Data Mining and Exploratory Statistics to Visualize Fractures and Migration Paths in the WCBS*

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Abstract

Data mining and exploratory statistics have many applications that make maximum use of various types of data, find trends previously missed, and solve problems by analogy. Dealing with very large amount of data reduces the level of uncertainty, a common feature of geological interpretation. Three-dimensional visualization gives the opportunity to identify with clarity 3-D geological features crossing stratigraphy and not recognized before. Data mining is most powerful when interactive and linked displays of cross plots, histograms, boxplots, are associated with 3-D views, graphic cluster analyses, and other ANOVA.

Various aspects and methods of data mining are demonstrated with a series of examples using different types of data. Major extensive west-east faults and fractures are shown as planar alignments of high pressure problems in wells. Two examples of cross-formational faults and fractures are shown: the first one visualizes in 3-D, abnormally high values of H_2S or CO_2 (with respect to formation specific depth trends), the second one deals with thickness of porous intervals in every formation after statistic normalization and visualization of the top 3% of the thickest porous intervals. Visualizing and assessing the relative timing of fault activity and fluid flow is demonstrated using cuttings data from Canstrat in the Peace River Area. The reliability of the findings is shown by demonstrating that trend repeatability is not source dependent (e.g. geologist).

Data mining is ideally suited for the Western Canadian Sedimentary Basin because of the incredible amount of data available; its successful use should dramatically increase in years to come.

Introduction

Most geologists focus their effort on discrete wells or individual horizons in geographically restricted areas. They rarely embark on cross formational studies as these require 3-D visualization software used by other groups of geologists (e.g. in reservoir modeling), such software specializing in integration of seismic and well data and mainly used by seismic interpreter and reservoir modelers. For multidisciplinary 3-D statistical analysis and data mining, very powerful interactive statistical programs have been available since the late 80’s and have found numerous markets but have failed to make in-roads in the geologist toolkit (Chatellier et al., 1996).

The Western Canadian Basin is ideally suited for such exploratory statistical analysis and data mining. Most of the drilling and production data is commonly available and digitally accessible, meaning hundreds of thousands of wells available at one’s fingertip.

Data Mining and Exploratory Statistics for Earth Scientists

Exploratory statistics programs provide interactive graphical tools for exploring and understanding data, finding patterns, relationships, and anomalies. Coupled with traditional statistics techniques, their insightful displays simplify intuitive investigation of geological, geophysical, and engineering data. The graphical nature of the programs allows anyone to perform analysis in three or more dimensions, even if the user has no statistics background.

These programs dynamically link graphs and analyses and make it easy to find patterns in any data set. Numerous interactive displays allow the geologist to identify very rapidly anomalies and their relationship with close or not-so-close neighbors.

The following paragraphs will focus on the use of exploratory statistics and data mining to reveal fault and fracture systems in the Western Canada Basin. The main emphasis is placed on methodology, dealing with uncertainties, and multidisciplinary integration.

Data Used to Reveal Faults and Fractures

The data sets, tools, and techniques to be presented have been intentionally restricted, the only purpose being to demonstrate the usefulness of exploratory statistics in a search for a better understanding of faults and fractures. They include problems in wells, abnormal gas compositions, pressures, porosities, or lithologies. The data comes from drilling, production, or from conventional well data analyses.

Trends recognized in two, three, or four dimensions are often associated with the following:

- Alignments of many points
- Alignments of a few points perfectly parallel to recognized and well defined alignments
- Absence of data points on either side of the alignment or on both sides

Regression lines are commonly misleading when dealing with anomaly search (Chatellier et al., 2002). Alignment on a map most likely indicate a vertical feature but only 3-D visualization will reveal non-vertical features (including horizontal and low angle faults).

One of the most important and powerful quality controls of interpretation is recognizing many trends from the same 3-D view point connecting then to one structural/stress regime.

Fractures and Faults from Porosity Data

Porosity values from the IPL data base have been used to identify alignments of abnormally high porosity. In order to compare highly differing lithologies and formation, statistics have been performed on a formation basis. For each formation, the top three percent thickest porous are visualized in a 3D volume; some outstanding porosity streaks are aligned along planes crossing stratigraphy and are interpreted as linked to fracture planes (Figure 1). The uncertainty related to the tops in some of the wells and the one related to the porosity estimate from logs are well compensated by the number of wells dealt with and the need to have well defined alignments of anomalous points.

Cutting descriptions are commonly perceived to be unreliable because of the very nature of the collecting process. Data mining can overcome the uncertainties associated with these cuttings descriptions. This will be shown in two selected examples of fracture expressions, the first one corresponds to grain fracturing and cataclasis, the second one relates to red stain associated with iron rich fluid flow through a fracture network.

Dominance of angular sand grains has been observed in one Mesozoic section of 4 out of 500 wells in Northwestern Alberta. These four wells are perfectly aligned indicating the existence of a well-defined fault. The interest of the example is that we obtained the list of geologists who described all of these wells for Canstrat. Together the three geologists have described 112 wells (Figure 2) but have only identified four wells with angular grains. Note that one of the three geologists had described 38 wells in the area under study before he documented the angular nature of the sand fraction in one well.

In a different dataset from the Peace River Area, 134 color combinations have been used to describe cuttings. Filtering and visualizing some specific red shades of colors has revealed fracture networks that have been the focus of iron-rich water flows. The light red stains are distributed and aligned in two broken planes exhibiting parallel geometries. The lower fracture plane crosses various stratigraphic units including the Precambrian, Cambrian, Wabamun, and Banff. Fractures cross-cutting stratigraphy are best expressed in the Banff Formation where the red stain gradually climbs from SW to NE from the lower Banff to the very upper Banff. Both fracture systems are characterized by a collapse domain interpreted to have taken place after the iron-rich fluid flow (Figure 3).

H_2S and CO_2 Linked to Fractures

When dealing with gas composition, too large an area leads to not recognizing trends because of the existence of different burial regimes (temperature pressure versus depth) or sub-basins. The H_2S example shows several series of values for the same sampling intervals; one interesting observation is the possible existence of a phase envelope that would constrain the maximum of H_2S content as a function of depth. Note that the proposed phase envelope gets a very strong support by the existence of two values at different depths in one single well (Figure 4).

Hydrogen sulfide is a component of some carbonate series and is sometimes present in clastic series. The existence of abnormally high content of H_2S in some formations is sometimes related to gases being introduced through fault and fracture networks. Anomalies of H_2S concentration with respect to depth or relative to the bearing formations commonly form 3D alignments interpreted as faults (Figure 5).

The maximum CO_2 content as a function of depth seems to be constrained by an envelope. In Figure 6, a series of samples show CO_2 values much larger than the commonly observed maximum trend. These points from different stratigraphic intervals line up on a depth trend and are perfectly aligned on two distinct planes with identical dips and strikes in distinct geographic areas. Note that the relationship between CO_2 concentration and depth is best expressed when using a modified depth reference not yet used by the oil industry.

Multidisciplinary Integration

Combining many disciplines to define fault and fracture systems can be extremely rewarding as it compensates for the limited amount of data available for each of the tools. One of the most compelling support for a 3D structural interpretation is finding the existence of several well defined planar alignments from a single 3-D view point.

Conclusions

Multidisciplinary integration, 3-D visualization, and data mining can go a long way to help being successful in the mature Western Canada Basin. Each of the tools presented has non-negligible uncertainties that can be dealt with if method is applied on a large enough data set and repeat of trends are observed for different tools and parameters.

References Cited

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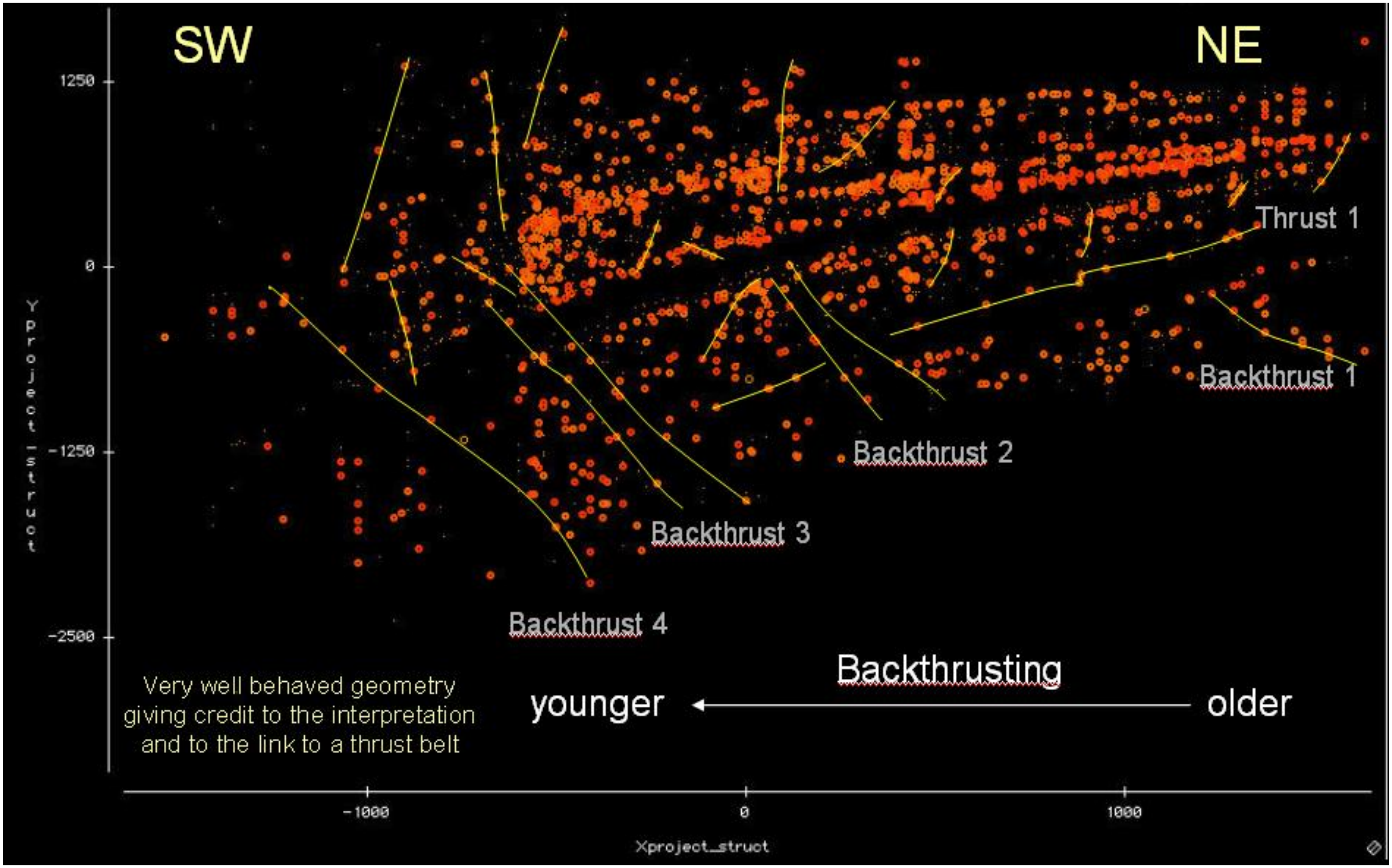

Figure 1. Projection of all top 3% of porous intervals in NW Alberta Cutting descriptions.

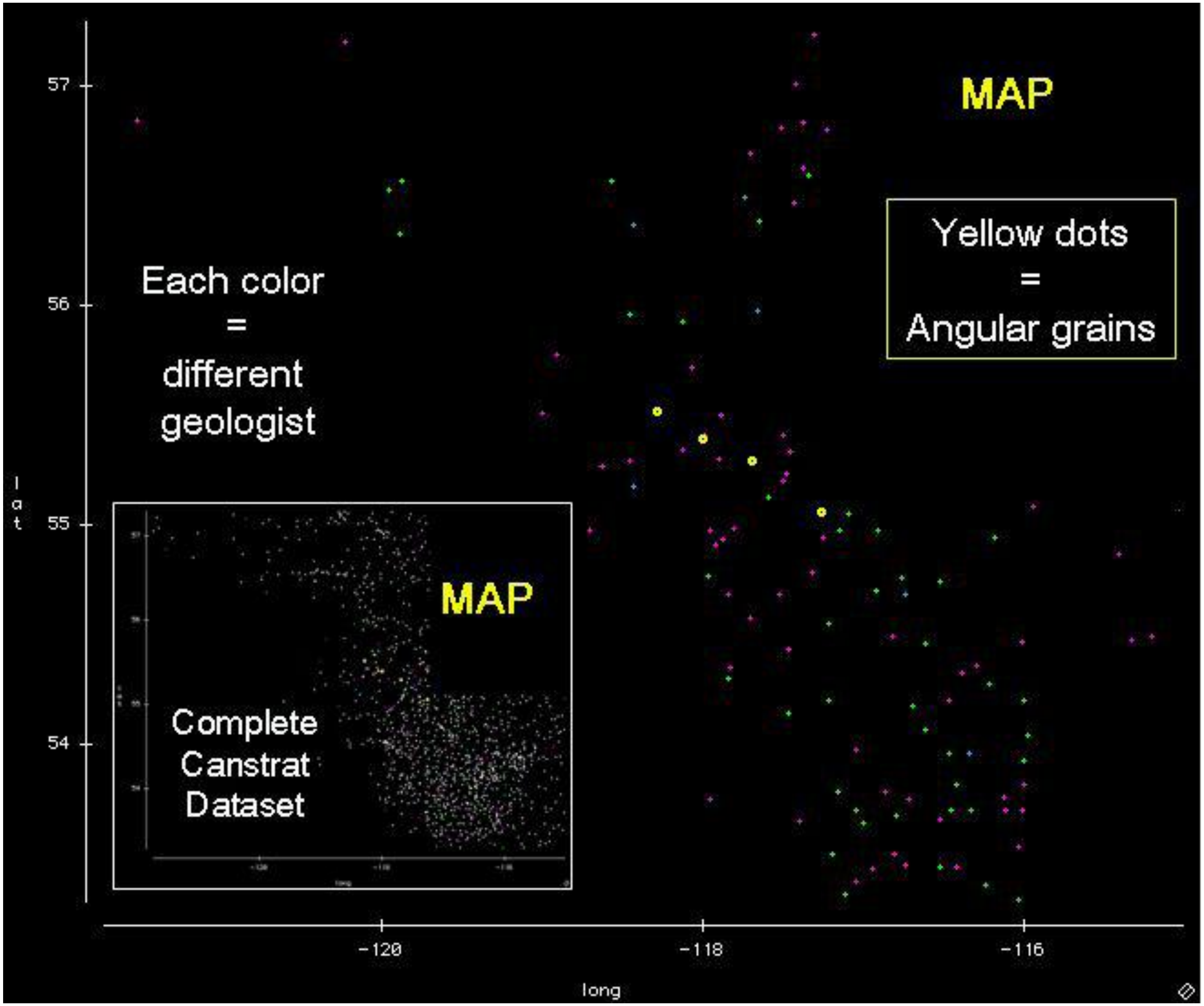

Figure 2. Map of sand grain roundness outlining linear pattern of angular grains.

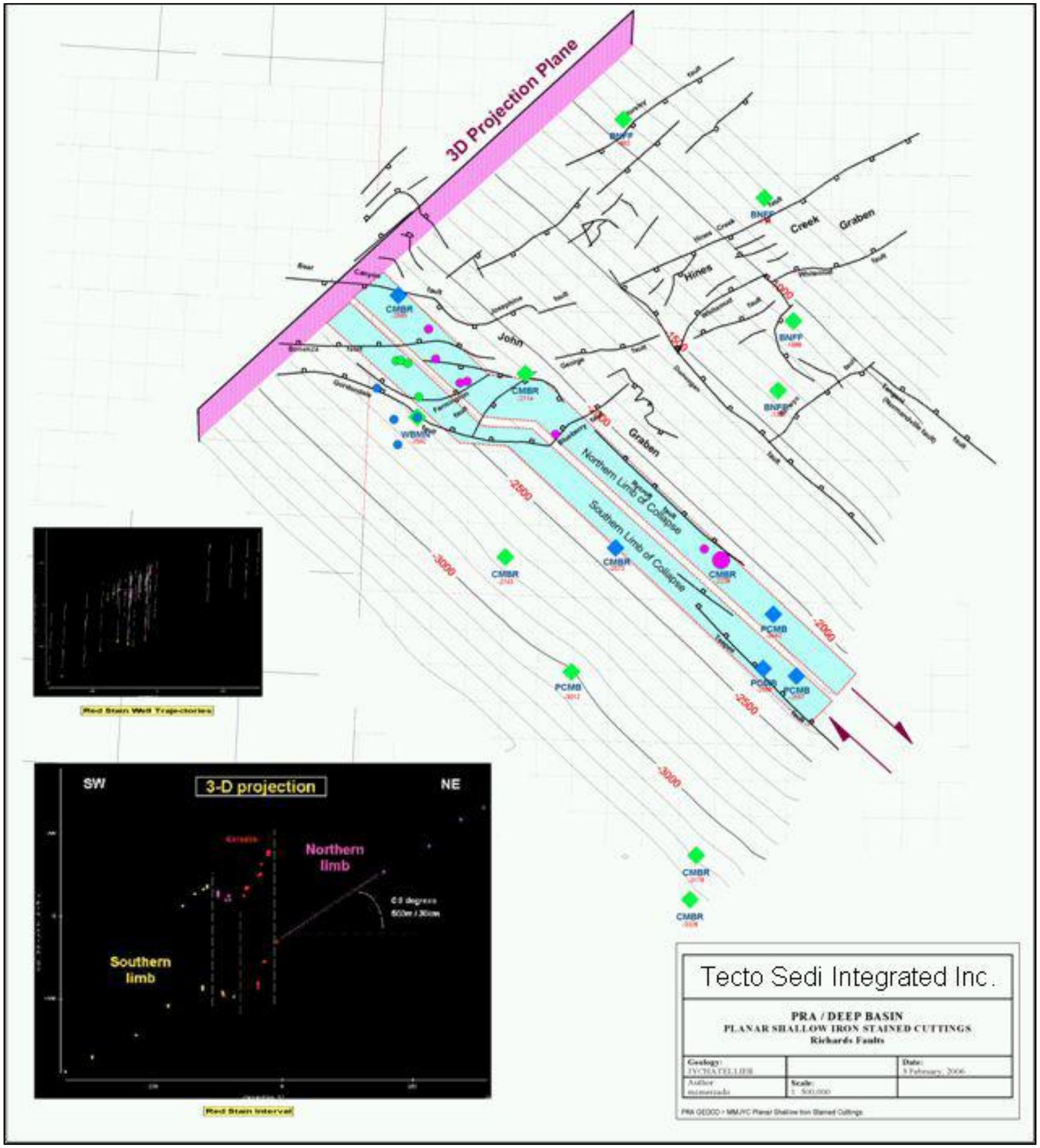

Figure 3. Cross-section and map of iron rich stain intervals and postdating collapse area.

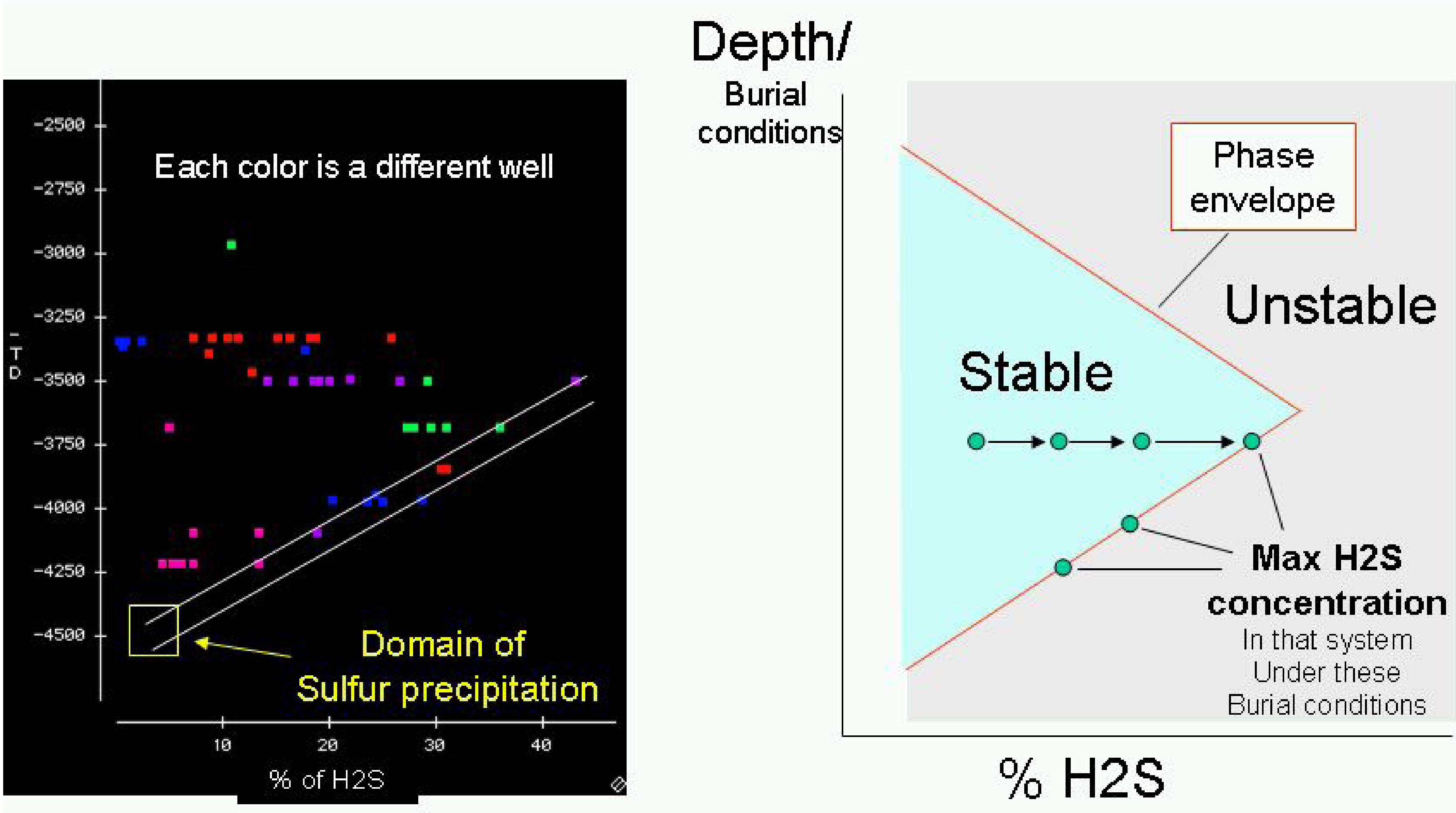

Figure 4. Proposed hydrogen sulfide phase envelope expressed by maximum H_2S concentrations in a depth plot.

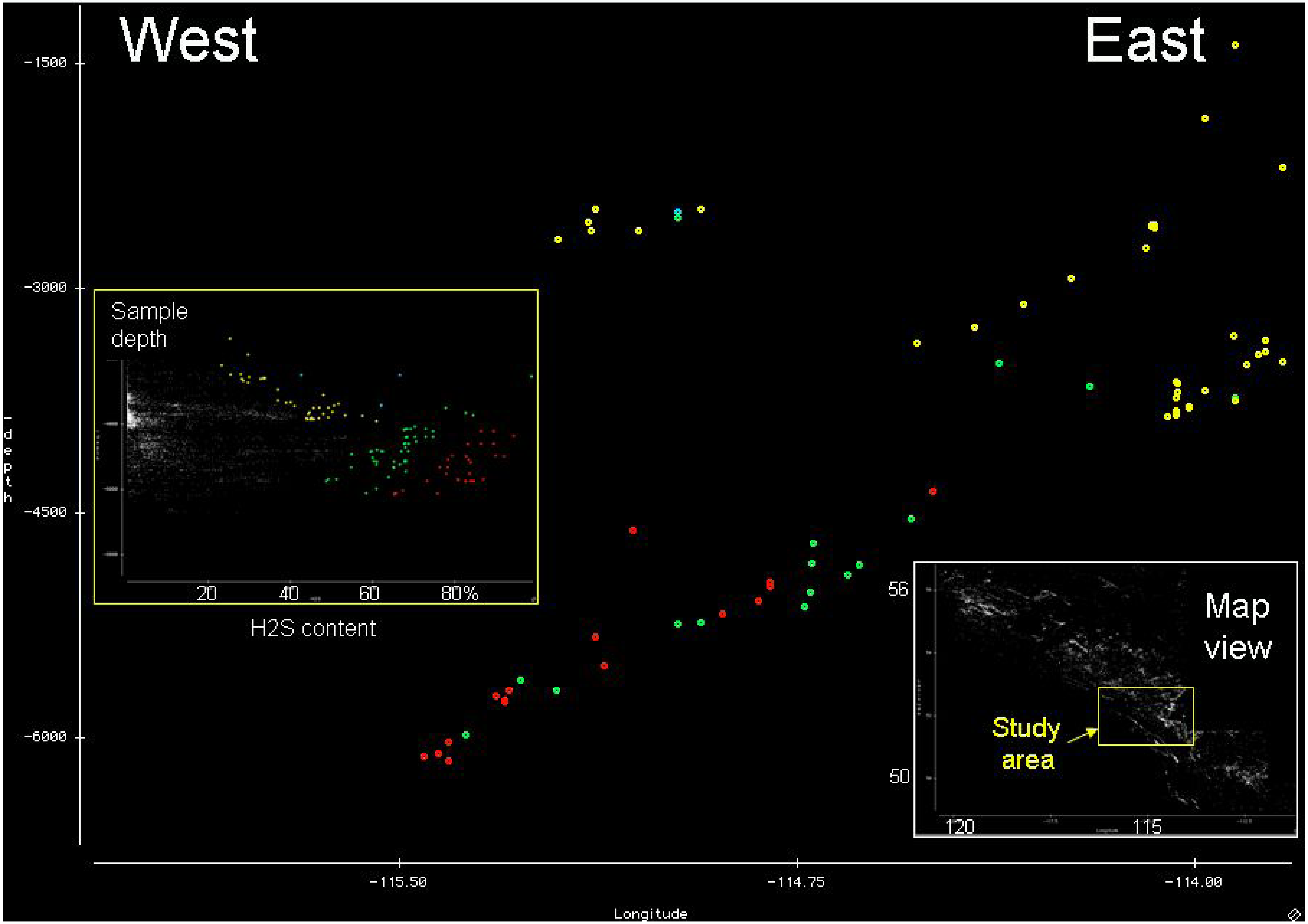

Figure 5. East-West projection of high and very high H_2S concentrations in Central Alberta possibly associated with faults.

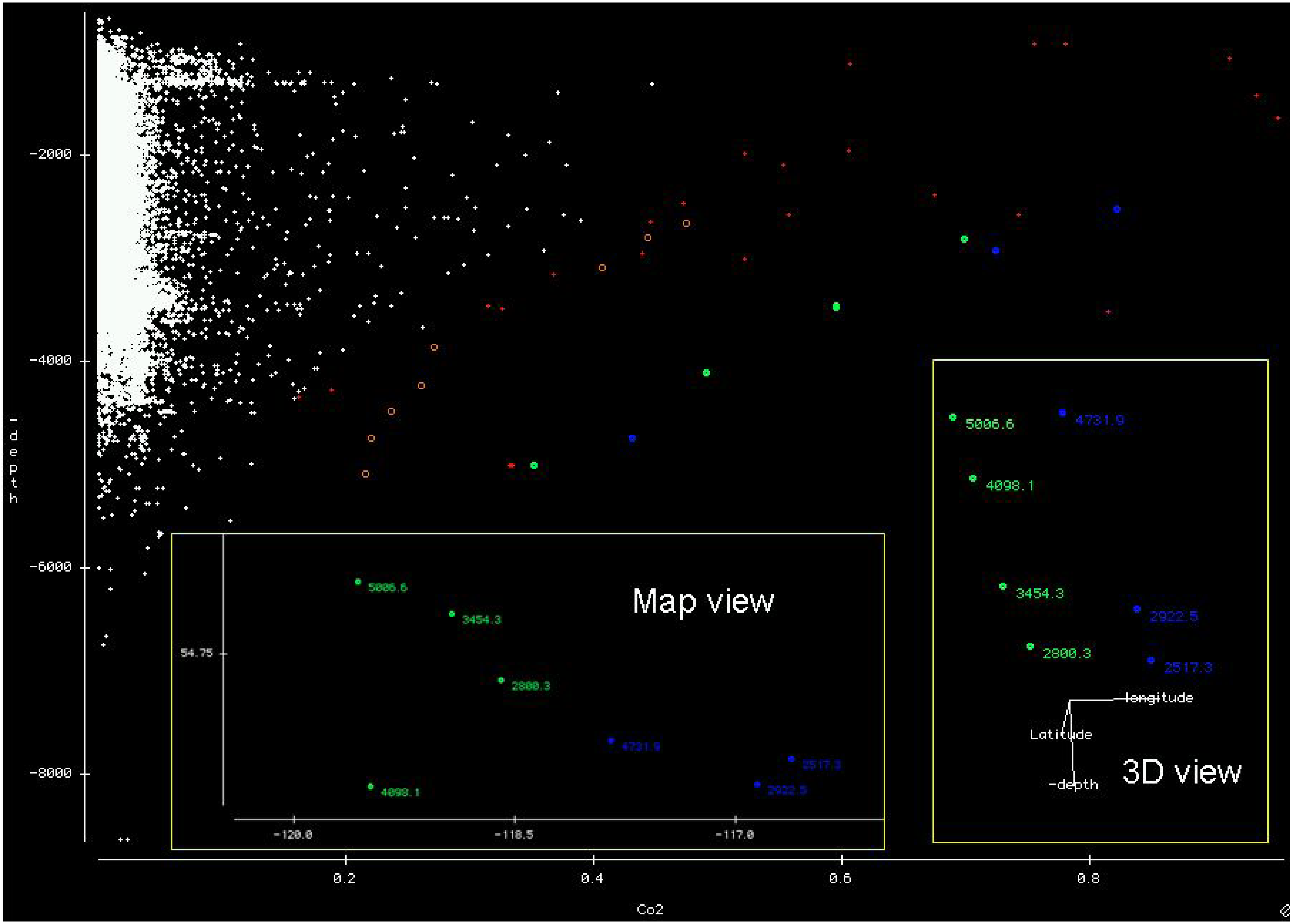

Figure 6. Depth trend and 3-D view of abnormally high CO_2 concentrations.