PS Using Structural Dip Modeling to Determine Structure and Stratigraphic Position*

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Abstract

As we explore for and develop more complex reservoirs the impact of borehole position becomes critical. When the bed dips are highly variable and complex, the interpretation of the dip and strike can be difficult. In addition, a horizontal or vertical well may pass through multiple structural domains within the reservoir horizon. While drilling, structural dip modeling (SDM) offers the ability to interpret the stratigraphic position of the borehole before a dip log or image log has been run. After drilling, SDM provides a means to fine tune both structure and stratigraphic position. In existing wells where dip data are not available, SDM enables one to determine both structure and stratigraphic position with only a correlation log and directional survey.

The modeling process involves adding dips and faults until a correlation log from near a offset well, called a "stratigraphic template", matches the correlation log of the well being modeled. The modeling process generates a modeled template log and a vector section™. The final result of the modeling includes formation tops as well as a structural interpretation.

One of the difficulties in dip interpretation in general is the visualization of the dips in 3D space. Many techniques have been created for this purpose, but nearly all of them involve first projecting the 3D information onto 2D entities. At first glance, a vector section appears to be a cross section, but it is a fully 3D object comprised of vectors perpendicular to structural dip whose length is based on true stratigraphic thickness (TST). Vector sections can be projected onto cross sections or be viewed directly in three dimensions. They can make realistic-looking cross sections with little interpretation.

The stratigraphic template is a log with depths in cumulative TST instead of measured depth. Templates can be created directly from measured depth in vertical wells with low dip, but otherwise TST must be calculated from dips and deviations to create a

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template. The modeled template log is calculated by first adding or subtracting a constant TST to the template such that it is aligned at a point common to both the template log and the correlation log in the modeled well. The modeled template log is created by moving log values from the template to match TST calculated in the borehole. Examples are given of horizontal and vertical structural modeling in the Canadian Rockies Foothills province using RDA Dip Interpretation Suite.

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by Charles R. Berg[1] and Andrew C. Newson[2]

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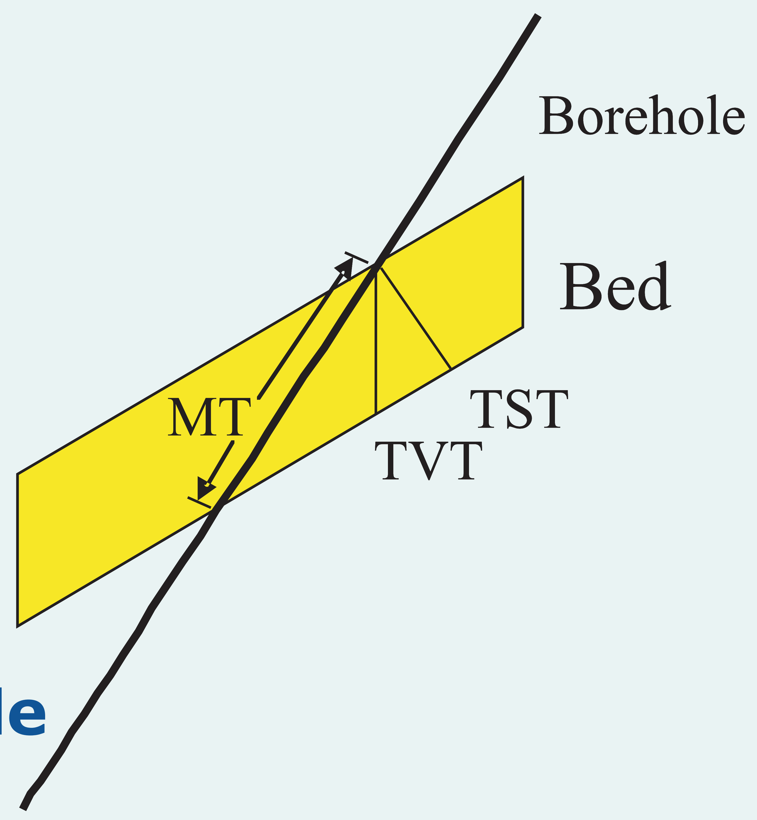
Calculation

Calculation of True Stratigraphic Thickness (TST)

TVT *MT* cos sin cos tan

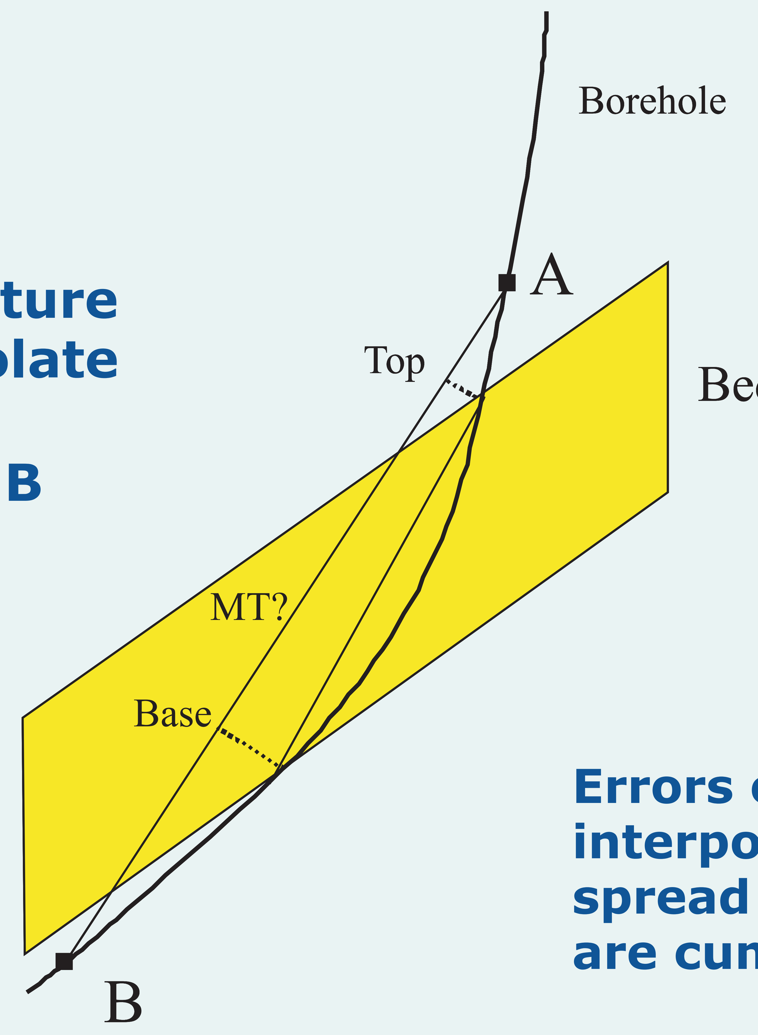
TST *TVT* cos



MT = measured thickness,
TVT = true vertical thickness,
TST = true stratigraphic thickness,
Ø= dip, phi
= the dip azimuth minus the borehole azimuth, alpha
= borehole inclination from vertical, psi

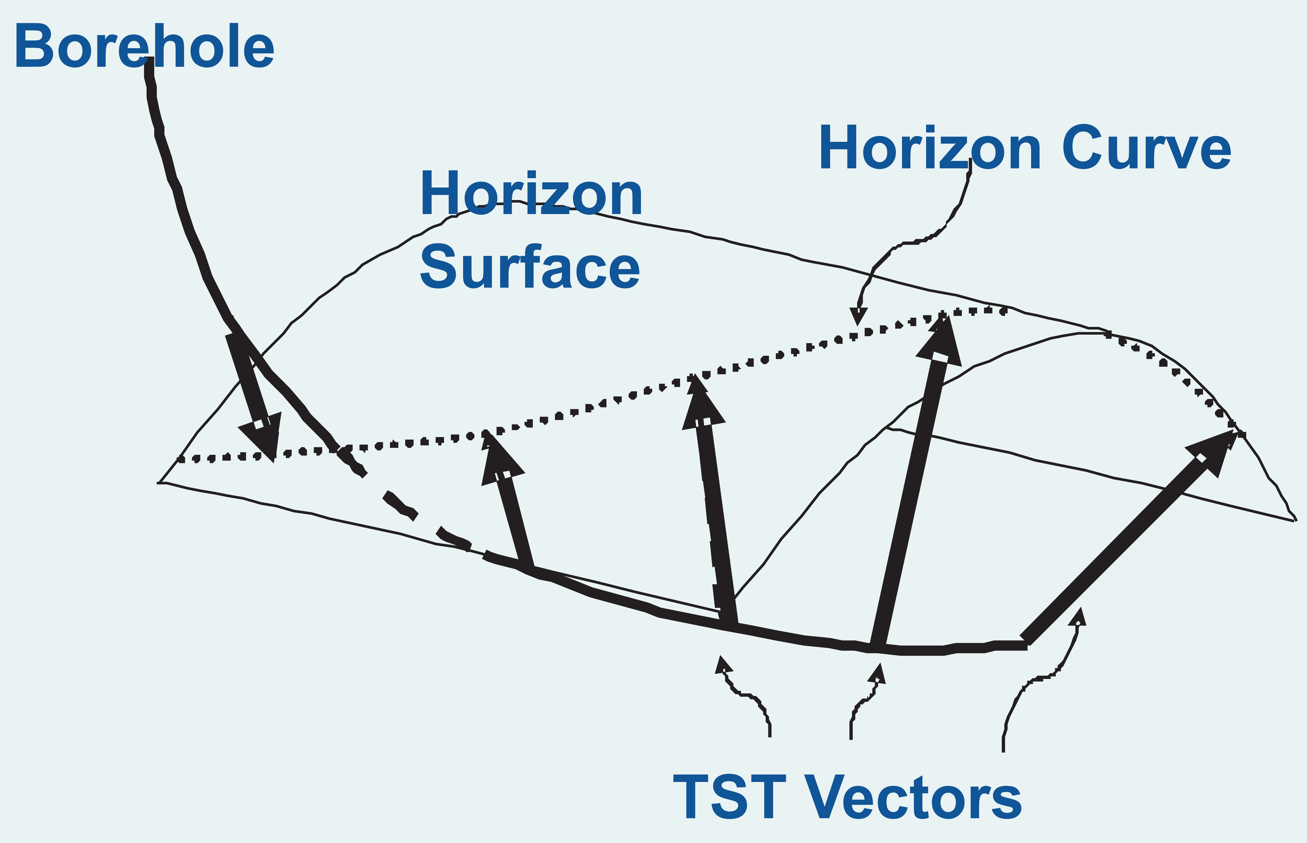
Tearpock and Bischke(1991)

Minimum curvature used to extrapolate the well path between A and B



Errors occur if linear interpolation is used (eg spread sheets) which are cumulative.

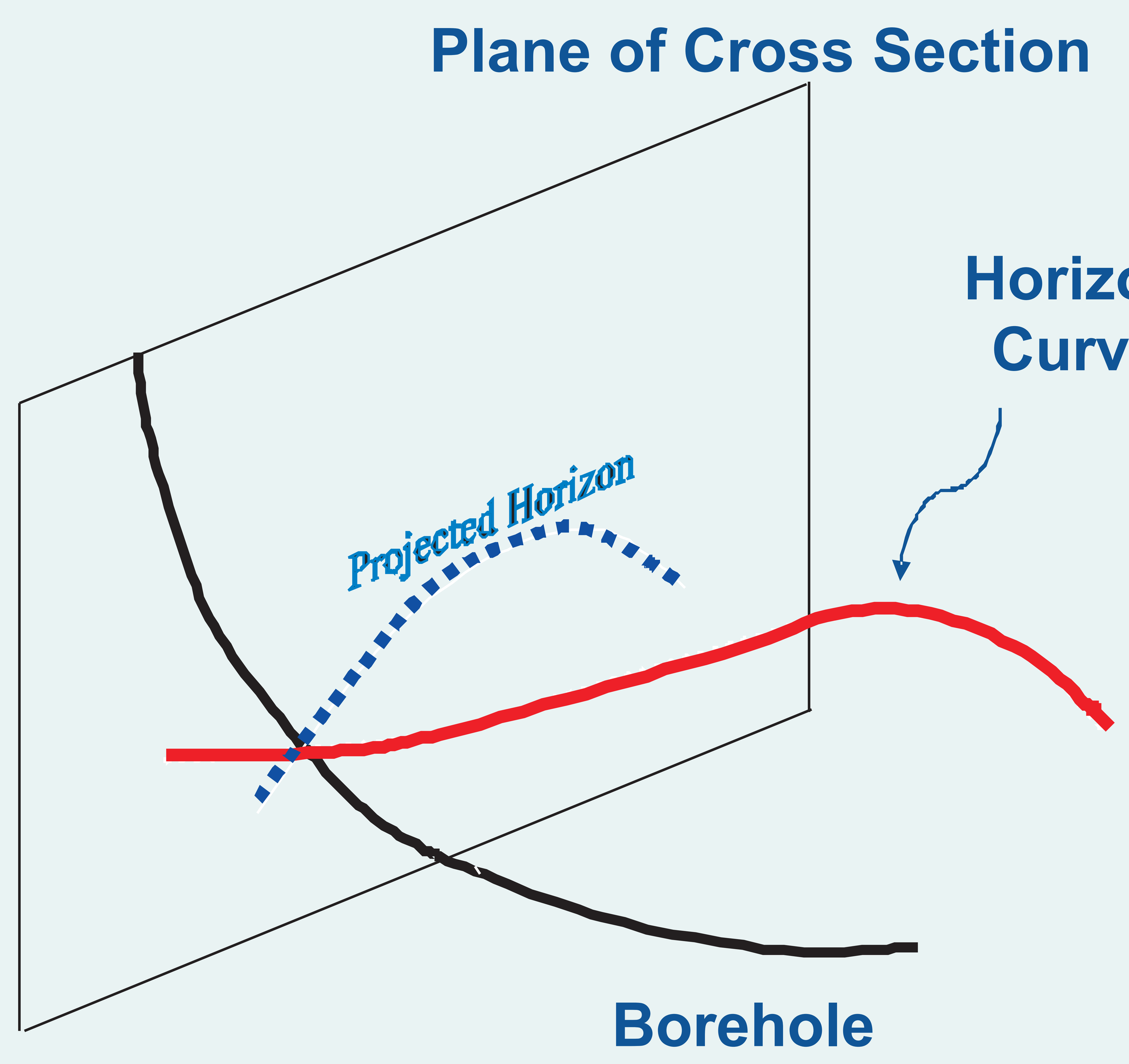
Using TST and Dip to Build a Vector Section™



The vector is constructed such that if a given stratigraphic horizon is above the current point in the borehole, the vector points up and if the horizon is below that point, the vector points down.

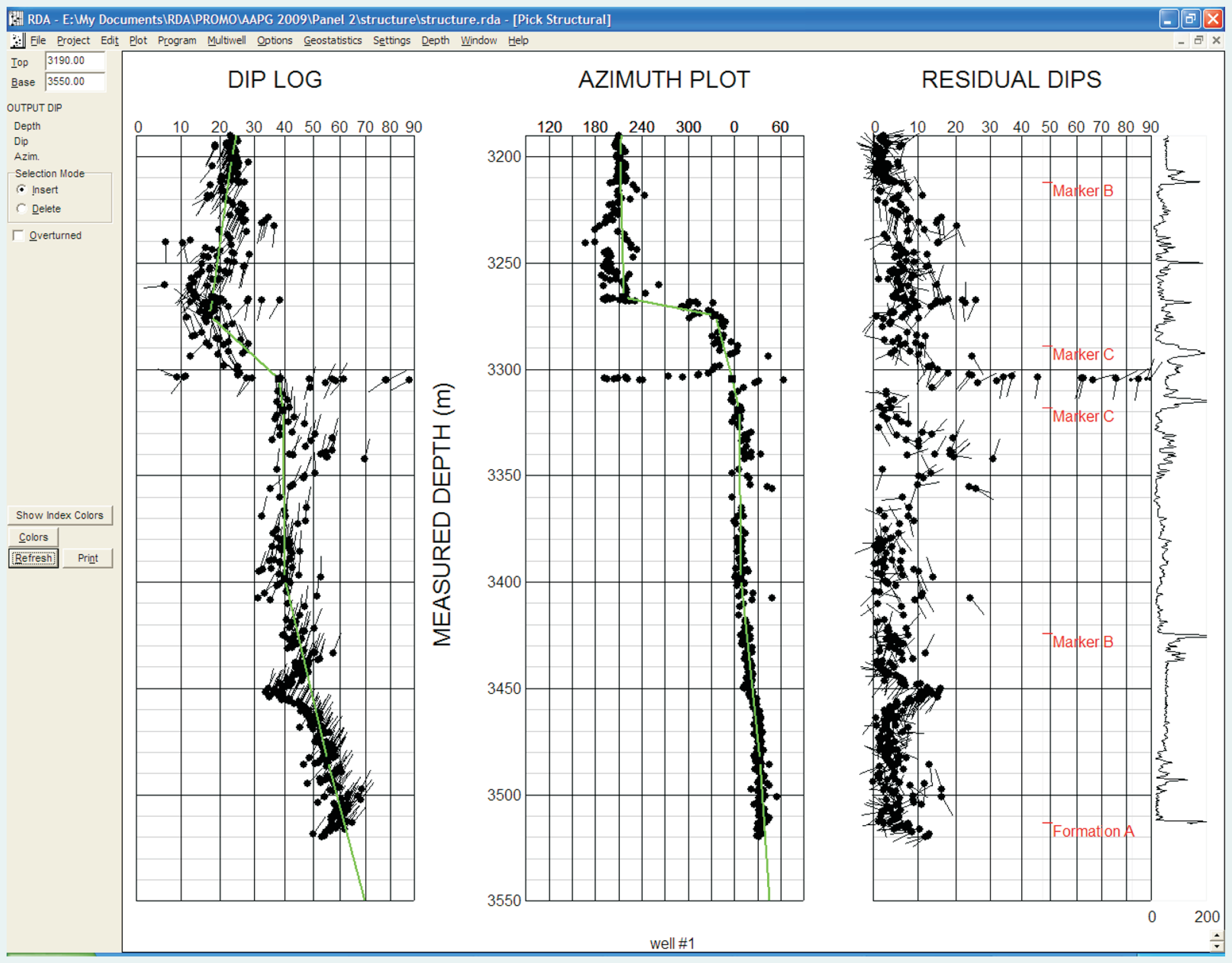
A series of vectors defines a horizon curve that represents a line on the horizon surface.

Once the horizon curve is defined, it is projected onto the cross section



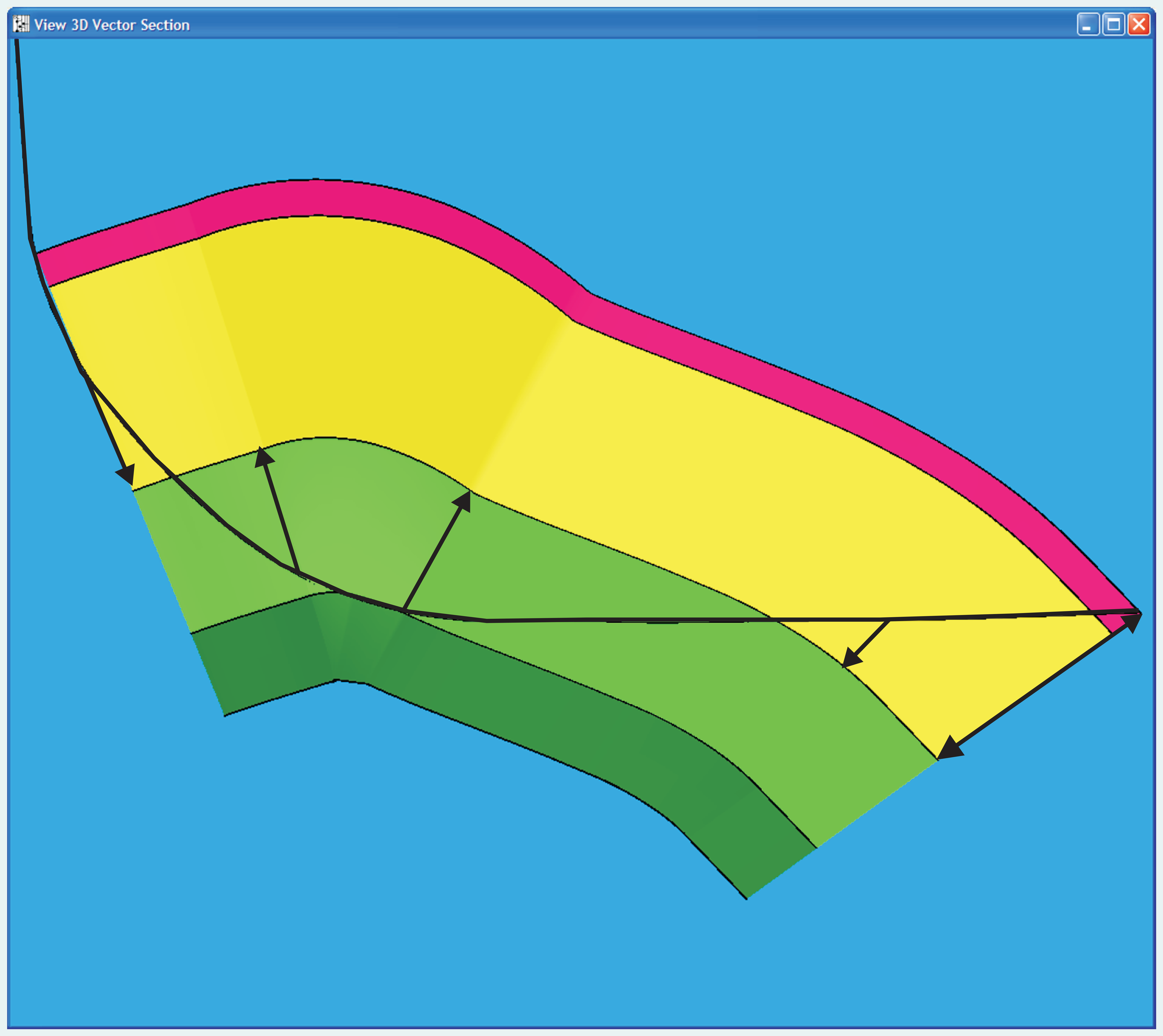
Making a Vector Section™

Pick the Structural Dip



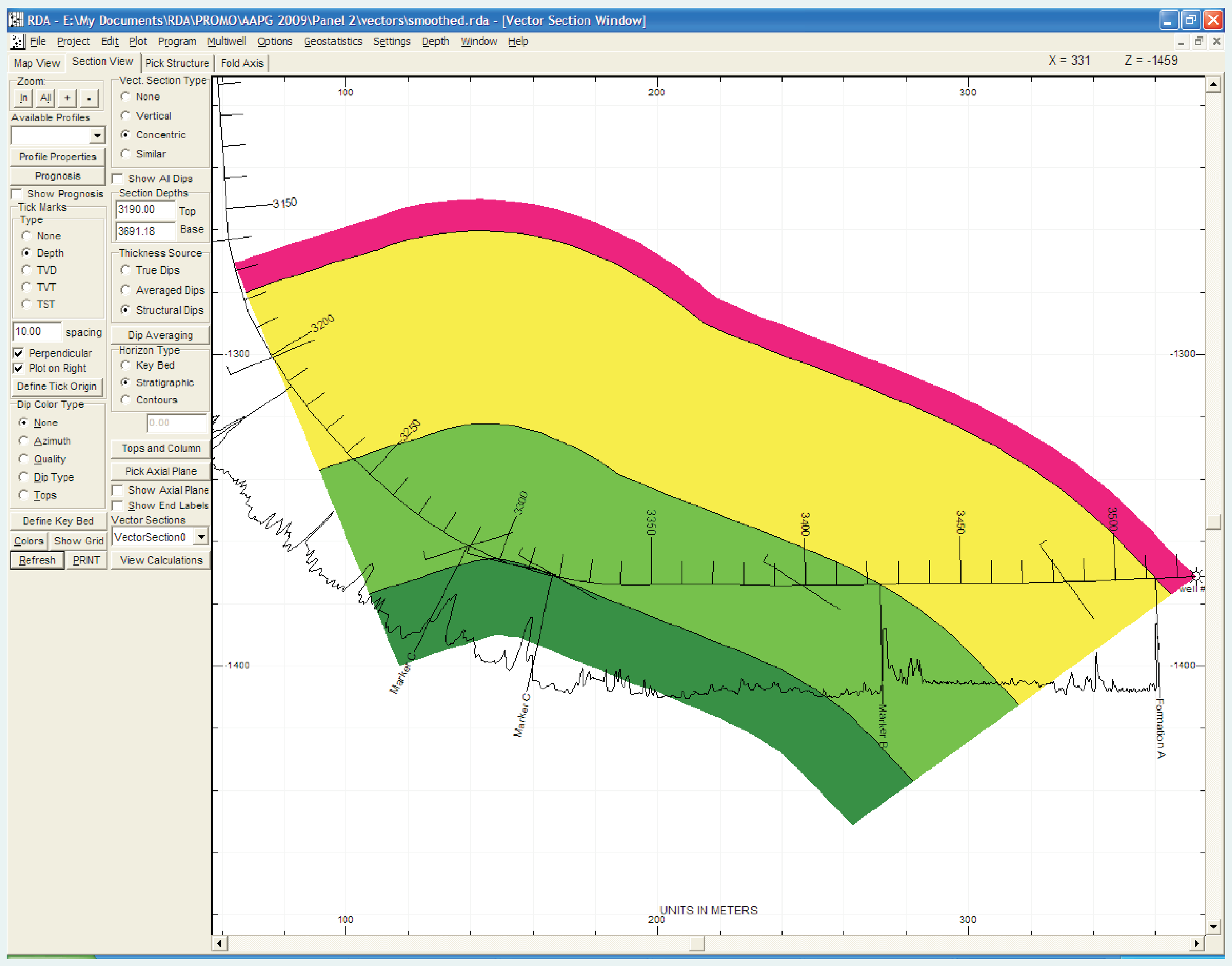
Structural dips are picked to smooth out the scatter inherent in dip data. This scatter is caused by variability within the dipscaused by measurement error, stratigraphically related variability, and minor structures.

Use the Structural Dips and TST to Make the Vectors

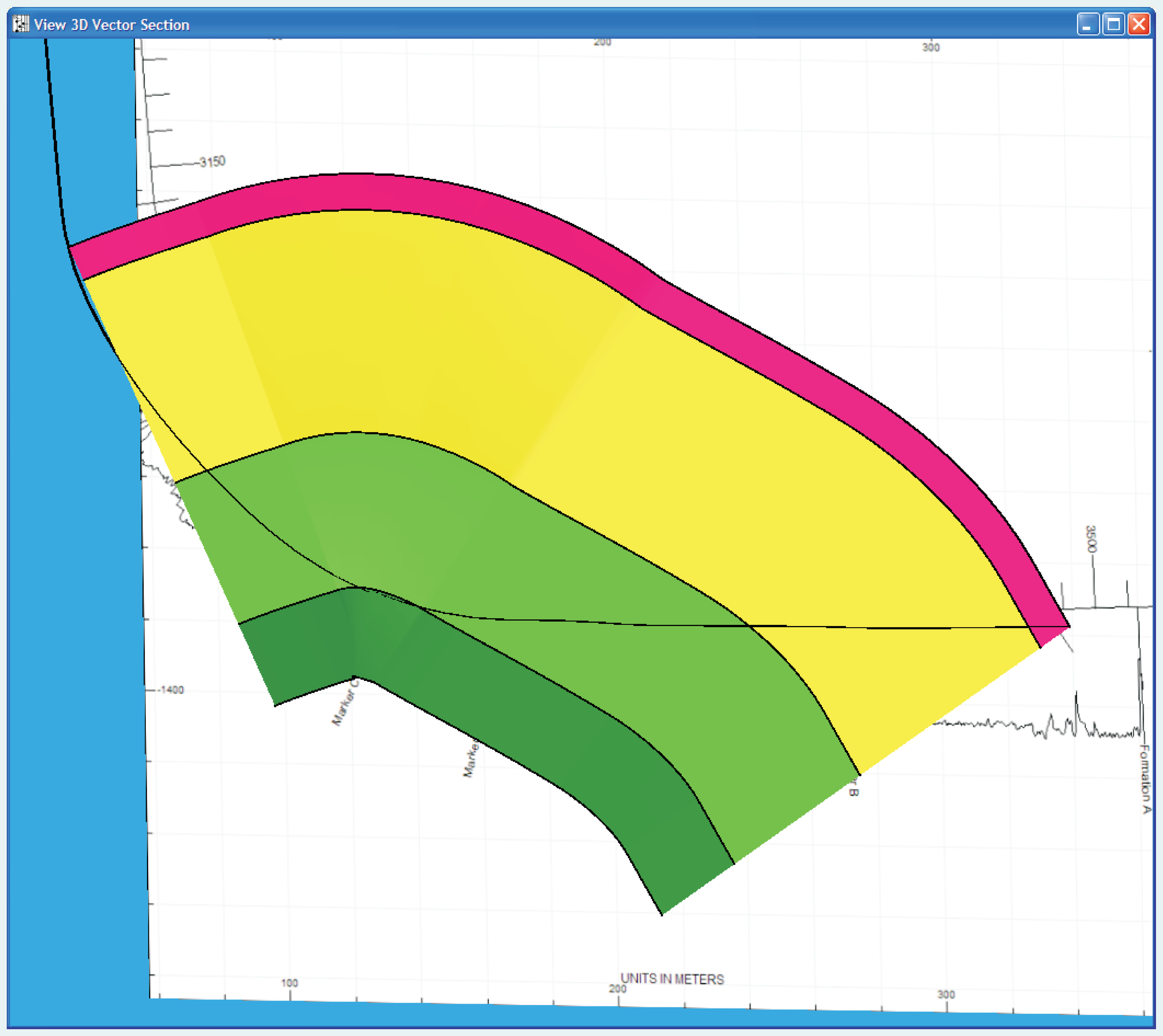


The structural dips that are picked on the left are used for the vector directions as well as for calculating TST for the vector lengths. In the downward-pointing vectors, the formation has a positive TST in relation to that point in the borehole. In the upward-pointing vectors, the TST is negative.

Project onto Cross Section



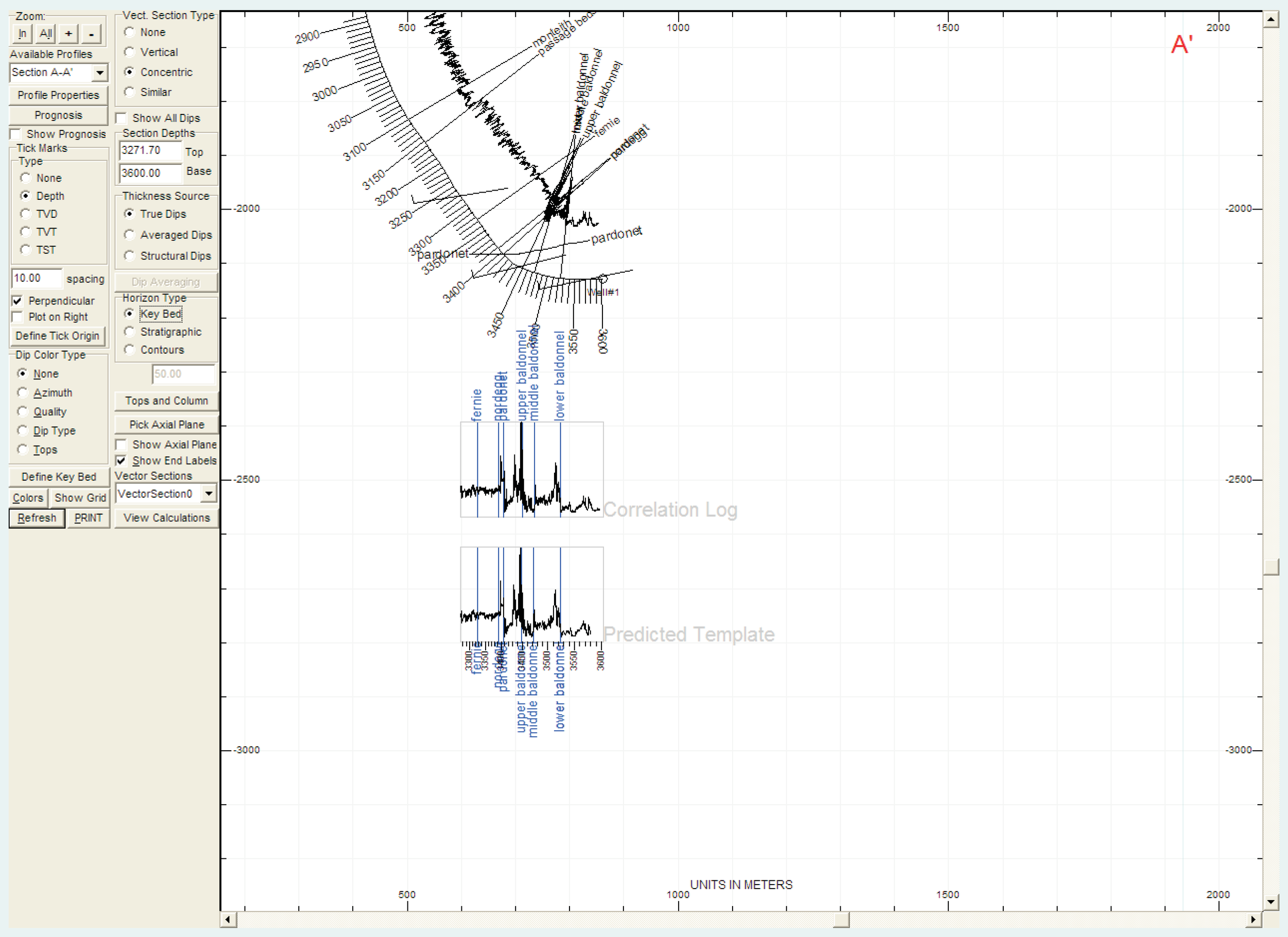
3D View Down Plunge



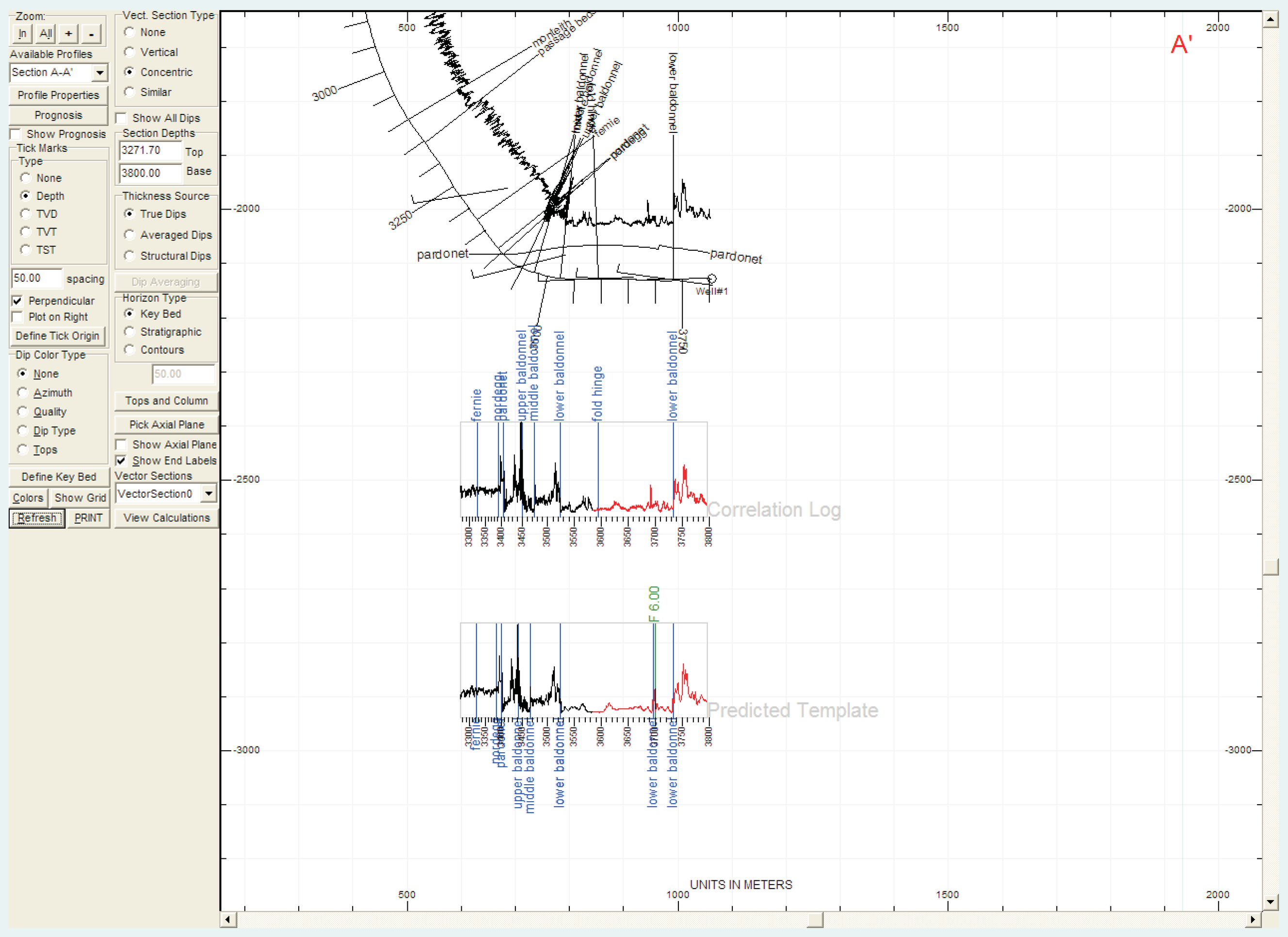
Structural Dip Modeling

Modeling dips and faults while drilling

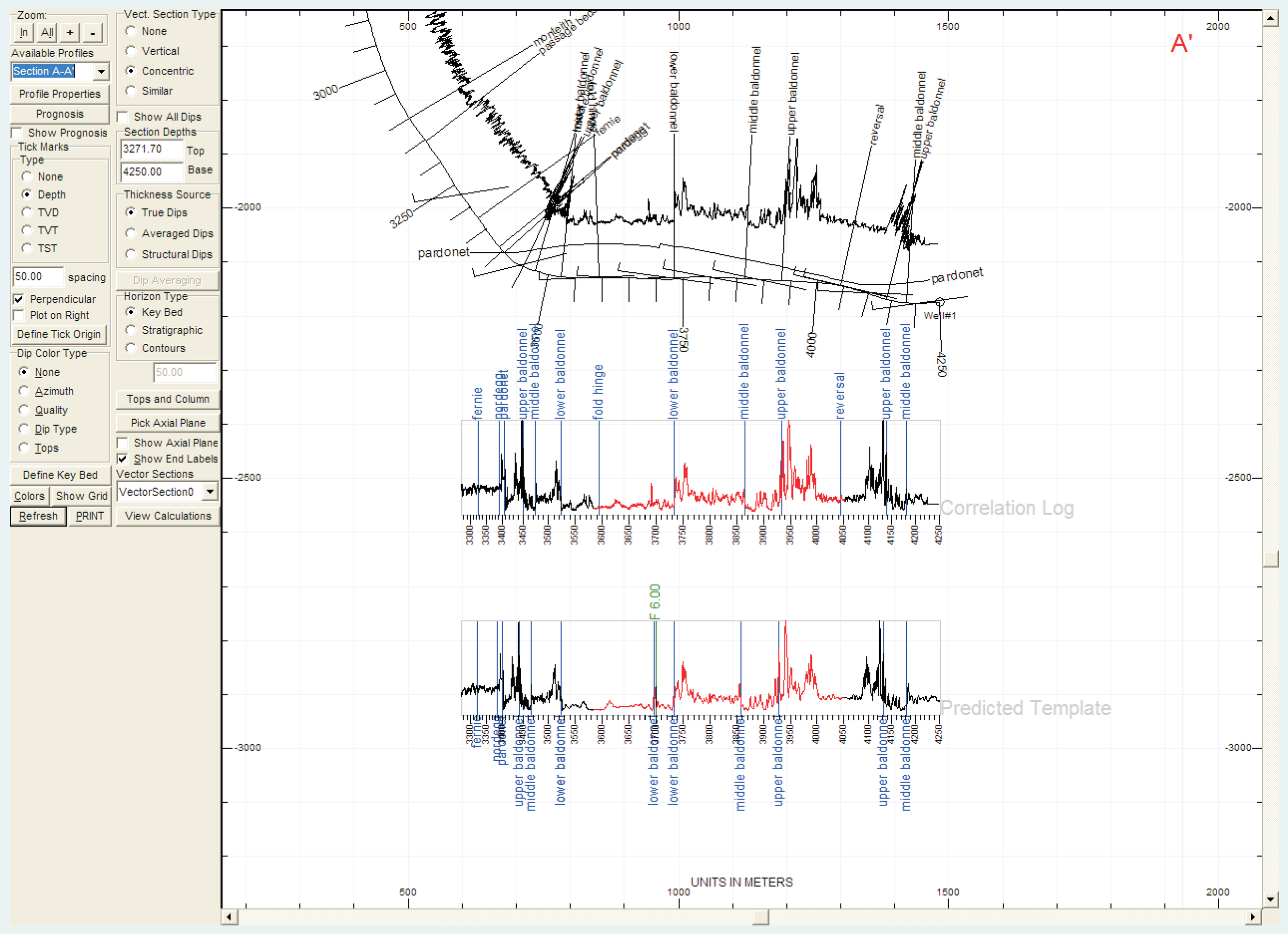
After Kickoff



Crossing Axial Crest

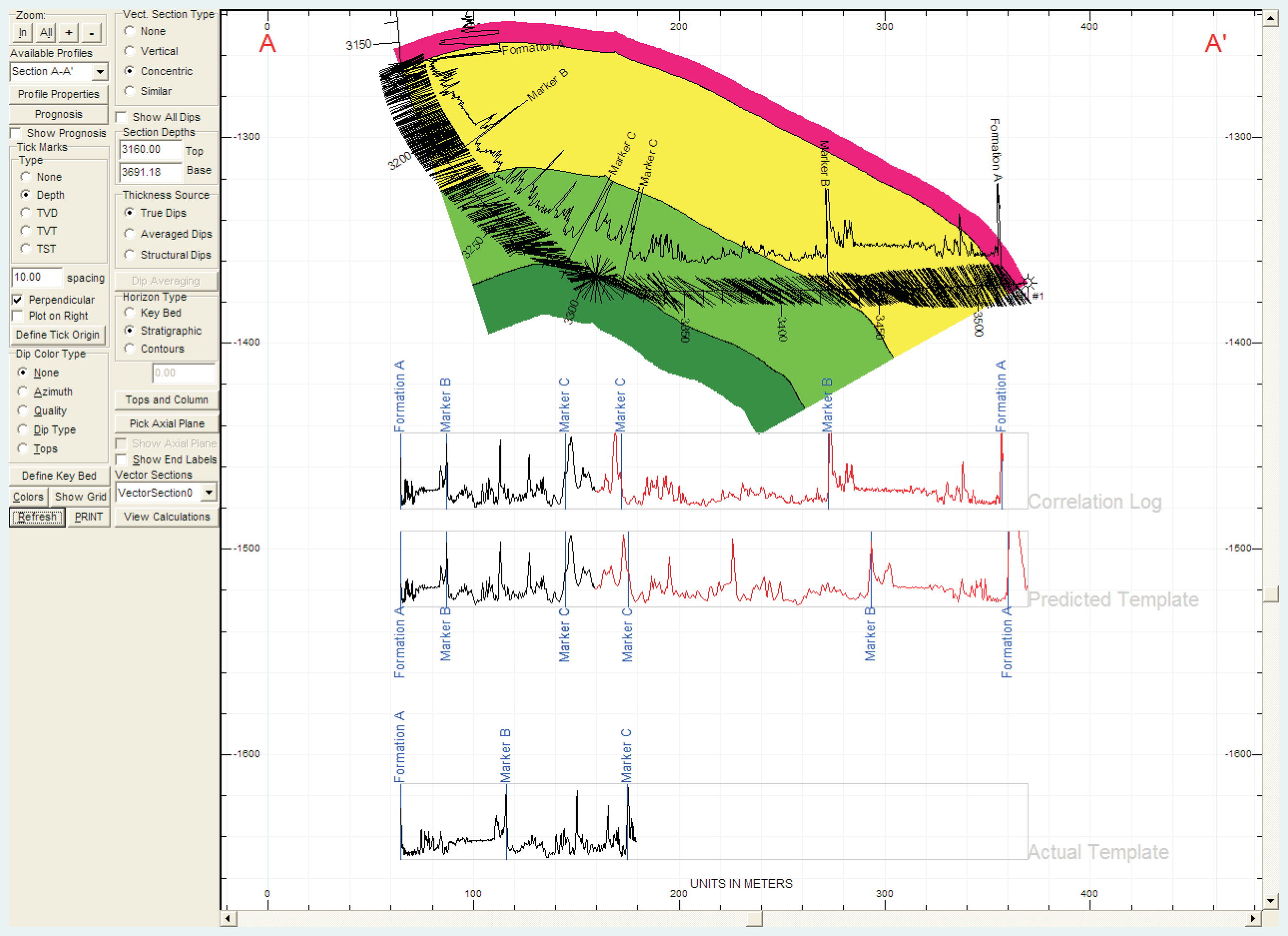


At Total Depth

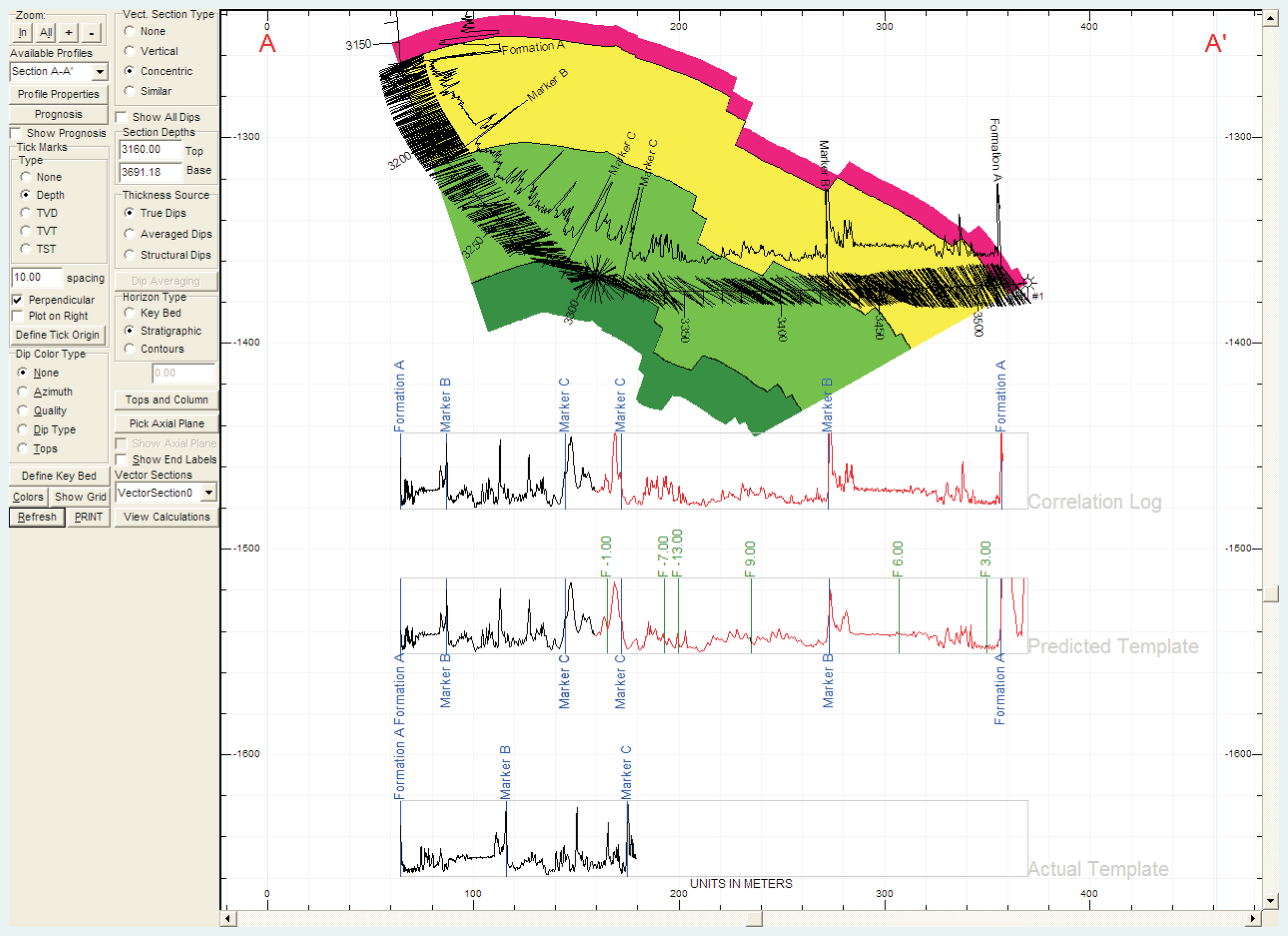


Adding faults to existing dips and getting a prognosis.

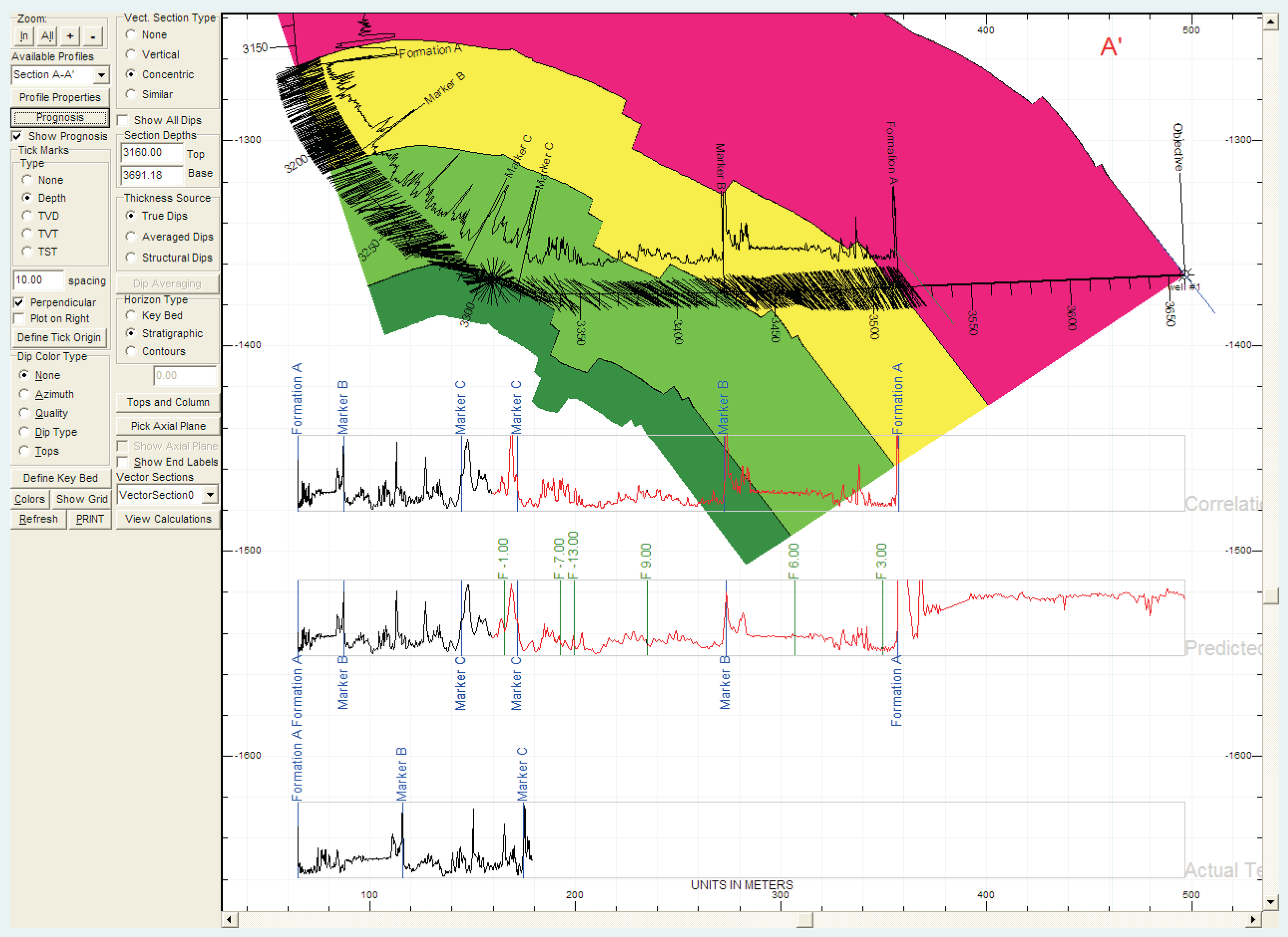
Using Bedding Dips from Formation Imager Log



Modeling Faults to Fit Gamma Log



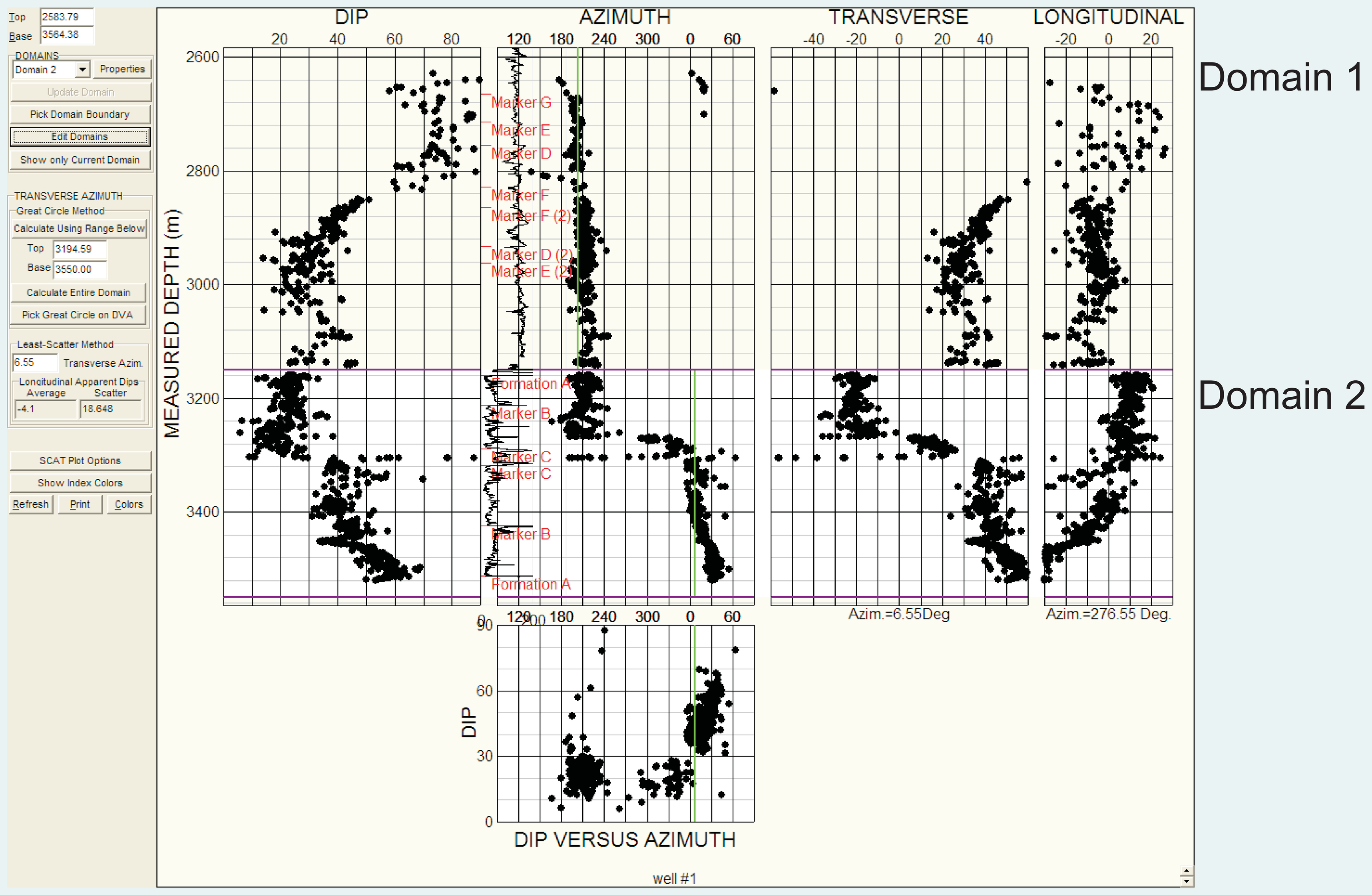
Prognosis to 100m higher Stratigraphically (-100m TST)

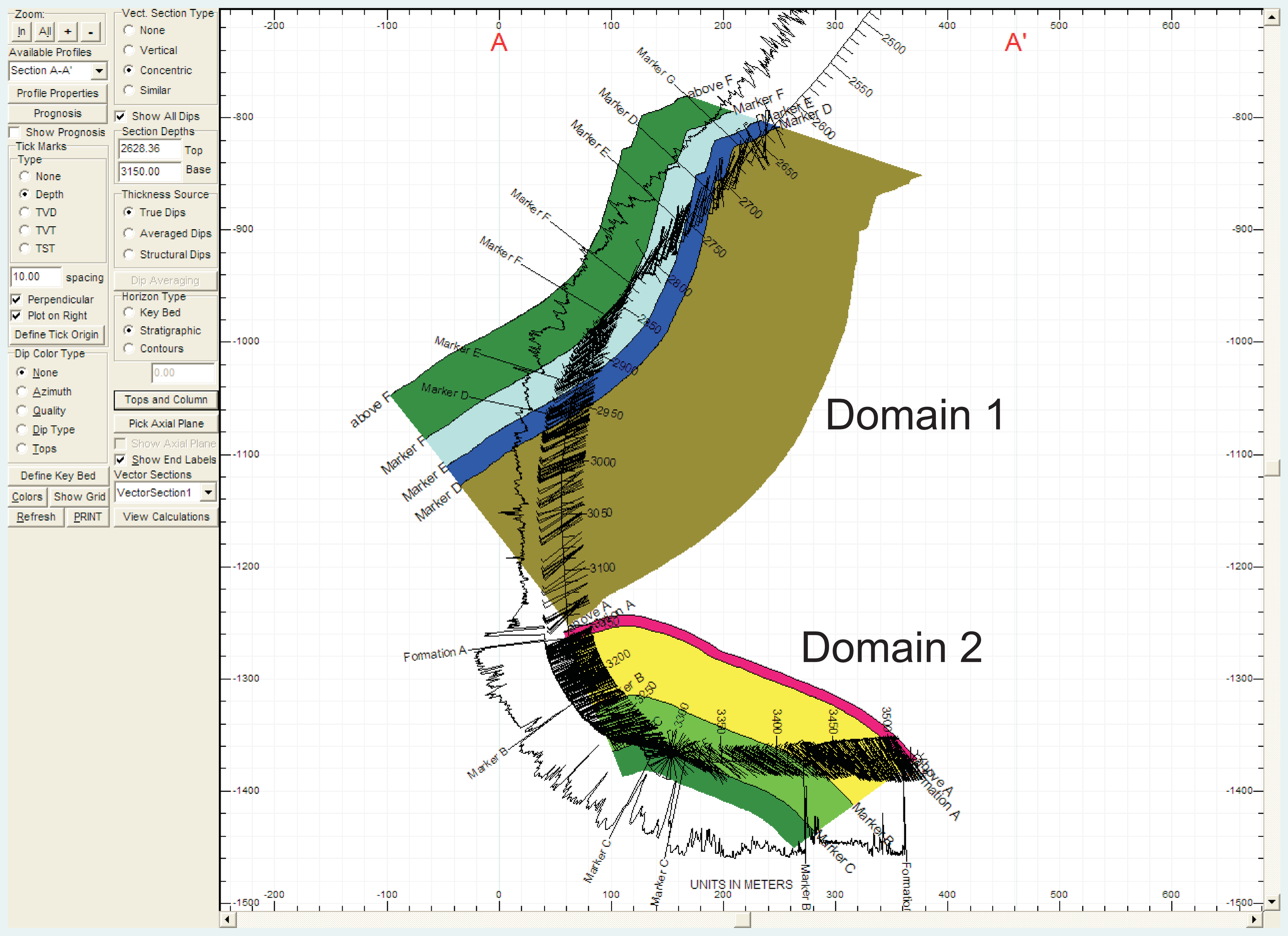


Compare and Contrast

SCAT and Vector Sections™

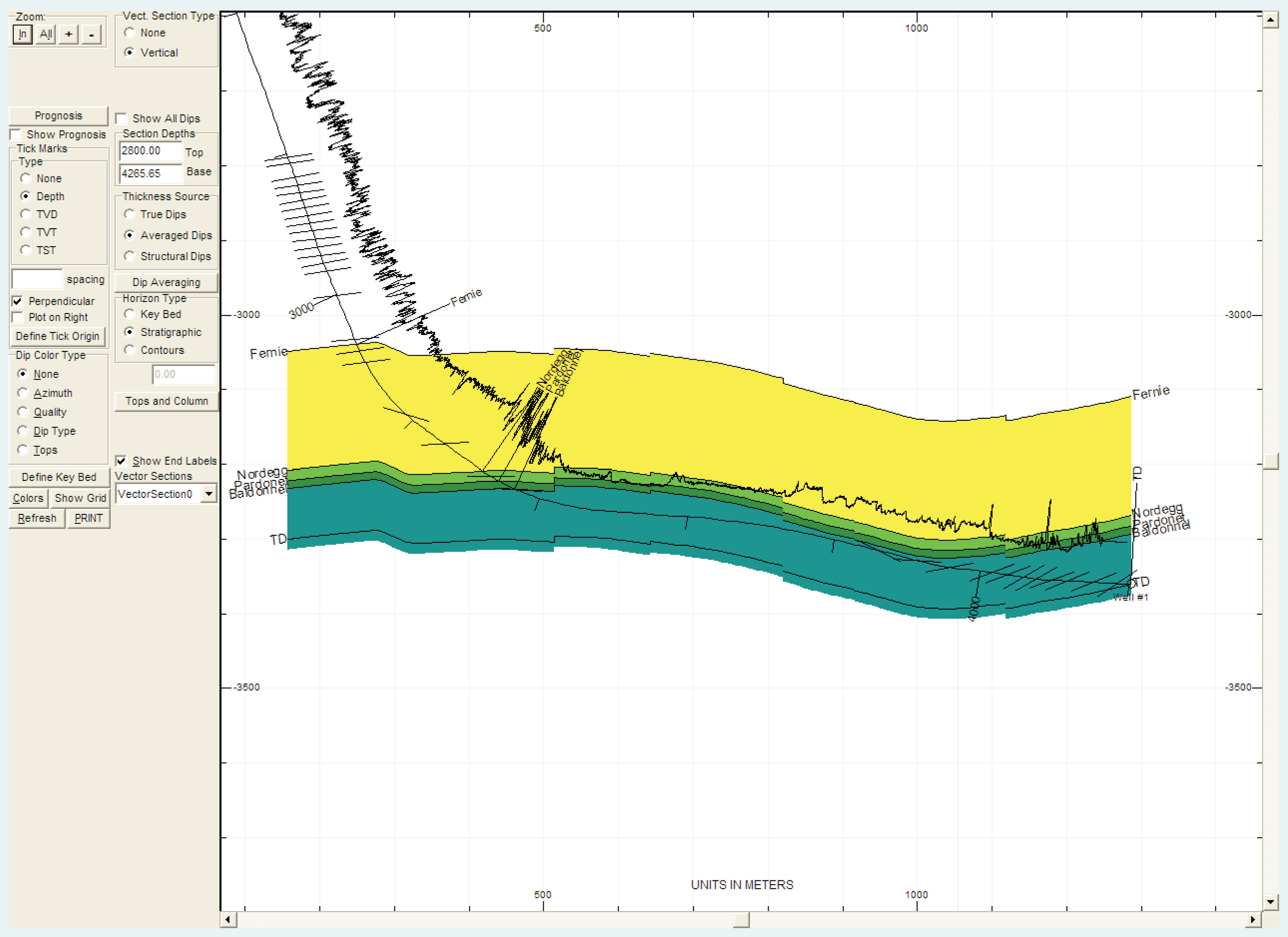
At first glance, it would appear that the domains should be split at about 3300m, because of the large change in azimuth. The azimuth jump, however, is caused by crossing the axial crest of Domain 2. The actual domain boundary is at 3150m.

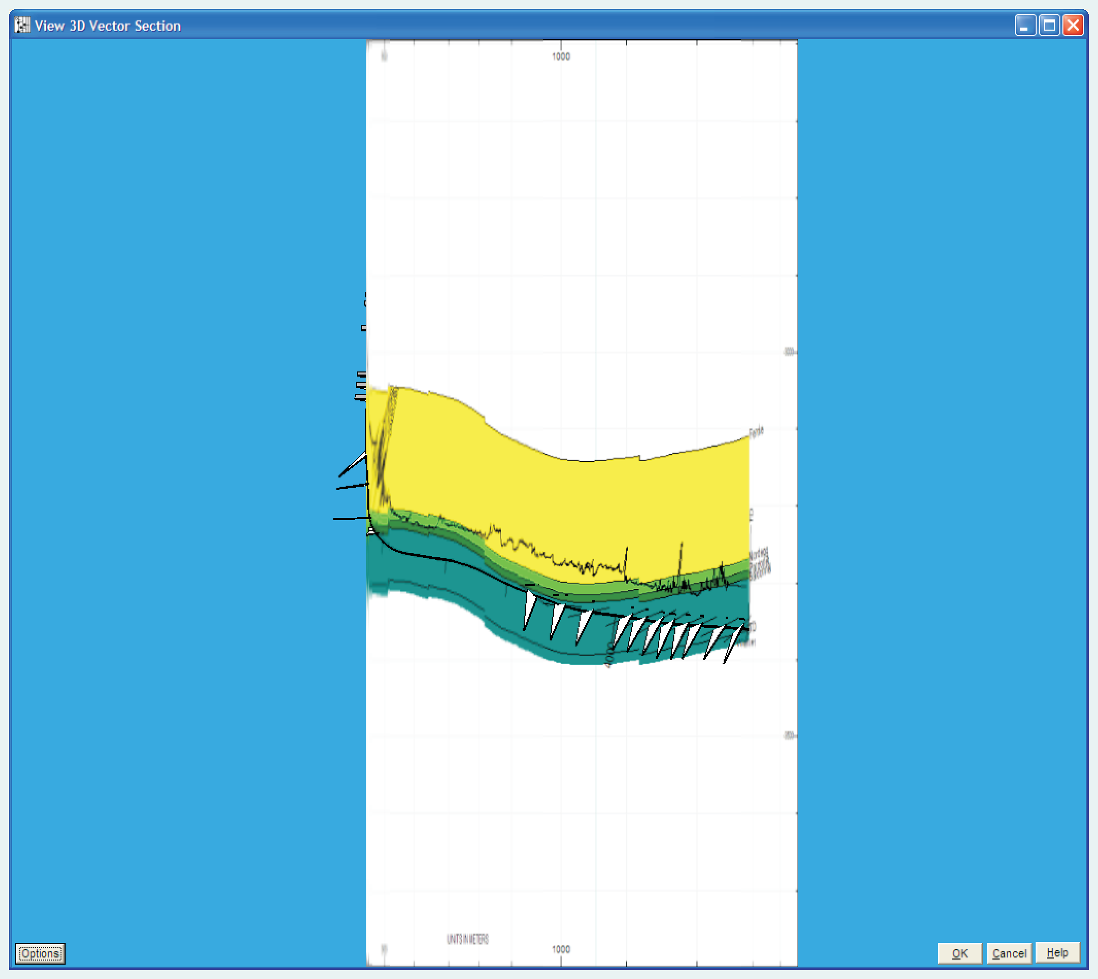




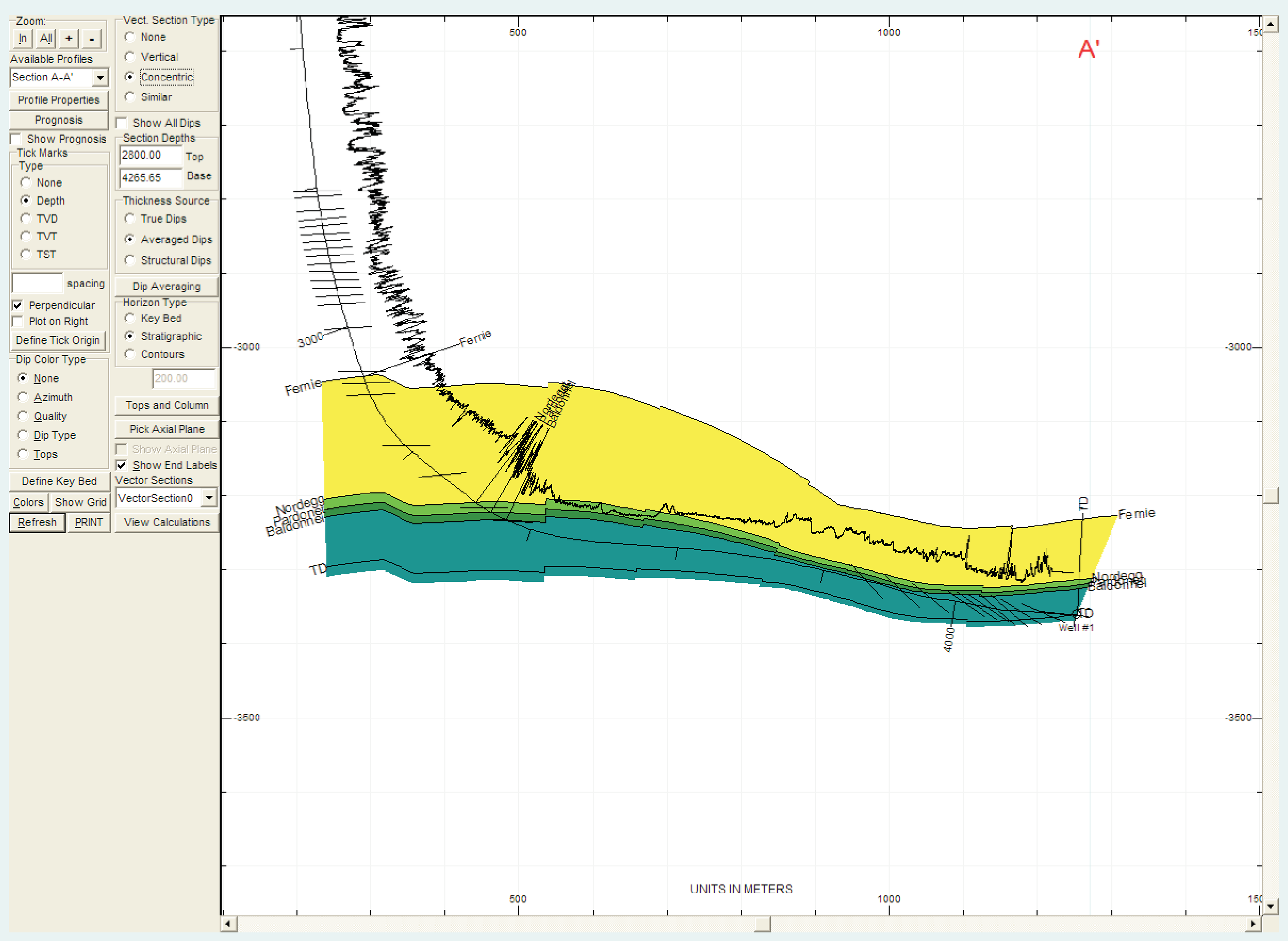
Vector Sections™ *vs* Vertical Sections

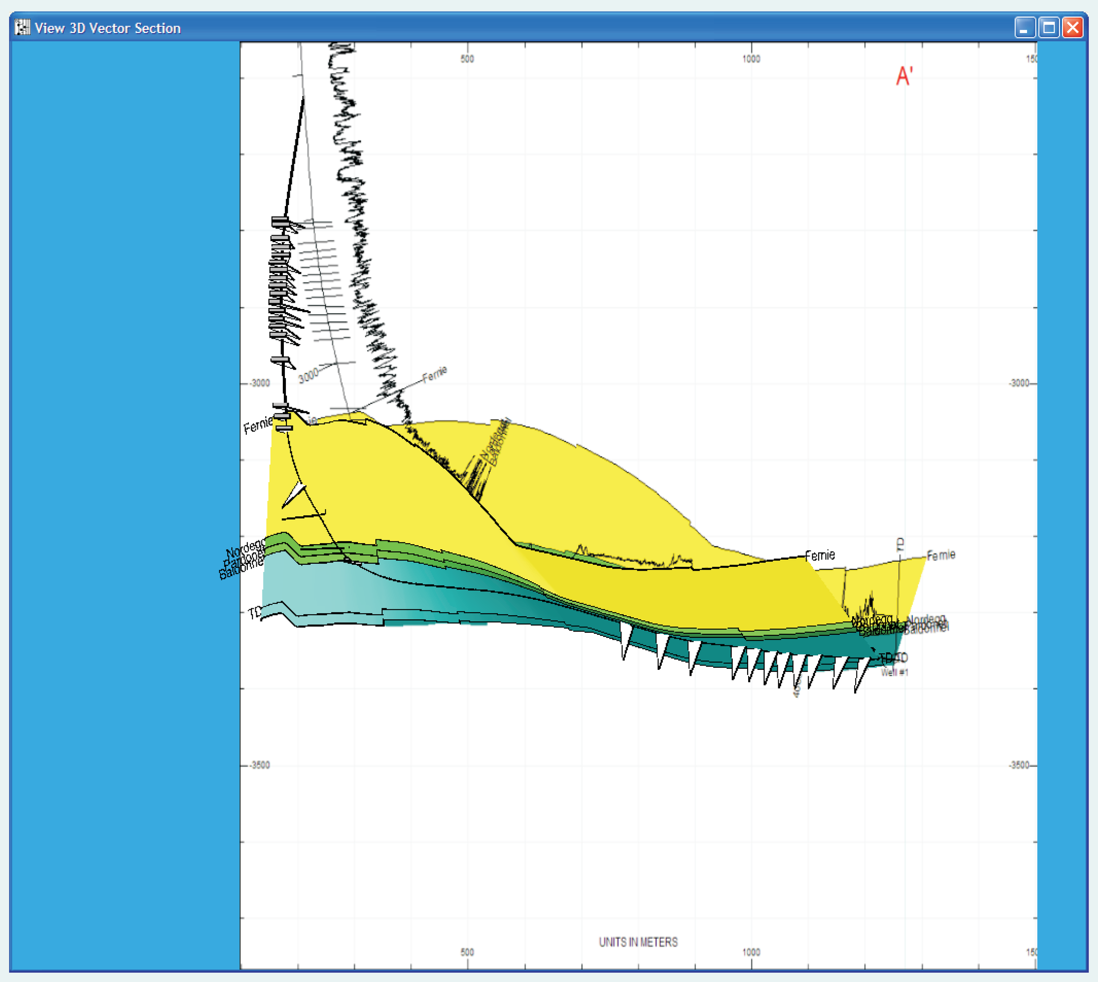
In Vertical Sections, horizons are assumed to be vertically above or below the borehole according to TST. Superimposed dips will “cut through” apparent dips on the 3D vertical section.



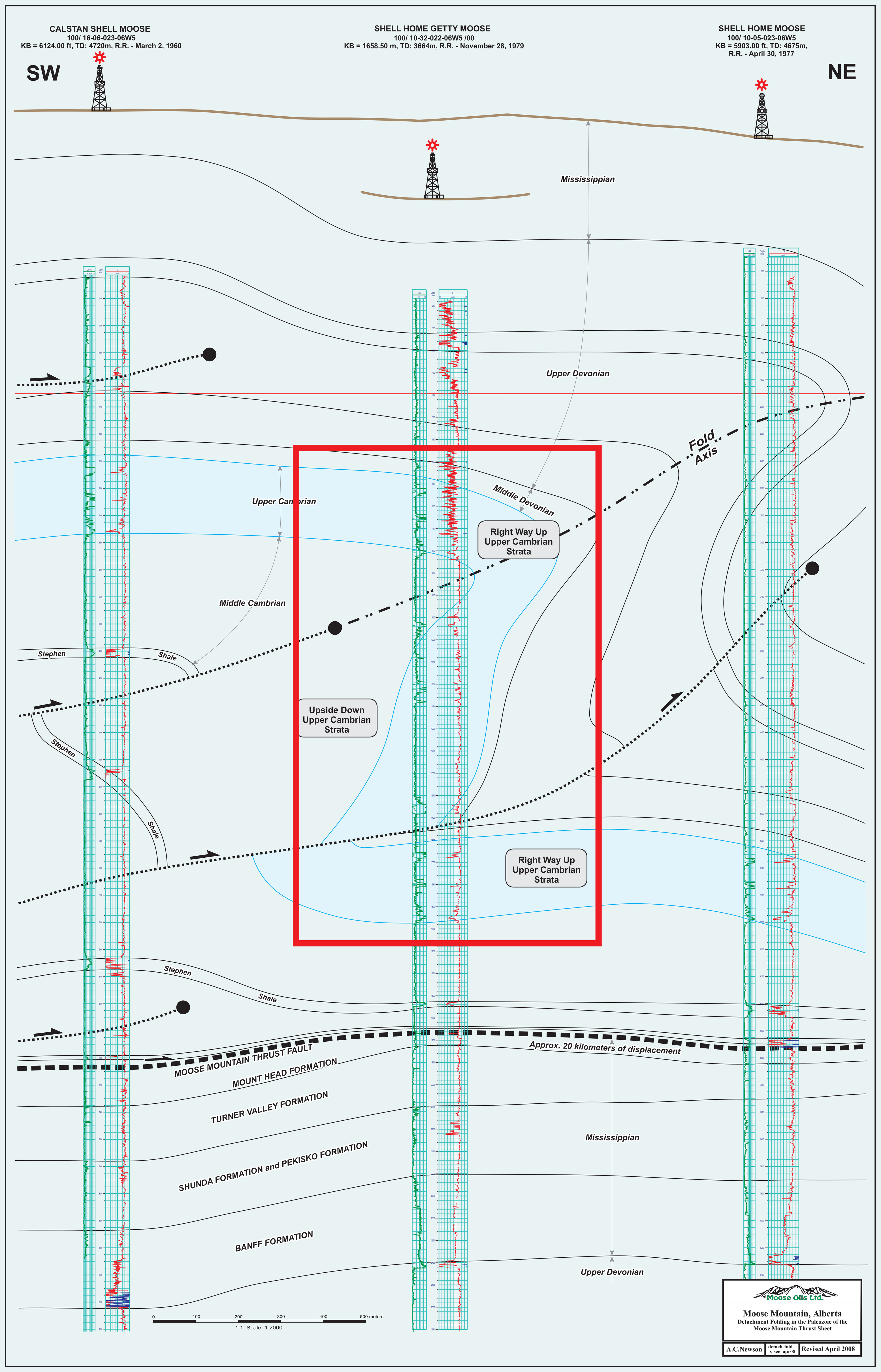


In Vector Sections, vectors point above or below the borehole perpendicular to dip with vector lengths in TST. Superimposed dips will parallel the horizon lines on the 3D vector section.

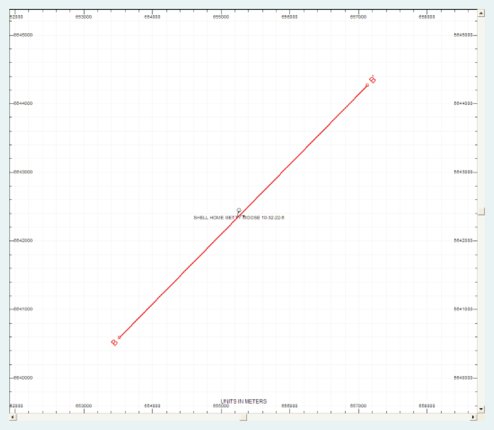


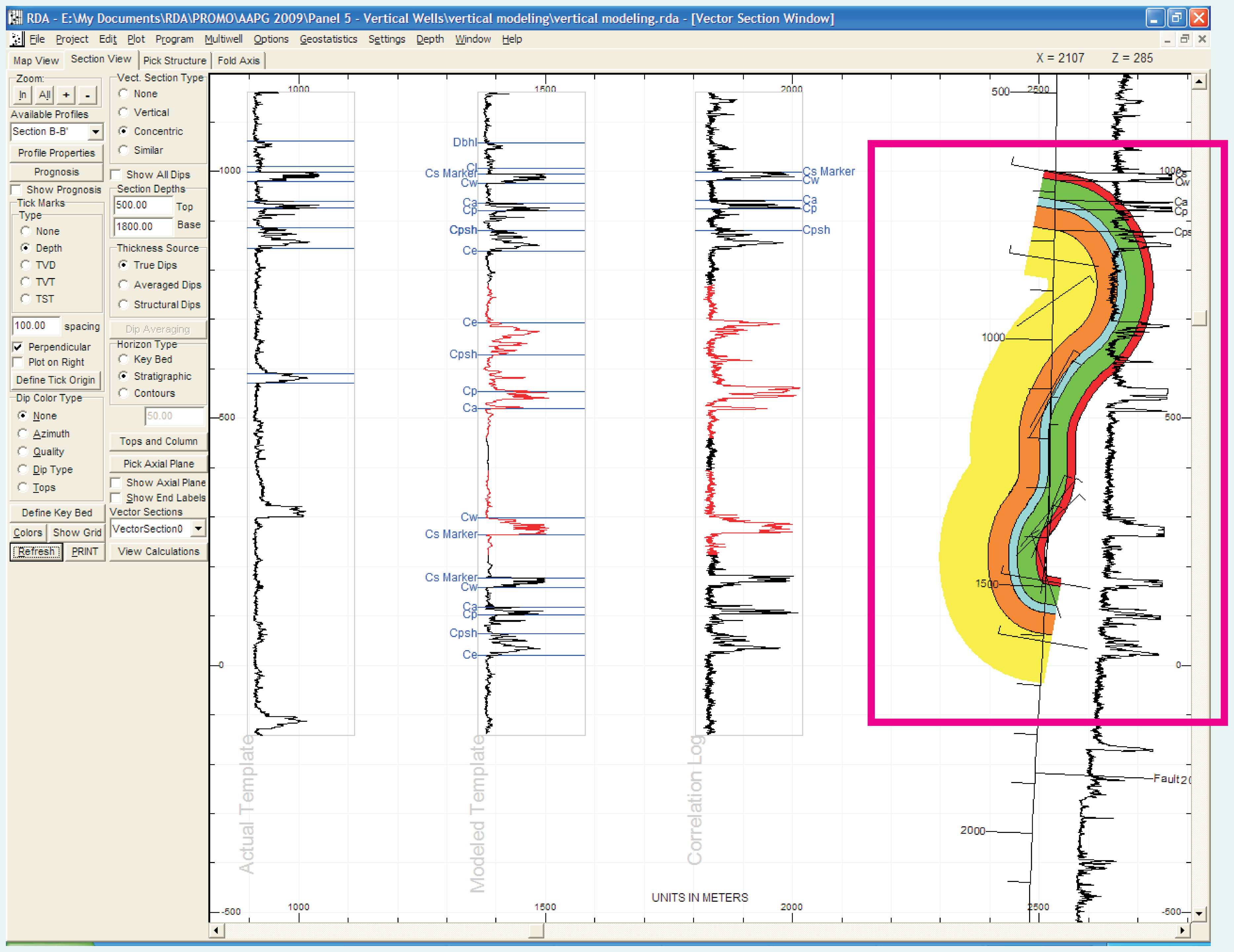


Vertical Wells



Vertical Modeling





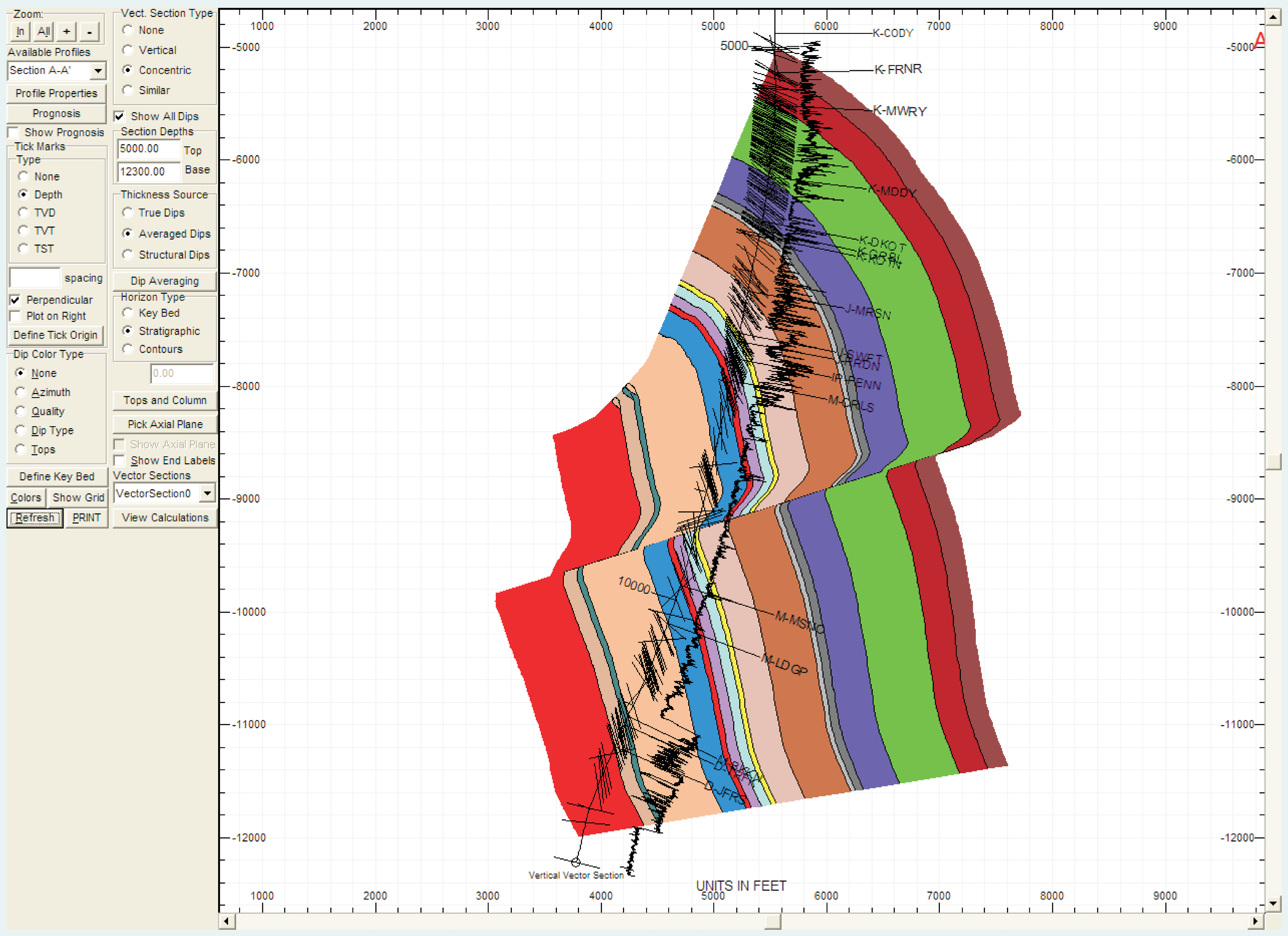
This well was modeled with only a gamma log and a deviation survey. On the left is an earlier, independently drawn cross section with essentially the same interpretation.

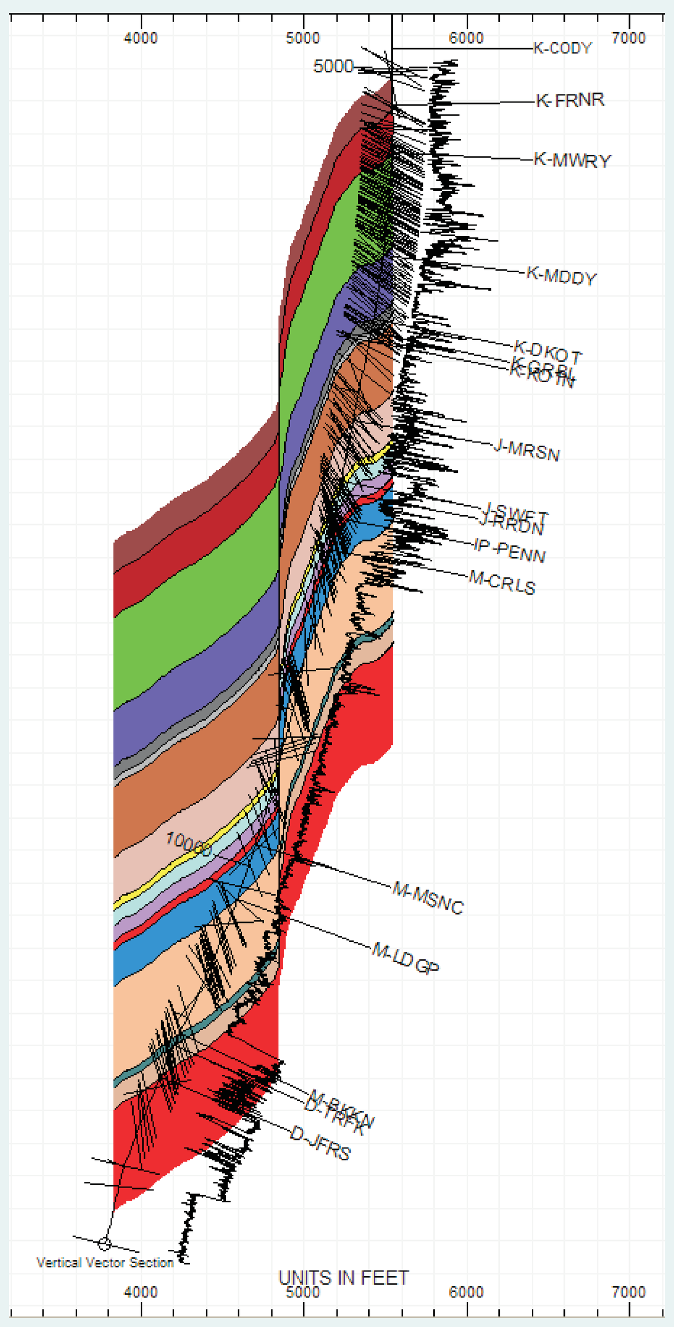
Vector Section™ *vs* Vertical Section

The vector section™ on the near right was made using dips from a dipmeter. The equivalent vertical section is on the far right.

Had the well been fully vertical, the vertical section would basically be a vertical line.

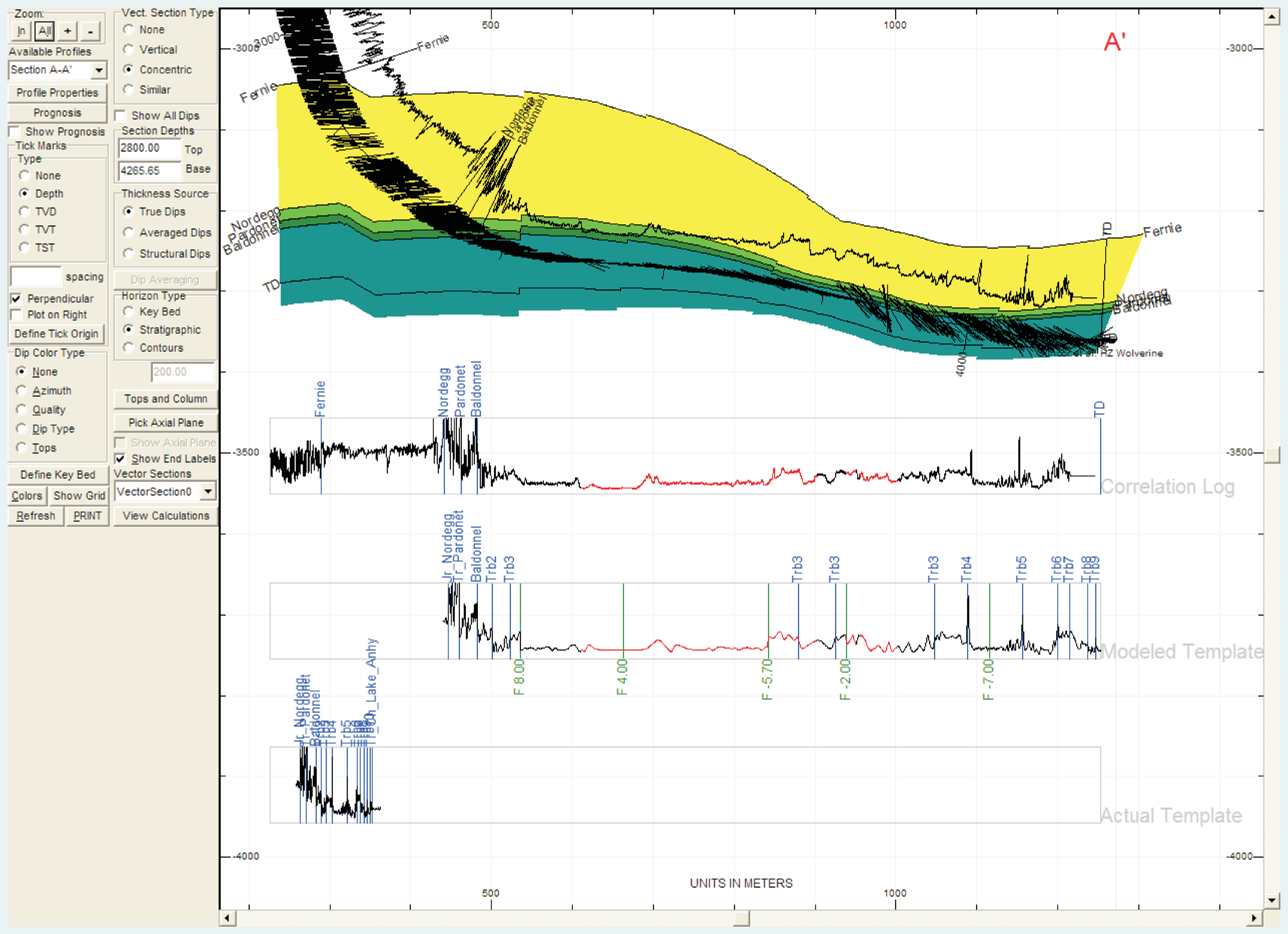
This well is in the U.S. part of the Rocky Mountain Overthrust Belt.



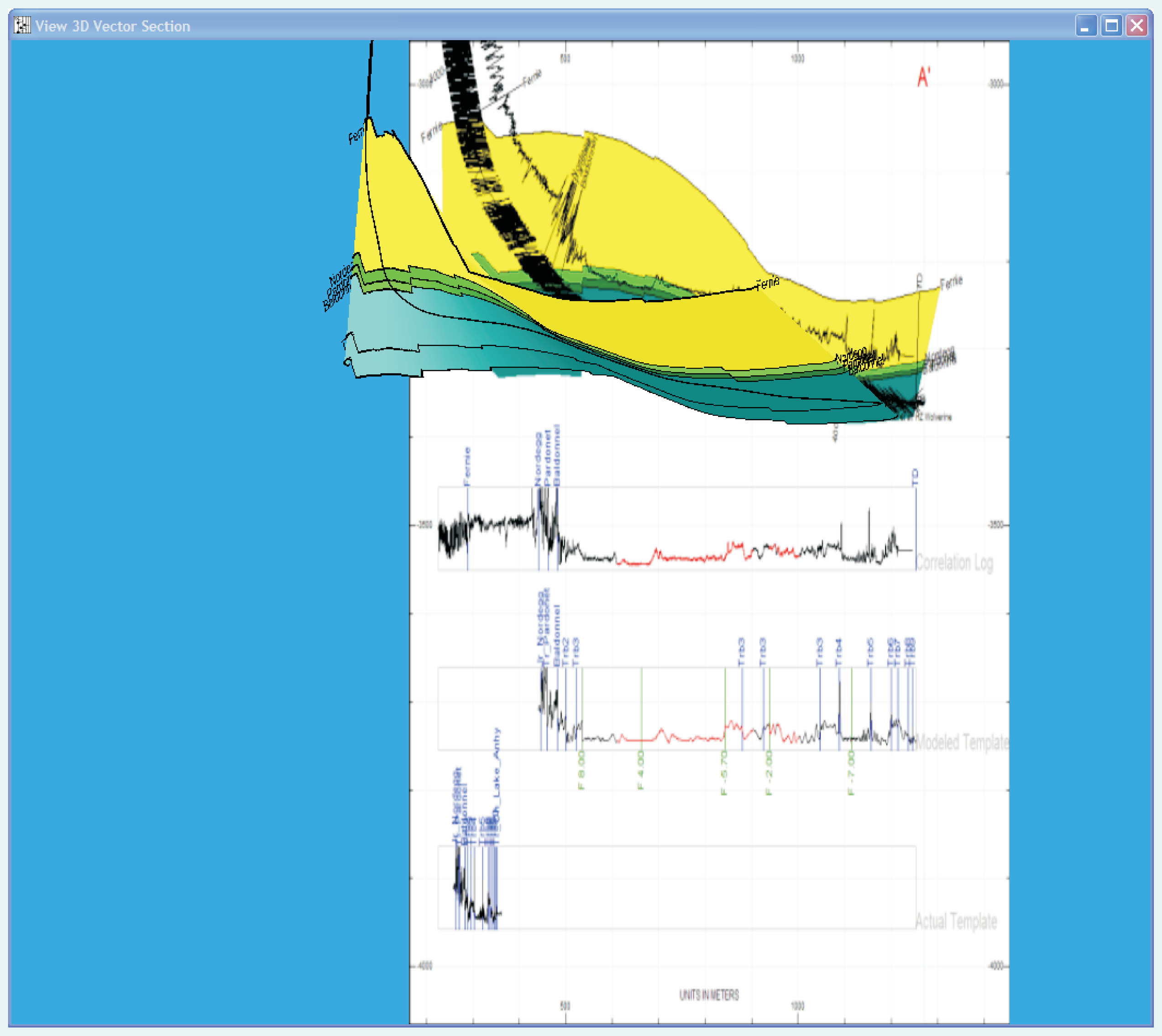


Structural Dip Modeling Examples

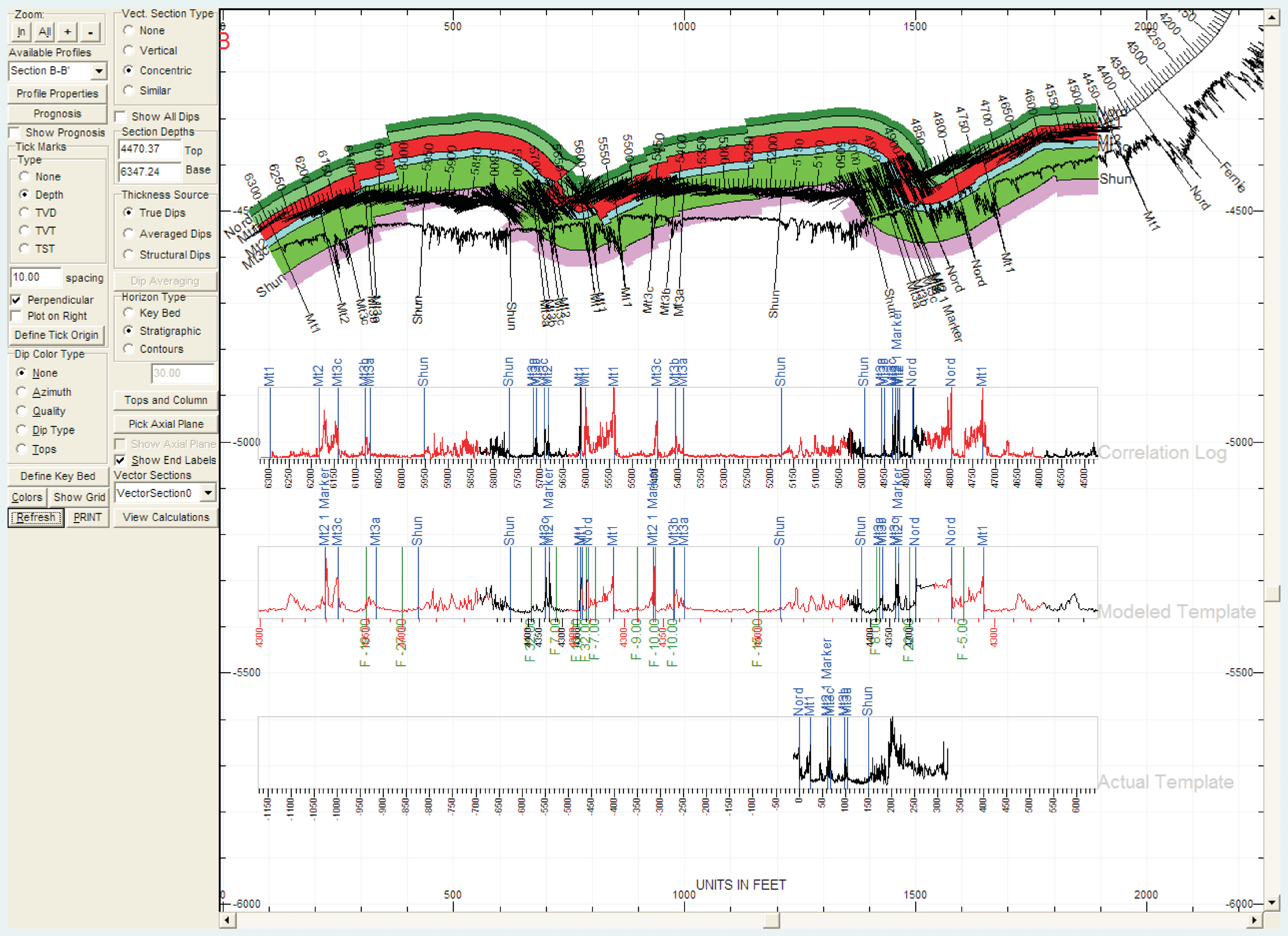
Steep dip



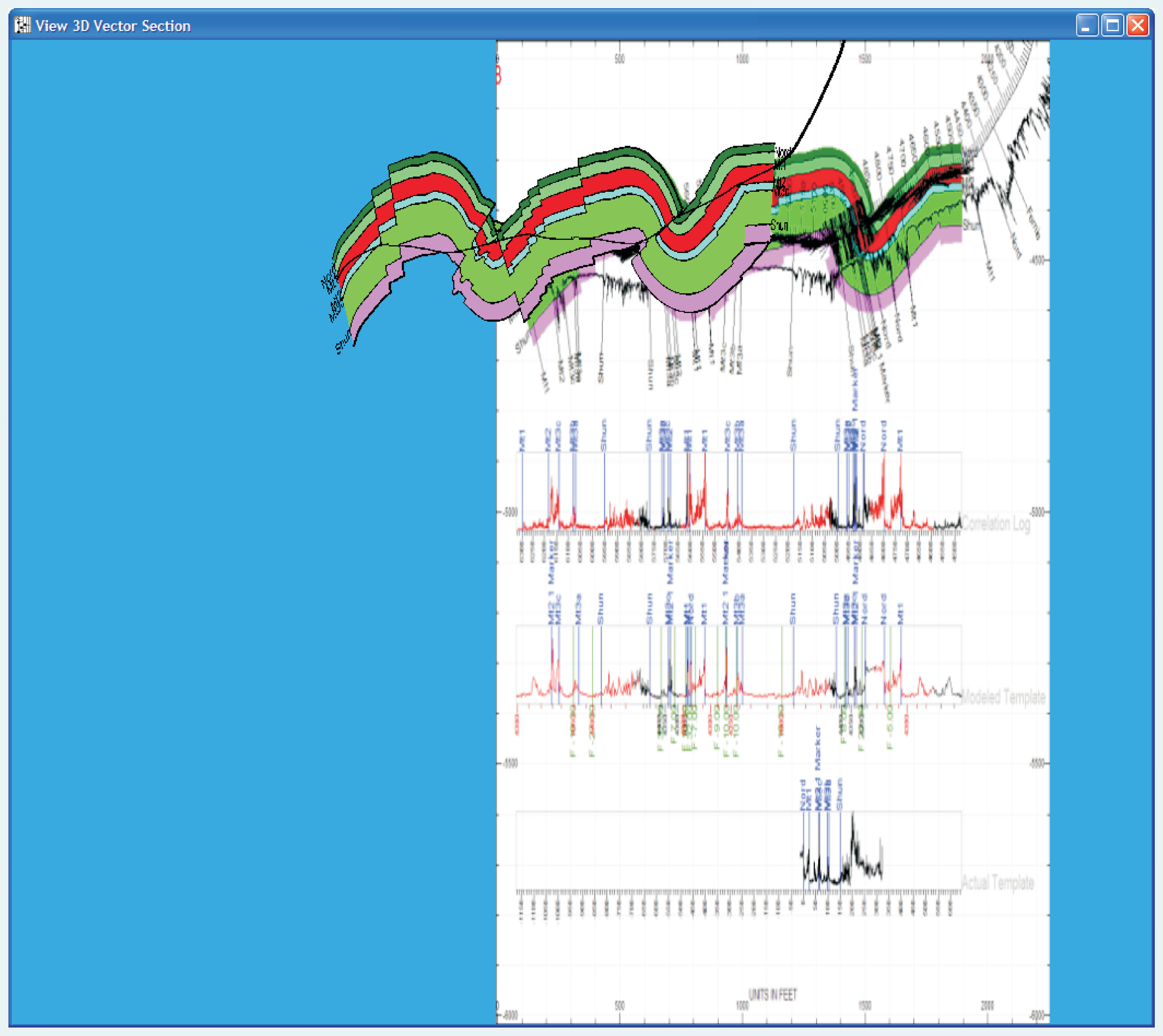
3D Side View



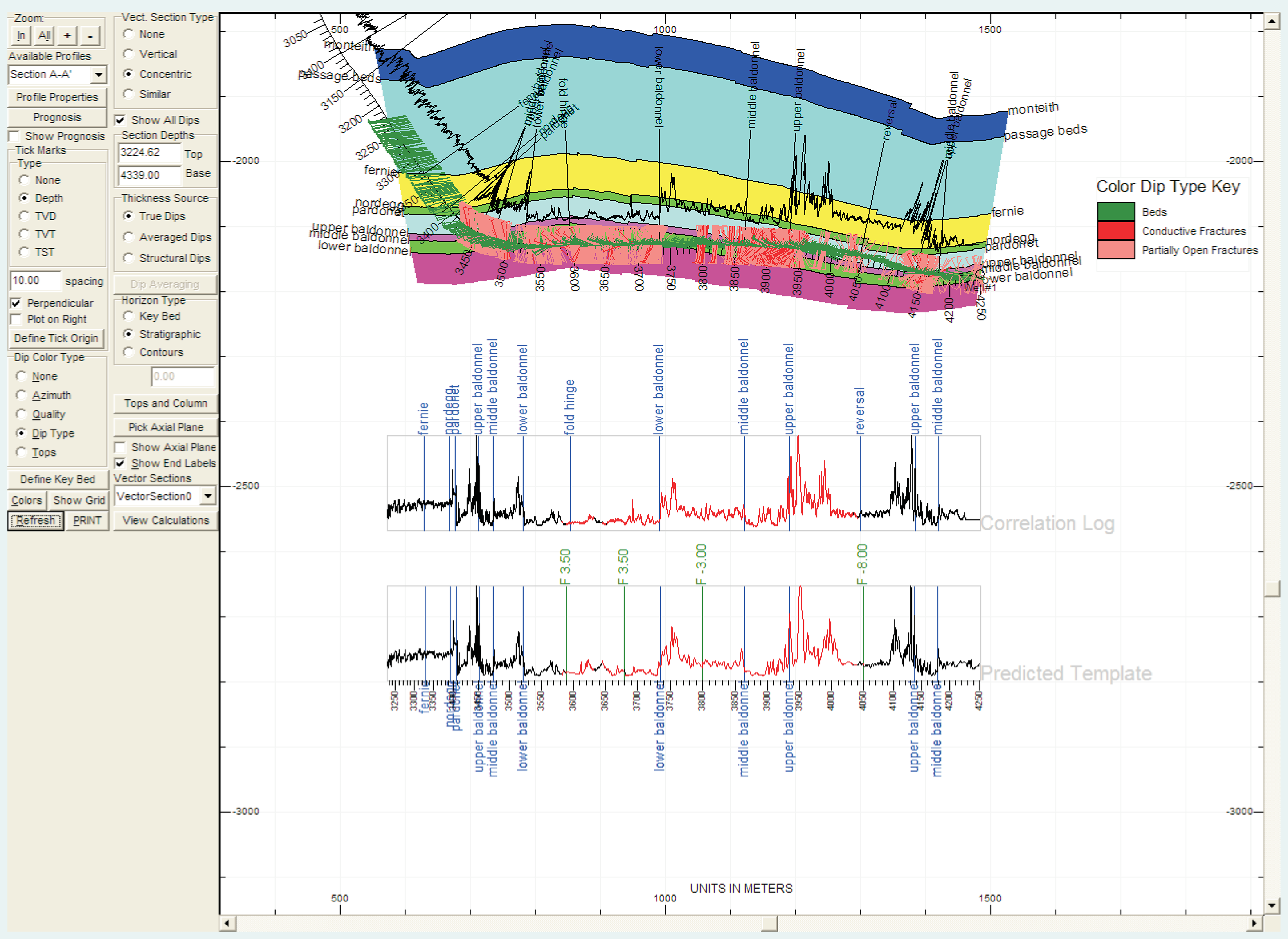
Multiple Thrusts



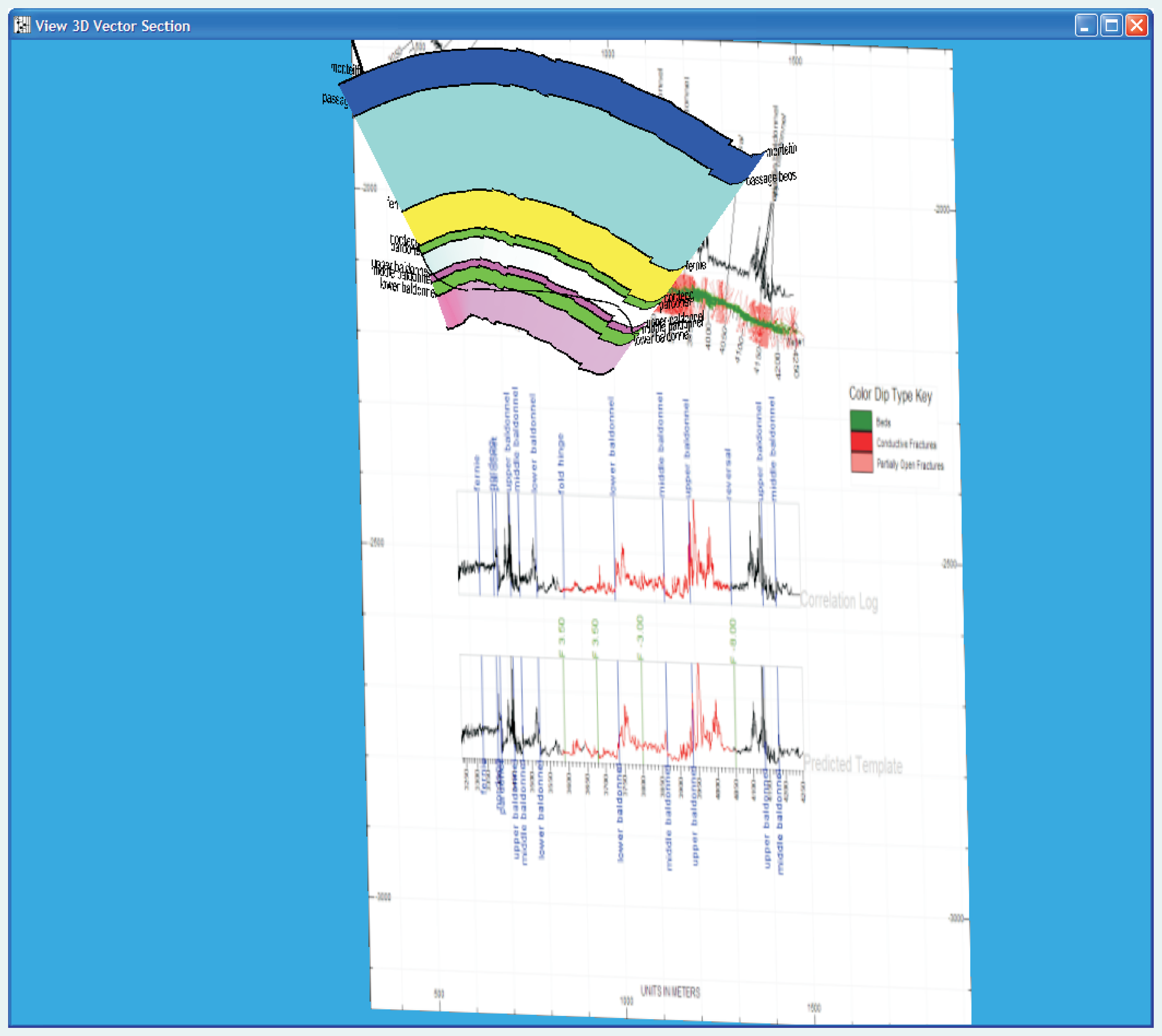
3D Side View



Crossing Crest



3D, Down-Plunge View



Reference

Tearpock, D.J. and R.E. Bischke, 1991, Applied Subsurface Geological Mapping: Prentice Hall, 648 p.