# Abstract

START HERE!

A new tool for exploration is a data volume of rock properties in a form compatible with seismic data, but derived from well information. Such volumes can be prepared for fundamental rock properties such as shale P-wave velocity, or for derived properties such as gas sand shear wave velocity, normal incidence reflectivity at a shale-gas sand interface, or Poisson reflectivity of an oil sand.

# Introduction

One of the perennial problems in exploration is putting well information into a form where it can be easily related to seismic data. An additional tool for this is now available: data volumes of rock properties in SEG-Y format, generated from well logs. These volumes are compatible with all standard seismic interpretation systems, and can be used by the interpreter to constrain interpretation of seismic data by giving the probable properties of rocks in an undrilled prospect.

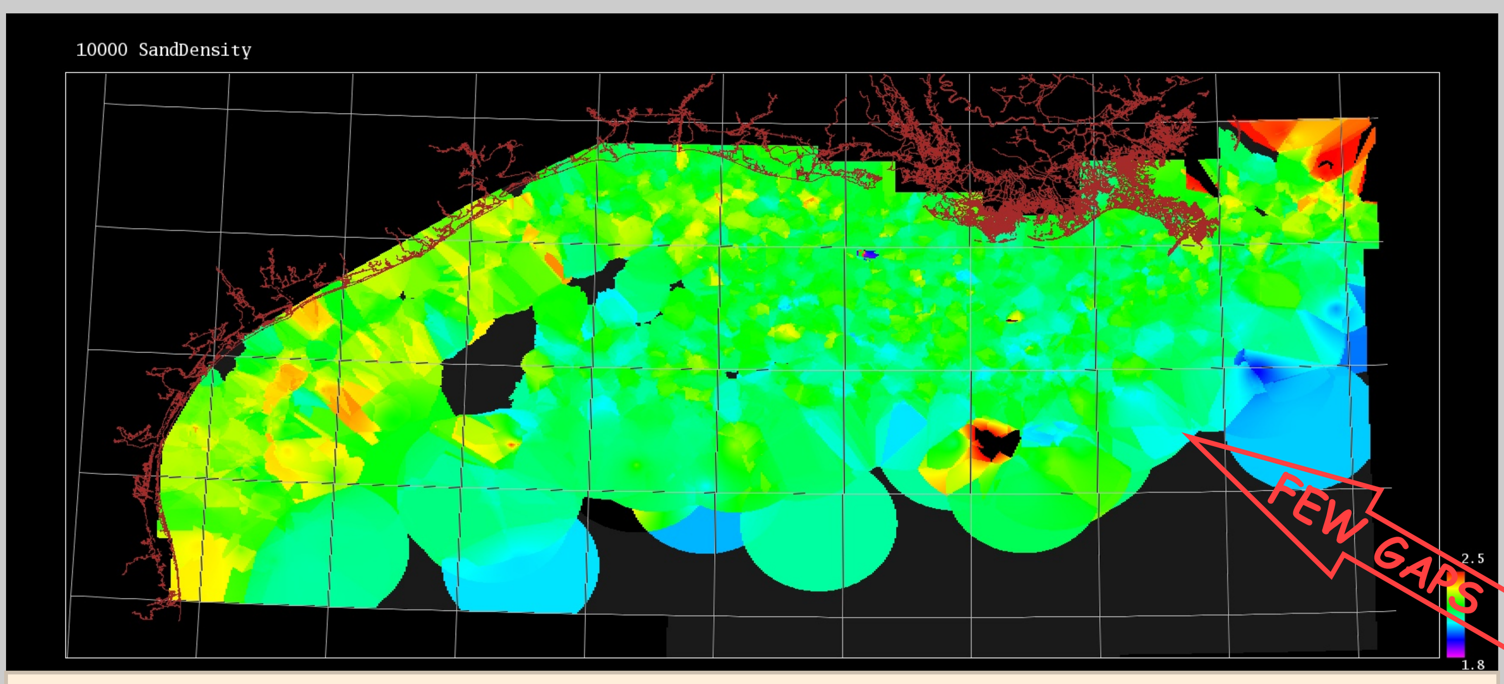


Figure 1 Sand density at 10000 ft (3050 m)

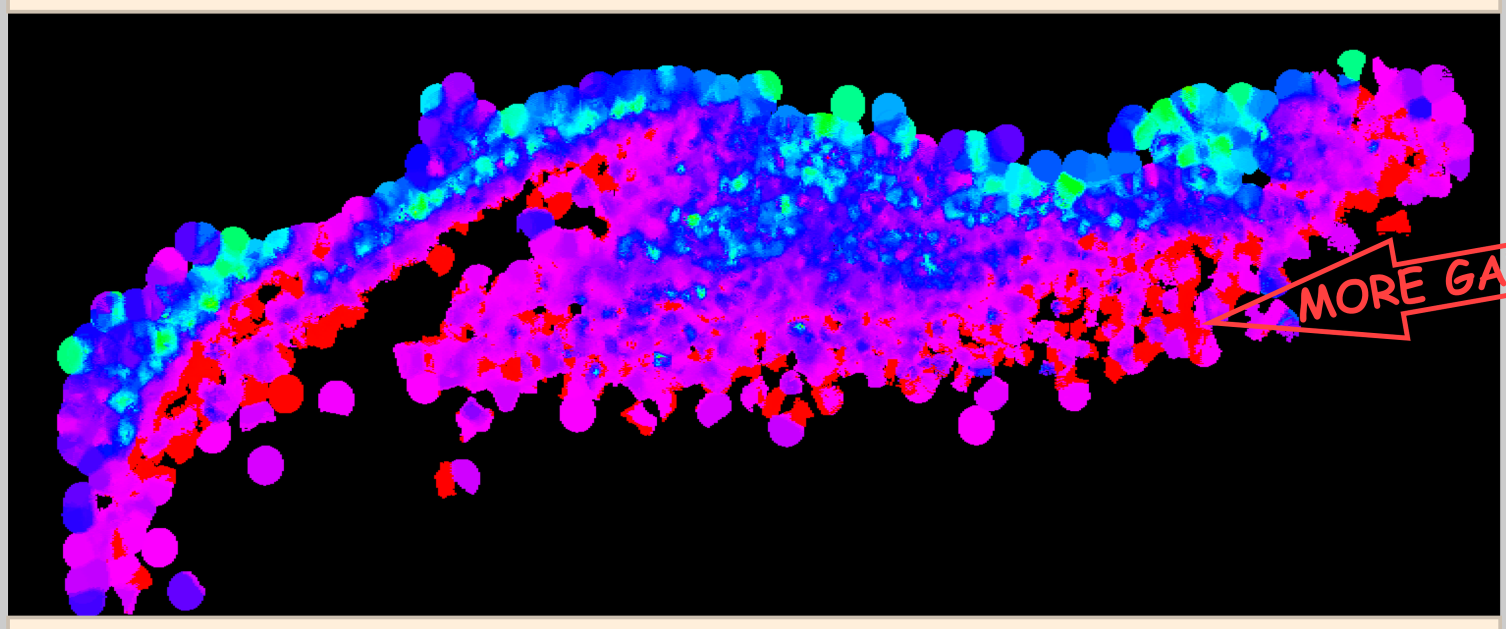


Figure 2 Proportion of sand at 5000 ft (1524 m) using what is apparently a barely adequate extrapolation distance between wells. The individual wells can be seen as circles in many places, and there are significant gaps in the data.

# How the volumes are generated

The starting point for the rock property volumes is the standard suite of well logs recorded in most wells. The standard set of rock properties in a dominantly clastic sequence requires velocity, density and resistivity logs. Properties computed using fluid replacement require measurements or assumptions about properties of the fluids, especially density of the oil and gas, and salinity of the water. Temperatures used are based on the temperature measurements made while logging, and formation pressures are estimated from drilling mud weights.

A petrophysicist classifies the rocks penetrated by each well, separating intervals into water-filled sand, shale, and all other lithologies (salt, coal, limestone, hydrocarbon-filled sand, etc.). These last intervals are excluded from the analysis.

Wells are then divided into uniform depth intervals, using an interval large enough to contain significant quantities of both shale and water-filled sand, but small enough to adequately describe systematic variations. If the chosen interval is too small, many of the intervals will contain only sand, or only shale. If the interval is too large, there may be significant differences in rock properties from top to bottom, due to the difference in compaction, and more depth samples will include rocks with widely varying depositional environments. For the Gulf of Mexico, the interval chosen is 200 ft (61 m).

For each interval, the averages of the fundamental properties of sand and shale are computed, along with the amounts of sand and shale within the interval and the variation of each property within the interval (recorded as standard deviation). Additional rock properties can be computed from the fundamental properties using standard procedures such as the Greenberg-Castagna technique(Greenberg & Castagna, 1992) for computing shear-wave velocities, inverse Gassmann's equation (Gassmann, 1951) for computing dry-rock properties, and Gassmann's equation along with the dry-rock properties to compute the properties of hydrocarbon-filled sands (Hilterman et al, 1999, Hilterman, 1990, Hilterman et al, 1998).

Once the well database is constructed, the SEG-Y volumes can be generated. There are several points to be considered:

The questions start at the top of the next column .

# The Questions

## What trace interval should be used for the volume?

A close trace interval is likely to be more useful in comparing rock properties with seismic data, but may give a misleading impression of reliable detail. A trace grid exactly matching that of an existing 3D survey may be particularly useful. Most of the work done so far involves regional data volumes with a trace spacing much larger than normally used for seismic data. Where logs are available from a large number of wells in a developed field the horizontal sampling by the wells may be comparable to the seismic sampling. In such cases, the detail in the well data volume may be as good as that in the seismic volume.

## How far should we interpolate between wells or extrapolate from a single well?

In areas with many wells, this is not a critical decision, but in the deep water areas of the Gulf, for example, where wells are widely spaced, it is an important parameter. Even when interpolation is adequate at shallow depths (Figure 2) it may not be deeper (Figure 3). A plot of the valid samples for each trace (Figure 5) may help the user choose the best compromise: using too large a distance rapidly increases the computation effort and may give the impression of reliable information where there is none; and using too short a distance leaves large gaps in the data volume.

THIS ONE'S MOSTLY GAPS

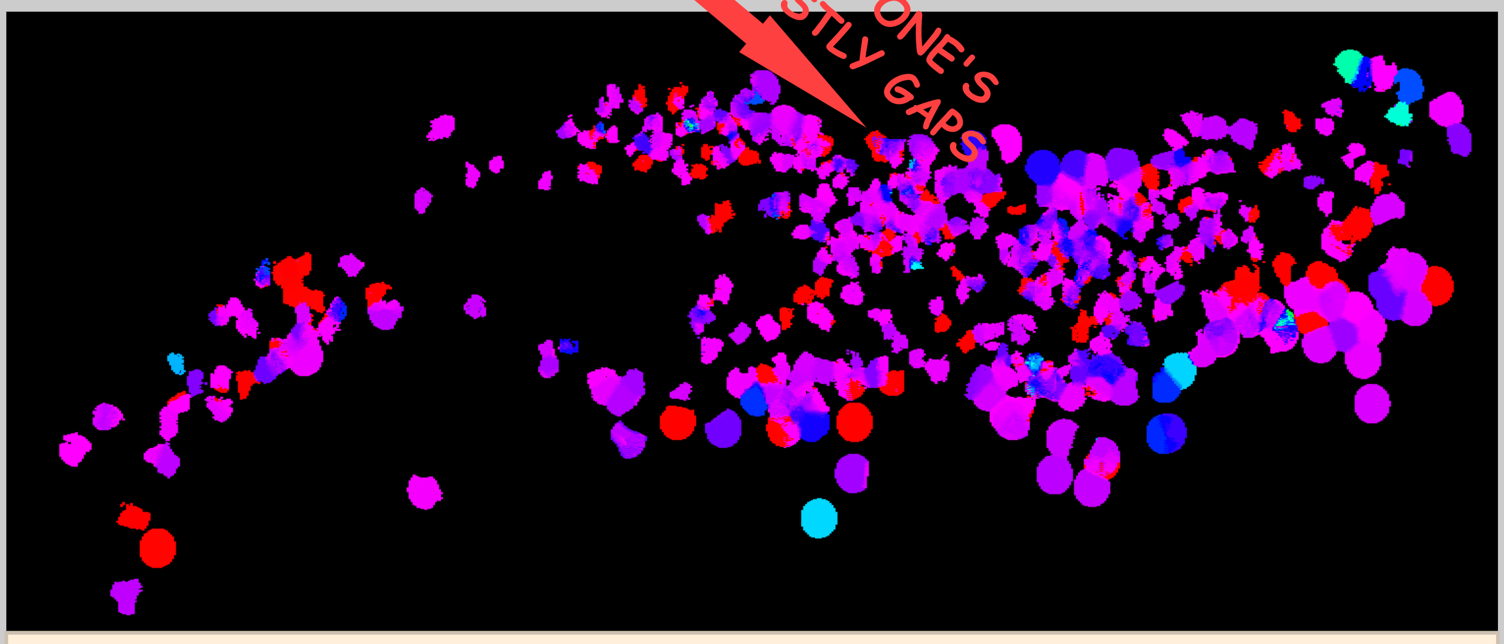

Figure 3 Proportion of sand at 10000 ft (3050 m) using the same extrapolation as Figure 2. At this depth the extrapolation distance is clearly inadequate.

## What map projection should be used?

The well locations are defined in latitude and longitude, but a SEG-Y 3D data volume must be defined in a projection. For a regional volume, the differences between projections can be quite noticeable: we have generated volumes over most of the Gulf of Mexico using both the Louisiana South projection and Universal Transverse Mercator Zone 15 Figure 4). In both cases the area covered goes well beyond the area normally used for the projection.

IT MAKES A DIFFERENCE WHEN YOU GET AWAY FROM THE ORIGIN

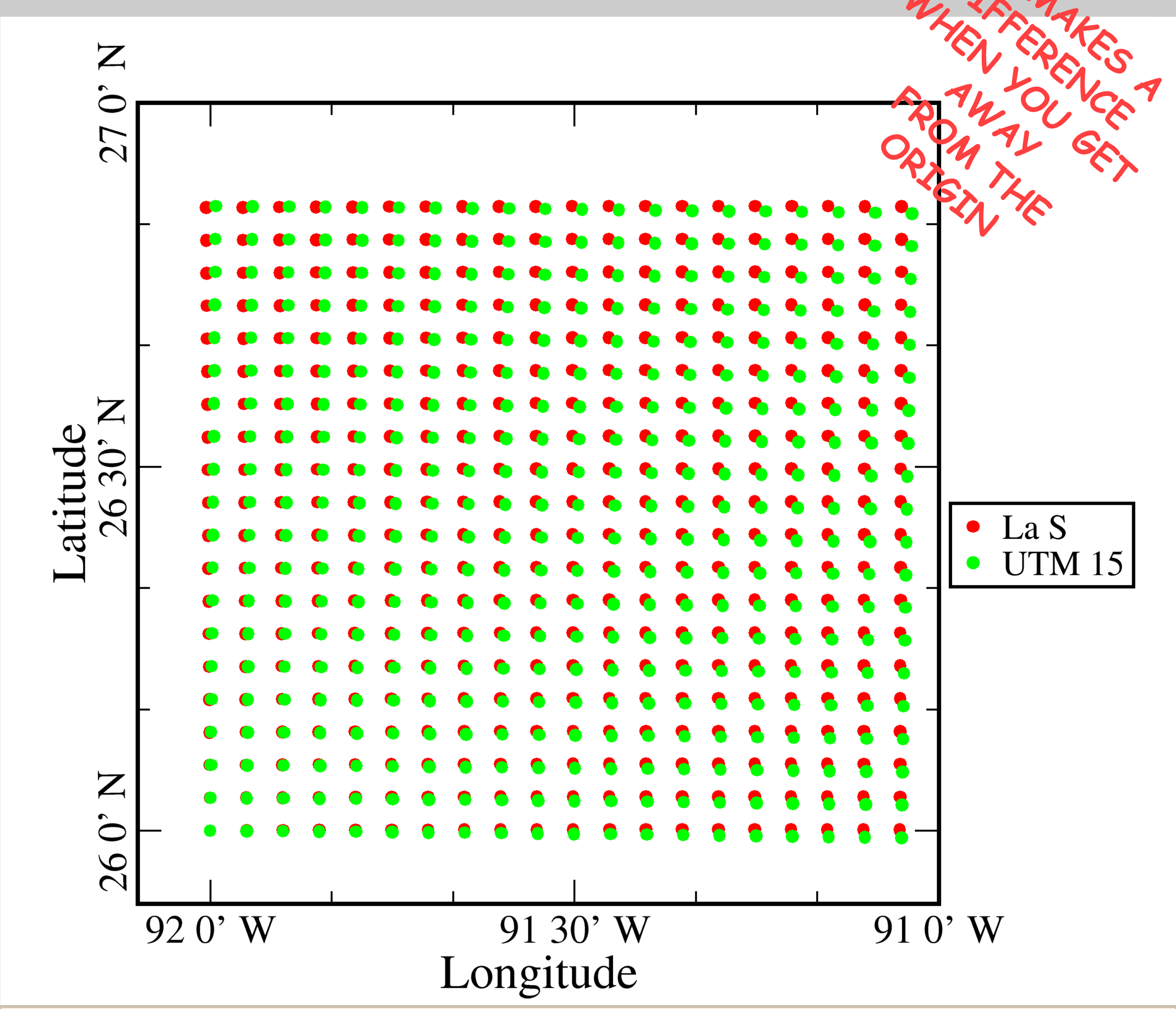


Figure 4 Bin centers computed on two different projections: Louisiana South State Plane, and Universal Transverse Mercator Zone 15

More questions next poster

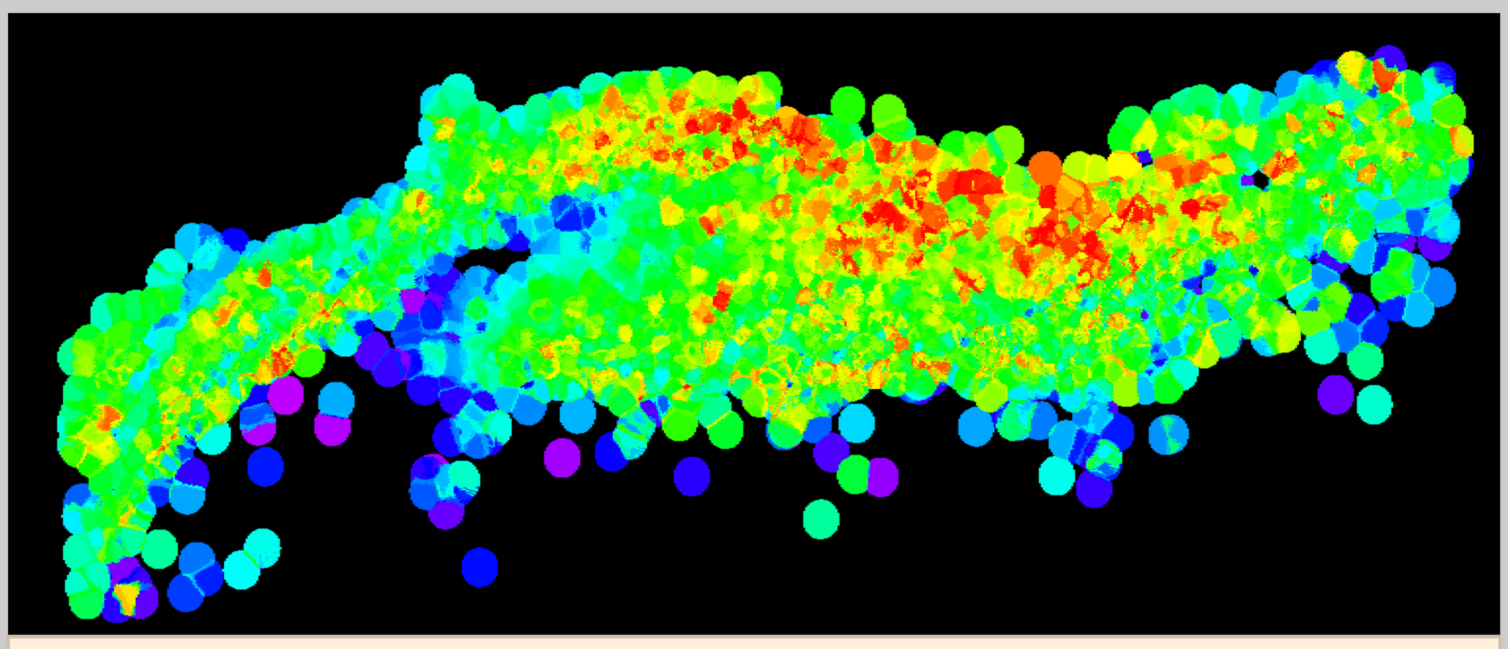

Figure 5 Total number of valid samples per trace for the data volume shown in Figures 2 and 3. The red values are high, and the blue and magenta values are low.

## How far should we interpolate or extrapolate vertically?

Wells are often missing log data from part of their depth range, and sand properties may be missing over a depth range simply because there is no sand for several hundred feet. The well database is carefully constructed to leave gaps where data is missing, but by producing traces on a regular grid we always generate values where there are no data. How far do we want to carry this process? (Figures 6-9)

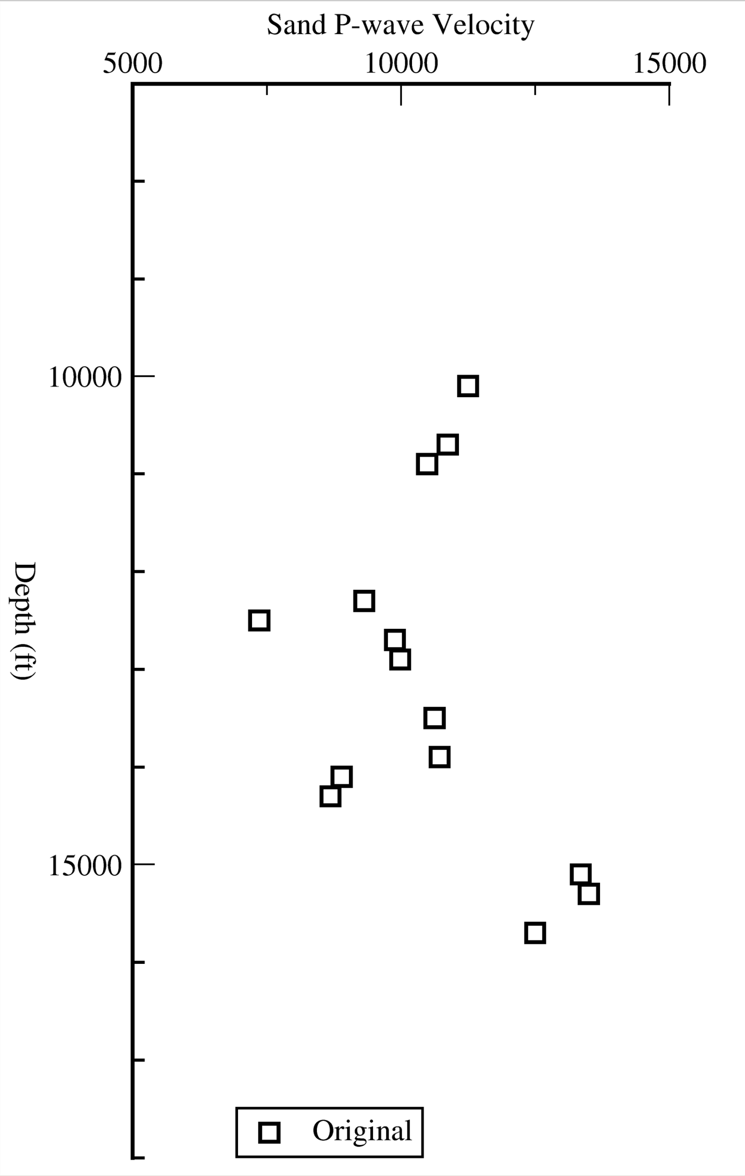


Figure 6 Sand velocity data: 200 ft sample interval, with many gaps.

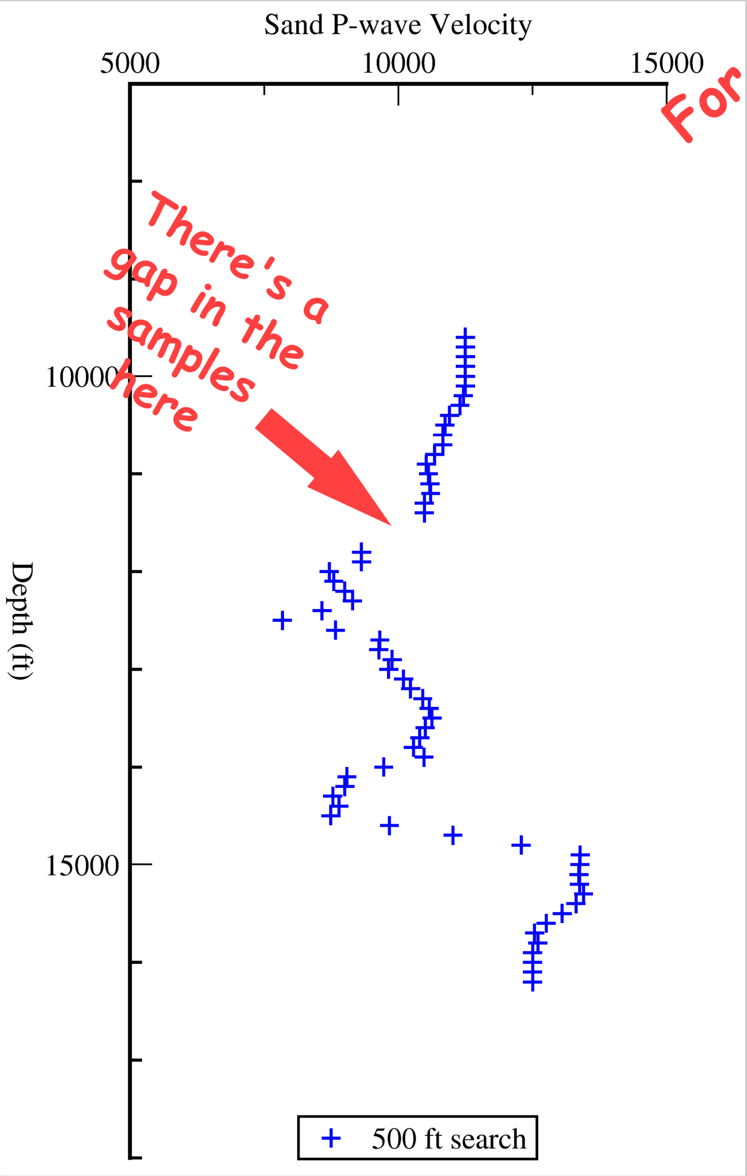


Figure 7 Interpolated with 100 ft samples and 500 ft vertical search distance.

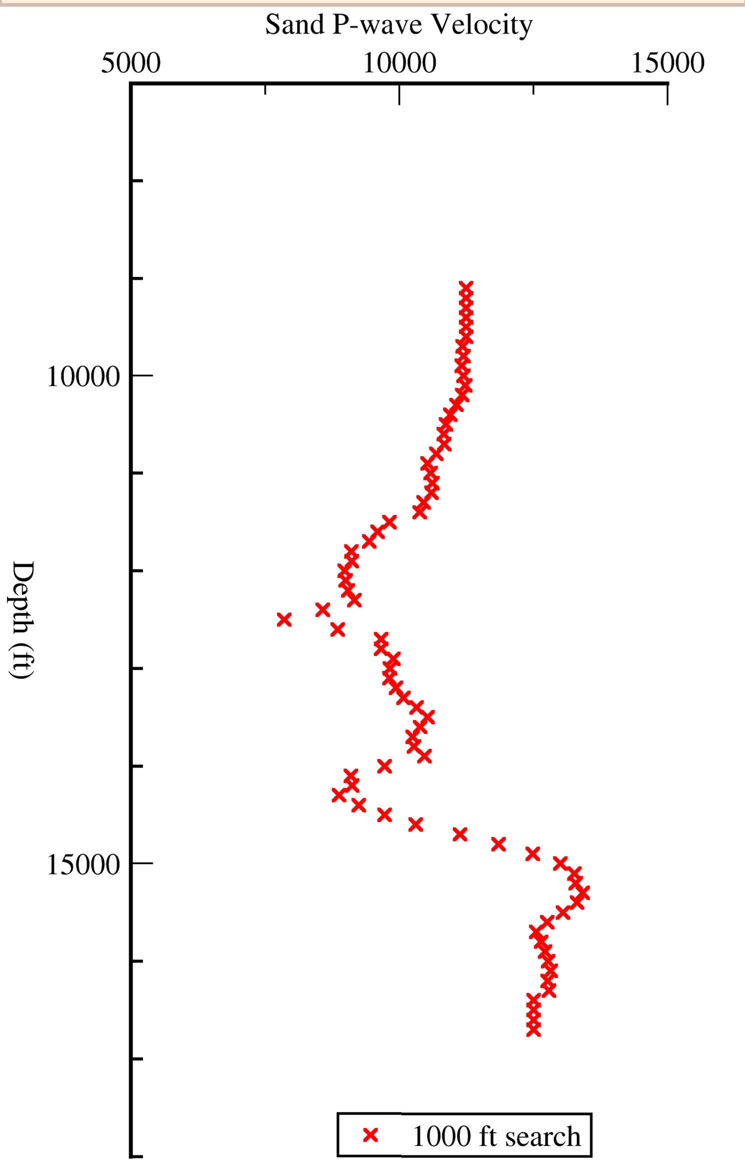


Figure 8 Velocities interpolated with 100 ft samples and 1000 ft vertical search.

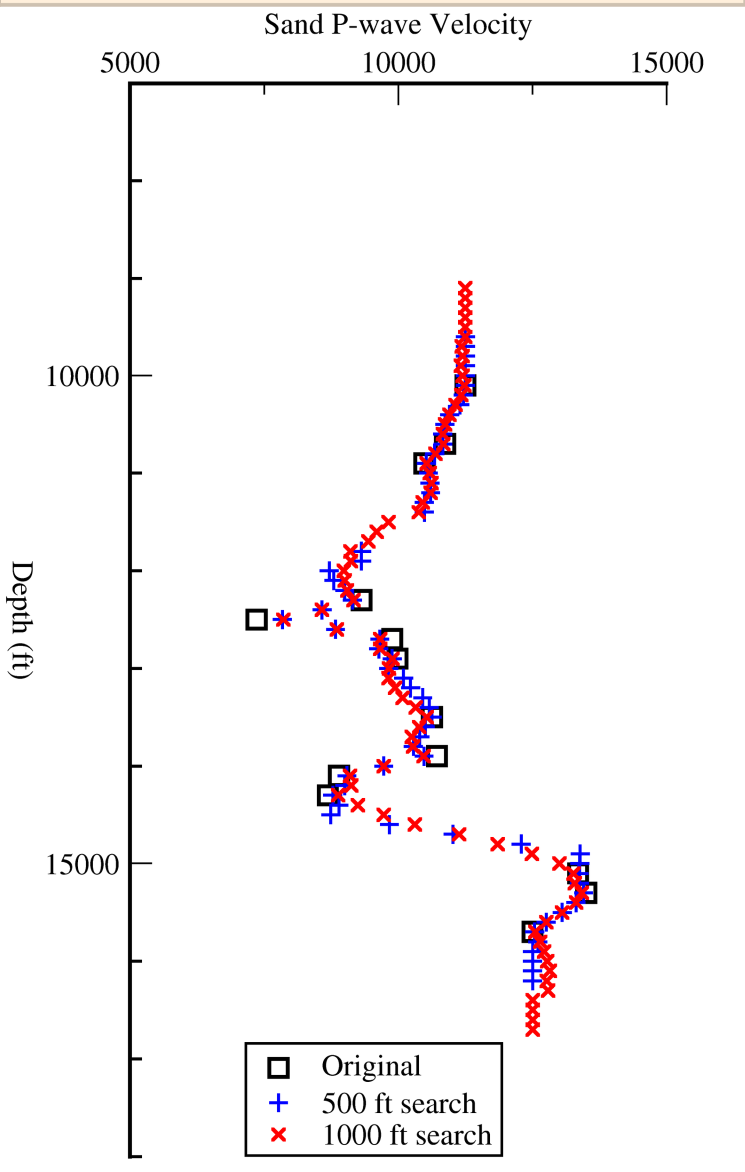


Figure 9 Original velocities with both interpolations.

## What vertical sample interval should be used?

The wells are sampled at a fixed interval, but there is no reason why the volume generated should use the same interval. A closer interval will give a smoother transition in areas where there are abrupt changes in properties with depth. The volume could also be generated in reflection time, to match seismic data, if desired. In most cases there will be adequate velocity control from the well information alone to do this.

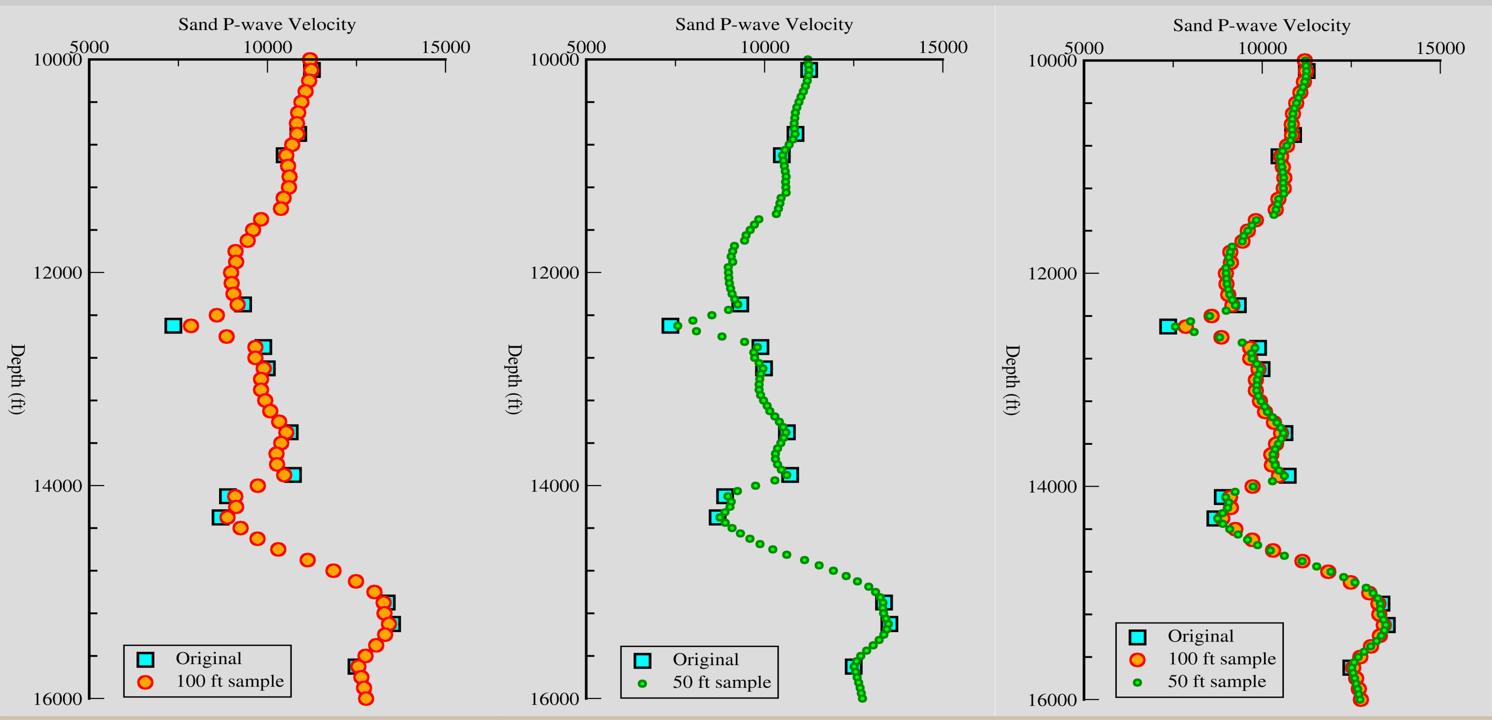


Figure 10 Vertical sampling at 50 ft and 100 ft intervals

Another question at the top of the next column

## Should the area of the volume be limited?

You might want to do this to restrict computation to a lease line, or to stop extrapolation of the data into an area of low interest or sparse data or across a major fault. This was done in Figure 1 On your left

## With these questions answered, we can start computing the volume

For each trace

Compute the X and Y coordinates for each bin center, using the specified grid: origin, orientation and spacing of inlines and crosslines. This sets up the grid

Convert the location to latitude and longitude (the only uniform location information in the well database for all wells is the geographic location: the map projection used for X and Y coordinates varies with state and zone).

Check that the trace is within the area of interest (if defined by a limiting polygon).

Identify all wells within the specified extrapolation distance.

within each trace

For each sample:

1. Search the identified wells for data within the vertical interpolation distance specified.
2. Compute a weighted average value of the desired rock property, weighting the well data inversely with distance, and inversely with difference in depth from the depth of the sample.

As each trace is completed, it is written in 32-bit floating point format to a standard SEG Y format file.

This file can be loaded into any standard seismic interpretation system.

The generation of these volumes takes time, so we generate graphical progress reports (updated every 1000 traces), allowing the user to check that the values used for interpolation and limits on the area covered are realistic without waiting for the job to finish.

These plots are of two forms:

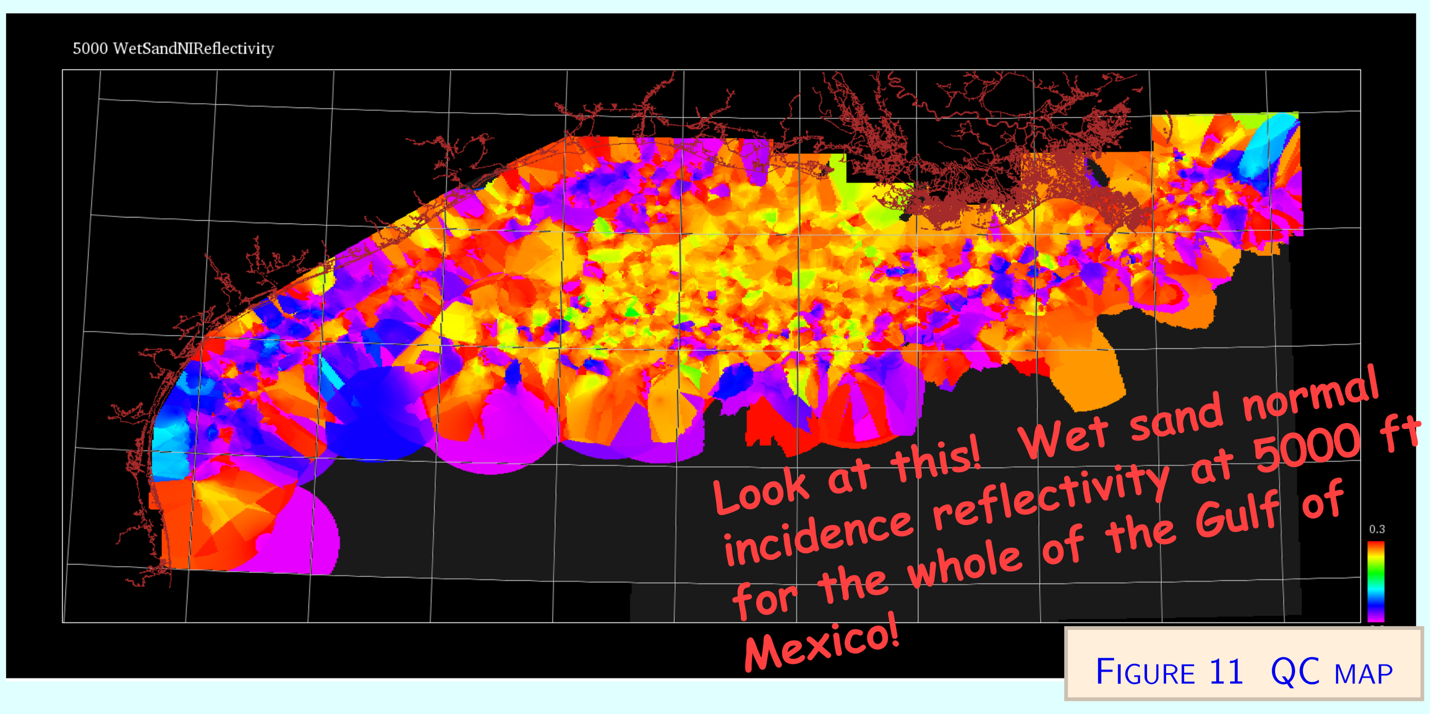


Figure 11 QC map

Maps . . .

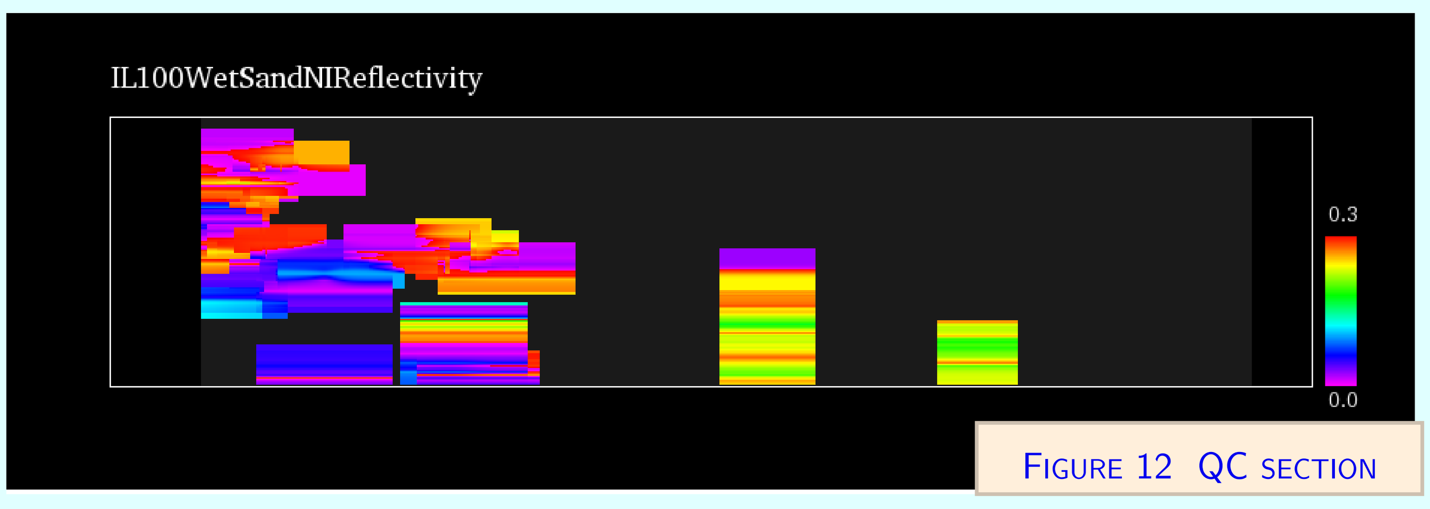


Figure 12 QC section

. . . and sections.

Thanks for dropping by! Don't forget to look at details of the database on posters 4 and 5.

# Rock Property Data Volumes from Well Logs

L. R. Denham*, Interactive Interpretation & Training, Inc.
H. Roice Nelson, Jr., Geokinetics Processing & Interpretation

## How the volumes are generated

## How the database was built

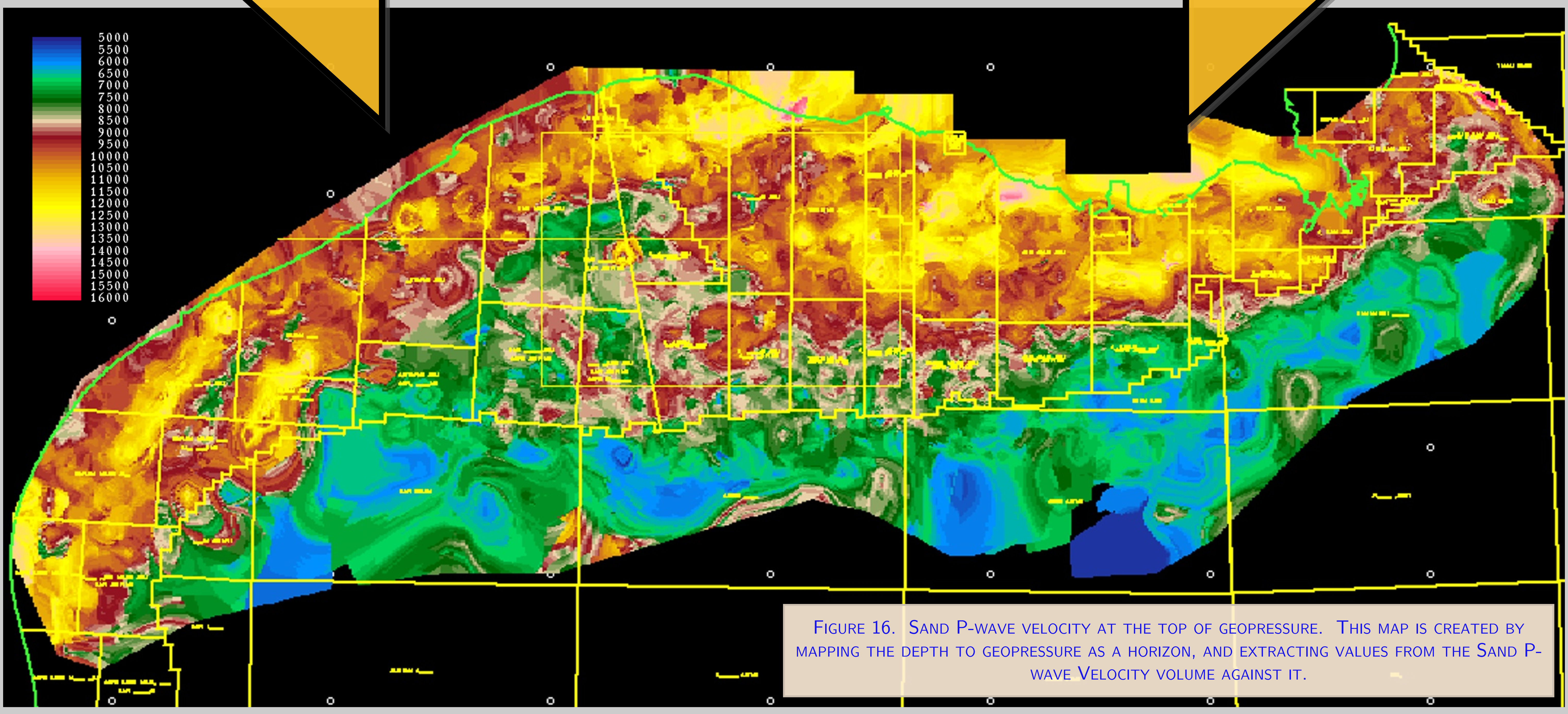

Figure 16. Sand P-wave velocity at the top of geopressure. This map is created by mapping the depth to geopressure as a horizon, and extracting values from the Sand P-wave Velocity volume against it.

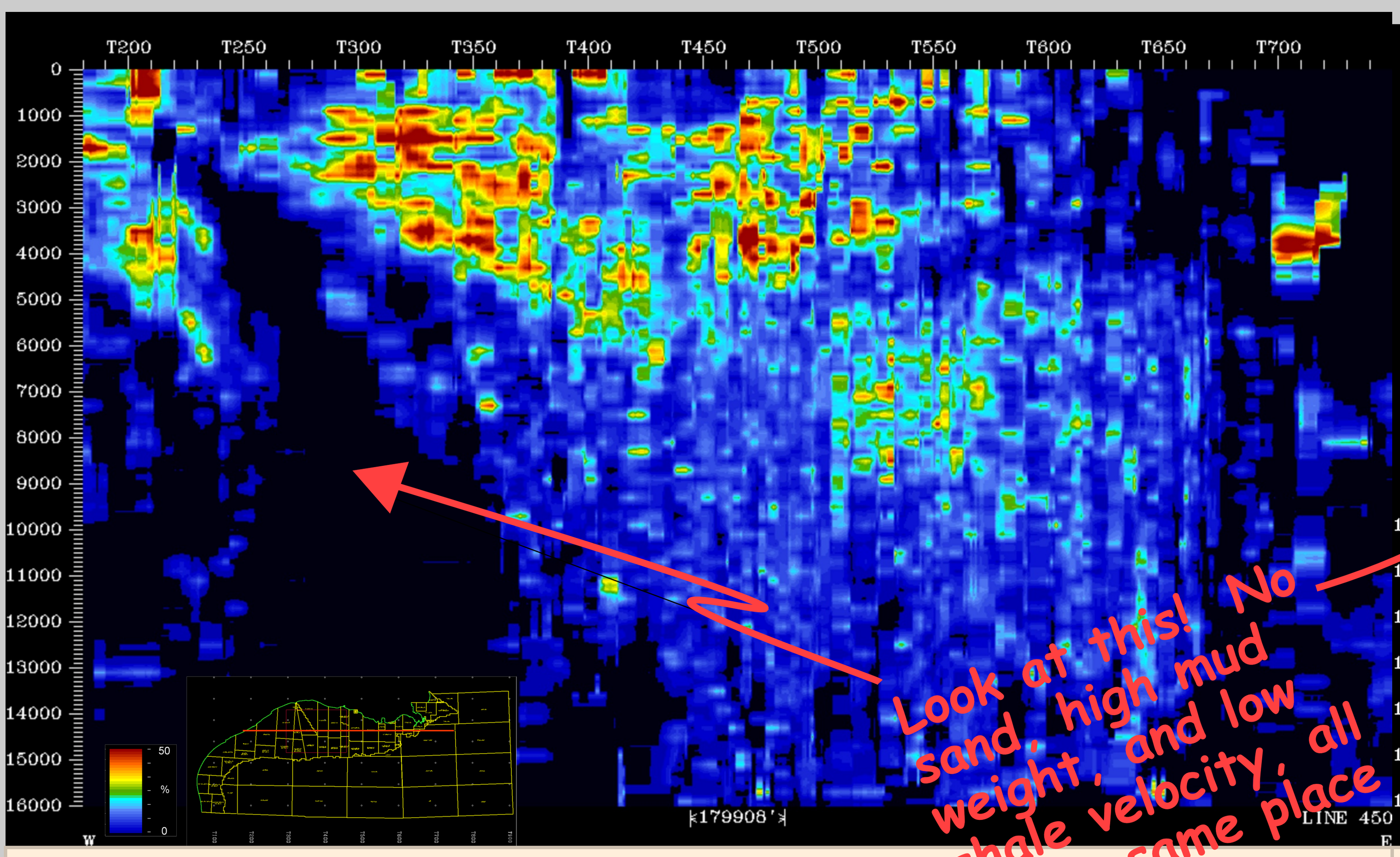


Figure 17 Vertical section through Sand Percentage Volume

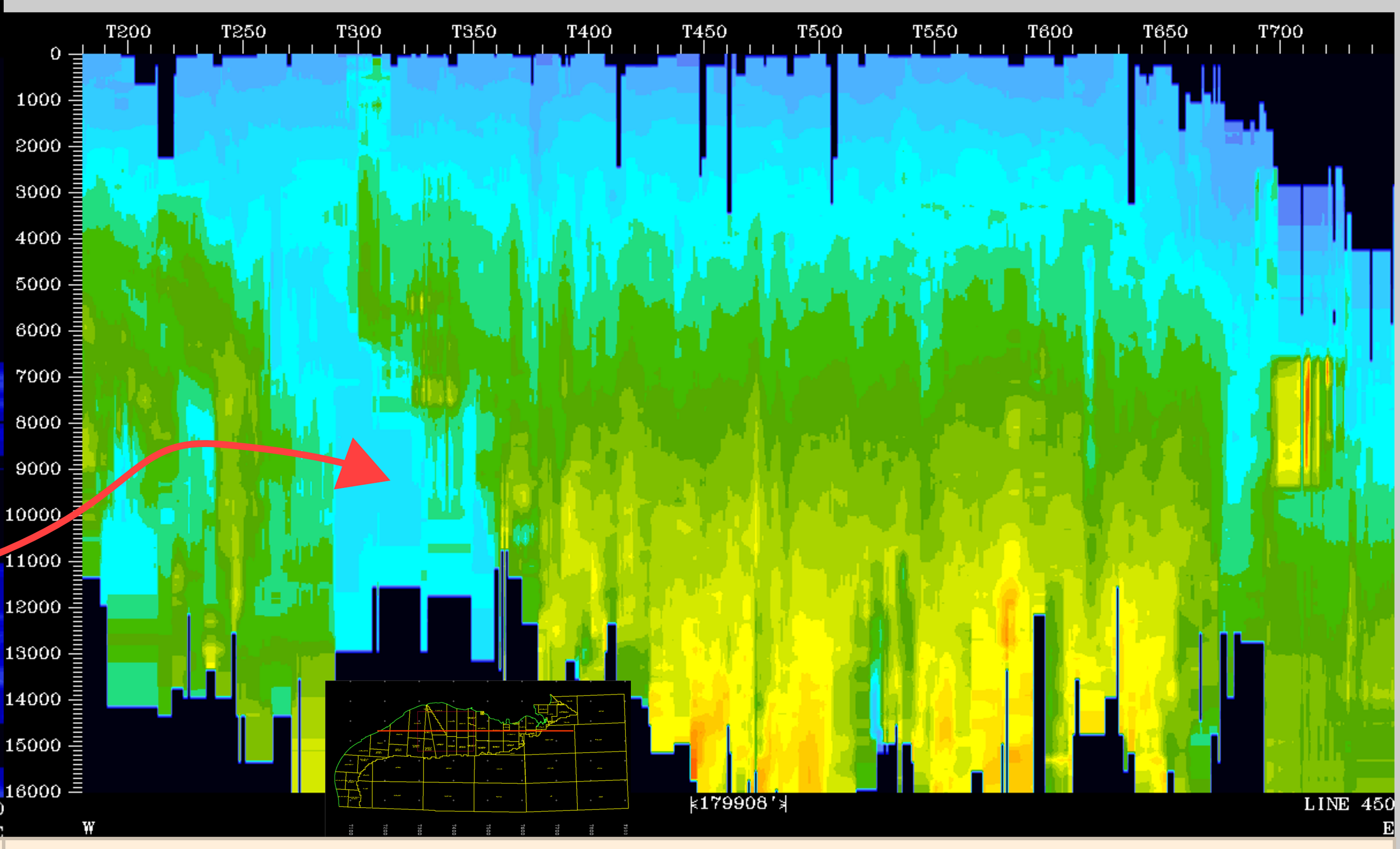

Figure 18 Vertical section through Shale P-wave Velocity Volume

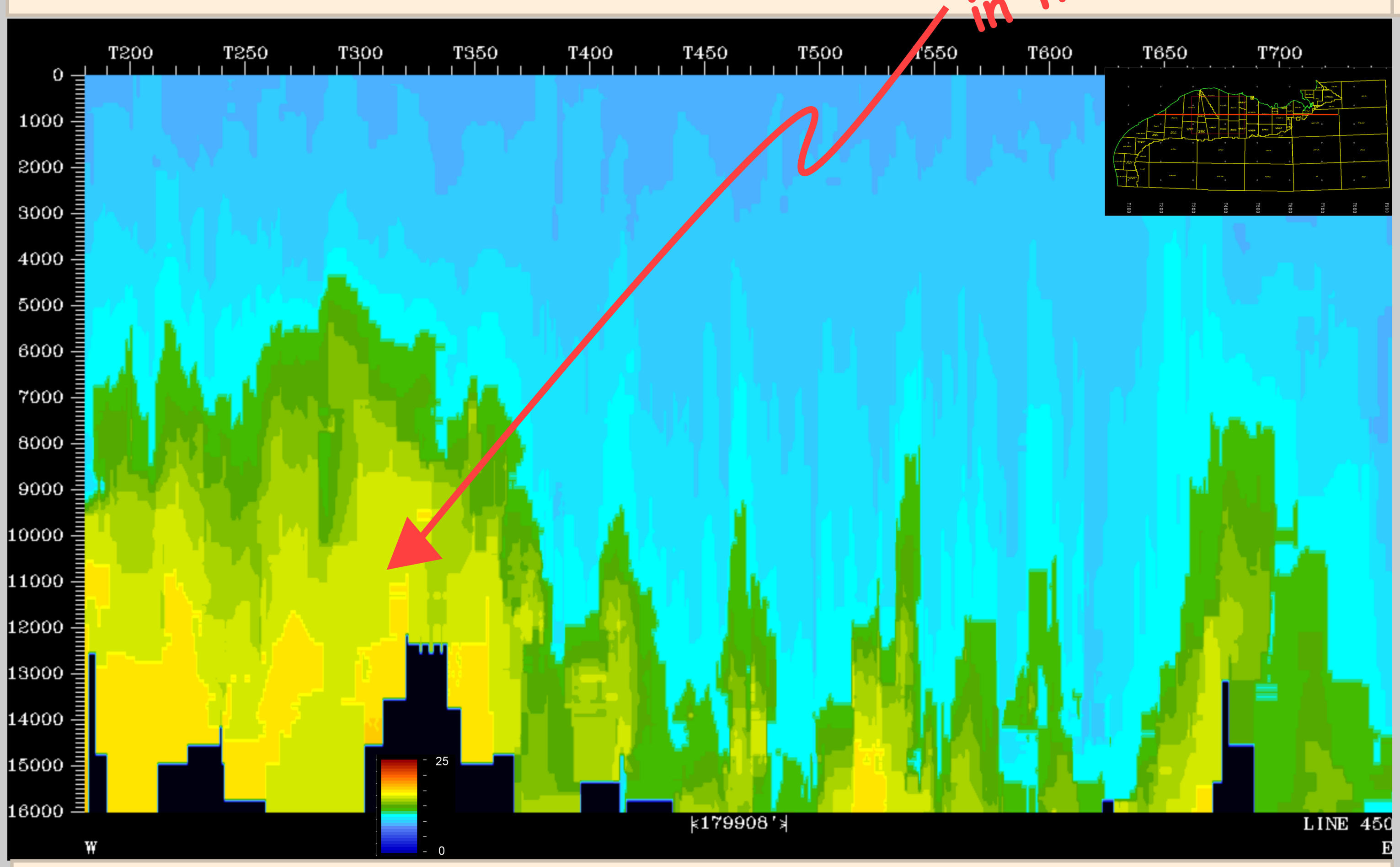

Figure 19 Vertical section through Mud Weight Volume

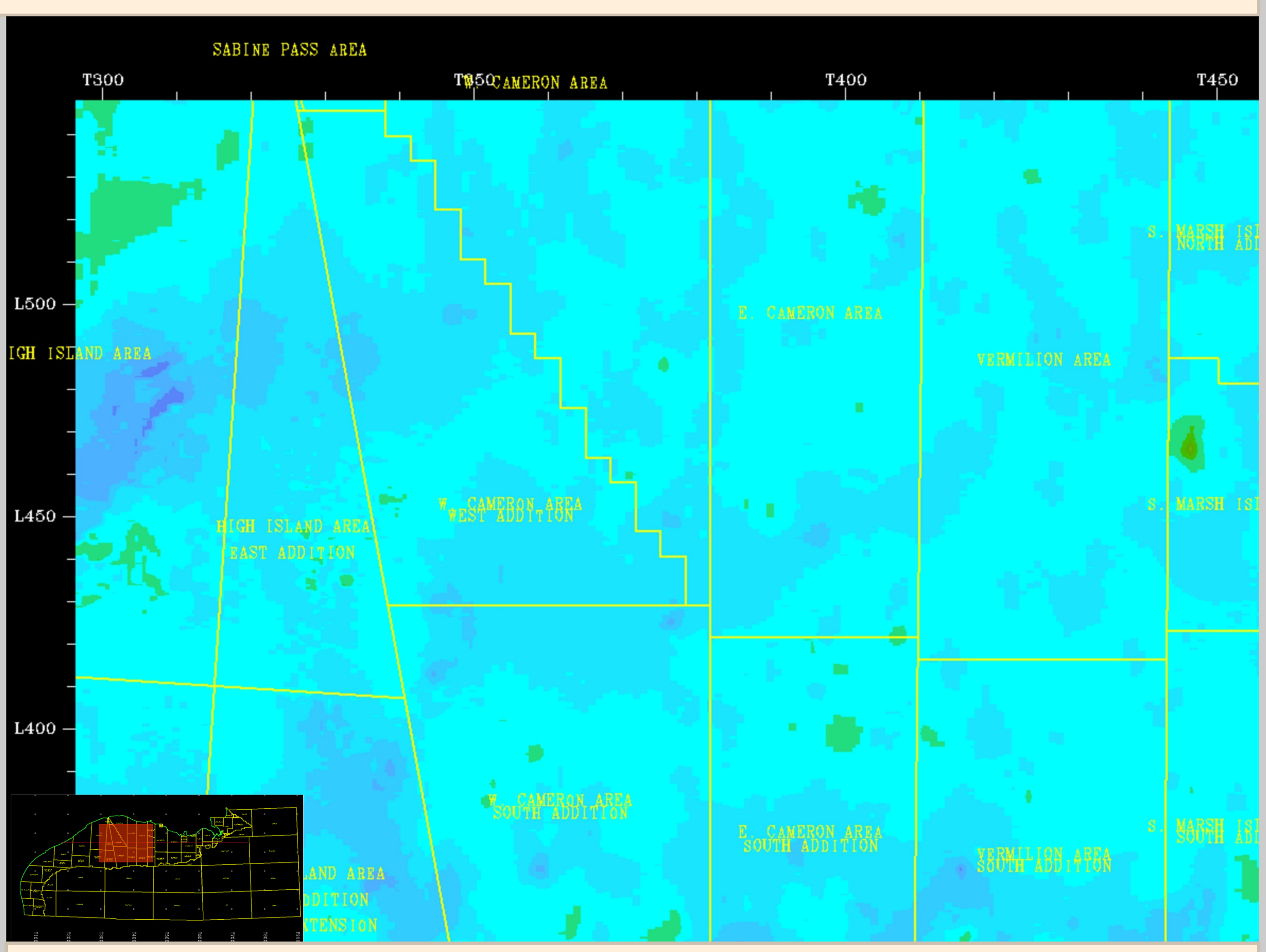

Figure 20 Depth slice through Shale P-wave Velocity Volume at 6000 ft

References

Barry, K. M., Cavers, D. A., and Kneale, C. W., 1975, Report on recommended standards for digital tape formats: Geophysics, 40, no. 02, 344–352.

Denham, L. R., and Johnson, D., 2006, Estimating probability of hydrocarbon content from seismic amplitude anomalies: Soc. Explor. Geoph. 76th Annual Meeting, INT3.3.

Gassmann, F., 1951, Elastic waves through a packing of spheres: Geophysics, 16, no. 04, 673–685.

Greenberg, M. L., and Castagna, J. P., 1992, Shear-wave velocity estimation in porous rocks: Theoretical formulation, preliminary verification and applications: Geophys. Prosp., 40, no. 02, 195–210.

Hilterman, F., Sherwood, J. W. C., Schellhorn, R., Bankhead, B., and DeVault, B., 1998, Identification of lithology in the Gulf of Mexico: The Leading Edge, 17, no. 02, 215–222.

Hilterman, F., Verm, R., Wilson, M., and Liang, L., 1999, Calibration of rock properties for deepwater seismic: 69th Ann. Internat. Mtg, 65–68.

Hilterman, F., 1990, Is AVO the seismic signature of lithology? A case history of Ship Shoal-south addition: The Leading Edge, 09, no. 06, 15–22.

Thanks to Geokinetics Processing & Interpretation for permission to present this paper, and for the use of the GDC Rock Property and Well Log databases.

Posters prepared using Scribus

# From well log to database

Over 5500 wells in the database

The raw well log

The edited well log

What goes in the database

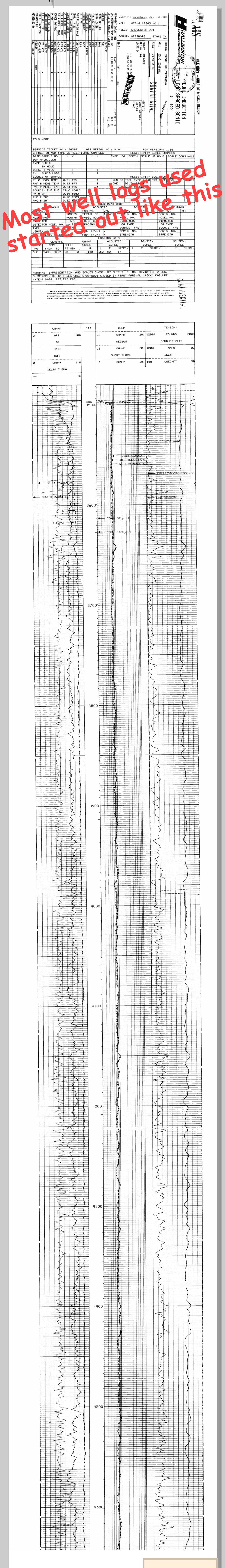

Figure 13

Most well logs used started out like this

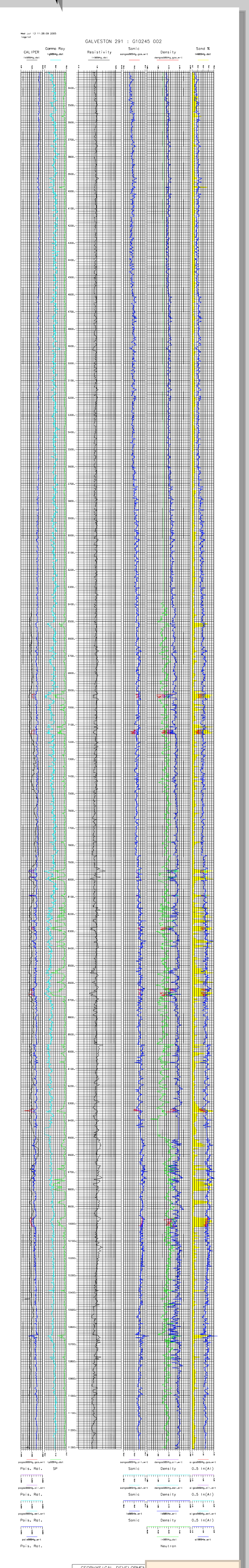

Figure 14

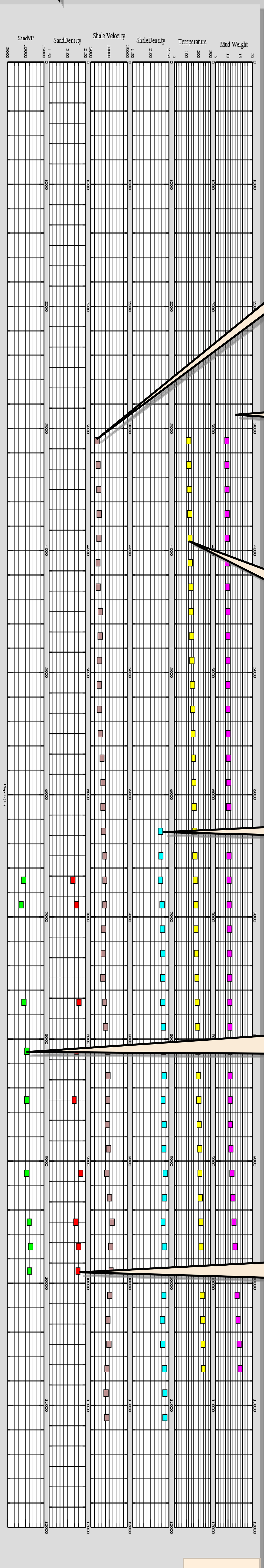

Figure 15

Shale velocity: values every 200 ft from shallowest velocity log to the deepest. There is at least one shale sample in any 200 ft interval.

Mud weight: values interpolated every 200 ft from shallowest measurement to the deepest

Temperature: values interpolated every 200 ft from shallowest measurement to the deepest

Shale density: values every 200 ft from shallowest density log to the deepest. There is at least one shale sample in any 200 ft interval.

Sand velocity: values are not every 200 ft from shallowest velocity log to the deepest. There is not always one sand sample in a 200 ft interval.

Sand density: values are not every 200 ft from shallowest density log to the deepest. There is not always one sand sample in a 200 ft interval.

The scanned image is digitized at 1 ft intervals and edited

The data comes in as a scanned paper log in TIFF format

And it wasn't a good copy that was scanned

Using the interpreted sand log, average values for each lithology are computed for each 200 ft interval

A volume can be built from any of these

Other derived attributes are possible

## Primary Properties from Logs

Some of these are in Figure 15

- ✔ Sand P-wave Velocity
- ✔ Sand Density
- ✔ Sand Total Footage
- ✔ Shale P-wave Velocity
- ✔ Shale Density
- ✔ Shale Total Footage

If the rest is shale, divide by 2 and it's percentage sand!

## Computed from the Primary Properties

- ✔ Wet Sand P-wave Velocity Standard Deviation
- ✔ Wet Sand Density Standard Deviation
- ✔ Shale P-wave Velocity Standard Deviation
- ✔ Shale Density Standard Deviation
- ✔ Average P-wave Velocity
- ✔ Average P-wave Velocity Standard Deviation
- ✔ Average Density
- ✔ Average Density Standard Deviation

## Interpolated from Well Measurements

- ✔ Temperature
- ✔ Mud Weight

This is in Figure 15

Figures 15 and 19

## Computed properties (Greenberg-Castagna)

- ✔ Wet Sand Shear Wave Velocity
- ✔ Shale Shear Wave Velocity

## Computed by Fluid Substitution (Gassmann)

- ✔ Gas Sand P-wave Velocity
- ✔ Gas Sand Density
- ✔ Gas Sand Shear Wave Velocity
- ✔ Dead Oil Sand P-wave Velocity
- ✔ Dead Oil Sand Density
- ✔ Dead Oil Sand Shear Wave Velocity
- ✔ Live Oil Sand P-wave Velocity
- ✔ Live Oil Sand Density
- ✔ Live Oil Sand Shear Wave Velocity

Dead Oil is oil with no dissolved gas

Live Oil is gas-saturated

The Poisson reflectivity $R_\sigma$ is a pseudo-reflectivity given by $R_\sigma = \frac{\sigma_l - \sigma_u}{0.5(\sigma_l + \sigma_u)}$. Once we have computed Poisson's ratio $\sigma$ we can compute Poisson reflectivity.

What is GEOPHYSICS without an EQUATION? (This is the token equation)

## Additional Computed Properties

- ✔ Wet Sand P-wave/S-wave Velocity Ratio
- ✔ Wet Sand Poisson's Ratio
- ✔ Wet Sand Acoustic Impedance
- ✔ Wet Sand Normal Incidence Reflectivity
- ✔ Wet Sand Delta P-wave Velocity
- ✔ Wet Sand Delta Density
- ✔ Wet Sand Delta Poisson's Ratio
- ✔ Wet Sand Intercept
- ✔ Wet Sand Slope
- ✔ Dead Oil Sand P-wave/S-wave Velocity Ratio
- ✔ Dead Oil Sand Poisson's Ratio
- ✔ Dead Oil Sand Acoustic Impedance
- ✔ Dead Oil Sand Normal Incidence Reflectivity
- ✔ Dead Oil Sand Delta P-wave Velocity
- ✔ Dead Oil Sand Delta Density
- ✔ Dead Oil Sand Delta Poisson's Ratio
- ✔ Dead Oil Sand Intercept
- ✔ Dead Oil Sand Slope
- ✔ Live Oil Sand P-wave/S-wave Velocity Ratio
- ✔ Live Oil Sand Poisson's Ratio
- ✔ Live Oil Sand Acoustic Impedance
- ✔ Live Oil Sand Normal Incidence Reflectivity
- ✔ Live Oil Sand Delta P-wave Velocity
- ✔ Live Oil Sand Delta Density
- ✔ Live Oil Sand Delta Poisson's Ratio
- ✔ Live Oil Sand Intercept
- ✔ Live Oil Sand Slope
- ✔ Gas Sand P-wave/S-wave Velocity Ratio
- ✔ Gas Sand Poisson's Ratio
- ✔ Gas Sand Acoustic Impedance
- ✔ Gas Sand Normal Incidence Reflectivity
- ✔ Gas Sand Delta P-wave Velocity
- ✔ Gas Sand Delta Density
- ✔ Gas Sand Delta Poisson's Ratio
- ✔ Gas Sand Intercept
- ✔ Gas Sand Slope

Look at Figure 11!