DEVELOPMENT AND USE OF A PROFILING SONAR PROBE FOR MAPPING FLOODED UNDERGROUND MINE WORKINGS

Mike Sharp
Oklahoma Conservation Commission
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January 9, 2009

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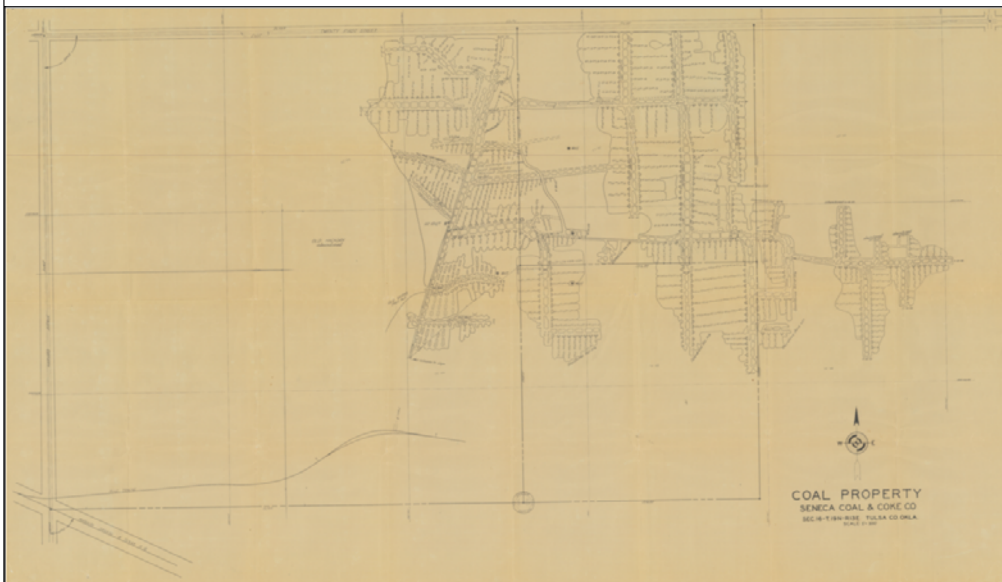
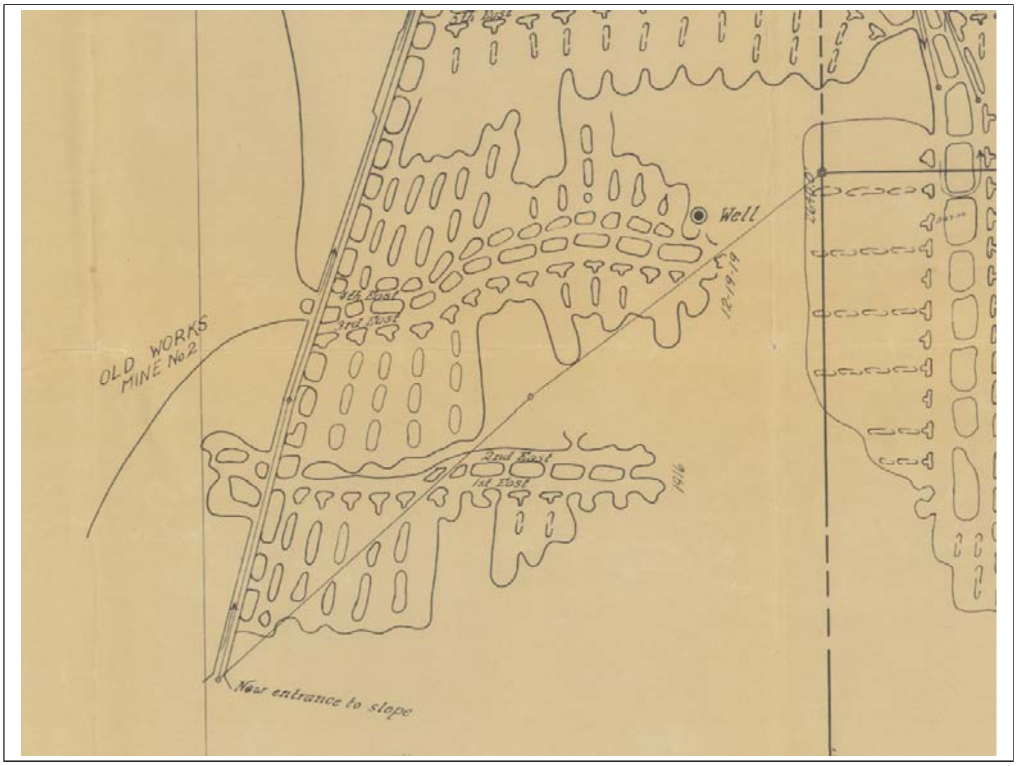
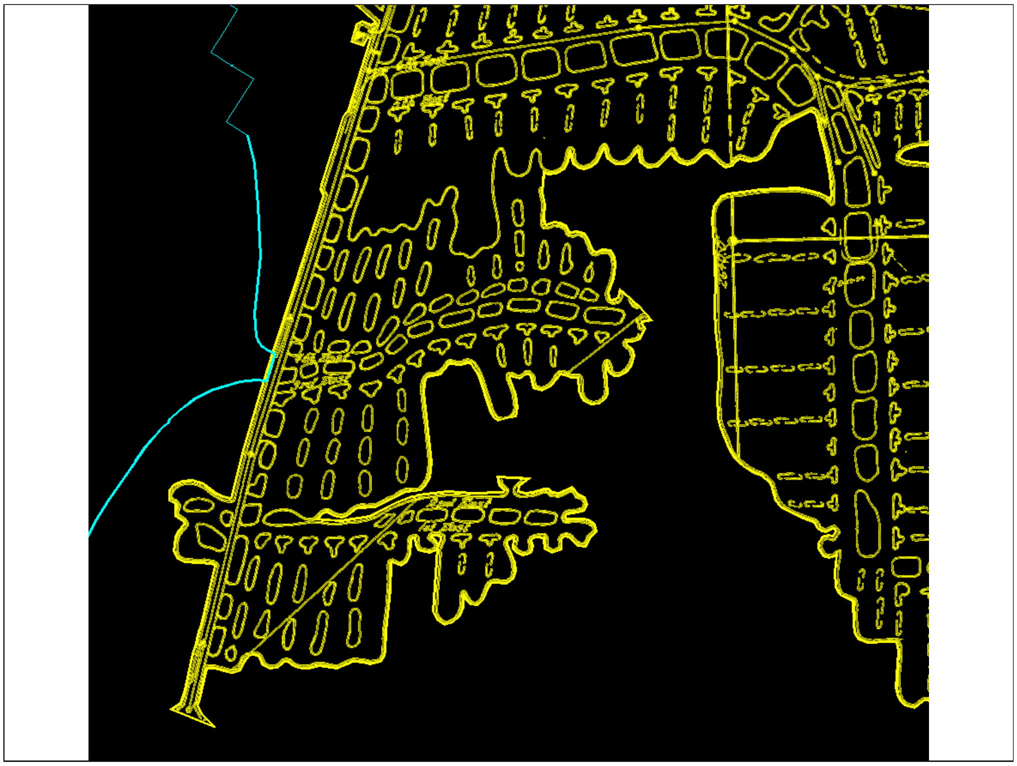
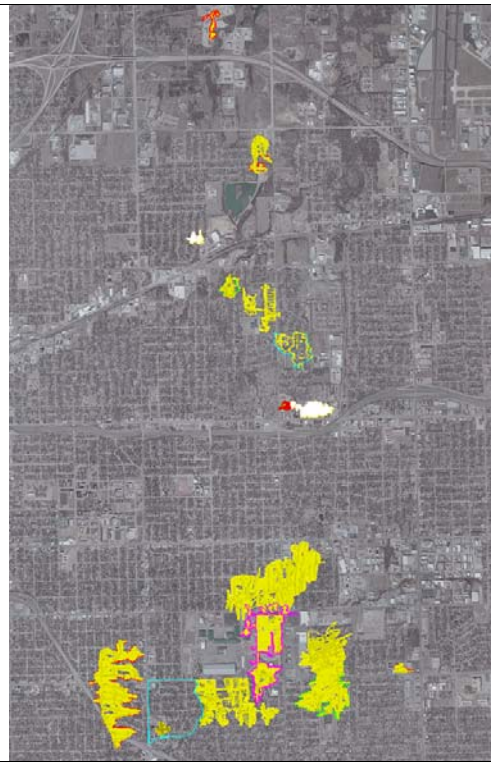
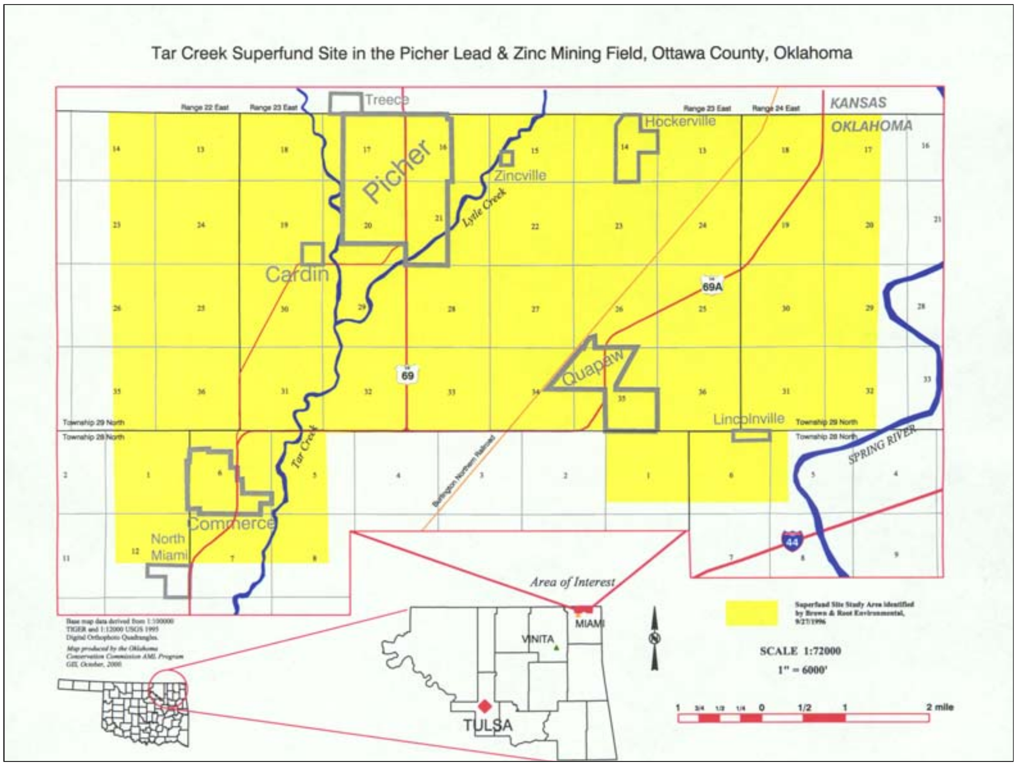

COAL PROPERTY
SENECA COAL & COKE CO
TULSA CO OKLA

Open shaft in Lead/Zinc mining district. Approximate depth = 250 feet.


OLD WORKS
MINE No.2
Well
4th East
3rd East
2nd East
1st East
12-19-19
1916
New entrance to slope



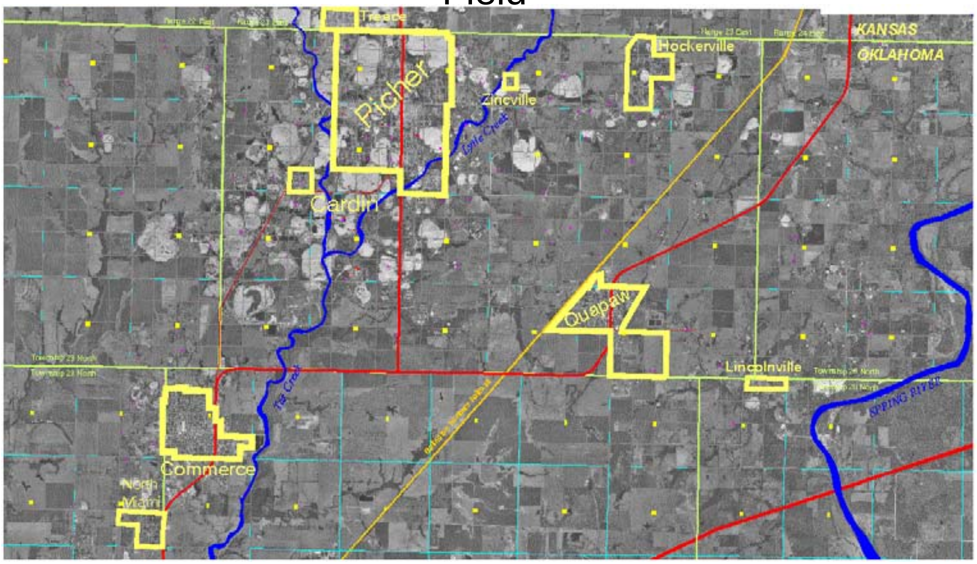


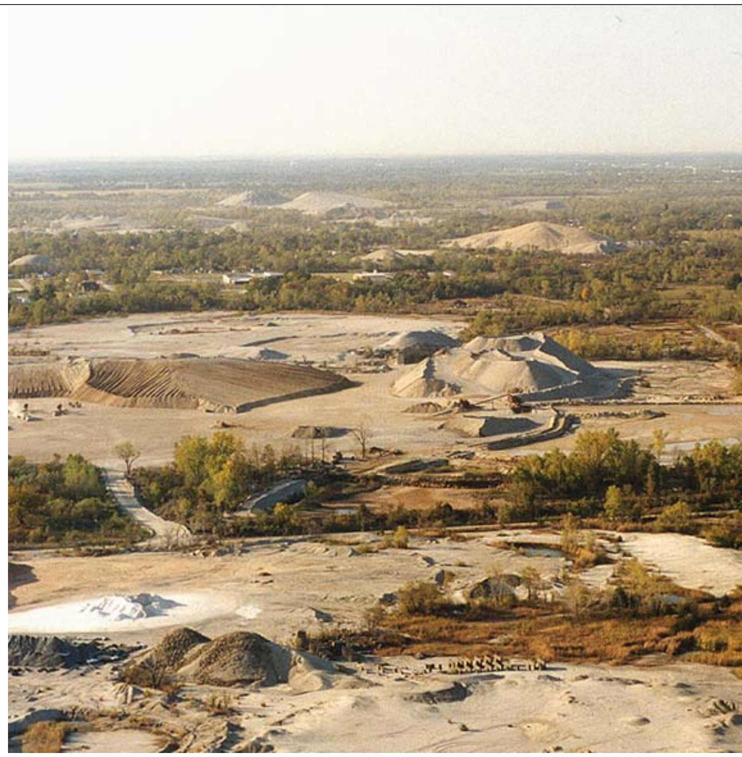


Mississippian rock units, principally the Boone Formation, are the host for most of the ore deposits. The Boone

Formation is composed of fossiliferous limestone and thick beds of nodular chert.

Aerial View of Picher Lead & Zinc Mining Field

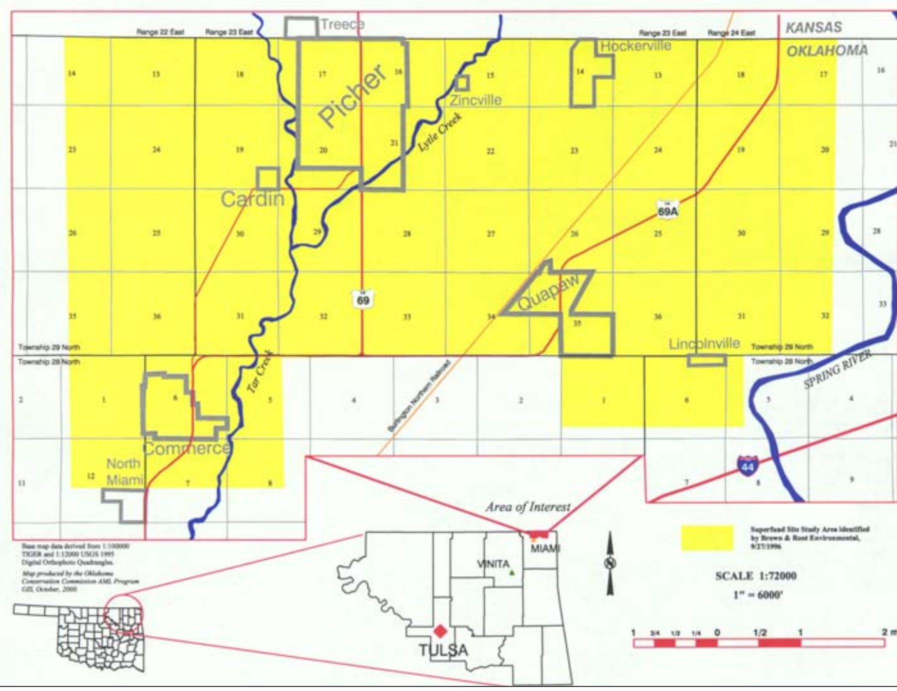




Chat waste pile East of Picher, OK.

Chat waste pile in Picher mining field.

Tar Creek Superfund Site in the Picher Lead & Zinc Mining Field, Ottawa County, Oklahoma



USDA-NAIP 2003 aerial photo before construction.

The 190 acre West Commerce AML Project, N-S extent approximately 1 mile

10 landowners involved

Site was heavily impacted by dumping of residential and industrial waste

Construction began February 14, 2006, Work completed (including vegetation) September 24, 2007

Major work items:

44 mine shafts explored/filled/sealed

26 Well casings plugged and removed

Numerous hazardous structures removed

280,459 cy of dirt excavated and placed

351,149 cy of chat (mine waste) removed and buried

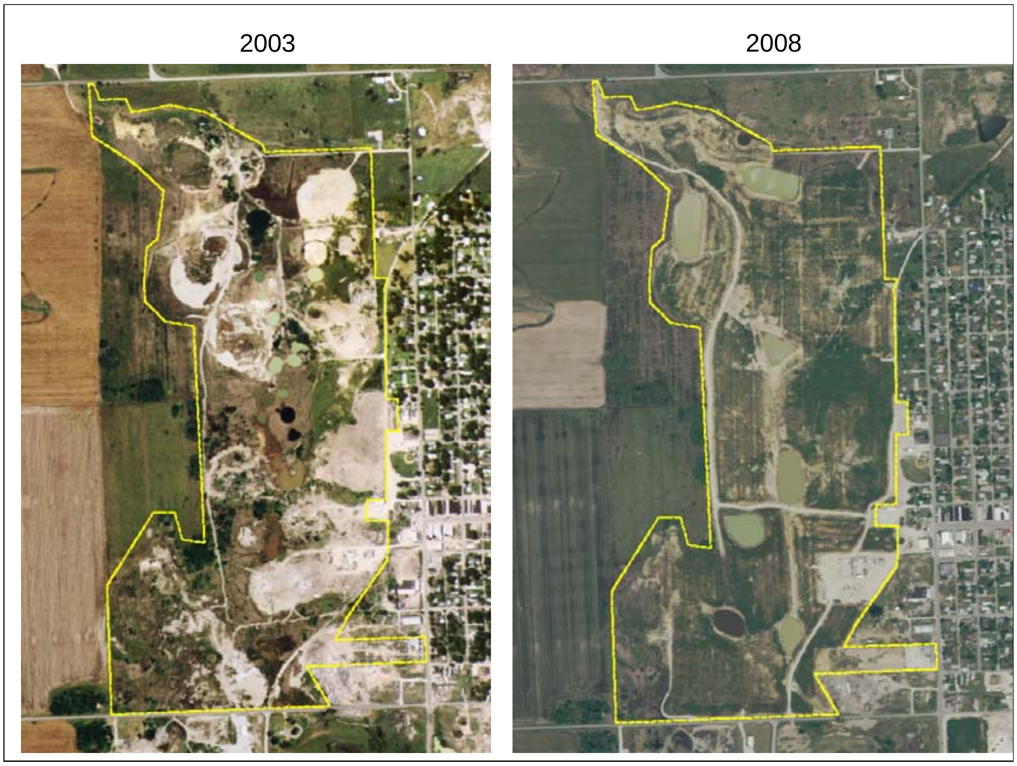
10,298 cy of chat slurried and placed in flooded underground mine voids

5 ponds built providing over 11 acres of surface water

Various erosion control and hydrologic structures installed

Site was seeded no-till with fescue, annual ryegrass, native pasture mix into standing German millet

Total construction cost = $ 2,346,808



USDA-NAIP aerial photos.

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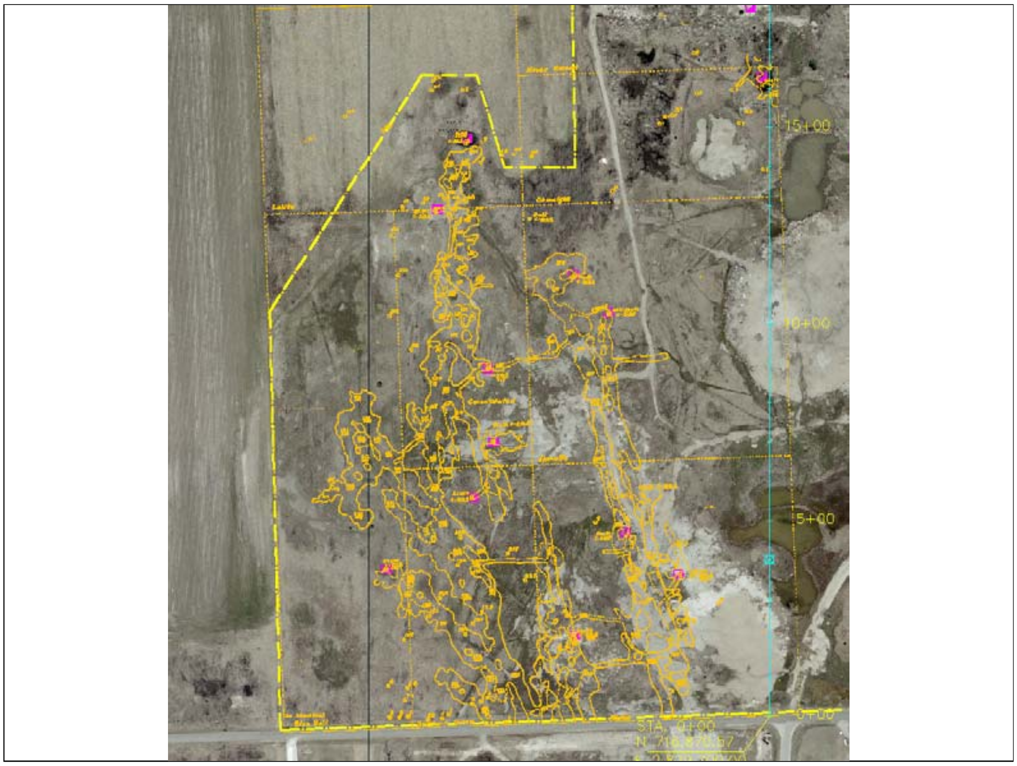
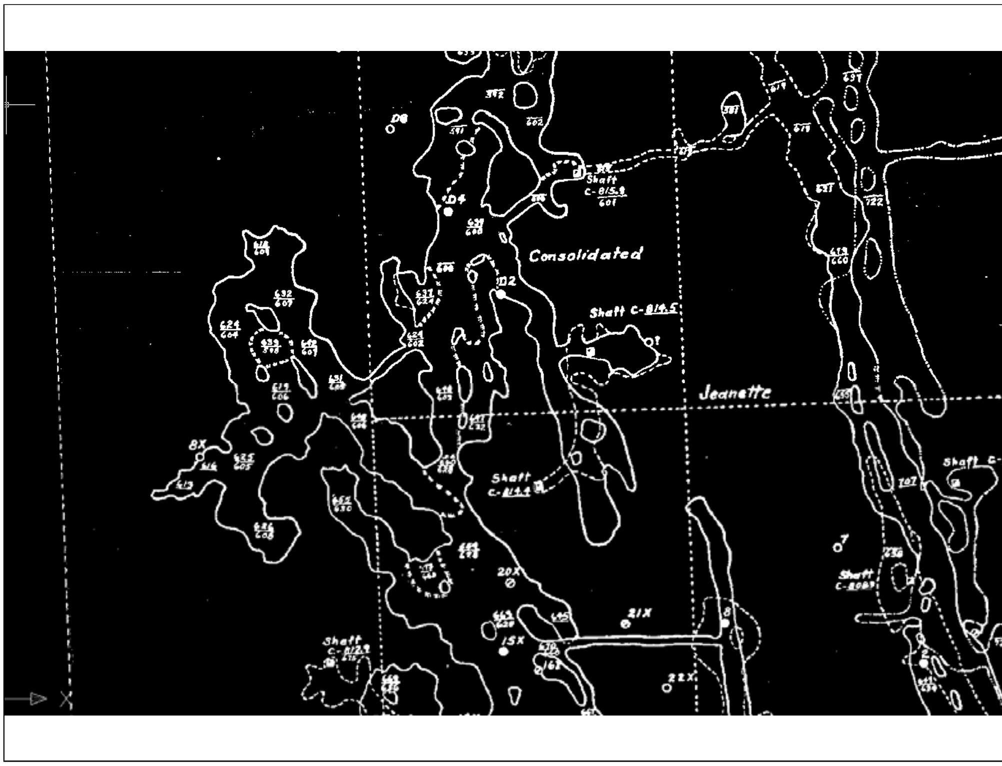
The site was extensively mined for Pb and Zn from approx. 1908-1920's, new mining in the mid-late 1940's.

During this time period there were 20 individual and separate mining leases operating their own mining and milling operation within the project area.

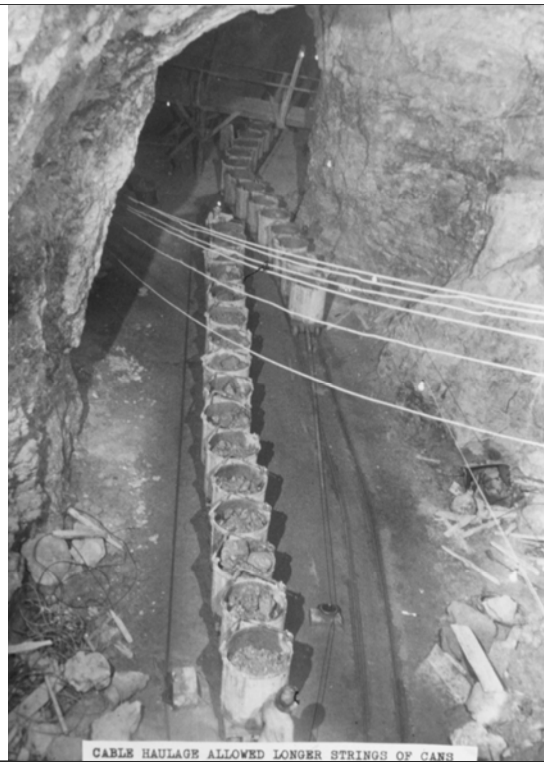
Ore was extracted from underground mines from depths ranging from 80 to 350 feet below the surface from multiple mining levels.



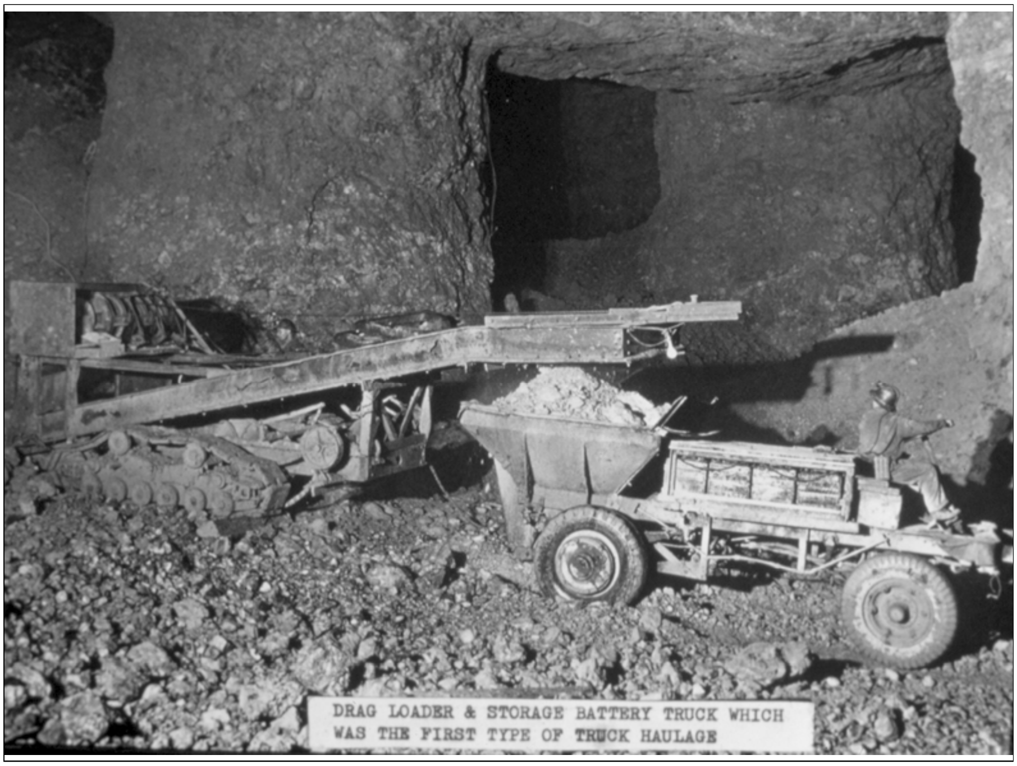
The Cactus Mine was operated by the Eagle Picher Mining Co. in the 1940's. The quality of the mine maps for this area were far superior to those occurring on the remainder of the project. Detailed floor and roof elevations made it possible to locate areas suitable for disposal of chat into the underground mine workings.



Consolidated
Jeanette
Shaft C-814.5
D4
D2
8X
20X
21X
22X
15X



Photograph illustrating the irregular configuration typical of the Pb and Zn mines in the Tri-State mining district of NE Oklahoma, SE Kansas and SW Missouri.



Another photo of Pb and Zn mining in the Picher field. Equipment such as this were left abandoned in the mine workings when mining ceased in the field. One could expect to see sonar reflections from various pieces of abandoned equipment left throughout the mining field.

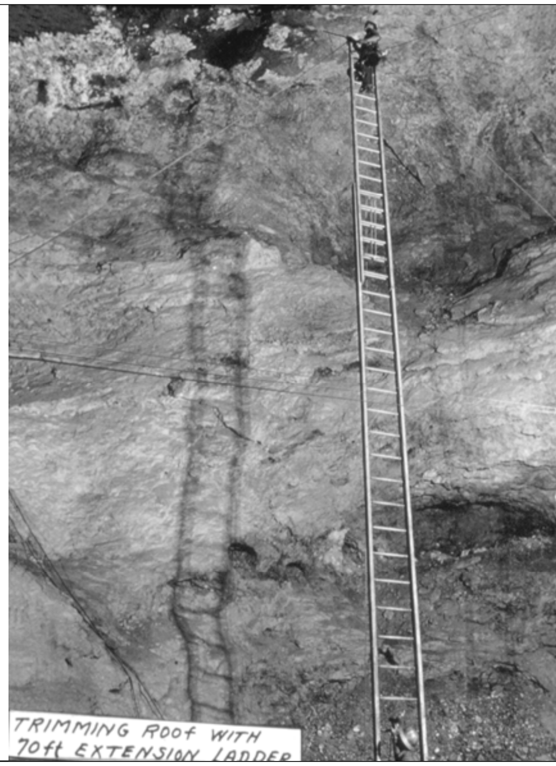


Photo illustrating the size of some of the Pb and Zn mine workings. Roof heights of 30 to 50 feet were common throughout the mining field. Some were in the 60 to 100 foot range.

IMAGENEX MODEL 881A
DIGITAL MULTI-FREQUENCY
PROFILING SONAR

APPLICATIONS:

- Profiling
- ROV, AUV, & UUV
- Offshore Oil & Gas
- Surveying
- Dam Face Inspection
- Pipeline Inspection
- Underwater Archaeology
- Scientific Research

FEATURES:

- Programmable
- Multi-frequency
- High performance
- Lower cost
- Low power
- Simple set-up and installation
- Digital telemetry
- 1 to 100 m operation (full scale)
- Compact size
- Communication format available to user

Now with Multi-frequency Sonar, operators can fine-tune their profiling range resolution. The Model 881A Profiling Sonar Head is a programmable, multi-frequency, digital scanning sonar that you can operate using default settings or customize the configurations for your own situation. High performance, lower cost, low power and simple set-up and installation, make this sonar perfect for all profiling applications.

The product description of the Imagenex (http://www.imagenex.com) Model 881A Profiling Sonar device. In **Profiling** a narrow pencil-shaped sonar beam scans across the surface of a given area generating a single profile line on the display monitor. This line, which may consist of a few hundred or thousand points, accurately describes the cross-section of the targeted area. A key to the **Profiling** process is the selection of the echo returns for plotting. The sonar device selects the echo returns, typically one or two returns for each "shot", based on a given criterion for the echo return strength and the minimum profiling range. The information gathered from the selection criteria forms a data set containing the range and bearing figures.

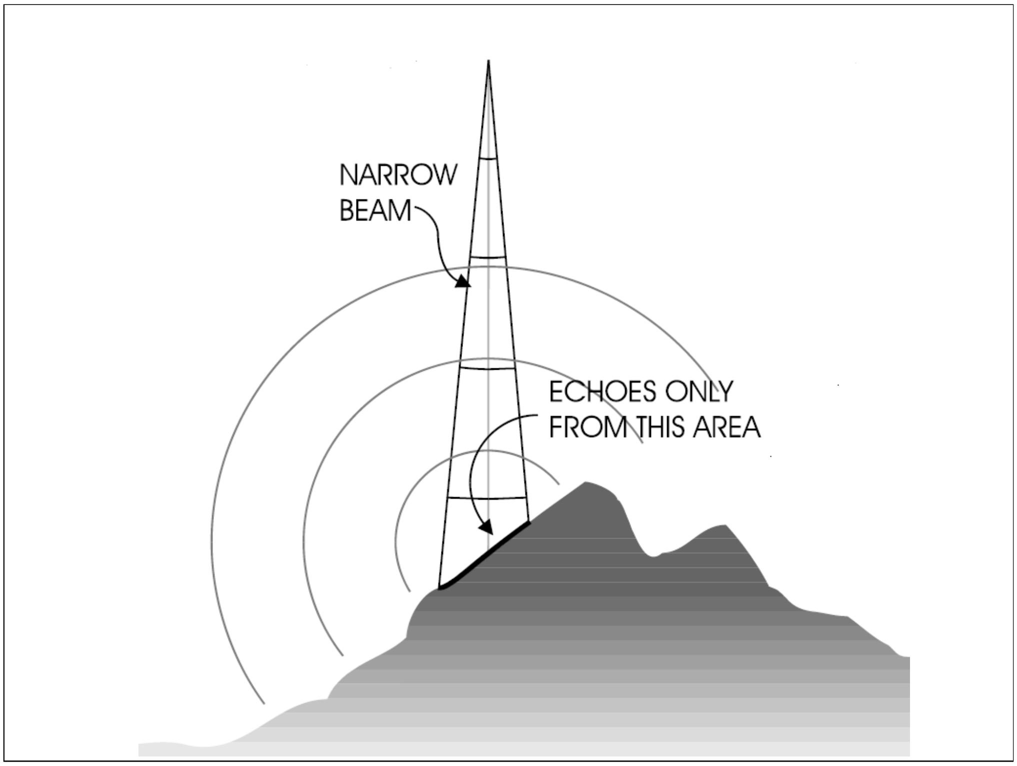
HARDWARE SPECIFICATIONS:	
FREQUENCY	675 kHz -Other frequencies can be selected through programmable software configurations (Tunable from 600 kHz to 1 MHz in 5 kHz steps)
TRANSDUCER	Profiling type, fluid compensated
TRANSDUCER BEAM WIDTH	600 kHz: 2.4° 675 kHz: 2.1° 1 MHz: 1.4°
RANGE RESOLUTION	1 m - 4 m: 2 mm (0.08") 5 m & up: 10 mm (0.4")
MIN. DETECTABLE RANGE	150 mm (6")
MAX. OPERATING DEPTH	1000 m and 3000 m available
MAX. CABLE LENGTH	1000 m on typical twisted shielded pair (RS-485)
INTERFACE	RS-485 serial interface @ 115.2 kbps (or optional RS-232)
CONNECTOR	Side mounted, four conductor, wet mateable (Impulse MCBH-4-MP-SS) Optional right angle or end mount connector
POWER SUPPLY	20 - 36 VDC at less than 5 Watts
DIMENSIONS (for both depth ratings)	79.4 mm (3.125") diameter x 234 mm (9.2") length
WEIGHT: In Air	1000 m unit: 1.8 kg (4 lbs) 3000 m unit: 2.2 kg (4.8 lbs)
In Water	1000 m unit: 0.6 kg (1.3 lbs) 3000 m unit: 1 kg (2.2 lbs)
MATERIALS	1000 m unit: 6061-T6 Aluminum & Polyurethane 3000 m unit: Titanium, Polyurethane & 300 series stainless steel
FINISH	Hard Anodize

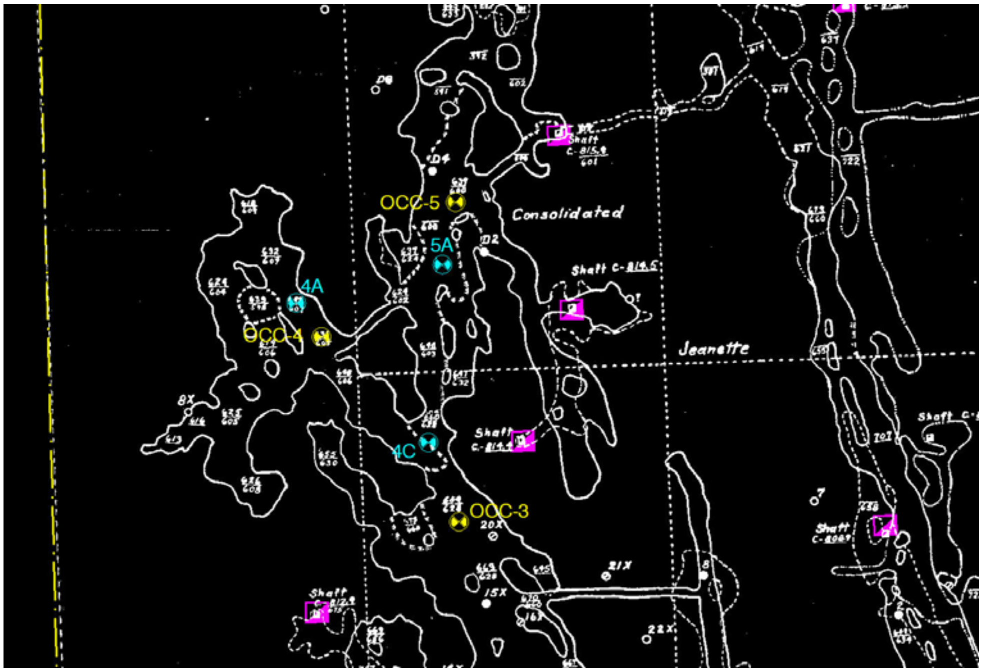
Hardware specifications of the Imagenex 881A

SOFTWARE SPECIFICATIONS:	Win881A.exe
WINDOWS™ OPERATING SYSTEM	Windows™ 95, 98, Me, NT*, 2000*, XP*, Vista*
MODES	Side Scan, Polar, and Sector
RANGE SCALES	1 m, 2 m, 3 m, 4 m, 5 m, 10 m, 20 m, 30 m, 40 m, 50 m, 60 m, 80 m, 100 m
TRAIN ANGLES	Continuous rotation, 3° increments
SECTOR SIZE: SECTOR MODE POLAR MODE	 0° - 180°, 3° increments 0° - 357°, 3° increments, or Continuous rotation
STEP SIZES	Slow (0.3°), Medium (0.6°), Fast (0.9°), Faster (1.2°), Fastest (2.4°)
GRID TYPES	Polar and rectangular
FILE FORMAT	(filename).81a
RECOMMENDED MINIMUM COMPUTER REQUIREMENTS:	100 MHz Pentium 16 MB RAM 1 GB Hard Disk 800 x 600 x 256 colour graphics

*Requires Win881A.exe v2.00 or higher (Free upgrade available for older versions - Contact Imagenex)

Additional specifications of the Imagenex 881A Profiling Sonar.


NARROW
BEAM
ECHOES ONLY
FROM THIS AREA



In the summer of 2005 three 6-inch diameter wells were drilled into the underground mine workings at OCC-3, OCC-4 and OCC-5. The mine cavities were mapped using a sonar tool operated by Workhorse Technology from Pittsburgh, PA. In the fall of 2006, three additional 12-inch diameter wells were installed for disposal of chat into the mine workings. A water intake well located at 4C while two disposal wells were located at 4A and 5A.

Drilling 6-in exploratory well number OCC-5 on the West Commerce project, summer 2005.

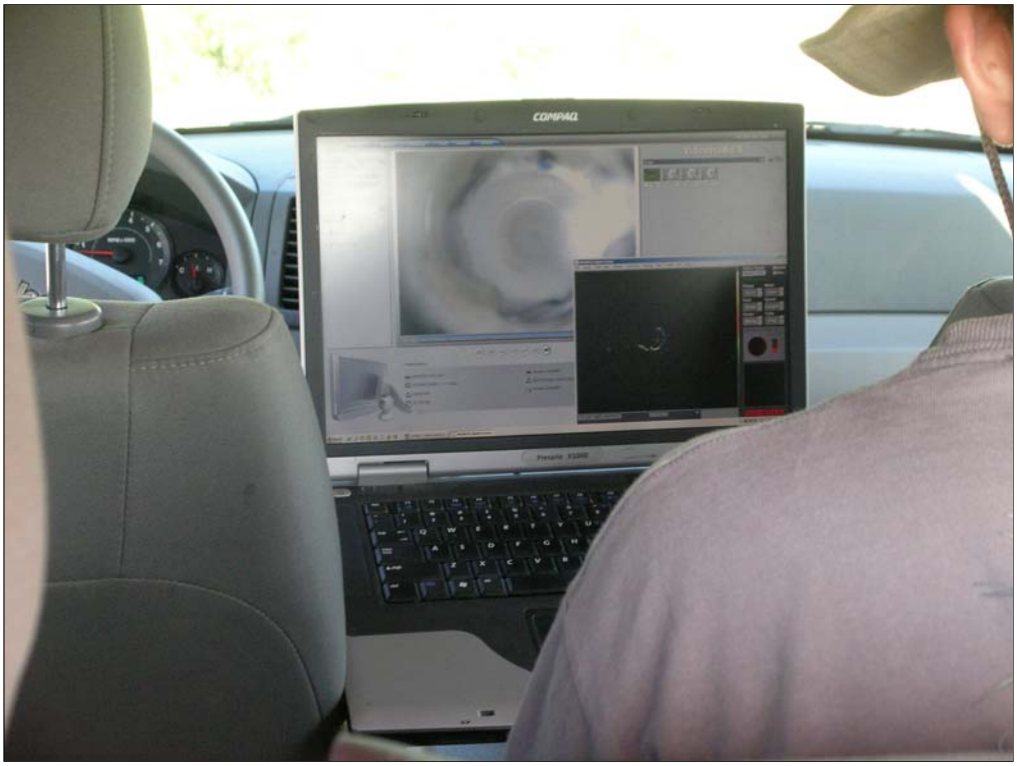
West Commerce project, summer 2006. View looking east with the City of Commerce water tower in background and OCC-5 well in foreground. Chat pile behind the well is part of the 11,000 cy of chat that is planned to be injected into the flooded underground mine voids.

Well OCC-1 on the east side of the project illustrated the difficulty in maintaining some of the well bores. They seem to be popular targets.

Workhorse Technologies, Inc.
484 West 7th Avenue
Homestead, PA 15120

Initial sonar investigations were conducted by Workhorse Technologies (http://www.workhorsetech.com/etomite0613/main.html). Established in 2002 by roboticists from the Robotics Institute at Carnegie Mellon University in Pittsburgh, PA, Workhorse Technologies designs rugged and intelligent systems to explore, model and map remote underground voids.

Workhorse’s sonar tool is shown here prior to deployment. The device was free to rotate within the mine void making it impossible to know the orientation of the sonar beam relative to north. Workhorse attempted to determine the spatial orientation of the sonar by attaching a video camera just below the bottom of the sonar head (red). The camera was focused on a simple magnetic compass. Due to problems with air bubbles and poor visibility, this technique proved to be unsatisfactory. Also, note the three different leads from the top of the tool frame. The yellow rope was the tether line to support the tool, the black cable was for power and data while the fiber tape was for measuring the depth of the tool below ground.



A view of the laptop screen monitoring the sonar return data and the camera view of the compass. The sonar data is being displayed in the lower right of the screen while the camera view of the magnetic compass is shown in the center of the screen. The inability of this method to determine the orientation of the sonar is readily apparent.

Laying out of cabling, tether and measure tape prior to deployment of the Workhorse sonar at OCC-1. Note the three separate lines to be managed while lowering the tool into the mine workings. Depth to the top of the mine void is 250 feet below the surface. The mine void at this location is 20 feet in height.

Chuck Whittaker with Workhorse Technologies reading depth of tool at OCC-1.

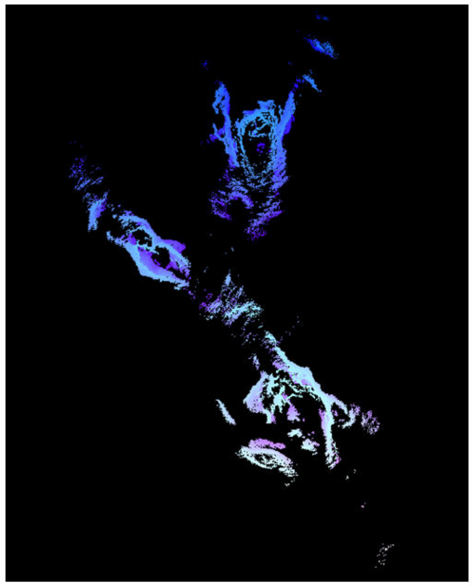
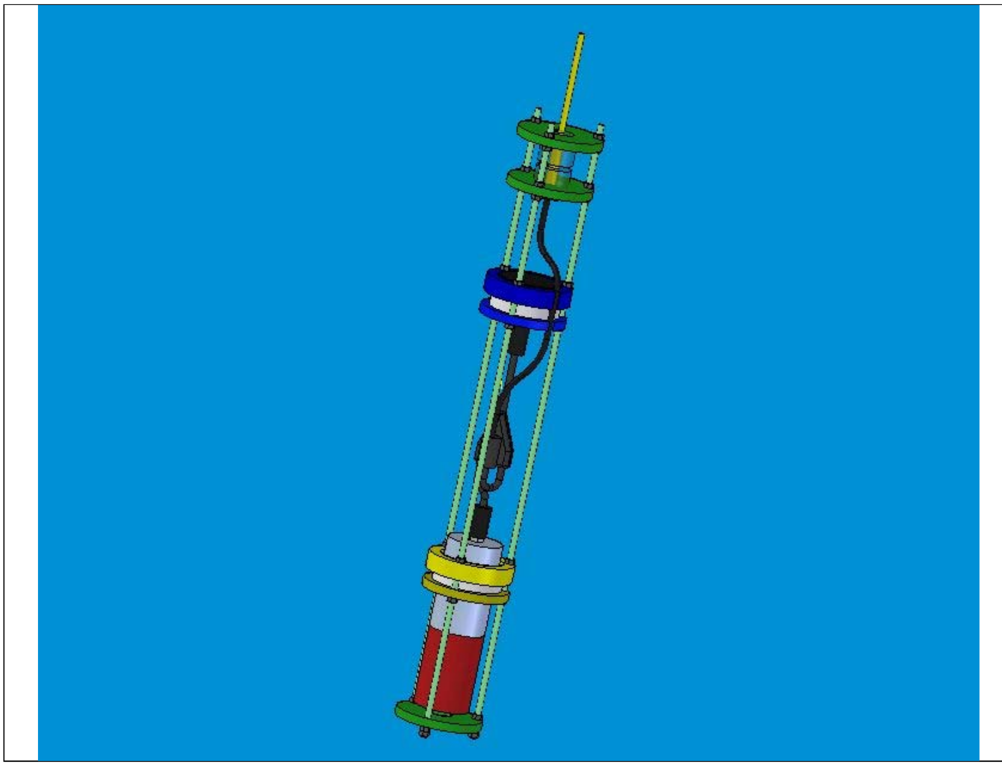


Figure 3: Boreholes 3, 4, & 5 plan view model of data collected

Point cloud data generated by Workhorse from sonar data collected at OCC-3, 4 and 5. Since the camera/compass was unsuccessful in determining the orientation of the sonar data, the mine map was used to best fit the data. In the fall of 2006, data collected with the OCC sonar tool, which uses an electronic magnetic compass, found that the Workhorse point cloud data for OCC-5 was 180 degrees in error.



Conceptual view of the OCC sonar tool. The profiling sonar head (red) and electronics and drive mechanism (silver) are electrically coupled with an electronic magnetic compass. Data from both modules is passed through an RS-485 serial two-wire data channel. The 4-wire yellow cable is Kevlar reinforced providing a 1000 lb breaking strength tether along with a 24-volt power and RS-485 data path. Additionally, the cable was marked in 1-foot increments to allow measuring the depth of the tool below the surface.

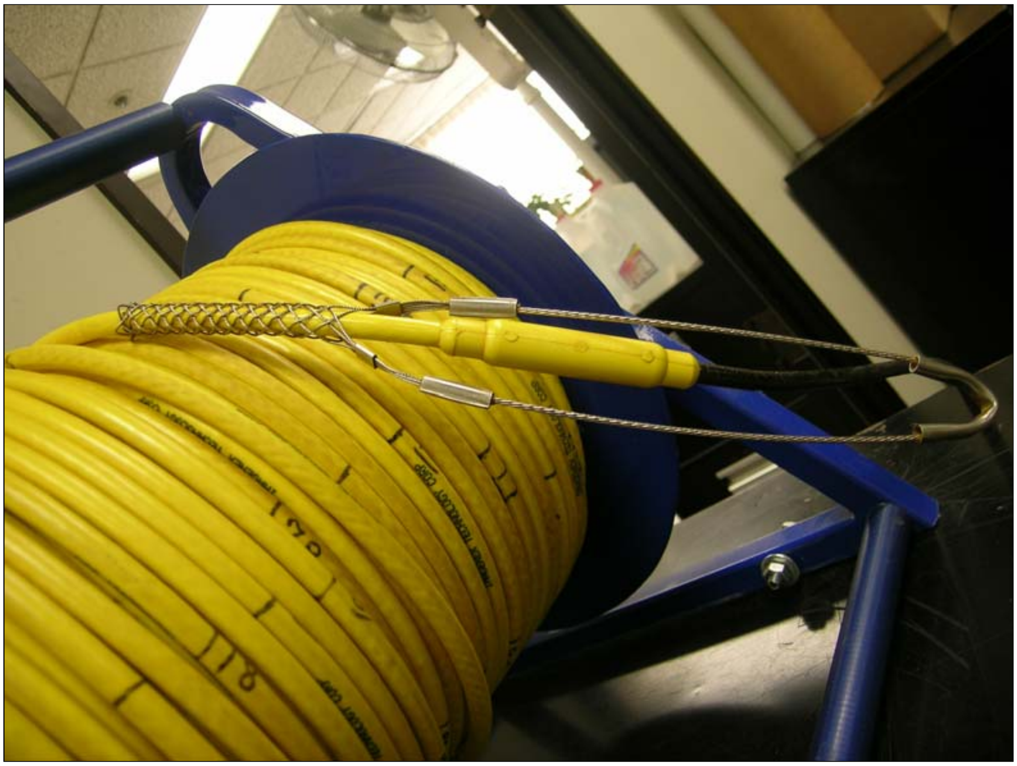
Prototype of the OCC sonar tool. The tool is 47 inches high and 5 inches in diameter. The cable/reel assembly is also shown. Cost of the system was $ 19,605 (Includes Imagenex 881A profiling sonar head, Imagenex orientation module, Imagenex power supply, 500 feet Kevlar reinforced cable, SeaLevel RS-485 to USB serial converter, RoboProbe cable hand reel, and miscellaneous parts and materials). Costs not included are labor and machine tool costs, vehicle power inverter, laptop/field computer and Matlab software.

Close-up view of the sonar device and the clamping system. Flat Aluminum plates were used to cut 5 inch diameter stock. A clamping system was developed which involved two Aluminum plates bored out such that the thicker plate had an inside taper cut to match that cut on a split sleeve bushing of Ultra High Molecular Weight Polyethylene (UHMW) [The white material between the two Aluminum plates]. As the plates are compressed together, the UHMW bushing diameter is reduced resulting in a non-destructive clamping of the sonar device. Non-magnetic stainless steel all-thread and nuts along with the Aluminum plates provided the main frame for supporting the sonar and compass.

Wet mate-able connectors were used to connect the sonar and compass to the main cable.

The electronic compass, also manufactured by Imagenex, was clamped similar to that of the sonar device. The north orientation of the compass was aligned with the zero or center point of the sonar device. Note in the upper right the Kellum or cable-support grip attached to the cable. The loop in the grip is the point supporting the weight of the tool when deployed.

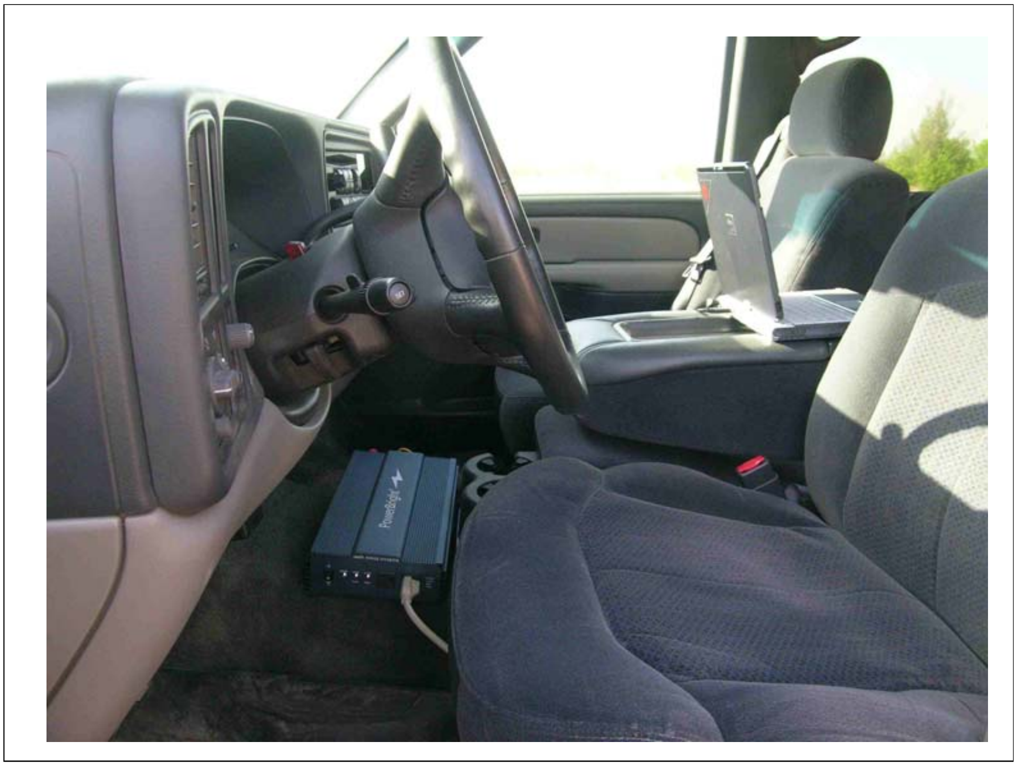
Side view of “nose cone” frame.



A Kellum or cable-support grip was placed onto the cable to bind it to the probe framework. The cable grip acts like a Chinese handcuff tightly gripping the yellow, Kevlar reinforced cable.

Point of attachment of the cable to the sonar tool's framework. The stainless steel loop of the cable-supoort grip is inserted into the notch in the wooden block and secured with the bolt.

The cable reel did not come equipped with a brake or reel locking mechanism. A locking mechanism was fabricated out of a piece of UHMW polyethylene where holes were drilled in a radial pattern that would accept a locking pin mounted on the reel frame. The reel was temporarily secured in the vehicle with ropes but this was later replaced with a 3/4” plywood base with rails where the reel frame could be bolted securely to the rails.



1000 watt power inverter

A shroud was fabricated from a piece of 6” sewer and drain pvc pipe. The thin wall nature of this material made it easy to form the pipe to fit the 5 “ diameter sonar tool. The purpose of the shroud was to prevent the tool from snagging protruding rock fragments in unlined boreholes and to provide additional protection for the sensors. The shroud did not affect the sonar tool’s operational performance, ie attenuation of the sonar signal. Note a nose cone was fabricated from some scrap PVC fittings and duct tape as seen on the top of the sonar tool.

The shroud was secured to the sonar tool frame with cable ties and duct tape. The nose cone is secured to the shroud and cable with duct tape. At this point the tool is ready for compass calibration and deployment.

A 8-point calibration is performed using software that came with the orientation module. Although shown here with out the shroud, calibration of the sonar tool is performed with the tool shrouded and prepared for deployment.

Screen shot of the orientation module during calibration. Besides providing heading information, the orientation module outputs roll, pitch and internal temperature data.

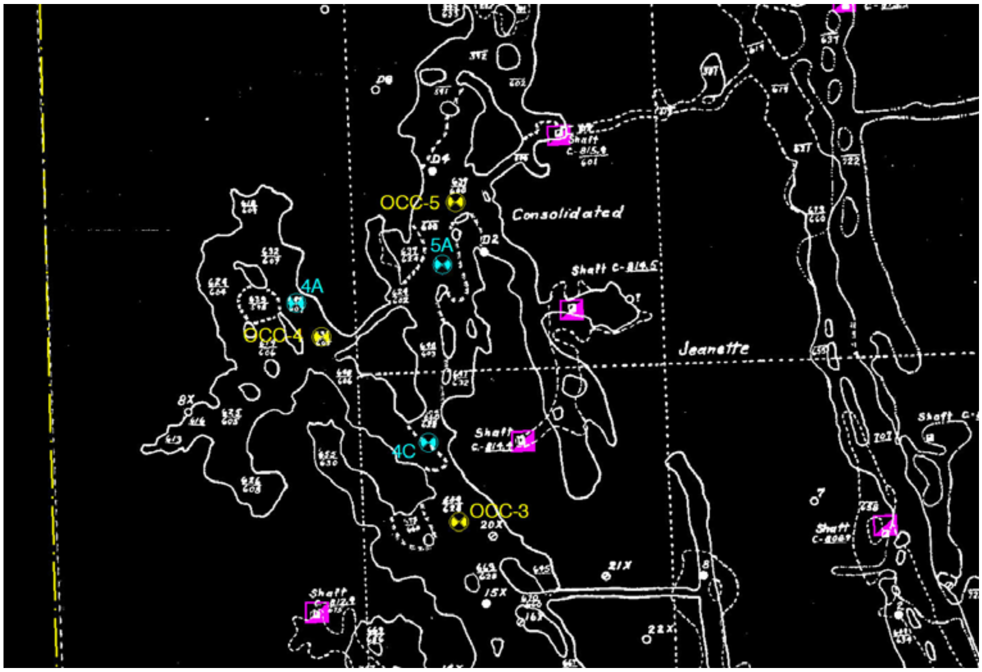
Screen shot of sonar display software that is provided with the sonar device.

Borehole fitted with cable guide designed to keep sonar tool centered in the borehole during deployment. Also, the gradual fixed radius of the guide helped to minimize the strain on the cable and to prevent the possibility of getting any kinks in the cable. The guide was constructed to fit inside an 8” diameter pvc pipe. Shown here it is mounted in an 8” to 6” reducer. The guide can be mounted in an 8” pvc coupler or in an 8” to 12” adapter.

Cable guide was fabricated from scraps of 2x4 wood, pvc electrical conduit sweep and strips of UHMW polyethylene. The strips of UHMW were heated with a heat gun, formed to the radius of the conduit and riveted to the conduit. Purpose of the UHMW was to decrease cable friction and provide a more wear resistant surface.

Guide and cable are aligned to provide a straight shot between the well bore and the cable reel.

Sonar tool coming back out of the well bore.



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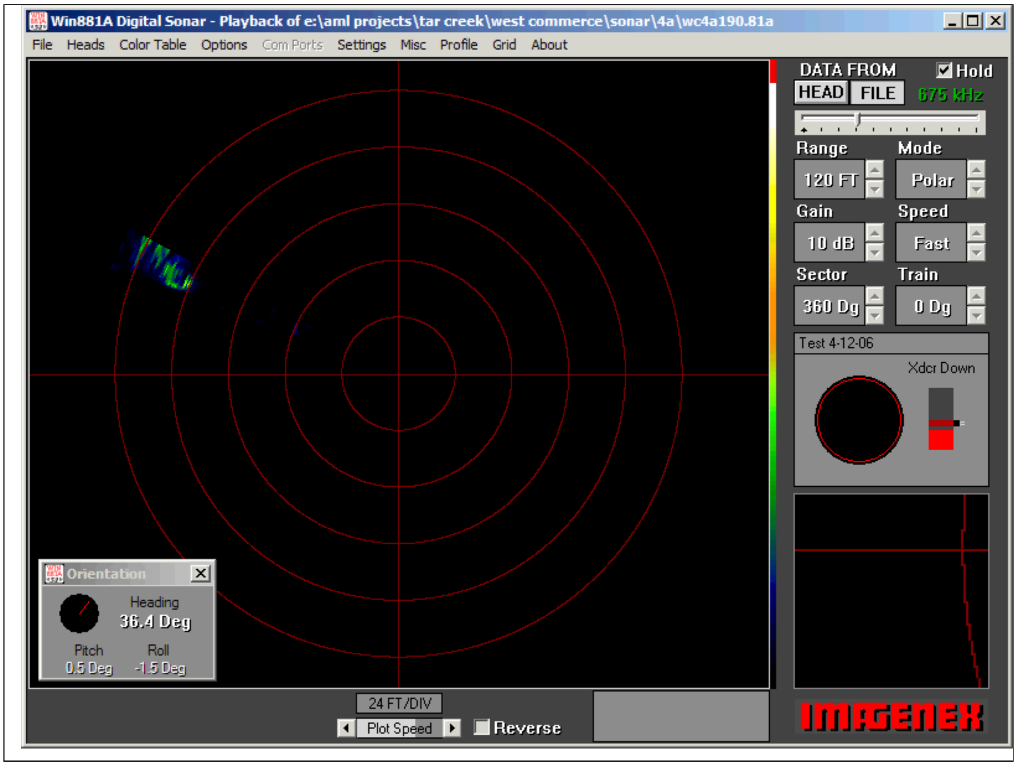
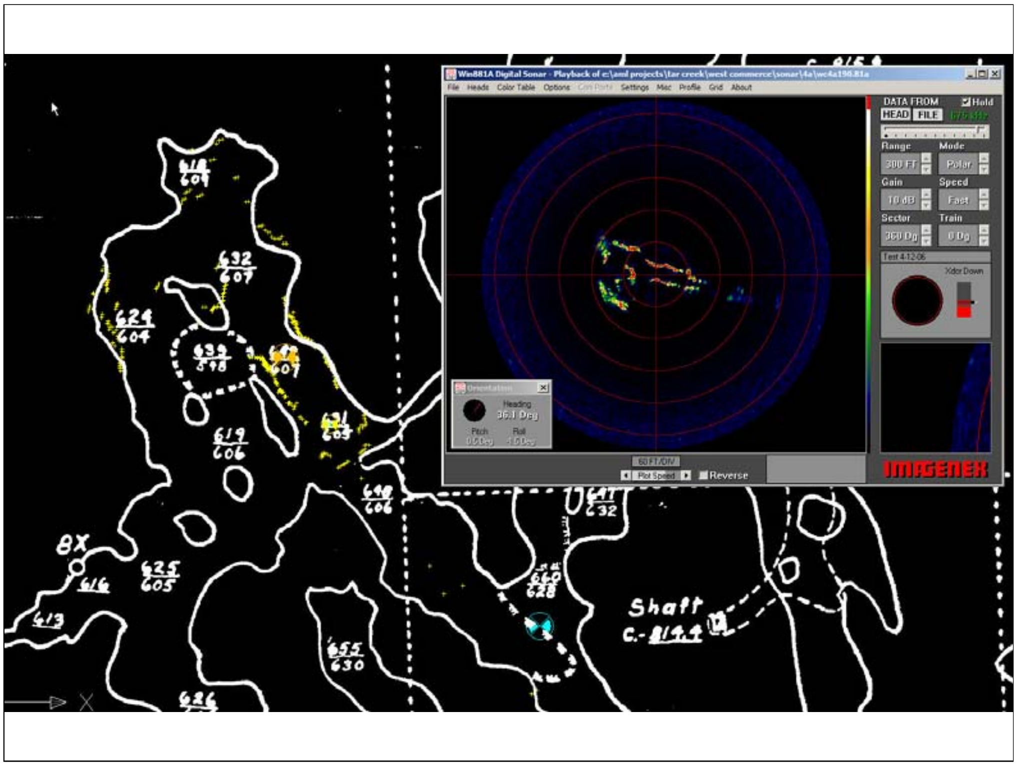
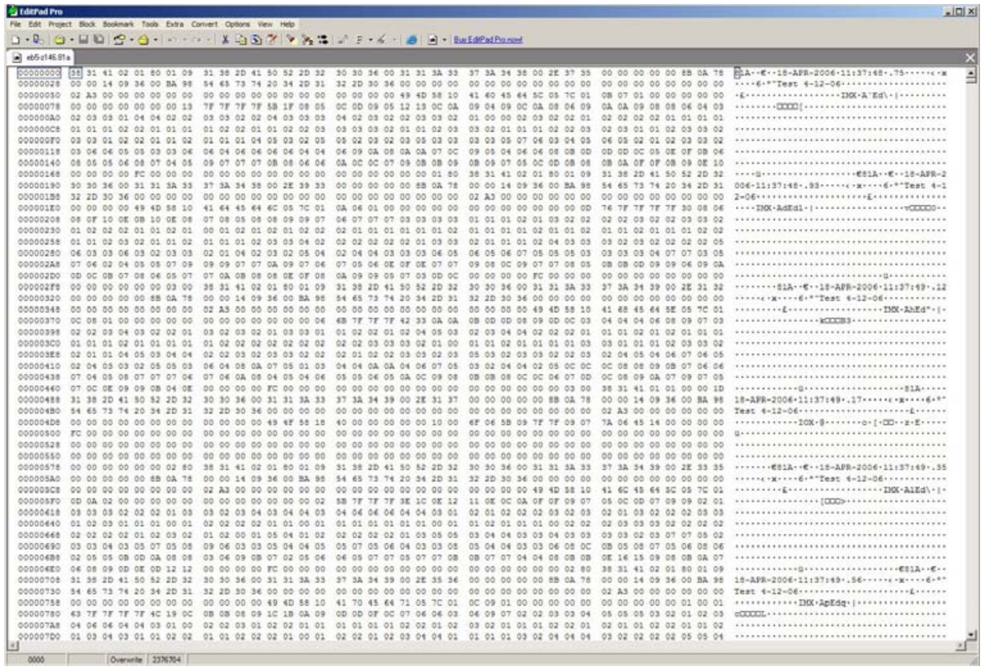


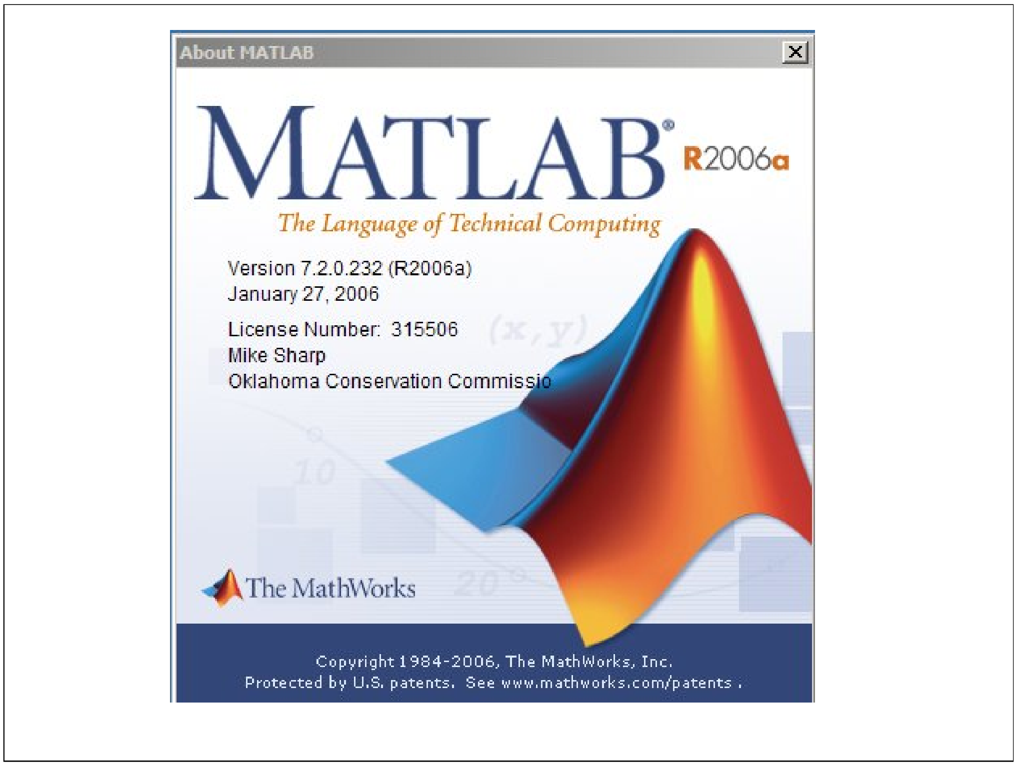
Movie of sonar scan of West Commerce borehole 4a at elevation of 614 msl. View is of display software that comes with the sonar device. The software is in playback mode reading from a file previously recorded. The file (xxx.81a format) is a binary file consisting of combined output from the sonar device and orientation module. If the software is in the record mode, various parameters are available for adjusting such as range, gain, angular speed of the sonar head, the mode (polar, sector or side scan) and the size of the sector scan. When observing the screen display as this file is being played back, note the orientation readings in the lower left of the screen. In the center right of the screen there is a circle with a rotating red dot showing the position of the sonar beam. Also, note the scale of the display shown in the bottom center (ie, 24 ft/div). When observing the sonar return, the red colors are the hardest or more intense return signals with a graduation down to the weakest returns shown in blue. As the movie progresses, note the range will change from 120 ft to 300 ft.



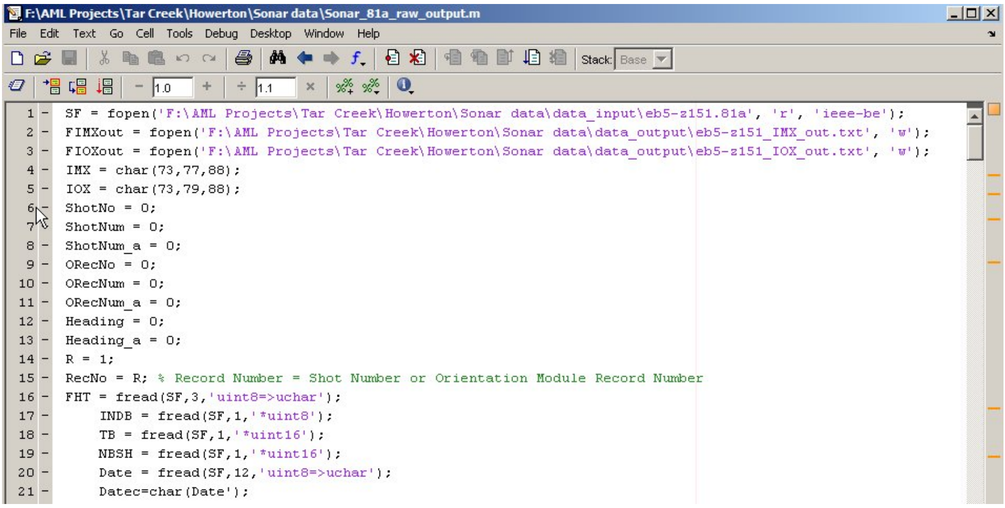
Screen shot of raw sonar scan along with processed data displayed onto the geo-referenced mine map. Based on heading information in the file, the data is corrected to true north orientation and given the geographic correct coordinates based on the coordinates of the well bore. The data can then be imported into a GIS displaying the geo-referenced mine map.



Hex and ASCII display of binary records of .81A sonar file. Note on the right side of the display each new record begins with “81A”. Also note there are two types of records, IMX records which is data from the sonar head and an IOX record which is data from the orientation module. The objective is to parse these records from the data stream, bracket the IMX records found between two IOX records and then use the heading data from the bounding IOX records to adjust the sonar data from the bracketed IMX records. Although somewhat crude, this makes some allowance of any heading drift that may occur between the preceding and trailing IOX records.

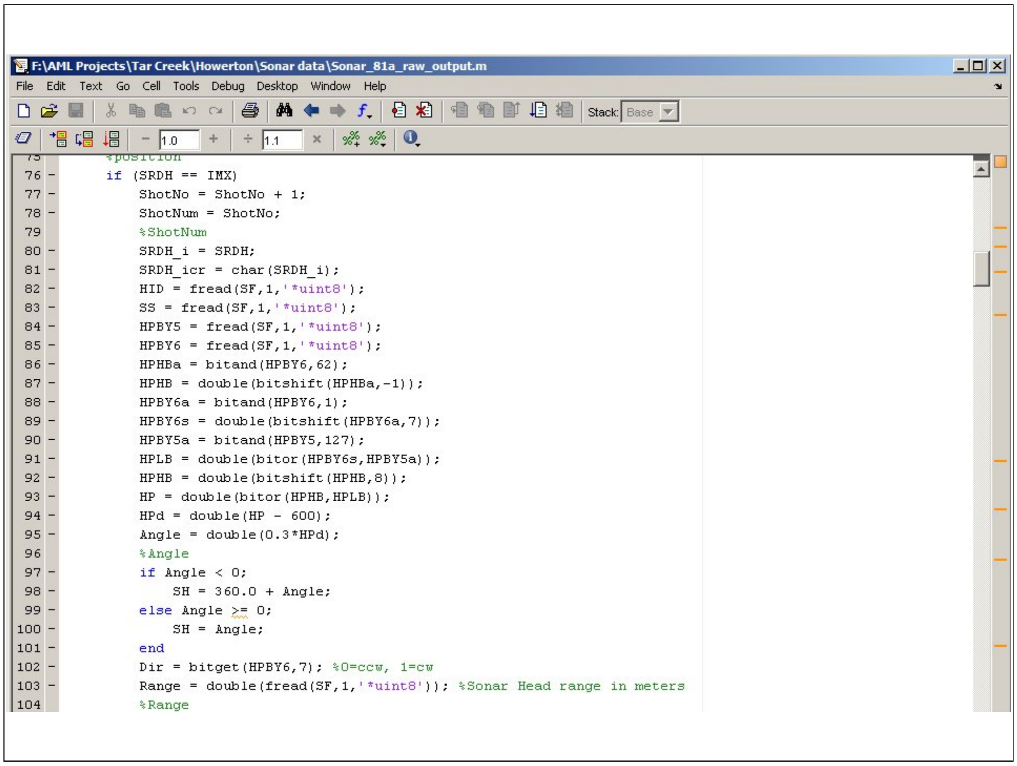


Matlab was chosen as the technical computing language to write programs to process the binary .81A file.

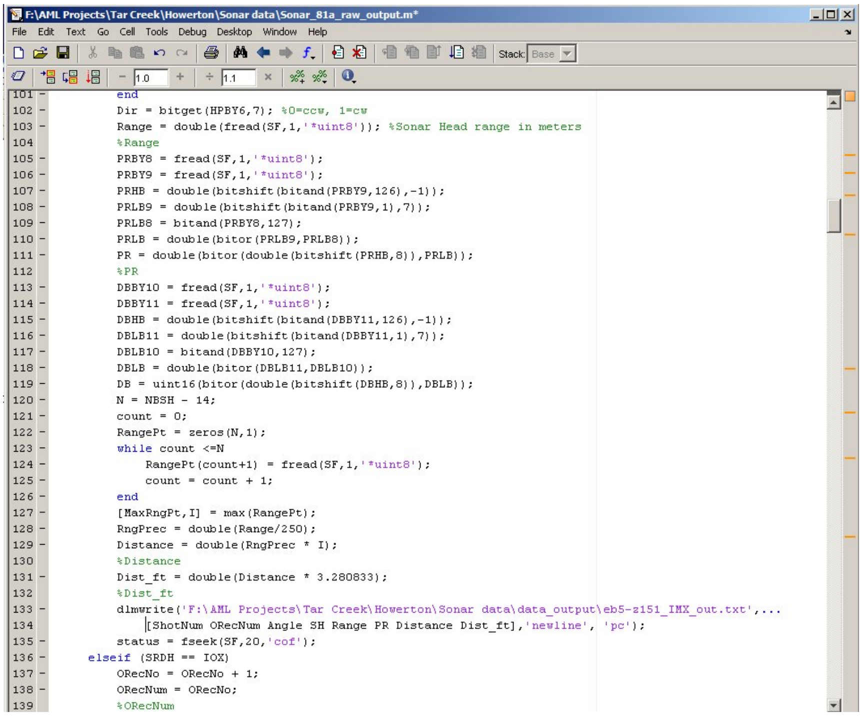



```
SF = fopen('F:\AML Projects\Tar Creek\Howerton\Sonar data\data_input\eb5-z151.81a', 'r', 'ieee-be');
FIMXout = fopen('F:\AML Projects\Tar Creek\Howerton\Sonar data\data_output\eb5-z151_IMX_out.txt', 'w');
FIOXout = fopen('F:\AML Projects\Tar Creek\Howerton\Sonar data\data_output\eb5-z151_IOX_out.txt', 'w');
IMX = char(73,77,88);
IOX = char(73,79,88);
ShotNo = 0;
ShotNum = 0;
ShotNum_a = 0;
ORecNo = 0;
ORecNum = 0;
ORecNum_a = 0;
Heading = 0;
Heading_a = 0;
R = 1;
RecNo = R; % Record Number = Shot Number or Orientation Module Record Number
FHT = fread(SF,3,'uint8=>uchar');
    INDB = fread(SF,1,'*uint8');
    TB = fread(SF,1,'*uint16');
    NBSH = fread(SF,1,'*uint16');
    Date = fread(SF,12,'uint8=>uchar');
    Datec=char(Date');
```

Beginning of a Matlab program that separates sonar head data (IMX) from the orientation module data (IOX) and places the parsed data into separate files.

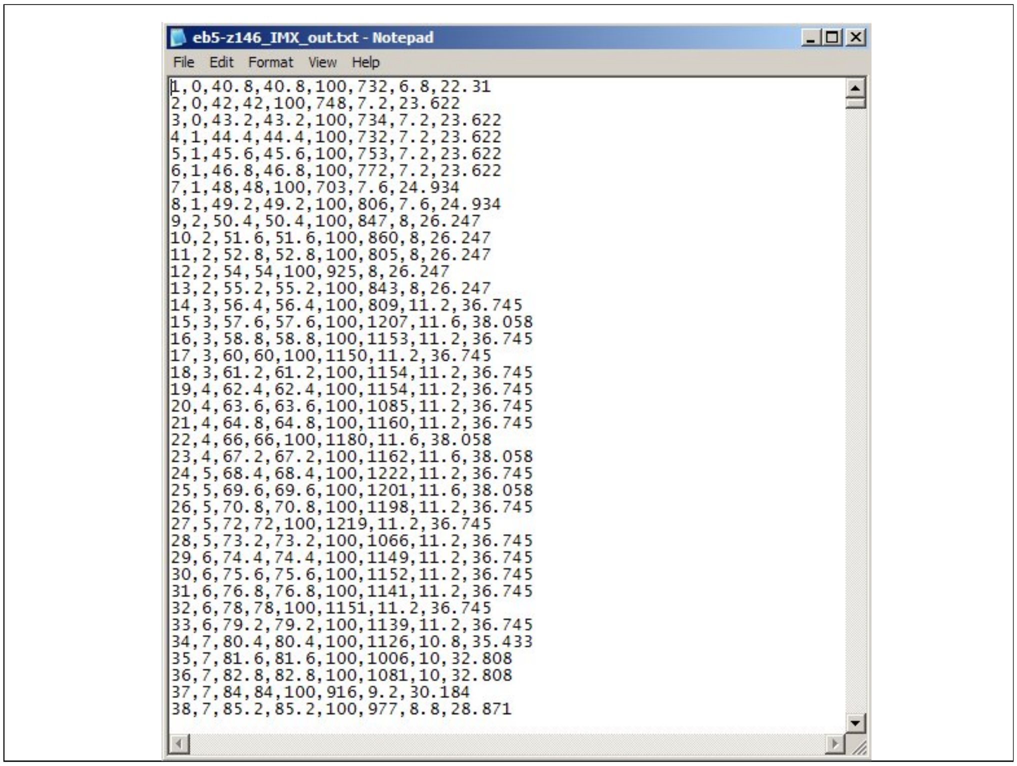


Binary arithmetic functions built into Matlab make it easy to extract various important parameters and variables from each sonar shot. Shown here is the functions and program coding to extract the angle of the sonar head relative to the sonar device center point.




```
            end
            Dir = bitget(HPBY6,7); %0=ccw, 1=cw
            Range = double(fread(SF,1,'*uint8')); %Sonar Head range in meters
            %Range
            PRBY8 = fread(SF,1,'*uint8');
            PRBY9 = fread(SF,1,'*uint8');
            PRHB = double(bitshift(bitand(PRBY9,126),-1));
            PRLB9 = double(bitshift(bitand(PRBY9,1),7));
            PRLB8 = bitand(PRBY8,127);
            PRLB = double(bitor(PRLB9,PRLB8));
            PR = double(bitor(double(bitshift(PRHB,8)),PRLB));
            %PR
            DBBY10 = fread(SF,1,'*uint8');
            DBBY11 = fread(SF,1,'*uint8');
            DBHB = double(bitshift(bitand(DBBY11,126),-1));
            DBLB11 = double(bitshift(bitand(DBBY11,1),7));
            DBLB10 = bitand(DBBY10,127);
            DBLB = double(bitor(DBLB11,DBLB10));
            DB = uint16(bitor(double(bitshift(DBHB,8)),DBLB));
            N = NBSH - 14;
            count = 0;
            RangePt = zeros(N,1);
            while count <=N
                RangePt(count+1) = fread(SF,1,'*uint8');
                count = count + 1;
            end
            [MaxRngPt,I] = max(RangePt);
            RngPrec = double(Range/250);
            Distance = double(RngPrec * I);
            %Distance
            Dist_ft = double(Distance * 3.280833);
            %Dist_ft
            dlmwrite('F:\AML Projects\Tar Creek\Howerton\Sonar data\data_output\eb5-z151_IMX_out.txt',...
                [ShotNum ORecNum Angle SH Range PR Distance Dist_ft],'newline', 'pc');
            status = fseek(SF,20,'cof');
        elseif (SRDH == IOX)
            ORecNo = ORecNo + 1;
            ORecNum = ORecNo;
            %ORecNum
```

Coding for extracting distance to target ranging data (PR) and writing selected sonar head data to the IMX.out file. The amplitude of the echo return data is scaled to a 107 color table where black is the lowest level, increasing to blue, then green, orange, yellow, white and red being the max signal level. The user can chose whether to allow the sonar head to digitize the profile range (PR) distance to the target using threshold settings internal to the sonar head that utilizes the center of pulse detection or the user can manually adjust the threshold detection settings (range of 10-90 % of the color level scale) as well as whether to use start of pulse or center of pulse detection. The distance to the target can also be extracted from the color table for each sonar shot by examining the intensity level of the return pulses. Using a Matlab function that will return the maximum value (intensity) and its position (corresponding to distance [time x speed of sound in water] from the sonar head) within a given set of echo return data for a given shot, one can calculate the distance to the target. It was found that the latter method of distance calculation (corresponding to the Distance variable) did not give data that agreed with the mine map data as well as the PR data using the internal settings from the sonar head. Additional experience and research is needed to further investigate the data quality when manually adjusting the profiling range settings.



eb5-z146_IMX_out.txt - Notepad

File Edit Format View Help

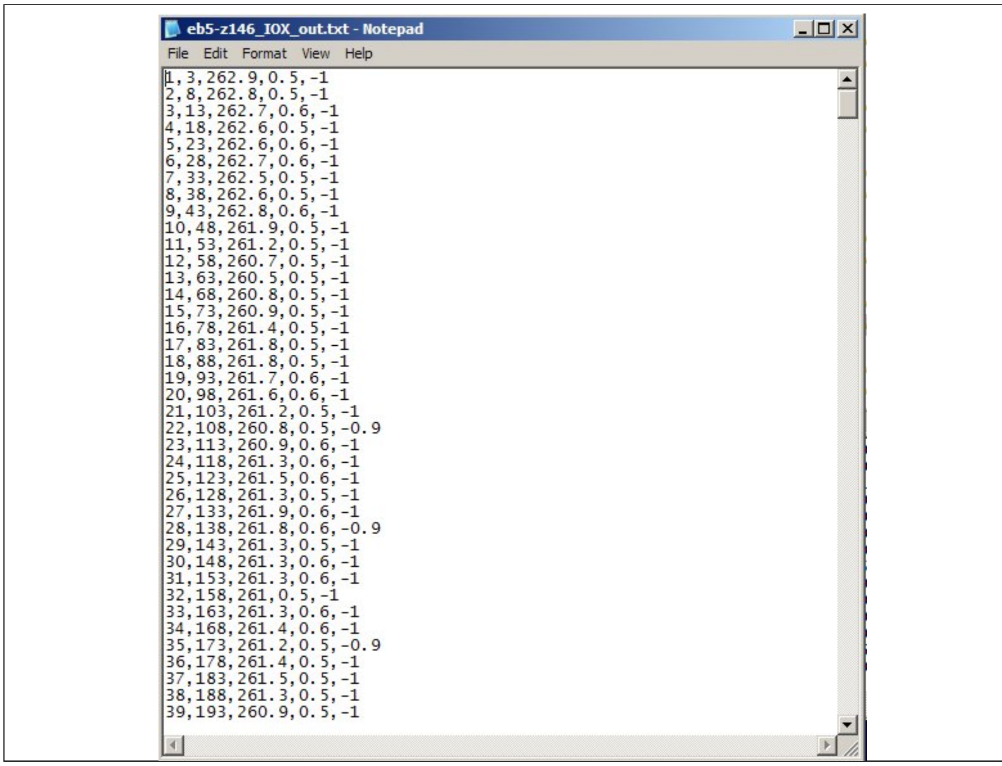
```
1,0,40.8,40.8,100,732,6.8,22.31
2,0,42,42,100,748,7.2,23.622
3,0,43.2,43.2,100,734,7.2,23.622
4,1,44.4,44.4,100,732,7.2,23.622
5,1,45.6,45.6,100,753,7.2,23.622
6,1,46.8,46.8,100,772,7.2,23.622
7,1,48,48,100,703,7.6,24.934
8,1,49.2,49.2,100,806,7.6,24.934
9,2,50.4,50.4,100,847,8,26.247
10,2,51.6,51.6,100,860,8,26.247
11,2,52.8,52.8,100,805,8,26.247
12,2,54,54,100,925,8,26.247
13,2,55.2,55.2,100,843,8,26.247
14,3,56.4,56.4,100,809,11.2,36.745
15,3,57.6,57.6,100,1207,11.6,38.058
16,3,58.8,58.8,100,1153,11.2,36.745
17,3,60,60,100,1150,11.2,36.745
18,3,61.2,61.2,100,1154,11.2,36.745
19,4,62.4,62.4,100,1154,11.2,36.745
20,4,63.6,63.6,100,1085,11.2,36.745
21,4,64.8,64.8,100,1160,11.2,36.745
22,4,66,66,100,1180,11.6,38.058
23,4,67.2,67.2,100,1162,11.6,38.058
24,5,68.4,68.4,100,1222,11.2,36.745
25,5,69.6,69.6,100,1201,11.6,38.058
26,5,70.8,70.8,100,1198,11.2,36.745
27,5,72,72,100,1219,11.2,36.745
28,5,73.2,73.2,100,1066,11.2,36.745
29,6,74.4,74.4,100,1149,11.2,36.745
30,6,75.6,75.6,100,1152,11.2,36.745
31,6,76.8,76.8,100,1141,11.2,36.745
32,6,78,78,100,1151,11.2,36.745
33,6,79.2,79.2,100,1139,11.2,36.745
34,7,80.4,80.4,100,1126,10.8,35.433
35,7,81.6,81.6,100,1006,10,32.808
36,7,82.8,82.8,100,1081,10,32.808
37,7,84,84,100,916,9.2,30.184
38,7,85.2,85.2,100,977,8.8,28.871
```

Example of a portion of an IMX_out file. Each record is contains the shot number, leading IOX record number, angle of shot relative to sonar device center point which is aligned with the magnetic north arrow of the compass (values range from -180 to 180 degrees), sonar head position relative to the north arrow of the compass (values range from 0-360 degrees), range setting of sonar device (values from 5 - 100 meters in discrete settings), PR or profiling range distance in centimeters, Distance in meters to target using maximum color intensity of echo data detection, Distance in feet to target using maximum color intensity of echo data detection.

F:\AML Projects\Tar Creek\Howerton\Sonar data\Sonar_81a_raw_output.m*

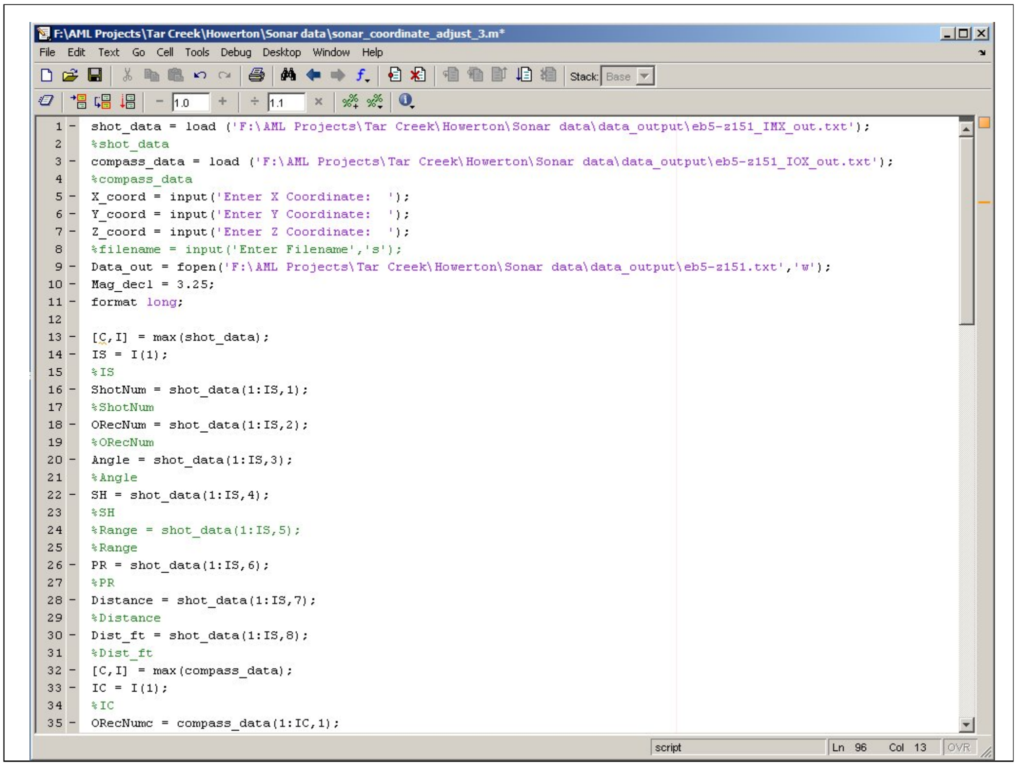
```
        %RHB
        RLB21 = double(bitshift(bitand(R21,1),7));
        %RLB21
        RLB20 = bitand(R20,127);
        %RLB20
        RLB = double(bitor(RLB21,RLB20));
        %RLB
        Roll = double(bitor(double(bitshift(RHB,8)),RLB));
        %Roll
        Roll_out = (Roll - 900)/10;
        %Roll_out
        H22 = fread(SF,1,'*uint8');
        %H22
        H23 = fread(SF,1,'*uint8');
        %H23
        HHB = double(bitshift(bitand(H23,126),-1));
        %HHB
        HLB23 = double(bitshift(bitand(H23,1),7));
        %HLB23
        HLB22 = bitand(H22,127);
        %HLB22
        HLB = double(bitor(HLB23,HLB22));
        %HLB
        H = bitor(bitshift(HHB,8),HLB);
        %H
        Heading = H/10;
        %Heading
        dlmwrite('F:\AML Projects\Tar Creek\Howerton\Sonar data\data_output\eb5-z151_IOX_out.txt',...
            [ORecNum ShotNum Heading Pitch_out Roll_out],'newline', 'pc');
        status = fseek(SF,132,'cof');

    end
    position = ftell(SF);
    R = R + 1;
    %R


while feof(SF)<1;
```

Coding for extracting heading, roll and pitch data and writing data to an external file, IOX_out, containing selected orientation module data.

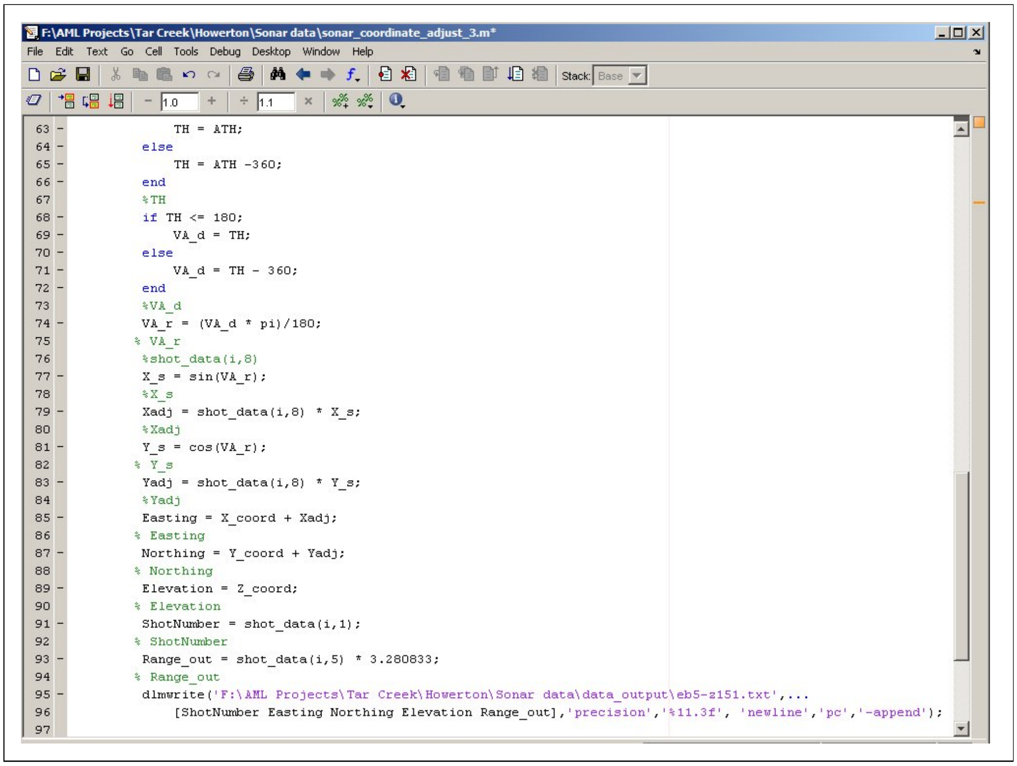



```
1,3,262.9,0.5,-1
2,8,262.8,0.5,-1
3,13,262.7,0.6,-1
4,18,262.6,0.5,-1
5,23,262.6,0.6,-1
6,28,262.7,0.6,-1
7,33,262.5,0.5,-1
8,38,262.6,0.5,-1
9,43,262.8,0.6,-1
10,48,261.9,0.5,-1
11,53,261.2,0.5,-1
12,58,260.7,0.5,-1
13,63,260.5,0.5,-1
14,68,260.8,0.5,-1
15,73,260.9,0.5,-1
16,78,261.4,0.5,-1
17,83,261.8,0.5,-1
18,88,261.8,0.5,-1
19,93,261.7,0.6,-1
20,98,261.6,0.6,-1
21,103,261.2,0.5,-1
22,108,260.8,0.5,-0.9
23,113,260.9,0.6,-1
24,118,261.3,0.6,-1
25,123,261.5,0.6,-1
26,128,261.3,0.5,-1
27,133,261.9,0.6,-1
28,138,261.8,0.6,-0.9
29,143,261.3,0.5,-1
30,148,261.3,0.6,-1
31,153,261.3,0.6,-1
32,158,261,0.5,-1
33,163,261.3,0.6,-1
34,168,261.4,0.6,-1
35,173,261.2,0.5,-0.9
36,178,261.4,0.5,-1
37,183,261.5,0.5,-1
38,188,261.3,0.5,-1
39,193,260.9,0.5,-1
```

Example of a portion of an IOX_out file. Each record consists of Orientation module record number, shot number just prior to this record, heading of module, pitch, roll.

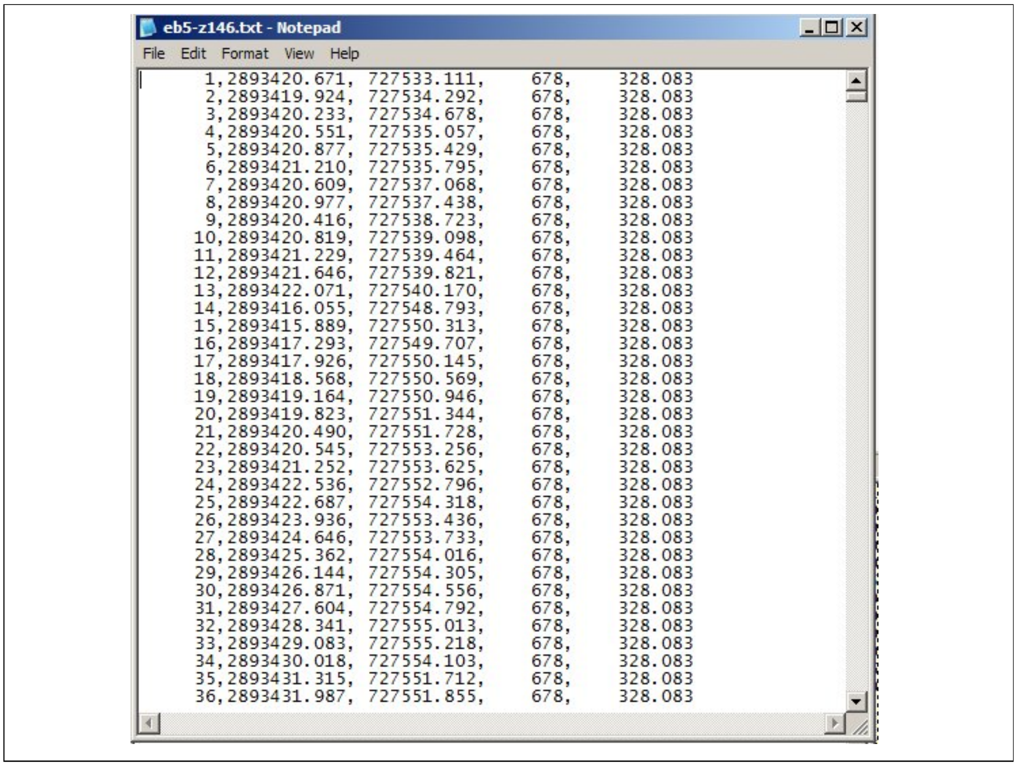


Beginning of the second Matlab program that takes data from both IMX and IOX files and calculates the x,y and z coordinate of each sonar shot. Each sonar shot is adjusted for heading drift in the sonar tool using IOX data that brackets a set of IMX data. Generally there is one IOX record for multiple IMX records. The number of IMX records between two IOX records is dependent on the scanning speed setting.



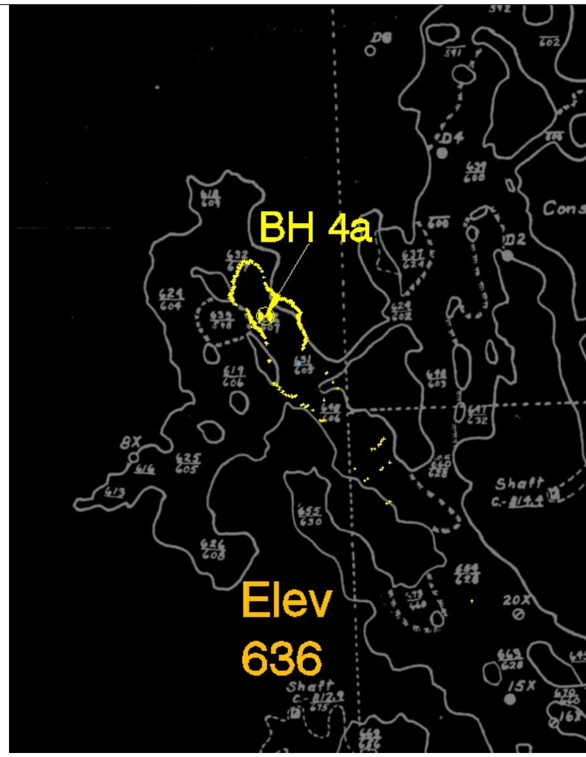

```
        TH = ATH;
    else
        TH = ATH -360;
    end
    %TH
    if TH <= 180;
        VA_d = TH;
    else
        VA_d = TH - 360;
    end
    %VA_d
    VA_r = (VA_d * pi)/180;
   % VA_r
    %shot_data(i,8)
    X_s = sin(VA_r);
    %X_s
    Xadj = shot_data(i,8) * X_s;
    %Xadj
    Y_s = cos(VA_r);
   % Y_s
    Yadj = shot_data(i,8) * Y_s;
    %Yadj
    Easting = X_coord + Xadj;
   % Easting
    Northing = Y_coord + Yadj;
   % Northing
    Elevation = Z_coord;
   % Elevation
    ShotNumber = shot_data(i,1);
   % ShotNumber
    Range_out = shot_data(i,5) * 3.280833;
   % Range_out
    dlmwrite('F:\AML Projects\Tar Creek\Howerton\Sonar data\data_output\eb5-z151.txt',...
        [ShotNumber Easting Northing Elevation Range_out],'precision','%11.3f', 'newline','pc','-append');
```

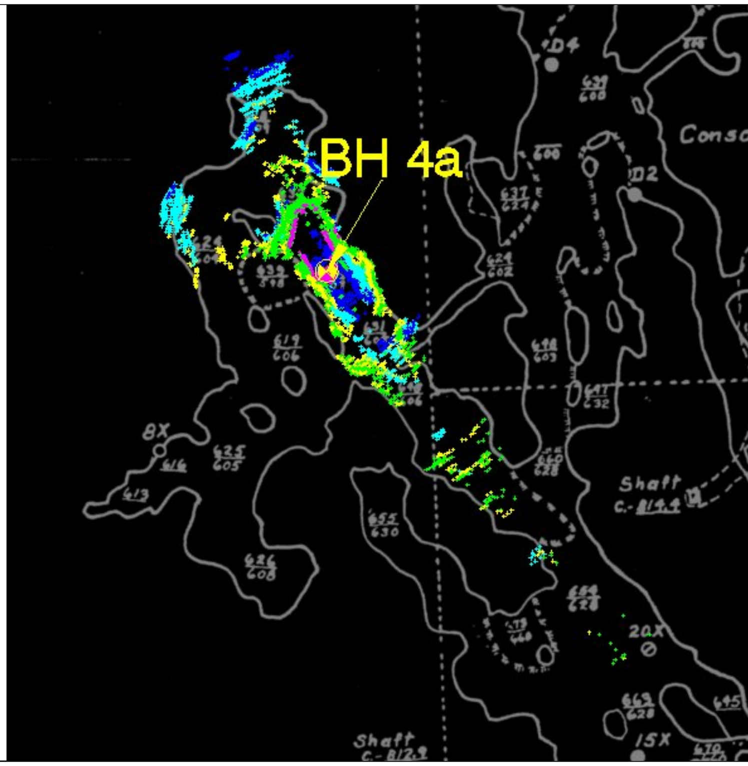
Some of the coding for calculating coordinates for each sonar shot and writing the shot number, x,y,z coordinates and range into an external ASCII data file which can be imported directly into a CAD or GIS program.

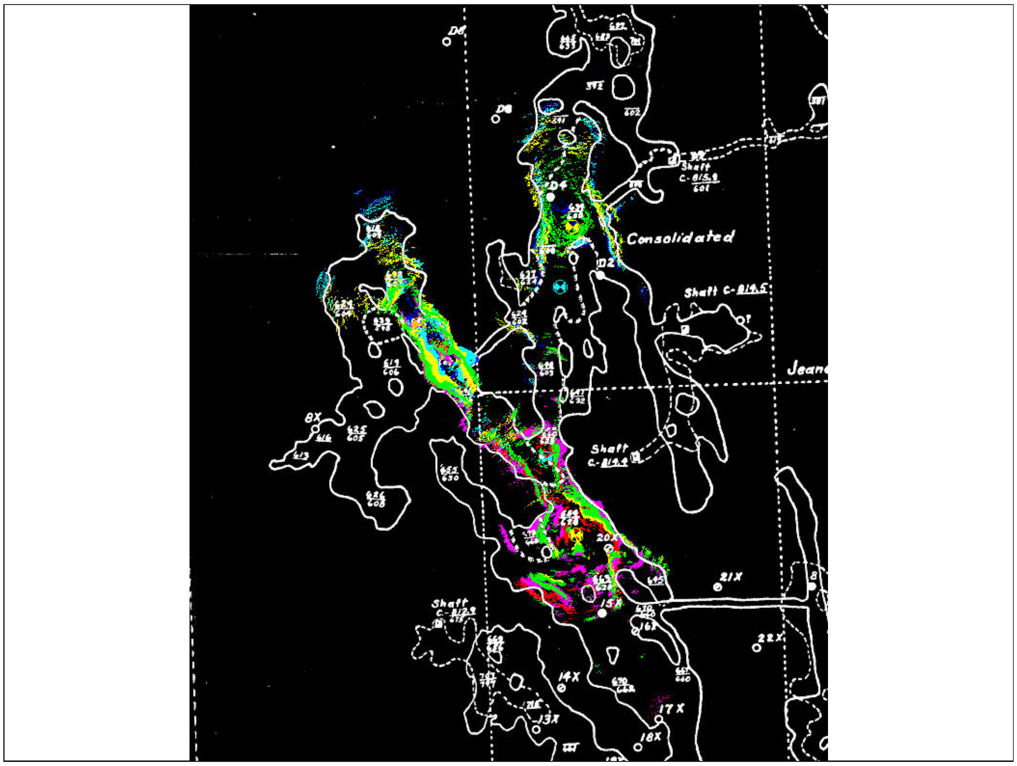



```
 1,2893420.671, 727533.111,    678,     328.083
 2,2893419.924, 727534.292,    678,     328.083
 3,2893420.233, 727534.678,    678,     328.083
 4,2893420.551, 727535.057,    678,     328.083
 5,2893420.877, 727535.429,    678,     328.083
 6,2893421.210, 727535.795,    678,     328.083
 7,2893420.609, 727537.068,    678,     328.083
 8,2893420.977, 727537.438,    678,     328.083
 9,2893420.416, 727538.723,    678,     328.083
10,2893420.819, 727539.098,    678,     328.083
11,2893421.229, 727539.464,    678,     328.083
12,2893421.646, 727539.821,    678,     328.083
13,2893422.071, 727540.170,    678,     328.083
14,2893416.055, 727548.793,    678,     328.083
15,2893415.889, 727550.313,    678,     328.083
16,2893417.293, 727549.707,    678,     328.083
17,2893417.926, 727550.145,    678,     328.083
18,2893418.568, 727550.569,    678,     328.083
19,2893419.164, 727550.946,    678,     328.083
20,2893419.823, 727551.344,    678,     328.083
21,2893420.490, 727551.728,    678,     328.083
22,2893420.545, 727553.256,    678,     328.083
23,2893421.252, 727553.625,    678,     328.083
24,2893422.536, 727552.796,    678,     328.083
25,2893422.687, 727554.318,    678,     328.083
26,2893423.936, 727553.436,    678,     328.083
27,2893424.646, 727553.733,    678,     328.083
28,2893425.362, 727554.016,    678,     328.083
29,2893426.144, 727554.305,    678,     328.083
30,2893426.871, 727554.556,    678,     328.083
31,2893427.604, 727554.792,    678,     328.083
32,2893428.341, 727555.013,    678,     328.083
33,2893429.083, 727555.218,    678,     328.083
34,2893430.018, 727554.103,    678,     328.083
35,2893431.315, 727551.712,    678,     328.083
36,2893431.987, 727551.855,    678,     328.083
```

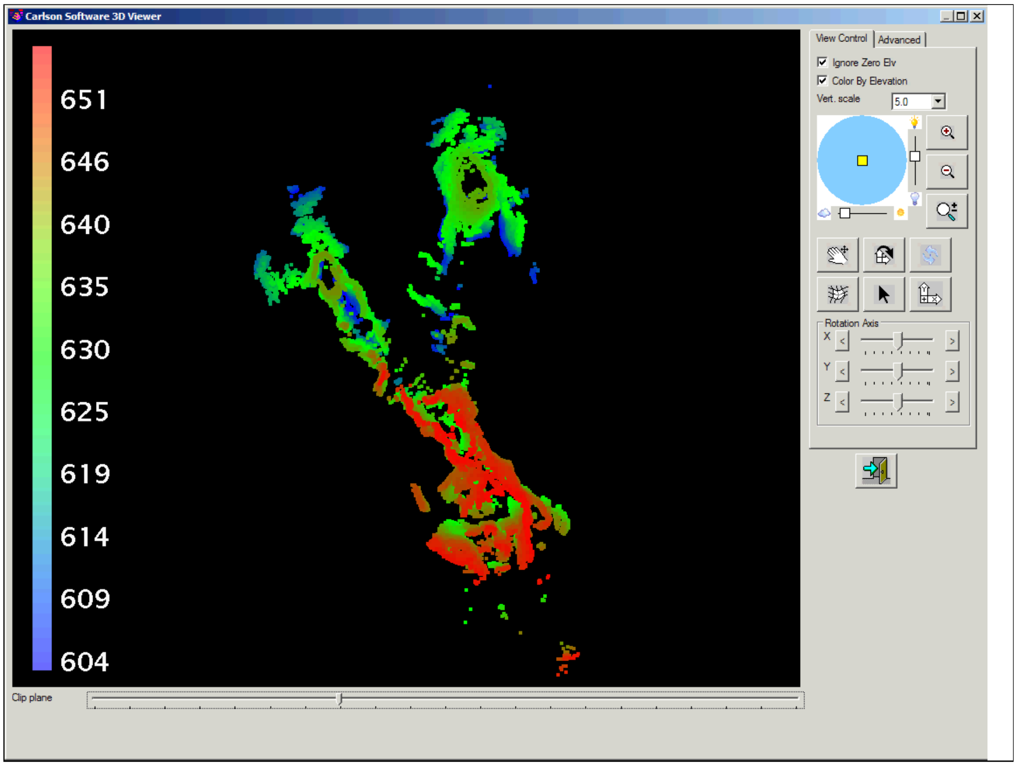
Example of ASCII data output file. Each record consists of shot number, x coordinate, y coordinate, z coordinate, range setting of sonar device.


BH 4a
Elev
636
D4
D2
8X
20X
15X
Shaft
Shaft

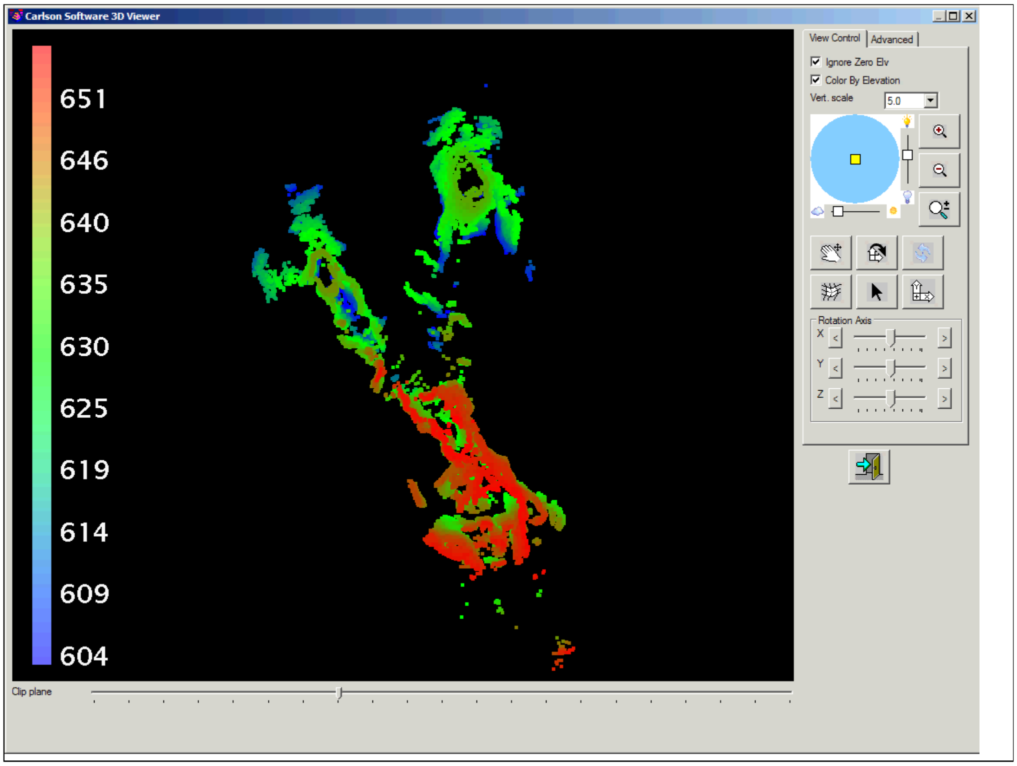

BH 4a
D4
D2
Consol
Shaft
8X
20X
15X
Shaft



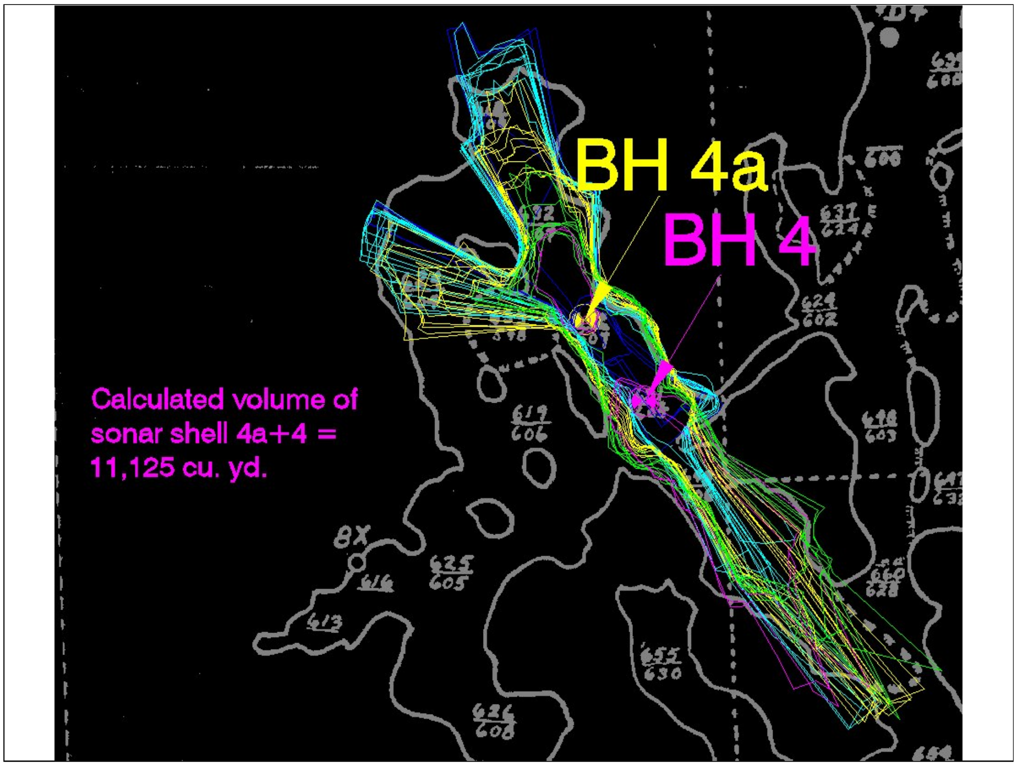
Sonar data in the form of point clouds from West Commerce project well bores OCC-3, OCC-4, OCC-5, 4A and 4C.



Dynamic view and clip plane of plan view of 4a, OCC-4, 4c, OCC-3 and OCC-5



Dynamic view and rotation of plan view of 4a, OCC-4, 4c, OCC-3 and OCC-5

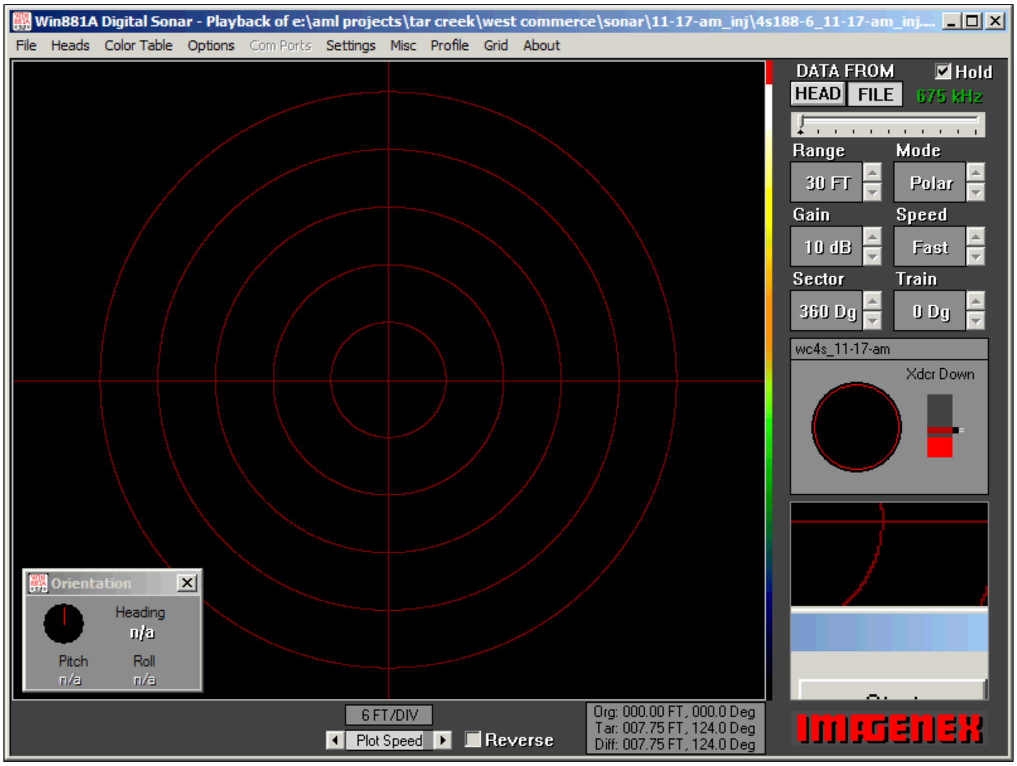

BH 4a
BH 4
Calculated volume of
sonar shell 4a+4 =
11,125 cu. yd.

Drilling injection well 5A and view of 11,000 cy yd chat pile to be injected into the mine workings.

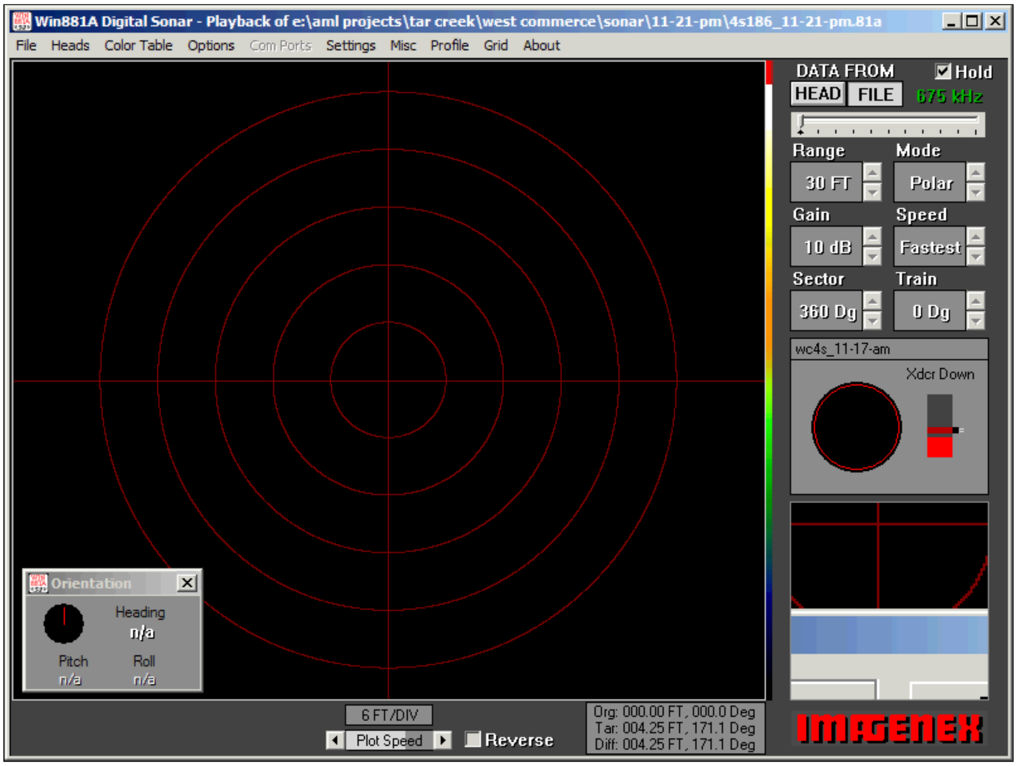

16-174


BELT-WAY®
F1
F5
T1
F2
F6
T2
F3
F7
T3

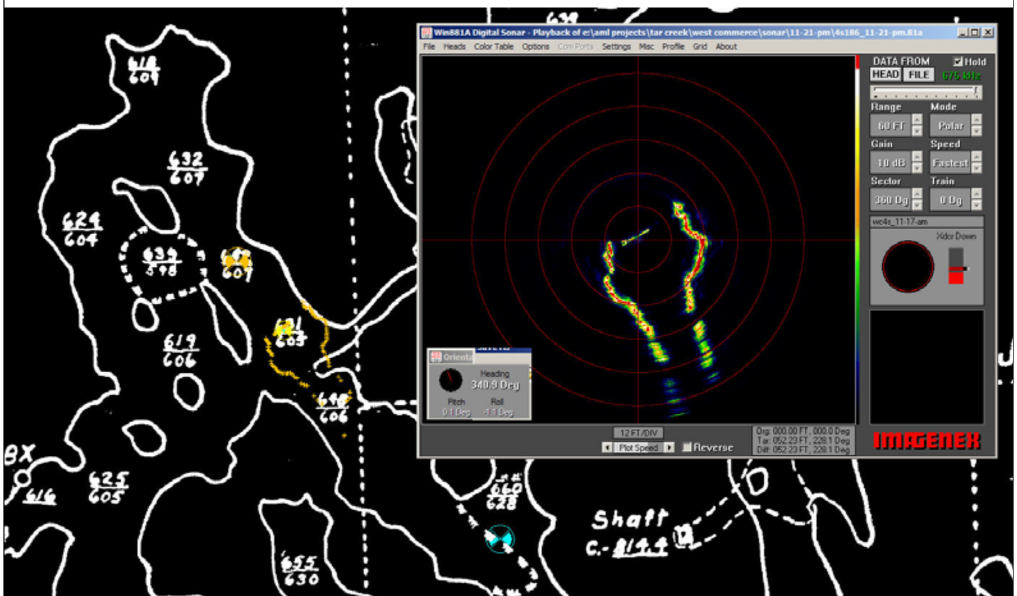

Reynolds
& Reynolds
Records Efficiency System



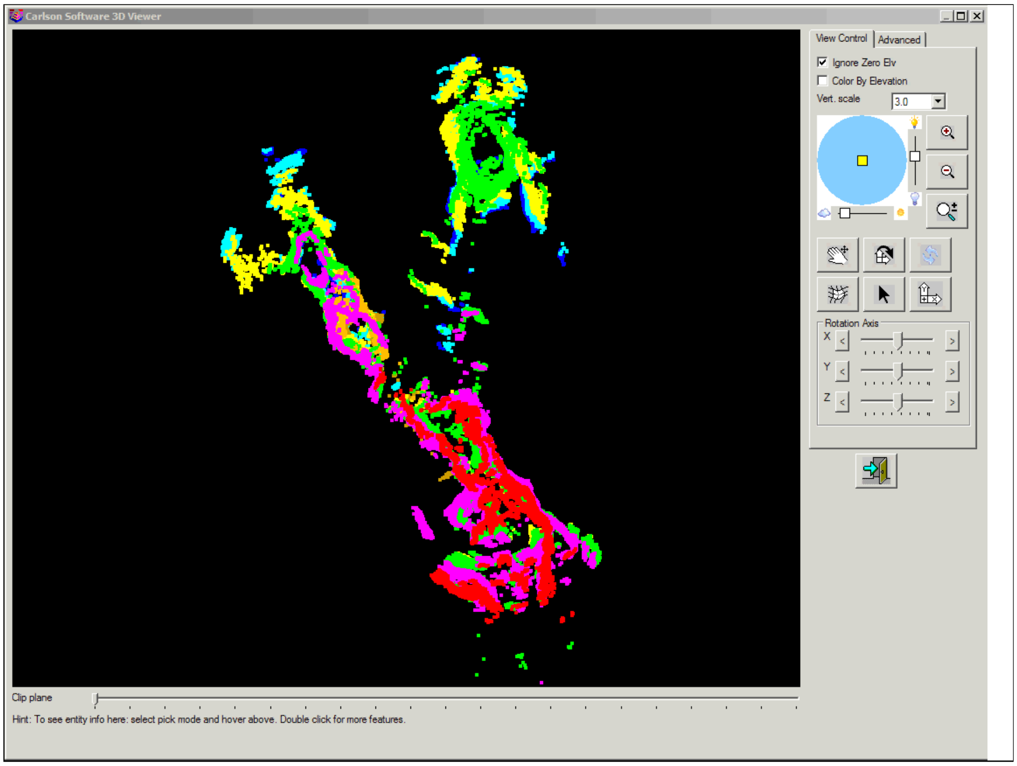
Sonar observations of chat injection at West Commerce well 4A. Sonar tool is down well bore OCC-4 located at the center of the display. Injection well 4a is located approximately 50 feet into the lower left quadrant. The sonar is showing the face of the underground chat pile and its intersection with the ribs of the mine workings. Note as the movie is playing the disturbances at each point where the face of the pile intersects the mine walls. This is the chat moving down the face of the pile. Note that the sonar head is about 6 feet from the face of the pile. Observing the orientation module readout shows that there is some small amount of turbulence at this location.



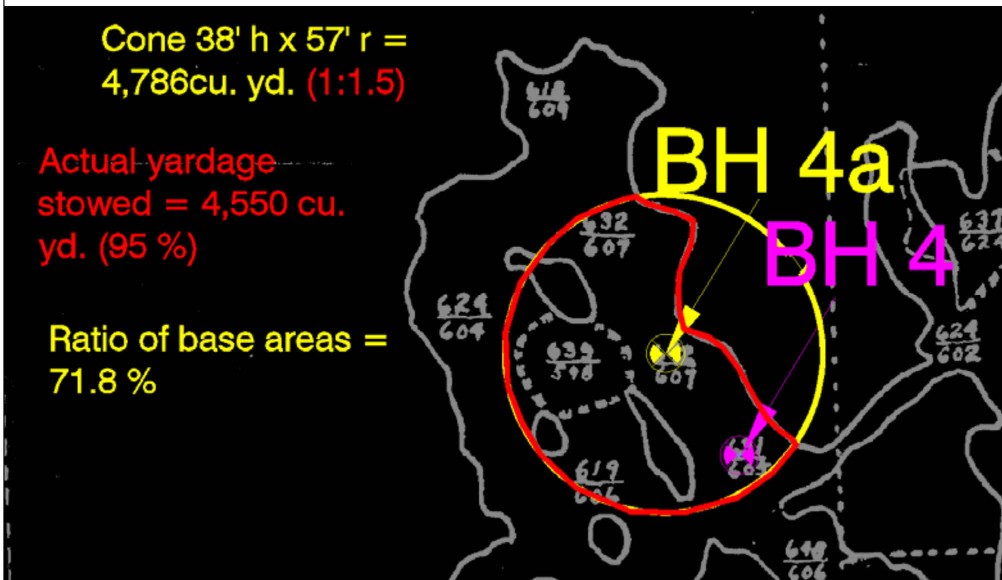
Approximately 2-3 minutes after turning off the injection pump all is quiet at the face of the pile. Note that in this view the sonar head is about 2 feet or less from the face of the pile. Also, the orientation of the sonar has changed compared to the previous movie slide. This screen view was taken a couple of hours after the previous screen view was taken.

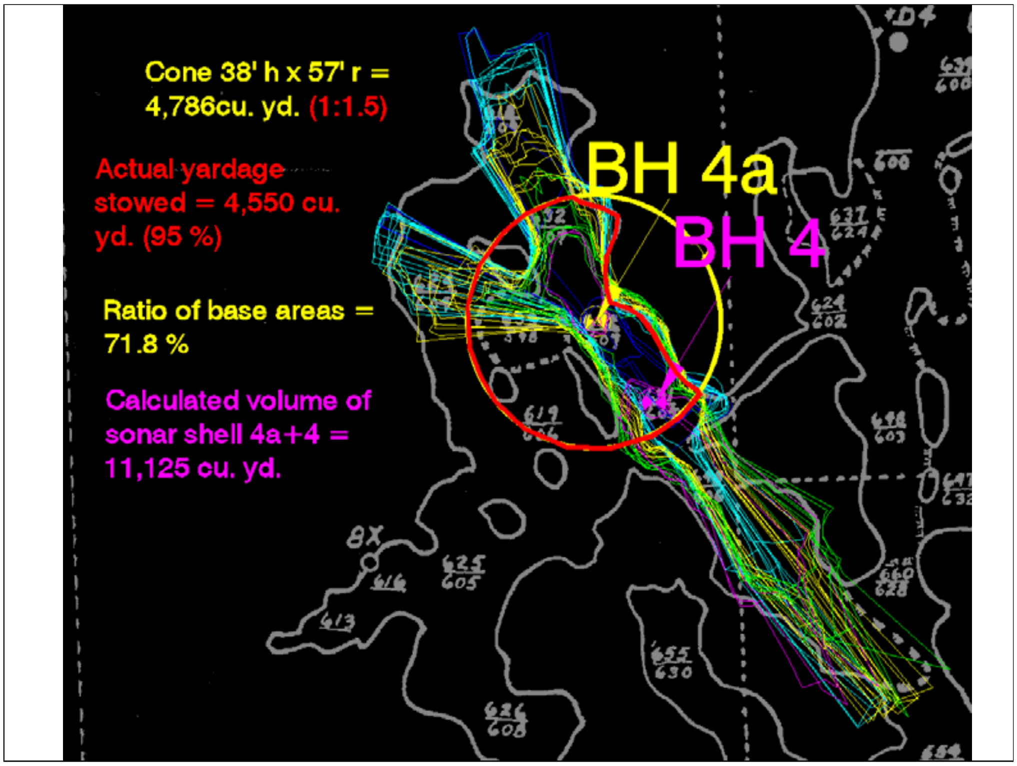


Sonar raw data shown with corrected data plotted on the mine map.



Dynamic view and clip plane of plan view of 4a, 4, 4c, 3 and 5 after chat injection into 4a. Note that the orange color range of elevations mainly depicts the location of the underground chat pile. The slope of the pile is approximately 1:1.5.


Cone 38' h x 57' r =
4,786cu. yd. (1:1.5)
Actual yardage
stowed = 4,550 cu.
yd. (95 %)
Ratio of base areas =
71.8 %
BH 4a
BH 4



Cone 38' h x 57' r =
4,786cu. yd. (1:1.5)
Actual yardage
stowed = 4,550 cu.
yd. (95 %)
Ratio of base areas =
71.8 %
Calculated volume of
sonar shell 4a+4 =
11,125 cu. yd.
BH 4a
BH 4