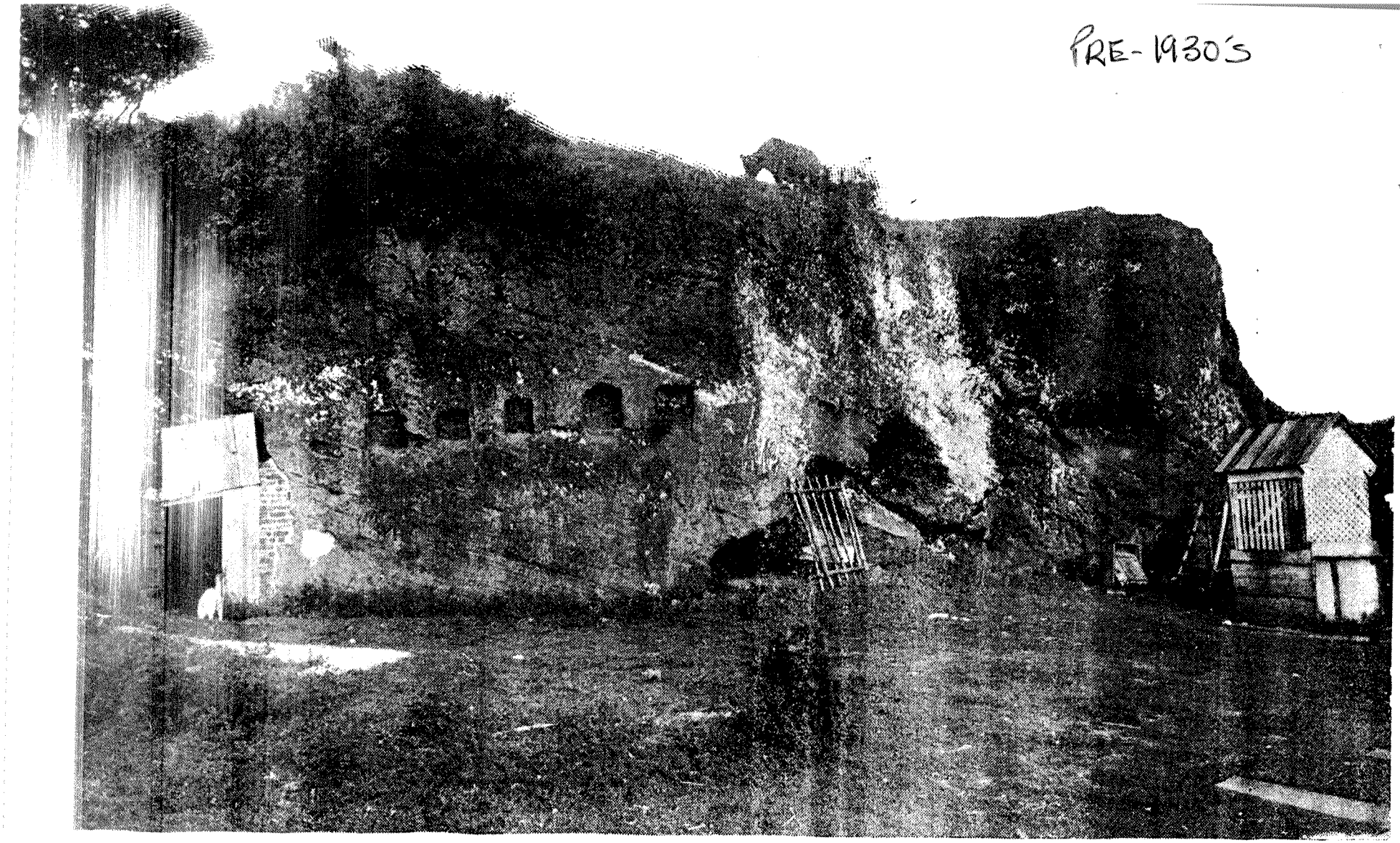
PRE-1930's



ADD TOM JONES, CINCINNATI, OHIO

CENT POSTAGE

CORWALLIS CAVE
YORKTOWN, VA

FIGURE 1

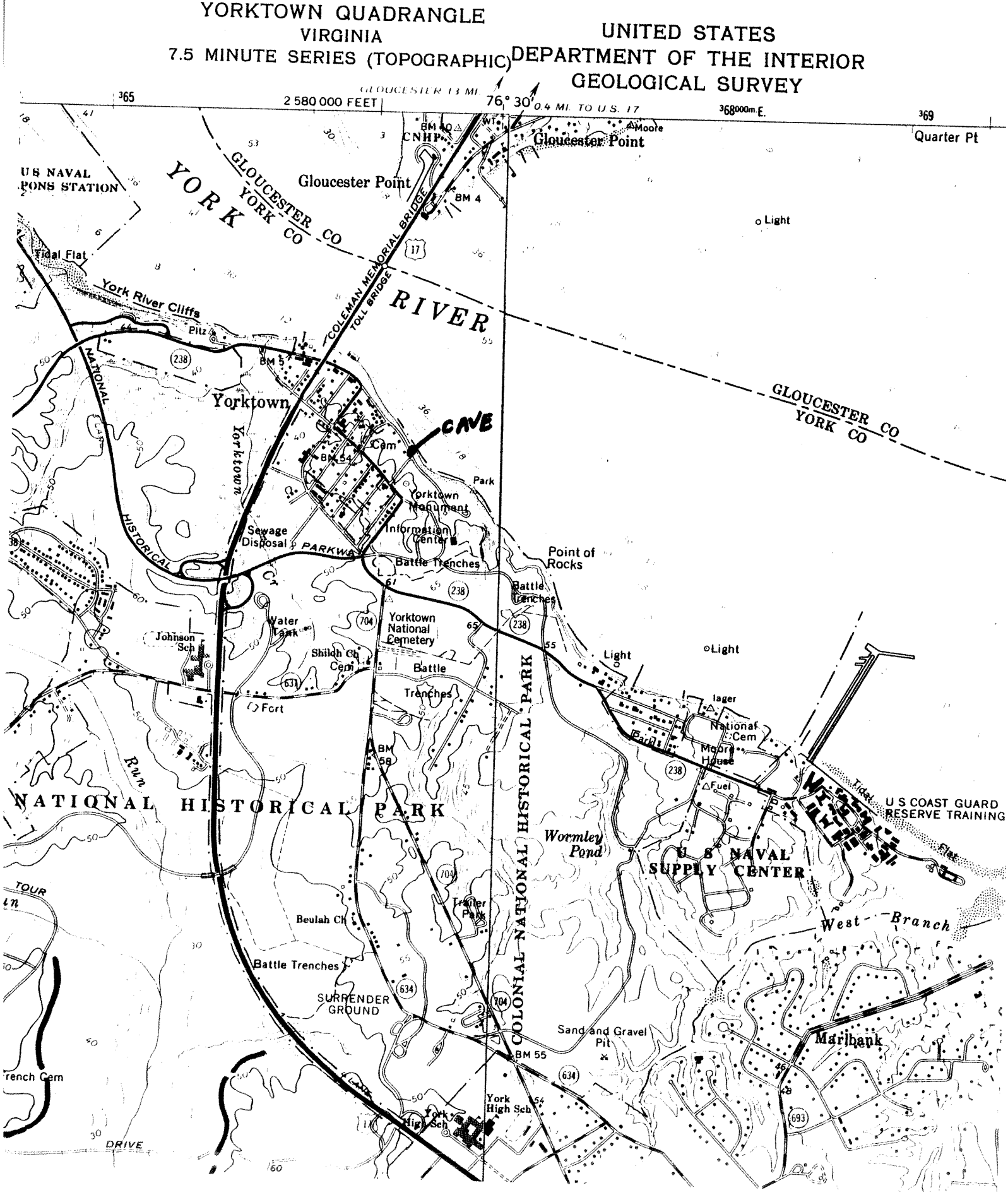
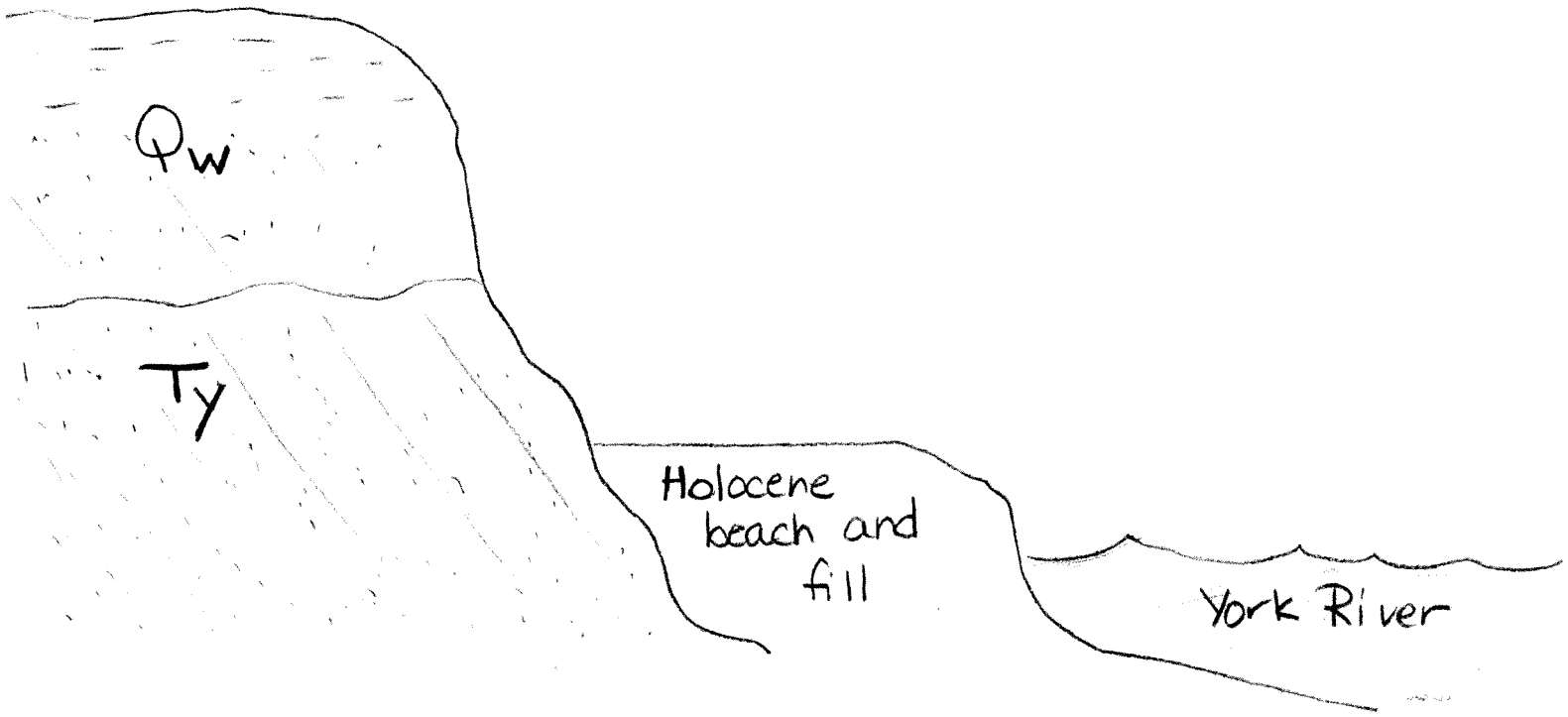

YORKTOWN QUADRANGLE
VIRGINIA
7.5 MINUTE SERIES (TOPOGRAPHIC)
UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
2 580 000 FEET
76° 30'
0.4 MI. TO U.S. 17
368000m.E.
Gloucester Point
Quarter Pt
CNHP
Moore
US NAVAL
PONS STATION
YORK CO
GLOUCESTER CO
YORK CO
Gloucester Point
BM 4
COLEMAN MEMORIAL BRIDGE
TOLL BRIDGE
Light
Tidal Flat
York River Cliffs
RIVER
Pltz
BM 5
GLOUCESTER CO
YORK CO
Yorktown
CAVE
Cem
BM 54
Park
Yorktown Monument
Information Center
Sewage Disposal
PARKWAY
Battle Trenches
Point of Rocks
Battle Trenches
Yorktown
HISTORICAL
Water Tank
Yorktown National Cemetery
Johnson Sch
Shiloh Ch Cem
Battle Trenches
Light
Light
Fort
Run
NATIONAL HISTORICAL PARK
BM 58
COLONIAL NATIONAL HISTORICAL PARK
Wormley Pond
U S NAVAL SUPPLY CENTER
U S COAST GUARD RESERVE TRAINING
Tidal Flat
West Branch
TOUR
Beulah Ch
Trailer Park
Battle Trenches
SURRENDER GROUND
Sand and Gravel Pit
BM 55
Marlbank
York High Sch
DRIVE

FIGURE 2

Figure 3. Map showing the principal geomorphic features in the Yorktown, Poquoson West, and Poquoson East quadrangles.

FIGURE 3



Qw - Windsor Formation - lower cross-bedded sand unit, upper silty unit

Ty - Yorktown Formation - large-scale cross bedded sands

FIGURE 4

Vertical burrows in Cornwallis Cave.



Photo taken by. Dr. G. Johnson.

FIGURE 5

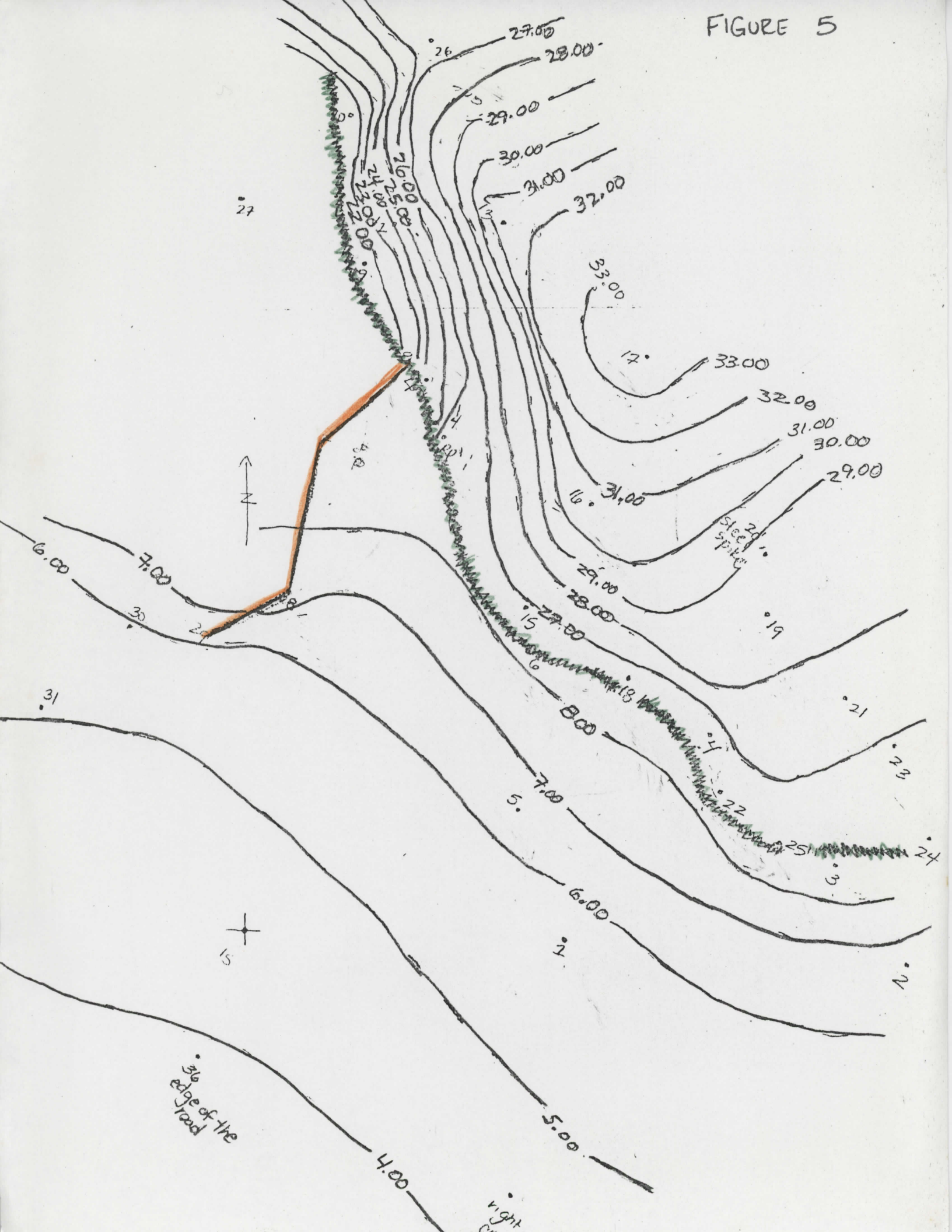

27.00
28.00
29.00
30.00
31.00
32.00
33.00
26.00
25.00
24.00
23.00
22.00
6.00
7.00
8.00
5.00
4.00
N
Steep slope
edge of the road

FIGURE 7.

Large-scale cross-beds in Cornwallis Cave.





Photos taken by Dr. G. Johnson.

FIGURE 10

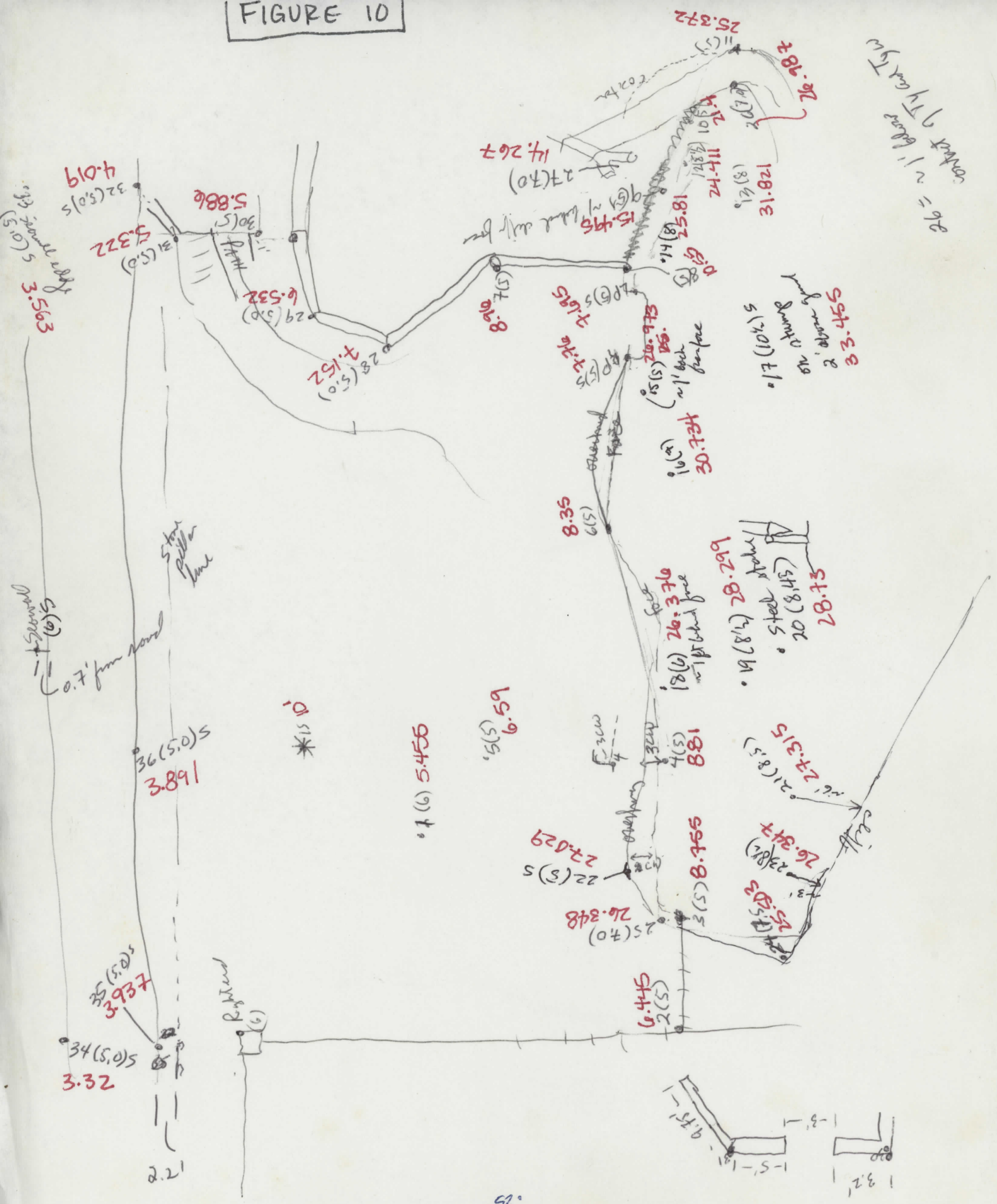


FIGURE 13A

Photos showing fractures in Cornwallis Cave.





Photos taken by Dr. G. Johnson

Figure 13B

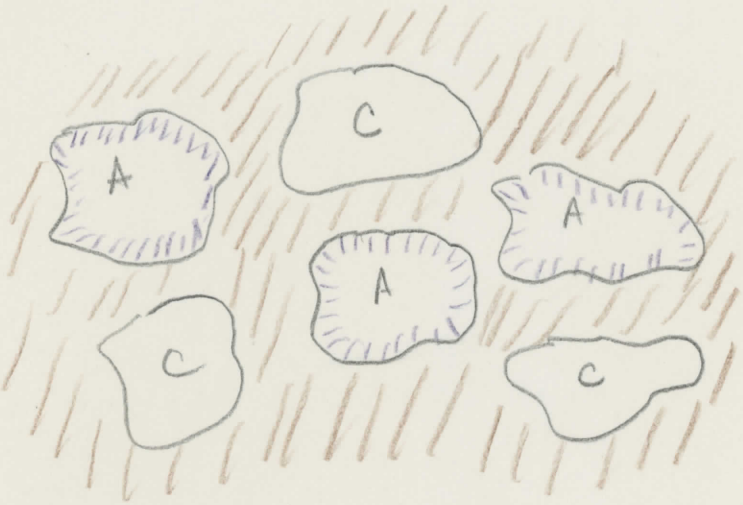
Photos showing large-scale cross-bedded sands with color changes.





Photos taken by Dr. G. Johnson.

FIGURE 14



A aragonite

C calcite

//// calcite cement

//// area of aragonite dissolution due to H_2CO_3

(aragonite grains will fall out of cement)

FIGURE 16

Photos showing human impact on Cornwallis Cave.





Photos taken by Dr. G. Johnson.

FIGURE 15B

1" = 10'
cave face
fence
CI = 1 ft.
— thickness of ceiling rock
Second fence line up
edge of the wood
light clay of fence
N

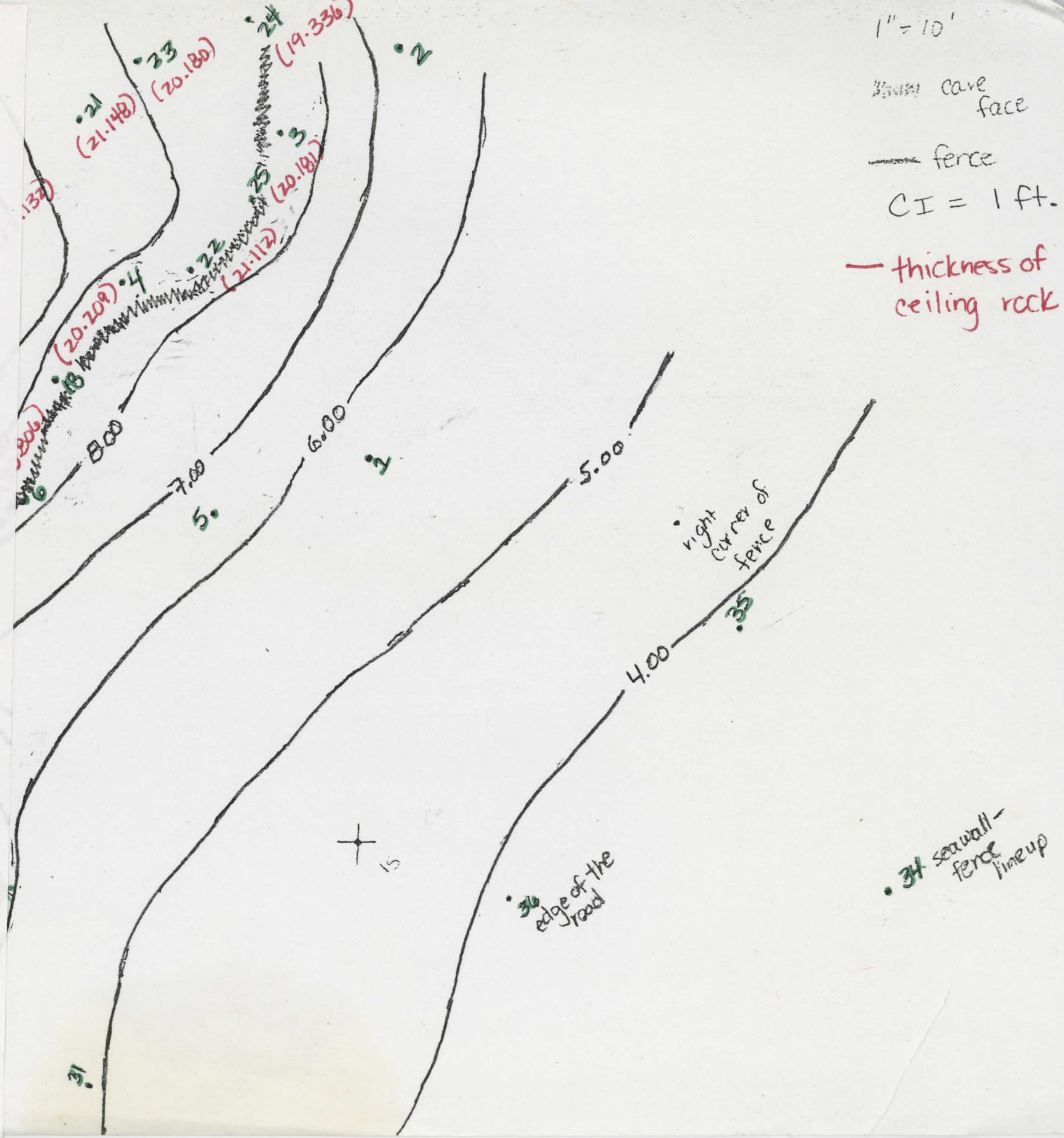
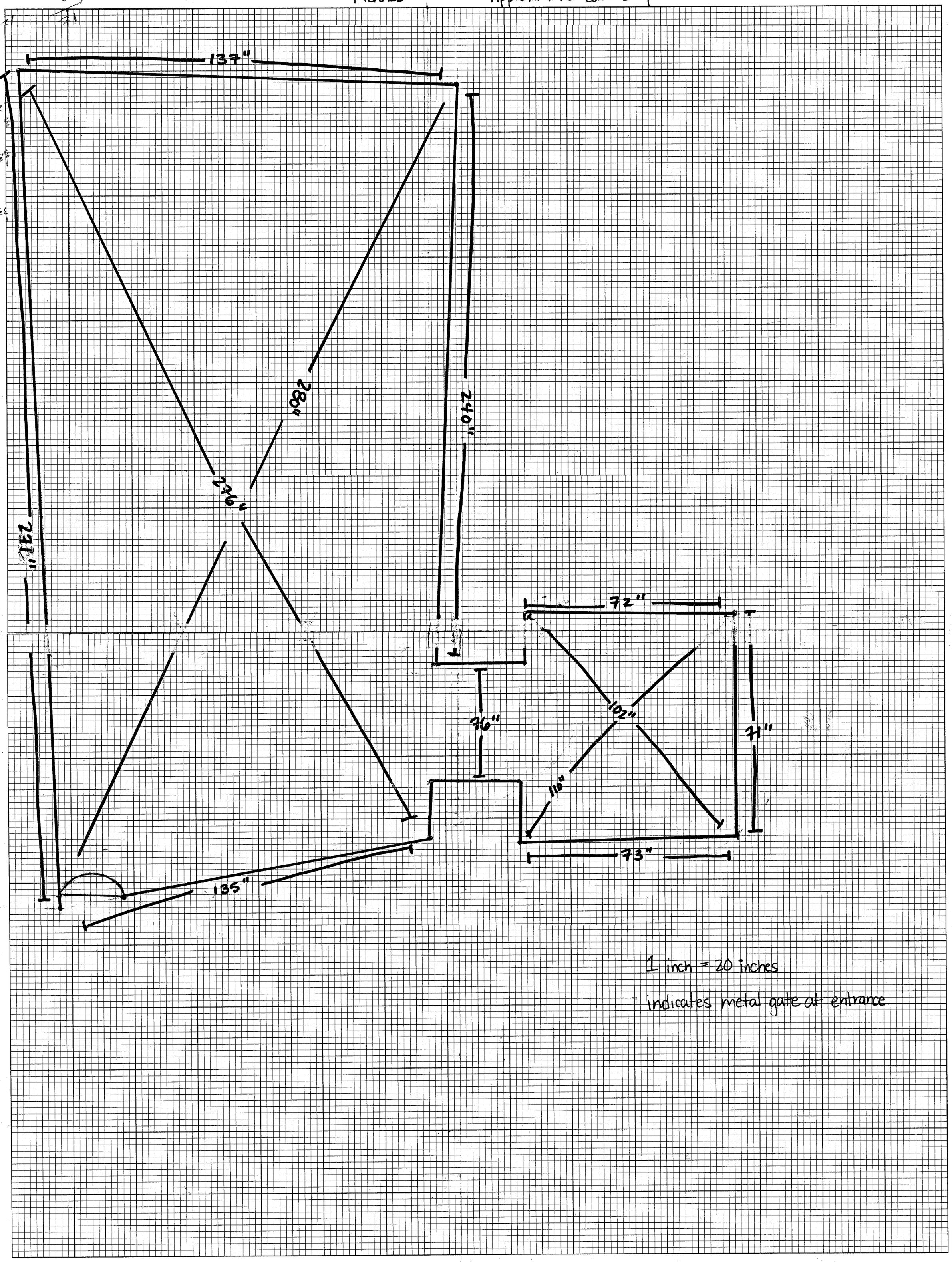

1" = 10'
cave face
fence
CI = 1 ft.
thickness of ceiling rock
8.00
7.00
6.00
5.00
4.00
right corner of fence
edge of the road
seawall-fence lineup
(20.209)
(21.148)
(20.180)
(19.336)
(20.181)
(21.112)

FIGURE 15B

FIGURE 6 Approximate cave shape and dimensions.



1 inch = 20 inches

indicates metal gate at entrance

1 inch = 2 ft.

K+E 10 X 10 TO THE INCH • 10 X 15 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.
47 0780

Figure 8

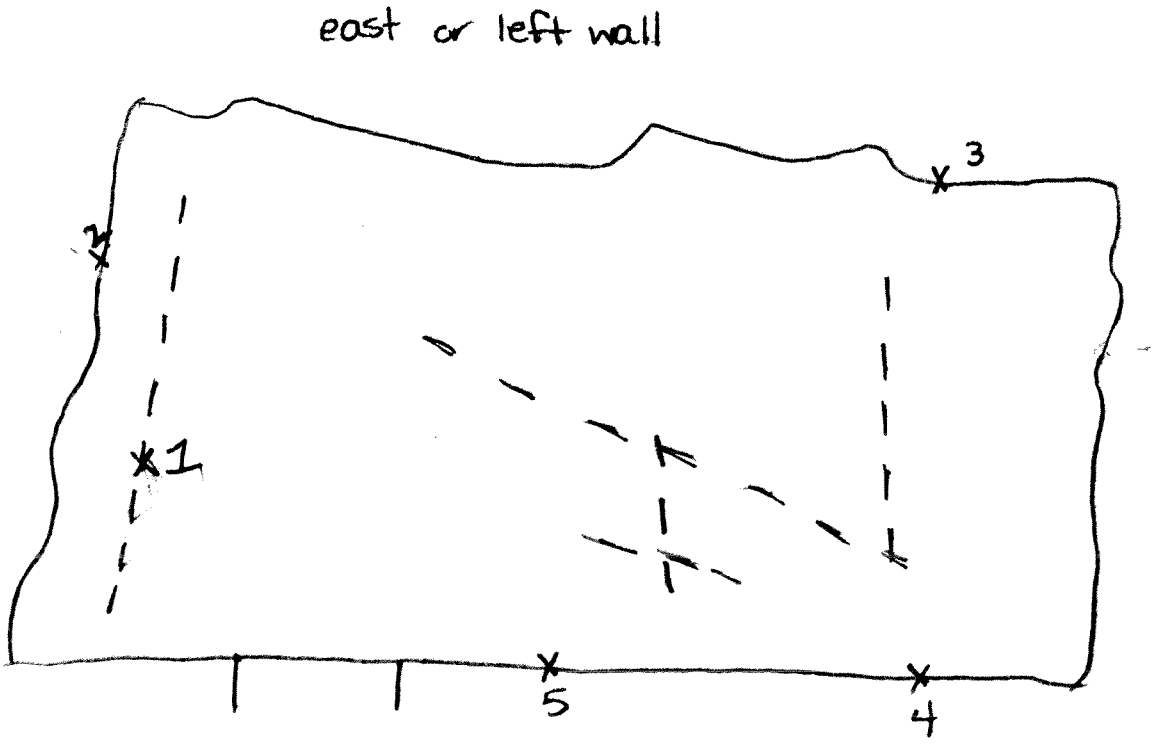
Measurements of strike and dip of fractures in Cornwallis cave.

	strike	dip
1.	N-S	78E
2.	N60E	88NW
3.	N16E	74NE
4.	N43W	81NE
5.	N37W	70NE

*measured in degrees

*point 4 is a face, all other points are fractures

*magnetic declination is 7.5 degrees



Approximate locations of measured fractures.

--- indicates a ceiling fracture

FIGURE 11

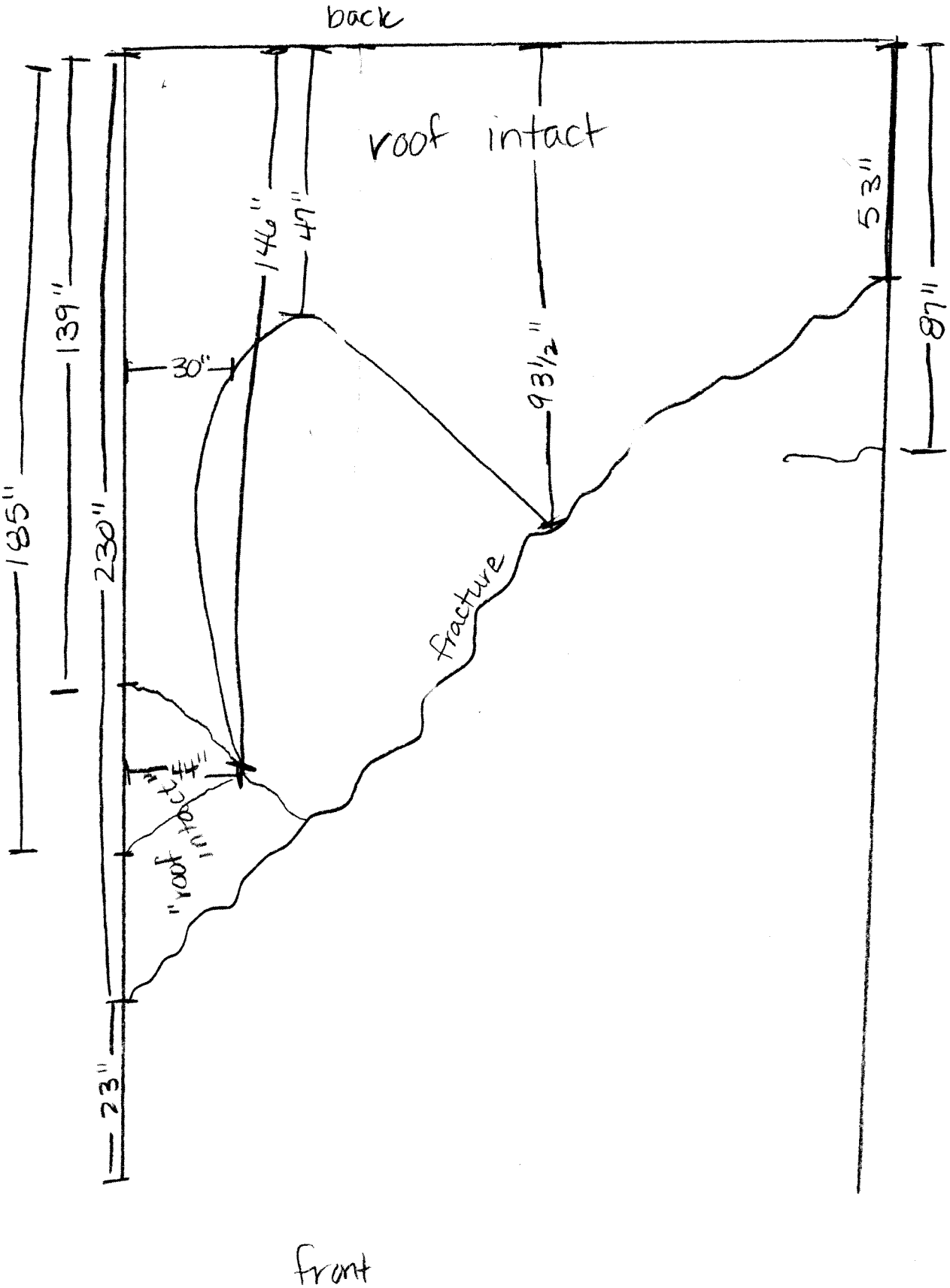
1" = 10'

cave face

fence

FIGURE 12

Location of ceiling fractures.



page 1 zeroed @ left radio tower ID+10 - staff ht

(in ft)

Dr. Johnson
Katie Langford

point	V ∠	HOR ∠	▷	ID	= ▷	COMMENTS elevation
zero	when instrument is focused on left radio tower					staff @ 6'
Sea wall	88.44.57	60.07.03	33.62.00 33.620	0.735	33.61.00	arbitrary elevation = 4.735 ft.
Right corner of fence	88.44.10	314.46.45	32.340	0.710	32.335	4.710
1	86.57.23	271.20.34	27.355	1.455	27.315	5.455
2	88.32.07	272.56.14	56.435	1.445	56.415	staff at 5' 6.445
3	85.46.19	264.08.19	50.900	3.755	50.760	8.755
4	84.59.40	246.42.00	43.680	3.810	43.510	8.81
5	86.28.35	246.00.01	25.850	1.590	25.800	6.59
6	84.25.44	224.44.55	34.490	3.350	34.325	5ft 8.35
Left portal	86.34.13	201.58.46	46.195	2.760	46.110	5ft 7.76
Left portal	86.56.41	197.44.17	50.510	2.695	50.440	5ft 7.695

point	V∠	HOR ∠	▷	▷	▷	COMMENTS	elevation (ft)
7 ✓	84.50.54	189.56.08	44.105	3.960	43.925	5ft staff	✓8.96
8 ✓	83.47.12	196.06.23	51.265	5.550	50.960	"	✓10.55
9 ✓	79.53.48	192.29.53	59.835	10.495	58.905	"	✓15.495
10 ✓	77.02.22	187.30.04	73.110	16.400	71.245	"	✓21.4
11 ✓	76.30.32	185.00.05	87.321 26.614	20.372 6.209	84.912 25.880	"	25.372 ✓
12 ✓	70.00.36	192.08.34	67.021 20.427	22.911 6.983	19.196 62.982	8.5 ft staff	24.411 ✓
13 ✓	65.31.12	200.44.54	71.969 21.935	29.821 9.089	65.499 19.963	8.0 staff	31.821 ✓
14 ✓	63.07.13	200.38.04	52.683 16.057	23.810 7.257	46.974 14.317	"	25.81
15 ✓	59.26.42	220.07.07	43.221 13.173	21.973 6.697	37.220 11.344	staff 5 ft	26.973 ✓
16 ✓	59.53.46	218.39.10	55.295 16.853	27.734 8.453	47.837 14.580	staff 7 ft	30.734 ✓
17 ✓	~~60.51.13~~ 60.45.18	215.58.36	69.501 21.183	33.955 ~~10.349~~ 10.349	~~60.643~~ 18.483	10.5 ft staff	33.455 ✓
18 ✓	60.30.44	235.52.43	~~45.458~~ 13.855	~~22.376~~ 6.820	~~39.569~~ 12.060	6ft staff	~~26.376~~ ✓
19 ✓	62.58.19	237.49.43	~~58.976~~ 17.975	~~26.799~~ 8.168	52.535 16.012	8.5 ft staff	28.299 ✓
20 ✓	63.51.03	234.01.55	61.673 18.797	27.180 8.284	55.360 16.873	8.45 ft	28.73 ✓

point		V∠	HOR ∠	△	⊥	▷	COMMENTS	elevation ft
21	✓	65.00.30	218.52.31	61.102 18.623	25.815 7.868	55.380 16.879	8.5ft staff	✓27.315
22	✓	62.40.41	253.16.18	47.991 14.627	22.029 6.714	42.637 12.995	5ft staff	27.029 ✓
23	✓	60.40.16	253.40.09	62.743 19.123	24.847 7.573	57.614 17.560	8.5 ft staff	26.347 ✓
24	✓	68.40.00	262.10.40	63.035 19.212	23.003 7.011	58.897 17.951	7.5 ft staff	✓25.503
25	✓	63.11.53	260.08.51	51.777 15.781	23.348 7.116	46.216 14.086	7.0 ft staff	✓26.348
26	✓	73.09.07	190.34.33	82.767 25.226	23.987 7.311	79.213 24.143	7.0 ft staff	✓26.987
27	✓	79.58.05	179.42.56	64.803 19.715	11.267 3.434	63.017 19.414	7.0 ft staff	✓14.267
28	✓	85.54.36	186.46.58	30.198 9.204	2.152 .6556	30.123 9.181	5.0 ft staff	✓7.152
29	✓	86.40.56	173.56.43	26.448 8.061	1.532 0.467	26.402 8.047	5.0 ft staff	6.532 ✓
30	✓	88.13.41	158.32.35	28.607 8.719	.886 0.270	28.594 8.715	5.0 ft	✓5.886
31	✓	89.17.42	137.05.12	26.156 7.972	.322 0.098	26.153 7.971	5.0 ft	✓5.322
32	✓	91.21.12	118.34.06	41.541 12.661	−.981 −.299	41.520 12.657	[illegible]	✓4.019
wall east	✓	91.38.47	94.53.14	50.029 15.248	−1.437 −.438	50.009 15.242	5.0 ft 5 0 f t	✓3.563

POINT	V∢	HOR ∢	▷	I▷	▷	COMMENTS	elevation (ft)
4 seawall-fence line up ✓	92.29.94	4.55.19	38.542 11.747	-1.680 -0.512	38.506 11.736	5.0 ft Staff	✓3.32
5 ✓	91.54.44	330.39.41	31.852 9.708	-1.063 -0.324	31.836 9.703	5.0 ft staff	✓3.937
6 ✓ top of roof	95.34.18	19.36.45	11.434 3.485	-1.109 -0.338	11.382 3.469	5.0 ft staff	✓3.891

4D

FIGURE 15A

Thickness of ceiling rock.

- assume roof ceiling height = 74" = 6.167 ft

point	elevation (ft)	thickness of ceiling rock (in ft)
12	24.411	18.244
13	31.821	25.654
14	25.810	19.643
15	26.973	20.806
16	30.734	24.567
17	33.705	27.538
18	26.376	20.209
19	28.299	22.132
20	28.980	22.813
21	27.315	21.148
22	27.279	21.112
23	26.347	20.180
24	25.503	19.336
25	26.348	20.181
26	26.987	20.82
		average = 20.105 feet

FIGURE 4

Vertical burrows in Cornwallis Cave.



Photo taken by. Dr. G. Johnson.

FIGURE 5

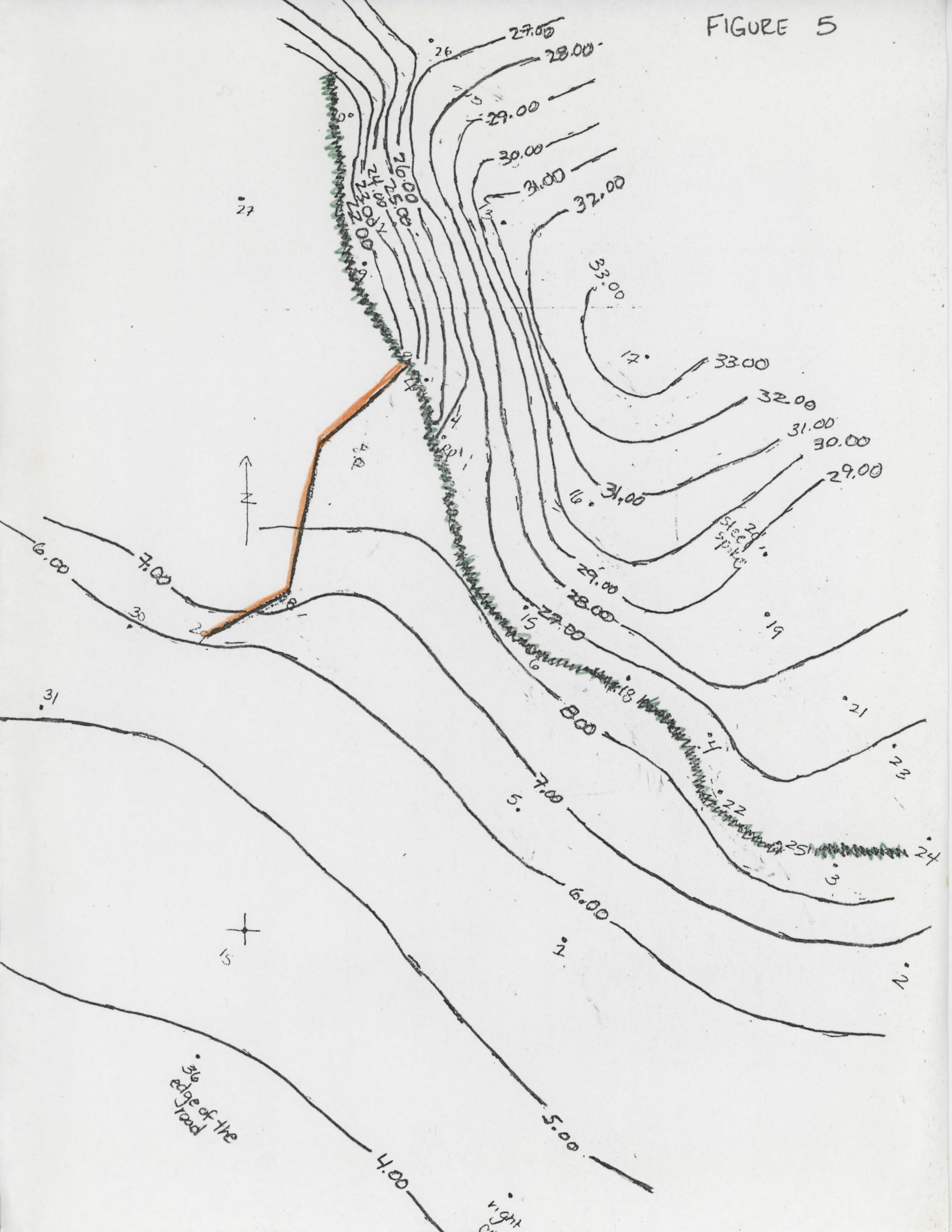

27.00
28.00
29.00
30.00
31.00
32.00
33.00
26.00
25.00
24.00
23.00
22.00
6.00
7.00
8.00
5.00
4.00
N
Steep slope
edge of the road

FIGURE 7.

Large-scale cross-beds in Cornwallis Cave.





Photos taken by Dr. G. Johnson.

FIGURE 10

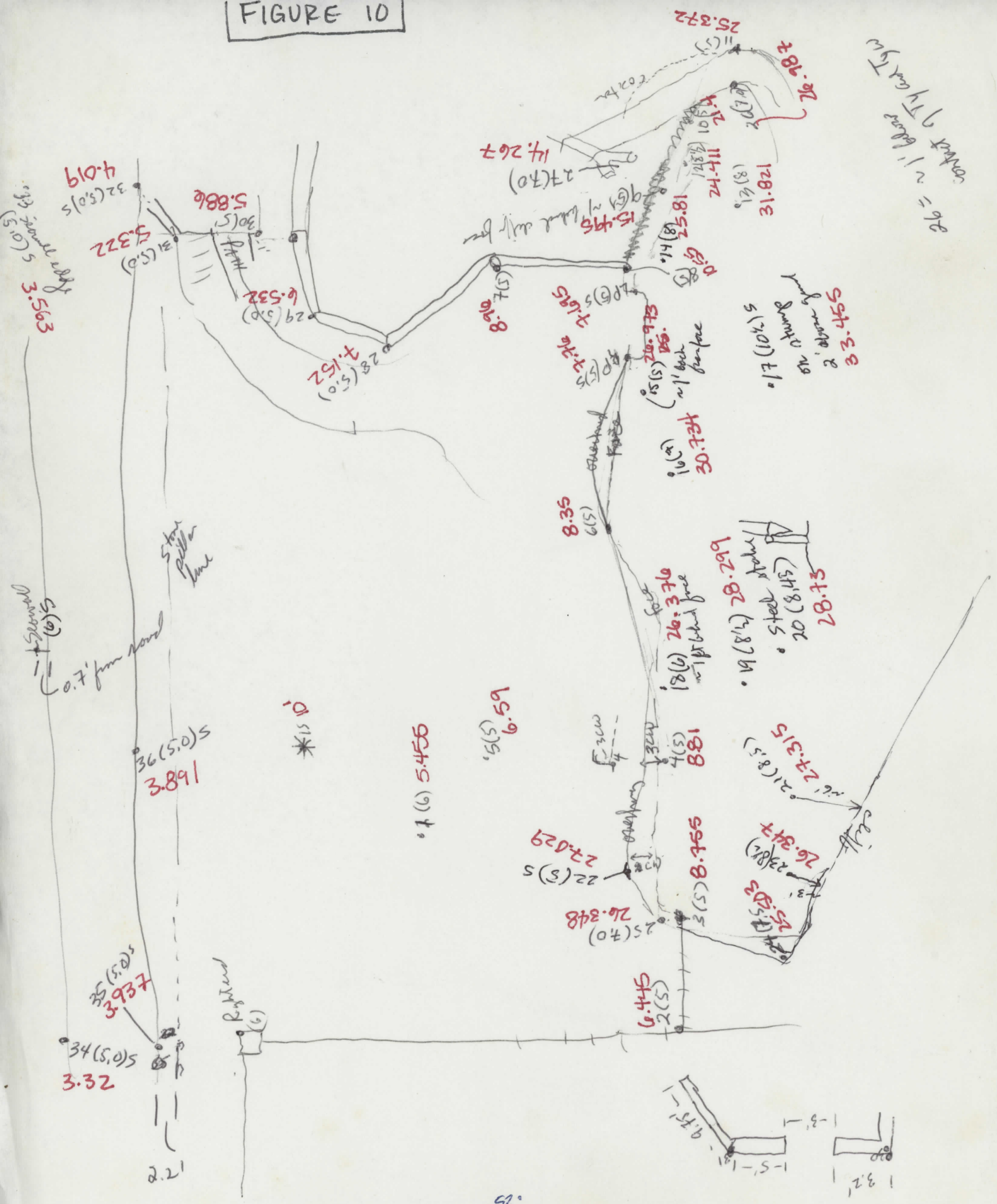


FIGURE 13A

Photos showing fractures in Cornwallis Cave.





Photos taken by Dr. G. Johnson

Figure 13B

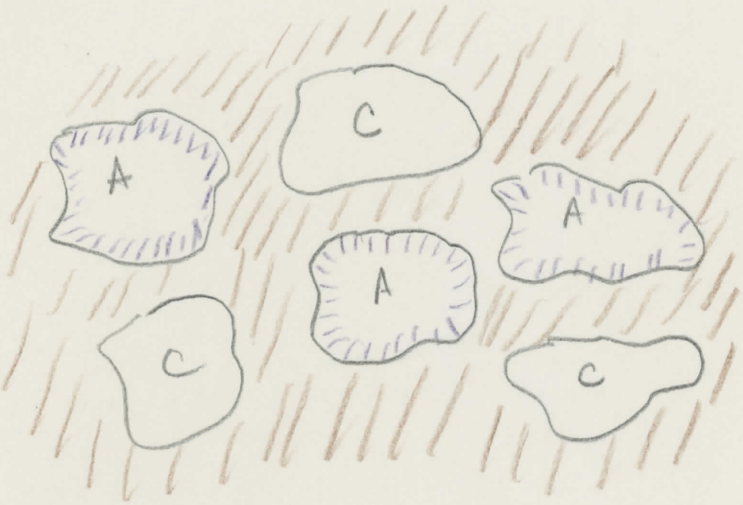
Photos showing large-scale cross-bedded sands with color changes.





Photos taken by Dr. G. Johnson.

FIGURE 14



A aragonite

C calcite

//// calcite cement

//// area of aragonite dissolution due to H_2CO_3

(aragonite grains will fall out of cement)

FIGURE 16

Photos showing human impact on Cornwallis Cave.





Photos taken by Dr. G. Johnson.

FIGURE 15B

1" = 10'
cave face
fence
CI = 1 ft.
— thickness of ceiling rock
Second fence line up
edge of the wood
light clay of fence
N

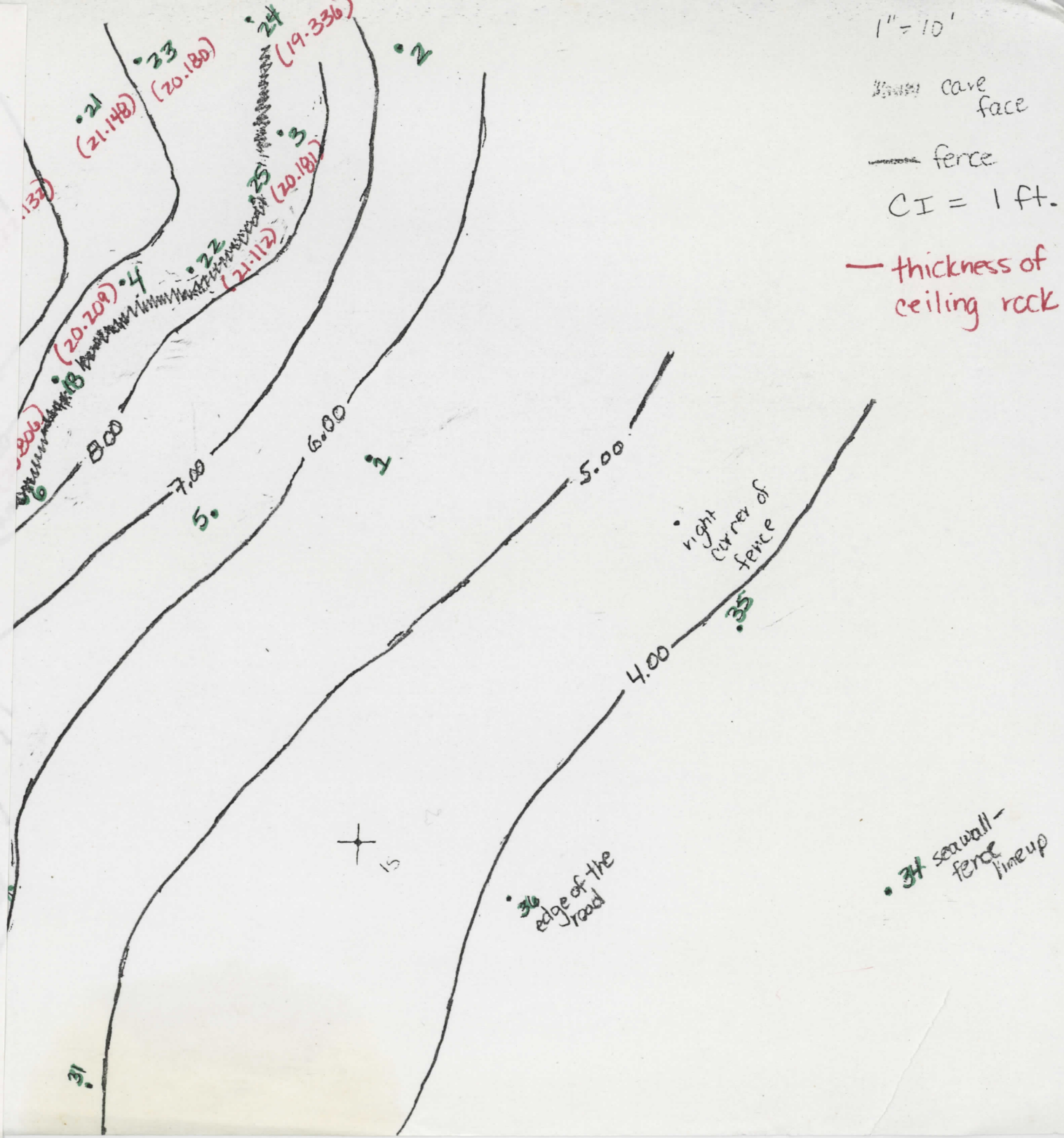

1" = 10'
cave face
fence
CI = 1 ft.
thickness of ceiling rock
8.00
7.00
6.00
5.00
4.00
right corner of fence
edge of the road
seawall-fence lineup
(20.209)
(21.148)
(20.180)
(19.336)
(20.181)
(21.112)

FIGURE 15B

The Failure of Cornwallis Cave

in Yorktown, Virginia

Christine Patton
April 30, 1991
Independent Study

INTRODUCTION

Cornwallis Cave is a historic structure located in Yorktown, Virginia, along the York River, on U.S. National Park Service land (Figure 1). The park service has been investigating the cave, for it is literally "falling apart", and the rate of deterioation has increased in the past decade.

This cave, thought to have been occupied by Lord Cornwallis during the Revolutionary War, lies within the Coastal Plain of Virginia. It cuts into the Yorktown Formation, which is comprised of shelly sands and clays.

The cave's problem seems to be two-fold. First, there is granular disintegration, or a breaking up of individual grains, both inside and outside the cave. Second, there are fractures that run throughout the cave structure. The granular disintegration seems to be a result of interactions between groundwater and the rock of the cave. The combination of gravity acting on an unsupported slope and the cross-bedded nature of the cave probably caused the fracture pattern. The objectives of this study were to try and discover possible reasons for the failure of the cave.

HISTORY

Cornwallis Cave was named after the British commander Lord Cornwallis, who played an instrumental position in the Seige of Yorktown in 1781, a battle which signified the end of the Revolutionary War. In The Story of the Campaign and Seige of Yorktown, H.J. Eckenrode relates

the details of this battle. According to Eckenrode, Cornwallis led his troops into Yorktown in August of 1781, and shortly thereafter, Washington followed with his troops. Washington's earlier actions had led the British to assume that his attack would be at New York rather than Yorktown, and therefore left them unprepared. Lafeyette, a French commander, held his troops in Williamsburg to prevent Cornwallis from crossing the James River and moving southward to avoid Washington's troops. From September 5-9, French and British forces battled on the water until the British realized that they were outnumbered, and began to sail back to New York to make repairs. Now Cornwallis was left on his own to stand against both the troops at land and at sea. On September 28, allied troops left Williamsburg and began their march on Yorktown. Meanwhile, Cornwallis had set up his headquarters at the house of Thomas Nelson. It is said that at some point Cornwallis was forced to leave the Nelson house and meet in a grotto, presumably what is now known as Cornwallis Cave. An escape across the river was attempted on the night of October 16, but a storm forced Cornwallis to bring his forces back. On October 18, both sides met at the Moore house to discuss conditions of the surrender, and Cornwallis signed the necessary papers on the morning of October 19. Lord Cornwallis did not surrender in person to the allies, but instead he sent his sword with General O'Hara to be presented to the victors. On September 3, 1783, a final treaty with Great Britain was formally ratified, and the United States became an independent nation.

TOPOGRAPHY

Yorktown is located on the south bank of the York River, in the Coastal Plain of southeastern Virginia (Figure 1). The Coastal Plain consists of a series of alternating plains and scarps that range from 90 feet to sea level in elevation (Johnson, 1972). The lower York-James Peninsula area contains a succession of plains that dip eastward (Johnson, 1972). Yorktown is situated in the Grove plain, just south of the Camp Peary scarp (Johnson, 1972). (see Figure 2)

STRATIGRAPHY

Cornwallis Cave cuts into the Moore House Member of the Yorktown Formation (Figure 3). The Moore House is characterized by cross-bedded biofragmental sands which range in color from reddish to yellowish-brown. At Cornwallis Cave, these sand deposits have been cemented to form a durable rock.

The Yorktown Formation, which crops out along the York River, is overlain by the Windsor Formation (Johnson, 1972). It ranges from the Fall Zone in central Virginia to the lower end of the York-James Peninsula in southeastern Virginia, where it is its thickest at approximately 500 feet (Gibson, 1970). The Yorktown is an upper Pliocene deposit, which means that is was deposited around 3.4 to 1.6 million years ago, and is composed mostly of marine silt, sand, and shell fragments (Johnson, 1972).

Cornwallis Cave is carved out of the Moore House Member of the Yorktown Formation, which overlies the Morgarts Beach, Rushmere, and

Sunken Meadow Members. The Moore House Member is characterized by large-scale cross-bedded sands, which range in thickness from 3 feet to 15 feet or more. At Cornwallis Cave, these cross-beds dip 24 degrees NW (Johnson, 1972). The cross-bedding is thought to have formed from water moving over an underwater shoal. As the flow of water was obstructed and slowed by the shoal, it's capacity to carry sediment decreased, and the sediment dropped out of solution. Since coarser sand grains are heavier, they would have dropped out of the water first, followed by the finer grained sand, resulting in upwardly grading deposits (from coarse to fine grain). This type of bedding would continue as water washed over the shoal, making the large cross-beds that are seen in the formation today. The vertical burrows seen in the cave face are evidence that these beds are in fact cross-beds, and not beds that have been tilted, as the burrows would also have been tilted (Figure 4). These deposits include abundant shell fragments, indicating a shallow, medium to high energy, marine depositional environment. Shells of Mulinia, Crepidual, Pecten, Venericardia, and Glycermeris are the most abundant (Johnson, 1972).

After these beds were deposited as loose sands, they were cemented to form a durable rock. Since it is known that the cement is calcite, as are some of the shells found in the deposits, it can be assumed that these shells were the source of calcium carbonate for the cement. As groundwater or salt spray from the nearby York River moved through the deposits, and reacted with the carbon dioxide in the atmosphere, it formed carbonic acid. The carbonic acid then began to leach away at the

calcium carbonate in the shells, causing it to go into solution in the water. The calcium carbonate would precipitate out either as a result of lack of carbon dioxide to react with the water, or, more likely, as the water became saturated with calcium carbonate.

METHODS AND MATERIALS

A theodolite was used to determine elevations of the cave, which were then used in preparing a contour map of the location (Figure 5). The inside dimensions of the cave were measured with a tape measure, and plotted (Figure 6). Photographs were taken to show the nature of the cave material, locations of fractures, and the large-scale cross-bedding (Figure 7). A Brunton compass was used to measure strike and dip of several of the fractures in the cave, and the cave face, and a general sketch was drawn to show the locations of the measured fractures (Figure 8).

OBJECTIVES

As previously stated, there are basically two problems with the cave: a type of granular disintegration, and fracturing. The granular disintegration is evident in the abundant grains that lie in piles on the ground both inside and outside the cave. The grains are apparently falling from the walls and ceiling quite easily, as they can simply be removed by brushing against the cave surface. These grains are sand-sized, between approximately 1 and 2 mm in diameter. One objective of this study was to find out why this rock is falling apart so easily.

The second objective deals with the second, and perhaps more dangerous, problem - the fracturing. There are fractures in the walls inside and outside of the cave, as well as in the cave ceiling. Some of these fractures show movement.

PRESENTATION OF DATA

Most of the data collected and presented in this paper deal with the theodolite readings. Readings were taken for 38 points around and on top of the cave (Figures 9A, 9B, 9C, and 9D). A map was drawn while the theodolite readings were being taken in order to show the relative locations of the points measured (Figure 10). These points were then plotted, along with their elevations (Figure 11). The elevations were used in order to draw a final contour map (Figure 5).

Measurements with a tape measure were used to map the approximate shape of the cave (Figure 6). A sketch of the location of the ceiling fractures was drawn (Figure 12). Strike and dip measurements were made for several of the fractures in the cave and, the location of these fractures was sketched (Figure 8). Photographs of the cave were taken in order to show characteristics of the cave (Figures 13A and 13B).

DISCUSSION

The problem of granular disintegration can be attributed to the interaction of the rock of the cave with groundwater. The rock is very fossiliferous, with shells of bivalves, gastropods, and barnacles. These shells are composed of aragonite and calcite, while the cement of

the rock is calcite. Although both calcite and aragonite are forms of calcium carbonate, they differ in their rate of solubility. The solubility of aragonite is .00153 g/100cc at 25 degrees Celsius, and .00190 g/100cc at 75 degrees, whereas the solubililty of calcite is .001425 g/100cc at 25 degrees and .001875 g/100cc at 75 degrees (Lide, 1990). As groundwater moves through the rock, the aragonite shells are preferentially dissolved. As they dissolve, the bond between the shell and cement weakens and the shells fall out of the calcite cement (Figure 14). This produces all the granular material that is seen on the ground all around the cave.

Another obvious aspect of the cave was the fractures both inside and outside, some of which showed movement. These fractures are probably due to gravity acting on the unsupported dead weight of the cave ceiling. Since the rock has been excavated in order to make the cave, all support of the ceiling rock has been removed. The ceiling rock is an average of 20.105 feet thick (Figures 15A and 15B).

There are also some smaller contributing factors to the failure of the cave. Human impact has added to the rate of granular disintegration, as well as animals. Vegetation on top of the cave is not only an additional weight on the unsupported ceiling, but the roots also penetrate into the fractures. As the roots grow and expand, they cause the fractures to open up even more. Similarly, the process of freeze-thaw, where water within the fractures freezes, expands, and opens up the fractures, could also be a contributing factor.

CONCLUSIONS

Cornwallis Cave is deterioating in two ways. First, there is the process of granular disintegration. This is caused by the movement of groundwater through the cave. The groundwater causes leaching and dissolution of the aragonite shells, which then fall out of the rock, causing granular breakup of the cave.

Secondly, the cave is also experiencing fracturing. The main reason behind this seems to be the weight of the overlying rock of the cave ceiling, which is not supported. Although there was work on relating strike and dip of the fractures and the cross-bedding, the work proved inconclusive.

RECOMMENDATIONS

Possible remediation includes lining the entire cave with concrete supports, as has been done in one corner of the cave recently. Of course, this is not an aesthetically pleasing choice. Another problem that has not been fully addressed in this study is human impact on the cave. Inside and outside, there is graffitti which has been carved into the rock. Since the cave is now closed off by a metal fence at the cave mouth, a further step could be taken by fencing off the cave so that even the exterior of the cave is not accessible to the public. This also has a negative effect though, in that it would decrease the attraction of the cave. The removal of overlying vegetation would decrease the amount of dead weight that is exerting pressure on the ceiling. Even if the problems were solved or mitigated, the cave may be

damaged or even destroyed by a storm, due to its proximity to the shoreline.

ACKNOWLEDGEMENTS

The author wishes to express deepest gratitude to Dr. Gerald Johnson of the College of William and Mary for his endless time, patience, and guidance. Also, a big thank you to Mary Doroshenk, Katie Langford, Derek Unger, and Scott Harris for their time and help; and to Heather Scobie for the use of her computer.

BIBLIOGRAPHY

Eckenrode, Hamilton Jones, 1931, The Story of the Campaign and Siege of Yorktown: Washington, D.C., United States Government Printing Office, 54 pp.

Gibson, T.G., 1970, Late Mesozoic-Cenozoic Tectonic Aspects of the Atlantic Coastal Margin: Geological Society of America Bulletin, Vol. 81, pp.1813-1822.

Johnson, Gerald H., 1972, Geology of the Yorktown, Poquoson West, and Poquoson East Quadrangles, Virginia: Charlottesville, Virginia Division of Mineral Resources, 57 pp.

Lide, David R., editor, 1990, CRC Handbook of Chemistry and Physics: Boston, CRC Press, p. 4-52.

FIGURE 1

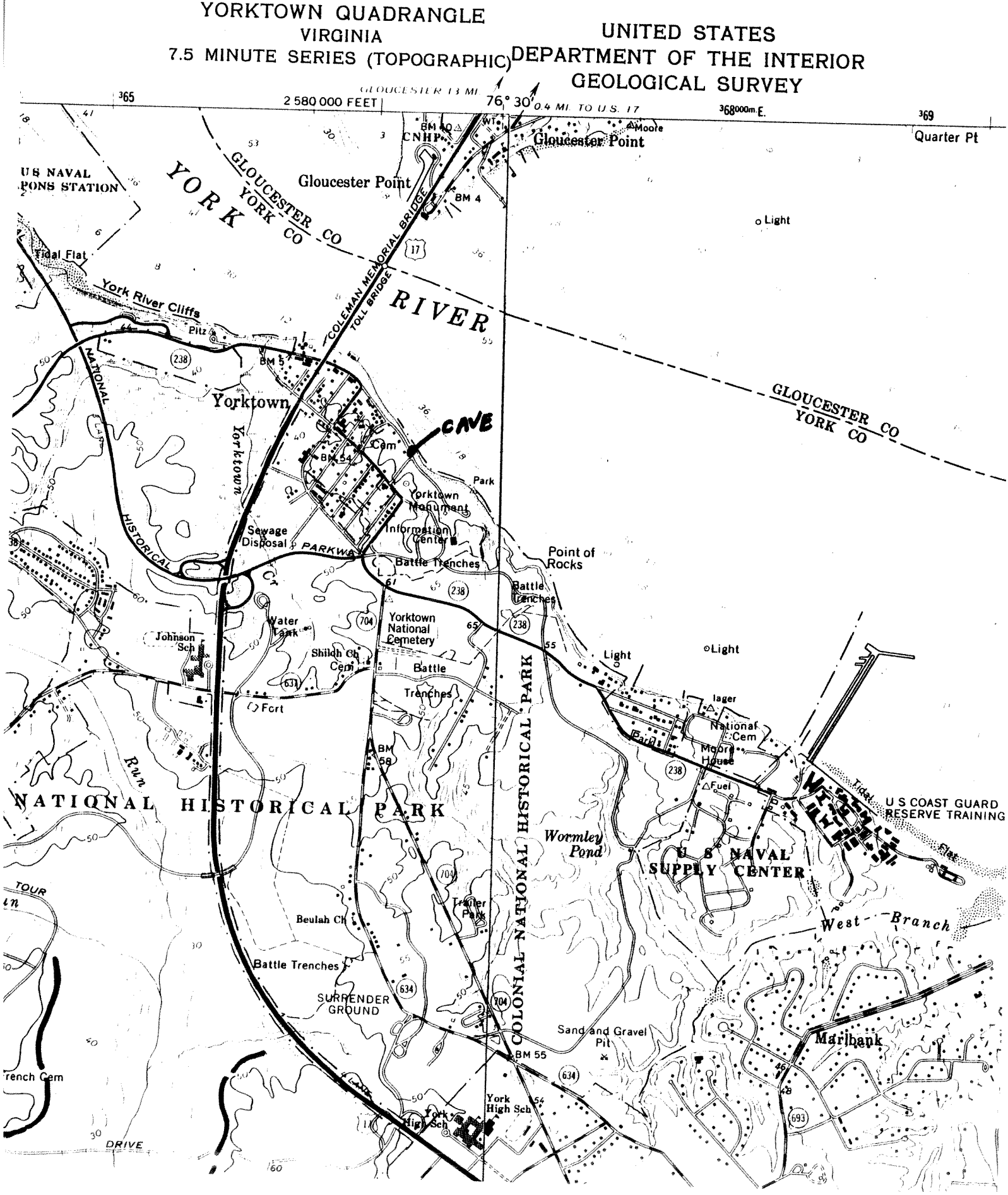
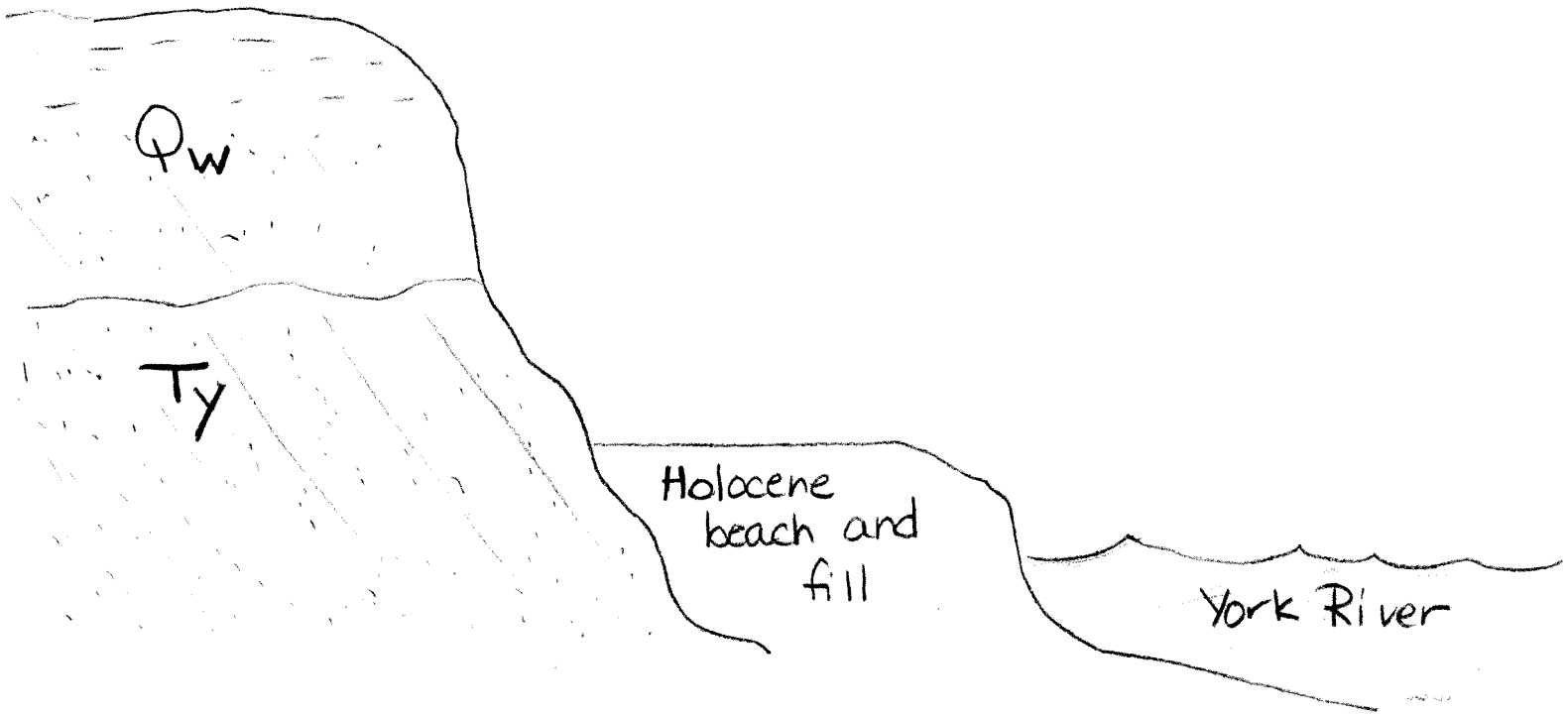

YORKTOWN QUADRANGLE
VIRGINIA
7.5 MINUTE SERIES (TOPOGRAPHIC)
UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
2 580 000 FEET
76° 30'
0.4 MI. TO U.S. 17
368000m.E.
Gloucester Point
Quarter Pt
CNHP
Moore
US NAVAL
PONS STATION
YORK CO
GLOUCESTER CO
YORK CO
Gloucester Point
BM 4
COLEMAN MEMORIAL BRIDGE
TOLL BRIDGE
Light
Tidal Flat
York River Cliffs
RIVER
Pltz
BM 5
GLOUCESTER CO
YORK CO
Yorktown
CAVE
Cem
BM 54
Park
Yorktown Monument
Information Center
Sewage Disposal
PARKWAY
Battle Trenches
Point of Rocks
Battle Trenches
Yorktown
HISTORICAL
Water Tank
Yorktown National Cemetery
Johnson Sch
Shiloh Ch Cem
Battle Trenches
Light
Light
Fort
Run
NATIONAL HISTORICAL PARK
BM 58
COLONIAL NATIONAL HISTORICAL PARK
Wormley Pond
U S NAVAL SUPPLY CENTER
U S COAST GUARD RESERVE TRAINING
Tidal Flat
West Branch
TOUR
Beulah Ch
Trailer Park
Battle Trenches
SURRENDER GROUND
Sand and Gravel Pit
BM 55
Marlbank
York High Sch
DRIVE

FIGURE 2

Figure 3. Map showing the principal geomorphic features in the Yorktown, Poquoson West, and Poquoson East quadrangles.

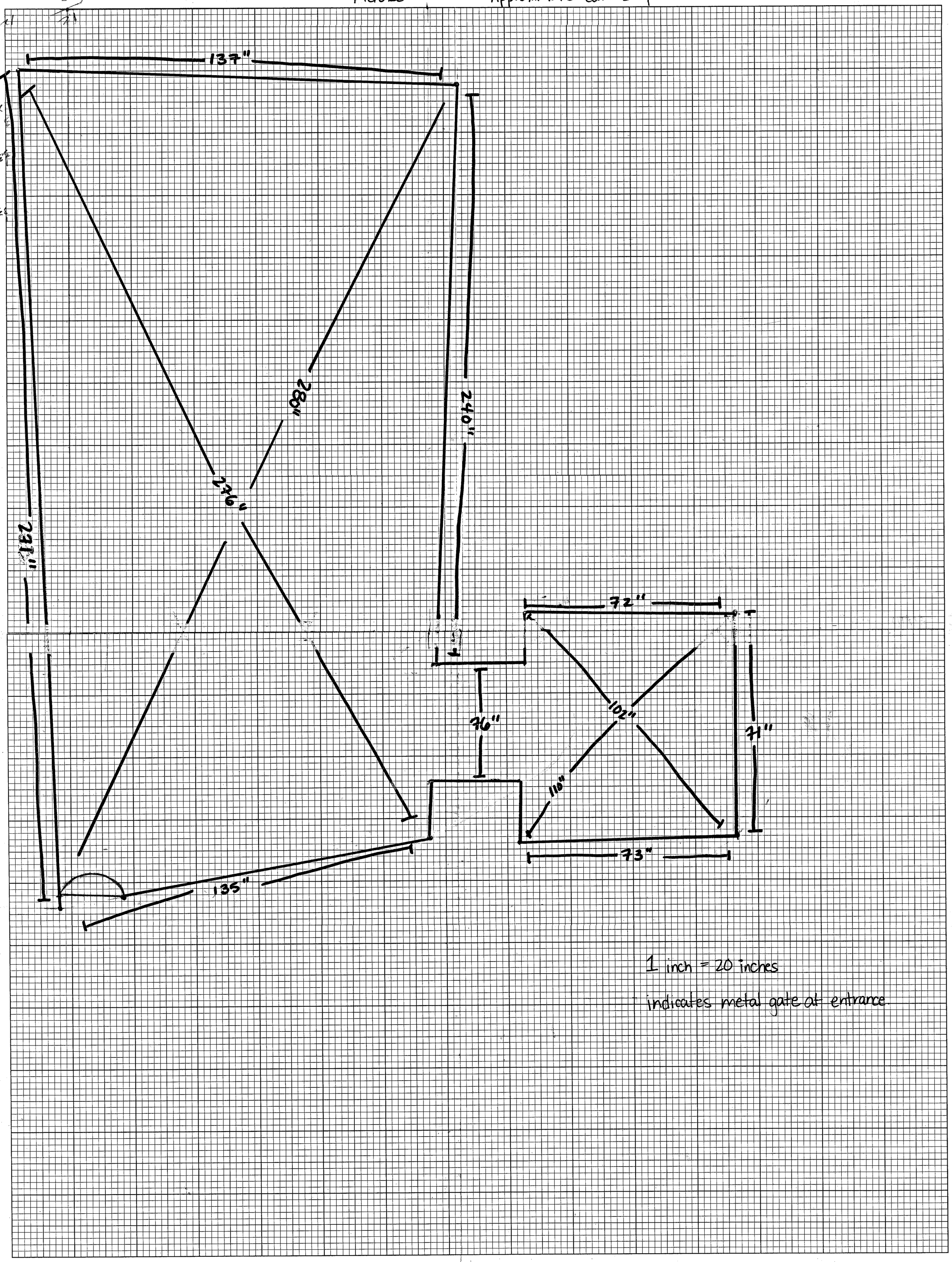
FIGURE 3



Qw - Windsor Formation - lower cross-bedded sand unit, upper silty unit

Ty - Yorktown Formation - large-scale cross bedded sands

FIGURE 6 Approximate cave shape and dimensions.



1 inch = 20 inches

indicates metal gate at entrance

1 inch = 2 ft.

K+E 10 X 10 TO THE INCH • 10 X 15 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.
47 0780

Figure 8

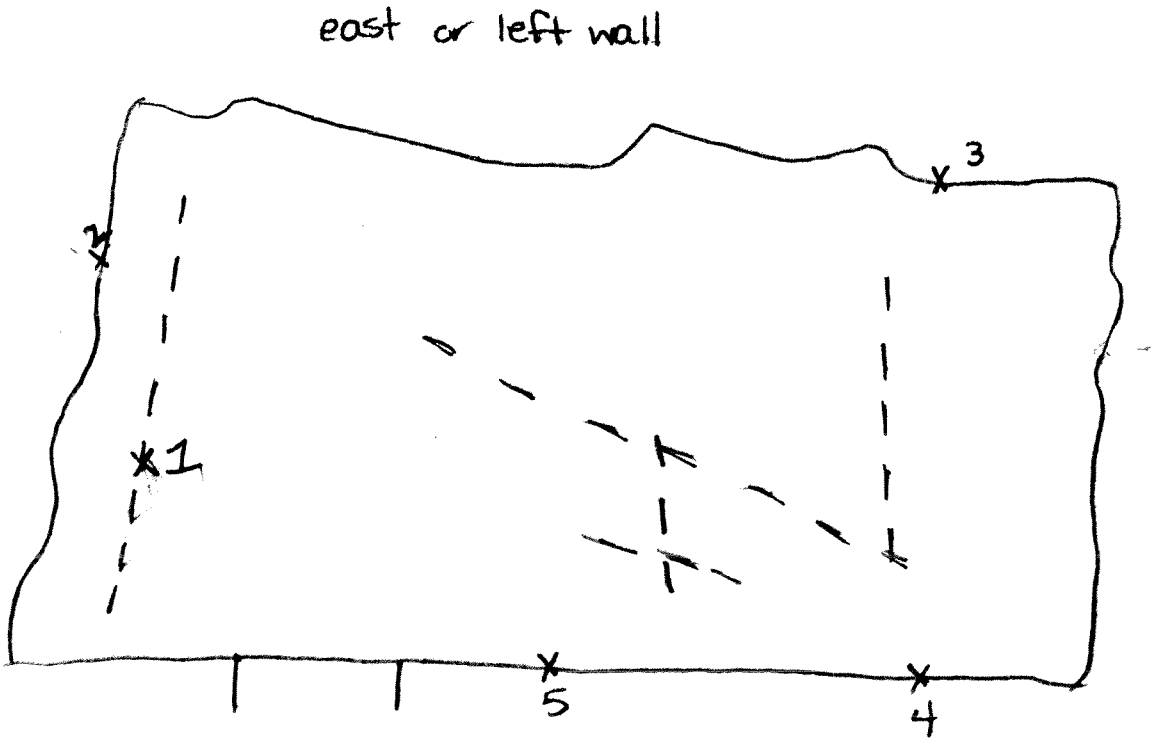
Measurements of strike and dip of fractures in Cornwallis cave.

	strike	dip
1.	N-S	78E
2.	N60E	88NW
3.	N16E	74NE
4.	N43W	81NE
5.	N37W	70NE

*measured in degrees

*point 4 is a face, all other points are fractures

*magnetic declination is 7.5 degrees



Approximate locations of measured fractures.

--- indicates a ceiling fracture

page 1 zeroed @ left radio tower ID+10 - staff ht

(in ft)

Dr. Johnson
Katie Langford

point	V ∠	HOR ∠	▷	ID	= ▷	COMMENTS elevation
zero	when instrument is focused on left radio tower					staff @ 6'
Sea wall	88.44.57	60.07.03	33.62.00 33.620	0.735	33.61.00	arbitrary elevation = 4.735 ft.
Right corner of fence	88.44.10	314.46.45	32.340	0.710	32.335	4.710
1	86.57.23	271.20.34	27.355	1.455	27.315	5.455
2	88.32.07	272.56.14	56.435	1.445	56.415	staff at 5' 6.445
3	85.46.19	264.08.19	50.900	3.755	50.760	8.755
4	84.59.40	246.42.00	43.680	3.810	43.510	8.81
5	86.28.35	246.00.01	25.850	1.590	25.800	6.59
6	84.25.44	224.44.55	34.490	3.350	34.325	5ft 8.35
Left portal	86.34.13	201.58.46	46.195	2.760	46.110	5ft 7.76
Left portal	86.56.41	197.44.17	50.510	2.695	50.440	5ft 7.695

point	V∠	HOR ∠	▷	▷	▷	COMMENTS	elevation (ft)
7 ✓	84.50.54	189.56.08	44.105	3.960	43.925	5ft staff	✓8.96
8 ✓	83.47.12	196.06.23	51.265	5.550	50.960	"	✓10.55
9 ✓	79.53.48	192.29.53	59.835	10.495	58.905	"	✓15.495
10 ✓	77.02.22	187.30.04	73.110	16.400	71.245	"	✓21.4
11 ✓	76.30.32	185.00.05	87.321 26.614	20.372 6.209	84.912 25.880	"	25.372 ✓
12 ✓	70.00.36	192.08.34	67.021 20.427	22.911 6.983	19.196 62.982	8.5 ft staff	24.411 ✓
13 ✓	65.31.12	200.44.54	71.969 21.935	29.821 9.089	65.499 19.963	8.0 staff	31.821 ✓
14 ✓	63.07.13	200.38.04	52.683 16.057	23.810 7.257	46.974 14.317	"	25.81
15 ✓	59.26.42	220.07.07	43.221 13.173	21.973 6.697	37.220 11.344	staff 5 ft	26.973 ✓
16 ✓	59.53.46	218.39.10	55.295 16.853	27.734 8.453	47.837 14.580	staff 7 ft	30.734 ✓
17 ✓	~~60.51.13~~ 60.45.18	215.58.36	69.501 21.183	33.955 ~~10.349~~ 10.349	~~60.643~~ 18.483	10.5 ft staff	33.455 ✓
18 ✓	60.30.44	235.52.43	~~45.458~~ 13.855	~~22.376~~ 6.820	~~39.569~~ 12.060	6ft staff	~~26.376~~ ✓
19 ✓	62.58.19	237.49.43	~~58.976~~ 17.975	~~26.799~~ 8.168	52.535 16.012	8.5 ft staff	28.299 ✓
20 ✓	63.51.03	234.01.55	61.673 18.797	27.180 8.284	55.360 16.873	8.45 ft	28.73 ✓

point		V∠	HOR ∠	△	⊥	▷	COMMENTS	elevation ft
21	✓	65.00.30	218.52.31	61.102 18.623	25.815 7.868	55.380 16.879	8.5ft staff	✓27.315
22	✓	62.40.41	253.16.18	47.991 14.627	22.029 6.714	42.637 12.995	5ft staff	27.029 ✓
23	✓	60.40.16	253.40.09	62.743 19.123	24.847 7.573	57.614 17.560	8.5 ft staff	26.347 ✓
24	✓	68.40.00	262.10.40	63.035 19.212	23.003 7.011	58.897 17.951	7.5 ft staff	✓25.503
25	✓	63.11.53	260.08.51	51.777 15.781	23.348 7.116	46.216 14.086	7.0 ft staff	✓26.348
26	✓	73.09.07	190.34.33	82.767 25.226	23.987 7.311	79.213 24.143	7.0 ft staff	✓26.987
27	✓	79.58.05	179.42.56	64.803 19.715	11.267 3.434	63.017 19.414	7.0 ft staff	✓14.267
28	✓	85.54.36	186.46.58	30.198 9.204	2.152 .6556	30.123 9.181	5.0 ft staff	✓7.152
29	✓	86.40.56	173.56.43	26.448 8.061	1.532 0.467	26.402 8.047	5.0 ft staff	6.532 ✓
30	✓	88.13.41	158.32.35	28.607 8.719	.886 0.270	28.594 8.715	5.0 ft	✓5.886
31	✓	89.17.42	137.05.12	26.156 7.972	.322 0.098	26.153 7.971	5.0 ft	✓5.322
32	✓	91.21.12	118.34.06	41.541 12.661	−.981 −.299	41.520 12.657	[illegible]	✓4.019
wall east	✓	91.38.47	94.53.14	50.029 15.248	−1.437 −.438	50.009 15.242	5.0 ft 5 0 f t	✓3.563

POINT	V∢	HOR ∢	▷	I▷	▷	COMMENTS	elevation (ft)
4 seawall-fence line up ✓	92.29.94	4.55.19	38.542 11.747	-1.680 -0.512	38.506 11.736	5.0 ft Staff	✓3.32
5 ✓	91.54.44	330.39.41	31.852 9.708	-1.063 -0.324	31.836 9.703	5.0 ft staff	✓3.937
6 ✓ top of roof	95.34.18	19.36.45	11.434 3.485	-1.109 -0.338	11.382 3.469	5.0 ft staff	✓3.891

4D

FIGURE 15A

Thickness of ceiling rock.

- assume roof ceiling height = 74" = 6.167 ft

point	elevation (ft)	thickness of ceiling rock (in ft)
12	24.411	18.244
13	31.821	25.654
14	25.810	19.643
15	26.973	20.806
16	30.734	24.567
17	33.705	27.538
18	26.376	20.209
19	28.299	22.132
20	28.980	22.813
21	27.315	21.148
22	27.279	21.112
23	26.347	20.180
24	25.503	19.336
25	26.348	20.181
26	26.987	20.82
		average = 20.105 feet

FIGURE 11

1" = 10'

cave face

fence

FIGURE 12

Location of ceiling fractures.

