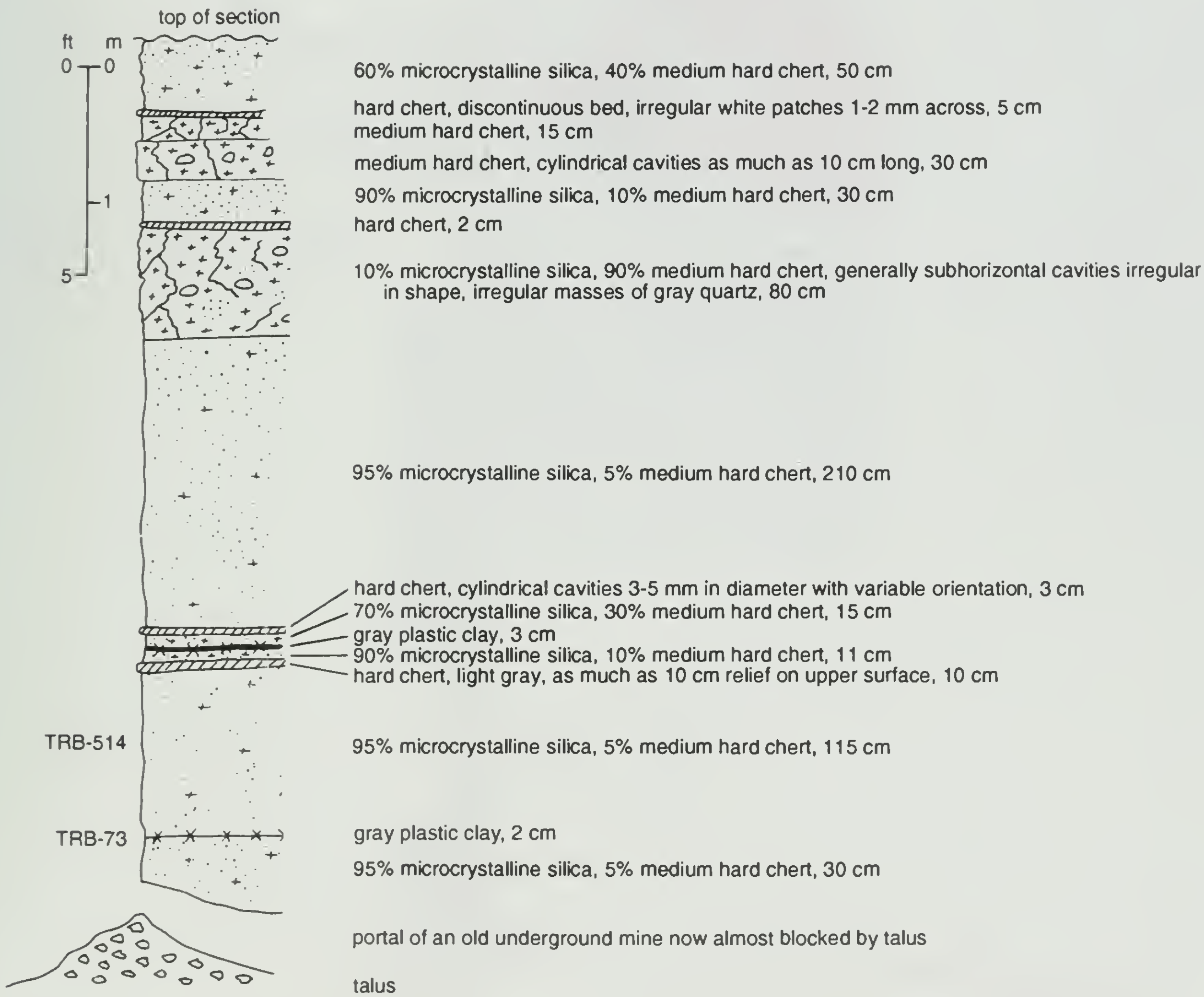
Section 7 Natural exposure of Clear Creek Chert at creek level on the east side of a gully in the SE NE NE, Section 16, T14S, R2W.



Section 8 Small exposure of Clear Creek Chert visible from the road in the NW NE NE, Section 16, T14S, R2W.



Section 9 Exposure of the uppermost chert beds in the subsidence area, very close to the center of Section 11 (site 39, appendix A and plate 1).



Section 10 Exposure of the Clear Creek Chert in the Jason mine (site 8, appendix A and fig. 5). See figure 19 for the location of the described section in the mine.

TIME STRATIGRAPHY		ROCK STRATIGRAP
Cretaceous?	Kc	Tuscaloosa Fm (?), c
Middle Devonian	Ddc	Dutch Creek Sandsto
Lower Devonian	Dccu	Clear Creek Chert, m
	Dcc	Clear Creek Chert

7 — attitude of inclined be

horizontal beds

80 D U — attitude of inclined fa (degrees, U = upthro

vertical fault

? ? lithologic contact appr

16 — adit of inactive silica

18 — exploratory adit (site

17 — adit caved at portal (s

15 — prospect cut (site nun

open cut silica mine, to appendix A)

area of subsidence

N 0 1000 2000 ft; 0 500 m

cont
base
Qua

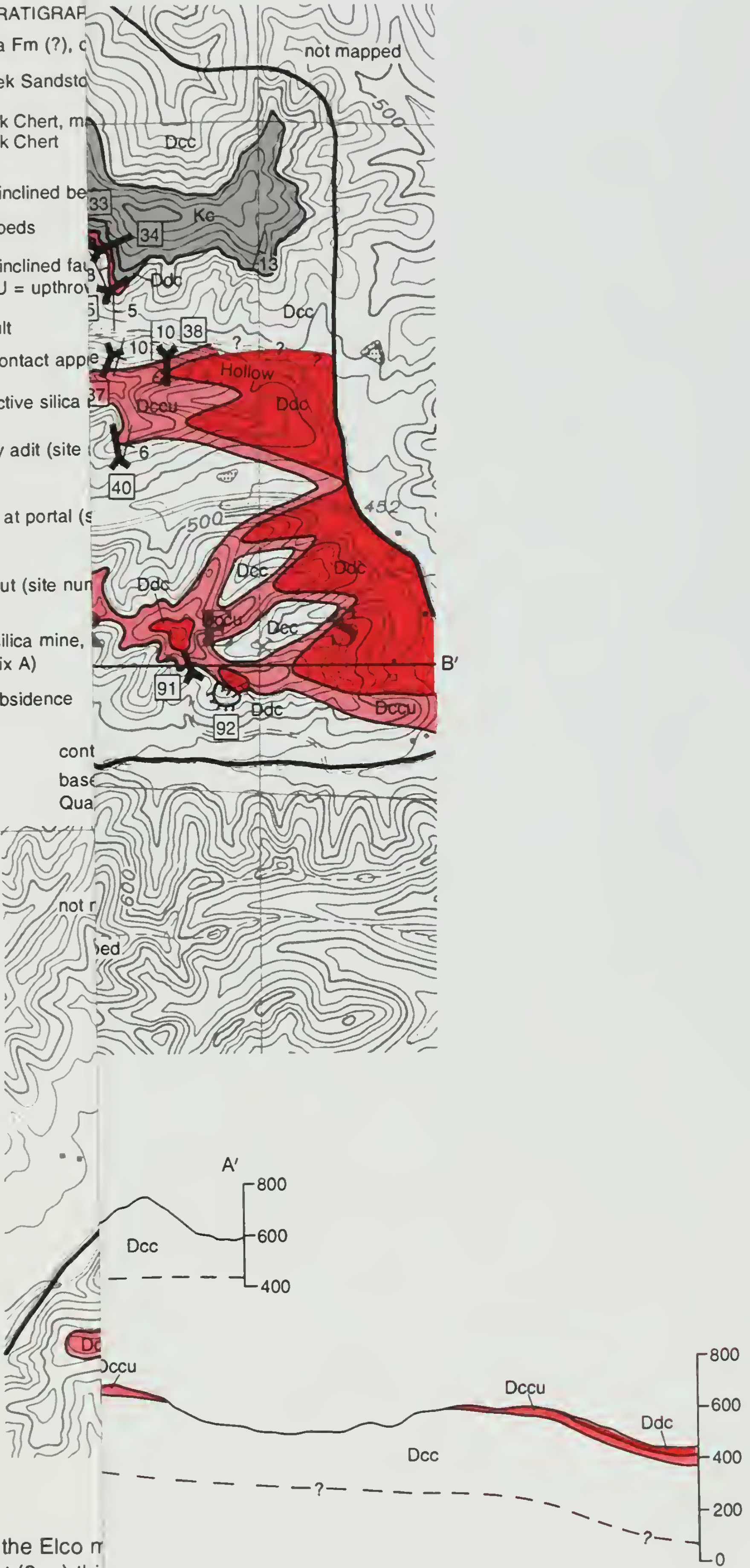


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Plate 1 Geologic map of part of the Elco m
Quaternary deposits up to 30 feet (9 m) thic

TIME STRATIGRAPHY		ROCK STRATIGRAPHY
Cretaceous?	Kc	Tuscaloosa Fm (?), chert-pebble conglomerate
Middle Devonian	Ddc	Dutch Creek Sandstone Member, Grand Tower Limestone
Lower Devonian	Dccu	Clear Creek Chert, massive chert beds at top
	Dcc	Clear Creek Chert

- 7 — attitude of inclined beds (degrees)
- horizontal beds
- 80 D U — attitude of inclined fault showing relative movement (degrees, U = upthrown, D = downthrown)
- vertical fault
- ? ? — lithologic contact approximate; queried where inferred
- 16 — adit of inactive silica mine (site number refers to appendix A)
- 18 — exploratory adit (site number refers to appendix A)
- 17 — adit caved at portal (site number refers to appendix A)
- 15 — prospect cut (site number refers to appendix A)
- open cut silica mine, hachures on high wall (site number refers to appendix A)
- area of subsidence

N 0 1000 2000 ft; 0 500 m

contour interval 20 feet

base map enlarged from Mill Creek 7.5-Minute Quadrangle (1947, photorevised 1990)

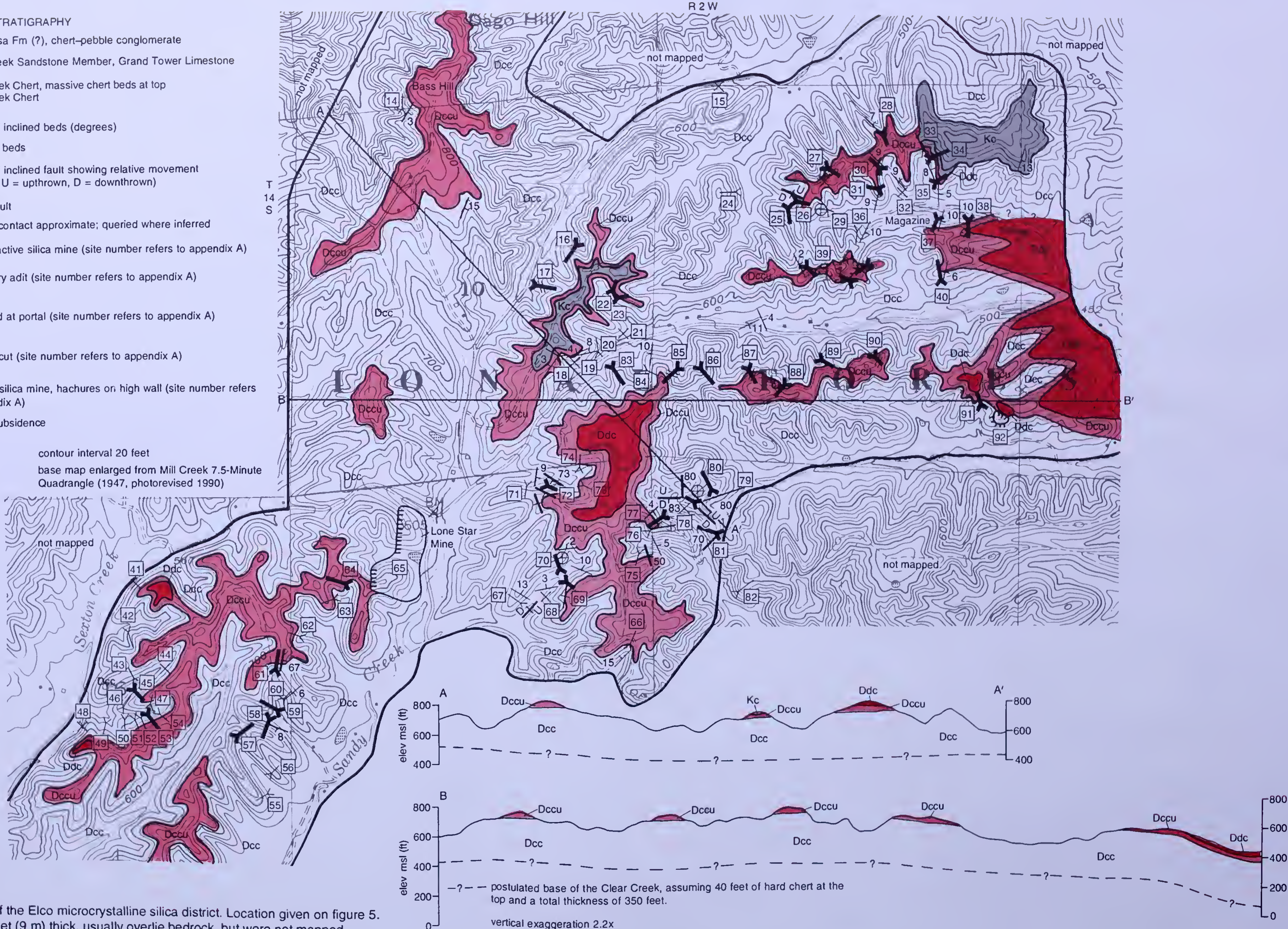

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Plate 1 Geologic map of part of the Elco microcrystalline silica district. Location given on figure 5. Quaternary deposits up to 30 feet (9 m) thick, usually overlie bedrock, but were not mapped.