ARI

Acoustic Reservoir Imaging

Background and involvement in passive seismic

Passive Seismic in the Literature

World Oil Article

Passive low frequency spectral analysis: Exploring a new field in geophysics

This pathfinder/DHI technique is under rapid development and uptake for exploration.

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In 2003, a group of scientists in Switzerland set out to answer some intriguing questions with implications for the way oil and gas reserves are discovered and produced. Research conducted by Dr. Stefan Dangel at the University of Zurich had highlighted a strong and consistent empirical relationship between low-frequency spectral anomalies in seismic background wavefields and geological characteristics of a collection of reservoirs, mainly in the Middle East. Similar observations have also been reported in the Russian literature since the early 1990s.

Dangel's research was robust by any standard, but focused on one feature in particular: curious amplitude peaks clustered around 3 Hz in surface velocity data measured above hydrocarbon reservoirs. [1] The possibility of a universal hydrocarbon-indicator, while attention-grabbing, did not sit well with the real-world complexities that the industry confronts day-to-day. Moreover, the reasons for such features were left largely open.

The question was whether Dangel's research pointed more generally to coherent patterns in low-frequency background waves. If so, could these be directly related to reservoirs and other subsurface structures in a way that would provide new data for exploration and production decisions?

An accumulating body of knowledge in the earth science world suggested this might be the case, but the subject had never been seriously tackled with an eye on oil and gas. The seismic industry systematically disregards seismic data below 10 Hz as noise, and for good reason: conventional geophones are insensitive in this domain and little useful data can be expected. As one geologist put it, "All my career I've been fighting noise. Now you want me to believe the noise is information?"

Yet, low-frequency waves are less susceptible to many of the problems that plague conventional seismic and electromagnetic methods, particularly in areas with poor seismic response or obstacles such as thick basalt or conglomerate layers. Successful unraveling of these patterns observed in the sub-10-Hz domain would be a valuable new contribution to exploration geophysics.

A high-quality effort would need to acquire new, high-quality datasets and tackle the physical mechanisms behind these "hydrocarbon micro-tremors" that Dangel [1] and others [2,3,4,5] have found. A strong scientific team, substantial research funding and the support of credible operating partners would also be required. All of this came at a time when investment in geophysical services, not to mention funding for technology start-ups, was at a low ebb.

With barely a scent of the present exploration boom in the air, Spectraseis Technology Inc. was founded in early 2003 to begin the task of acquiring low-frequency seismic data and to develop industrial applications as the research progressed. Promising early work with Petrobras in Brazil and a Shell affiliate in Austria drew Swiss government funding for a dedicated research group at ETH Zurich. An investment by the new technology ventures group of Norsk Hydro in 2005 helped to accelerate and expand the development of commercial acquisition systems and data processing software.

Today, with a research and development team of 10 scientists and commercial land surveys planned or in progress with Petrobras in Brazil, Pemex in Mexico, Norsk Hydro in Libya and KOC in the Arabian Peninsula, it is evident that low-frequency analysis will be part of the exploration and reservoir characterization toolkit of the future. The questions now are which applications will prove most useful and how quickly the rest of the industry will embrace them.

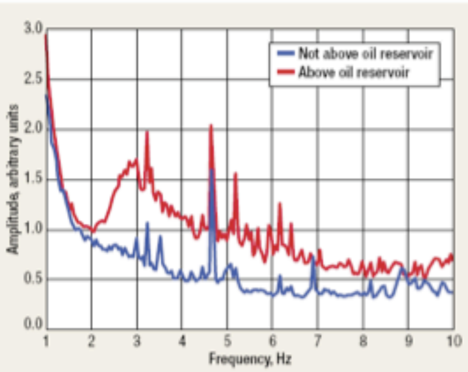

Fig 1. Data from a survey in Brazil showing inconsistent anomalies in the Fourier spectra of surface velocities, measured within and outside the boundaries of a know oil reservoir.

HYDROCARBON MICROTREMORS

The starting point for our work has been the empirical observations of Dangel, et al.

Geo Expo Article

RECENT ADVANCES IN TECHNOLOGY

Low-frequency Seismic Noise:

The Music of oil?

Passive low-frequency seismic is an area of active research and development, and is rapidly being taken up as a new direct hydrocarbon indicator (DHI) technique for exploration. The interest in the method is high, in particular since Spectraseis AG, the leading provider of low-frequency geophysical solutions to the oil and gas industry won the World Oil Award for Best Exploration Technology in October 2007. However, despite the empirical evidence supporting the technique, the underlying physical mechanism has not yet been fully identified.

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Technologists like technology that succeeds greatly, often as a result of megabucks of research and development. Conversely, technologists are somewhat suspicious of technology that comes easily and seems too simple. They think: how could the big brains in the industry overlook this simple idea? Or did they look into it and reject it?

In this issue of GEO ExPro the authors present a technology that is partly in the latter category. Even though a significant amount of research on low-frequency seismic has been conducted over the past five years, it is a technology that needs better understanding to fully judge its potential and validity.

Low frequency ambient seismic waves are ubiquitous in the earth's crust. Recording this "voice" of nature by employing arrays of geophones on the ground actually may give information about the near-surface geology. Japanese seismologists over the last 25 years have developed the use of background noise into a mature science for engineering-scale studies.

But does passive seismic listening hold potential for oil and gas prospecting? Do hydrocarbon reservoirs produce a unique low-frequency signature or a kind of "music" that can be measured to provide valuable information about their locations and characteristics?

Brief history

According to www.anchar.ru a group of Russian scientists, today part of the geophysical service company ANCHAR, performed studies over fields in East Siberia and North Caucasus in the early 1990's, and demonstrated that the spectral power of background noise above the hydrocarbon reservoir in the frequency range 1-10 Hz is higher than it is outside the hydrocarbon reservoir.

Could this empirical observation point to a possible universal hydrocarbon indicator?

In the west, the company ADNR Technology (recently launched as GeoDynamics) was formed in the mid-1990's to work on the use of passive low-frequency noise to detect hydrocarbons.

Passive low-frequency seismic for exploration received new and high attention when *Dangel and co-workers* in 2003 reported amplitude peaks clustered around 3 Hz in seismic data measured above hydrocarbon-bearing reservoirs in the Middle East. The key observation was that the seismic background noise seemed to be modified in the low frequency range above hydrocarbon filled structures relative to the background noise measured above water filled structures.

Based on the results of Dangel, Spectraseis AG was founded in 2003 to acquire low-frequency seismic data and to develop industrial applications as research progressed. Funding from the Swiss government and investment in 2005 by Hydro Technology Ventures helped the company to develop commercial acquisition systems and data processing software. In November 2007 Warburg Pincus, a global private equity firm, acquired a significant minority stake in Spectraseis, providing new equity to finance the company's growth plans. StatoilHydro Venture Capital now owns a stake in the company together with Spectraseis' management team.

An early technology blind test of the Spectraseis technology took place for Petrobras in 2004. The survey covered a producing oil field in the Potiguar basin in northeastern Brazil. According to Spectraseis (see Graf et al. 2007), "the test clearly identified two, and partly revealed the third, producing zone within the block". The figure, which is adapted from Graf et al., shows the published amplitude frequency spectra of the seismic background noise within (red curve) and outside (black curve) the boundaries of the reservoir. The low-frequency signal anomalies in the 2-4 Hz band is what we here call the "music" or "voice" of

AAGP Explorer Article

Is the Future of Seismic Passive?

Passive-seismic technology encompasses any procedure by which seismic data are recorded without the use of an active seismic source.

by Bob Hardage

When passive-seismic data are acquired there is no vibrator vehicle, no shothole explosive, no impact source and no air gun. Instead, seismic wavefields are generated by natural phenomena such as wind, microseisms, ocean waves or by human-made noises such as moving vehicles, passing aircraft or mechanical vibrations of operating machinery.

One passive-seismic application that is gaining attention is the acquisition and analysis of low-frequency natural seismic wavefields that seem to indicate the presence of subsurface oil and gas accumulations. In this application, data are acquired using high-sensitivity three-component geophones deployed across the earth's surface.

Data are recorded for time periods of many minutes to days in order to have data that are appropriate for analysis.

An example of this low-frequency, passive-seismic application is shown as figure 1, in which responses of vertical geophones at sites 1 and 2 along a profile are displayed. Site 1 is atop a hydrocarbon producing area; site 2 is not.

Data analysis usually focuses on the amount of seismic energy between 1 and 6 Hz in order to distinguish the presence of hydrocarbons – but tests now imply that there is a narrow frequency band extending from approximately 1 Hz up to about 4 Hz that often is the most diagnostic indication of the presence of hydrocarbons for the data sets acquired to date.

Restricting data analysis to this narrow frequency band:

- ✓ Rejects energy created by ocean waves, which tend to have frequencies less than 0.2 Hz.
- ✓ Also rejects energy created by anthropogenic sources (human activity), which tend to have frequencies greater than 4 Hz.

Ocean-wave energy is ubiquitous and can be observed in the interior of continents far from coastlines. The amount of anthropogenic energy varies from site to site, depending on the nature of human culture from area to area.

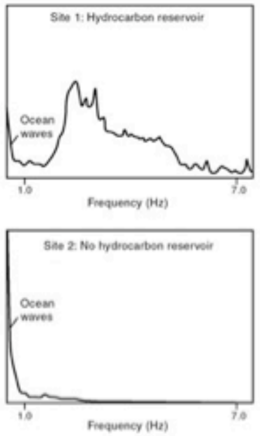


Figure 1. Natural-source seismic wavefields appear to exhibit higher amplitude responses in the frequency range between 1 and 4 Hz when measured above hydrocarbon reservoirs (top) than when measured above areas with no hydrocarbons (bottom). These data are the responses of surface-based vertical geophones.

Basic Equipment

Gear and ATV

Seismometer

Data Recorder

Monitor Hookup

Problems

Problems

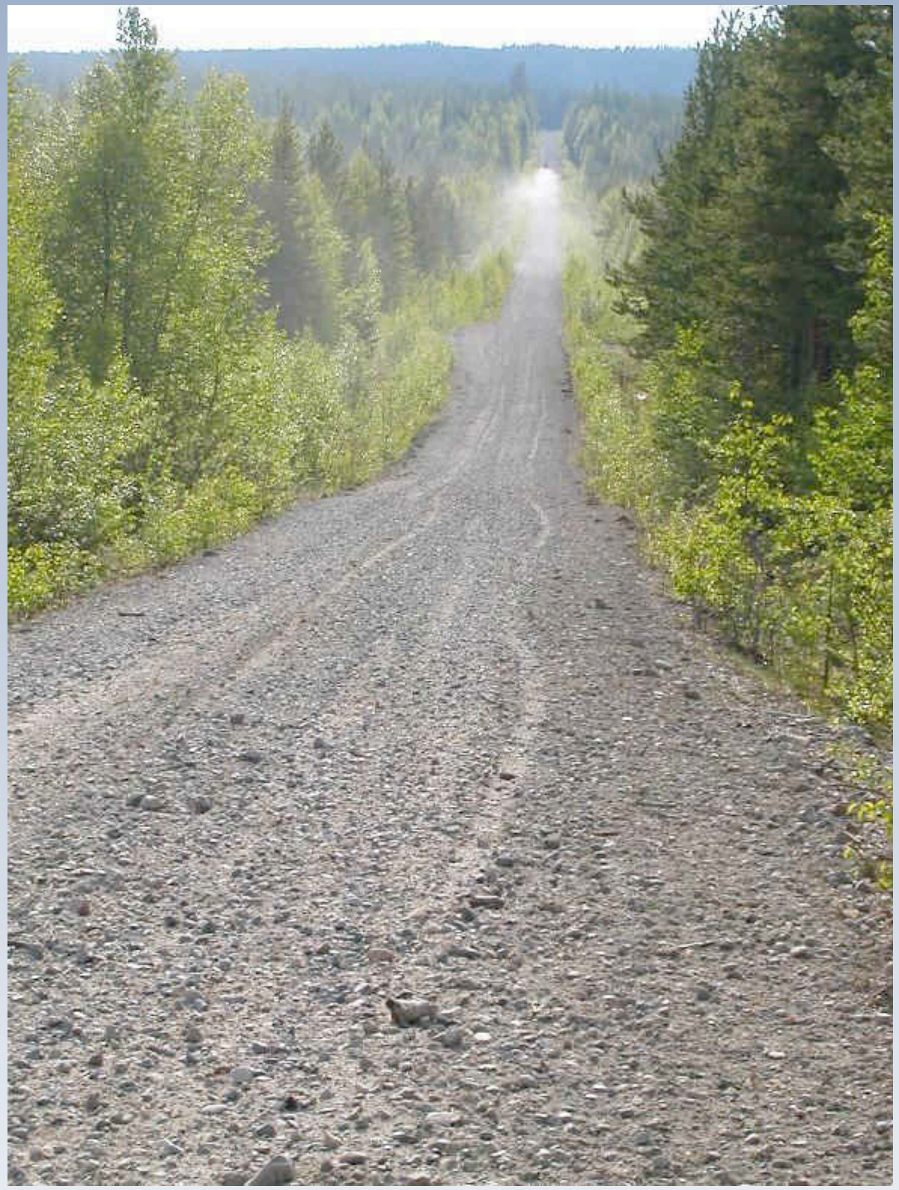
Wind

Dependent on vegetation but especially when greater than approximately 15 mph

Problems

Nearby Heavy Traffic

Especially on gravel roads



Problems

Pumping Units

Especially gas engines

Problems

Water Injection Wells

Problems

Livestock

Cows and camels

Problems

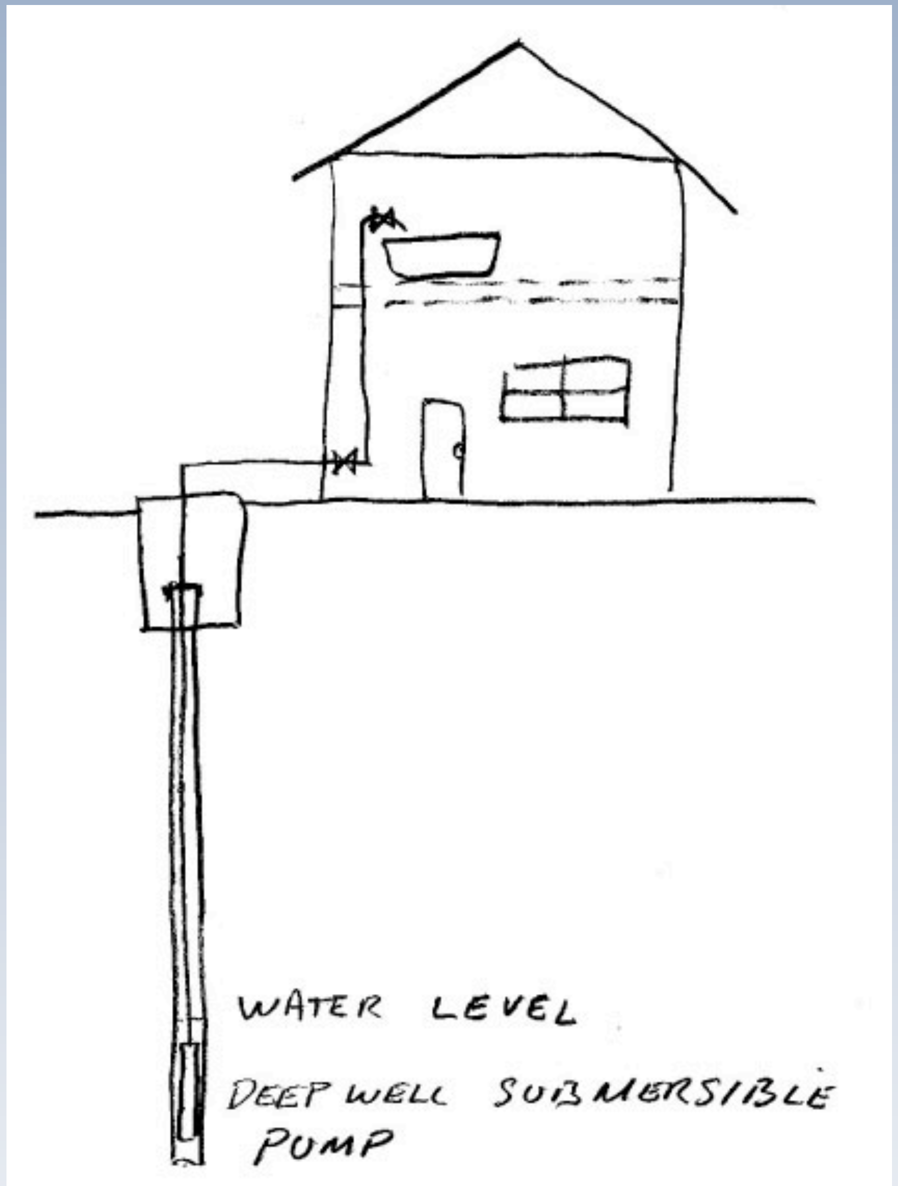
Farm Equipment

Plowing or planting

Problems

Submergible Pumps

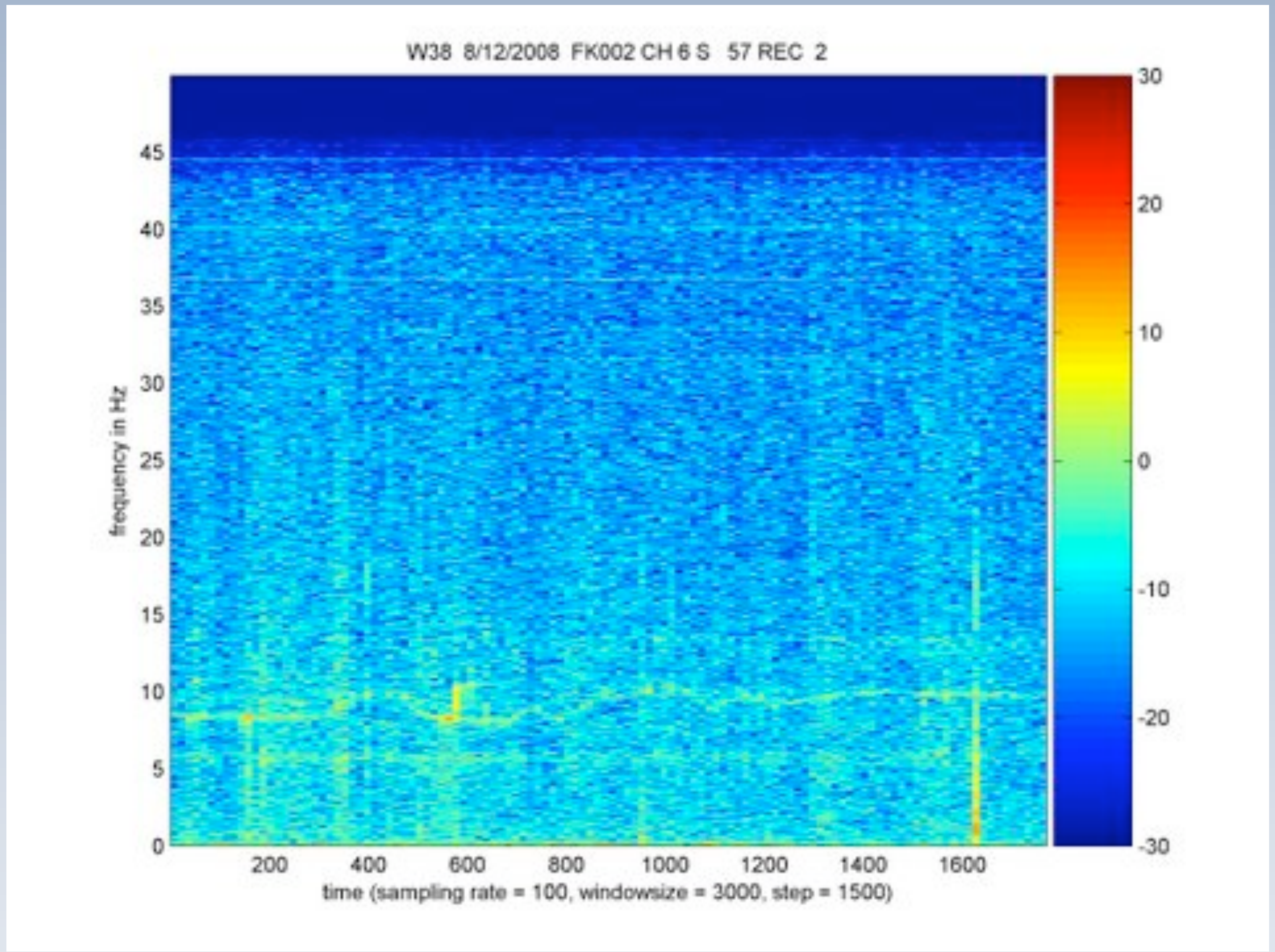
Oil production or domestic water wells



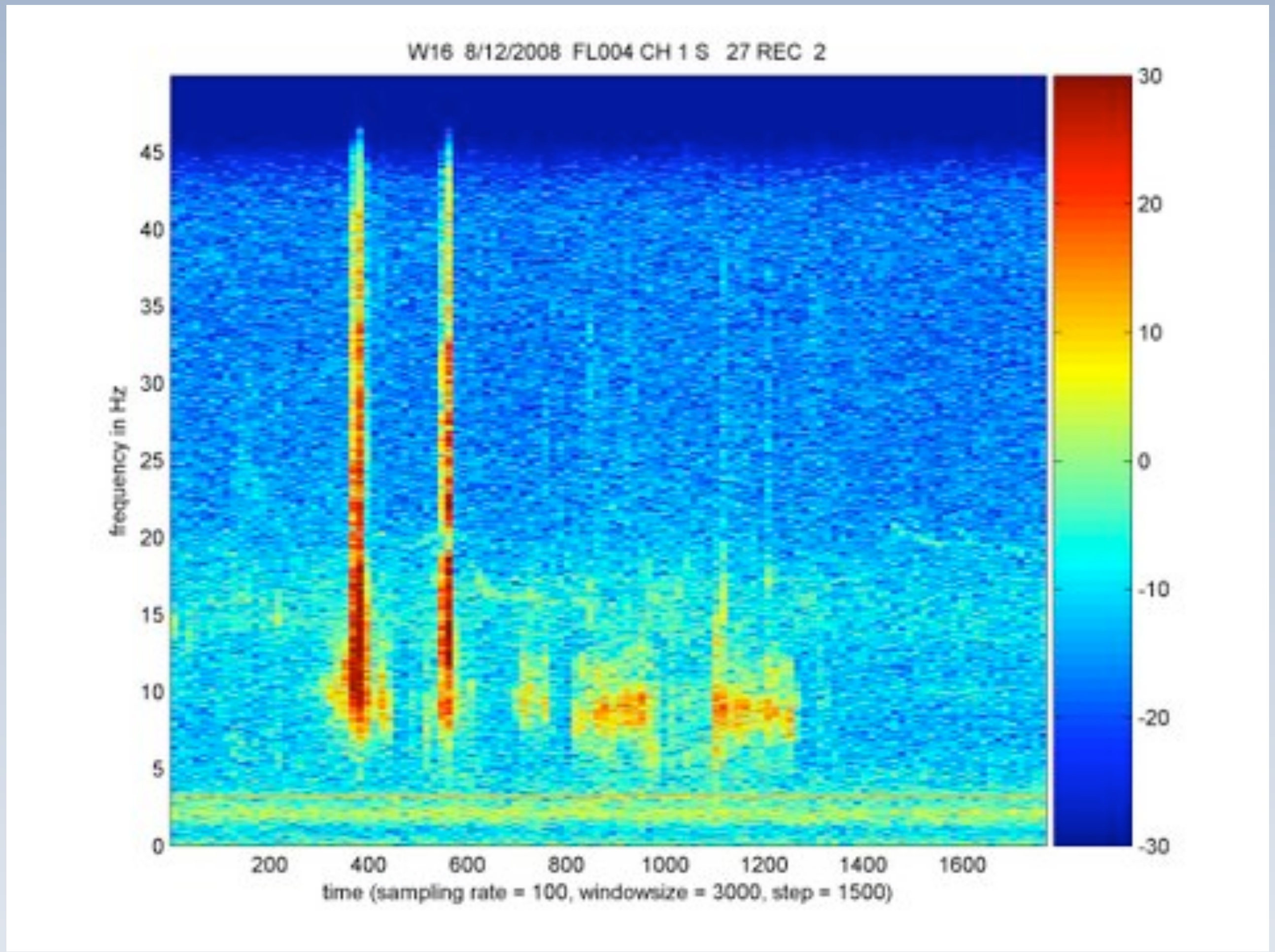
Problems

Rain and Thunderstorms

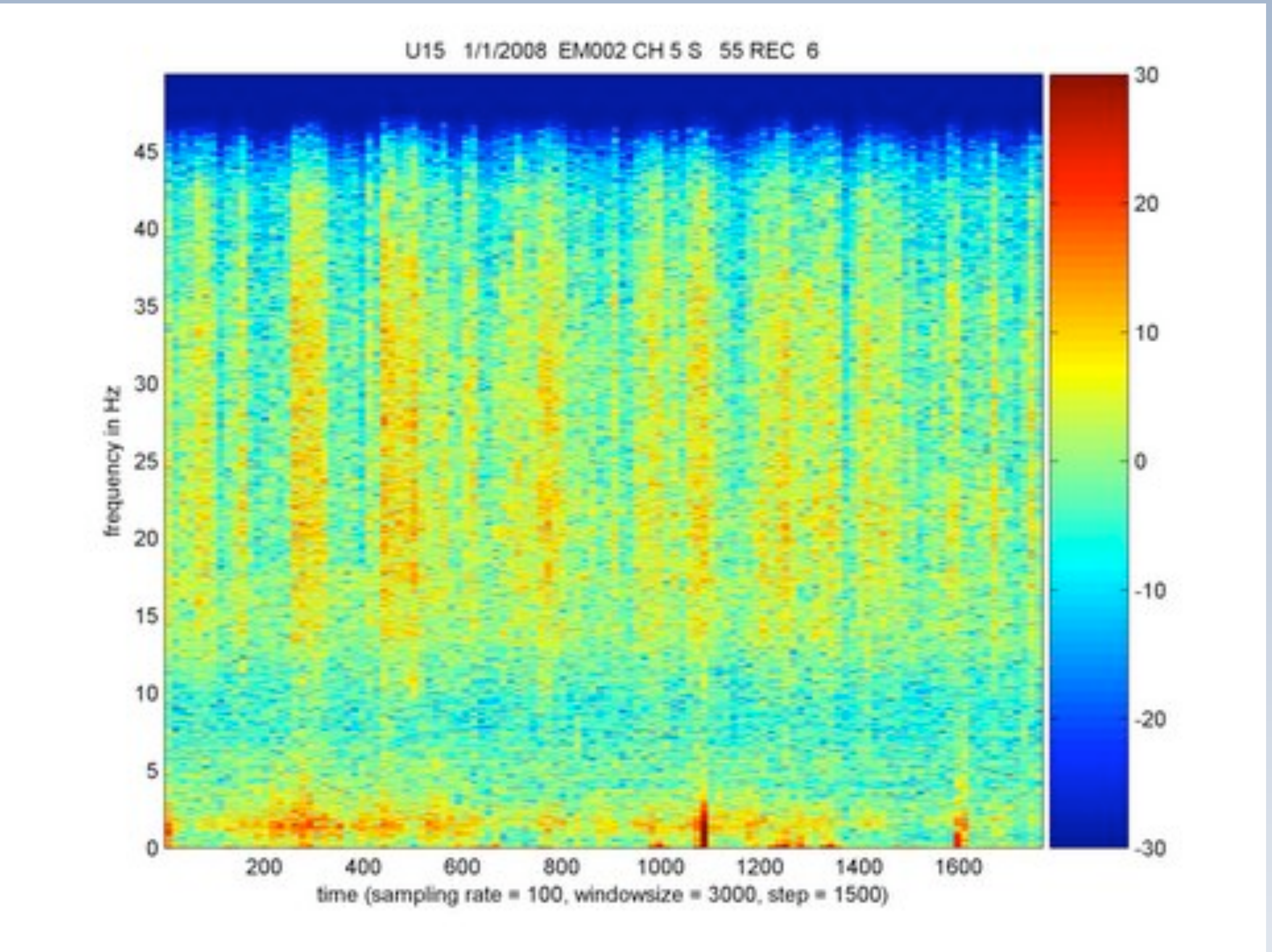
Data Analysis



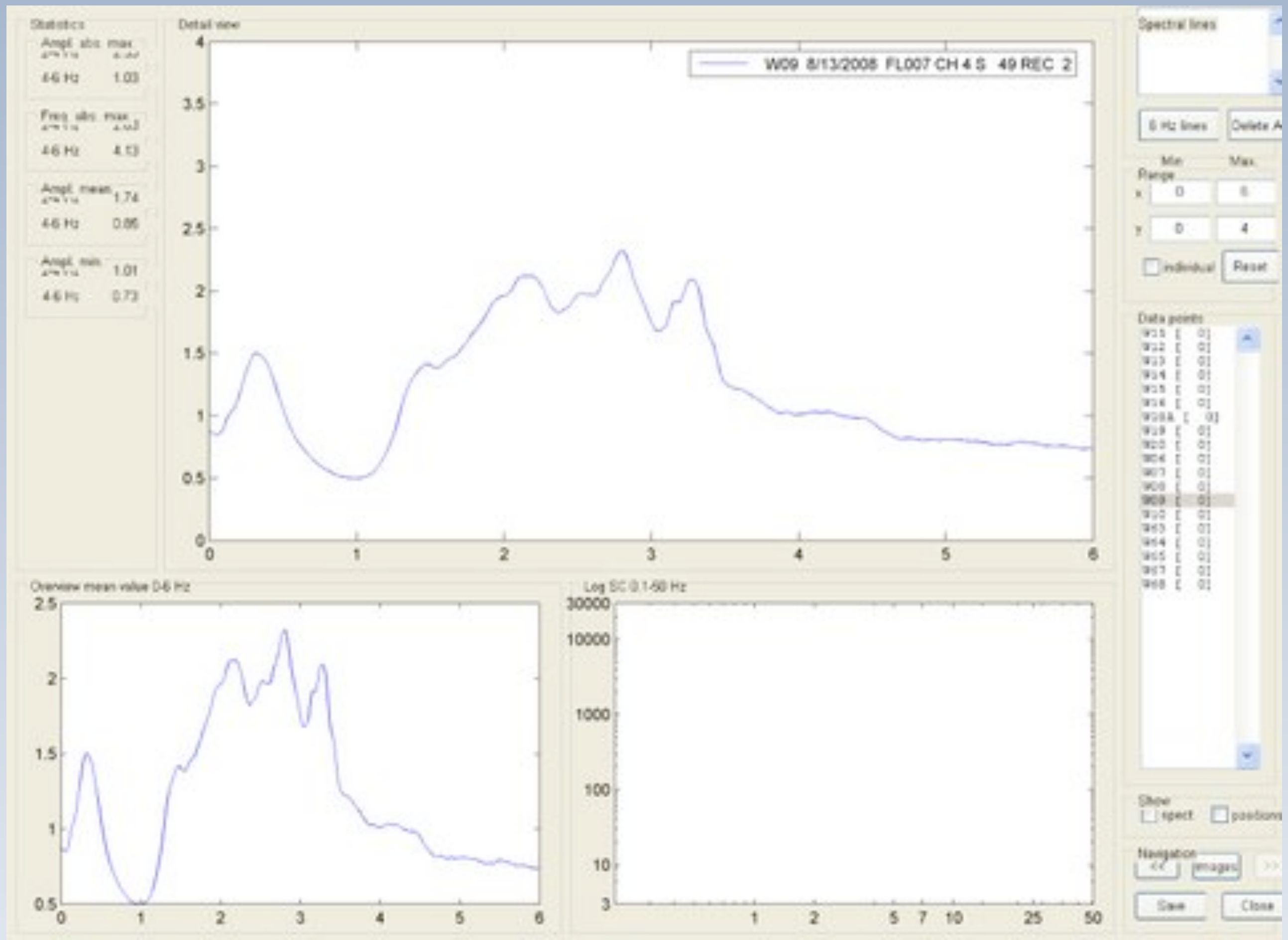
Data Analysis



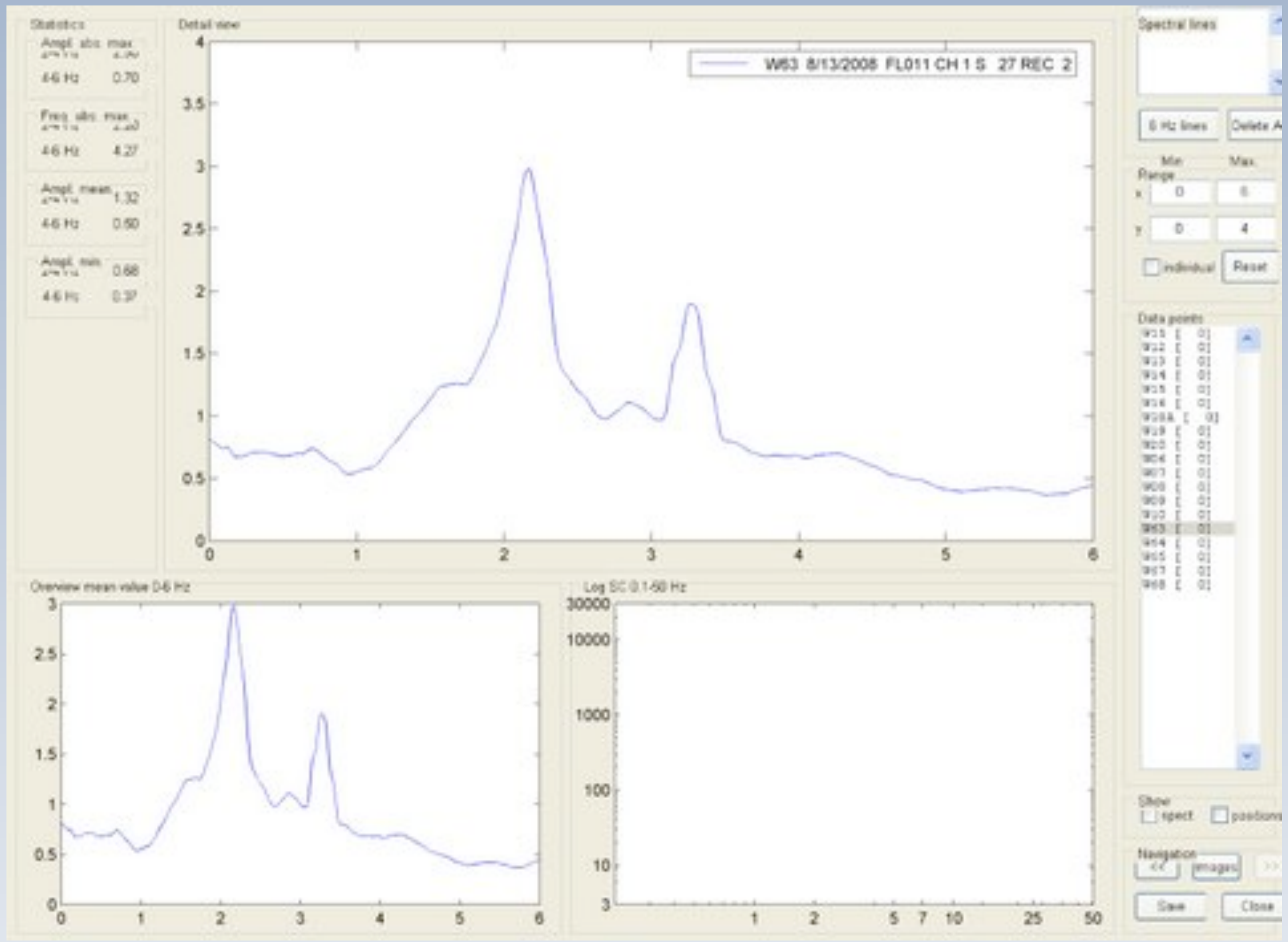
Data Analysis



Data Analysis

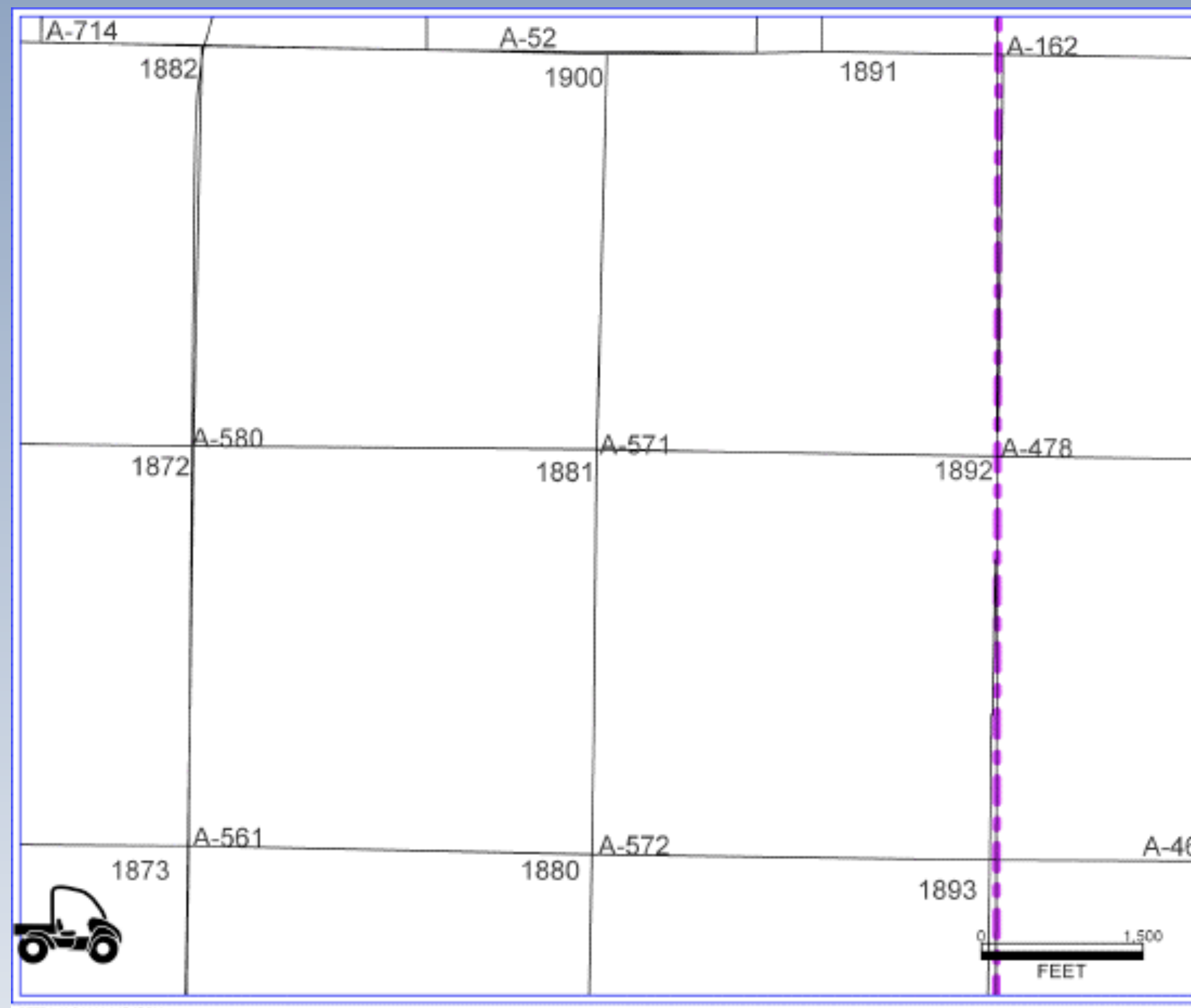


Data Analysis

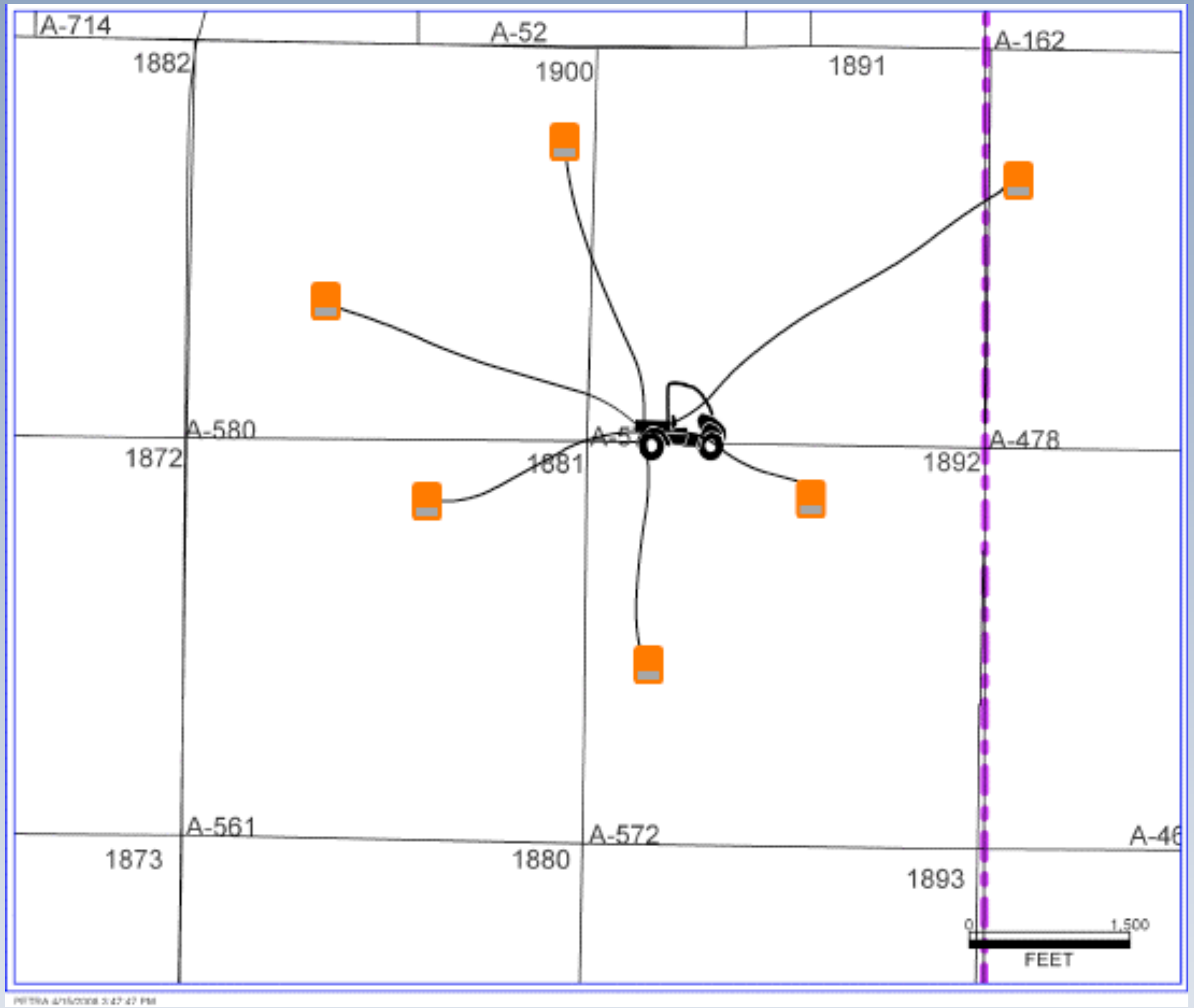


Data Analysis

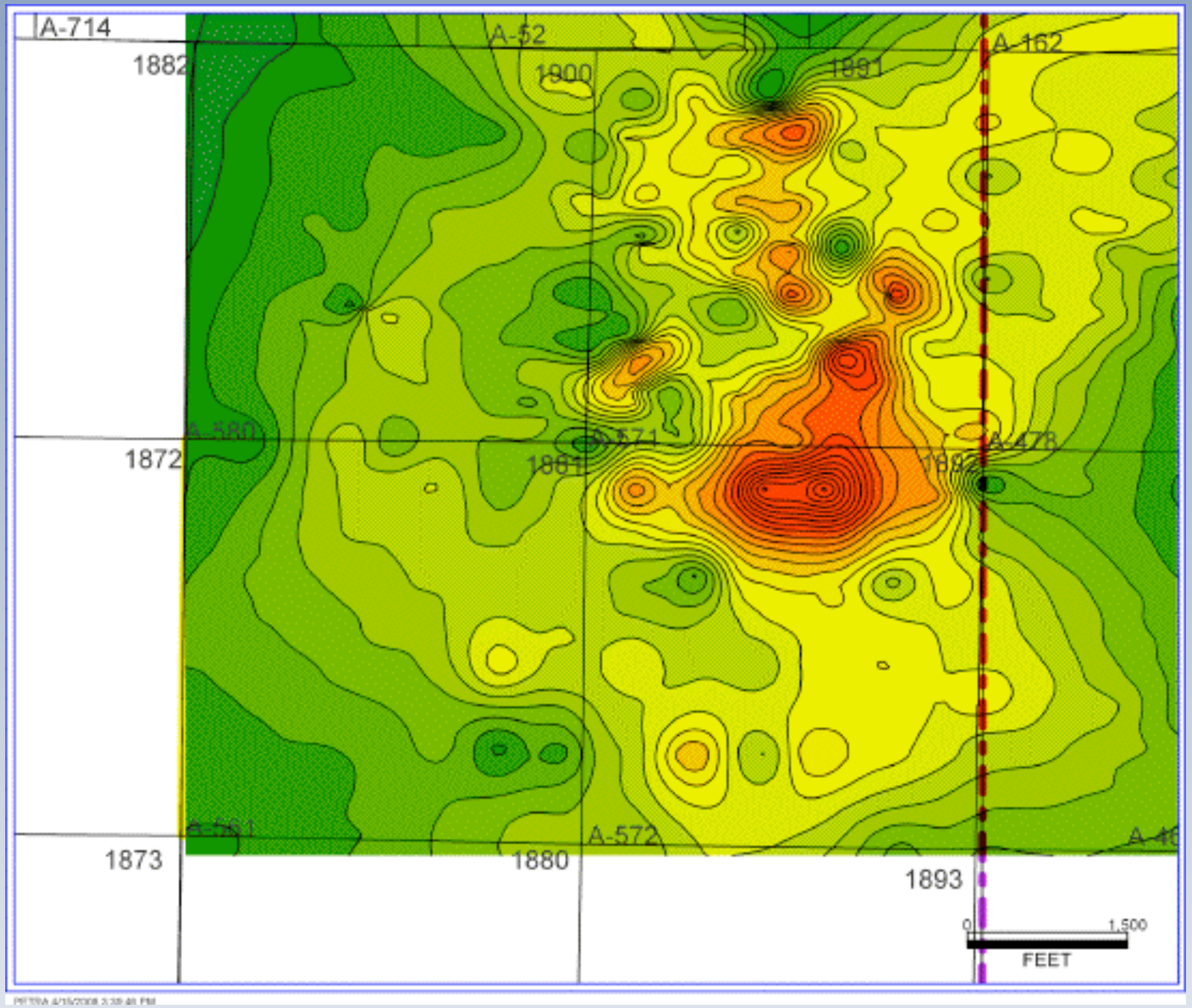
Survey Process



Survey Process



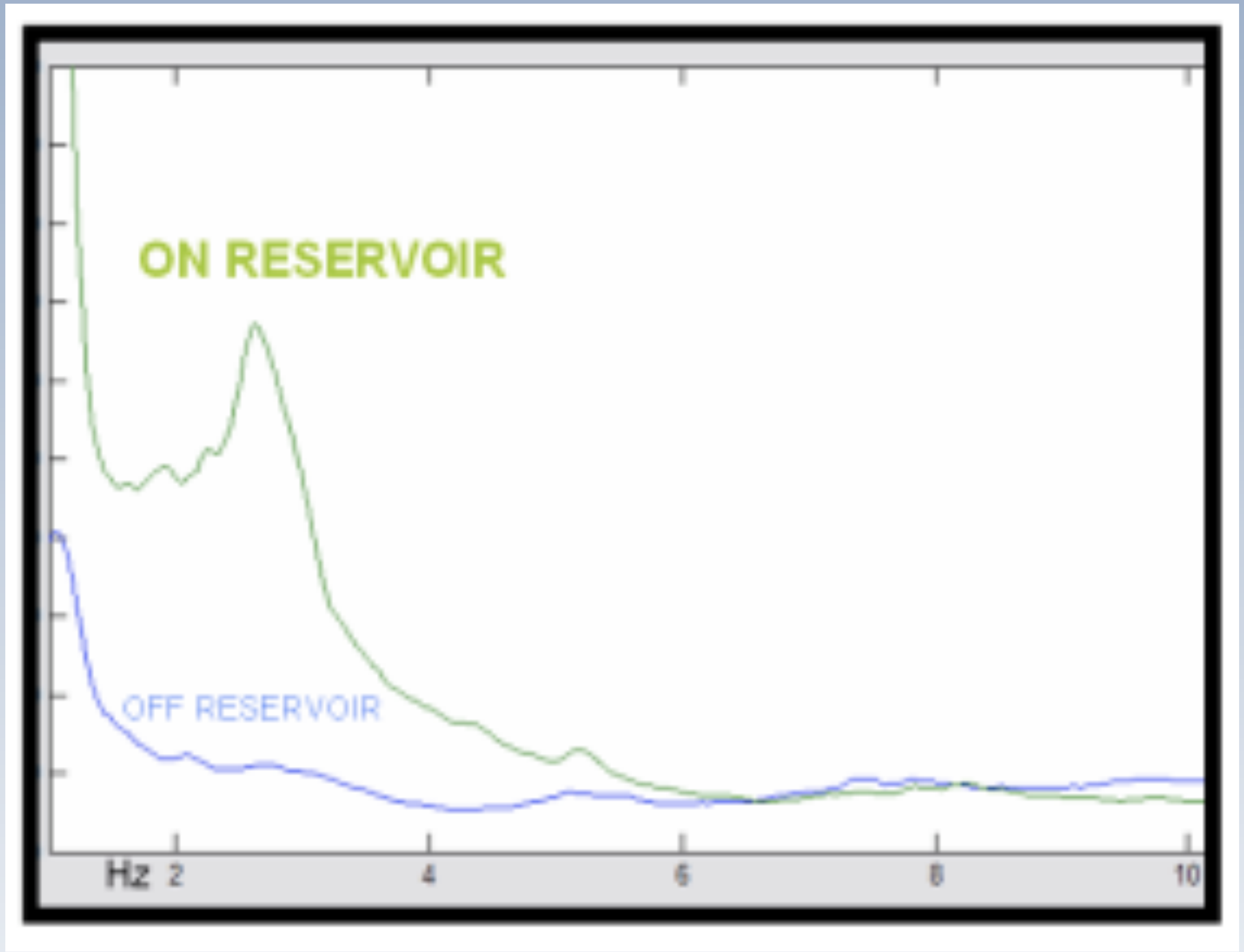
Survey Process



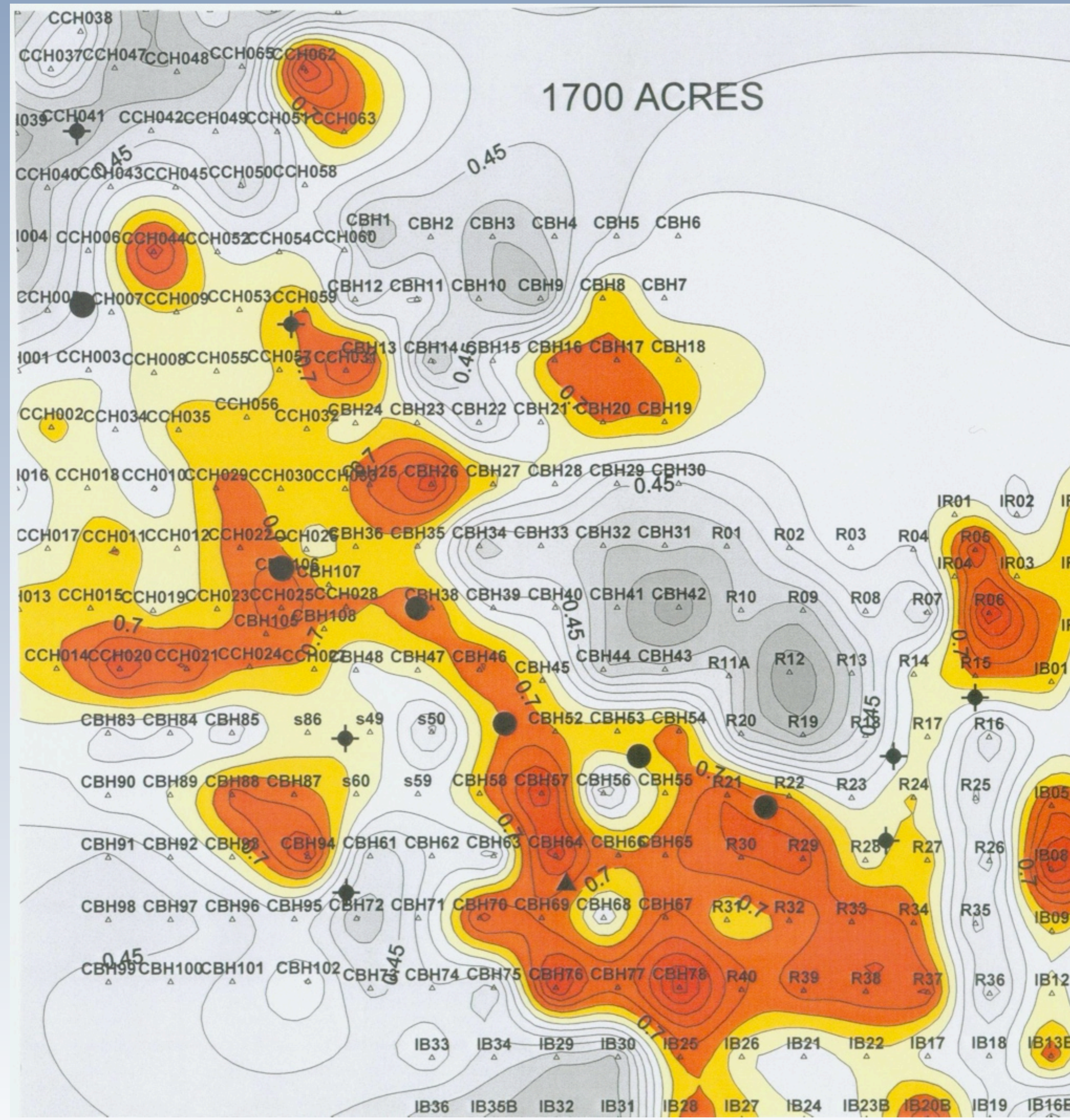
Survey Process

Examples

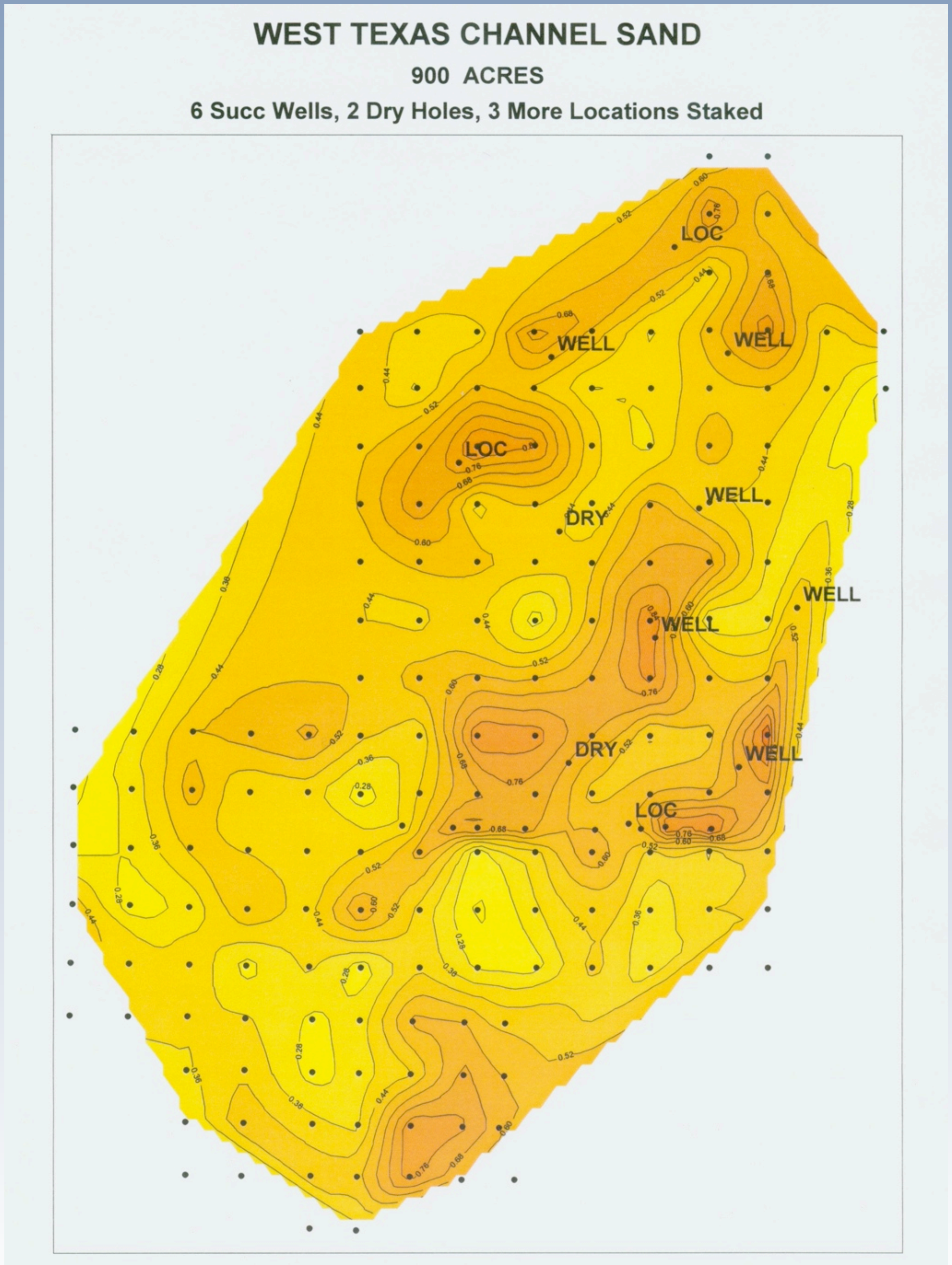
Alabama On Reservoir Example



West Texas 1700 Acres

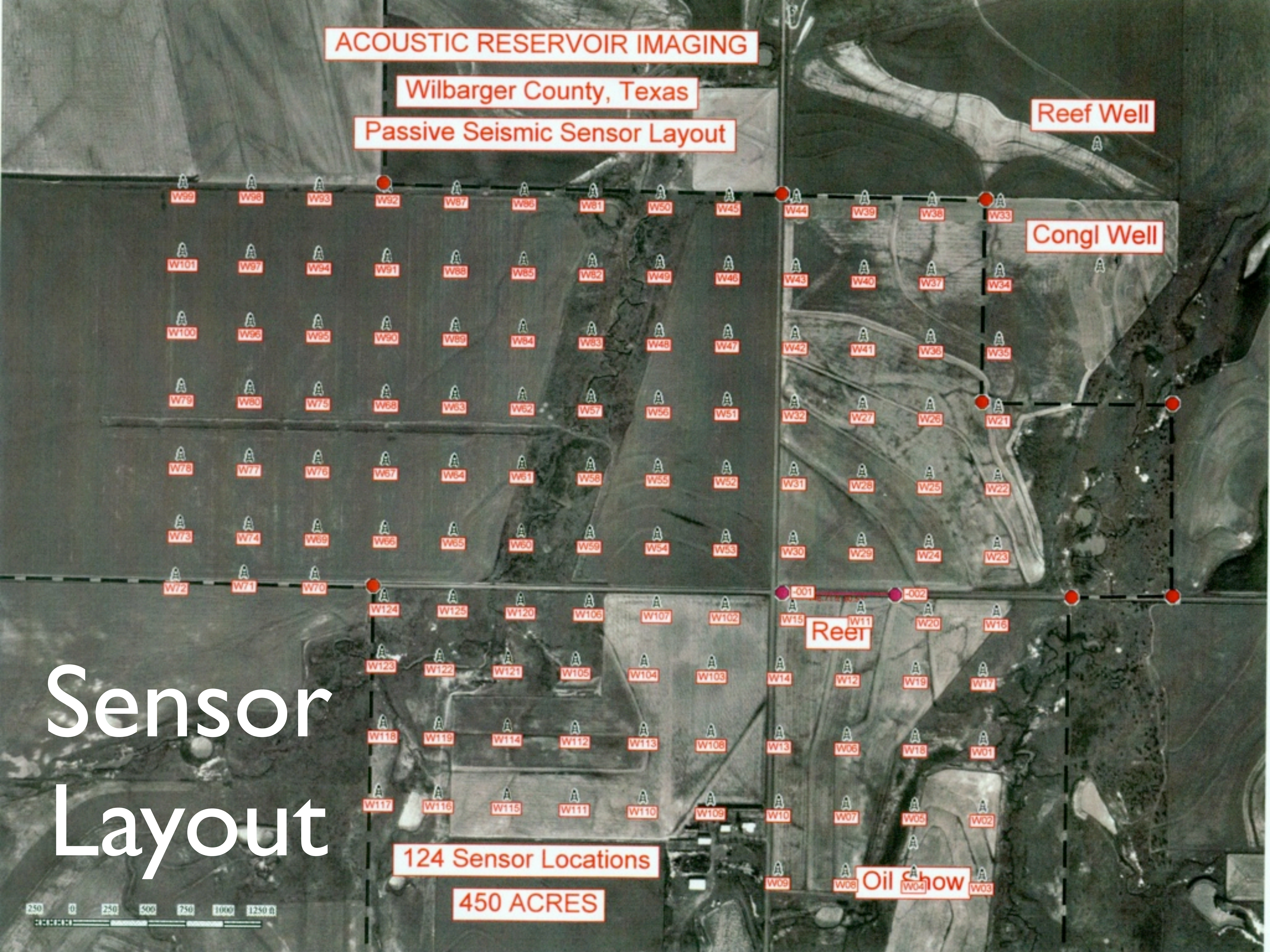


West Texas 900 Acres

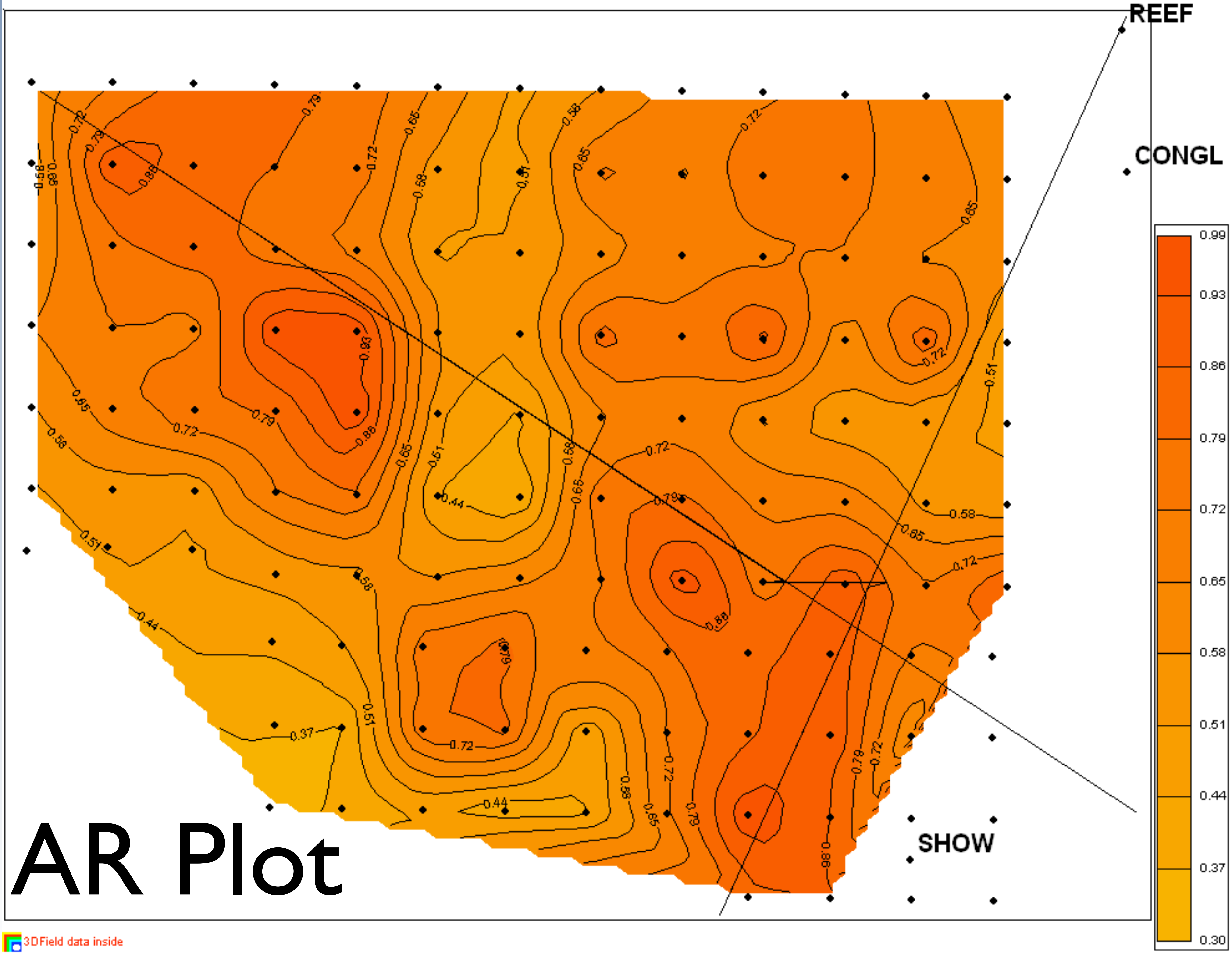


Wilbarger Case Study

Sensor Layout



AR Plot


REEF
CONGL
SHOW
0.99
0.93
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0.51
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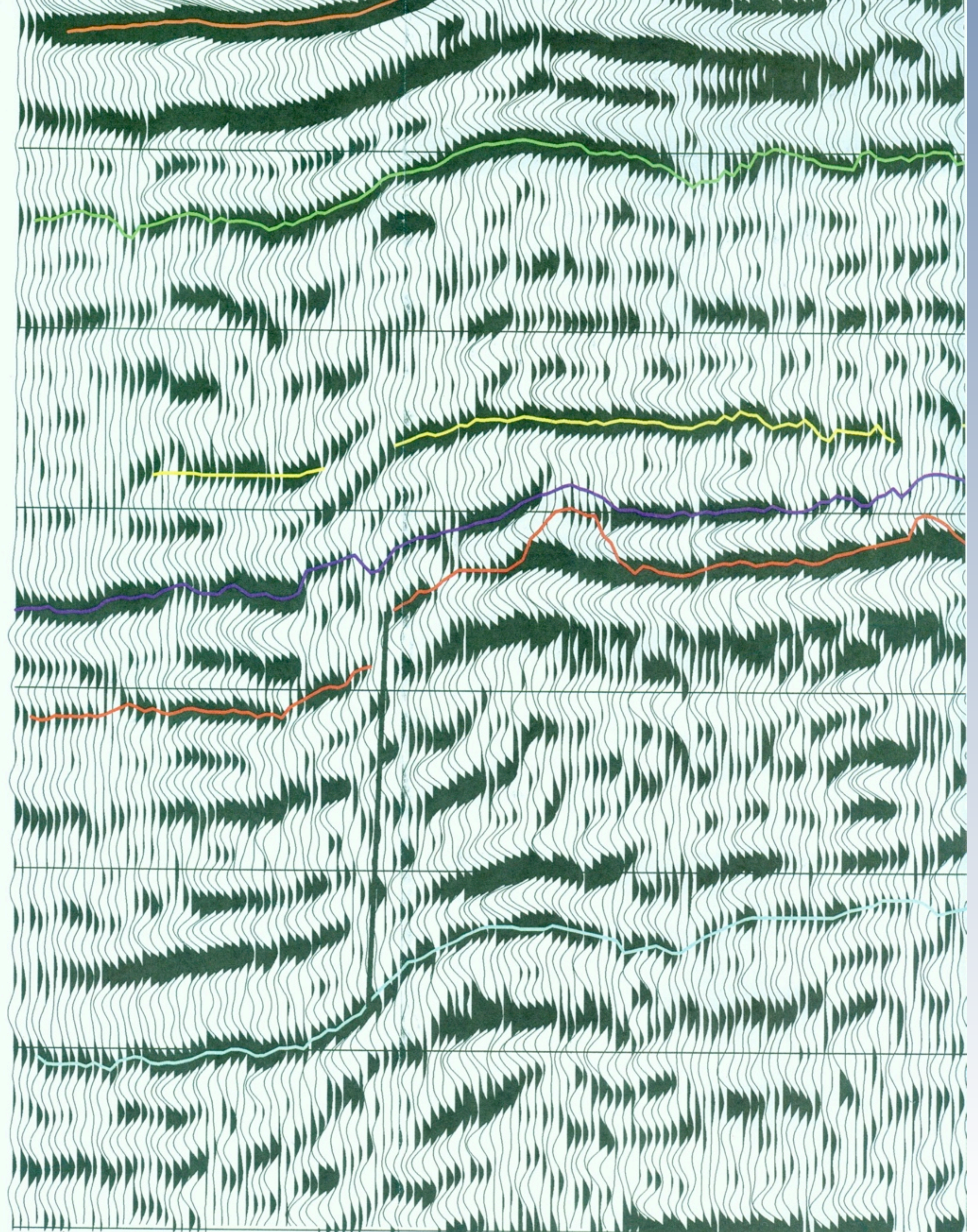
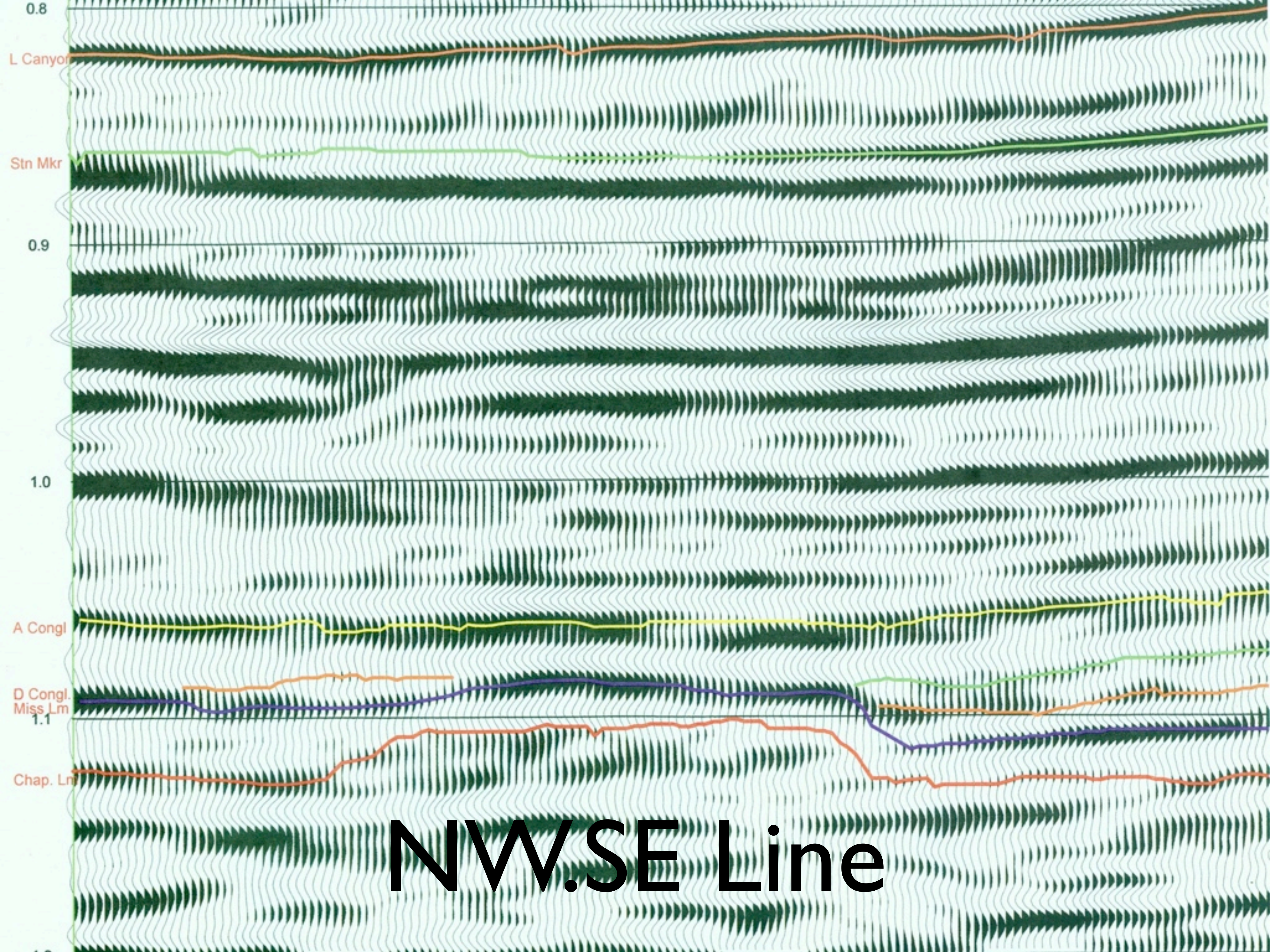
0.30
3DField data inside

Reprocessed Line




NE.SW Line



NW.SE Line

Discussion of Improved Data Acquisition and Interpretation with New Equipment and Processing Program

ARI

Acoustic Reservoir Imaging