Association of Missouri Geologists

37th Annual Field Trip and Meeting

September 28–29, 1990

Field Trip Guidebook

Stratigraphy of the Rolla Area

by

Alfred C. Spreng and Robert C. Laudon

and

Geology of the East-Central Missouri Fireclay District

by

Charles E. Stack and James F. Westcott

ASSOCIATION OF MISSOURI GEOLOGISTS

37th ANNUAL MEETING AND FIELD TRIP

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HOST: A. P. Green Refractories
and
The University of Missouri, Rolla

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FRIDAY AFTERNOON FIELD TRIP

STRATIGRAPHY OF THE ROLLA AREA

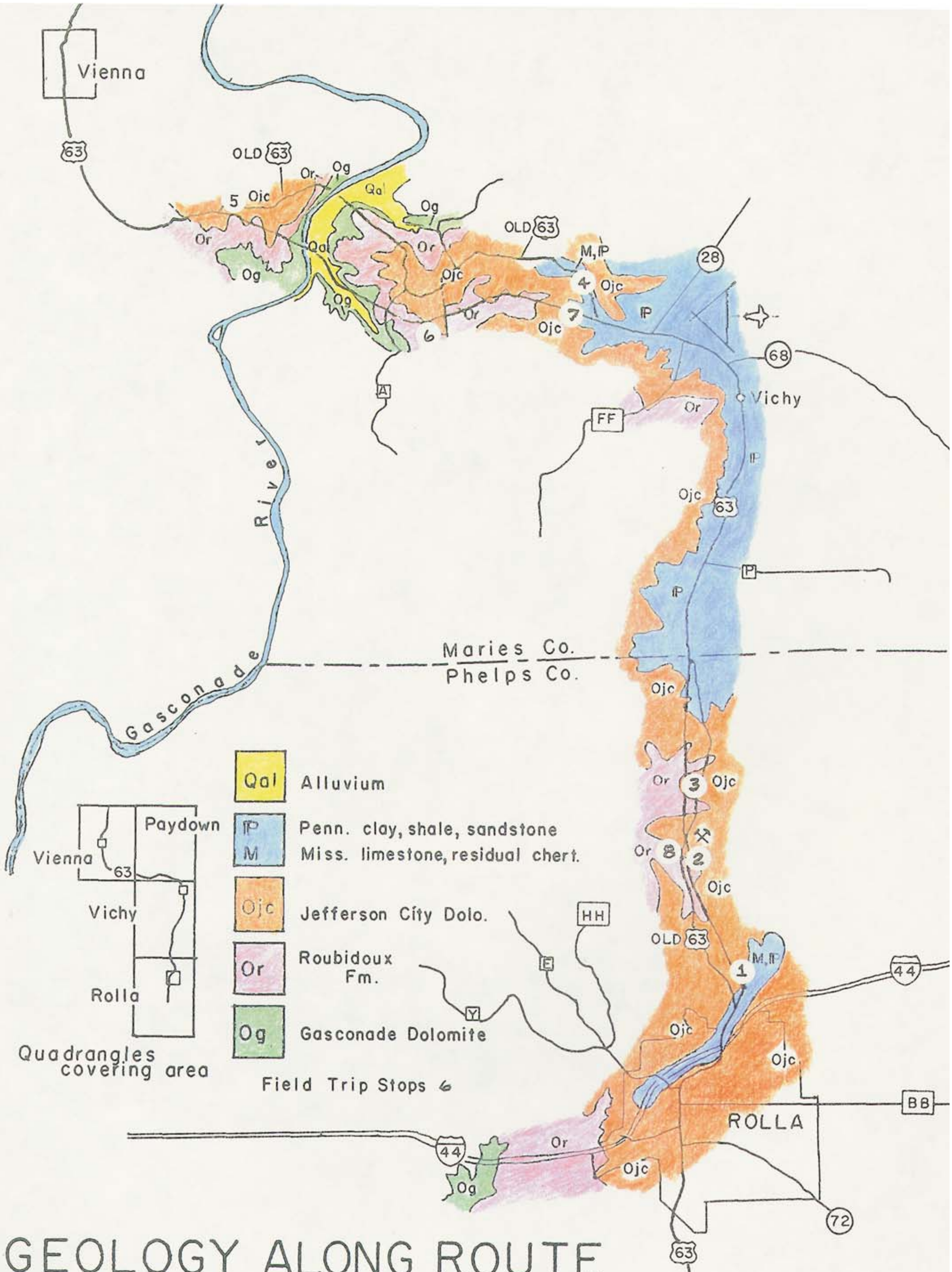
by

Alfred C. Spreng and Robert C. Laudon

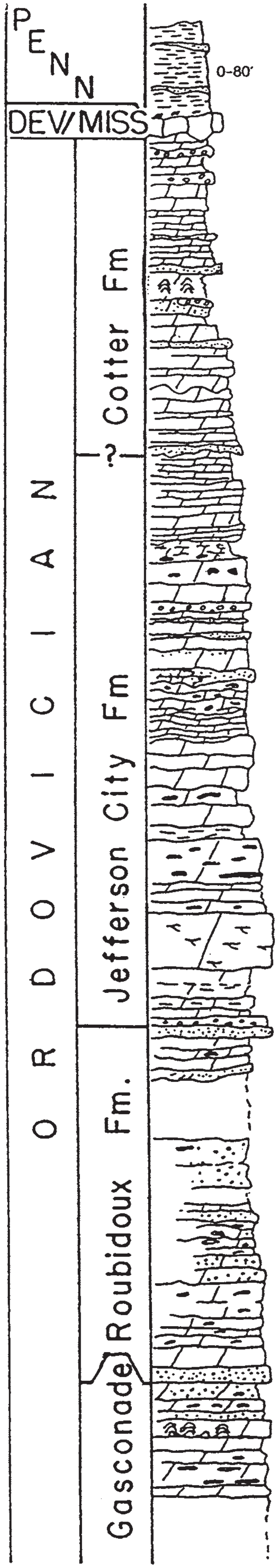
Field trip instructions:

All field trips will leave from the south side of the McNutt Building on 14th street. Friday afternoon field trip will leave at 1:00 P.M.

Saturday morning field trip will leave at 8:00 A.M. Saturday lunch will be at Cricket's (Dutch Treat) in Owensville.



GEOLOGY ALONG ROUTE of FRIDAY FIELD TRIP



0-80' PENN: Shale, maroon and gray; sandstone and clayey sandstone. Thickest in sink fills and under Springfield Plateau.

MISS: Fossiliferous chert and rare limestone.

DEV?: Massive brown chert.

100' Dolomite, brown to buff, thin- to thick-bedded, green shale partings; thin reddish brown sandstone layers and silicified, oolitic cherts distinctive.

Location of Jefferson City-Cotter contact uncertain.

170' Dolomite, mostly buff and tan, fine-grained ("cotton rock"), thin- to medium-bedded; parts that have thin shale layers or partings are usually mud-cracked; fossils (gastropods, trilobite pygidia, cephalopods and algal mounds) occur as molds and in chert; more fossiliferous here than the Cotter.
Massive gray fucoidal dolomite ("Quarry Ledge") near the base is useful horizon for mapping.

(8-12') "Quarry Ledge"

– "Maries County Oolite"

80-140? Poorly exposed in field trip area.
Sandstone and dolomite. Sandstone, red, ripple-marked; not as well indurated as south and west of Rolla. Dolomite, buff, cherty and sandy. Chert is often gray, sandy, and oolitic. Dolomite dominant in lower portion of formation. Algal mounds, often silicified, developed at top of some dolomite layers.

260-290' Dolomite and cherty dolomite. Only the upper part of the Gasconade is exposed in the field trip area. This part contains little chert and is mainly a medium- to thick-bedded dolomite. Some of the dolomite layers near the Roubidoux contact contain broken inch-wide chips of chert. The contact with Roubidoux is marked by a three-foot thick sandstone. The contact with the underlying Eminence is recognized in the subsurface by a thin sandstone (Gunter Sandstone Member).

GENERALIZED SECTION FOR FIELD TRIP AREA

FIELD TRIP LOG

Mileage

0.0 Assembly area. UMR parking lot 13 south of McNutt Hall and east of the Bureau of Mines Laboratory/Office.

Depart from north side of lot and turn left (west).

0.2 Stop light at Bishop Ave.(Highway 63, city I-44). Turn right on Highway 63.

0.3 Stonehenge replica at northwest edge of McNutt Hall area.

This is a half-scale replica in which the solstices and equinoxes may be observed. An analemma within the structure shows the day of the year.

0.9 Stop lights at Highway 63 overpass over I-44. Continue through lights on Highway 63 north.

1.75 Pass Northwye turnoff to right (east).

1.9 STOP I . Jefferson City Dolomite; sink fills; solution features.

This roadcut exposes the upper part of the Jefferson City Dolomite as developed in the Rolla area. These beds lie about 200 ft above the Quarry Ledge Member which occurs near the base of the formation.

These dolomite layers weather to a brown color as do other higher Jefferson City beds in the field trip area. This is possibly due to more intense weathering of the beds at this locality.

The darkest brown dolomite bands contain white cherts nodules and occur in several exposures along this field trip route; sometimes there are more than one such layers in an exposure.

These layers show interesting sedimentological features; for example, the long axis of some chert nodules is not parallel to the bedding, the usual orientation. Faults of small displacements also occur in the chert nodules.

Several sinks and solution structures cap the section. Maroon and gray shales that fill the structures are presumed to be Pennsylvanian in age. Mississippian cherts occur in the sinks as well as in the intersink areas.

4.5 STOP II. Highway 63 roadcut exposure just south of Beck Quarry entrance.

Rare (unique?) reef mound at the top of the Quarry Ledge Member of the Jefferson City Dolomite. The cherts in the upper part of the mound contain trilobite pygidia and cephalons and planispired gastropods. The mound is composed of fine-grained dolomite. It contains ostracodes, small, straight cephalopods, and possible brachiopods. These fossils are associated with the mound and not with the adjacent Jefferson City beds.

4.7 Junction with old 63. Beck Materials Co. turnoff.

5.6 STOP III. Highway 63 Roadcut. Stratigraphic section on following pages.

Excellent exposure of the low to middle Jefferson City Dolomite of this area and a collapse-sink fill. Here the sink fill is quite different from that seen at the first stop at Northwye in that the fill in this exposure is entirely material from the Jefferson City Formation.

The Quarry Ledge Member (14.5 ft thick) is exposed at the south end of the cut.

7.5 Road has passed through several roadcuts involving the upper Jefferson City Formation in the lower cuts and Pennsylvanian sandstones, shales and conglomerates in the higher cuts. There are apparently no Mississippian or Devonian sediments in the cuts. More than 30 ft of Pennsylvanian is exposed at the highest cut. The total thickness of Pennsylvanian sediments which can be inferred for this area depends on whether it is a tabular deposit or whether it drapes over the Jefferson City. Up to 80 ft of Pennsylvanian sediments are encountered in well between here and Vichy.

7.7 End of new stretch of Highway 63 at County Rd 32. Also the Phelps-Maries County line.

10.6 Pine tree grove on the left.

12.0 Town of Vichy. (What can be said about it?).
Speed limit was recently raised from 35 to 45 mph. Implication?

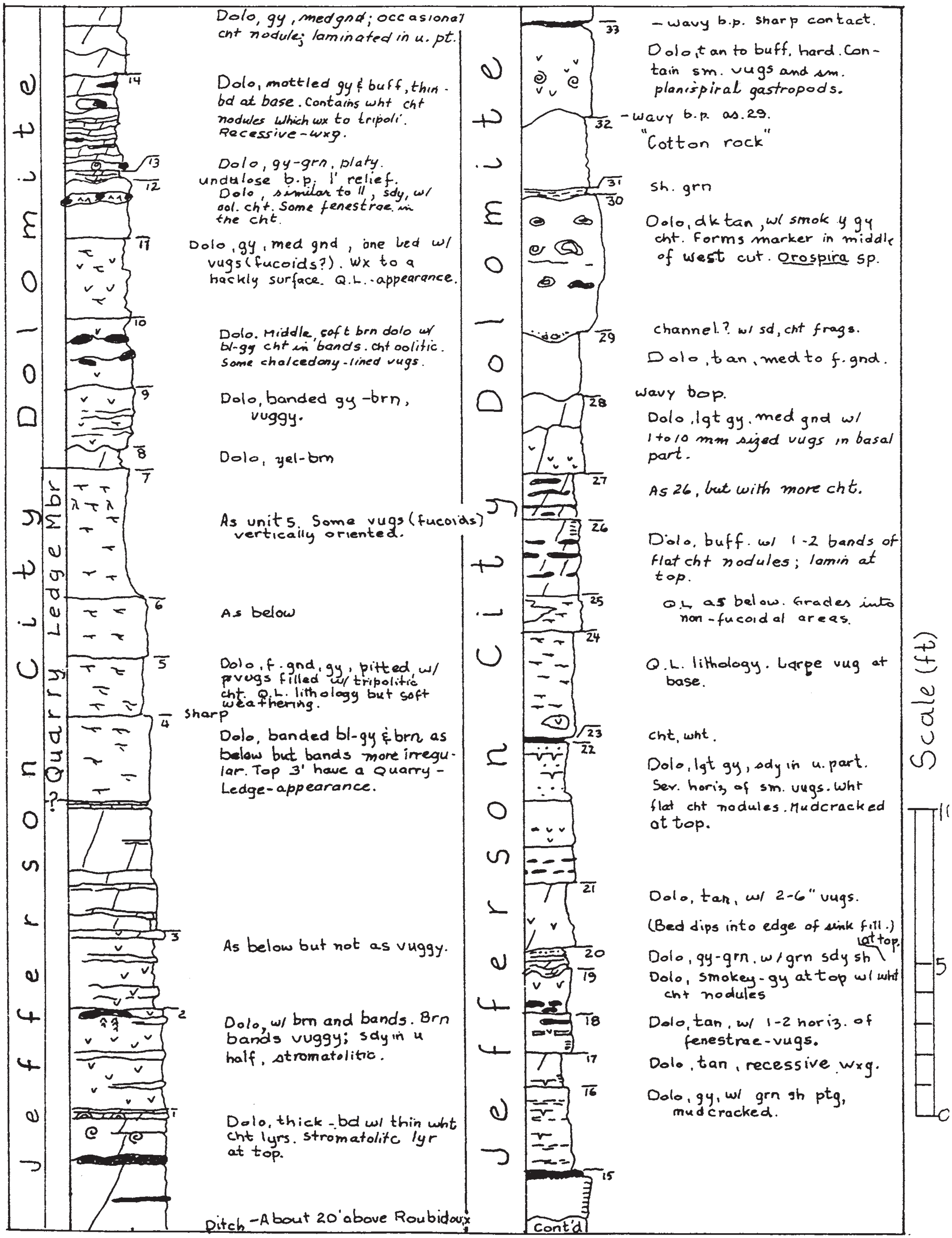
12.5 Junction with Highway 68. Stay on 63.

12.8 Vichy Airport on the right.

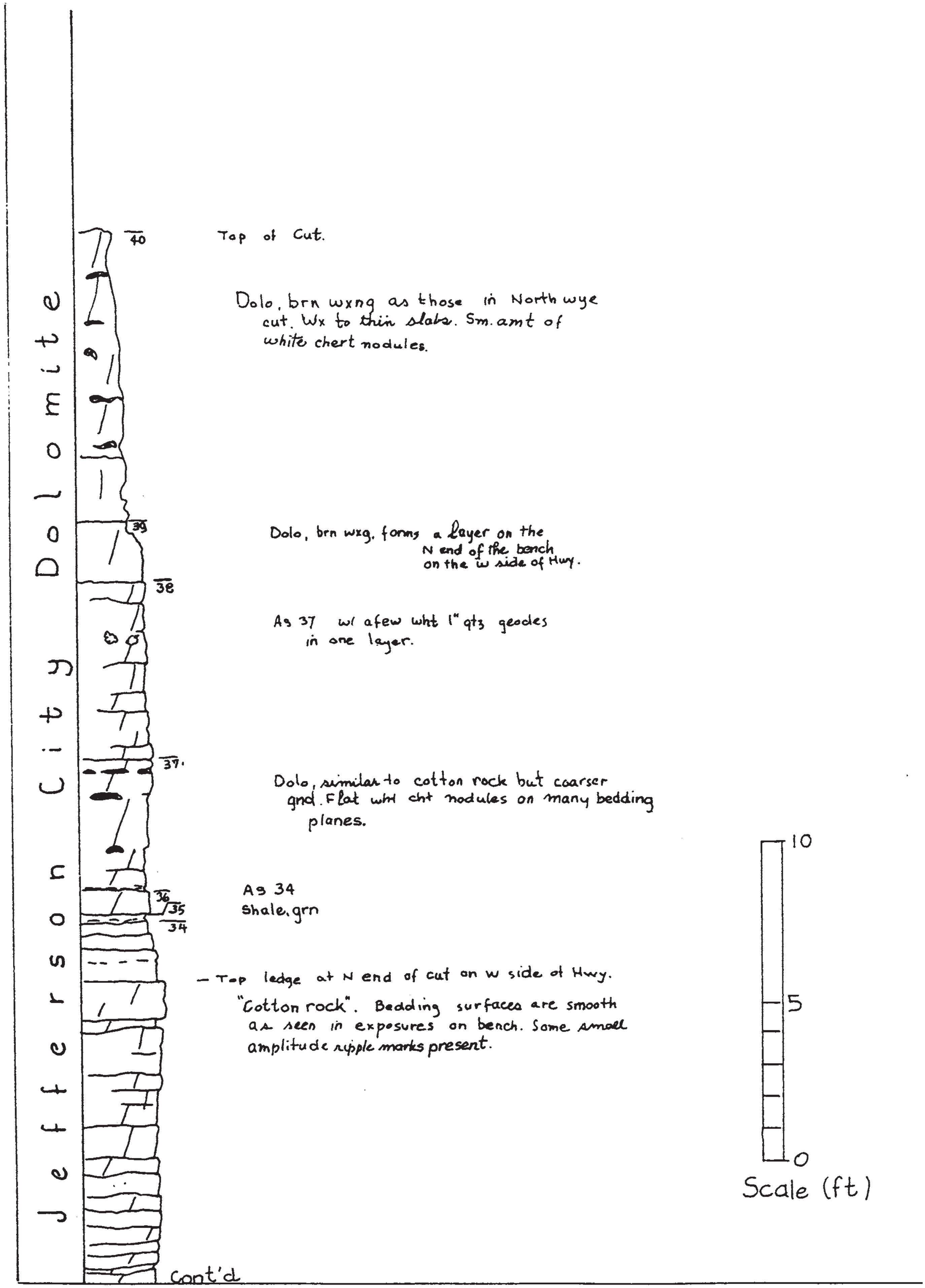
This airport was built during WWII as an emergency landing field. It has two one-mile runways and one 3500 ft runway. The airport was released to the city of Rolla in 1959. The field is located on the edge of the Salem Platform at an elevation of 1150 ft.

13.7 Junction with Highway 28. Stay on 63.

14.6 Scenic View turnoff at left. Turn right onto old Highway 63.



Roadcut section along Highway 63 at Macedonia Church



Roadcut section along Highway 63 at Macedonia Church (concl.)

14.9 Exposure in woods and along road of Pennsylvanian shale and sandstone and some Mississippian limestone and chert.

15.5 STOP IV. Viewing turnoff at left.

A good spot to view the dissected Salem Platform along the south side of the Gasconade River valley.

The old Highway 63 route has followed a narrow drainage divide after we left the airport area. The capping rock on the ridge consists of some Devonian silicified limestone, Mississippian limestone and chert and Pennsylvanian shales/clays and sandstones. Mined-out clay pits occur along the edge of the Salem Platform just to the northeast.

15.9 Vichy Fire Lookout Tower/ Spring Creek Gap State Forest picnic area. Elev. base lookout tower is 1103 ft.

Road beyond this area descends to the Gasconade River valley providing a very scenic view.

18.5 Turn left off old Highway 63 onto paved road which descends to new Highway 63.

19.1 Junction with new Highway 63. Proceed right (west) on Highway 63.

19.4 Upper Gasconade cut on the right. 2½-ft thick reef horizon can be seen at top. Roubidoux contact is above this but is not in view from the road.

20.8 Gasconade River.

Exposure just beyond (west of) bridge is the upper Gasconade Dolomite capped by the lower part of the Roubidoux Formation.

21.4 STOP V. Exposure of the Lower Ordovician section on the west side of the Gasconade River valley. See the sketched cross-section at the right.

We will stop only at the highest roadcut to look at the Jefferson City Dolomite and another of the ever-present sink structures. A graphic section for the Jefferson City is found on the following page.

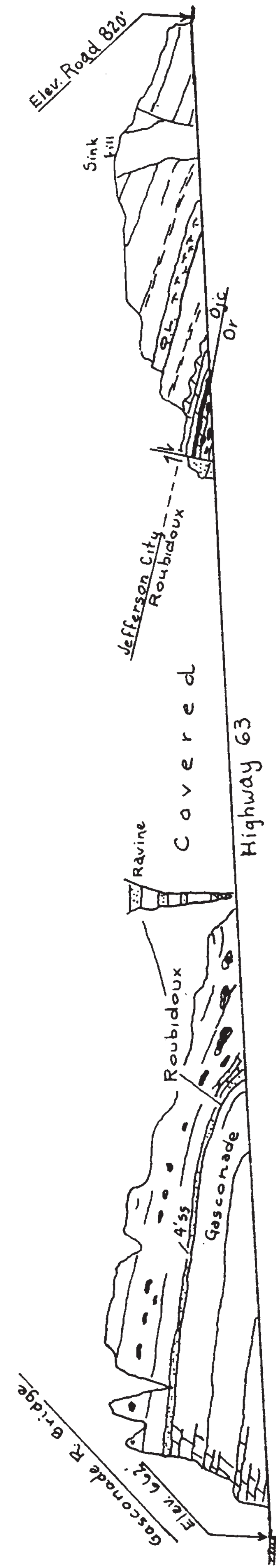
The underlying Roubidoux is mostly covered by inhospitable lespedeza which insures that the weathered red sandstones remain obscure. Well logs show that interbedded dolomites are abundant in the subsurface but been dissolved in the surface exposures.

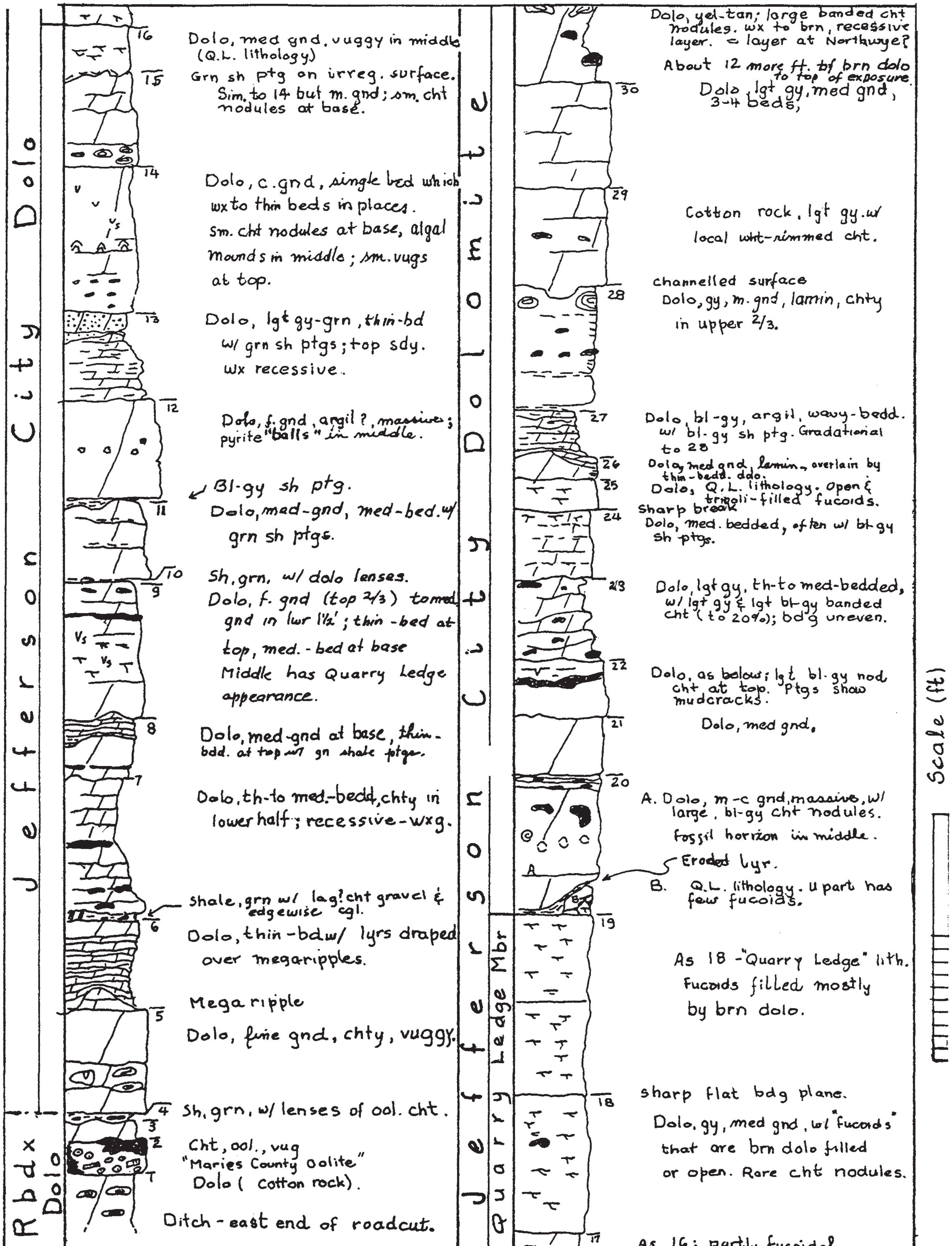
Proceed to top of hill to turn around at end of cut.

21.7 Turn around at farm road.

From here we will return to Rolla, mostly along current Highway 63.

24.0 Junction with Co.A. Continue on 63.

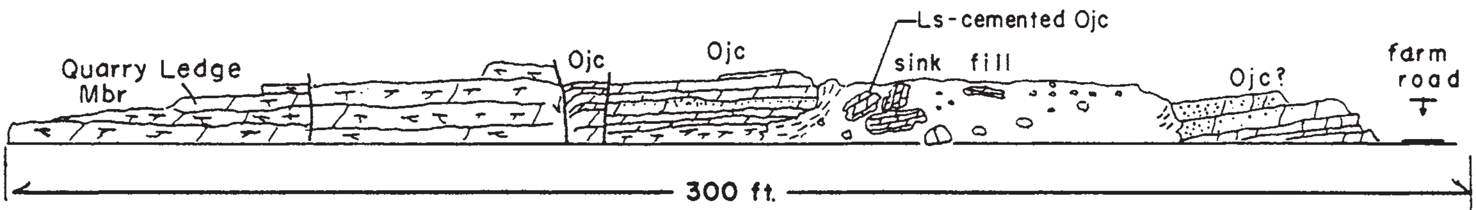




STOP V. Section in upper roadcut west of the Highway 63 Gasconade R. bridge

25.3 STOP VI. Exposure of Jefferson City, Quarry Ledge and sink fill in faulted exposure.

This filled sink in a faulted lower Jefferson City interval occurs at a lower elevation (about 725 ft) than other such sinks in the area which generally occur at an elevation of 1000 to 1150 ft. This sink also contains rocks of ages (Middle Devonian (?) / upper Middle Mississippian (?) and Burlington), not ordinarily seen in sinks in the area. Sketched cross-section below is for the roadcut on the south side of the highway.



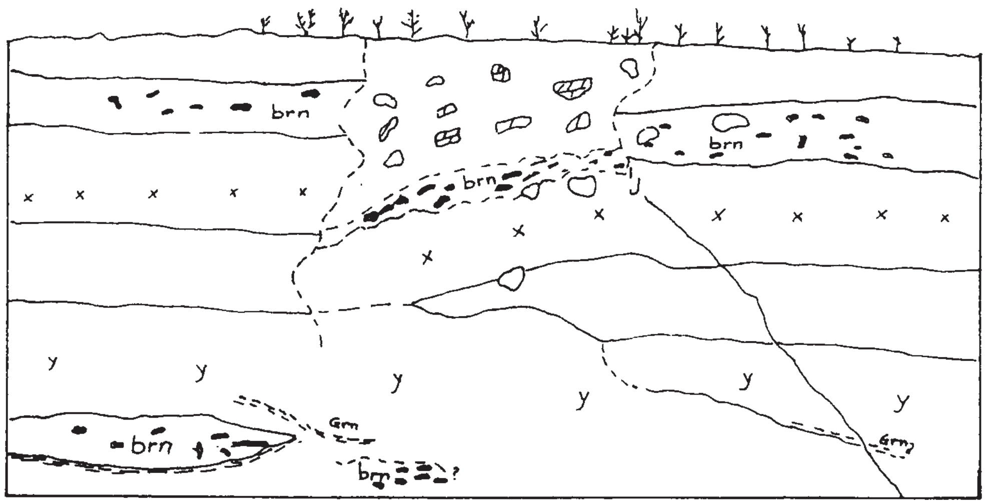
25.7 Left side of road. Exposure of sandstones in the upper Roubidoux and good exposure of the Roubidoux-Jefferson City contact. The "Maries County Oolite" marks the contact.

25.9 Exposure of Quarry Ledge on the left (north) side of the highway.

Faulted Quarry Ledge and sink structure within the Quarry Ledge. The elevation of the top of the Quarry Ledge is about 835 ft (as opposed to 725 ft at the previous stop in the valley.)

26.8 STOP VII. Series of Jefferson City-Cotter roadcut exposures on a long hill north of the Scenic View turnoff at the top of the hill. We will stop to view an incipient sink structure in the middle of the large cut. The base of the light-colored beds in the middle of the face is about 175 ft above the base of the Jefferson City Formation which is exposed at the bottom of the hill (mile 25.7). These beds would likely be placed in the Cotter based on the lower residues in this interval and the occurrence of hollow, siliceous oolites in the cherty layers in the higher beds.

Pennsylvanian sandstone and shale/clay overlie the formation and are exposed at the entrance to the Scenic View turnoff. The sketch below shows the effect of solution on the beds and structure at this stage of sink formation.



Continue south on Highway 63.

27.45 Turnoff to Scenic View area.

28.3 Junction with Highway 28.

30.0 Vichy.

31.5 Pine grove along the road on the right.

Well manicured grove of short leaf and loblolly pine along west side of highway. Several homes on the other side of the grove are located in a very scenic position overlooking the edge of the Salem Platform. The relief in the view is 250 ft.

37.4 Turn right onto <u>old</u> Highway 63 across from Beck Quarry.

37.5 <u>STOP VIII</u>. Roadcut in hill just to the northwest of STOP I on new Highway 63. Exposure is across highway from Beck Quarry.

Structures in the lower Jefferson City Dolomite. Features include incipient reef mounds(?), erosional terraces and a channel fill.

39.3 Crest of hill. Jefferson City and thin Pennsylvanian shales W.B. Howe's home on the right. Surprisingly, he avoided the Pennsylvanian as a site on which to build his home!

40.3 Roadcut behind (north of) Stop 1.
Jefferson City overlain by Pennsylvanian and some residual Mississippian.

40.5 Junction with Highway 63 at Northwye.
Turn right and retrace route back to UMR parking lot.

SATURDAY FIELD TRIP

GEOLOGY OF THE FLINT CLAY-DIASPORE AREA OF THE EAST-CENTRAL MISSOURI FIRECLAY DISTRICT.

by

CHARLES E. STACK AND JAMES F. WESTCOTT

SATURDAY, SEPTEMBER 29, 1990
FIELD TRIP
TO
FLINT CLAY - DIASPORE AREA OF
EAST-CENTRAL MISSOURI FIRECLAY DISTRICT

INTRODUCTION

The field trip area of Gasconade, Maries and Phelps Counties south of the Missouri River where the Cheltenham fire clays remain, are the remnants of widespread fire clay deposits laid down during early Pennsylvanian time. Only a fraction of the original deposits remain today due to three erosional intervals. The first was during Pennsylvanian after consolidation of the fire clay but before the deposition of an overlying green shale which presumably is of pre-Ft. Scott Age, the second occurred during the Ozark Uplift with the development of the valleys of the Missouri, Gasconade and Osage Rivers. The third was during Pleistocene and Holocene times.

The end result is that the remaining fire clay deposits occur only on the high peneplain areas not eroded by the downcutting valleys and in those areas where only the deeper sinks were developed. The underlying Ordovician formations dip to the north from the Ozark Dome and form the weathered karst topography upon which the Cheltenham clays were deposited.

There are a number of regional anticlines in the southern district where much of the Cheltenham clay has apparently been removed leaving only the deeper sink structures. Conversely, in a few areas a regional syncline has preserved most of the clays such as at the Farnberg and Bueker deposits in central Gasconade County (STOP #2) and the Jett pit north of Belle, Mo.

ROAD LOG

Mileage

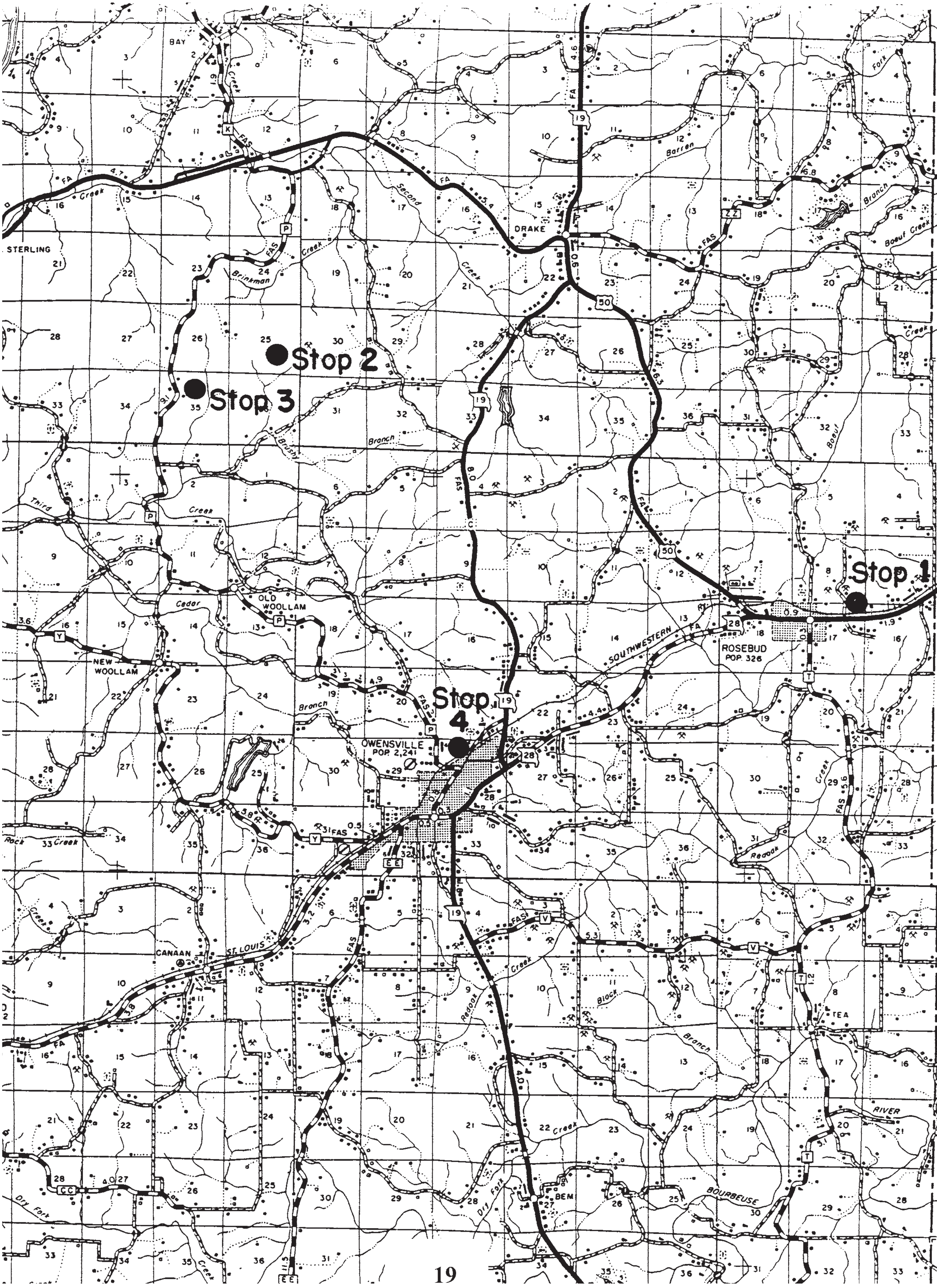
0	Zero odometer at V. H. McNutt Hall, UMR. Go North on U. S. Highway 63. Proceed North from Rolla to Vichy. There are a few fireclay pits, mostly East of the highway.
11.2	Village of Vichy - Worked fireclay pit on West side of highway at entrance to Vichy.
12.8	Junction U.S. Hiway 63 & Mo. Hiway 28 - Turn Right (North) on Hiway 28. Rolla Airport on Right of Highway - several fire-clay pits have been worked to the West.
17.9	Lanes Prairie - A number of fireclay pits occur in this area.
25.3	Belle, Mo. - A very productive area in past years for both high alumina and flint clay. Several stockpile areas are located in this area with clays being shipped in years past by rail to firebrick plants in north Missouri.
30.7	Bland, Mo. - A large number of fireclay pits occur East of Bland extending Eastward into the Owensville area.
35.0	Canaan, Mo. - Several large mined out clay pits have been used for landfill purposes in this area.
38.1	General Chemical Calcining Plant north of railroad. Flint fireclay was semi-calcined as the initial step in the manufacture of alum. The plant has been shut down for several years.
39.0	Owensville, Mo. - Stop Light - Continue East on Mo. Hiway 28.
44.4	Junction of U.S. Hiway 50 & Mo. Hiway 28 - turn Right (East) on U.S. 50. Between Owensville & Hiway 50, many diaspore and flint clay pits have been found and mined.
45.3	Rosebud, Mo. - Large stockpile areas are in and around Rosebud.
45.8	Turn Left (North) on Idel Road - Rail crossing at this point.
45.9	**STOP #1--M. HUERNER FLINT PIT #5**
46.1	Cross railroad and turn Right (return West on U.S. Hiway 50).
47.5	Junction U.S. Hiway 50 & Mo. Hiway 28. Continue West on Hiway 50.

Mileage

50.5	Turn Left (West) on Roethermeyer Road. Slow, winding gravel road.
51.5	Roethermeyer Fireclay Area - Several large flint clay pits on both sides of road.
52.0	Entering L. Scego Fireclay Area - Also a very productive flint clay area. Reclamation of recent pit in progress.
52.5	L. Scego Pit #3 - high alumina and flint clay pit being reclaimed on South side of road.
52.9	Mo. Hiway 19. Turn Right (North) on Hiway 19.
53.5	Wacker Stockpile area and flint pit (unmined) on West side of highway. Core drilled by USGS and Missouri Division of Geology in 1987.
53.6	Turn Left (West) on Brinkman Road.
55.8	Turn Left (West) on private clay haul road. Entrance to Posey-Farnberg-Bueker clay areas.
56.3	Old Posey diaspore and flint pit on Right. Mined by LaClede Christy during the 1940's & 1950's.
56.4	Farnberg Pit #20 on Left (flint clay).
56.8	Farnberg Pit #19 on Left (flint clay).
57.0	Bueker Pit on Right. Worked by General Refractories in 1940's & 1950's for high alumina and flint clay. The Excello shale and Ft. Scott limestone overlies the fire clay. Continue on haul road through stockpile areas.
57.6	Bueker Pit #1A - being worked by A. P. Green for flint clay.
57.7	**STOP #2--Bueker Pit #1B** - A continuation of Pit #1A--(irony flint is sold to cement companies). Turn around and follow road to Farnberg property.
58.4	Gate - West line of Farnberg Property.
58.6	Crossing over large flint pit (unmined).
58.9	Complex of old Farnberg pits which have been mined and are now used for sanitary landfill by Mr. Marvin Kahle.
59.7	Turn Left (North) on Brinkman Road.
60.0	Road crosses old shallow flint clay pits mined by General Chemical in the 1960's.

Mileage

62.2	Rock Quarry in Jefferson City dolomite on Right.
62.9	Intersection-Turn Left (West) on Old Hiway 50 (442).
63.4	Intersection-Turn Left (South) on Hwy. P.
67.9	**STOP #3--SCHAEFERKOETTER PIT** -Park along highway & walk to Schaeferkoetter pit to East.
69.6	Bridge over Third Creek.
71.8	Old Woolam - Area from Third Creek to three miles east is barren of sink deposits.
77.4	Owensville, Mo. - Intersection of Gasconade County P and Mo. Hiway 28 - Turn Right (West) on 28.
78.7	**LUNCH STOP - CRICKET'S** After lunch go back East on Hiway 28.
80.0	Intersection - Mo. Hiway 28 & Hwy P. Turn Left (North).
80.4	**STOP #4 - LACLEDE CHRISTY PLANT-EMHART GLASS**
80.6	Return to Intersection Gasconade County P & Mo. Hiway 28. Turn Left (East).
80.8	Junction - Mo. Hiways 28 & 19. Turn Right (South) on 19.
101.2	Junction - Mo. Hiway 19 & 44 at Cuba, Mo. Turn Right (Westbound Ramp) on I-44 - Return to Rolla through Rosati and St. James grape and wine country (22 miles).


Stop 1
Stop 2
Stop 3
Stop 4
BAY
STERLING
DRAKE
OLD WOOLLAM
NEW WOOLLAM
ROSEBUD POP. 326
OWENSVILLE POP. 2,241
CANAAN
TEA
BEM
SOUTHWESTERN
ST. LOUIS
Second Creek
Brinkman Creek
Brushy Branch
Third Creek
Cedar
Barren Fork
Boeuf Creek
Redoak Creek
Block Branch
Dry Fork Creek
Rock Creek
BOURBEUSE RIVER
T43N
T42N
T41N

GEOLOGY OF THE MISSOURI REFRACTORY CLAY DEPOSITS

The fire clays of Missouri occur in the Cheltenham formation (Pennsylvanian-Carboniferous), and exhibit compositional and mineralogical variations indicative of lithofacies changes within the formation. As shown on FIGURE 1, different lithofacies belts can be delineated which are roughly concentric to the Ozark uplift. The Cheltenham fireclays range from dominantly plastic and semi-flint clays in the northwest part of the fire clay district, through flint and finally mixed flint and diaspore clays as the Ozark dome is approached. Thus the plastic and semi-flint clays occur primarily to the north of the Missouri River.

The Cheltenham fire clays lie above an unconformity truncating sedimentary rocks ranging from Cambrian to Mississippian in age, dipping gently away from the Ozark Dome. The unconformity developed probably shortly after St. Louis (Mississippian) time. North of the Missouri River the fire clays occur as a relatively continuous deposit, varying greatly in thickness and quality, the irregularity in thickness being due to deposition on a very irregular surface, resulting from intensive karst development on the Mississippian surface.

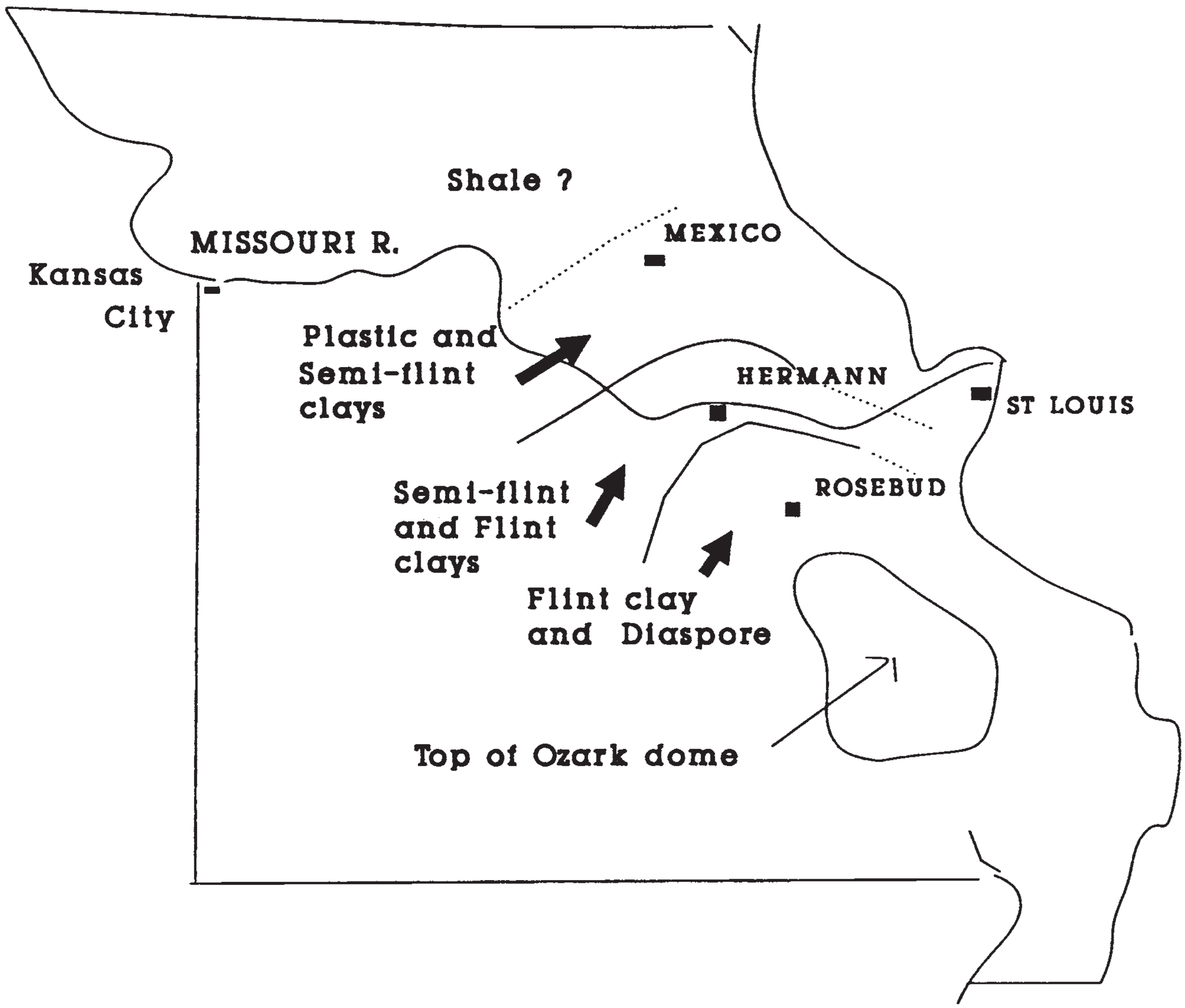
South of the Missouri River, clay deposits, particularly flint and diaspore clays, occur most often in isolated, circular pits, many of them representing solution basins and sinkholes developed in the underlying earlier Paleozoic carbonate rocks.

Generally the sediments immediately underlying the Cheltenham formation in the field trip area are poorly consolidated, unsorted, highly jumbled mixtures of quartz siltstones and sandstones, tripolitic chert, and variegated clays and shales. The jumbled nature of these rocks is taken as evidence of gradual solution of the underlying carbonates, with concomitant subsidence of the existing cover rock to become fill in many cases in so-called filled-sink structures. Thus solution, subsidence, clay deposition and leaching were all part of the local continuing karst development during Cheltenham time.

Mineralogically the semi-flint and plastic clays consist of mixtures of moderately disordered kaolinite and variable amounts of illite and quartz. Minor amounts of chlorite and organic matter are also common.

The flint clays are very fine-grained, moderately to highly ordered kaolinite. Some approach 100% kaolinite with the softer varieties containing more illite. Flint clays may grade gradually or abruptly into higher alumina clays.

FIGURE 1



Map of Missouri showing the distribution of high alumina clays, flint clays, plastic clays, and shales of Pennsylvanian age progressively down-structure in relation to the Ozark dome.

MINERALOGY OF MISSOURI FIRECLAYS

Kaolinite is the most abundant mineral occuring in all clays. Other common minerals are illite, chlorite, quartz, and diaspore. Minor amounts of mixed layer illite/smectite are present in some plastic clay. Iron oxides and sulphides and carbon are common in many clays. Excessive amount of iron minerals, quartz, or illite render the clay unusable for refractories.

Certain general correlations are recognized between mineralogy and clay type. Quartz is present in most all plastic clays. While quartz is common in abundant "sandy flint clay" it is generally absent in the highest quality flint and high alumina clays.

As shown in the following table (Chavez, 1986), there is a great variation in kaolinite and illite content in all clay types. Generally, however, the flint clays contain more kaolinite with the clean hard flints approaching 100% kaolinte. The softer flints contain up to 23% illite. Kaolinite in flint clays exhibits good crystallinity, whereas that in plastic and high alumina clay has poor crystallinity. Flint clay by definition breaks with a conchoidal fracture and resists slaking in water. These properties are attributed in large part to the texture of the clay which is revealed by SEM to be fine grain interlocking crystals of kaolinite.

TYPICAL MINERALOGY OF MISSOURI FIRECLAYS

	Percent					
	Kaolin	Illite	Chlorite	I/S	Quartz	Diaspore
Plastic	63-90	4-23	0-4	0-6	2-14	0
Semi-Flint	90-95	0-23	0-3	0	2-8	0
Flint	75-100	0-23	0-2	0	0	0
Burley	16-75	4-10	5-15	0	0	25-78
Diaspore	1-15	1-4	5-6	0	0	78-93

The illite content is greatest in plastic clays. Increasing illite content, less ordered kaolinite, and more carbon contribute to the plasticity of the semi-flints and plastic clays.

CHEMISTRY OF MISSOURI FIRECLAYS

Typical chemical analyses of plastic, semi-flint, flint and diaspore clays show a continuous decrease in silica, alkalies, alkaline earth, and iron, with an increase in alumina. Flint clay approaches the composition of ideal kaolinite. Titania is detected in all fire clays, usually from one to four percent. It correlates with alumina and is most likely residual anatase or rutile from the parent clay material.

TYPICAL CHEMICAL ANALYSIS

	Plastic	Semi-Flint	Flint	Diaspore
SiO_2	55.0	45.92	44.42	3.89
Al_2O_3	28.8	35.79	38.63	76.21
Fe_2O_3	2.8	0.75	0.55	0.98
TiO_2	1.7	2.28	2.12	3.52
CaO	0.4	0.06	0.04	0.08
MgO	0.4	0.36	0.10	0.06
Na_2O	0.1	0.44	0.30	0.79
K_2O	1.5	0.41	0.12	0.24
H_2O	9.3	13.06	13.90	14.56
Total	100.0	99.07	100.18	100.33

STOP #1 -- M. HUERNER FLINT CLAY PIT #5

M. Huerner Pit #5 represents a classic filled sink flint clay deposit. Excellent exposures of the sandstone rimrock and various grades of flint clay can be observed. The pit was originally stripped and partially mined in 1930. After mining a limited tonnage the pit was then abandoned. A. P. Green Industries acquired the deposit in 1953 and began the current mining operation this year after pumping water that had completely filled the partially mined pit since 1930. Pit #5 is one of five flint clay pits located on the 40 acre Huerner tract.

The eliptical shaped deposit has a diameter of 250' x 150' at the surface. The east rim or edge is nearly vertical while the other sides slope more gently. Maximum flint clay thickness exceeds 80' in the deepest part. The tonnage of usable flint is estimated at 45,000 tons.

A wide variety of flint clay types occur in Pit #5. Minor occurrences of coal were also encountered in association with highly carbonaceous flint clay. Limited burley flint with alumina content of 45% - 50% also occurs.

Much of the flint in the center of the pit is dark gray to black in color due to the high carbon content. Streaks of lignite and coal up to 3 inches thick occur in association with the darkest clay. Pyrite is commonly observed in the carbonaceous clay and occasionally in the adjacent clean white flint. Individual coal lenses, clay types and colors can be traced only a few feet. This is taken as evidence of intermittent movement or slumping as the sink structure developed.

An exception to the mixed nature of most of the pit is the consistent zone of clean hard flint adjacent to the rim. This is a common feature of many flint pits and is referred to as "rim flint" by the miners. This is the highest quality flint in Huerner Pit #5. It has considerably less iron and alkali than the other clays and develops a high fired density of 2.60 gm/cc. The high density and hardness (resistance to slaking) is attributed to its purity and interlocking crystal texture. The exact processes that formed this rim flint are unknown. It could be related to the permeability of the sandstone rim but more likely represents flint clay developed on the karst surface prior to more rapid subsidence of the sink structure.

A large amount of waste clay has been mined from Huerner Pit #5. Most of this unusable clay has excessive carbonaceous matter which adversely affects fired properties. It commonly causes bloating as the CO_2 gas formed in the glassy phase expands upon firing. Minor amounts of carbon and other volitiles reduce the fired density and limit the use of this clay. The carbon contentof the dark gray and black flint clay was measured at 0.5% and 2.50% respectively. The alkali content, namely potassium, of this softer flint is higher than the hard white flint and also contributes to lower density by promoting glass formation upon firing. The fluxing effect also reduces refractoriness. A comparison of chemistry for rim flint and softer grades in Huerner Pit #5 follows:

	Rim Flint	Soft Flint
Al_2O_3 (calcined)%	45.20	44.80
SiO_2	50.30	48.50
Fe_2O_3	0.90	1.21
TiO_2	2.20	2.25
CaO	0.14	0.21
MgO	0.27	0.35
K_2O	1.26	1.96
Na_2O	0.01	0.01
P_2O_5	0.17	0.40
2750°F Grain Density (gm/cc)	2.60	2.10-2.40

The country rock in this area is the Ordovician Jefferson City dolomite. A thick sequence of Pennsylvanian sandstone exposed in the haul ramp was deposited on a widespread karst surface. It has been spared from subsequent erosion because it was lowered during the formation of the adjacent sink (Huerner Pit #5) and the relative high elevation of the Rosebud area. This same sandstone is the source of the rimrock that surrounds most clay pits.

Numerous large and deep flint pits occur in the area immediately east of Rosebud. One deposit located 1,000 feet west of Huerner Pit #5 extends over 200' below the present surface. Erosion has removed much of the shallow Pennsylvanian karst accumation of clay, sandstone, and chert originally present in this area, however, most of the deeper sink structures have been preserved in total.

STOP #2--FARNBERG-BUEKER-POSEY FIRE CLAY AREA

The Farnberg property was first mined in 1927 with the mining on this deposit and connecting deposits continuing intermittently to the present. This clay deposit is the largest in the area south of the Missouri River and is a good example of the shallow, widespread type of deposit containing both flint and high alumina clays. Along with the adjoining Bueker and Posey properties, these deposits represent the type of deposition that occurred in Early Pennsylvanian across the southern district and are preserved from erosion due to the synclinal basin on Goerlich Ridge. The Farnberg Pits were worked by Rousset Brothers Clay Company until A. P. Green acquired the entire property in 1958.

The Bueker flint and diaspore pit was prospected in 1928-1930 and was worked by General Refractories Company from 1930 until the 1950's. The initial Bueker pit is unique in that it is one of two flint clay deposits located south of the Missouri River showing completely a Paleozoic rock cover over the fire clay. The geologic evidence is that the flint and diaspore clays were deposited, later oxidized and weathered on their upper surface during a Pre-Ft. Scott erosional period and then covered by green marine shale (Excello) and limestone (Ft. Scott).

The high alumina clay in this pit was in lenses, pockets and tabular masses lying at various angles. There was no particular orientation of the high alumina clays discovered during mining. The pit was 70' deep at the deepest point with overburden from 8 to 12 feet thick. A total of 560,000 tons of fire clay was mined: Diaspore - 10,000 tons, Burley clays - 80,000 to 100,000 tons, Flint clay - 450,000 tons.

The Posey pits were owned and mined by LaClede Christy Clay Products Company starting in the late 1920's and continuing until the 1960's. General Chemical Company mined and used much of the flint clay from Posey and also the Farnberg property, especially the slightly irony flint that was not suitable for refractories. A. P. Green acquired both Bueker and Posey in the early 1970's.

Current mining is from Bueker Pit #1. The deposit is owned by A. P. Green Industries, Inc. Mining is conducted by contractors Jones & Turner Mining, Linn, Mo. and Thomas Scego Mining, Owensville, Mo. In contrast to the separate pronounced sink structure of the Huerner pit and most flint pits, the clay in Bueker Pit #1 is relatively thin and covers a larger area. Pit #1 has an aerial extent of 20 acres. Over much of this area the clay thickness is less than 10 feet. Areas where the usable clay interval is less than 3 feet are considered uneconomical. The soil and gravel overburden varies from 15 feet thick on the ridge top to 3 feet along the outcrop. Much of the clay contains excessive iron making it unusable for refractories. Much of this unusable clay has a pink or maroon color with the iron finely disseminated through the clay. Most is believed to be primary iron relating to the environment of deposition and early diagensis. Secondary iron can be observed as oxide stain and scale in fractures in the clay. An interval of sandy clay is common at the contact with the underlying sandstone or chert residuum.

One large clay filled sink structure is located in the Bueker Pit #1 deposit. It is 250 feet in diameter with a maximum clay thickness of 180 feet. Mining to date has exposed only the upper interval of clay in this area of the pit. Core drilling indicates that much of the clay in the sink structure has a high iron and alkali content making it marginal or unusable for refractories. Carbonaceous clay is also common as well as streaks and pockets of coal and lignite. Clay containing over 2% Fe_2O_3 is normally unusable for refractories. Much of this clay is currently sold as "cement clay". Mining experience is required to separate the numerous grades of clay and maximize recovery of high grade flint.

STOP #3 -- SCHAEFFERKOETTER DIASPORE CLAY PIT

Although essentially all high-alumina (diaspore and boehmite) deposits in Missouri have been mined (Keller, 1979), this remaining Schaefferkoetter deposit, traditionally called a "pit", displays almost all of the characteristic geologic features of those deposits (Keller and Stevens, 1983). It was partly mined, exposing the sequence of rocks from sandstone rimrock to select high grade diaspore, at which stage the operation was closed down for economic-litigational reasons, fortunately at a stage in which the geological and mineralogical features can still be observed.

It is a sinkhole deposit, being located in a deep sinkhole that extended downward from an ancient, widespread, shallow, undulating karst topography. During Pennsylvanian time an extensive karstic surface was developed unconformably across a peneplane that truncated the Mississippian cherty Burlington limestone north of the present Missouri River, continuing southward onto the Ordovician cherty, sandy Jefferson City dolomite which is the country rock at the Schaefferkoetter pit (McQueen, 1943).

To inspect the deposit, it is logical to observe first the cherty, sandstone rimrock (Pennsylvanian age) that outlines the deposit and developed also as a liner for the deepening sinkhole. This sand and chert represents residuum derived from the Jefferson City dolomite, and sand also possibly contributed by the St. Peter sandstone which overlay the Jefferson dolomite. Protruding resistant ridges of sandstone may be used as clues for locating these clay deposits but not all sandstone ledges in the area are rims of sinkholes.

Moving toward the center of the pit, the sandstone grades into inward-dipping sandy flint clay which, in some places, is stained with brown or red iron oxides ("irony flint clay"). The fluxing effect of iron minerals with clay and free silica (quartz) reduces these zones of clay below the quality of commercial refractory clay.

Next inward is a dipping zone of first-quality flint clay. Flint clay was so named in the late 1800's because its fracture was similar to that of chert and flint (Keller, 1968). Mineralogically, however, first-quality flint clay is composed of kaolinite that typically is crystallographically well ordered and occurs as tightly interlocked packets of kaolinite flakes similar in texture to that of monomineralic igneous rock (Keller, 1981). Is this texture and origin unique among kaolin deposits? A representative specimen of the Schaefferkoetter unfired flint clay contained 39.4% Al_2O_3 (Keller and Stevens, 1983).

In diaspore (or boehmite) deposits the flint clay grades, as in this one, commonly into an oolite-containing phase, locally called burley-flint clay. The oolites were called "burls" by the miners. Typically the oolites are composed of diaspore (occasionally boehmite and, rarely in Missouri flint clays but more commonly in Kentucky flint clay, they may be kaolinite), hence the alumina content of burley flint is higher than that of flint clay.

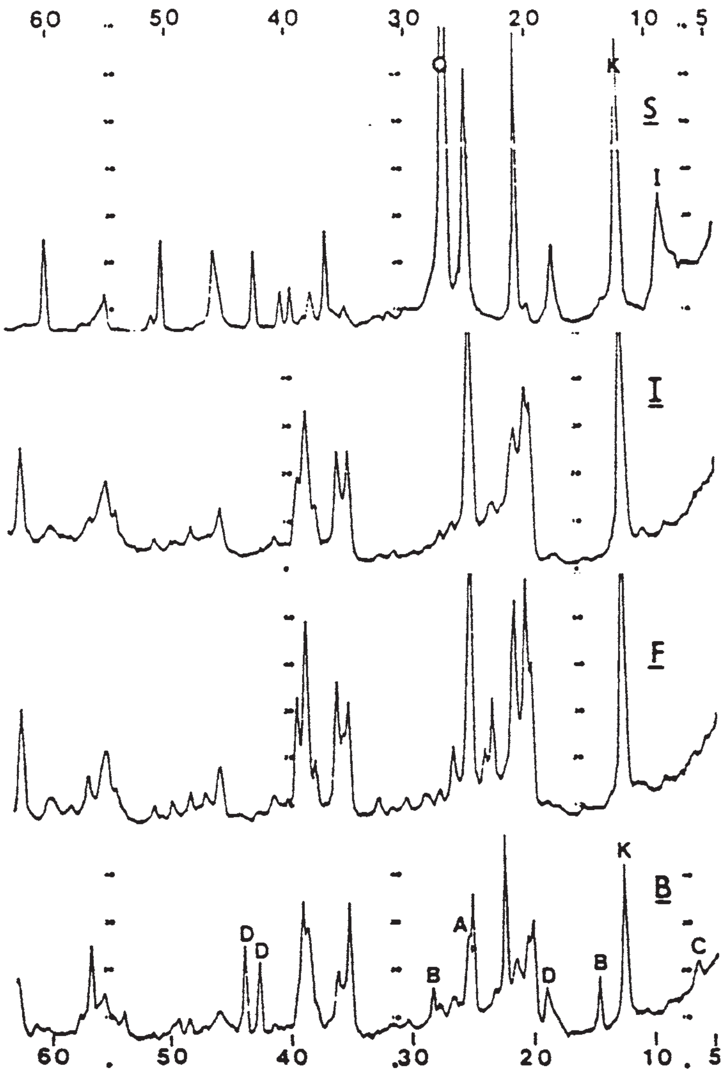


Figure 1. X-ray powder diffractograms of sandy flint clay, S, iron-oxide colored flint clay, I; first quality flint clay, F; burley-flint clay, B. A = a reflection of anatase; B = boehmite; C = chlorite; D = diaspore. Degrees 2θ are indicated along the base and top; CuKα radiation.

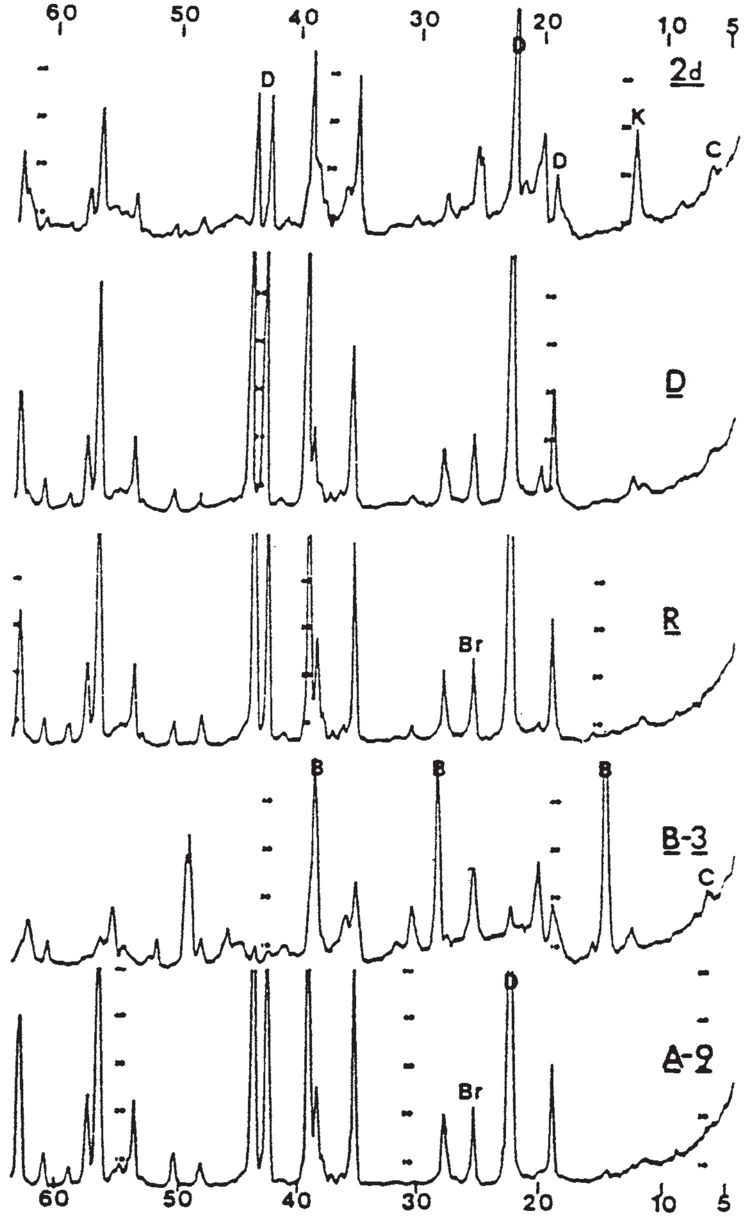


Figure 2. X-ray powder diffractograms of second-grade diaspore, 2d; first-grade diaspore, D; recrystallized diaspore, R; boehmite, Ocheskey deposit, B-3; diaspore, Ocheskey deposit, A-9. B = a reflection of boehmite; Br = brookite; C = chlorite; D = diaspore. Degrees 2θ indicated along the base and top, CuKα radiation.

As the diaspore content rises, evidenced by a further increase in the amount of oolites, and/or by dissemination of high-alumina mineral in fine crystals throughout the clay, a hackly, "rough" (the miner's term) fracture is developed, in contrast to the "slick break" of flint clay, and the clay is classified as burley. The correlation between physical properties of high-alumina and its alumina content is so reliable that experienced miners could select during their hand mining of a diaspore deposit, using only the visible texture and appearance of the clay, freight-car shipments accurate to within $\pm$ 5% of a specified alumina content within the clay-quality range of 40% to 70% Al_2O_3 (Keller, 1930). A representative specimen of burley from this deposit contained 53.6% alumina. The X-ray powder diffractogram of this burley shows kaolinite, diaspore, boehmite, anatase, and Li-chlorite (a proto-cookeite?), Figure 1.

With further increase in diaspore-boehmite content in the clay to about 60%-65% Al_2O_3, this rough-textured clay has been classified by the refractories industry as second-grade diaspore. In the Schaefferkoetter pit this zone of clay decreases in dip until it is almost horizontal. A representative specimen contained 61.1% of Al_2O_3, and yielded a power diffractogram showing diaspore, kaolinite, and chlorite, Figure 2.

Toward the center of the pit is "clay" containing from 68% to about 65% Al_2O_3 (raw, unfired basis) which is classified as "first-grade diaspore". Very little kolinite is present in such "clay", so if "clay" should refer only to a phyllosilicate, it is mineralogically incorrect, although industrially acceptable, to call this a "clay"; note that the powder diffractogram in Figure 2 shows almost only diaspore reflections to be present. A sample of diaspore from this zone contained 73.8% Al_2O_3.

Despite the relative insolubility of Al_2O_3 in pure water, some recrystallization of diaspore occurs in the ground water under surface-temperature conditions in Missouri (Keller, 1978a). A thin layer of relatively permeable and friable diaspore in a re-entrant ledge within the center of the pit has been recrystallized and enriched in Al_2O_3 to 77.6% Al_2O_3. Some brookite, accounting for the TiO_2 present, is shown with the diaspore in the diffractogram, Figure 2. The aqueous solubility of Al_2O_3 is greatly increased some 2000 to 3000 times in solutions containing .01M organic acids, such as citric, tartaric, and salicylic (Huang and Keller, 1972), which possibly could explain the mechanism of dissolution recrystallization of diaspore in some ground water.

Interpretation of The Origin of The Diaspore

After observing many diaspore pits before, during, and after mining, Keller, Westcott, and Bledsoe (1954) inferred the geologic history of their origin as follows. During the Cheltenham time of the Pennsylvanian Period, a low-lying peneplain extended from sea level north of Mexico, Mo., to a slightly higher paludal terrain southward up the Ozark Dome across the diaspore region. The peneplain, which had developed mainly on carbonate rocks, was characterized by a shallow undulating karstic surface that was punctuated here and there by deep, cone-shaped sinkholes. A modern area possibly somewhat analogous to the Pennsylvanian topography may be the Everglades region in Florida. In the Missouri refractory clay area intense chemical weathering of the exposed carbonate country rocks released chert (identified as Burlington or Jefferson City chert in the contiguous rim and basal rocks), quartz sand, and clay minerals such as remain when the limestones experimentally are dissolved in the laboratory (Robbins and Keller, 1952). The residual chert gravel and sand settled to the bottom of the paludal basins forming the "bottom rock" of sand and chert as observed today. Additional clay, both 2:1 and 1:1 layer minerals, presumably was brought in by streams from outside regions. The clay minerals continued to collect in the depressions of the undulating surface, thereby forming shallow clay deposits having flat upper, but undulating bottom, surfaces.

Many sinkholes within the karst continued to grow by deepening during this sedimentation episode, as is shown by their inward dipping rocks. A few, after being filled, collapsed further to develop a trap-door structure.

Vegetation was lush in and around most of these depositional basins, as is commonly shown by sporadic coal layers and/or carbonaceous clay in many pits. Coal from a diaspore pit at Aud, Mo., about 20 miles northwest of here, yielded a very low vitrinite reflectance indicating a residence temperature certainly less than $50^{\circ}C$ (personal communication, D. Houseknecht). Probably vegetation was abundant at all of the depositional areas, consistent with the indisputed interpretation that the climate during this period was humid with temperatures moderate to high. The combination of reactive fresh rain water, growing plants and organic (humic and fulvic?) compounds, leached the clay minerals and removed alkali and alkaline earth metals, most iron compounds, and silica. The end products of weathering were clay colloids of kaolinite composition, from which the flint clay crystallized as from a "magma", and also high-alumina segregations from which oolites (both solid and hollow) formed, and from which tiny crystals of diaspore or boehmite precipitated.

Insofar as downward leaching being operative, no doubt it took place if and where possible, but two lines of evidence suggest that downward dissolution was a less effective mechanism than the flushing of dissolved ions off the top of the swamps by action of rain water falling in the area and moving off and out by sheet flow. One line of evidence is that the "hardest", most kaolinitic and highest-fusion clay regularly occurs at the bottom of the deposits in the Mexico area. If the most effective leaching had been downward, the most highly leached (kaolinitic and flux-free) clay would have been at the top of the deposits, and metal fluxes would have been concentrated in the bottom clay--but this is not the geologic situation present. Furthermore, clay accumulating at the bottom of the basins was relatively impermeable to downward movement of fluids.

Diaspore typically occurs in the central core of the deposits, surrounded by flint clay on the sides and bottom, as here at Schaefferkoetter. The interior of the depositional basin thus shows the maximum leaching effect, not the peripheral zones over which newly arriving "feeder clay" was being brought in. In pits, however, where subsequent collapse or other late state structural activity occurred, secondary channels for downward leaching could become operative.

Summarizing, the leaching process by which kaolinite and high-alumina clays were formed has been interpreted, therefore, as operating by diffusion and dialysis of clay particles that removed fluxing metal ions, and dissolved silica, that moved mainly toward the top of the flooded swamps, and were then flushed off to the sea. The most intense leaching occurred highest on the Ozark Dome, which is the location of the diaspore region. The intensity of leaching declined down-dome into the kaolinite flint-clay zone, decreased further toward the lower-elevation region of semi-flint, semi-plastic, and plastic illite-containing refractory clays (Hughes and White, 1969; Keller, 1978b), and became almost nil at the marine shoreline at the north, (Keller, 1968).

In the diaspore region the uppermost shallow basins of clay deposition, interpreted to have been originally essentially continuous, have escaped removal by erosion in only a very few occurrences; these may be remnant synclinal lows. The diaspore in these deposits is "mixed" (miner's term) with the associated essentially horizontal flint clay. Most of such formerly, presumably abundant shallow clay, an originally huge deposit across the diaspore region, has been eroded and lost, whereupon only the relatively few deep pits that extended farther below the depositional surface remain. These represented the deepest sinkholes dissolved, in the order of 100 feet, below the main surface.

At two high-alumina pits, the Bueker (Keller, 1952) located only a few miles east of here, and another near Belle, Mo., 15-air-miles southwest, a cover of Pennsylvanian-age rocks (up through Ft. Scott) remains over the clay. At the Bueker pit, the top zone of the kaolinite flint clay is oxidized and weathered, sharply contrasting with the immediately overlying fresh, green, and dominantly illitic marine Excello shale. The historical sequence of the diaspore region is therefore, (1) deposition, diagenetic leaching of non-aluminous elements from, and consolidation of, the clay, (2) exposure partial weathering at the top of the Cheltenham clay, (3) lowering to below sea level, followed by deposition of the Excello shale, Ft. Scott limestone, and additional younger rocks (?), and (4) a hiatus that culminated in erosion which exposed the Cheltenham refractory clay and removed most of it in the diaspore region except for that in the bottom of deep sinkholes.

From a global perspective, high-alumina and flint clays, as in Missouri, are wide-spread in rocks of Carboniferous age--deposited at a time when the presently separated continents are presumed to have been connected or contiguous, and when the climate was relatively uniform across them. The "bauxitic kaolins" in Scotland are equivalent to "burley flints" in Missouri, or to "nodule" clays in Pennsylvania.

"Burnt" clays in Pennsylvania are equivalent to first- and second-grade diaspore in Missouri. Ohio and Kentucky have flint clay and oolitic flint clay. The Hammanskraal flint clay in south Africa, and some flint clay in India, have ceramic properties similar to Missouri clays. Flint-like clays in Russia are called "toasted" (as bread) clays. Karstic high-alumina deposits elsewhere have been described as karst bauxites by Bardossy (1982).

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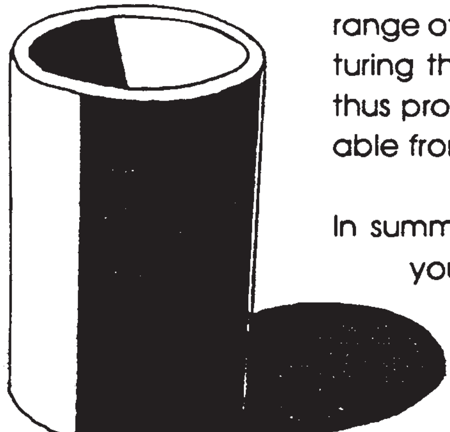

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