Exploitation of Remote Sensing and Geographic Information Systems Technology to Assess Underground Openings

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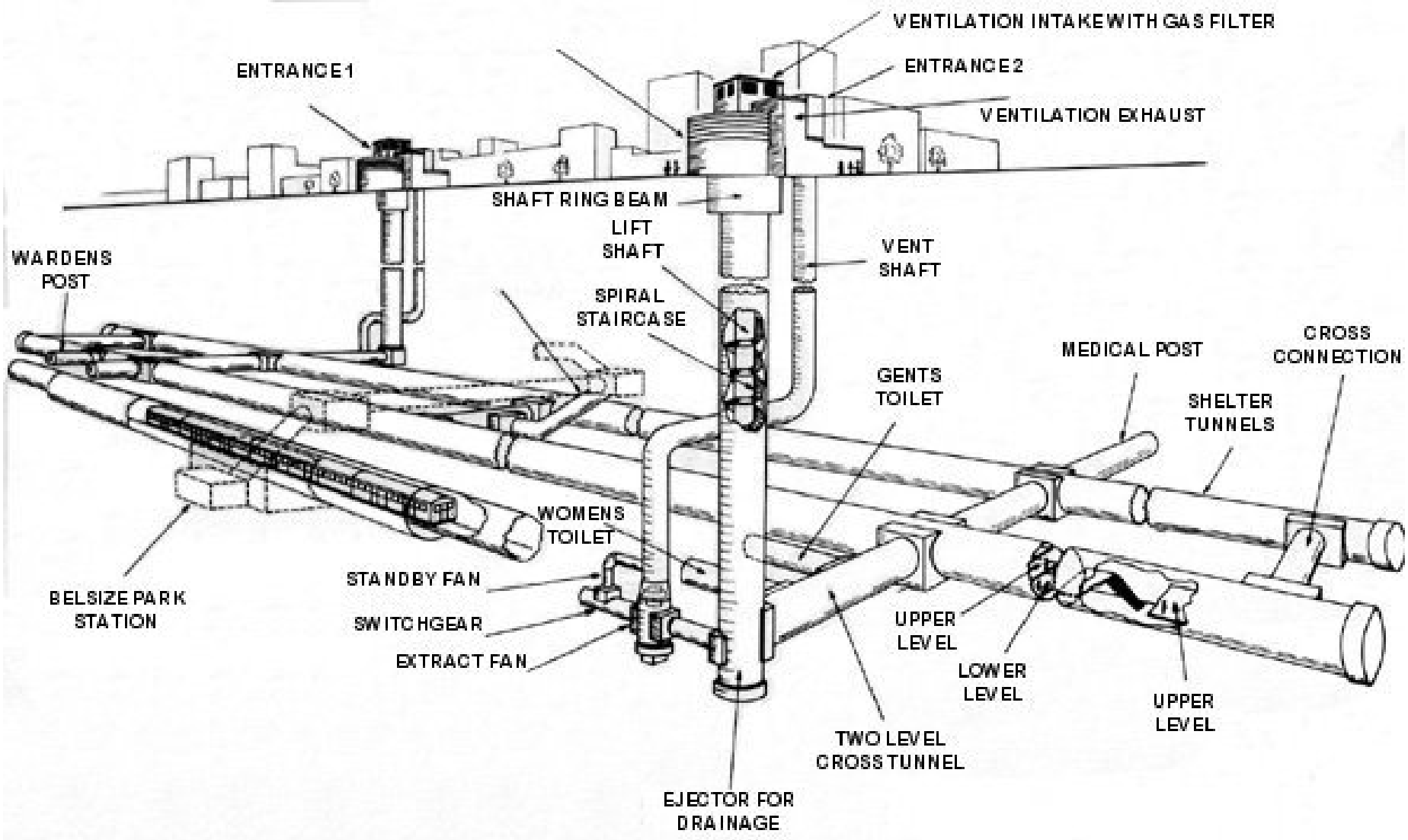
ADVENT OF PROTECTIVE STRUCTURES 1939-45

Aircraft achieved dominance during the Second World War, raining destruction on military and civilian targets

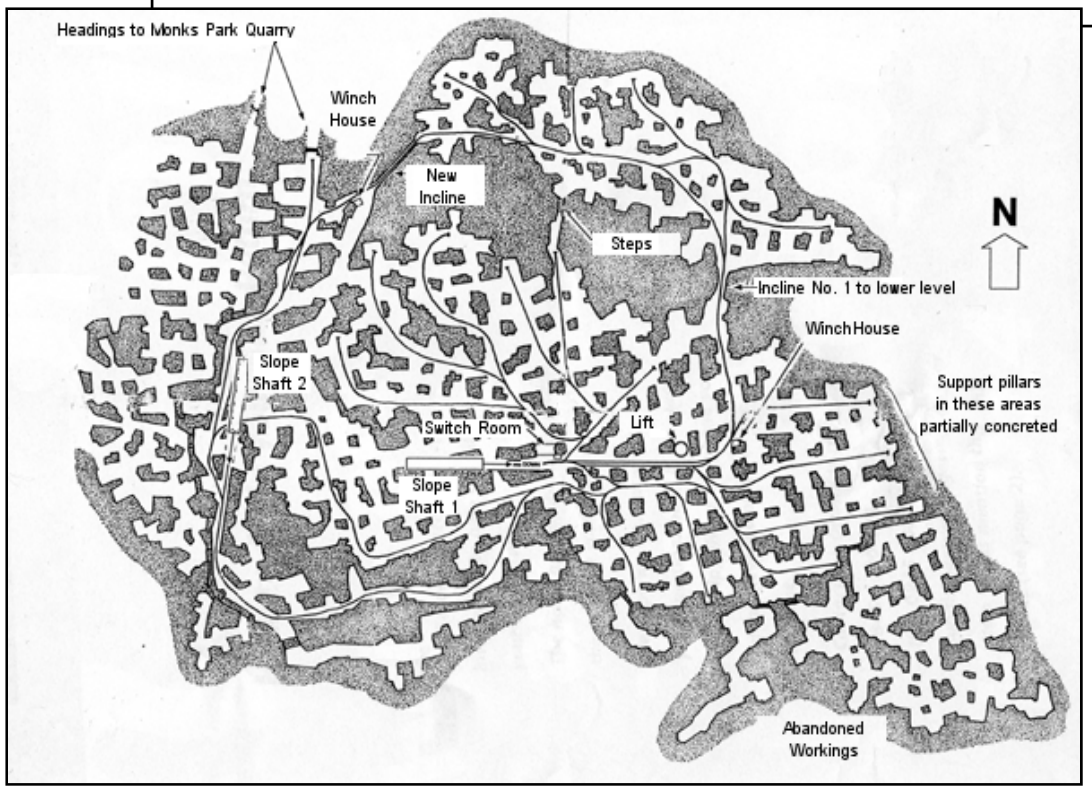
One of the first underground railway stations converted to bomb shelters during the night was Picadilly Station, shown here



- The second generation structures were constructed solely as shelters. This shows the deep level shelters at Belsize Park, which were accessed by two circular turrets, which contained elevators and a spiral staircase leading down to the twin tunnels below.

EXAMPLES OF UNDERGROUND MINES

Utilization of Underground Mines

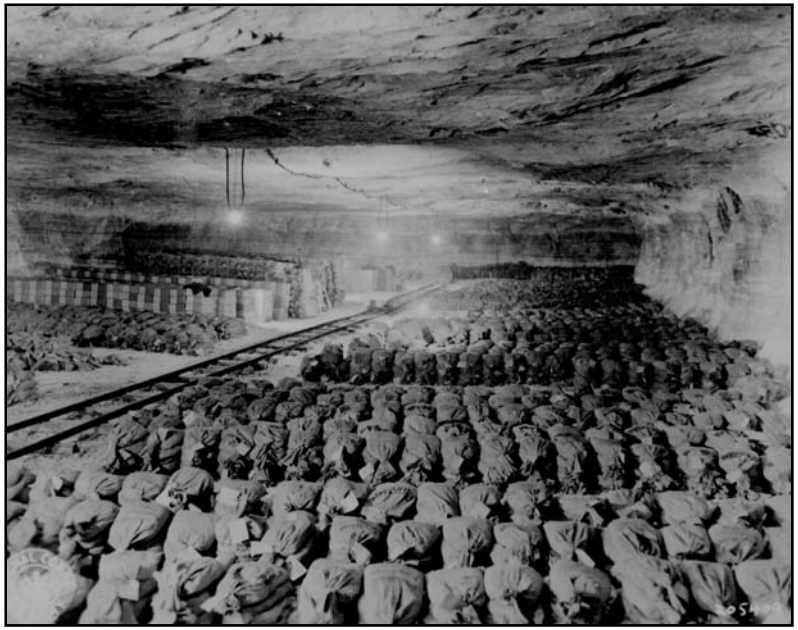


Map of the old Ridge Quarry, a room and pillar mine in Great Britain that was utilized for storage of munitions and other critical war materials

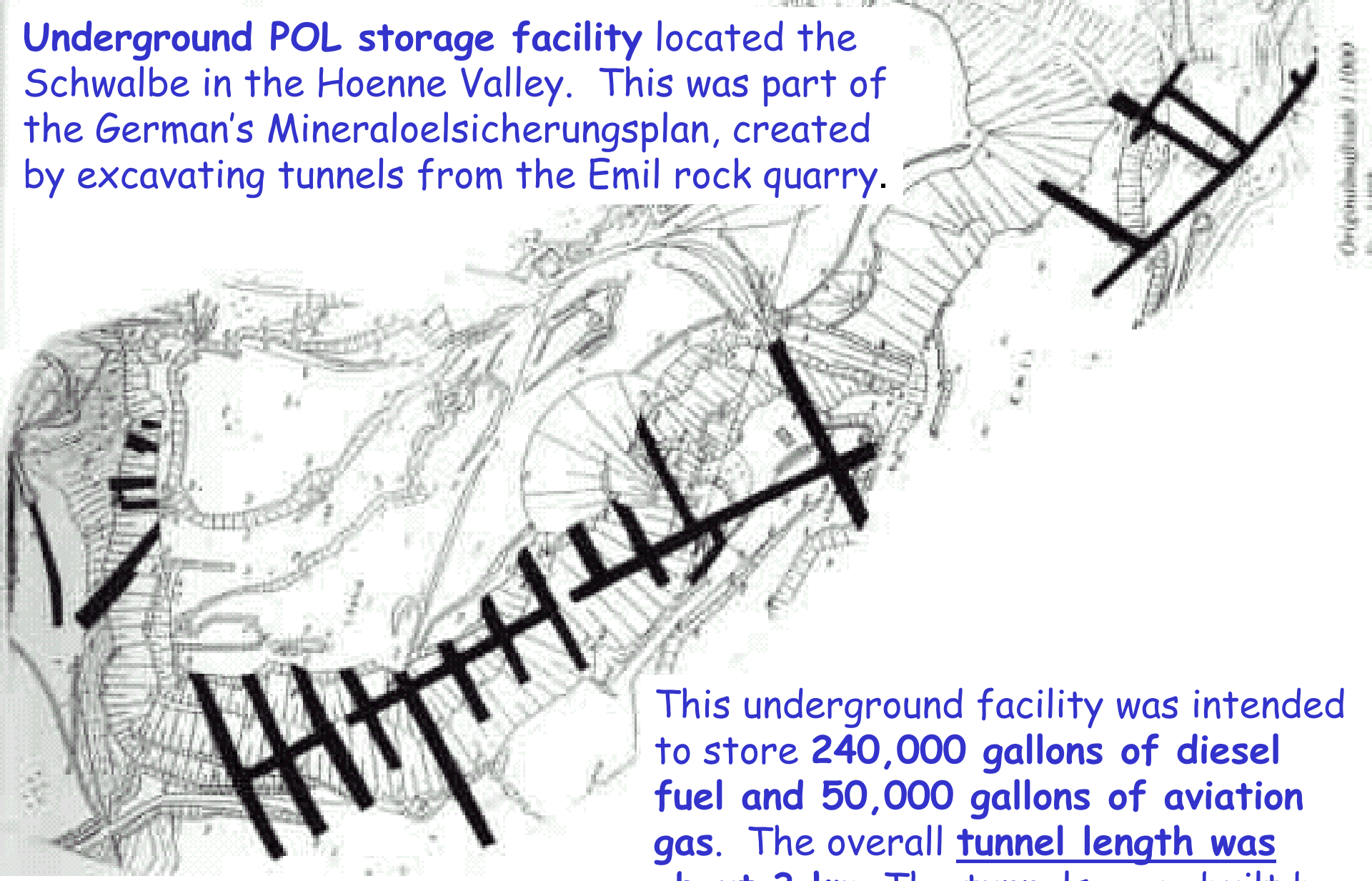
ROUND-THE-CLOCK STRATEGIC BOMBING

German war production plummeted as Allied bombing increased; persuading the Germans to take their critical facilities underground

German Underground Openings

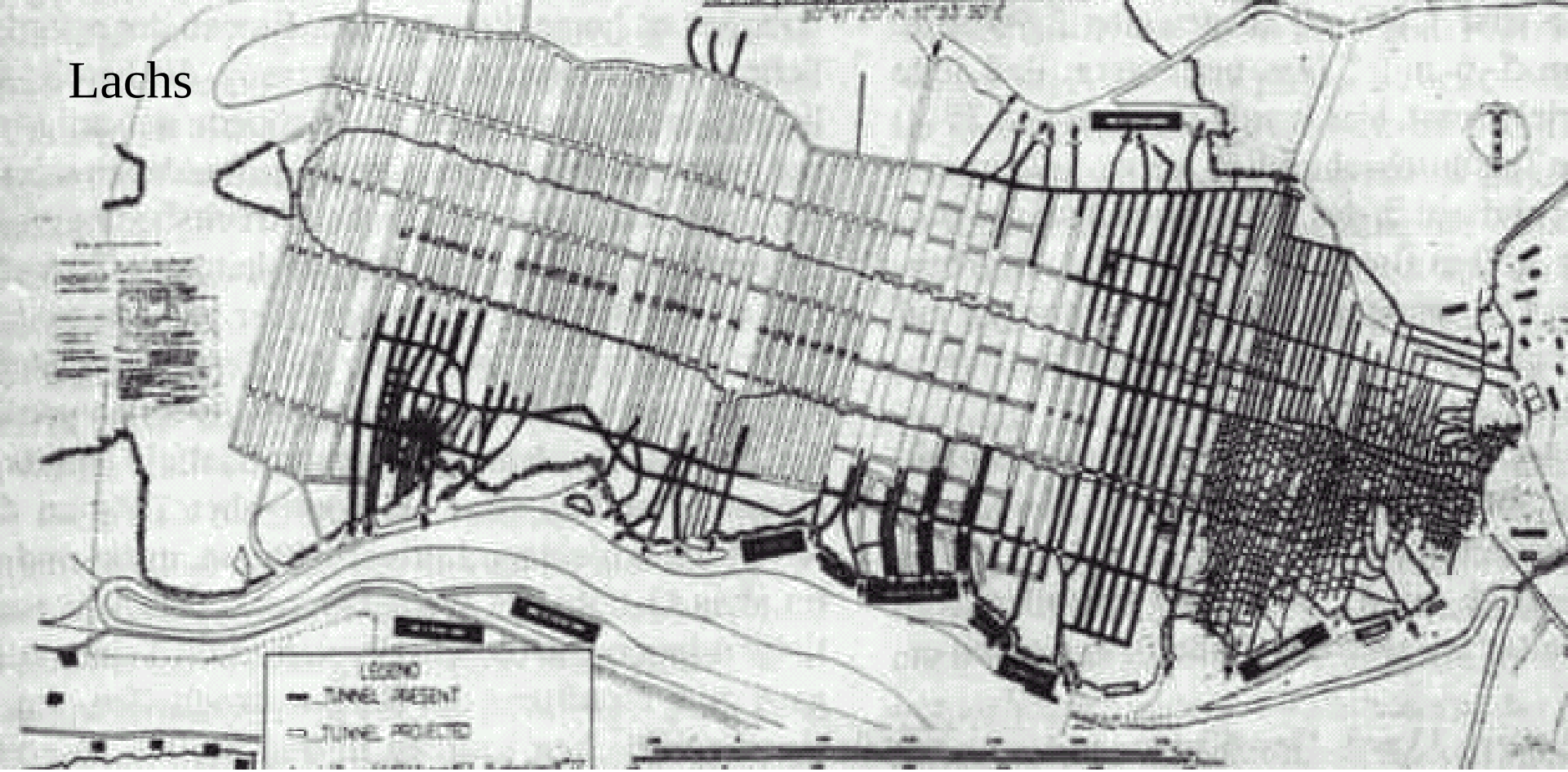


Underground POL storage facility located the Schwalbe in the Hoenne Valley. This was part of the German's Mineraloelsicherungsplan, created by excavating tunnels from the Emil rock quarry.

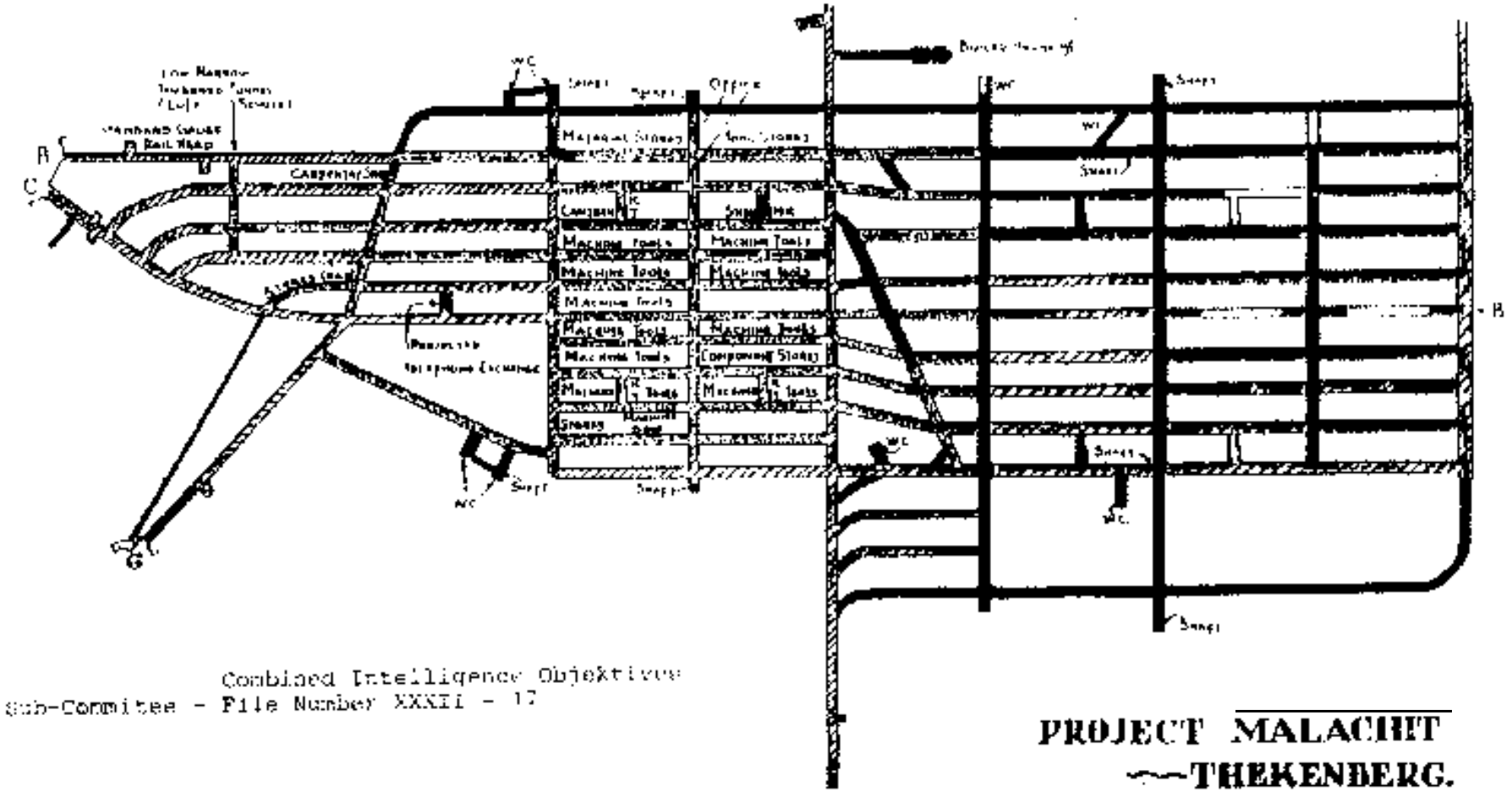


Schwalbe

This underground facility was intended to store **240,000 gallons of diesel fuel and 50,000 gallons of aviation gas**. The overall **tunnel length was about 3 km**. The tunnels were built by about 500 forced laborers and prisoners.



Me 262 factory in converted mine at Kahla/Grosseutersdorf, Thueringen. Following an old mine, an extensive tunnel system was built. The **whole tunnel system should reach 30 km**. The underground working conditions were very bad; there was **not sufficient fresh air**. Seven months after beginning the fresh air problem was not solved. Most of the work was carried out by **12,000 slave workers**; of which **991 deaths** were recorded due to malnutrition and accidents.



Junkers aircraft factory near Langenstein and Halberstadt. By the end of the war the Germans had lost 4819 workers by tunneling accidents and only 853 by building airplanes.

EXPLOITATION OF REMOTE SENSING TECHNIQUES FOR ASSESSING UNDERGROUND MINES

Emerald Mine Complex, PA

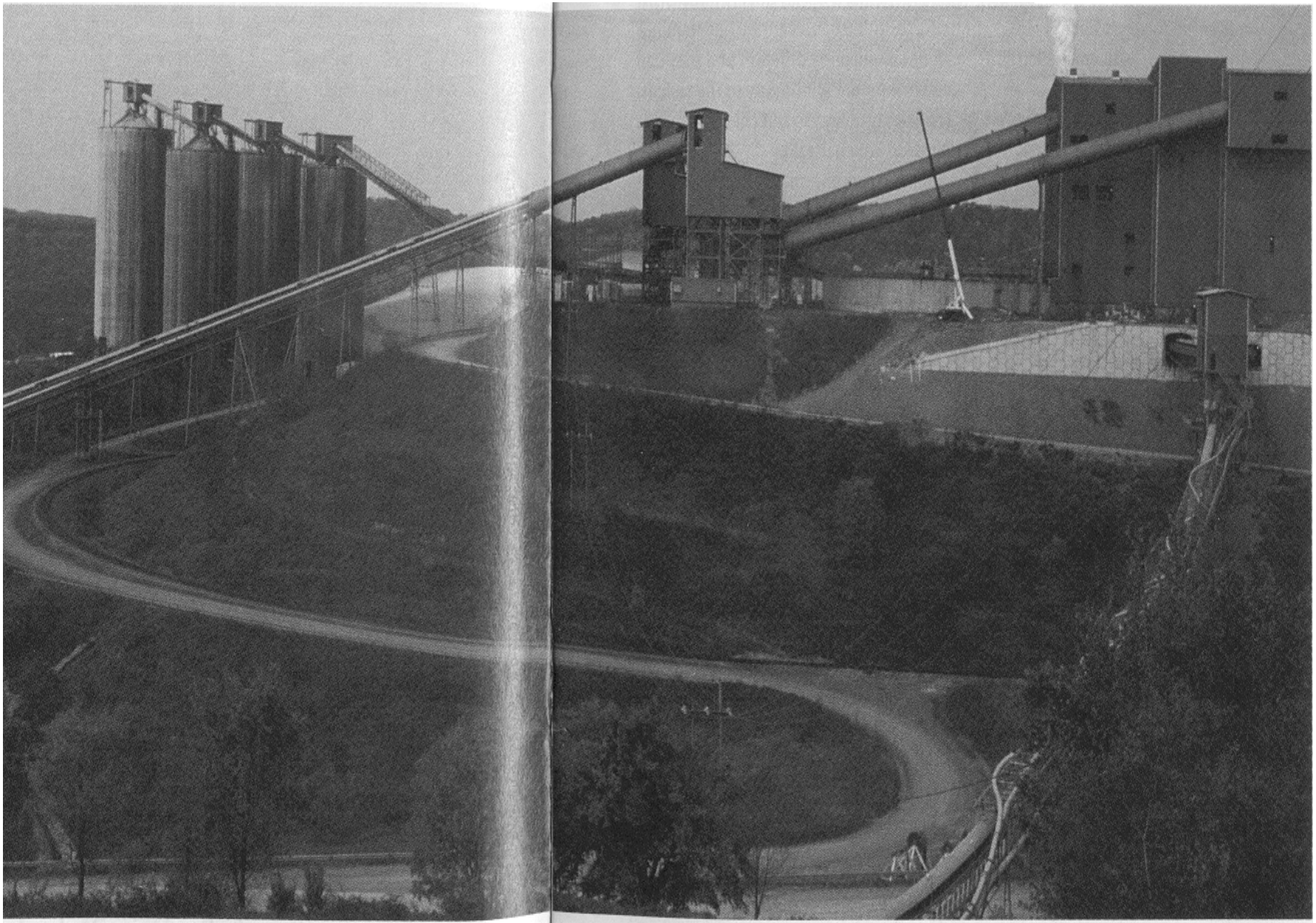
4 m resolution

= Slope going underground

Emerald Mine Prep Plant Area

1 m resolution

CONSOL's Bailey Mine Preparation Plant



Emerald Mine Slope and Original Portal Area

1 m resolution

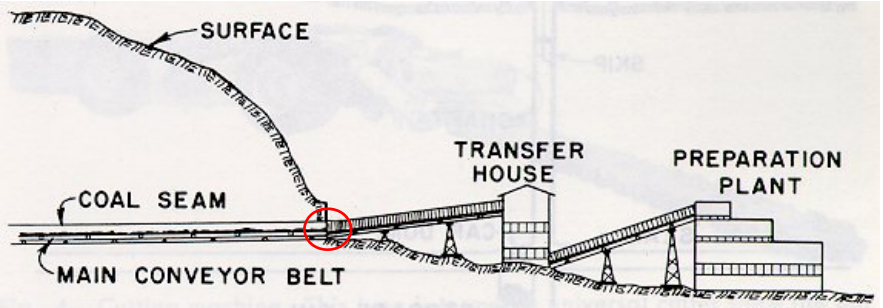


Fig. 1—Drift mine.

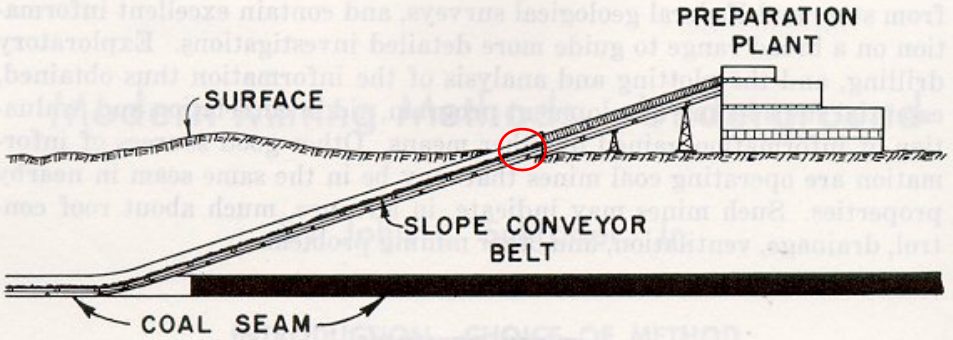


Fig. 2—Slope mine.

Access Methods

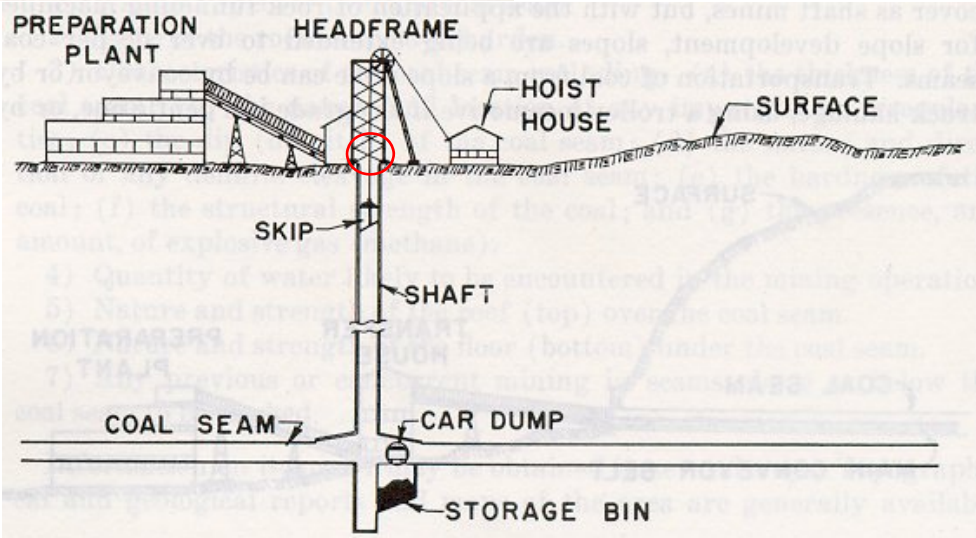


Fig. 3—Shaft mine.

Estimation of Horizontal Extent of Underground Mine Openings using

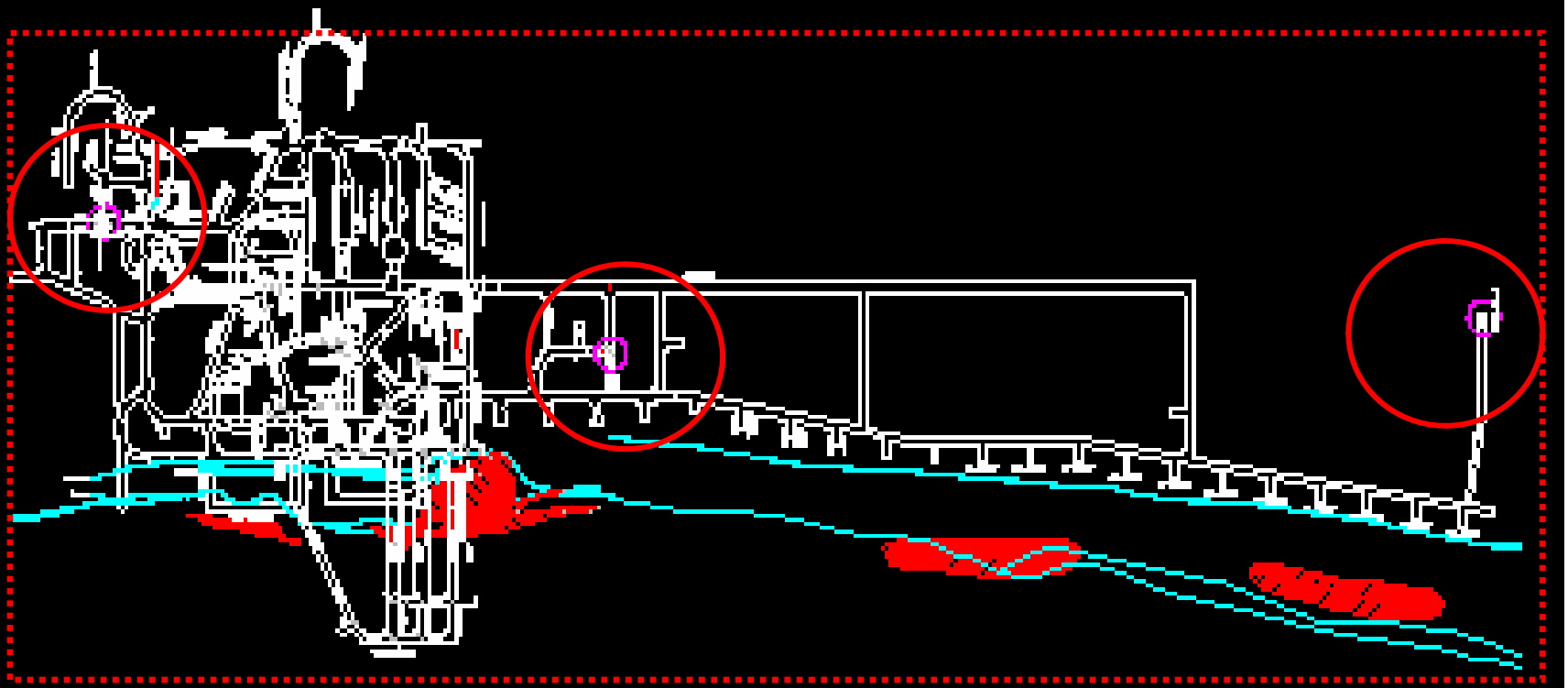
The McArthur River Uranium Mine in Canada

View of Surface Infrastructure of the McArthur River Uranium Mine

To approximate the horizontal extent of underground workings we start by identifying ventilation outlets

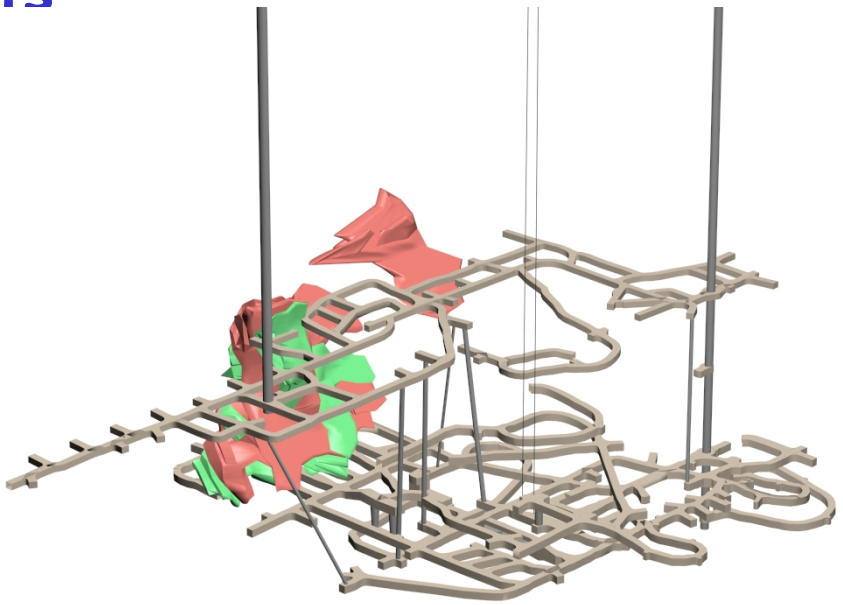
By knowing the location of ventilation outlets, we can approximate the horizontal extent of underground workings

To verify our assumptions we can overlay the predicted horizontal extent of underground workings with the mine's underground maps



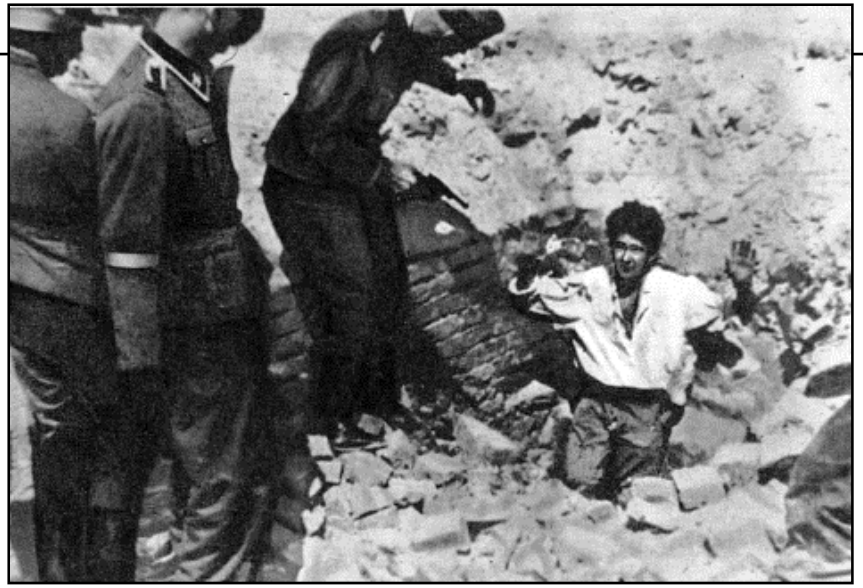
Limitations of the vent outlet technique

- This relatively simple technique of identifying ventilation outlets affords an estimate of the areal extent of the active underground workings.
- When dealing with a multi-lev structure such the McArthur River Uranium Mine, we need employ additional methods to estimate the overall size of tl mine workings; e.g. estimating mine airflows needed to ventilate the mine openings, measurement of mine tailings needed to estimate the volume of rock removed, etc.



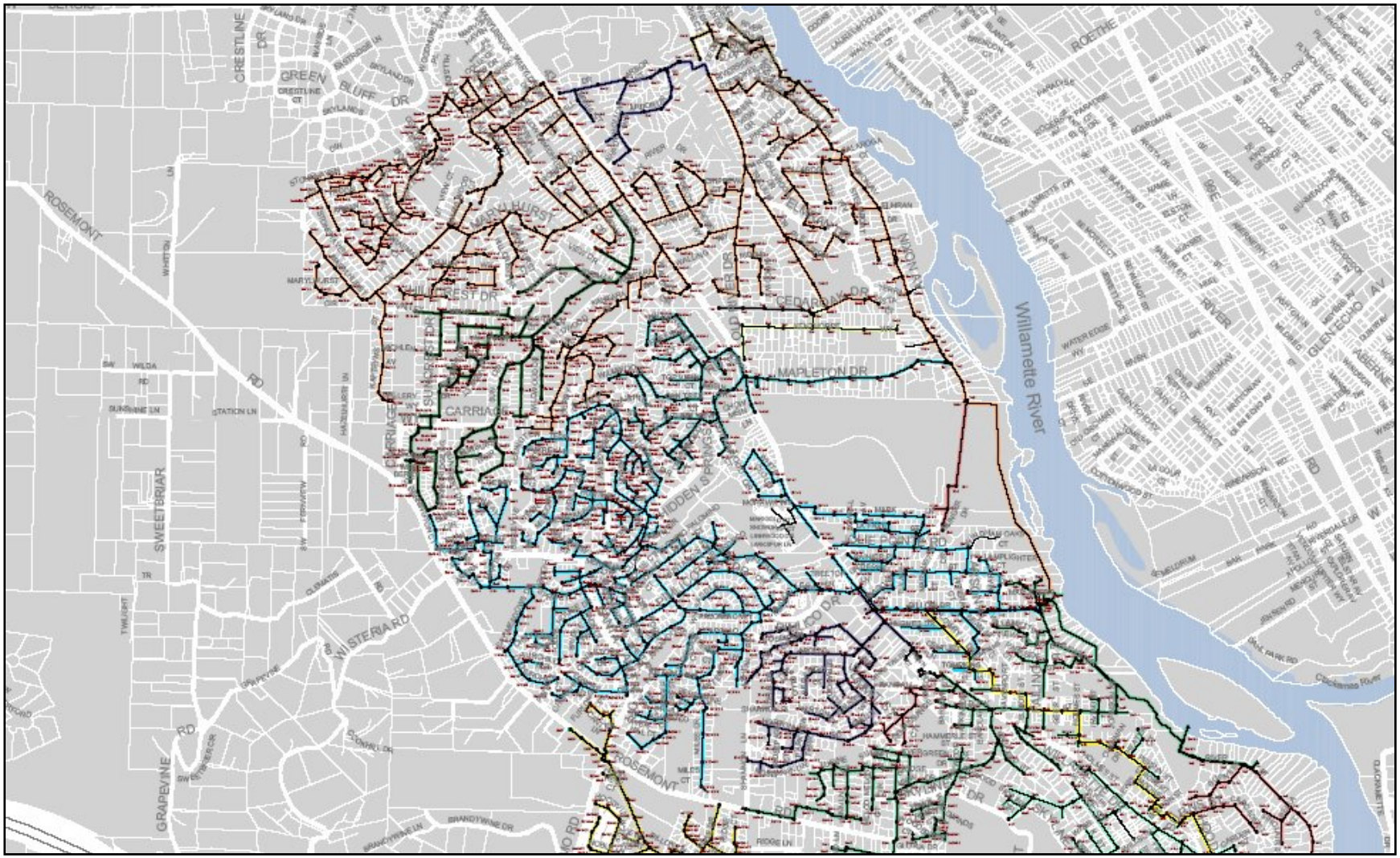
UNDERGROUND UTILITIES

WARSAW GHETTO REVOLT of 1943



During the Warsaw Ghetto Revolt of April-May 1943 Jewish fighters survived fire bombings, gassing and flame throwers by hiding in the underground sewers of Warsaw

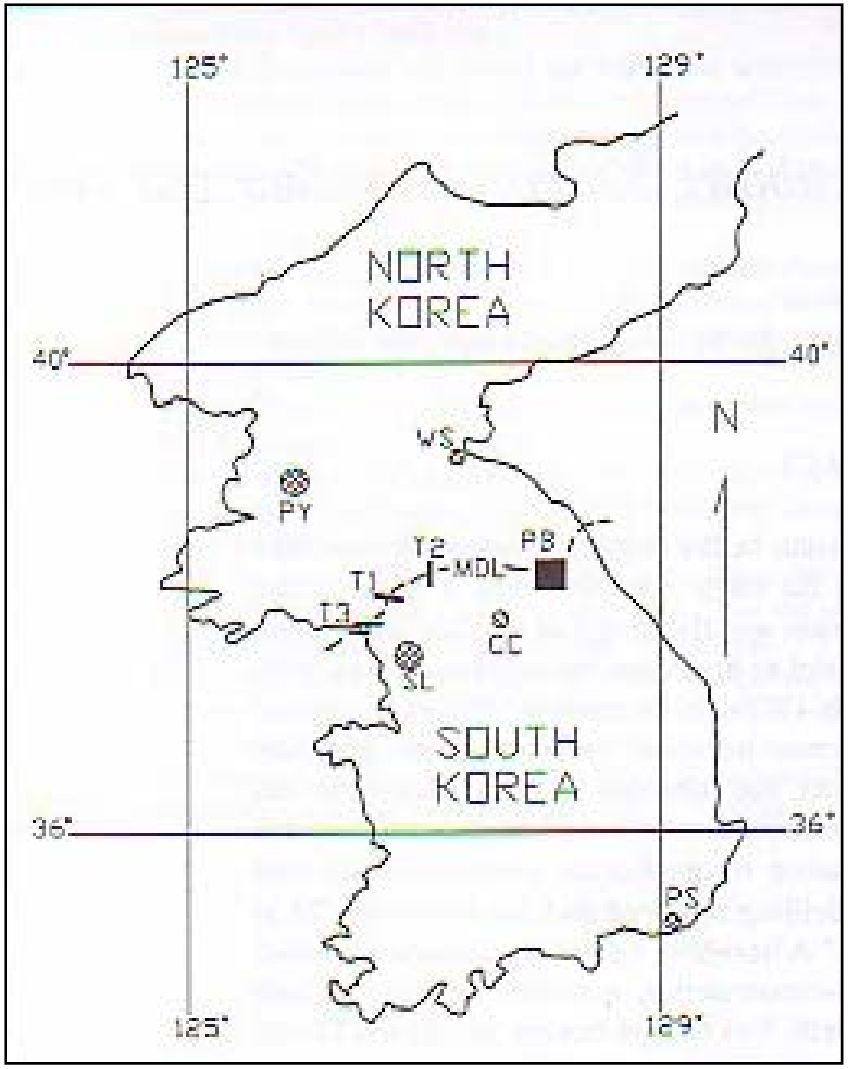
BURIED UTILITIES ABOUND

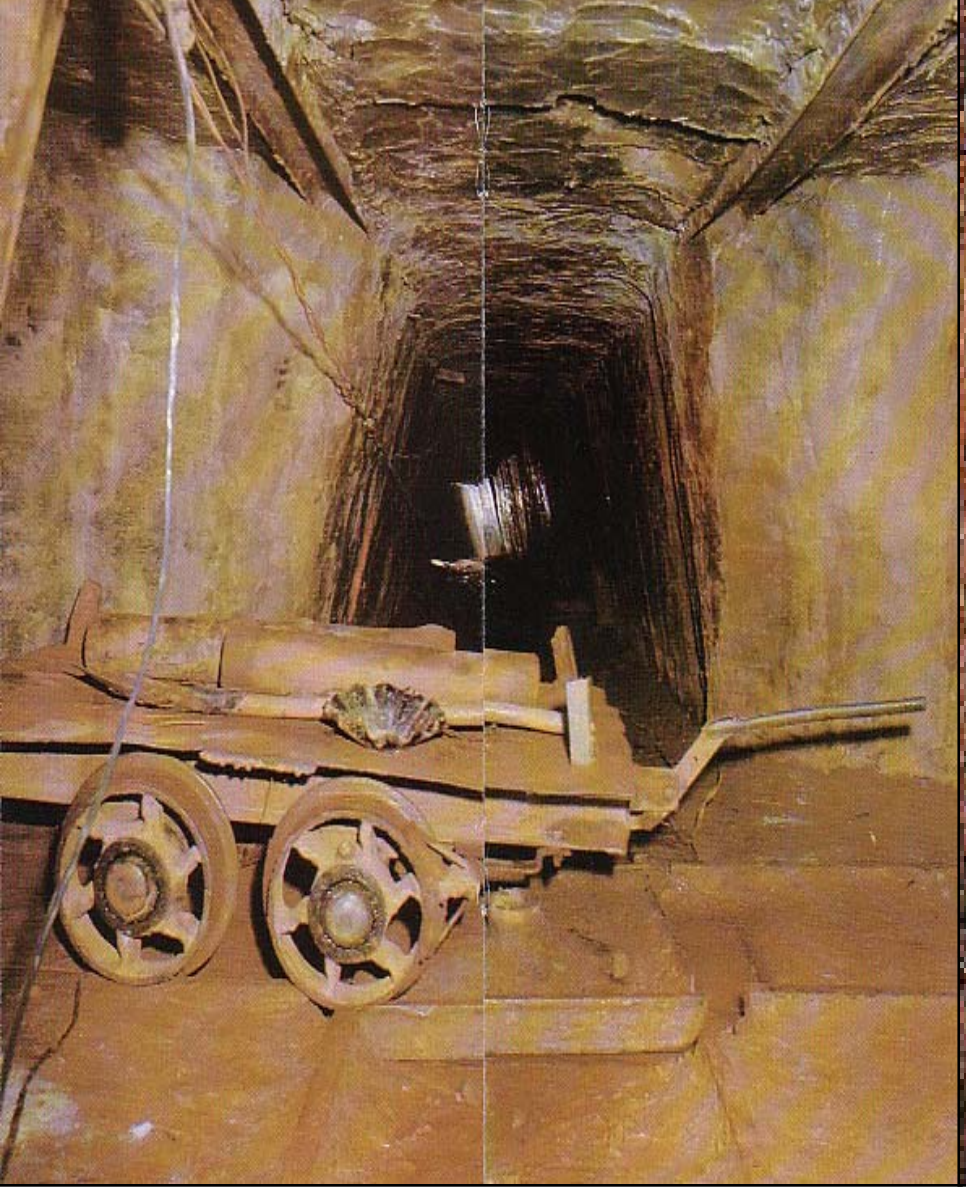


- Most sanitary sewer systems in the USA are inventoried on existing GIS

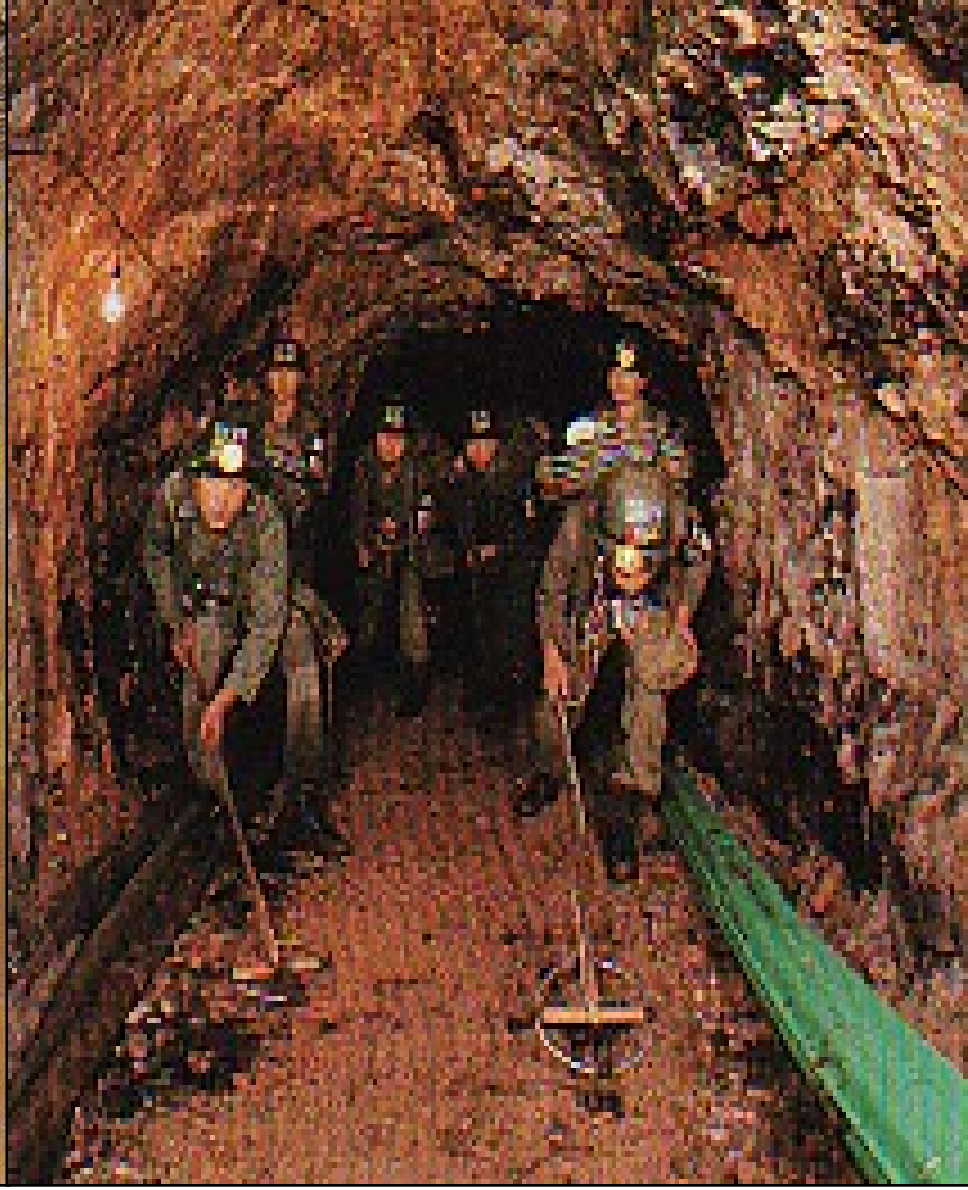
TUNNELS ARE NEFARIOUS STRUCTURES

KOREAN INFILTRATION TUNNELS





Tunnel #1

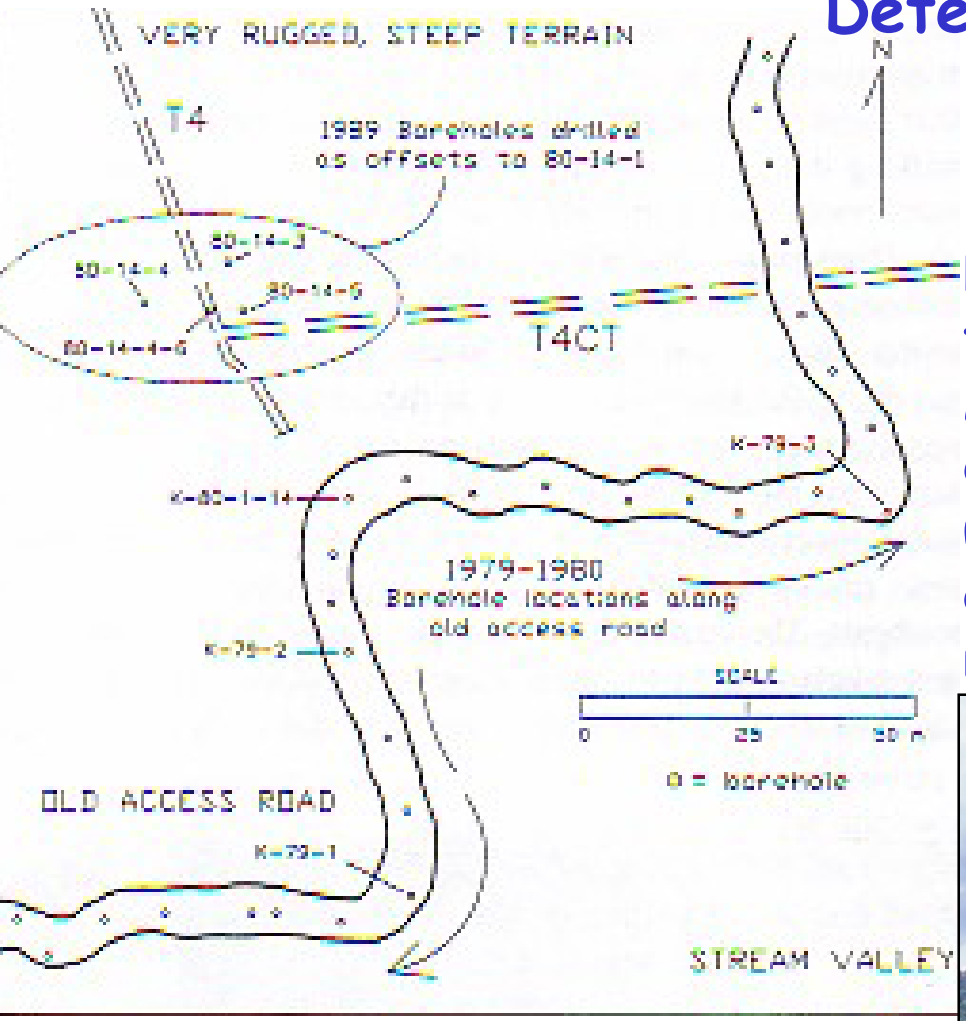


Tunnel #2

Tunnel #3: Notice the rails for muck cars and compressed air lines emplaced by the North Koreans

Tunnel #4 was 1.6 high and 2.6 m wide

Detection Methods and Techniques

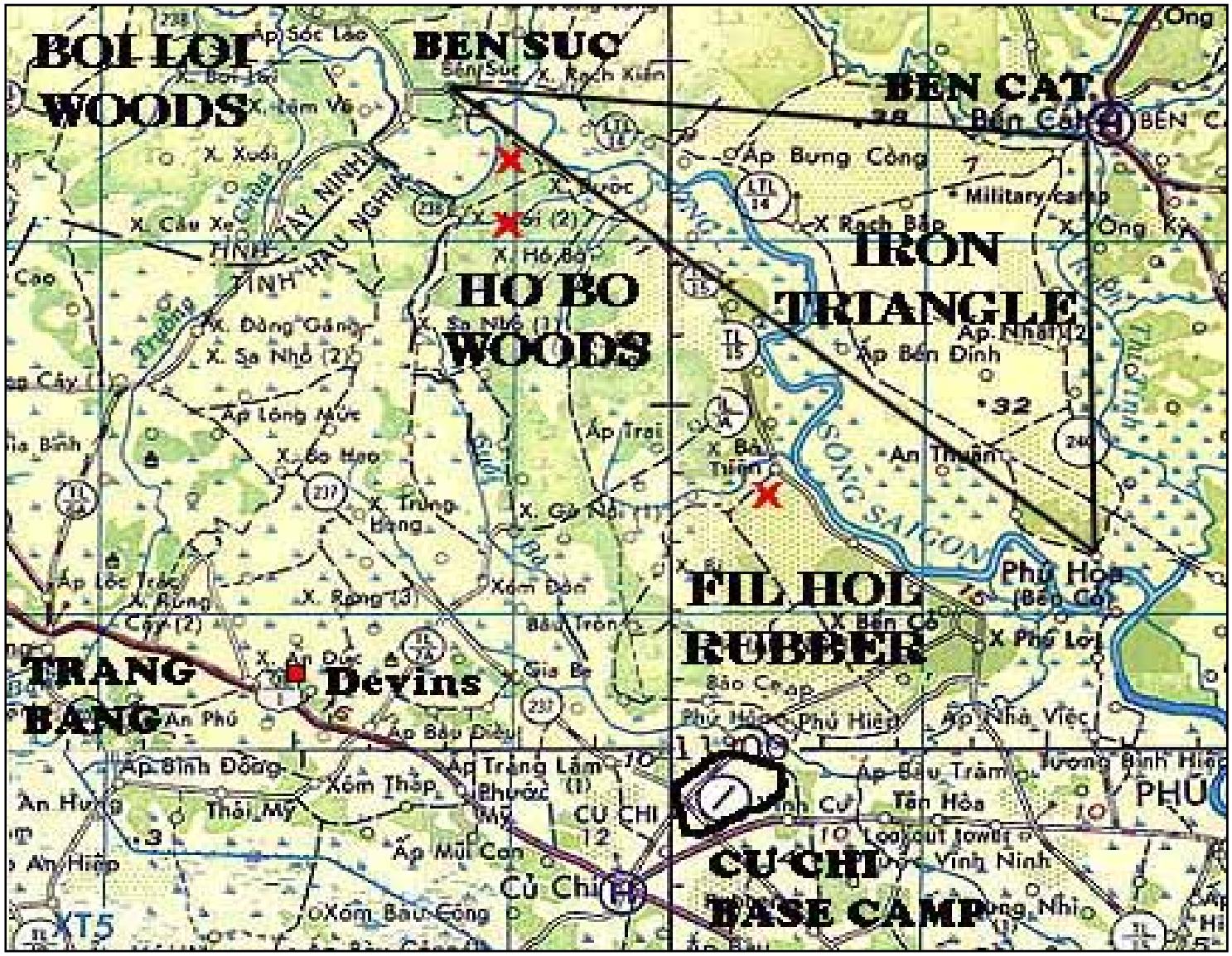


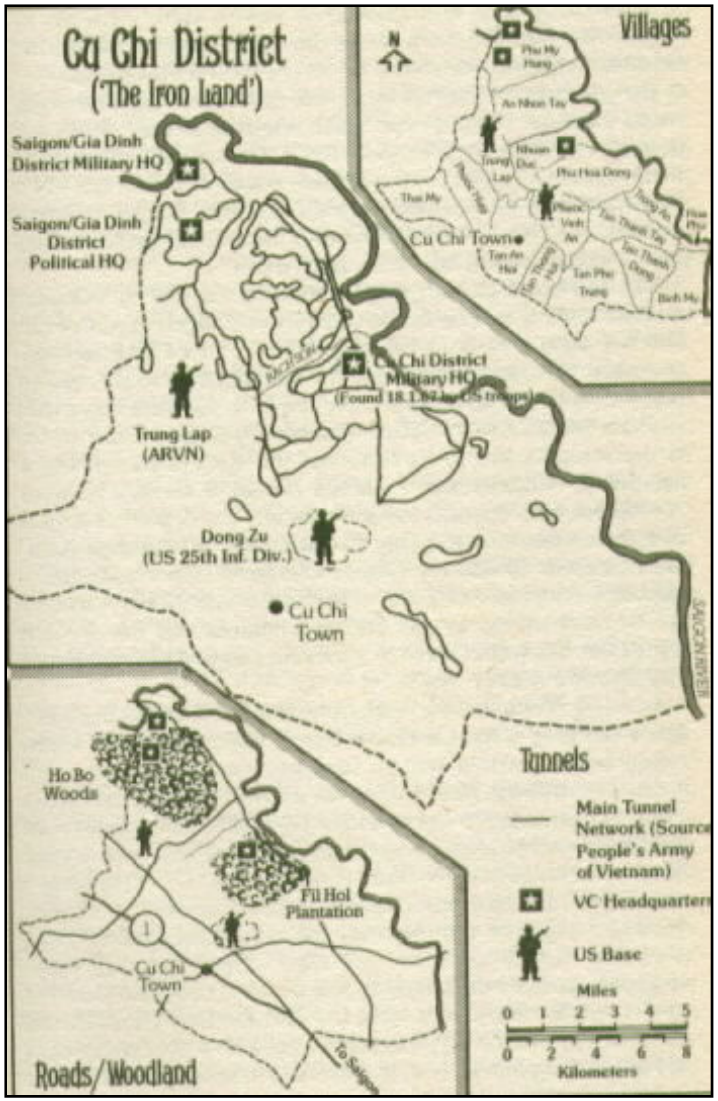
Boreholes used in exploration for Tunnel #4 and the intercept adit constructed by allied forces

ROK truck Mounted drill rig used on the old access road

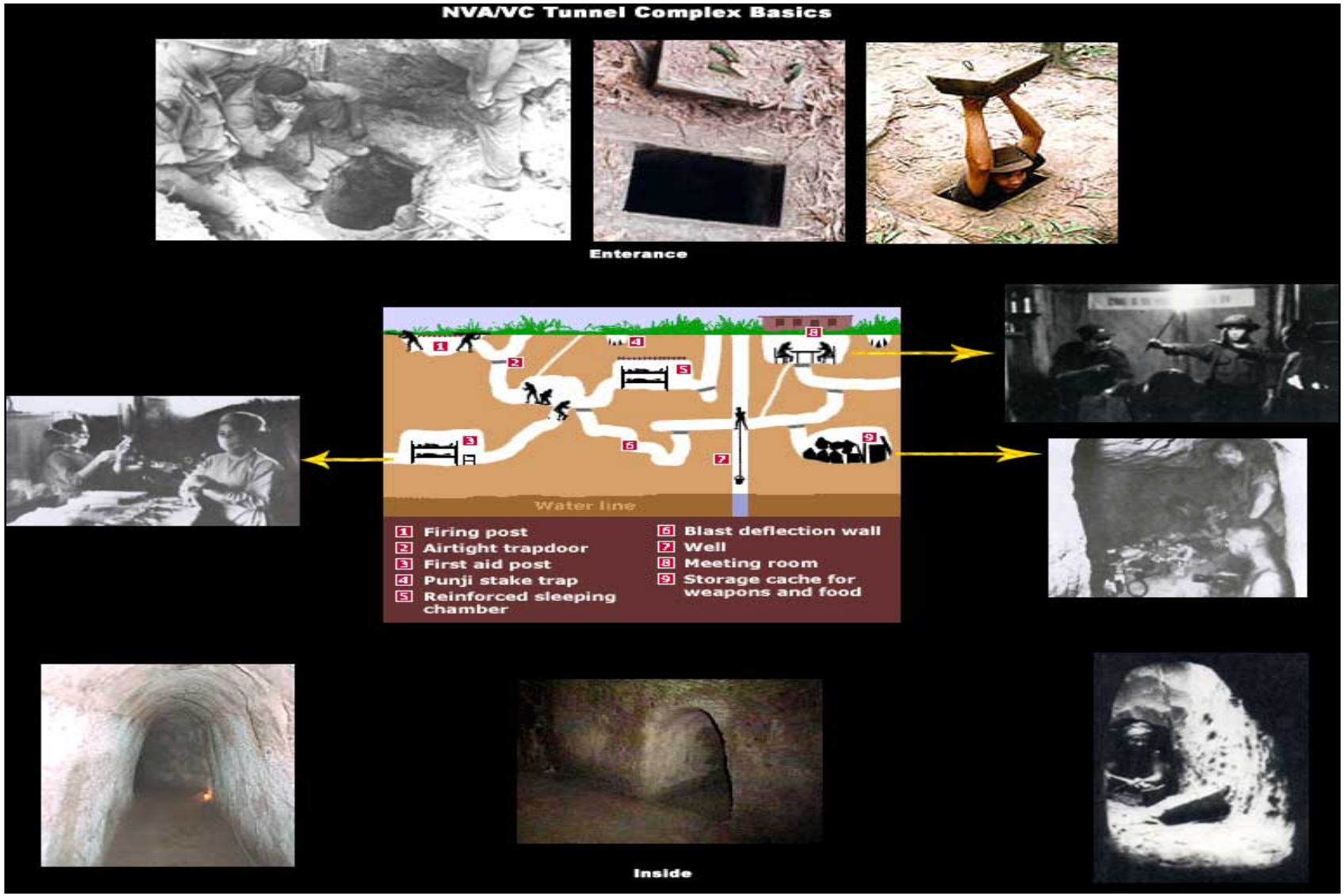
U.S. mobile (skid) drill rig used in the rugged steep terrain

THE VIETCONG TUNNELS OF CHU CHI WERE CONCENTRATED IN THE IRON TRIANGLE AREA





The Chu Chi tunnels were a serpentine labyrinth of interconnected openings with multiple levels, separated by water and air tight trap doors.



The tunnels were excavated in cemented laterite clay above the water table, which was at -9 m

Today some of the tunnels are set aside as a war memorial, intended to commemorate their success. Here the soil cover has been excavated to reveal their internal layout and structure.

NATURAL CAVES AND CAVERNS

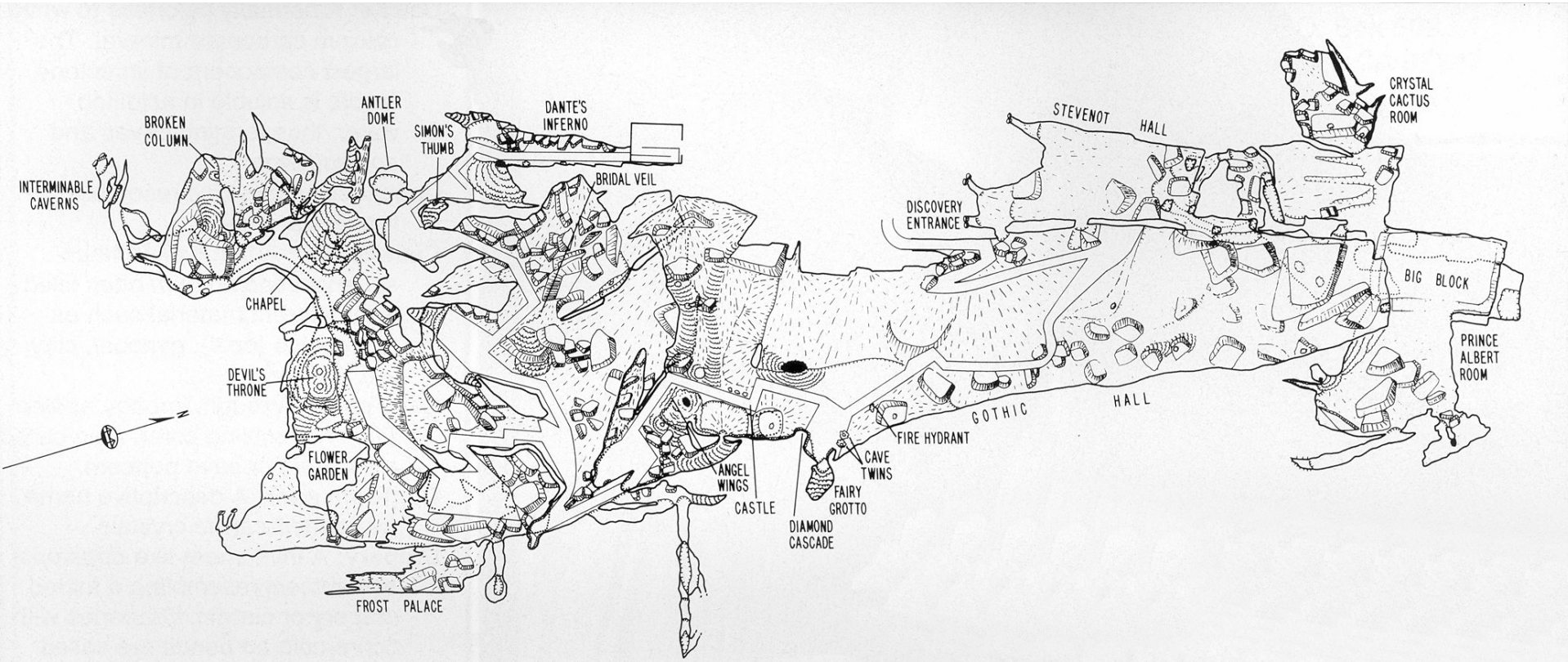
GEOFORENSICS AND THE WAR ON TERROR

Geotechnical databases can catalogue an unlimited variety of descriptive and spatial information, such as occurrence of rillenkarren in the Tora Bora Mountains.

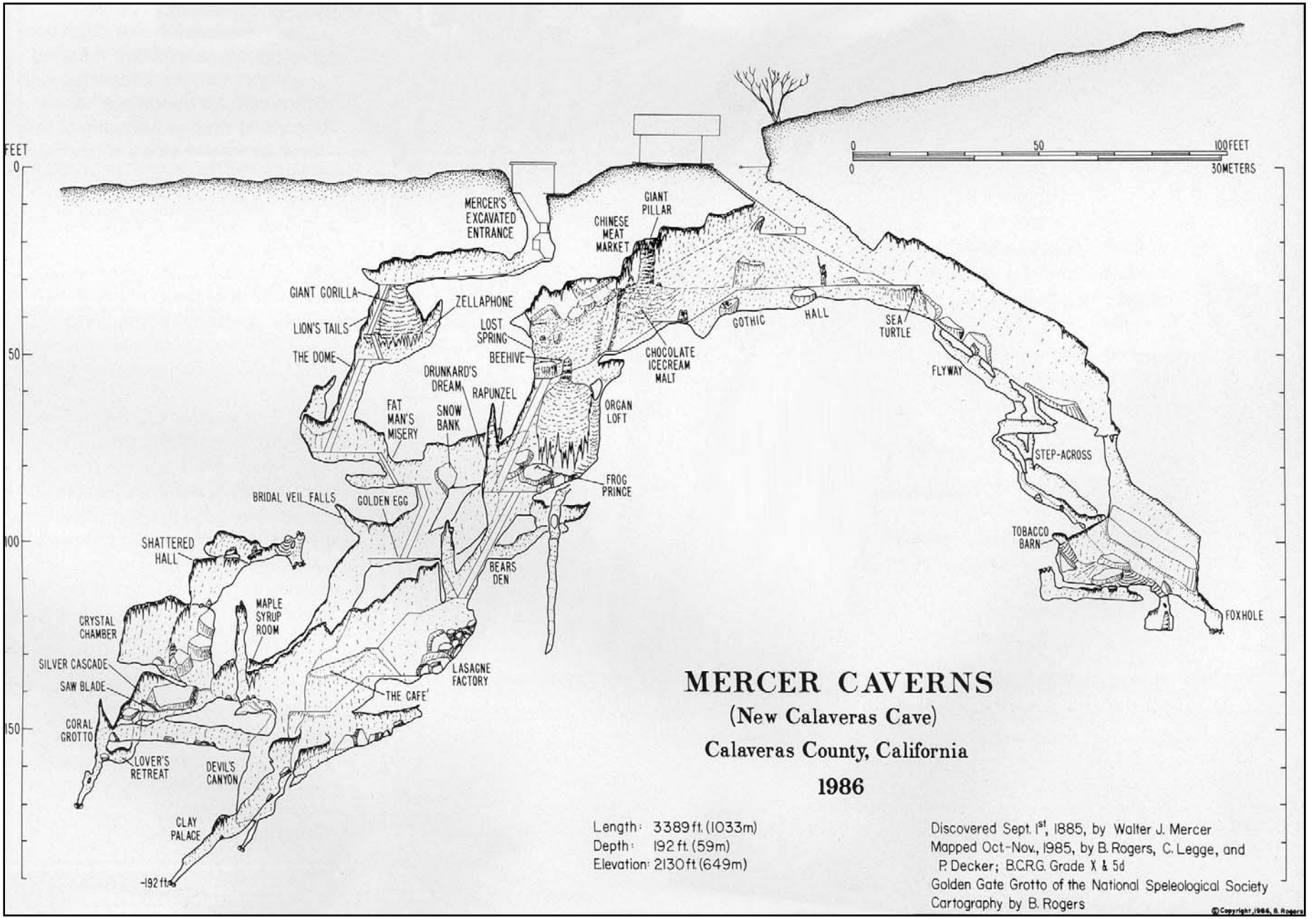
- Geoforensics is the use of geoscience principles to solve various mysteries involving earth and ocean systems. This includes applications to engineering failures as well as crimes involving our criminal justice system.
- The background in this photo of Osama bin Laden appears to be a type of karst feature called "rillenkarren". Not rare, but not that common either.

KARST FEATURES AND CAVERNS

- Approximately 22% of the United States is underlain by karst, including the Ozarks



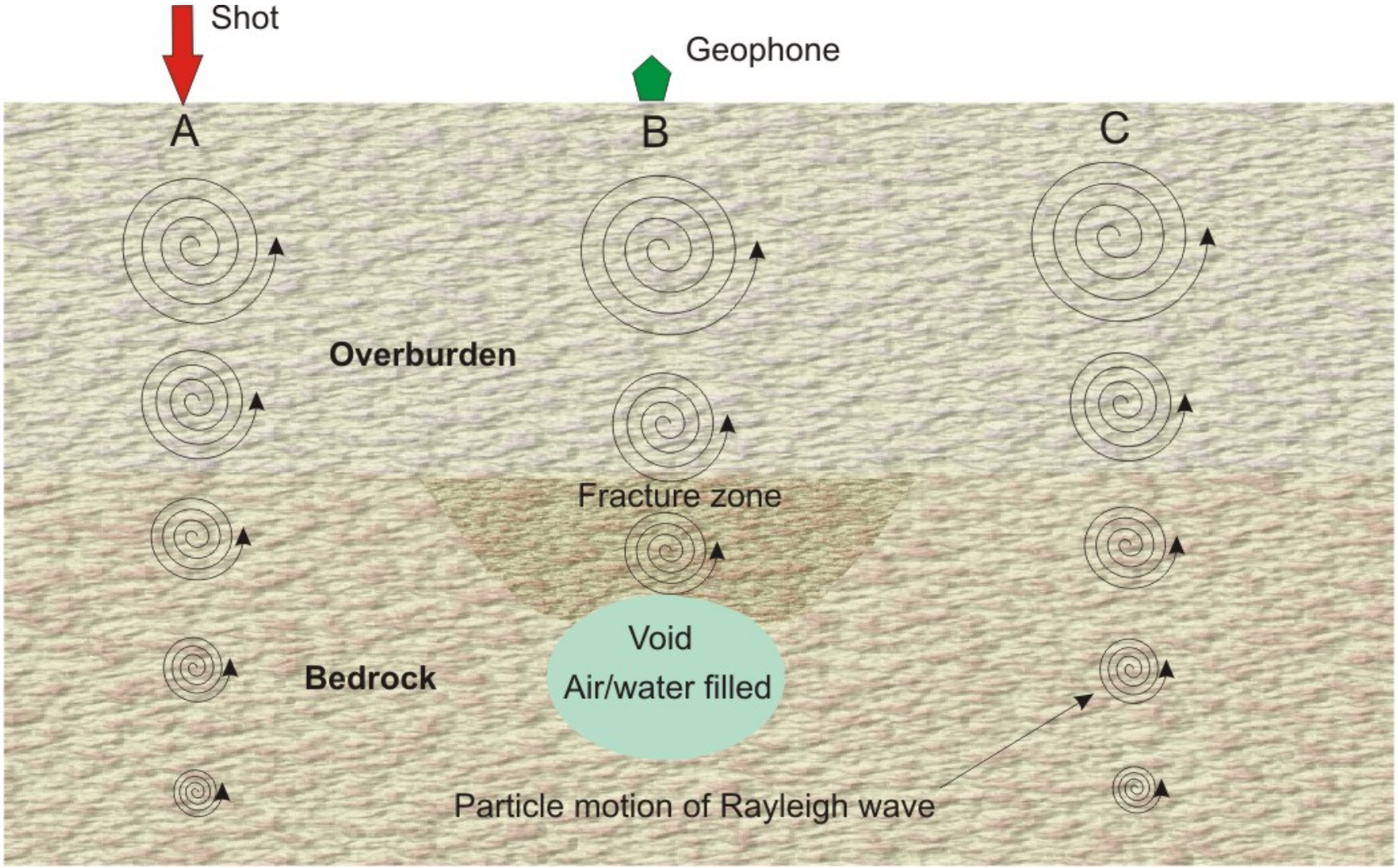
- **Plan view of Mercer Caverns in California prepared using methods recommended by the Cave Research Foundation: using a Suunto compass, inclinometer and fiberglass tape. <u>There is no more complicated structure to map than a natural karst cavern</u>.**



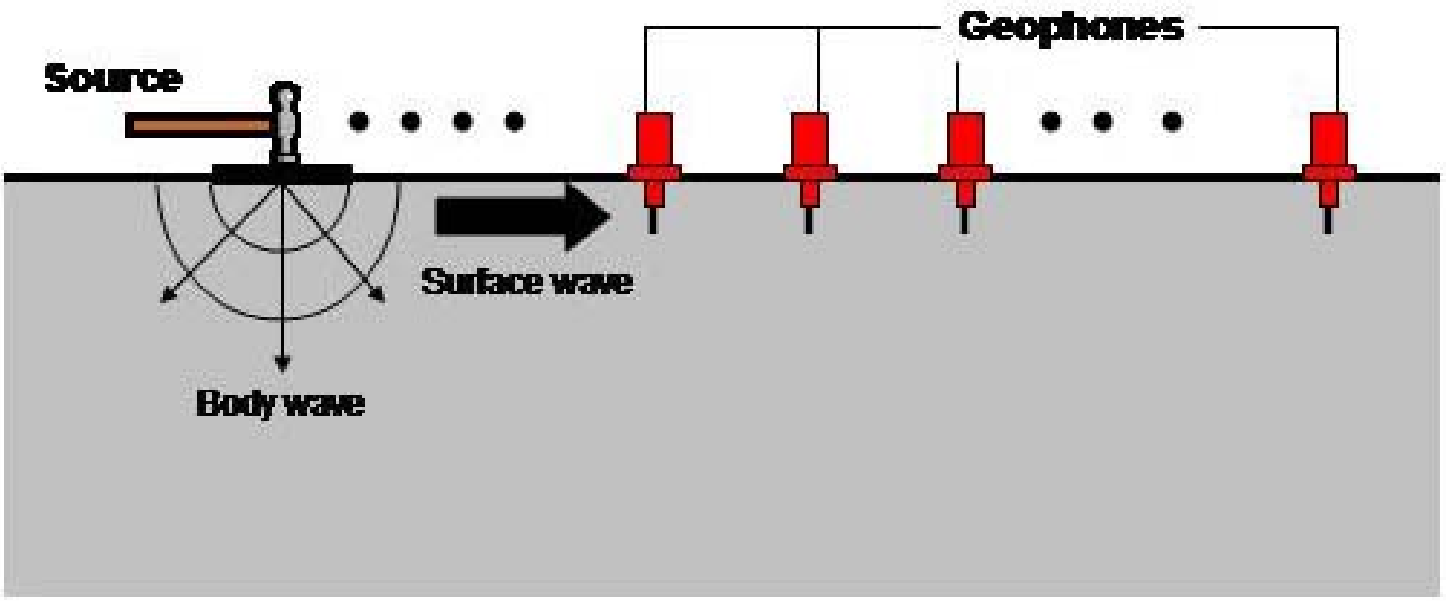
Section view of Mercer Caverns

EMERGING GEOPHYSICAL TECHNIQUES TO DETECT SHALLOW UNDERGROUND OPENINGS

Rayleigh Wave motion in proximity to void

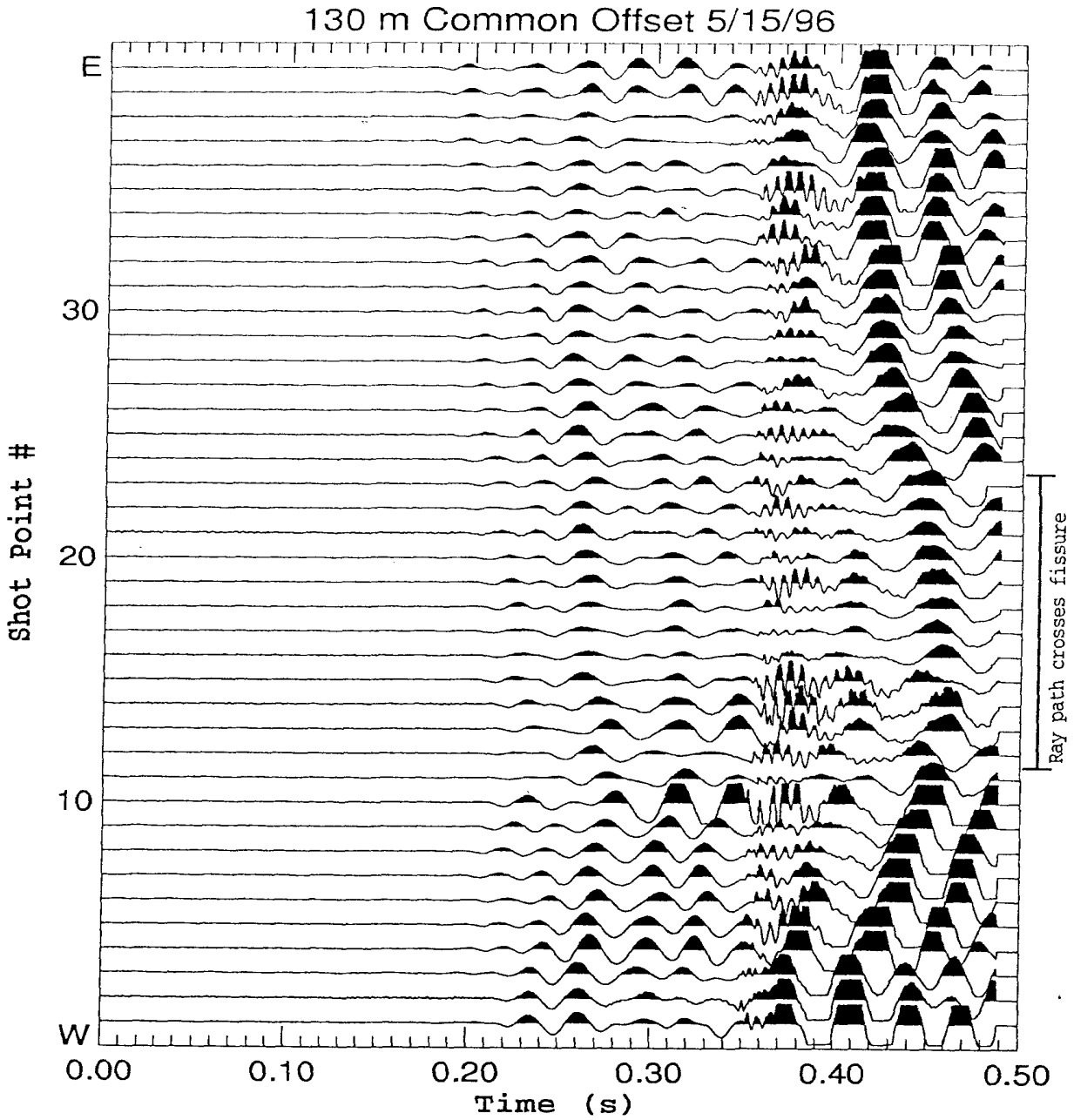


Acquisition of MASW field data



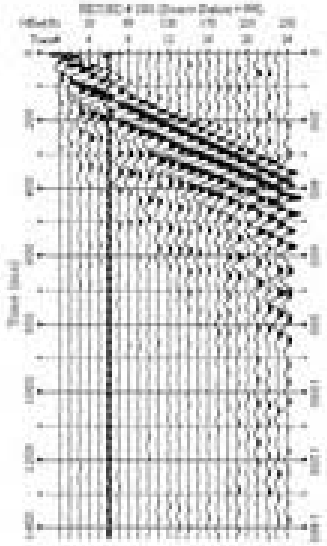
Active or passive energy sources!!!!

Expression of a void on surface-wave field records



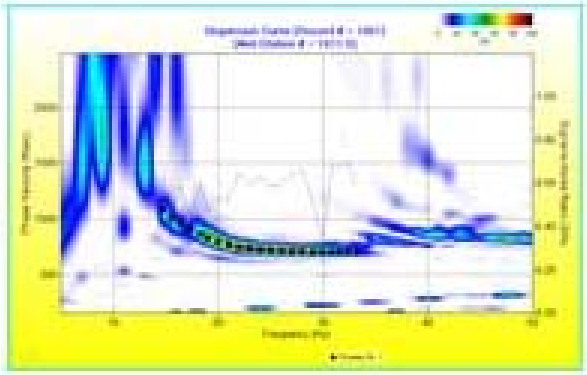
Processing of 1-D MASW field data

Acquisition



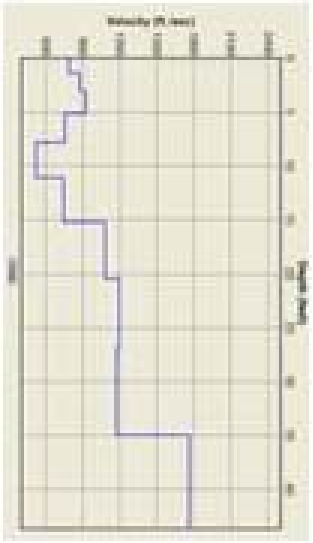
Time-Space

Dispersion curve Extraction



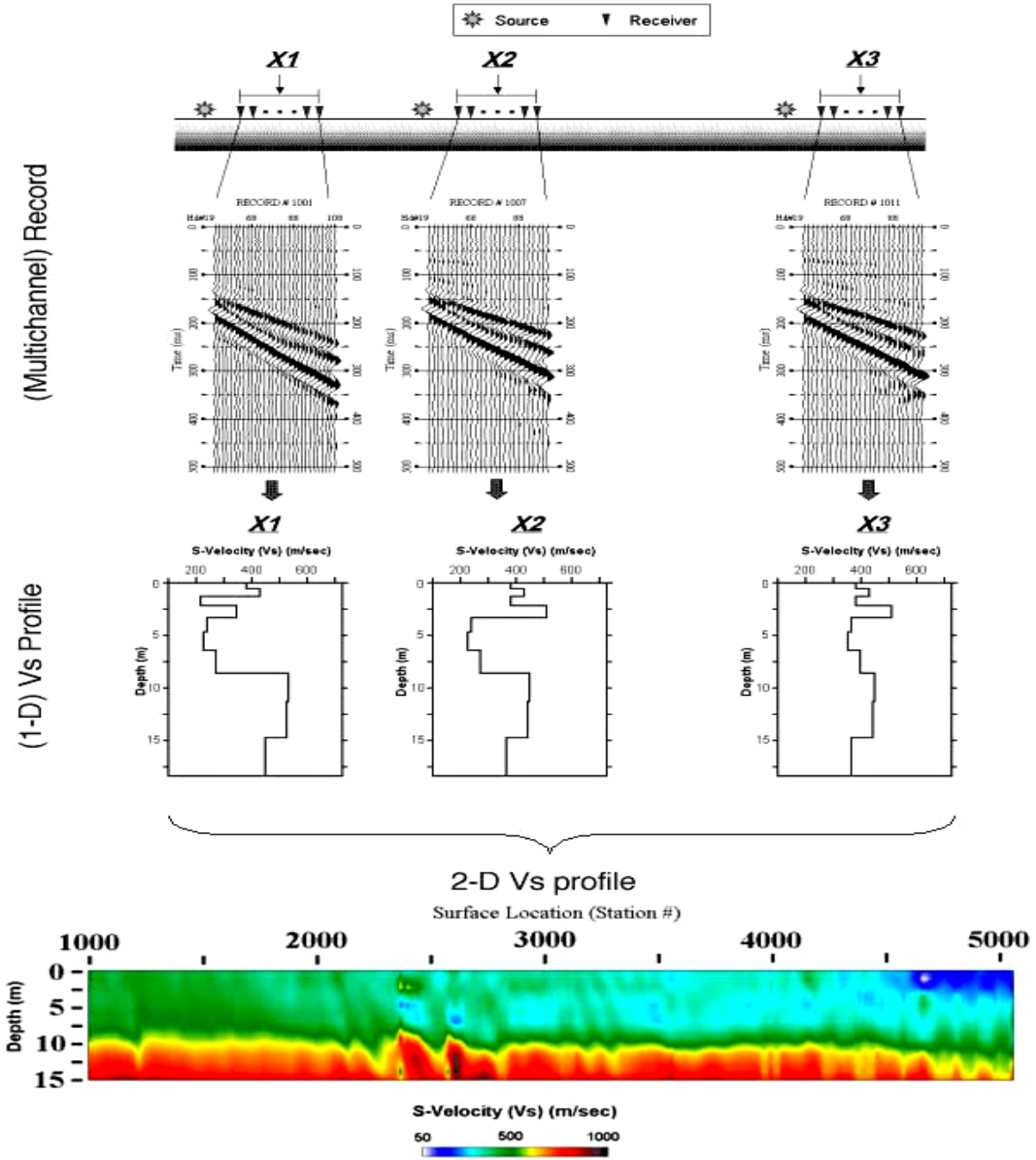
Frequency-Phase Velocity

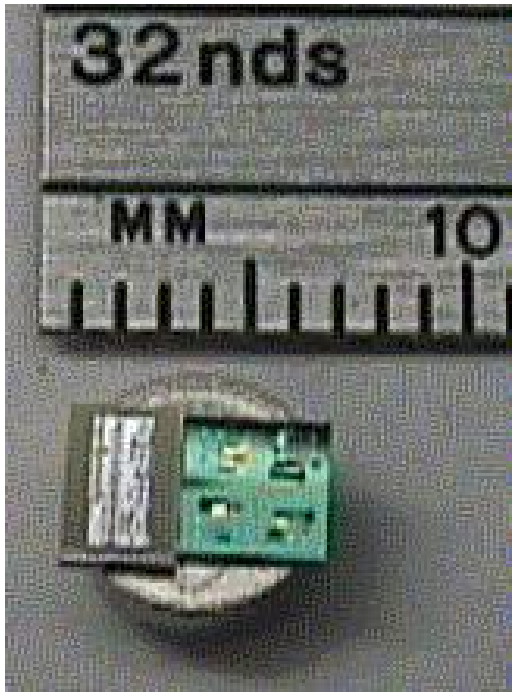
Inversion

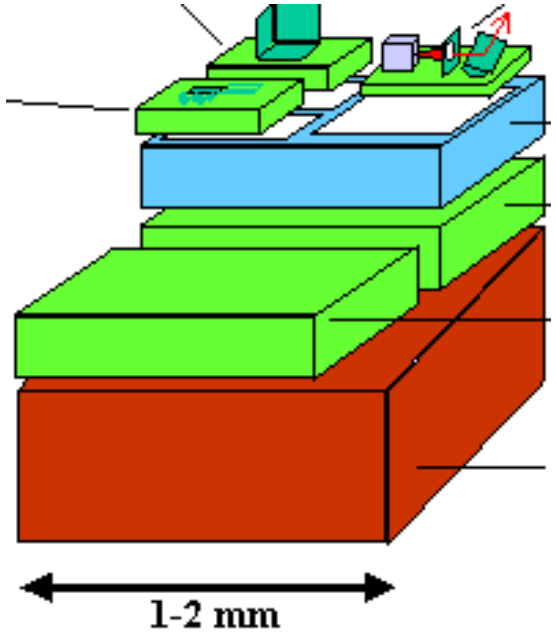


Depth-Vs

Generation of a 2-D MASW shear-wave velocity profile







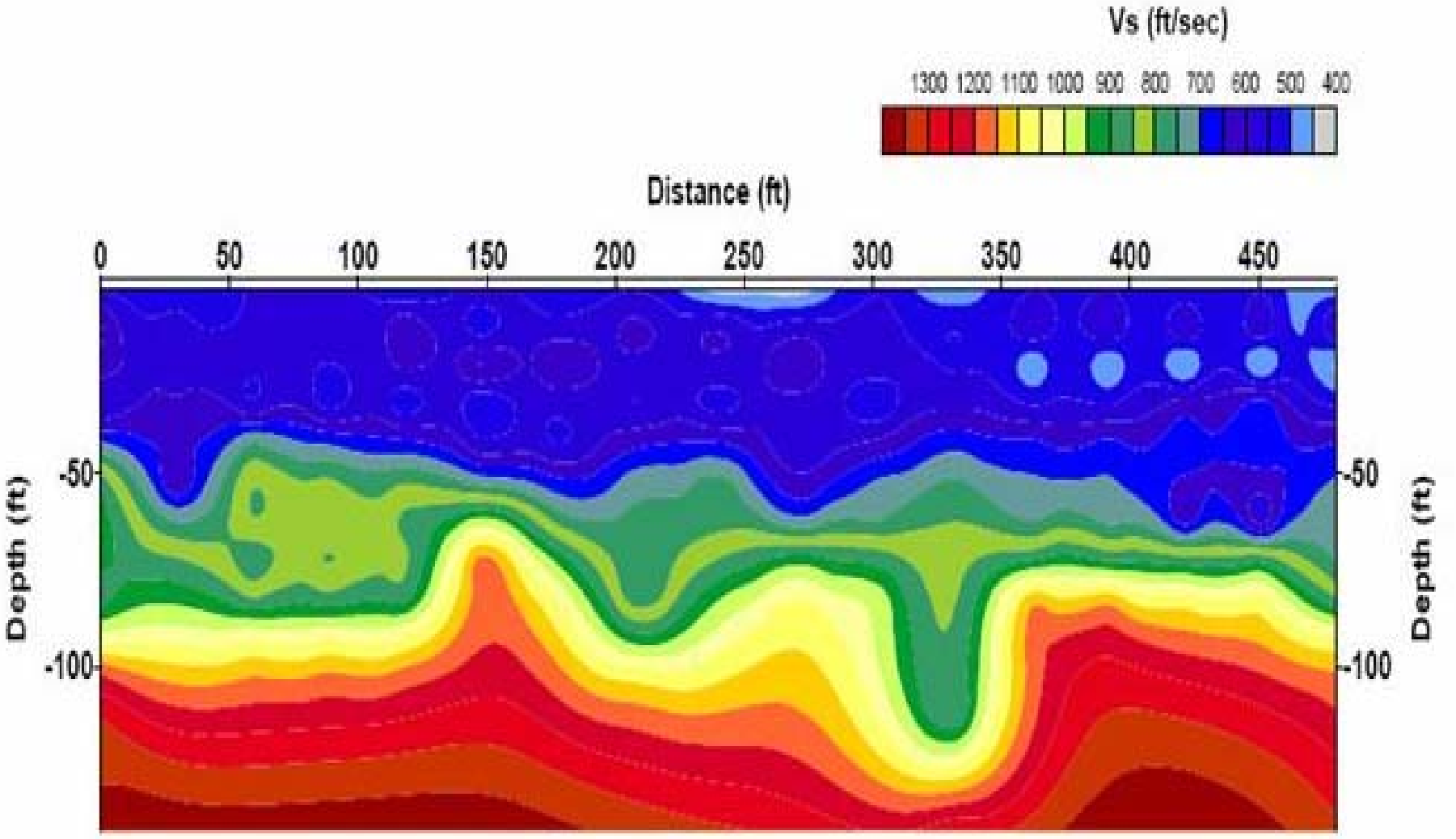
SMART DUST MOTES

- Invented by Berkeley EECS Professor Kris Pister (founder and CEO of Dust Networks)
- It may be feasible to drop smart dust motes with GPS chips and accelograph sensors to record passive energy sources (vehicles passing by, distant explosions, microtremors)
- These could remotely detect tunnels and underground openings to depths of about 100 feet

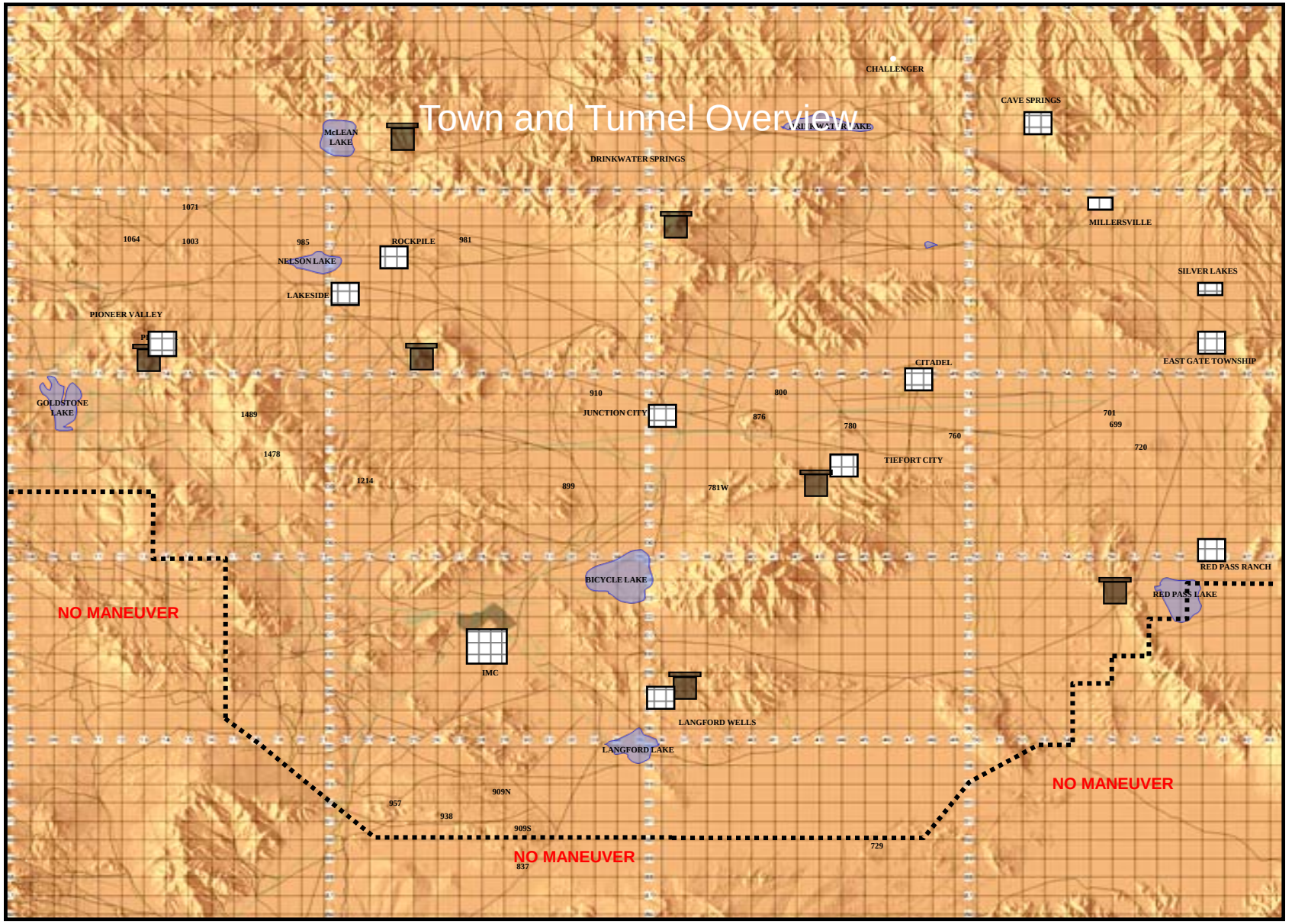
Remote Techniques Not New

- During the Vietnam War Operation Igloo White employed air-dropped geophone arrays to track vehicle movements along the Ho Chi Minh Trail

Typical 2-D cross sectional image



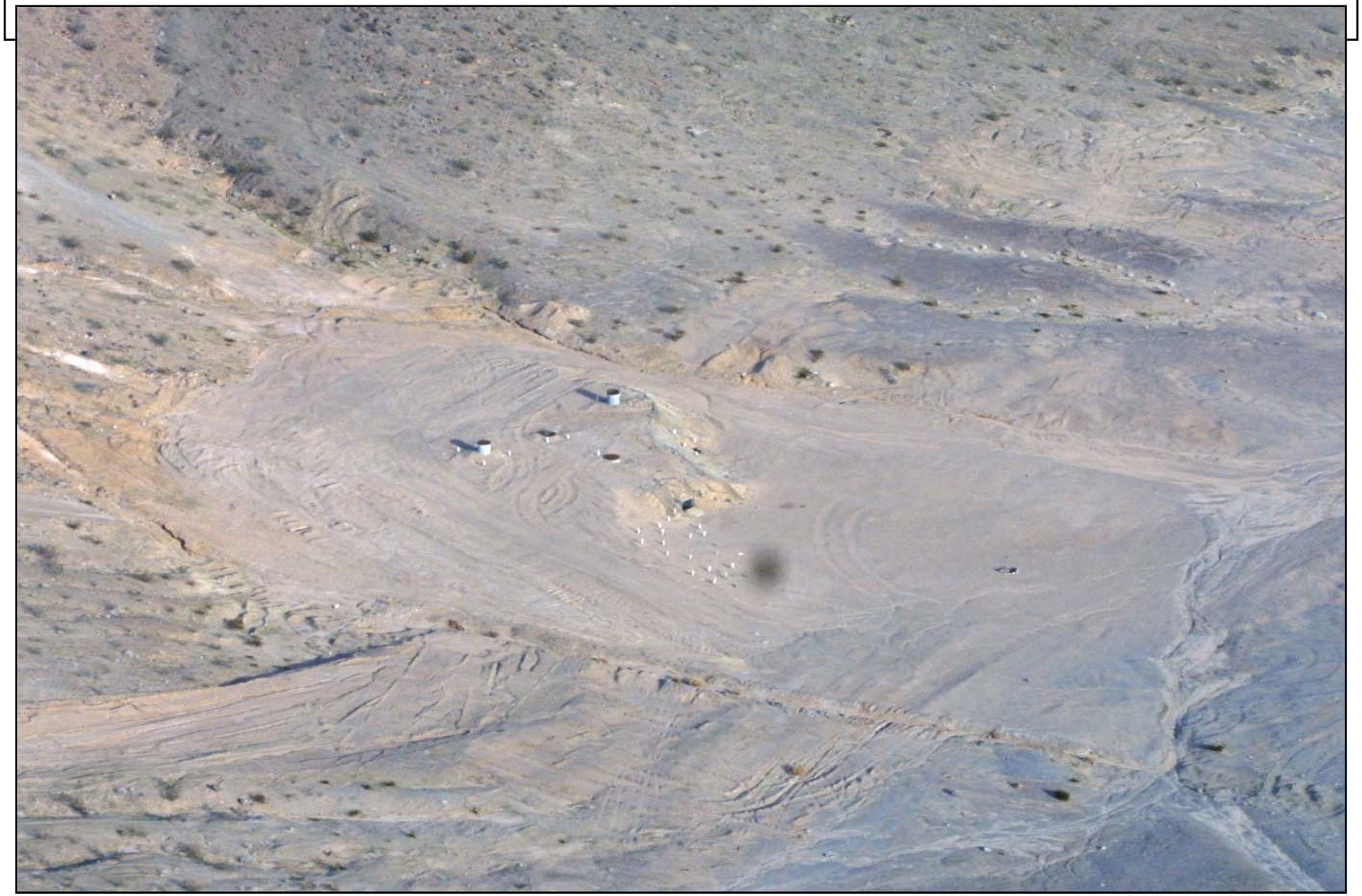
GEOPHYSICAL TECHNIQUES, SUCH AS MASW AND GPR, COULD BE VALIDATED AT PRTOTYPE SITES, LIKE THE NTC CAVE COMPLEXES AT FORT IRWIN



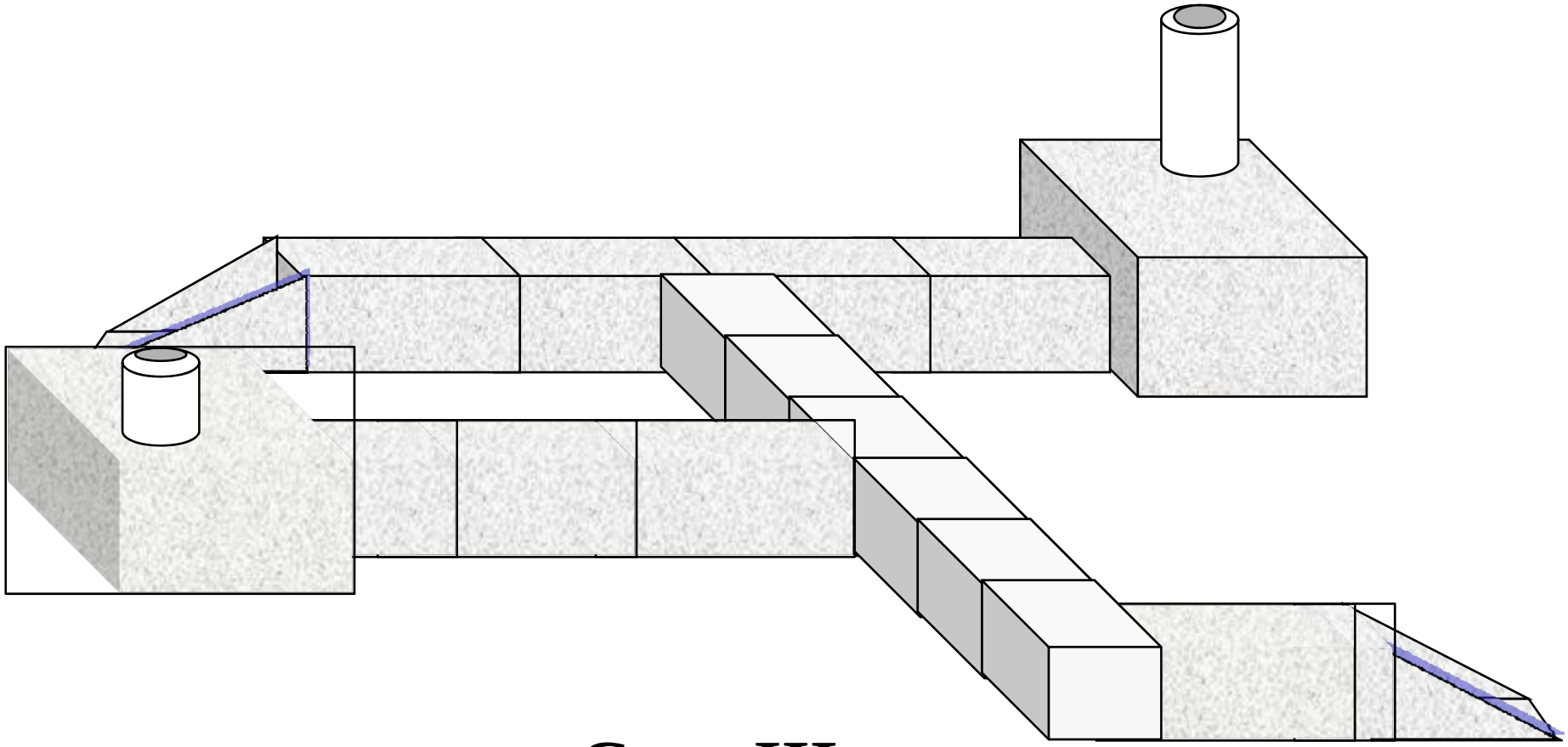
- Map of NTC tunnel training complex

Example Cave Complex Uncovered

Example Cave Complex Covered



Appendix 2 A

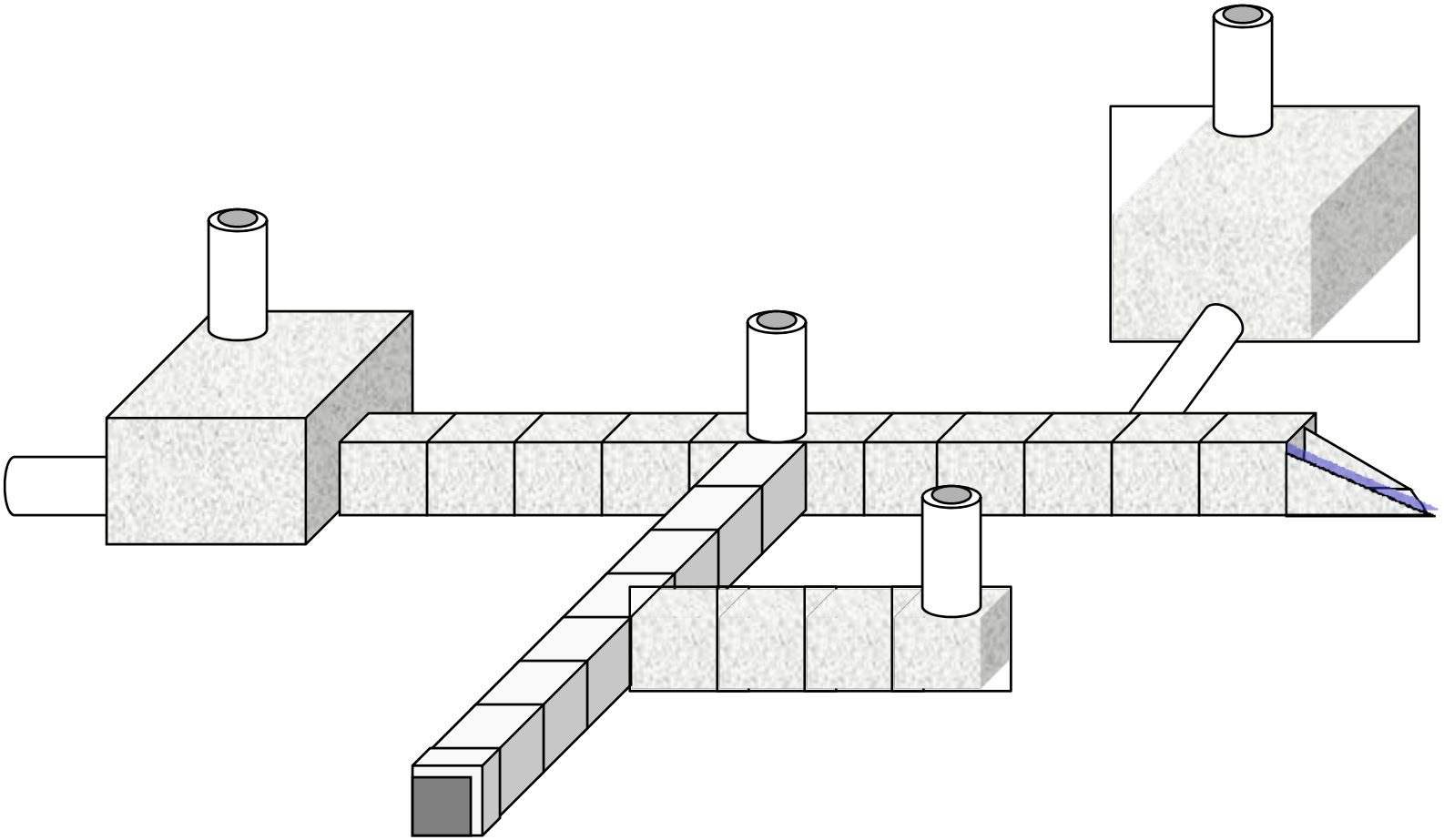


NV 43050 08050

Cave III

Hidden Valley

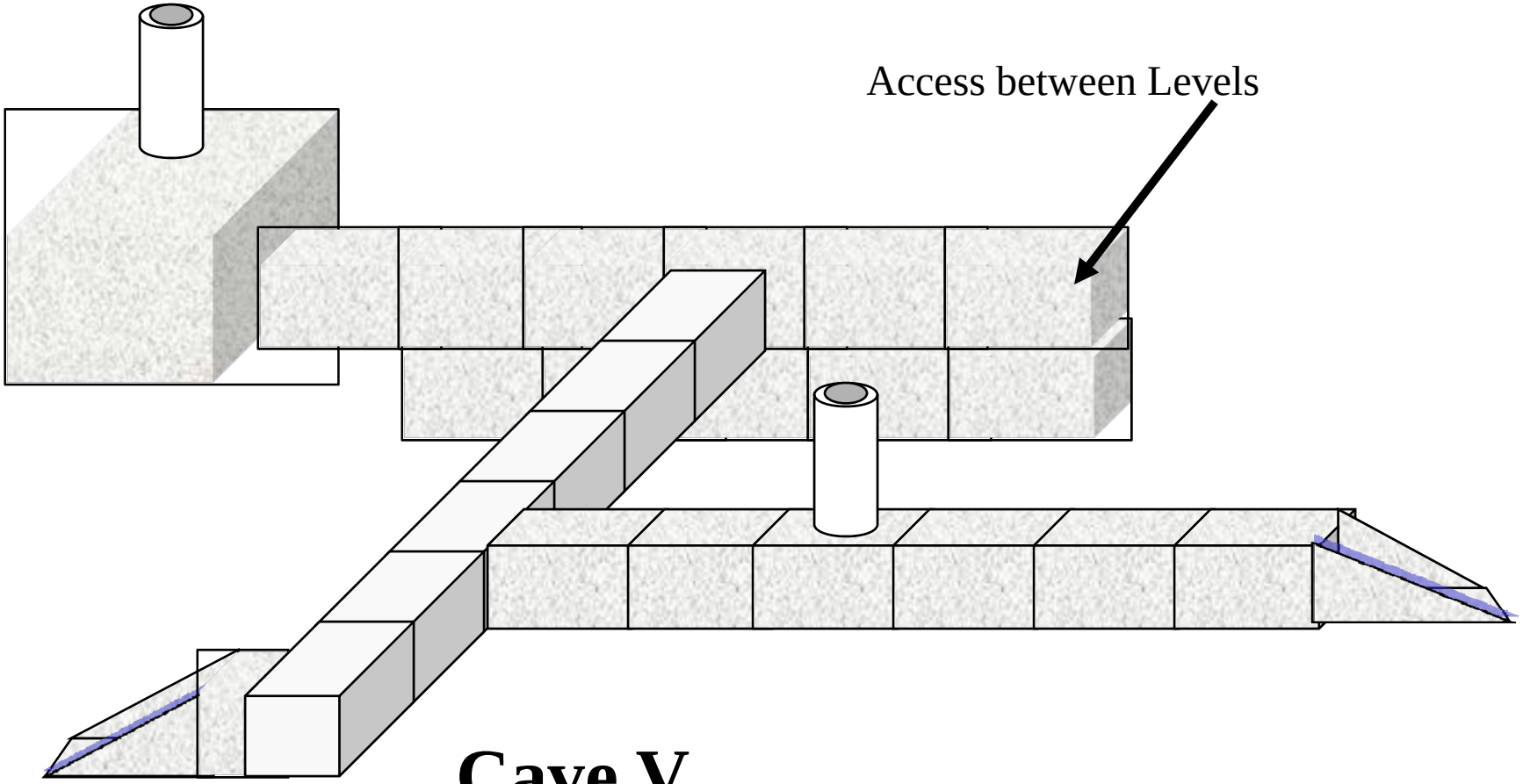
Appendix 2 B



NV 13833 15156

Cave IV
Pioneer

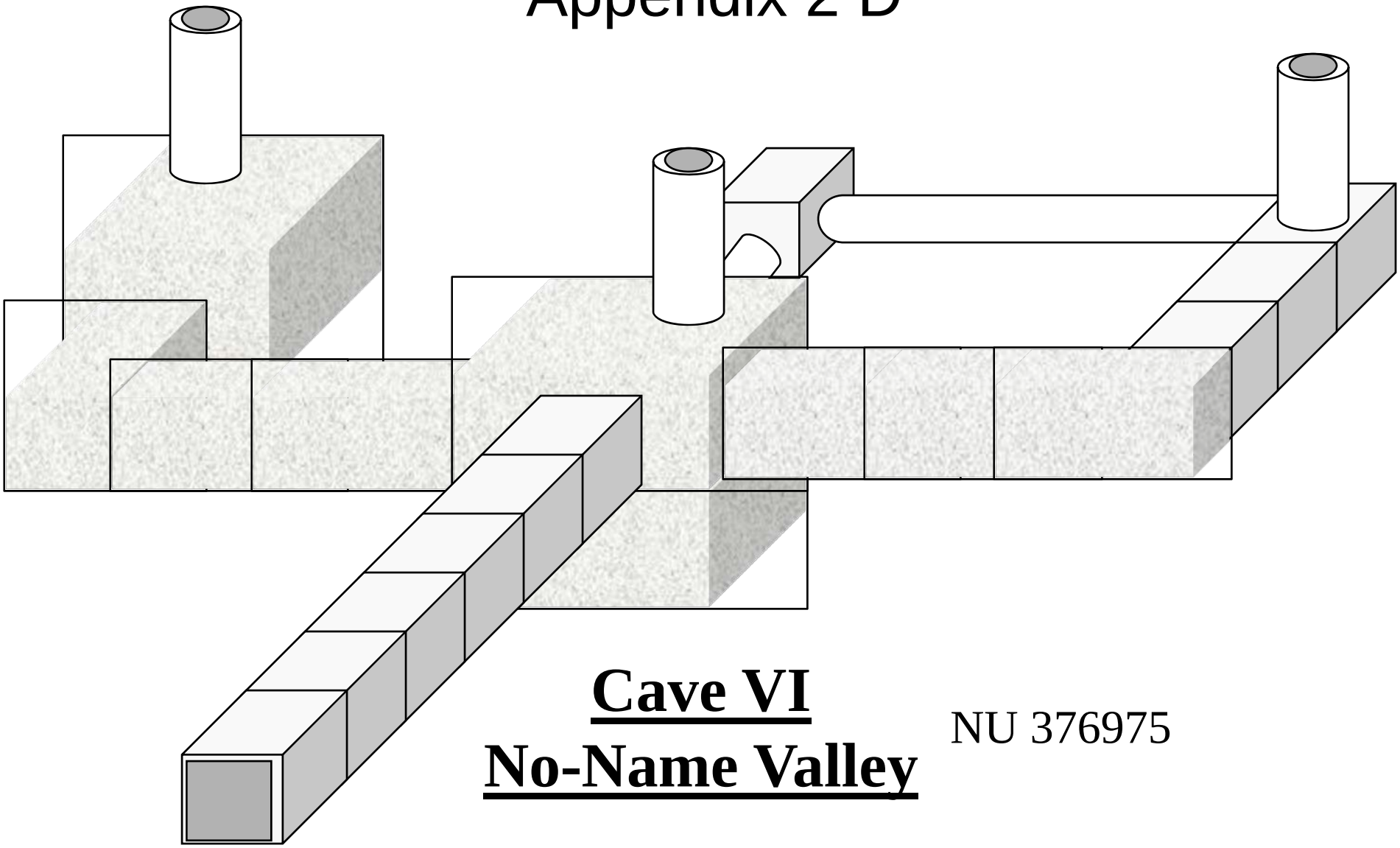
Appendix 2 C



Cave V

Alpine Valley NV 250270

Appendix 2 D

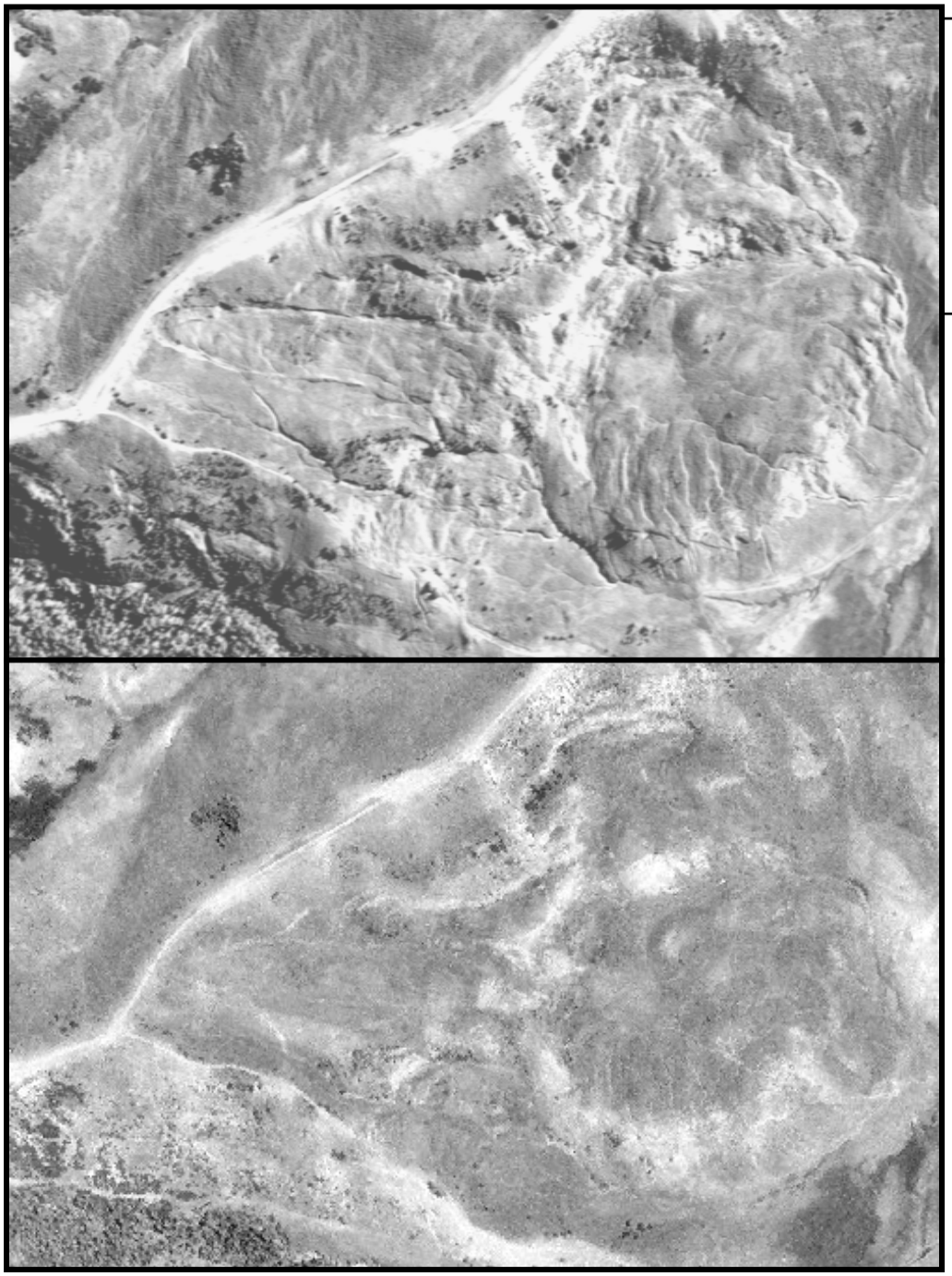


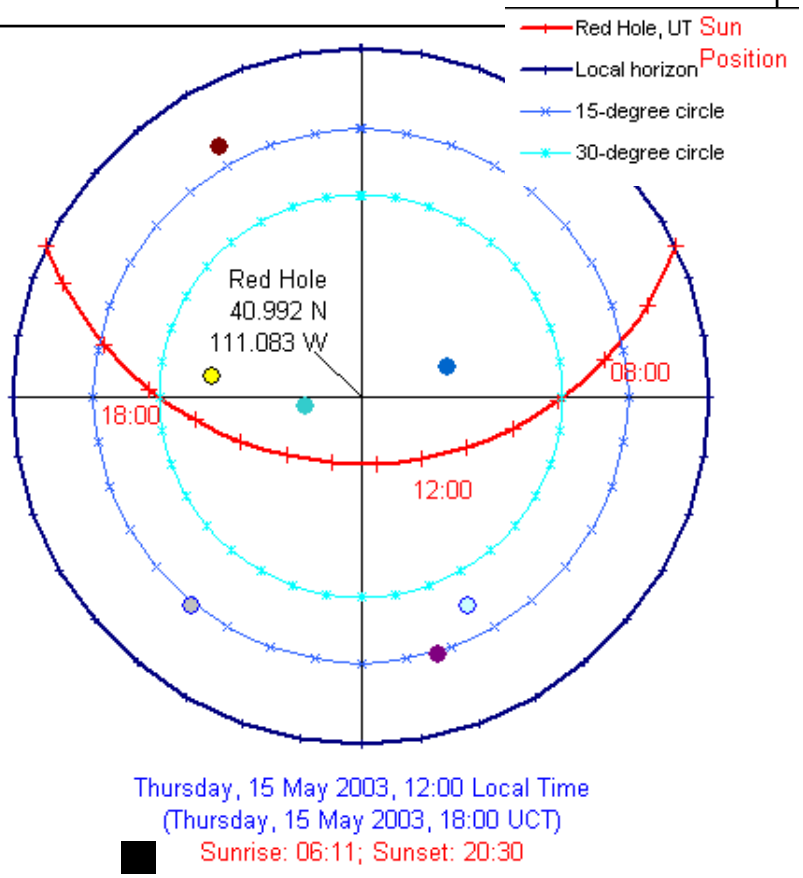
Cave VI
No-Name Valley

NU 376975

REMOTE SENSING TECHNIQUES TO ACQUIRE BARE EARTH ASSESSMENT

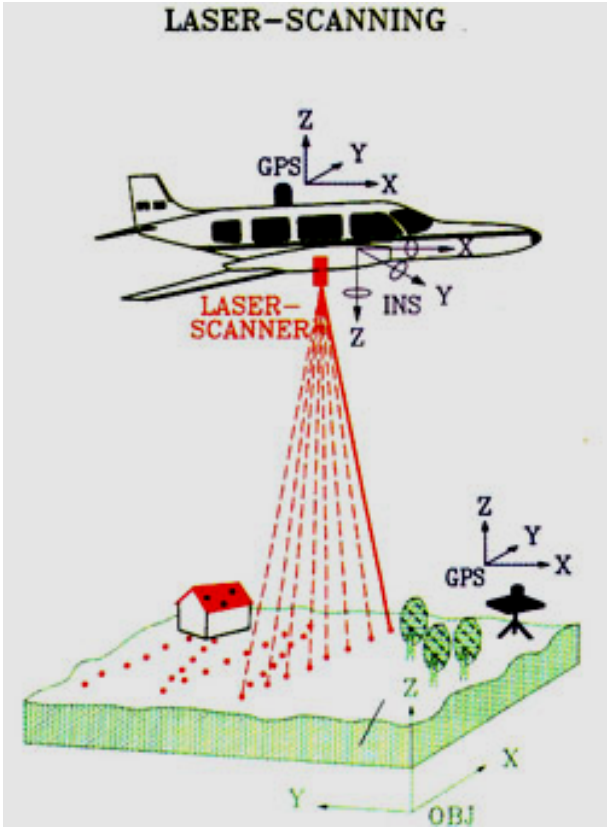
Low-Sun Angle Air Photo

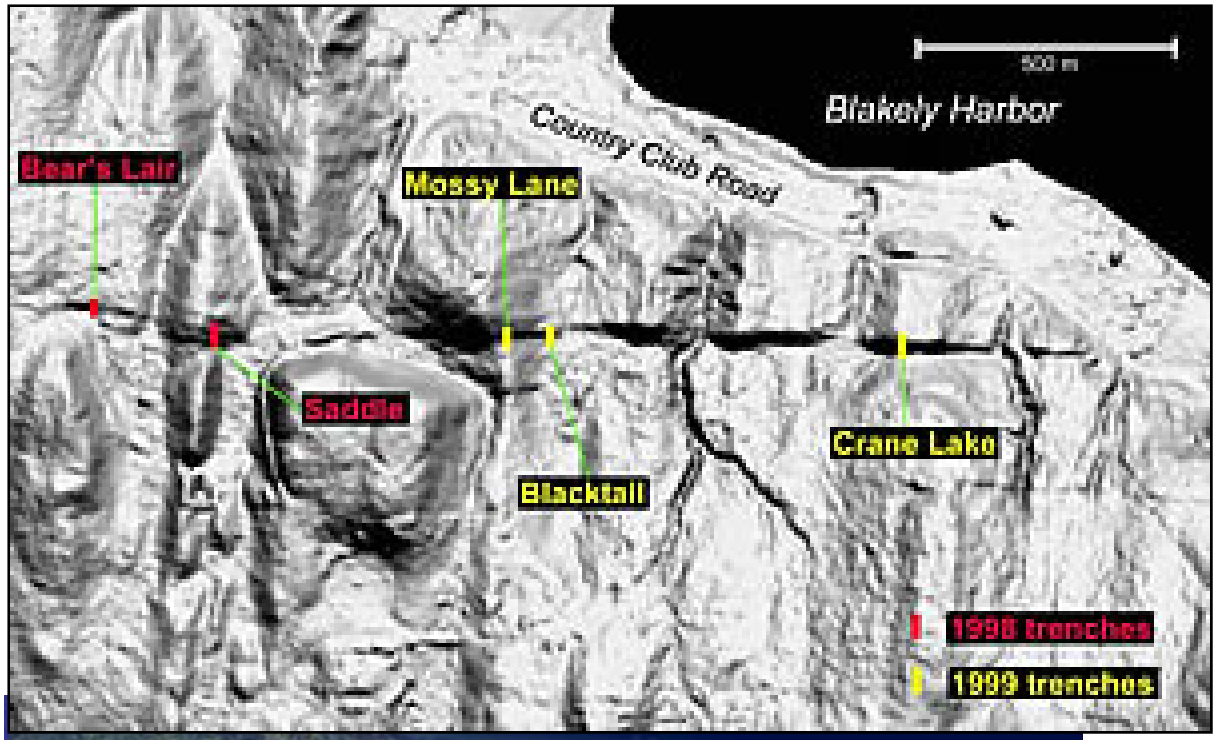




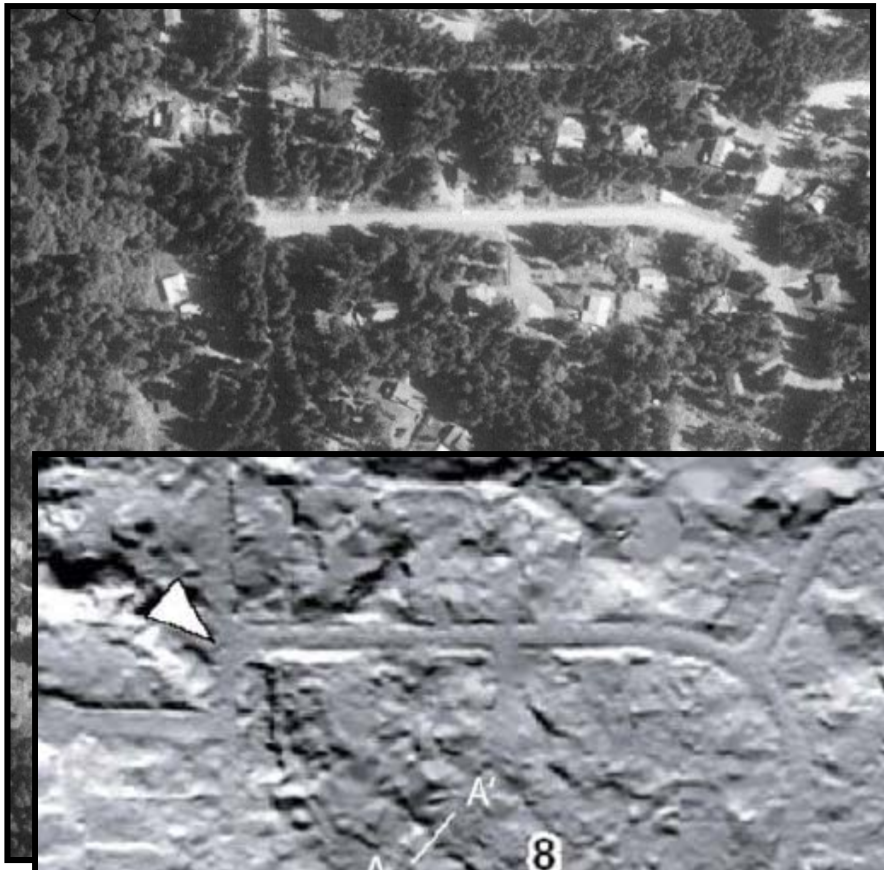
Thursday, 15 May 2003, 12:00 Local Time
(Thursday, 15 May 2003, 18:00 UCT)
Sunrise: 06:11; Sunset: 20:30

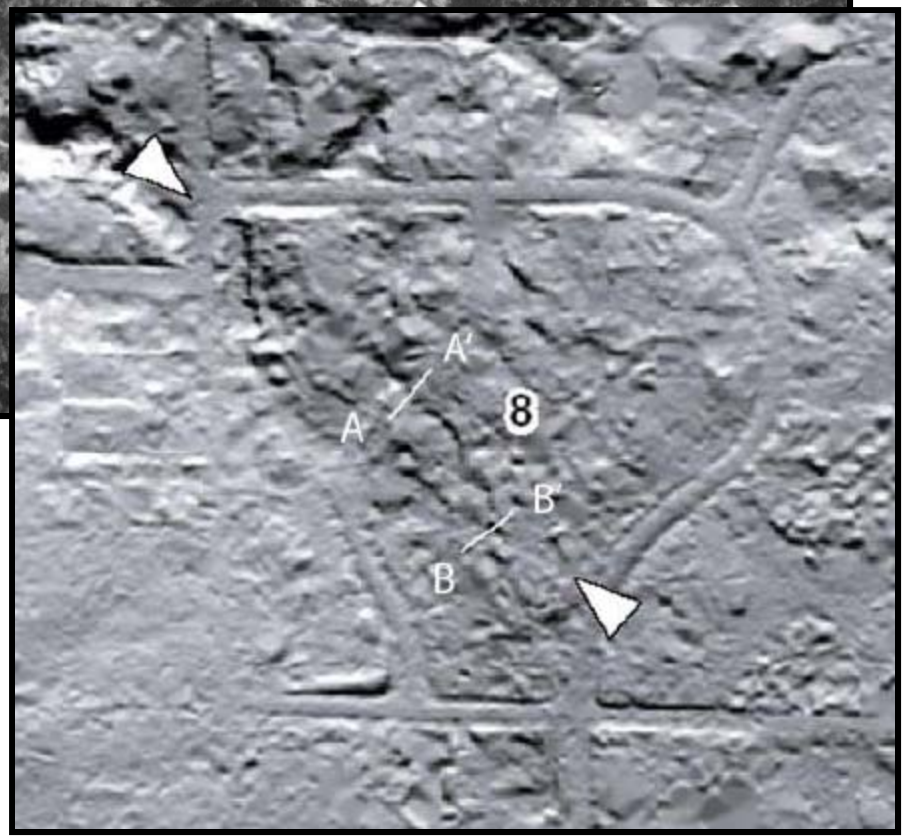
AIRBORNE LiDAR

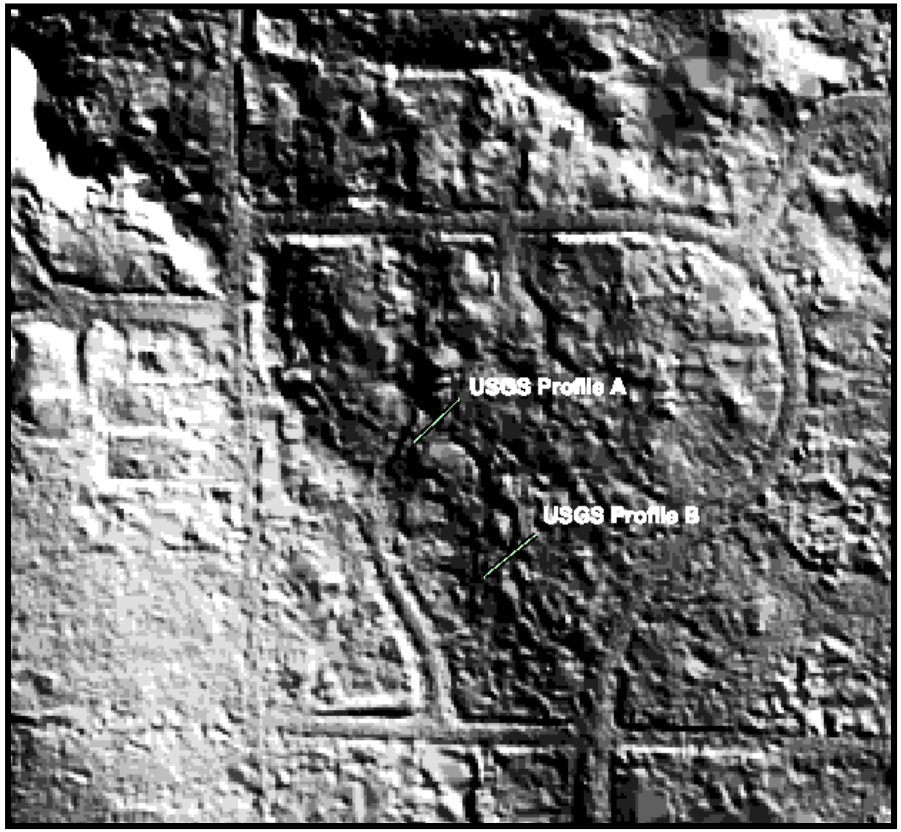




Hillshade with LiDAR



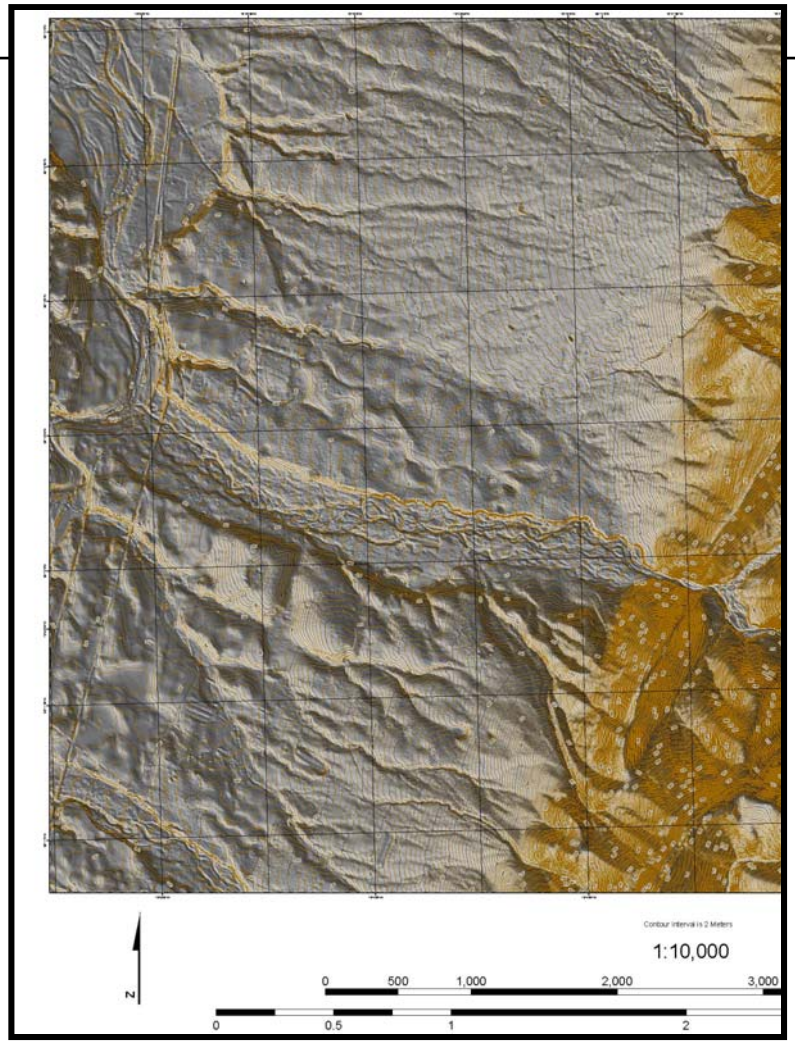




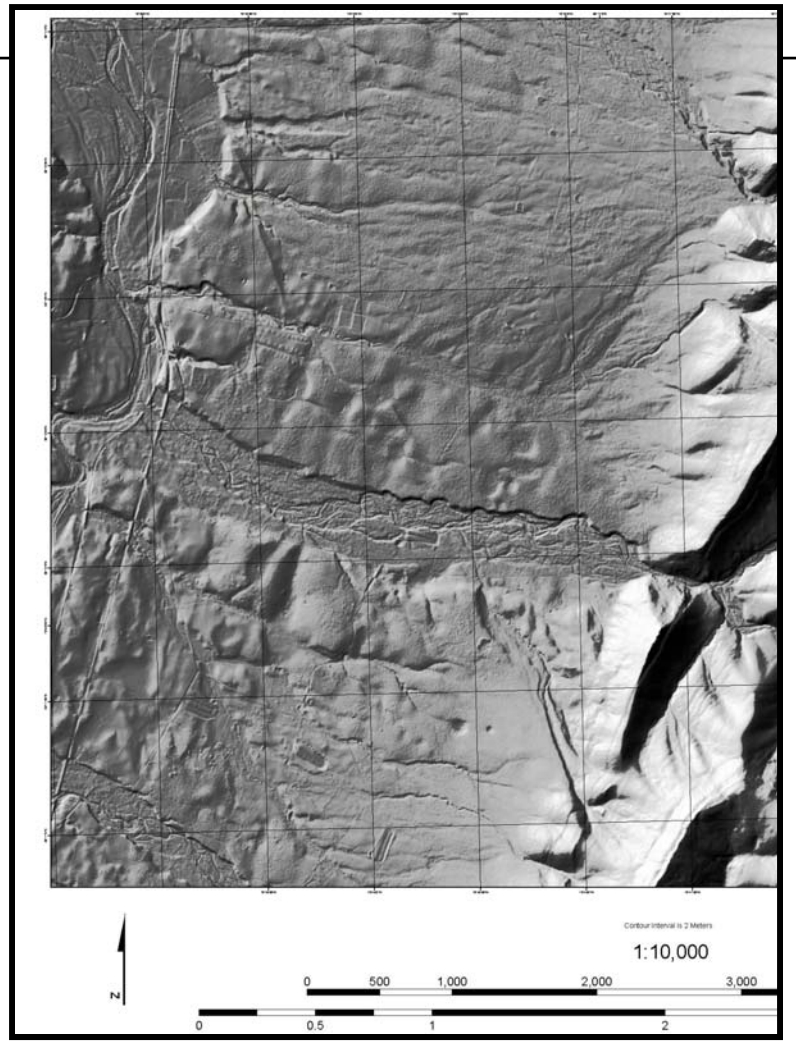
Multiple Sun Azimuths - USGS

Single Sun Azimuth - NE

Equivalent Low-Sun Angle with LiDAR



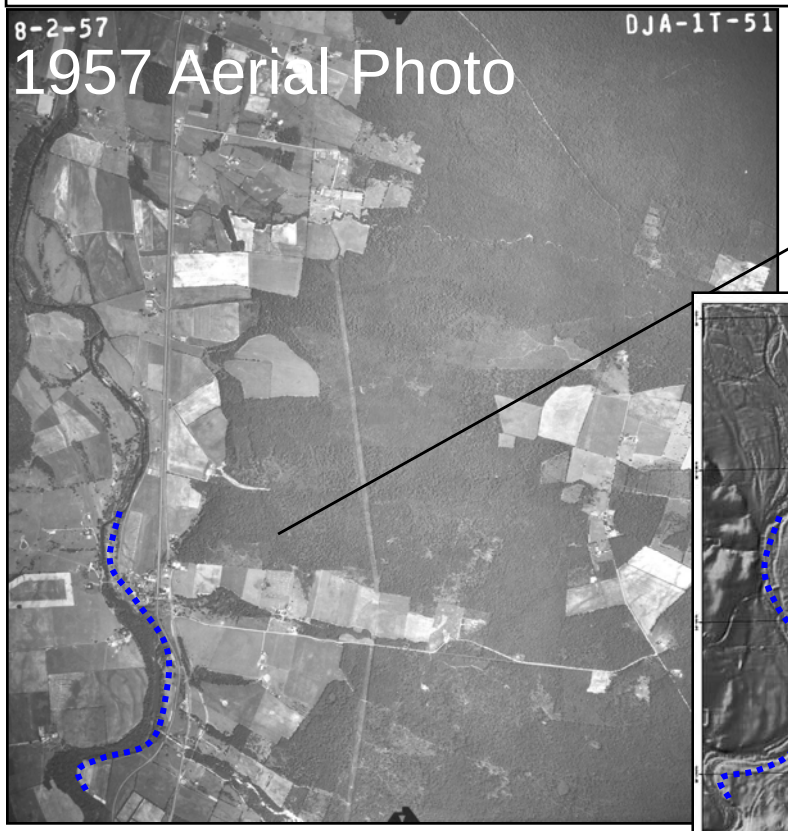
Equivalent Sun Azimuth = 225°



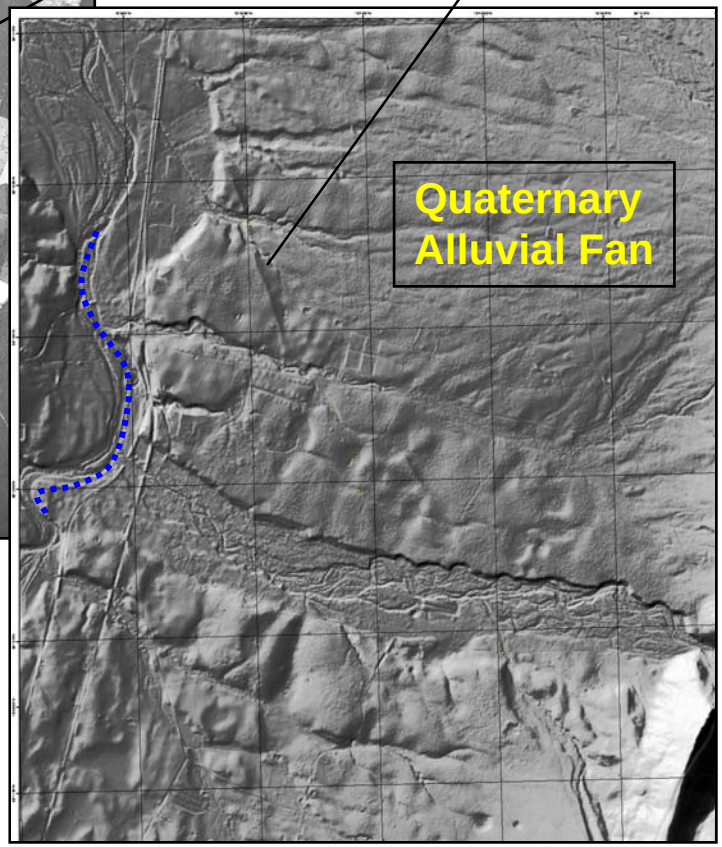
Equivalent Sun Azimuth = 315°

Images provided by USGS

Aerial Photo & Bare-Earth LiDAR Images

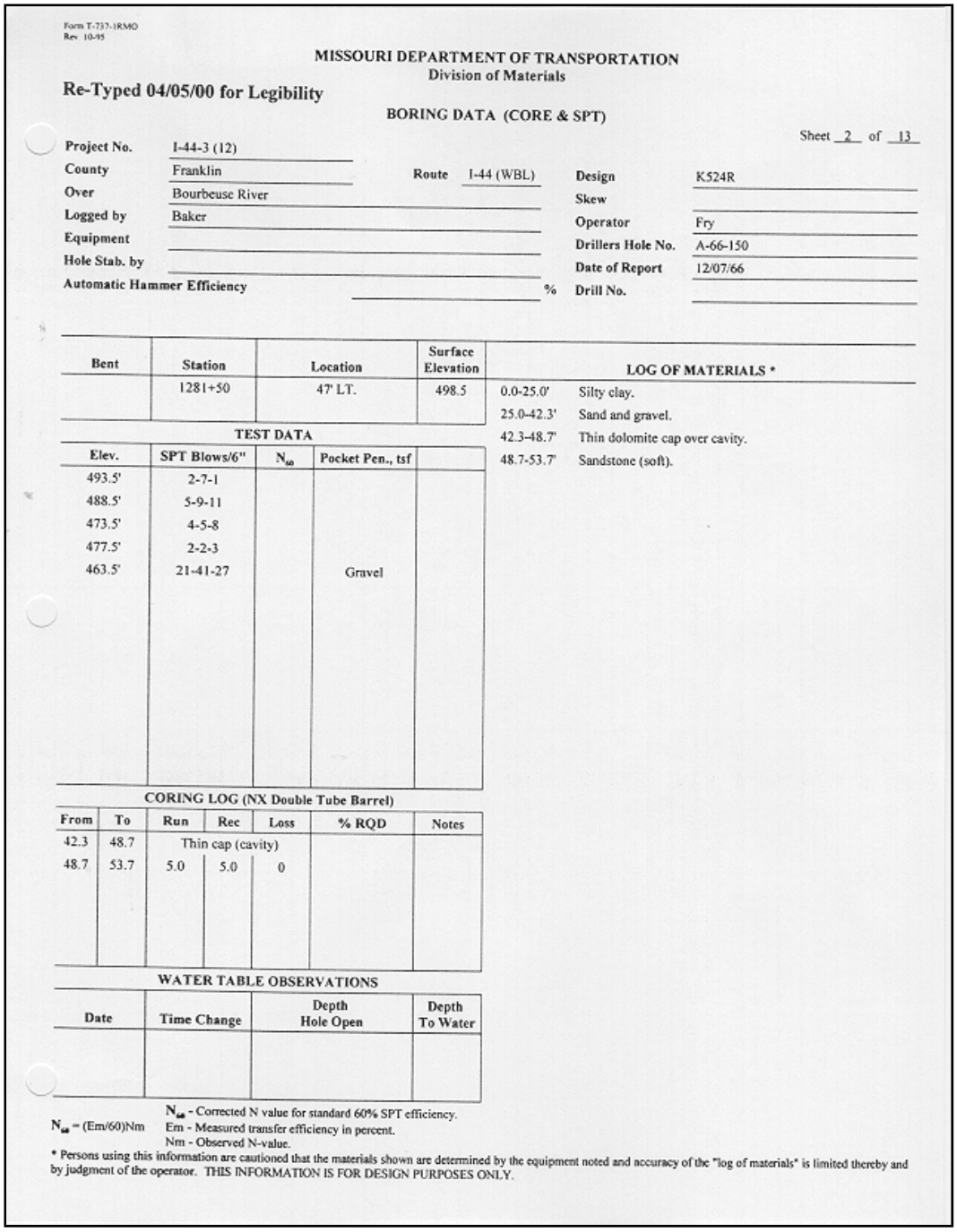


Scarp of Harriston fault, Virginia



Images provided by the USGS

VIRTUAL GEOTECHNICAL DATABASES



Form T-737-1RMO
Rev. 10-95

MISSOURI DEPARTMENT OF TRANSPORTATION
Division of Materials

Re-Typed 04/05/00 for Legibility

BORING DATA (CORE & SPT)

Sheet 2 of 13

Project No.	I-44-3 (12)				
County	Franklin	Route	I-44 (WBL)	Design	K524R
Over	Bourbeuse River			Skew	
Logged by	Baker			Operator	Fry
Equipment				Drillers Hole No.	A-66-150
Hole Stab. by				Date of Report	12/07/66
Automatic Hammer Efficiency		%		Drill No.	

Bent	Station	Location	Surface Elevation
	1281+50	47' LT.	498.5

LOG OF MATERIALS *

0.0-25.0'	Silty clay.
25.0-42.3'	Sand and gravel.
42.3-48.7'	Thin dolomite cap over cavity.
48.7-53.7'	Sandstone (soft).

TEST DATA

Elev.	SPT Blows/6"	N_{60}	Pocket Pen., tsf	
493.5'	2-7-1			
488.5'	5-9-11			
473.5'	4-5-8			
477.5'	2-2-3			
463.5'	21-41-27		Gravel	

CORING LOG (NX Double Tube Barrel)

From	To	Run	Rec	Loss	% RQD	Notes
42.3	48.7	Thin cap (cavity)				
48.7	53.7	5.0	5.0	0		

WATER TABLE OBSERVATIONS

Date	Time Change	Depth Hole Open	Depth To Water

N_{60} = (Em/60)Nm

N_{60} - Corrected N value for standard 60% SPT efficiency.
Em - Measured transfer efficiency in percent.
Nm - Observed N-value.

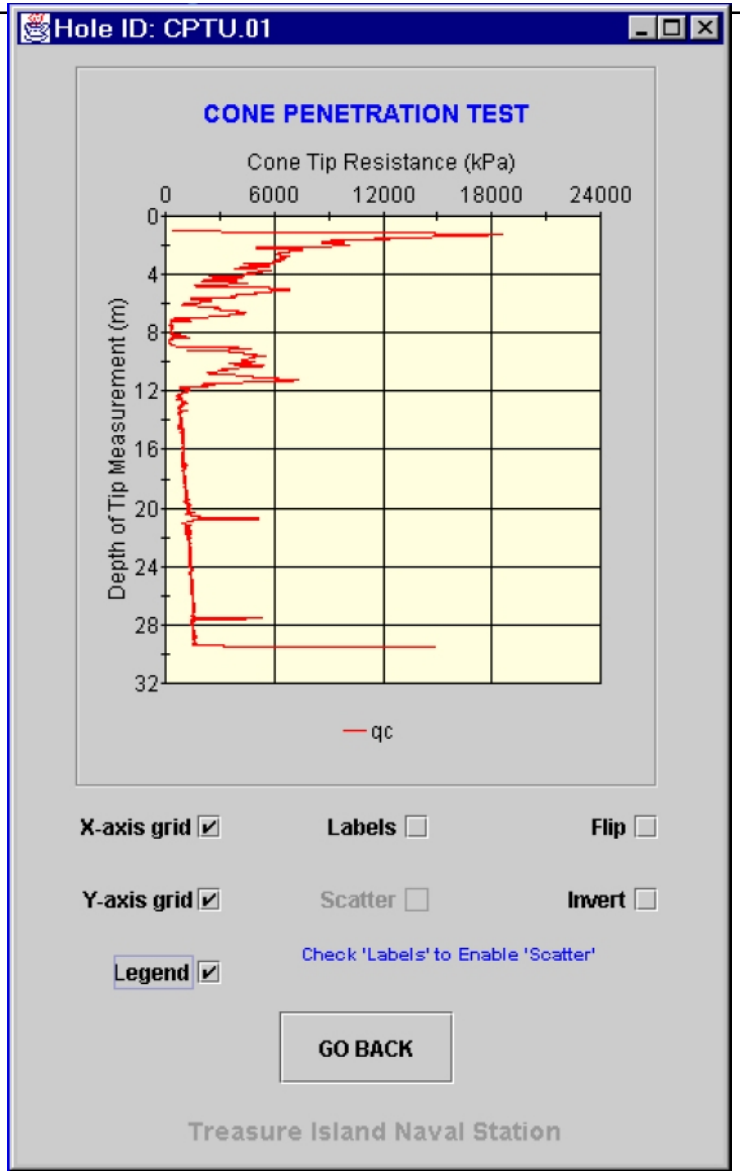
* Persons using this information are cautioned that the materials shown are determined by the equipment noted and accuracy of the "log of materials" is limited thereby and by judgment of the operator. THIS INFORMATION IS FOR DESIGN PURPOSES ONLY.

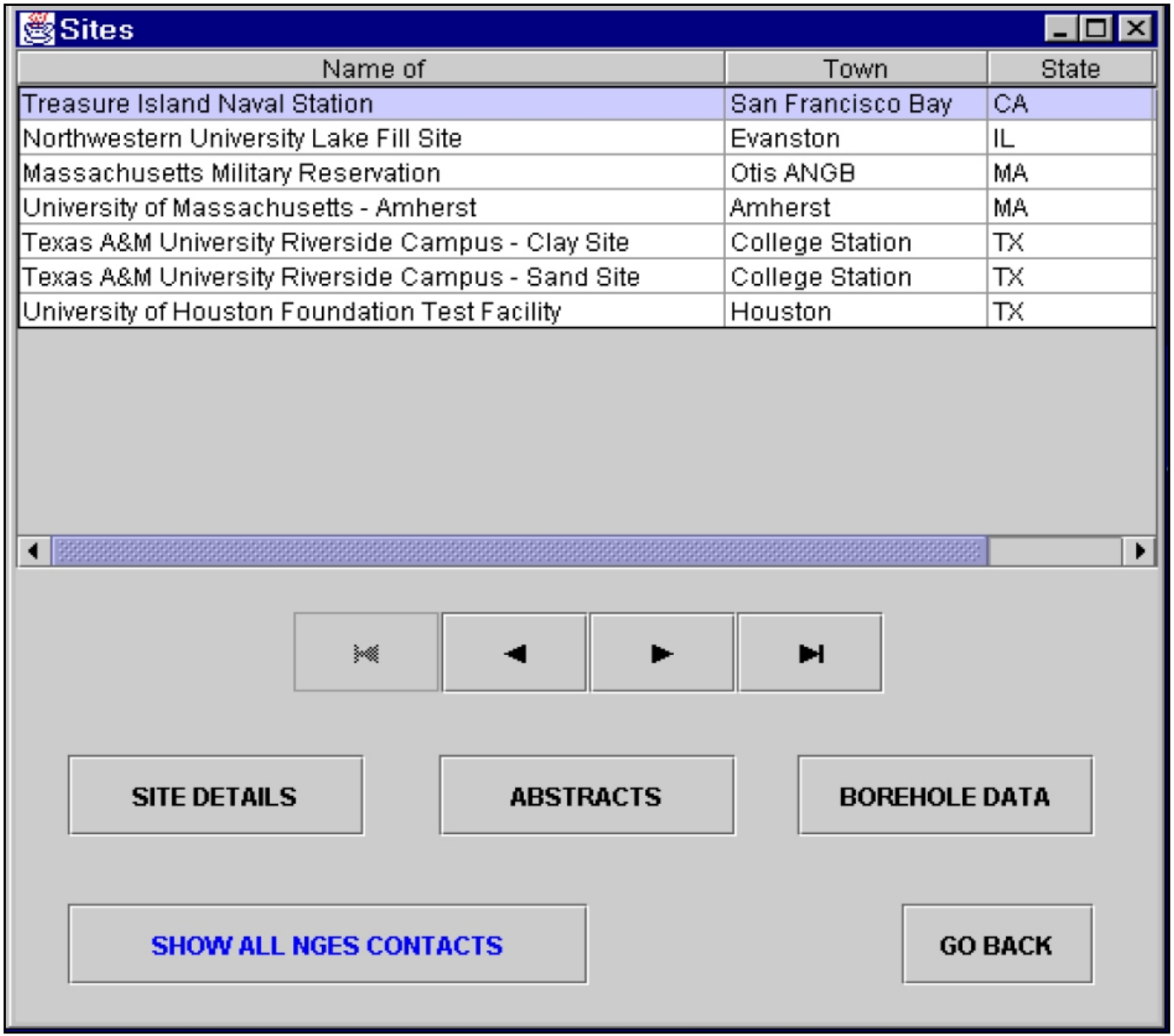
Well logs

are available for thousands of geotechnical, hydrologic, mining and petroleum exploration borings all over the world. Most of these are in analog format, like that shown at left.

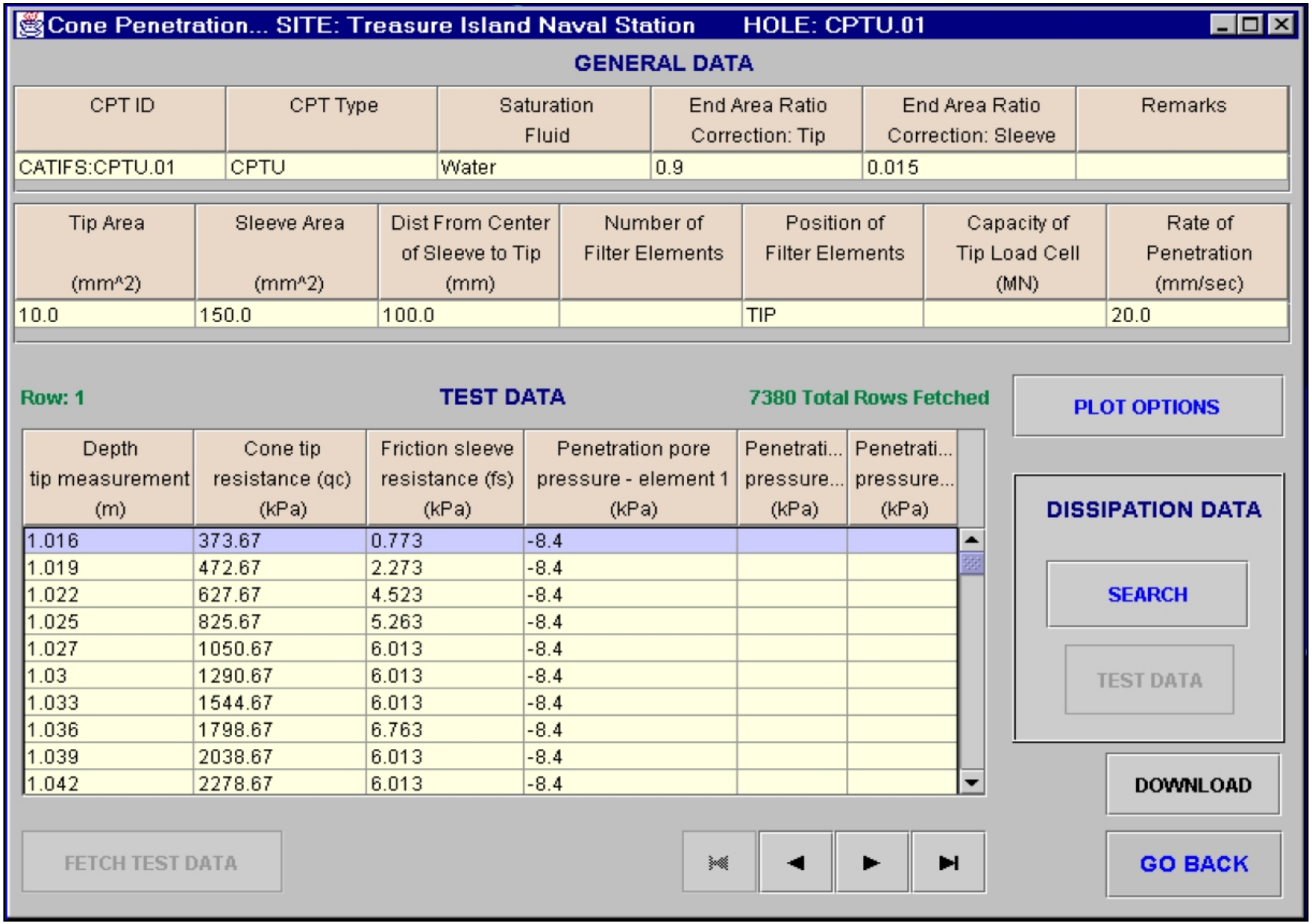
Cone Pentrometer Data on NGES site

- ID
- Code Space
- CPT ID
- Depth
- Tip Resistance
- Friction Resistance
- Pore Pressure
- Inclination
- Remarks
- Updates





The NGES sites are catalogued using the AGS architecture


Cone Penetration... SITE: Treasure Island Naval Station HOLE: CPTU.01
GENERAL DATA
CPT ID
CPT Type
Saturation Fluid
End Area Ratio Correction: Tip
End Area Ratio Correction: Sleeve
Remarks
CATIFS:CPTU.01
CPTU
Water
0.9
0.015
Tip Area (mm^2)
Sleeve Area (mm^2)
Dist From Center of Sleeve to Tip (mm)
Number of Filter Elements
Position of Filter Elements
Capacity of Tip Load Cell (MN)
Rate of Penetration (mm/sec)
10.0
150.0
100.0
TIP
20.0
Row: 1
TEST DATA
7380 Total Rows Fetched
PLOT OPTIONS
Depth tip measurement (m)
Cone tip resistance (qc) (kPa)
Friction sleeve resistance (fs) (kPa)
Penetration pore pressure - element 1 (kPa)
Penetrati... pressure... (kPa)
Penetrati... pressure... (kPa)
1.016 373.67 0.773 -8.4
1.019 472.67 2.273 -8.4
1.022 627.67 4.523 -8.4
1.025 825.67 5.263 -8.4
1.027 1050.67 6.013 -8.4
1.03 1290.67 6.013 -8.4
1.033 1544.67 6.013 -8.4
1.036 1798.67 6.763 -8.4
1.039 2038.67 6.013 -8.4
1.042 2278.67 6.013 -8.4
DISSIPATION DATA
SEARCH
TEST DATA
DOWNLOAD
FETCH TEST DATA
GO BACK

Select Data to Plot

Select y-axis Item
Click on Arrow for More Choices

Depth of Tip Measurement

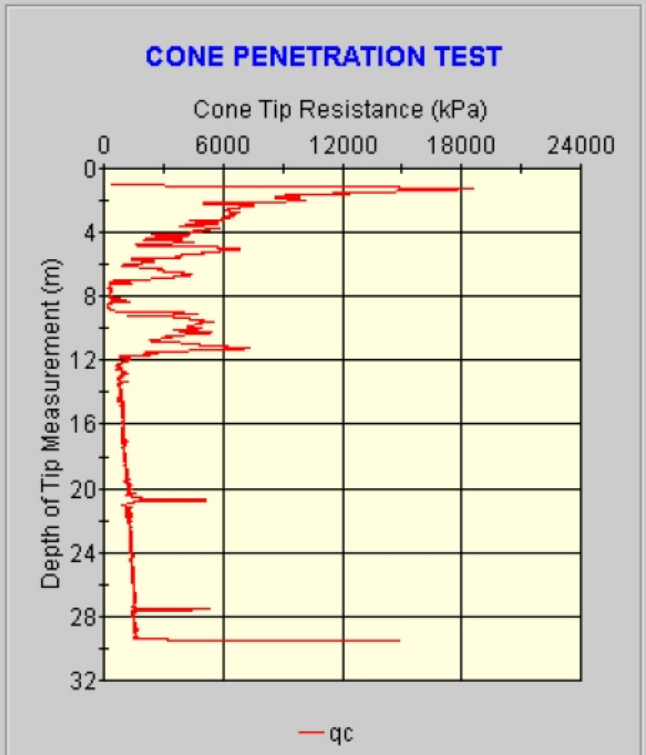
PLOT

GO BACK

Select x-axis Item(s); To Select Multiple Items,
Press 'ctrl' Key and Click on the Desired Items

- Cone Tip Resistance
- Friction Sleeve Resistance
- Penetration Pore Pressure - Cell 1
- Penetration Pore Pressure - Cell 2
- Penetration Pore Pressure - Cell 3
- Shear Wave Velocity

Hole ID: CPTU.01



X-axis grid ☑ Labels ☐ Flip ☐

Y-axis grid ☑ Scatter ☐ Invert ☐

Legend ☑

Check 'Labels' to Enable 'Scatter'

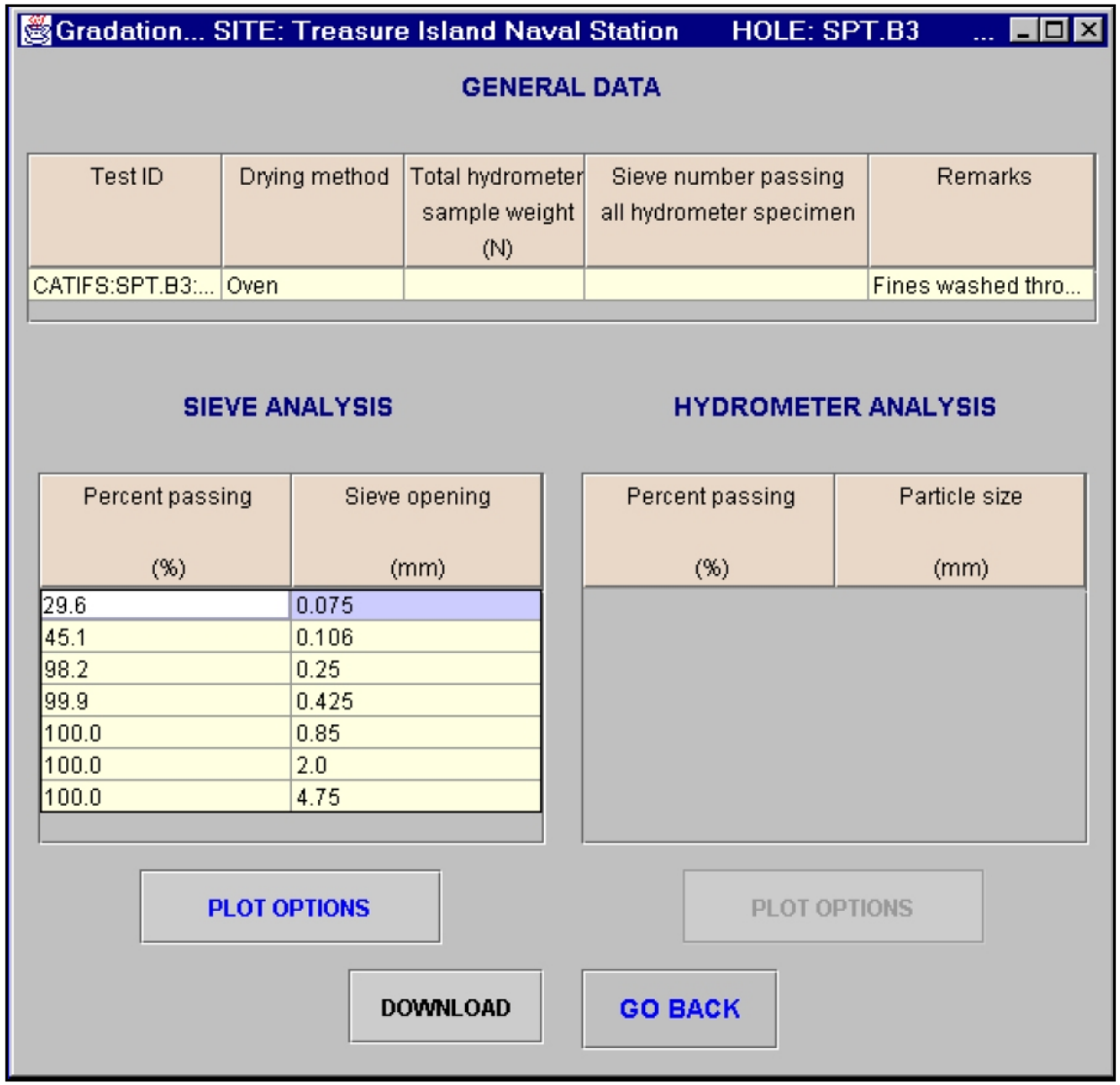
GO BACK

Treasure Island Naval Station

CPT Data in Database Form

CPT ID	DEPTH		TIP RESISTANCE		FRICTION RESISTANCE		PORE PRESSURE		INCLINATION DEGREES	REMARKS
731 TC	0.05	ft	893.87	ton	2.3355	na			0.45	
731 TC	0.1	ft	594.47	ton	4.4059	na			0.6	
731 TC	0.15	ft	415.73	ton	3.4361	na			0.1	
731 TC	0.2	ft	265.97	ton	2.5304	na			0.09	
731 TC	0.25	ft	223.64	ton	2.0594	na			0.06	
731 TC	0.3	ft	207.76	ton	1.9412	na			0.12	
731 TC	0.35	ft	158.67	ton	1.6396	na			0.07	
731 TC	0.4	ft	121.87	ton	0.9642	na			0.22	
731 TC	0.45	ft	88.03	ton	0.859	na			0.22	

Sieve Analysis



AGS-COSMOS-FHWA Virtual Geotechnical Database Architecture

- ESRI ArcIMS - Front Door
- XML (Excel) and COSMOS Database File System
- On the fly data stream transfer from member databases
- Java Script - Back end

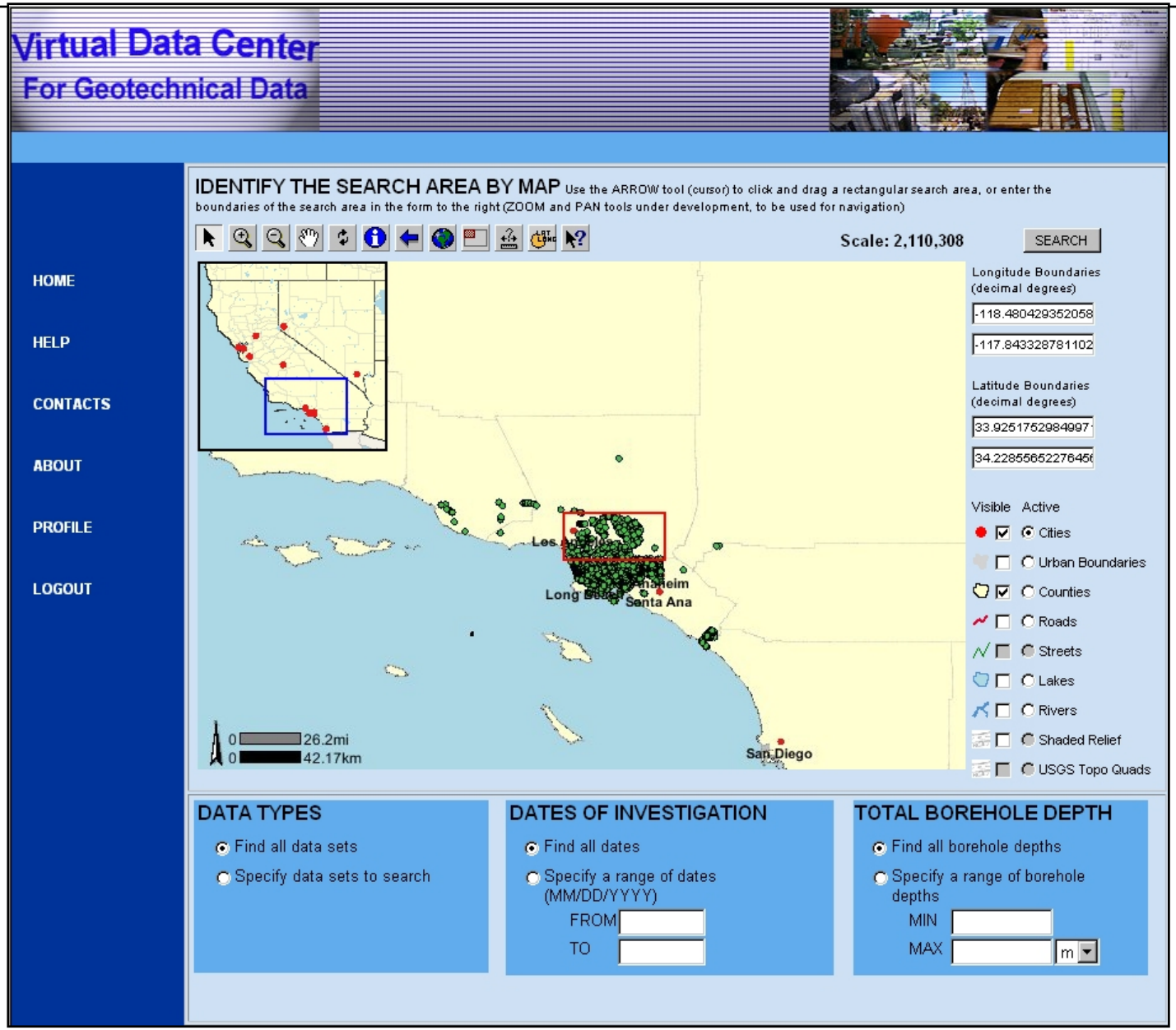
Long-Term Objective of the VGDC at SCEC in Los Angeles

- Extend the pilot system and develop a web-based system linking multiple data sets
- Capable of serving the broad needs of practicing geotechnical and earthquake hazards professionals for efficient access to geotechnical data
- Create GIS based hazard maps that can be incorporated into the geotechnical data set

Virtual Geotechnical Database
ArcIMS / XML System

Example Inquiry

Virtual Geotechnical Database



Virtual Data Center
For Geotechnical Data

HOME

HELP

CONTACTS

ABOUT

PROFILE

LOGOUT

Search Results

Your search returned 550 data sets from the following data sources:

PROJECT NAME	DATA TYPE	DATA SOURCE	PROJECT DATE	LAST UPDATED	DOWNLOADS/ CONTACT
ORANGE FWY 57 AND TONNER CANYON BRIDGE	DGC, FLL, BLG, SPT	50	1989-12-10	2002-03-14	
ORANGE FWY 57	BLG, DGC, FLL, SPT	60	1989-12-10	2002-03-14	
ORANGE FWY 57	DGC, FLL, BLG, SPT	85	1989-12-10	2002-03-14	
C.C. Industries	BLG, DGC	51	1989-12-10	2002-03-14	
Kayo Oil Company - Jet Gas Station	BLG, DGC, FLL, SPT	57	1989-12-10	2002-03-14	
Mobil Oil Corporation Service Station No. 18-F34	SPT, BLG, DGC, FLL	50	1989-12-10	2002-03-14	
Mobil Oil Corporation - Service Station No.18-F34	SPT, FLL, BLG, DGC	31.5	1989-12-10	2002-03-14	
Mobil Station 11-E13	BLG, DGC, FLL, SPT	51.5	1989-12-10	2002-03-14	
City of La Habra Fire Station No. 2	SPT, BLG, DGC, FLL	31	1989-12-10	2002-03-14	
Lincoln Mortgage	BLG, DGC, FLL, SPT	60	1989-12-10	2002-03-14	
Former Chevron Station No. 9-2214	BLG, DGC, FLL, SPT	35	1989-12-10	2002-03-14	
Air Conditioning Systems, Inc.	FLL, SPT, DGC, BLG	50	1989-12-10	2002-03-14	
Cleere Property	FLL, SPT, DGC, BLG	28	1989-12-10	2002-03-14	
UGST Site Assessment	BLG, DGC, FLL, SPT	36	1989-12-10	2002-03-14	

Virtual Data Center
For Geotechnical Data

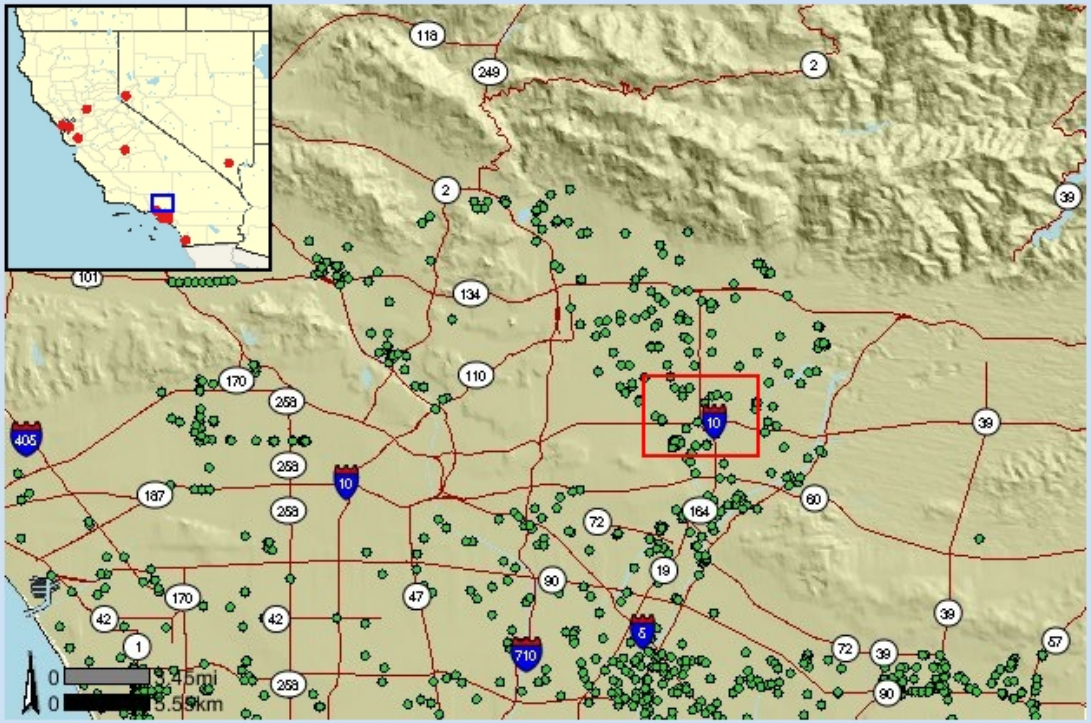
- HOME
- HELP
- CONTACTS
- ABOUT
- PROFILE
- LOGOUT

IDENTIFY THE SEARCH AREA BY MAP

Use the ARROW tool (cursor) to click and drag a rectangular search area, or enter the boundaries of the search area in the form to the right (ZOOM and PAN tools under development, to be used for navigation)

Scale: 420,013

SEARCH



Longitude Boundaries (decimal degrees)

-118.106474253112

-118.038590878051

Latitude Boundaries (decimal degrees)

34.052298362054

34.1002160385671(

Visible	Active	
●	☑	◉ Cities
	☐	○ Urban Boundaries
	☑	○ Counties
	☑	○ Roads
	☐	◉ Streets
	☐	○ Lakes
	☑	○ Rivers
	☑	◉ Shaded Relief
	☐	◉ USGS Topo Quads

DATA TYPES

- ◉ Find all data sets
- ○ Specify data sets to search

DATES OF INVESTIGATION

- ◉ Find all dates
- ○ Specify a range of dates (MM/DD/YYYY)

FROM

TO

TOTAL BOREHOLE DEPTH

- ◉ Find all borehole depths
- ○ Specify a range of borehole depths

MIN

MAX

m

Virtual Data Center
For Geotechnical Data

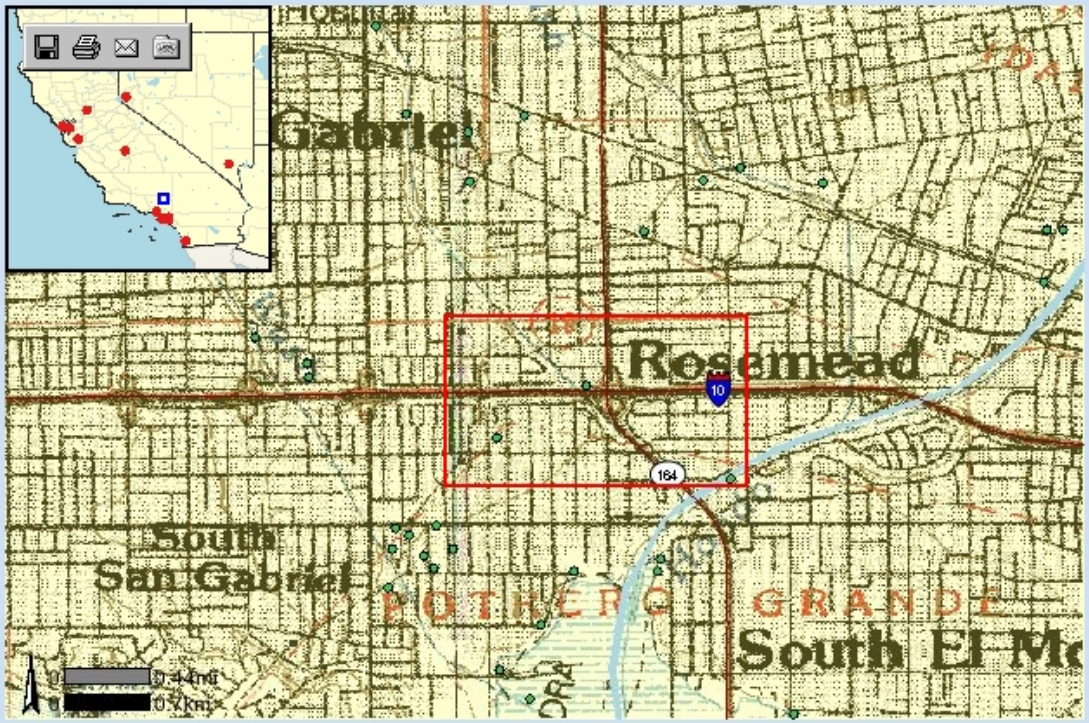
- HOME
- HELP
- CONTACTS
- ABOUT
- PROFILE
- LOGOUT

IDENTIFY THE SEARCH AREA BY MAP

Use the ARROW tool (cursor) to click and drag a rectangular search area, or enter the boundaries of the search area in the form to the right (ZOOM and PAN tools under development, to be used for navigation)

Scale: 53,011

SEARCH



Longitude Boundaries (decimal degrees)

-118.084894822134

-118.062719327825

Latitude Boundaries (decimal degrees)

34.0651888373295

34.0777885500049

Visible	Active	
●	☑	◉ Cities
	☐	○ Urban Boundaries
	☑	○ Counties
	☑	○ Roads
	☐	○ Streets
	☐	○ Lakes
	☑	○ Rivers
	☐	○ Shaded Relief
	☑	○ USGS Topo Quads

DATA TYPES

- ◉ Find all data sets
- ○ Specify data sets to search

DATES OF INVESTIGATION

- ◉ Find all dates
- ○ Specify a range of dates (MM/DD/YYYY)

FROM

TO

TOTAL BOREHOLE DEPTH

- ◉ Find all borehole depths
- ○ Specify a range of borehole depths

MIN

MAX m

Virtual Data Center
For Geotechnical Data

HOME

HELP

CONTACTS

ABOUT

PROFILE

LOGOUT

Search Results

Your search returned 2 data sets from the following data sources:

PROJECT NAME	DATA TYPE	DATA SOURCE	PROJECT DATE	LAST UPDATED	DOWNLOADS/ CONTACT
2922	BLG	Unknown	1700-01-01	2004-02-04	
2913K	BLG	Unknown	1700-01-01	2004-02-04	

Key to DOWNLOADS/CONTACT INFO:

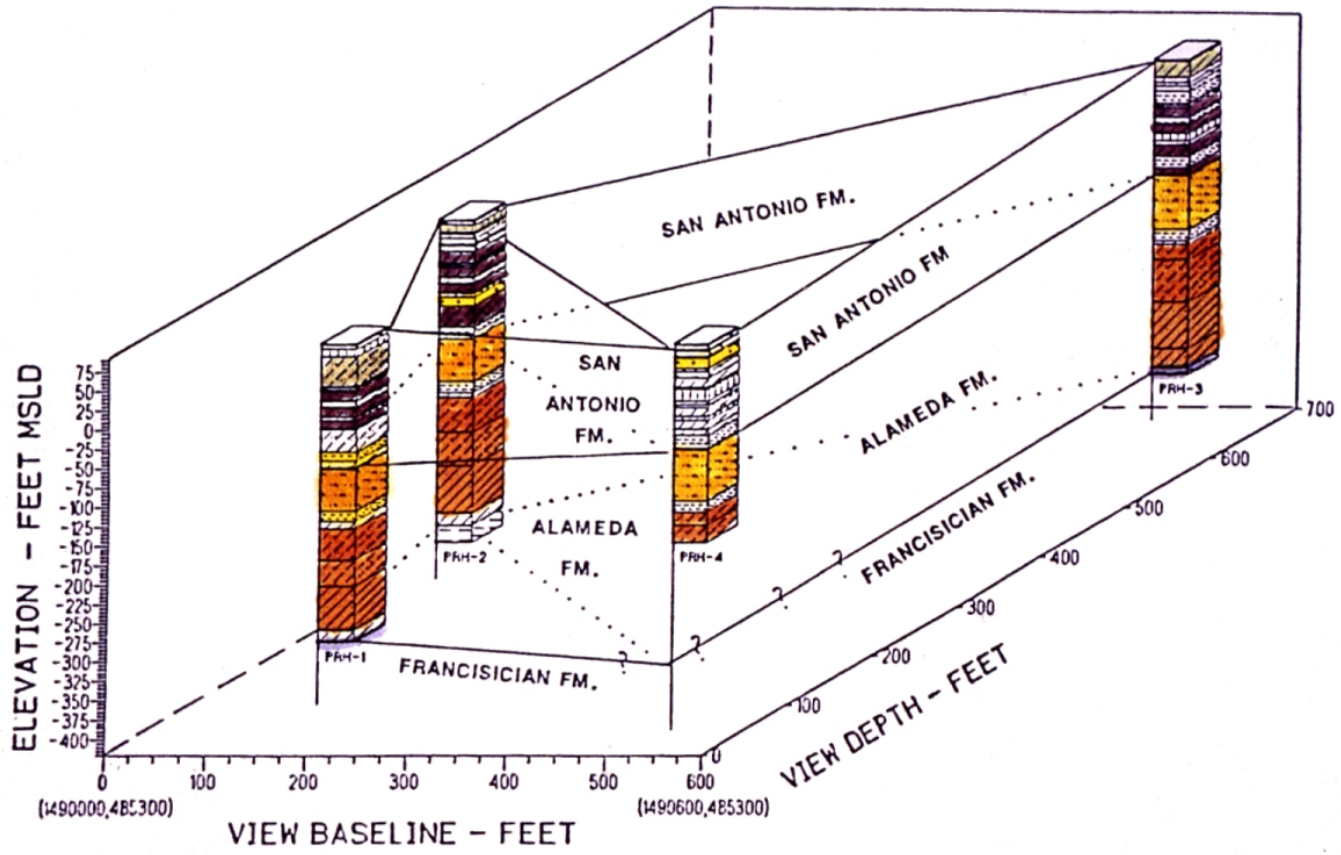
Download available in Microsoft Excel Format

Download available in COSMOS XML Format

PREVIEW *Graphical Preview of data is available*

NEW SEARCH

FENCE DIAGRAM



- The VGDC can provide graphic logs and an array of spatial correlations, such as this fence diagram, to provide predictive models of the understructure of the Earth

CONCLUSIONS

- Protocols could be developed for estimating size and extent of underground structures using remote sensing
- Geophysical techniques could be developed for black-box detection of tunnels, with validation studies in CONUS
- Subsurface information from variety of sources could be stored and retrieved from Virtual Geotechnical Databases, over the Internet