Discussion of Vector Sections and Structural Dip Modeling

RDA has some unique tools for visualization of dip data and for structural dip modeling. These include vector sections, modeling logs, and the prognosis tool. The Vector Section Window is designed specifically with these tools in mind, while the Horizontal Well Tracking Window has a subset of the functionality of the tools.

Vector Sections

In vector sections, true stratigraphic thickness (TST) is used as the length of a vector in which points in the direction of a normal to the dip plane (its pole). The length of the vector is the true stratigraphic thickness to the horizon. A 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. In overturned beds, the vectors are reversed. Fig. 1 shows how a series of these 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 (Fig. 2).

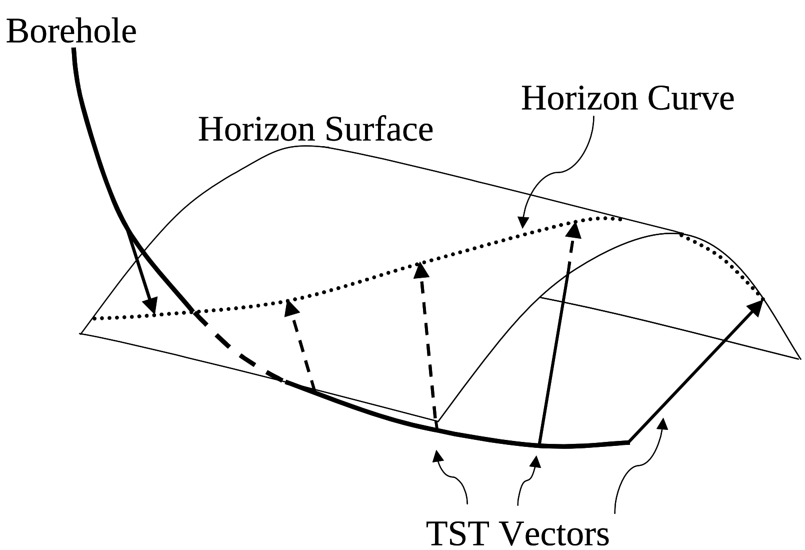

Fig. 1. In vector sections, TST vectors make predictions, based on structural dip, of the position of a curve on the surface of a stratigraphic horizon.

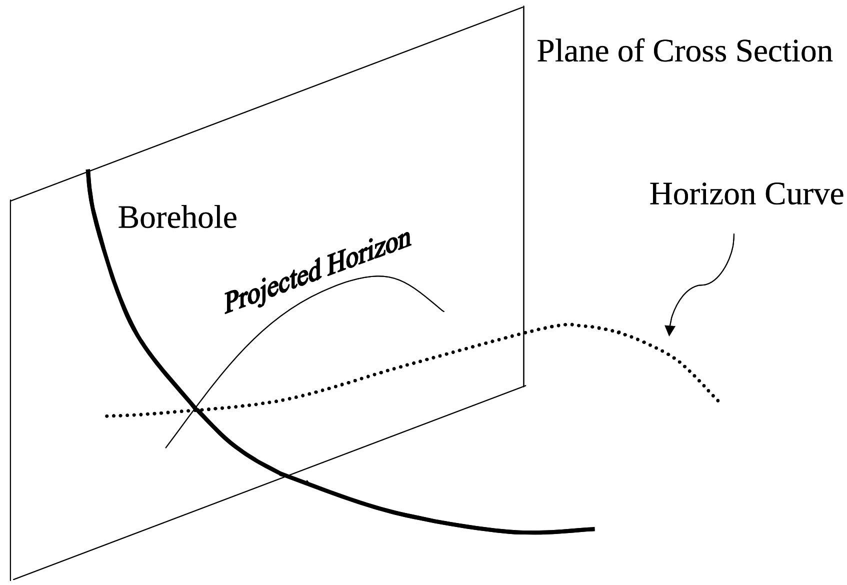

Fig. 2. The horizon curve from Fig. 1 projected onto the plane of section.

Building vector sections as described above implicitly assumes concentric folding. To model similar folds, the vectors are calculated with the same initial steps, but then the vectors are rotated, through the smallest possible angle, until they are parallel to the user-defined axial plane. Using the similar-folding assumption can sidestep the tendency of concentric folds to overlap when projecting toward the folding center. This well-known property of concentric folds requires that they be cored by rock capable of plastic-style deformation such as shales. ("Plastic-style" because cataclastic fracturing can accomplish the same end result.) A side effect of the similar-fold model is that rotation of vectors toward the axial plane will cause a mismatch between the structural dips and the section produced. This happens because folds are usually combinations of similar and concentric geometries. When building sections using only the similar model you can usually pick an axial plane that minimizes the discrepancy between the structural dip and the model. However, most similar folds will not match the dips as well as the concentric folds.

The examples shown in this topic are drawn using stratigraphic horizons, but vector sections can be also be displayed as a single key bed or as contours. The concept behind key beds and contours is identical to that of formations, but use lines of constant TST instead of formation tops.

A peculiarity in comparing vector sections with the apparent dips in stick plots is that they will sometimes appear not to match when they are, indeed, matching. This is because vector sections can be viewed as curtain-like features that are attached to the borehole. When the borehole direction does not match the line of section, the lines on the "curtains" will project at a different angle than apparent dips which are calculated using the dip plane and the line of section. In many of these cases, a displacement section will show much better agreement, because the borehole direction and the line of section are the same at each point. (The Horizontal Well Tracking Window uses a displacement section.)

In horizontal wells where the bedding dips are at fairly low angles relative to the borehole, vertical vector sections can approximate the structure fairly closely. Vertical vector sections have all of the vectors aligned vertically above and below the borehole. One advantage of vertical vector sections is that they do not need structural dips. A disadvantage of vertical vector sections is that they implicitly assume similar folds with vertical axial planes. However, as is usually the case with horizontal wells, when the bedding is at low angles relative to the borehole direction, the section is a reasonable approximation of the actual structure.

The structural dip for building vector sections is defined by selecting, at relatively large intervals, dips that represent the overall structure (not minor faulting or folding.) These dips are then interpolated onto the smaller intervals at which the TST is calculated. The interpolation method does not interpolate azimuth and dip separately, but does a full 3D interpolation by rotating the pole to dip through the shortest path between them (in other words, on a great circle).

In a uniformly dipping area, the points on the curve can be projected on strike. If a fold axis is known, the curve can be projected parallel to the axis. This makes it possible to have good cross sections other than in the dip direction and can provide predictions, based solely on the dip data, of stratigraphic horizons in nearby locations.

Fig. 3 shows an example of a vector section on the Vector Section Window. In the figure, tops are repeated as the borehole travels up section. The deepest tops are in alignment with the vector section while there is a mismatch with the upper ones. The sections are done this way in order to interface properly with the prognosis tool (described below). In other words, when tops are duplicated the program uses the deepest top to align the vector section with the borehole tops. In general, mismatches are probably because of faulting or dip measurement error, but they can also be because of thickness changes. More on this subject below.

Also shown are three horizontal logs: the correlation log in the well, the stratigraphic template log (the "Actual Template"), and a modeled template log. The mismatches on the vector section are also present between the modeled template and the correlation log, but these logs are aligned left to right as opposed to the vector section, which is aligned from right to left. With dips alone the match is fairly good.

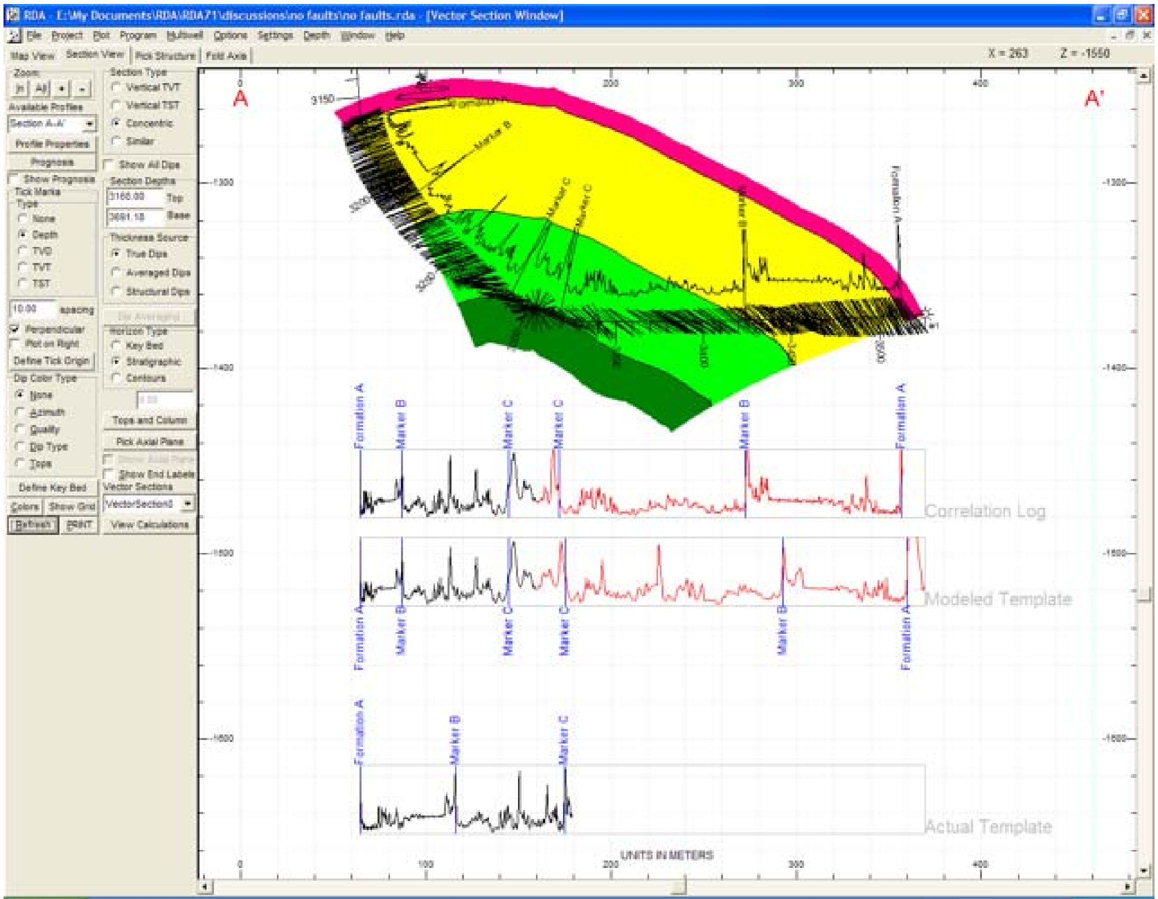

Fig. 3. A vector section in a well that cuts horizontally across an anticline. A stratigraphic template log (labeled "Actual Template") has been created from the correlation log by converting it to true stratigraphic thickness. (Stratigraphic templates can also be from nearby wells.) The template ends at about 3300 m or where the curve on the other two horizontal logs is red. Note the extreme difference in scales near Marker C between the actual template log and the other two. Using the actual template in conjunction with TST calculated for the vector section, the "Modeled Template" is fit to the correlation log using TST in both wells. Here, the modeled template is "hung" at Formation A. The match is fairly good with the correlation log from the well.

Fig. 4 is the same well as Fig. 3, but with some small faults added to more closely match the stratigraphic template log with the correlation log in the well. The addition of faults has made the match between the correlation log and the modeled template log very close. In addition, the vector-section horizons coincide exactly with the tops in the borehole. In those cases when dips are not available, structure can be modeled by adding dips as well as faults.

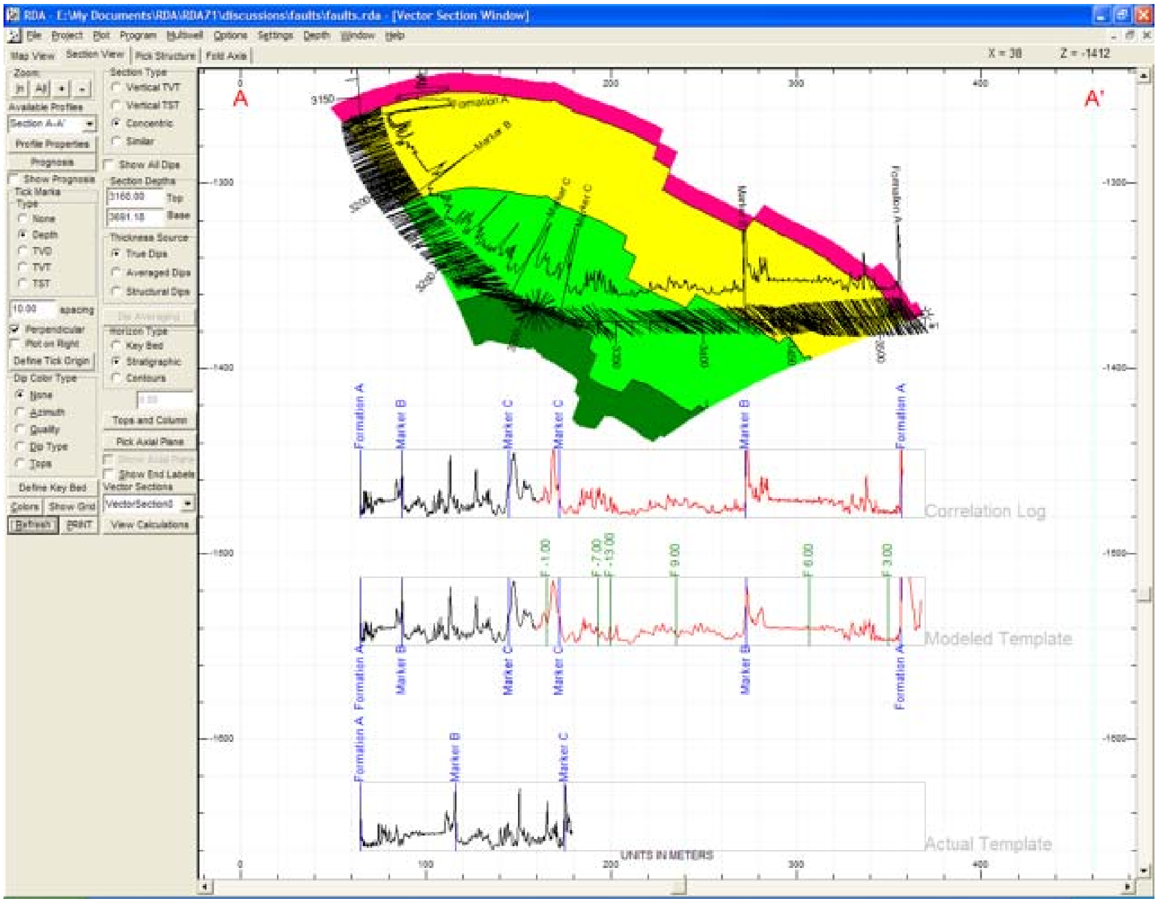

Fig. 4. Same well as Fig. 3 but with small faults that have been inserted to make the modeled template match the correlation log. The small faults are marked in green on the modeled template with an "F" for fault and with the added or missing TST in positive and negative meters, respectively. Note that the orientation of the faults is not intentional. They extend radially because fold type is concentric. In other words, the faults are simply added or missing section which lengthens or shortens the vectors accordingly. If this were a vertical vector section, the faults would extend vertically, and if the similar-fold option was chosen, the faults would be exactly parallel to the axial plane. With major faults, it is recommended that separate vector sections be built.

Structural Dip modeling

Fig. 5 is an example of structural dip modeling in a horizontal well. Adding dips and faults has reproduced the pattern in the correlation log. Although the dips were known in this particular well, this is a good illustration of the power of structural dip modeling. One thing that is important to mention is that because the dip modeling is, in essence, in apparent dip, that the out-of-plane structure can change considerably. In other words, because a pattern of dips can create a given vector section, it does not mean the structure wil be oriented in any particular direction. In a development situation, however, the structure should probably be known well enough that the model is fairly close to the actual structure.

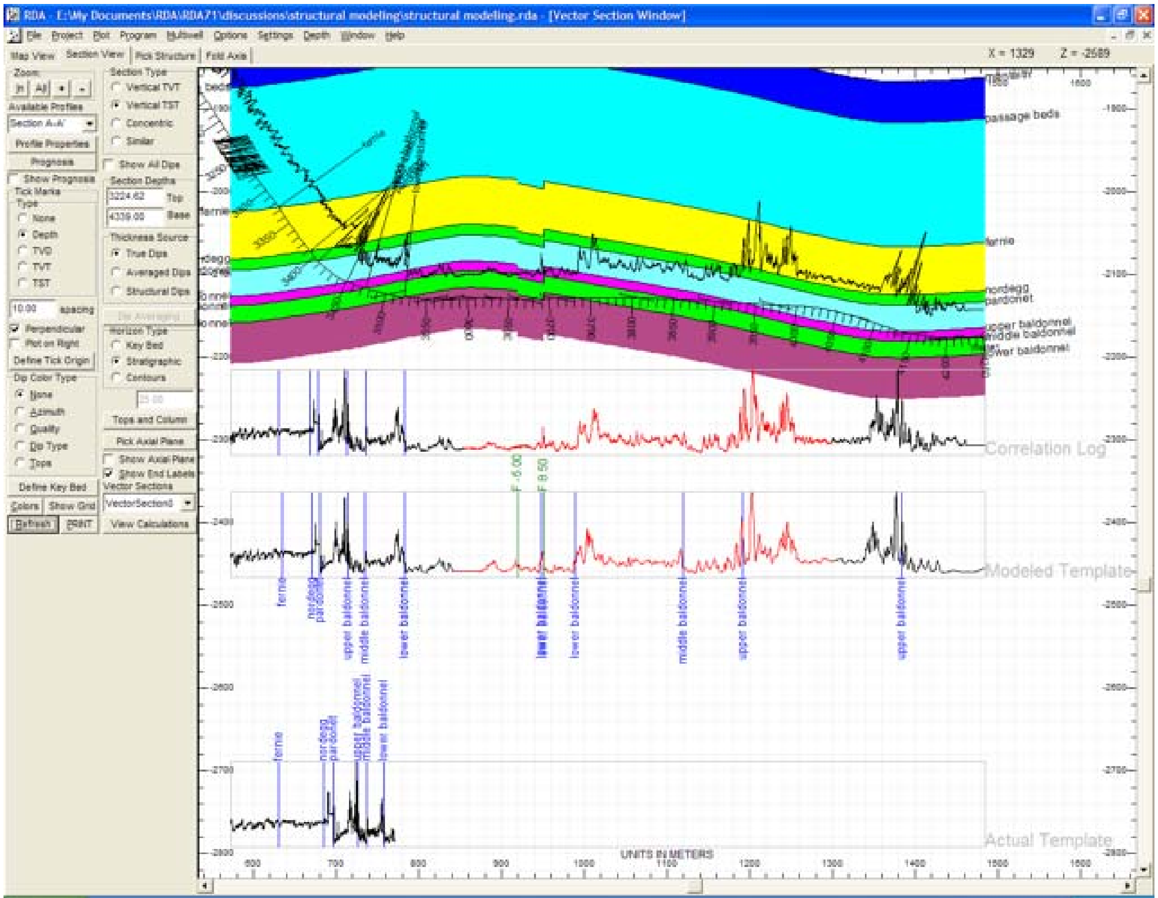

Fig. 5. An example of structural dip modeling in a horizontal well. As in the earlier example, the template was produced from the same well down to the point where the curves turn red. In this example, the type of vector section is vertical TST. The model has been created by adding dips and faults until the structure matched the well. Note how the fault at 3690 has reproduced the small gamma spike that was actually a shoulder at the base of the Middle Baldonnel.

The Prognosis Tool

Fig. 6 shows an example of the prognosis tool. In this case the objective is stratigraphically 50 meters above Formation A. (Remember when drilling up section that the true stratigraphic thickness to objective entered into the Prognosis Dialog should be a negative number—in this case -50.) The long apparent dip lines and heavy weight on the borehole define the prognosis. The prognosis dialog allows you to vary both dip and deviation in order to get an idea of error caused by either dip or deviation measurement. Be aware that many unforseen things may happen ahead of the borehole (for example, faults, dip changes or thickness changes) that may severely affect prognoses.

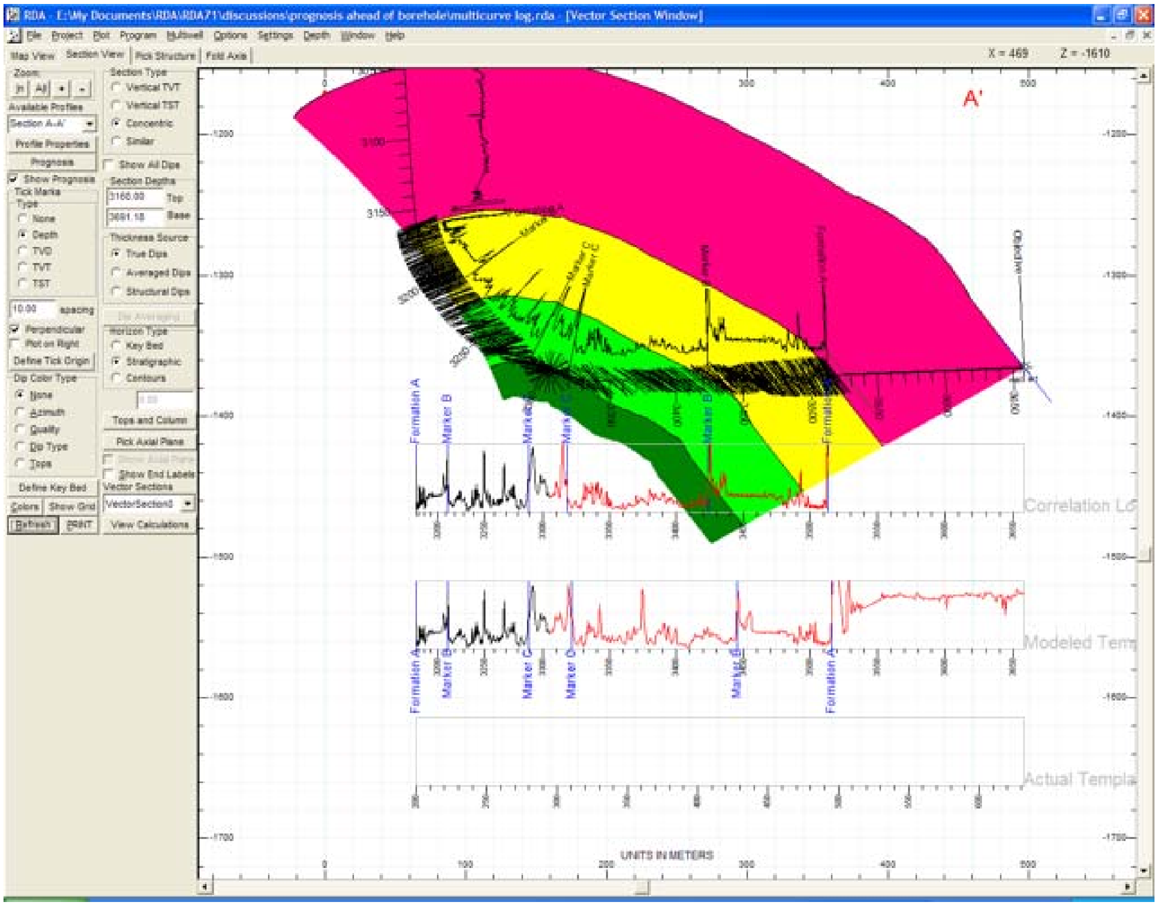

Fig. 6. An example of the use of the prognosis tool. The two long apparent dip lines on the right-hand side of the well show the dip, while the heavier line-weight shows the proposed well path. The vector section has been extended as if the prognosis dip and deviation were already part of the well. The modeled template log demonstrates how it is possible to anticipate character ahead of the bit and thus be able to adjust the prognosis accordingly.

Structural Dip modeling in Vertical Wells

Up to this point, the examples have been in horizontal wells. Fig. 7 is an example of structural dip modeling in a vertical well. The main difference in structural dip modeling between horizontal and vertical wells is that in vertical wells, vector sections with the vertical TST option do not work because the vector section ends up extremely narrow. In Fig. 7, the concentric fold option has been selected.

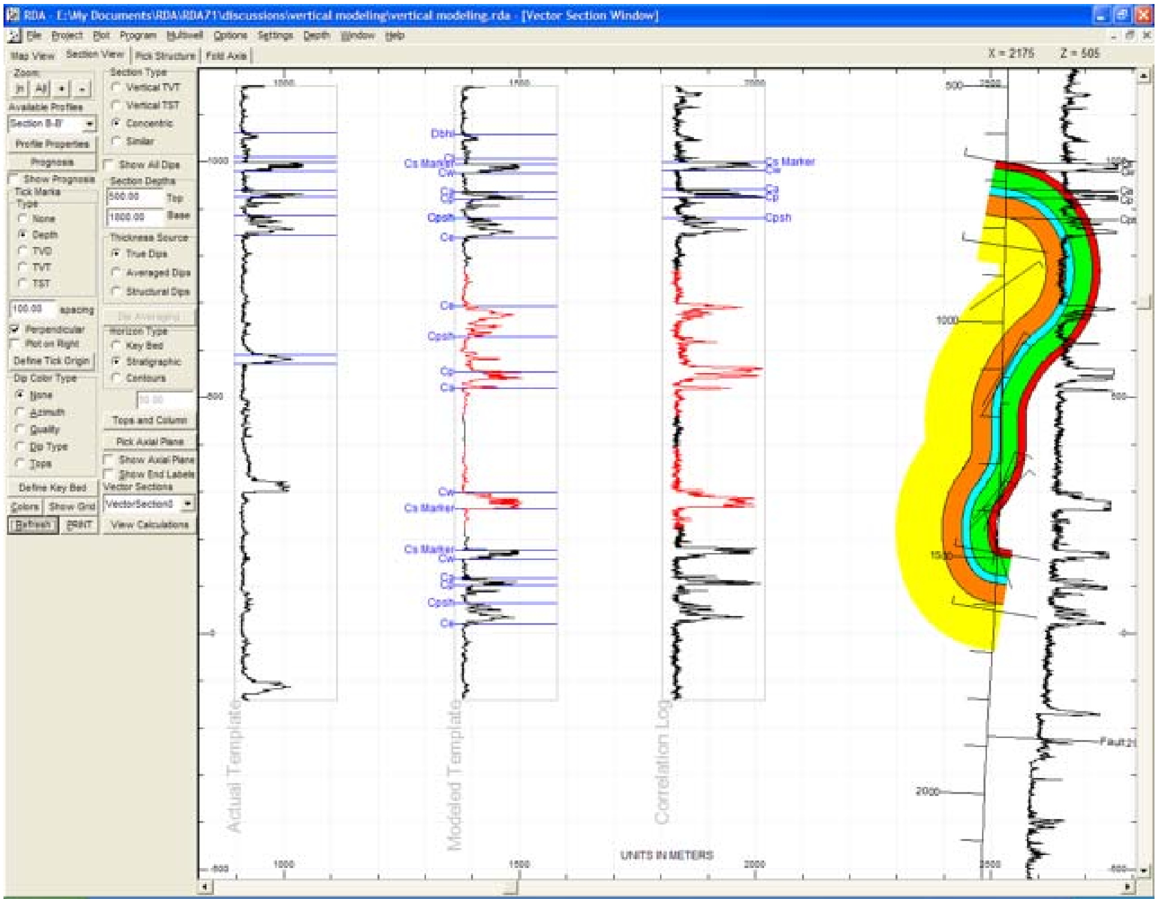

Fig. 7. Structural dip modeling in a vertical well. The only data sets from the well itself are the correlation log, the tops, and the borehole deviation survey. The dips are modeled and the actual template is derived from a nearby well.