

Geosteer Using the smartSTRAT Module and the GVERSE Geomodeling Live 3D Model

GVERSE Geomodeling



GVERSE GeoGraphix Support

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Introduction

smartSTRAT is the geosteering module for GVERSE GeoGraphix. Embedded within GVERSE Geomodeling (the live 3D modeling software for GVERSE GeoGraphix), smartSTRAT enables you to add control points to any surfaces displayed on a Vertical Section on the fly, thereby instantly updating the stratigraphic framework and providing the most accurate picture possible of the local geology. smartSTRAT can also be used to correlate horizontal wells after they have been drilled (even if not used in the geosteering process itself), allowing for the addition of control points to the GVERSE Geomodeling 3D geologic model.

The combination of smartSTRAT and GVERSE Geomodeling can therefore help you not only geosteer, but also improve the accuracy of your geologic interpretations in real time. This paper contains guidelines that allow you to optimize both, your geosteering workflows and “post-mortem” correlation of horizontal wells.

The goals of this paper are to:

- Discuss the importance of geosteering within a real-time 3D geologic framework
- Discuss the fundamental concepts that govern smartSTRAT’s Geosteering workflow
- Outline and discuss the optimum workflow for using smartSTRAT and updating the GVERSE Geomodeling 3D geologic model.

Why use smartSTRAT and GVERSE Geomodeling to Geosteer your Well

As noted above, the smartSTRAT module is tightly integrated with the GVERSE Geomodeling software. GVERSE Geomodeling is a 3D topological geologic modeling engine that can be used to quickly correlate and visualize structural and stratigraphic relationships in a given area. This 3D model integrates all well-related data in other GeoGraphix modules. In addition, GVERSE Geomodeling can build predictive surfaces using its **Conformance** tool. This tool can generate deeper, modeled surfaces based on the structural trends of shallower, better sampled surfaces concordant with the less constrained surfaces. These deeper surfaces are often the targets of unconventional wells.

smartSTRAT was built to take advantage of the GVERSE Geomodeling 3D geologic model. As a result, its workflow is governed by the geologic data present in all GeoGraphix modules. This data includes all WellBase formation tops and fault picks, GeoAtlas structure maps, maps generated from SeisVision’s seismic-based data, and conformable surfaces created in GVERSE Geomodeling. smartSTRAT allows you to not only geosteer the well bore based on outside data, but to geosteer within an environment that you have full control over, using a tool that automatically refines and updates the current geologic model for the next well on your drilling agenda.

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The GeoSteering Model: Use of the LWD Curve and Predicted Curve

smartSTRAT uses conventional geosteering methods that enable you to compare the LWD (Logging While Drilling) curve from the drilling well with a “predicted” curve. There are two distinct ways to generate the predicted curve:

1. The *predicted* curve can be generated from what is termed the *local well*. This is the default option and results in the *predicted* curve being created from the well that is being geosteered/correlated. In the simplest case, smartSTRAT records (at each step along the LWD log) the true vertical thickness (TVT) and associated GR API values between the Active Surface (the point at which the selected 2D Dip surface intersects the well bore) and the well bore’s first maximum TVT. This first max TVT point is the first point at which the well goes from deepening stratigraphically to cutting back up-section with respect to the 2D dip surface. The TVT/GR API pairs are then used to create the *predicted* curve. This method utilizes the closest possible control available to the drilling horizontal until it approaches, for example, a nearby vertical well. Note that using the local well to generate the *predicted* curve only works if the well lands stratigraphically, and then proceeds to generally drill back up-section. smartSTRAT can only be used once the well has landed stratigraphically. Prior to that, option 2 (below) must be used.
2. The *predicted* curve can also be created from what is termed an *offset type log*, which is usually a vertical well close to the drilling well (such as a pilot well). This is the only option that can be used if the well does not bottom stratigraphically, and continues to drill deeper into the section. Note that the structural configuration of the well is irrelevant; the *local* type log option can be used even if a well is continuously drilled deeper (i.e., the TVD of the well increases) as long as the well bottoms stratigraphically and then proceeds to drill up-section.

Be aware that the use of the *offset type log* option may result in a *predicted* curve that has less GR character than one generated via the **local well** option. This is because vertical wells generally only sample each foot (or half-foot) of stratigraphy, whereas that portion of the drilling horizontal well between the *Active Surface* and the first maximum TVT is usually at an angle between 45 and 90 degrees to bedding, resulting in far more GR samples per vertical foot of rock in, or proximal to, the target interval. This usually means that the *local well* option produces a more detailed *type log*.

It is important to note that the source of the *predicted* curve (i.e., the type log) can easily be changed as geosteering/correlation progresses without affecting any previous correlations done up-hole. For example, the local well can be used to generate the *predicted* curve in the first 2000 ft. of Vertical Section (VS), and can then be replaced by a vertical well that was drilled just off the proposed borehole path at VS=3000 ft.

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By adjusting the dip on the 2D dip surface, you can match the LWD curve values to the *predicted* curve and interpret the true dip and/or offset of the 2D dip surface along the length of the borehole. As you can make comparisons between the curve values associated with the LWD and *predicted* curve, you can add tie lines, correlate the horizontal well, and integrate the newly derived correlation information to your existing geologic model.

smartSTRAT offers three different predictive models that determine which values are used during the generation of the *predicted* curve from the local well. Care must be taken to choose the model best suited for the local geology, and borehole trajectory. The dip of the beds, the target zone, and the borehole path are all very important in determining which model to use. The models are summarized below.

Model 1: Use Only Values Down to First Local Maximum TVT

The **Use Only Values Down to the First Local Max TVT** model only reads, and uses LWD curve values in the drilling well, down to the first local maximum true vertical thickness (TVT). The only time you would probably use this model to generate a *predicted* curve, is when the well is drilling “toe up” and the sump is the deepest section in the well. In other words, the well is drilled up through the previously drilled stratigraphic horizon, and never drills into a stratigraphically deeper part of that geologic section. The well will, therefore, encounter the same stratigraphic section that has previously been drilled through. If the well drills through a deeper section, there will be no predicted curve generated in that interval. Therefore, you will only see a red curve, depicting the LWD curve, over this drilled interval in the Horizontal panel (the Horizontal panel is discussed later).

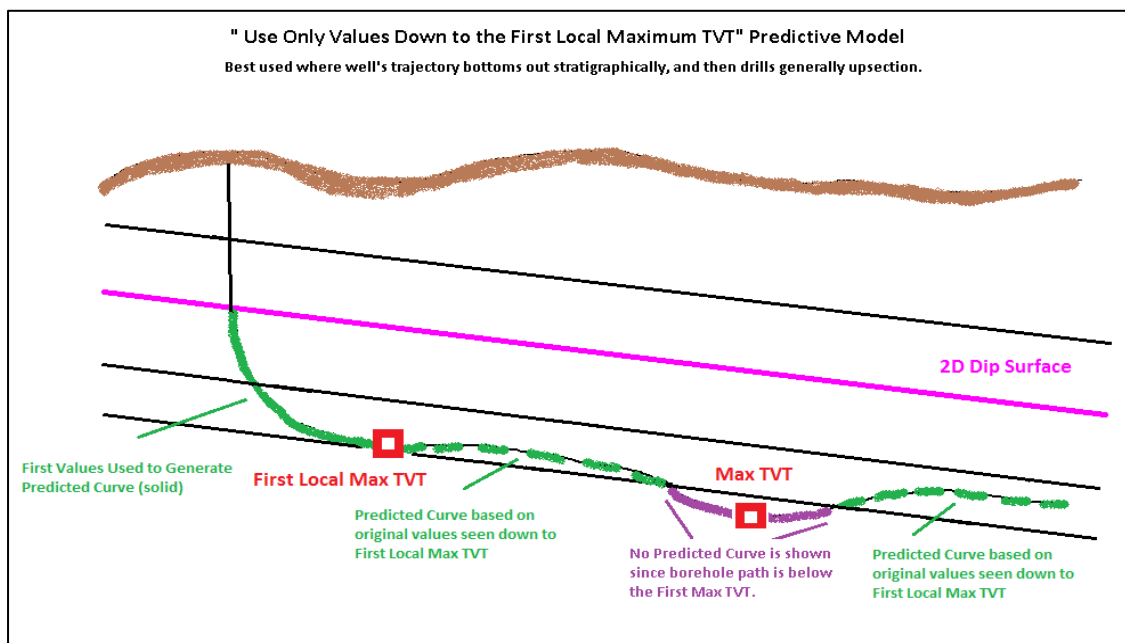


Figure 1: Diagram showing values used in the Use Only Values Down to First Local Maximum TVT model.

Model 2: Use First Values Encountered through Maximum TVT

The **Use First Values Encountered through Maximum TVT** model is often the most appropriate to use if the wellbore porpoises up and down and has multiple local maximum TVT points. The resulting *predicted* curve will use only the first occurrences of the log values relative to the 2D dip. This model will not create a folding back effect in the Vertical panel, since only unique values of the LWD log curve are used.

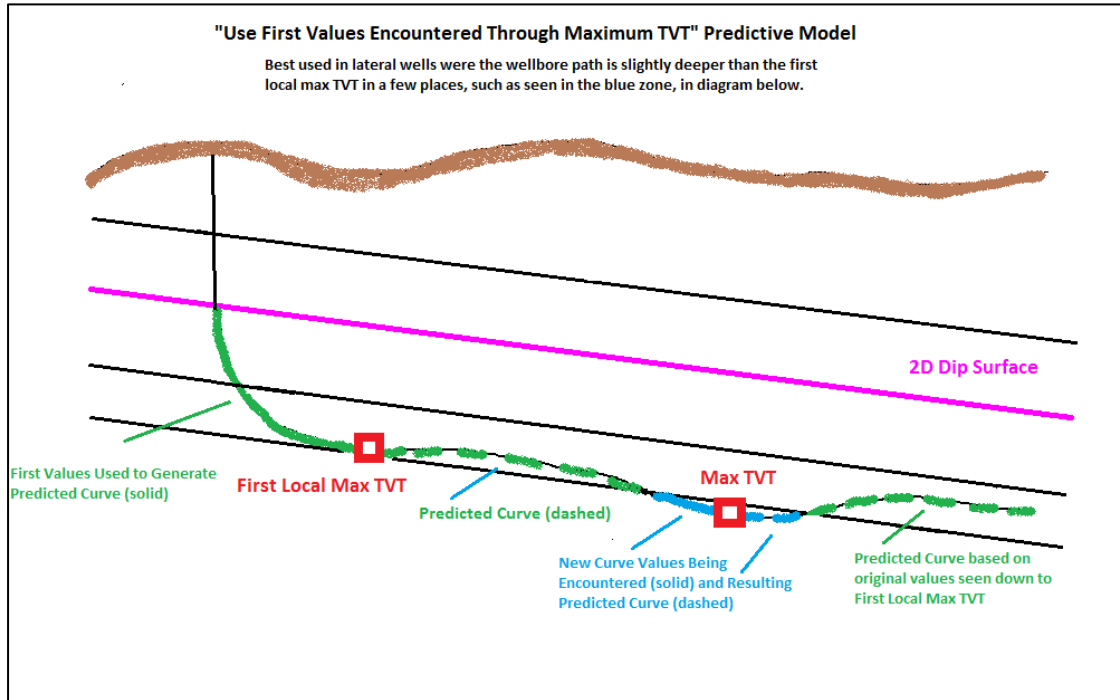


Figure 2: Diagram showing values used in the Use First Values Encountered through Max TVT model.

Model 3: Use all Values Through the Last MD (Measured Depth)

The **Use all Values Through the Last Measured Depth** model option uses all the values of the LWD log curve to create a TVT type log in the **Vertical** panel, and generates a *predicted* curve. This creates a very detailed *predicted* curve because the model uses all log values along the full length of the well bore (see Figure 3 below). The disadvantage of using this model is that if the borehole porpoises up and down relative to the chosen 2D dip surface, it will create a TVT type log that folds back on itself, making it difficult to correlate in the **Vertical** panel.

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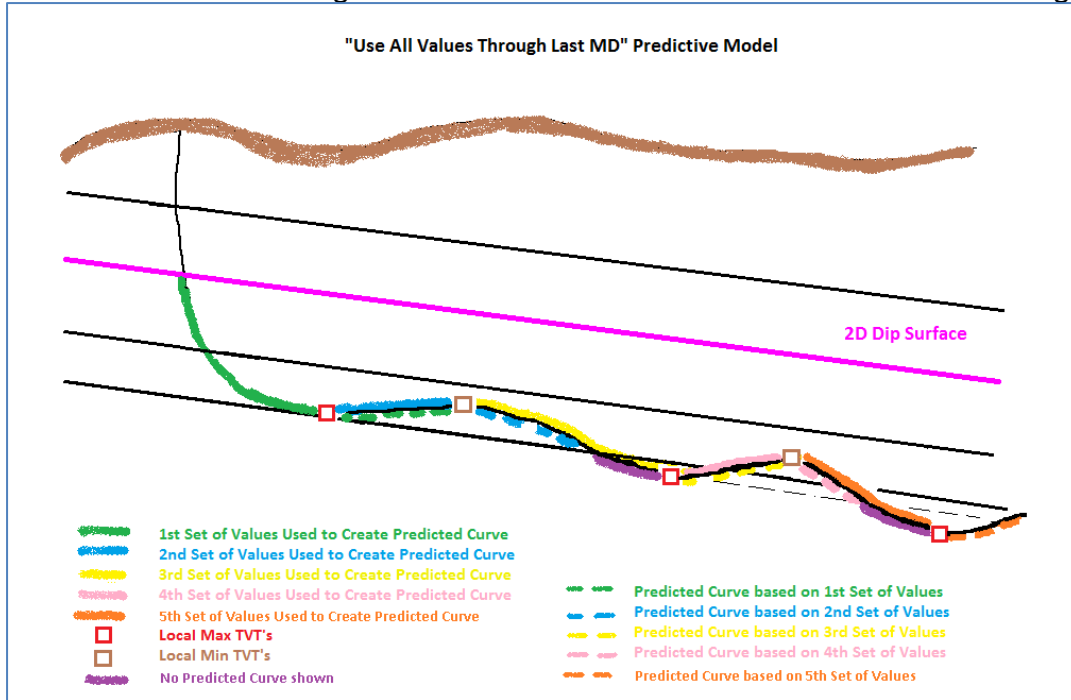


Figure 3: Diagram showing values used in the Use all Values Through the Last Measured Depth model.


All these models can be selected from the **Tie Points** tab in the **Options** dialog box. Choosing an appropriate model depends on the geologic relationships in the study area, and on how the target beds intersect the borehole path. The more you use the tool and gain experience, the easier it will be to select the appropriate model.

The Optimum Geosteering Workflow

The following workflow is a chronological list of steps which enables you to use smartSTRAT to geosteer a well within your GVERSE Geomodeling 3D geologic model. The remainder of this paper reviews each step in detail.


1. Launch GVERSE Geomodeling.
2. Create a filter that limits the number of wells used in the GVERSE Geomodeling 3D model.
3. Verify the source of the well and fault data being modeled.
4. Select desired GeoAtlas layers to display in GVERSE Geomodeling’s Map View.
5. Verify that all the formations and their resulting modeled surfaces are in correct chronostratigraphic order (using the **Strat Column Manager**).

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6. Select the formations to be modeled, and subsequently displayed in cross sections and in Map View.
7. Select the well to be steered in Map View, and create a **smartSTRAT Vertical Section**. If needed, create a projected line of section along the lateral portion of the borehole.
8. Verify the unique well ID of the well being drilled, and select a 2D Dip model surface in the **Models** tab of the **Options** dialog box in smartSTRAT.
9. Choose the appropriate **Type Log** geosteering model in the **Tie-Points** tab.
10. Select the LWD log curve type in the **Curves** tab, and enter an appropriate scale.
11. Select the **Horizontal**, **Vertical**, and **Display** tabs in the **Options** dialog box to select your favorite display colors.
12. If necessary, load an *offset log* (type log) to complete your geosteering correlation.
13. Select the **Tie Points** tab in the **Options** dialog box to vary dip angles and fault offsets in order to correlate the LWD and *predicted* curves in the **Horizontal** panel.
14. Use the **Vertical** panel to refine correlations in the selected *active* segments present in the **Horizontal** panel.
15. Update the GVERSE Geomodeling geologic surface models by inserting surface interwell points along the 2D dip surface.
16. Save the geosteering information in the **Models** tab of the **Options** dialog box. The next time you open this well in smartSTRAT, you can apply the .gsx file to see your recorded tie points and dip changes.
17. If necessary, use the **Create Wellbore Target Line**  tool, to email new borehole target information to a drilling engineer.
18. Send the results of your geosteering efforts to an onsite geologist.
A detailed description of each of these steps is given below.

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Step 1 – Launching GVERSE Geomodeling

smartSTRAT can only be accessed from GVERSE Geomodeling. Click the GVERSE Geomodeling icon  in ProjectExplorer to launch GVERSE Geomodeling, or select the **Tools >> GeoGraphix >> GVERSE Geomodeling** menu option. The **Open Interpretation** dialog box displays, prompting you to use an existing Interpretation, or create a new one.

An Interpretation is a mini-working project consisting of cross sections, selected formation surfaces, and selected GeoAtlas layers. Interpretations are often created for a small area containing several horizontal wells with a similar target. Multiple cross sections can be made in this Interpretation.

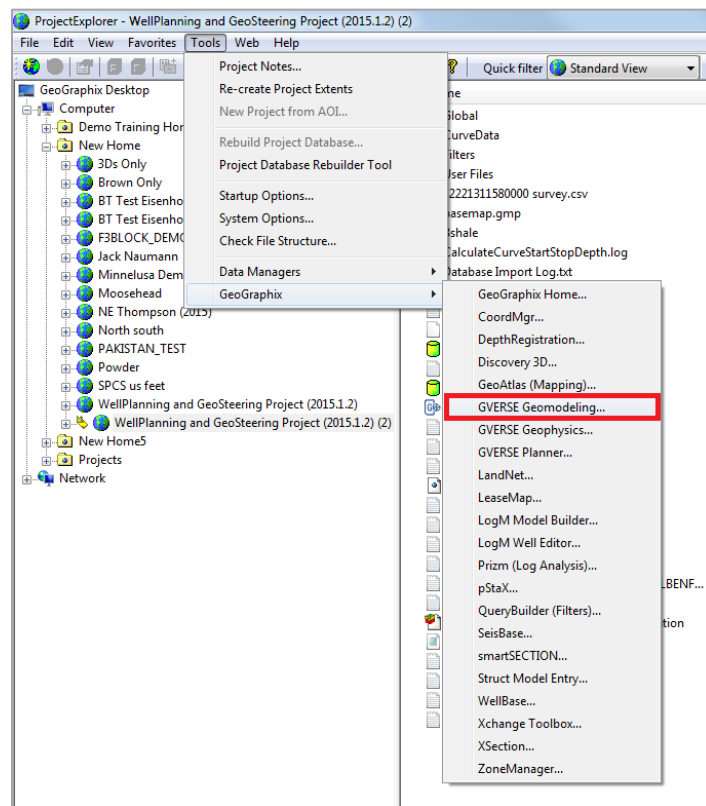


Figure 4: Location of GVERSE Geomodeling icon in ProjectExplorer.

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Step 2 – Creating a filter to limit the number of wells used in the GVERSE Geomodeling 3D Geologic Model

When GVERSE Geomodeling launches, the project wells display in GVERSE Geomodeling’s Map View, provided you have the “Well Spots” WellBase layer in your GeoGraphix project. If not, select the **Edit >> Interpretation Options** menu option and select the **Load All Wells when Opening Interpretation** option to see all wells in the area; or select a filtered set of wells. It is recommended that you use a filter to limit the number of wells modeled in the project. This can be done in one of two ways:

- Create an AOI which includes only the wells in your immediate drilling area
- Create a filter that limits the number of wells used in the model.

It is recommended that you use the second option. To apply a WellBase filter, select the **Edit >> Interpretation Options** menu option in GVERSE Geomodeling, select the **Load Wells on Demand** option, DO NOT toggle on the **Preload Wells with Modeled Surfaces and Zones** option, and click **Add Filter(s)** to add your filter. If you do not have a filter, you can make one in GeoAtlas – it will automatically be listed in the **Available Filters** list.

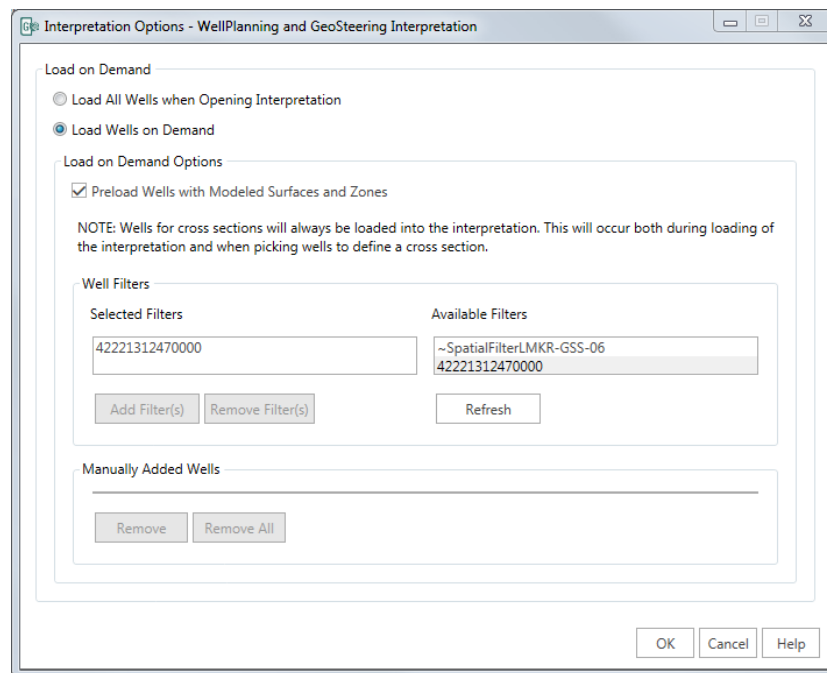


Figure 5: The GVERSE Geomodeling Interpretation Options dialog box. This lets you select filters to limit the areal extent of your modeling.

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Click **OK** to apply the filter.

Note: It is important to select enough wells to create a well-constrained geological model; however, the software will perform quicker with fewer wells.

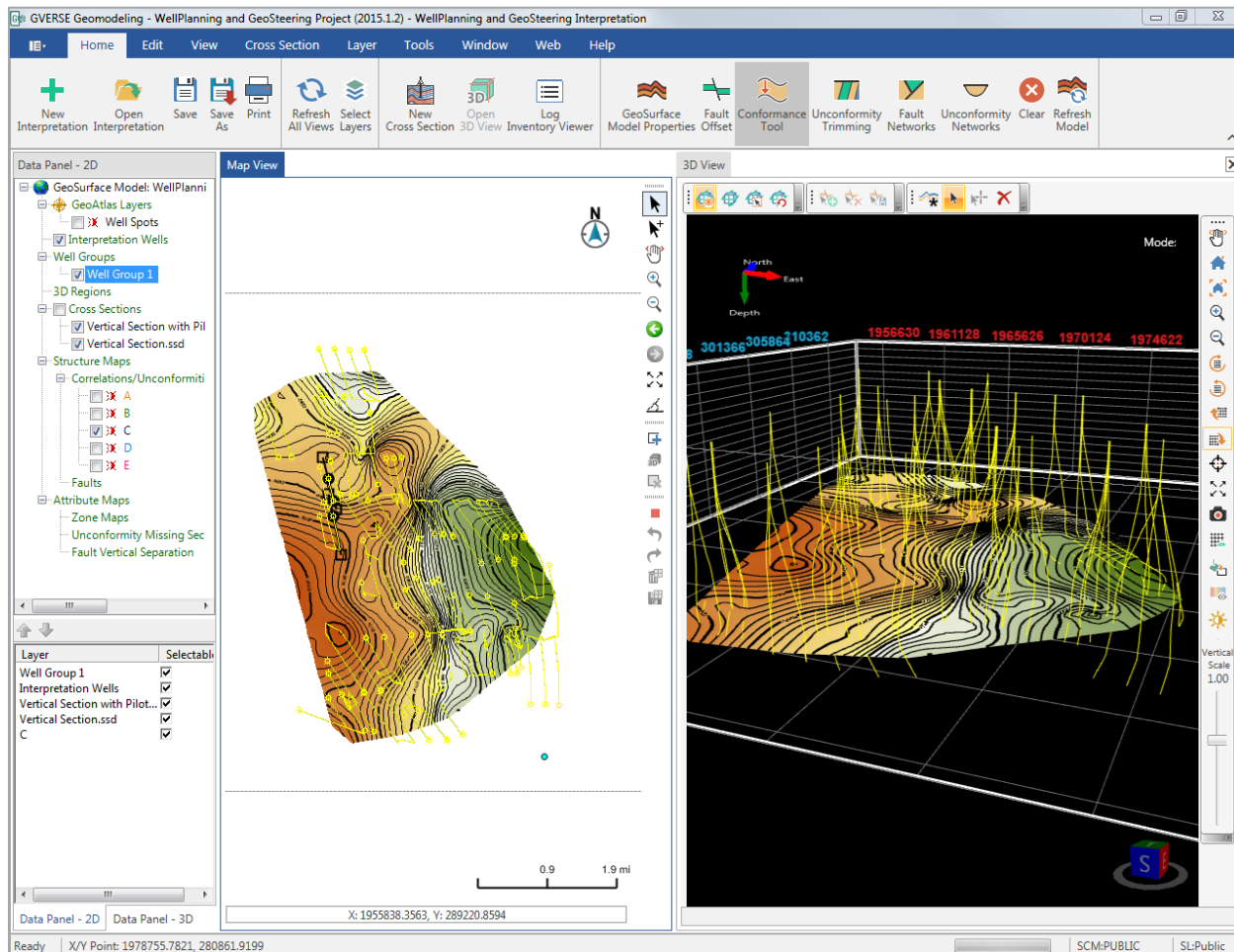


Figure 6: GVERSE Geomodeling's application window displaying Map View & 3D view, well boreholes, and selected surface.

Step 3 – Verifying the source of the well and fault data being modeled

It is very important to verify the source(s) of the data you are working with, and establish the source you want new data to be associated with. Select the **Edit >> Saved Sources** menu option, click [Source Manager] and verify the contents of the chosen **Source Manager** list. It is best to limit the number of sources being used. In addition, choose whether you want future interwell formation picks made during the geosteering process to be associated with your own source name, or the source at the top of the **Source Manager** list. Although both options might be the same source, you should still make sure that the new picks will be saved to the source of your choice. GVERSE Geomodeling will use whatever **WellBase Source Manager** is currently selected, so if you wish to change the contents of the Source

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Manager, you must do so in Source Manager, and then verify the selection of the source to be associated with future data changes in the **Source assigned to saved Formation Tops**, dialog box.

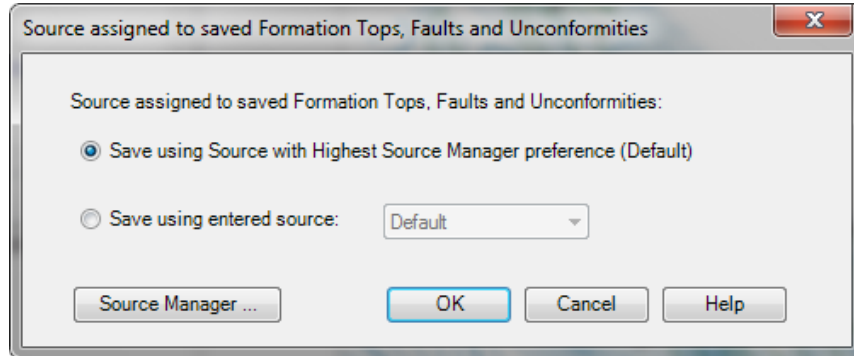


Figure 7: Source assigned to saved Formation Tops, Faults and Unconformities dialog box.

Step 4 – Selecting and displaying your favorite GeoAtlas layers in Map View

If desired, you can add your favorite GeoAtlas layers to GVERSE Geomodeling’s Map View. Select **GeoAtlas Layers** in the tree in the left panel, right-click, and select **Select Layers**.

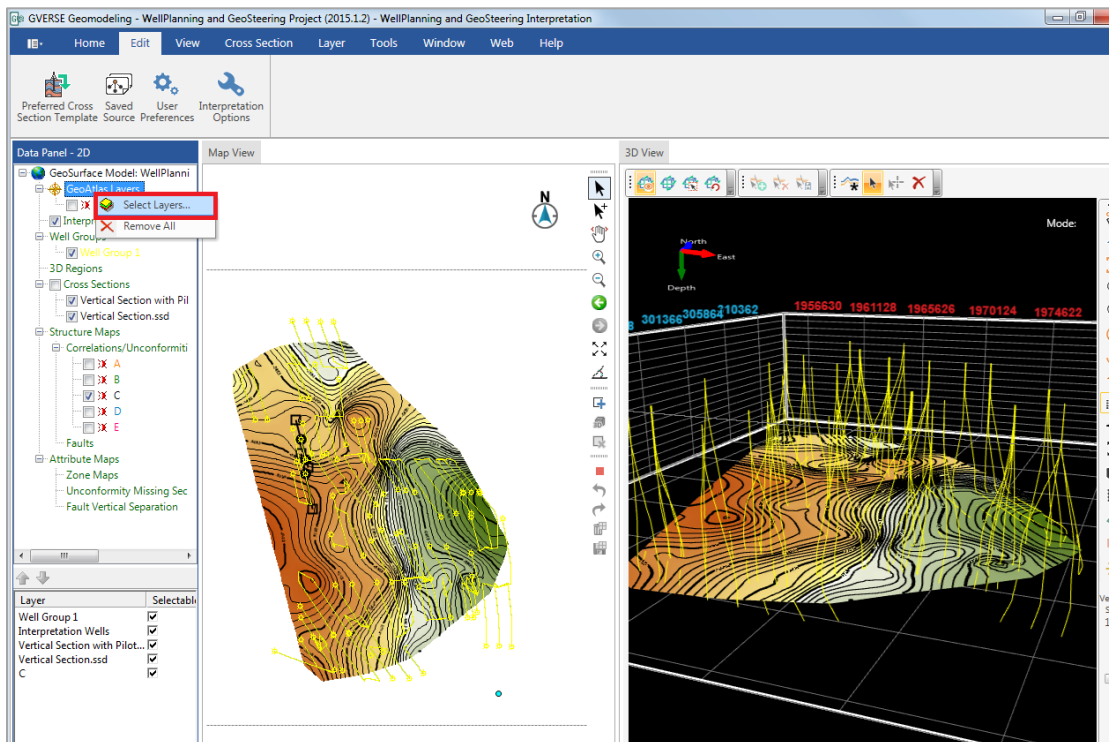


Figure 8: Selecting GeoAtlas and WellBase layers to display in Map View.

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The **Layer Selection** dialog box displays. Select an existing layer in your GeoGraphix project. The most frequently selected layers include: land grids, favorite well spot layers, and IsoMap layers. Click [OK] to display the layers in GVERSE Geomodeling’s **Map View**. Once selected, these layers can easily be toggled on and off.

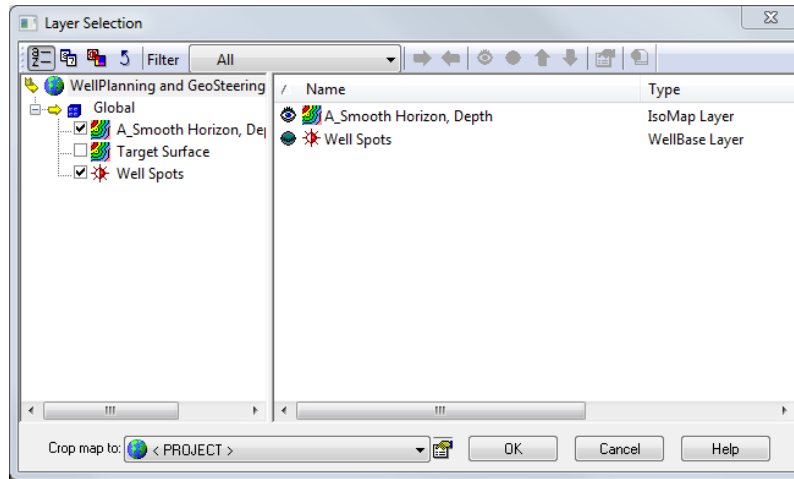


Figure 9: Layer Selection dialog box.

Step 5 – Verifying the correct chronostratigraphic order for all surfaces to be modeled

After selecting the desired sources, and defining the area and wells to be modeled, you must verify that all the formations used in the geologic model are in correct chronostratigraphic order. GVERSE Geomodeling uses algorithms and a geologic model that assumes that the younger geologic formations are shallower than the older, or deeper formations. Therefore, it is very important to access the **Strat Column Manager** and verify the stratigraphic order of the formations being modeled. You can access **Strat Column Manager** from **WellBase** through the **Tools >> Strat Column Manager** menu option, or from GVERSE Geomodeling through the **Tools >> Strat Column Manager** menu option. If the formations are not in order, you can select them and drag them up or down to their correct position. When you are finished, click **Update Strat Order**, and then click **Close**. This will update the chronostratigraphic order of the formations in GVERSE Geomodeling.

Note: If you add new formations in GVERSE Geomodeling, they will automatically be inserted into the bottom of the **Strat Column Manager** list, so remember to return to **Strat Column Manager**, after each new addition, and correct the new formation’s stratigraphic order. It is strongly recommended that you create your own **Strat Column Manager** list when working in GVERSE Geomodeling to make it easier to find and select your desired formations during the modeling process.

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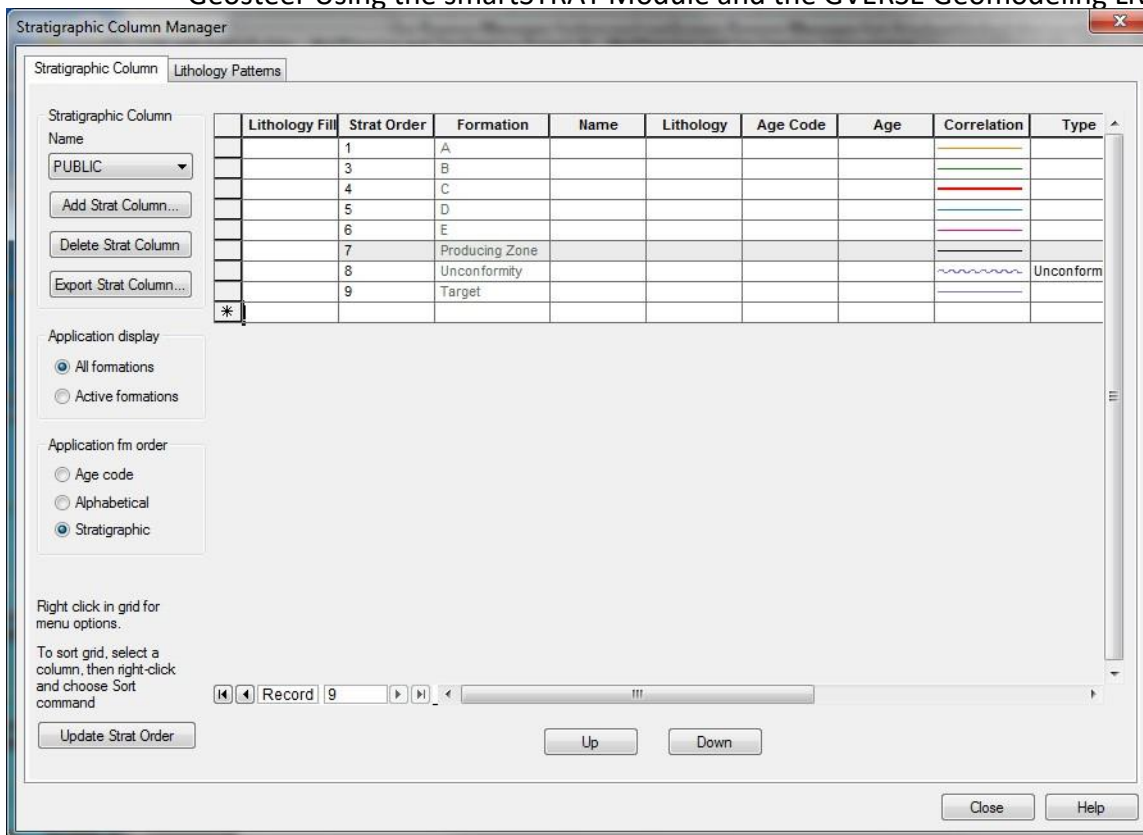


Figure 10: Stratigraphic Column Manager dialog box showing the list of formations and their Strat Order.

Step 6 – Selecting the surfaces (formation tops) to be modeled in Cross Section View and Map View

Next, it is important to select and model your desired formation picks. This will create surfaces for all formations you wish to display in the cross section while you are geosteering. To turn on, and model the surfaces, select the **GeoSurface Model Properties** tool.

In the **Surfaces** tab, toggle on the formation names of the surfaces you wish to model. A list of all the surfaces present in the selected **Strat Column Manager** will be displayed. You can also decide whether to associate the chosen surfaces with WellBase picks or to associate them with a gridded IsoMap layer built in GeoAtlas. By default, all formations are initially associated with WellBase picks. If you wish to associate a surface with an IsoMap grid, select the surface name, toggle on **IsoMap Grid**, and select the gridded IsoMap layer you wish to associate.

Note: It is recommended that you create a new formation name equivalent to the gridded IsoMap surface name, and associate the grid with that name. Do this to avoid confusing IsoMap surfaces with surfaces generated by GVERSE Geomodeling.

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 Click **OK** when you are ready to model the surfaces. To display these surfaces, you will need to toggle them on the Surfaces tab in each respective cross section window.

Note: Only gridded IsoMap layers can be displayed in GVERSE Geomodeling.

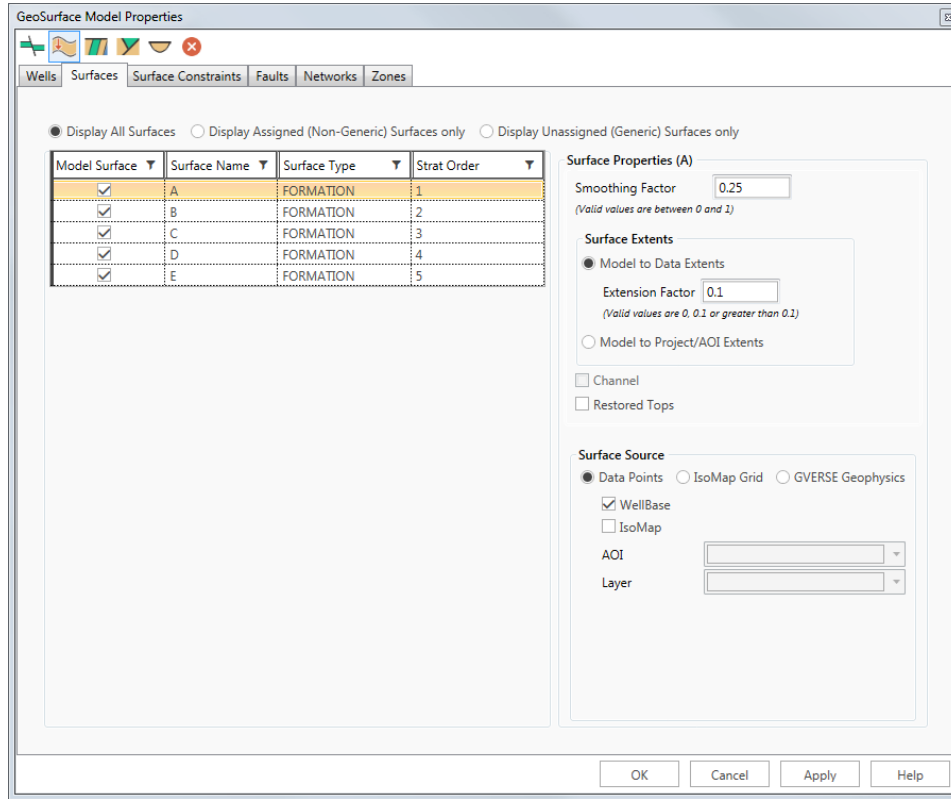


Figure 11: GeoSurface Model Properties dialog box displaying a list of formations.

Step 7 – Displaying the formation surfaces in Map View & 3D view

After being modeled, the selected formation surfaces will be listed at the left of the **Map View** window, 3D View, and in the **Surfaces** tab in each cross section you create. You can display the structure contour maps for these surfaces. To display the surface, toggle the surface on from 2D & 3D Data panel on the left.

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Note: It is important to verify that your surfaces extend over the map area where the well is being geosteered. This guarantees you will see those surfaces in your cross section. If the surfaces do not extend, select the **GeoSurface Properties** tab and increase the **Extension Factor** for the formations that are not extending. To do so, select the surface name, and enter a higher value for **Extension Factor**. Click [OK]. Make sure the surface is still toggled on before you return to Map View. If the surfaces still do not extend, contact Customer Support.

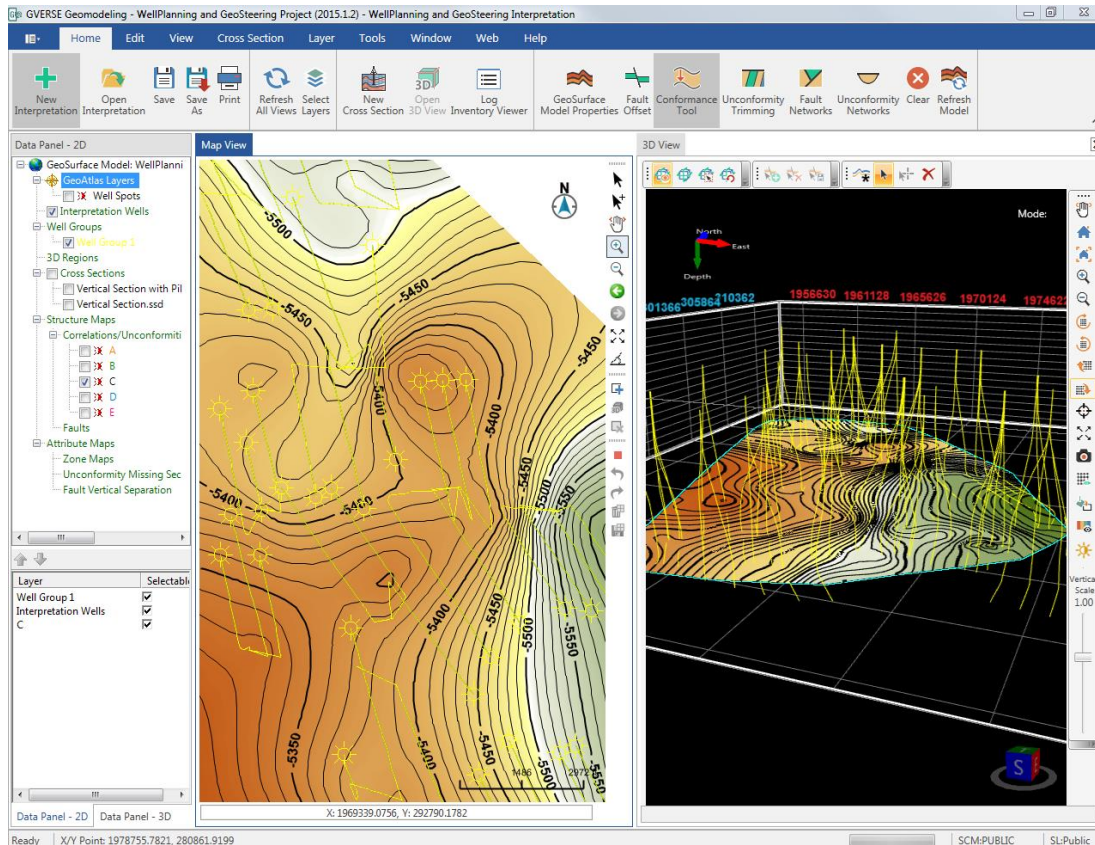


Figure 12: Displaying structure contour map & 3D.

It is also possible to use the **Conformance** tool to view a target surface, or better model a deeper surface that has fewer picks. This tool will constrain a deeper surface to a shallower surface that has more picks.

To use the **Conformance** tool, select the **GeoSurface Model Properties** tool, select the **Surface Constraints** tab, and drag the surfaces to be constrained under the constraining surface of choice. Ensure the **Conformance** tool is turned on. The tool will conform the deeper surface to the shallower surface. To un-constrain a surface, right-click the surface, and select **Remove Constraint**.

Note: Refer to GVERSE Geomodeling-Conformance-Tool whitepaper.

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If you want to create a new surface that is coincident with your lateral target surface, you can create a brand new formation name, pick the target surface on at least one well, and then constrain this surface to an existing surface that is shallower and well correlated. You can name this new surface Target or Landing Point, for example, conform that surface to a shallower surface in the **Constraints** tab, and select the **Conformance** tool. This will provide a target that you can display and view as you watch the position of the new borehole with respect to this target interval. Please call Customer Support if you require more information on how to do this. You must pick this new surface in a minimum of one well in order to enable the **Conformance** tool.

Note: Formations must be toggled on in the **Surfaces** tab in the left panel in order for them to be displayed.

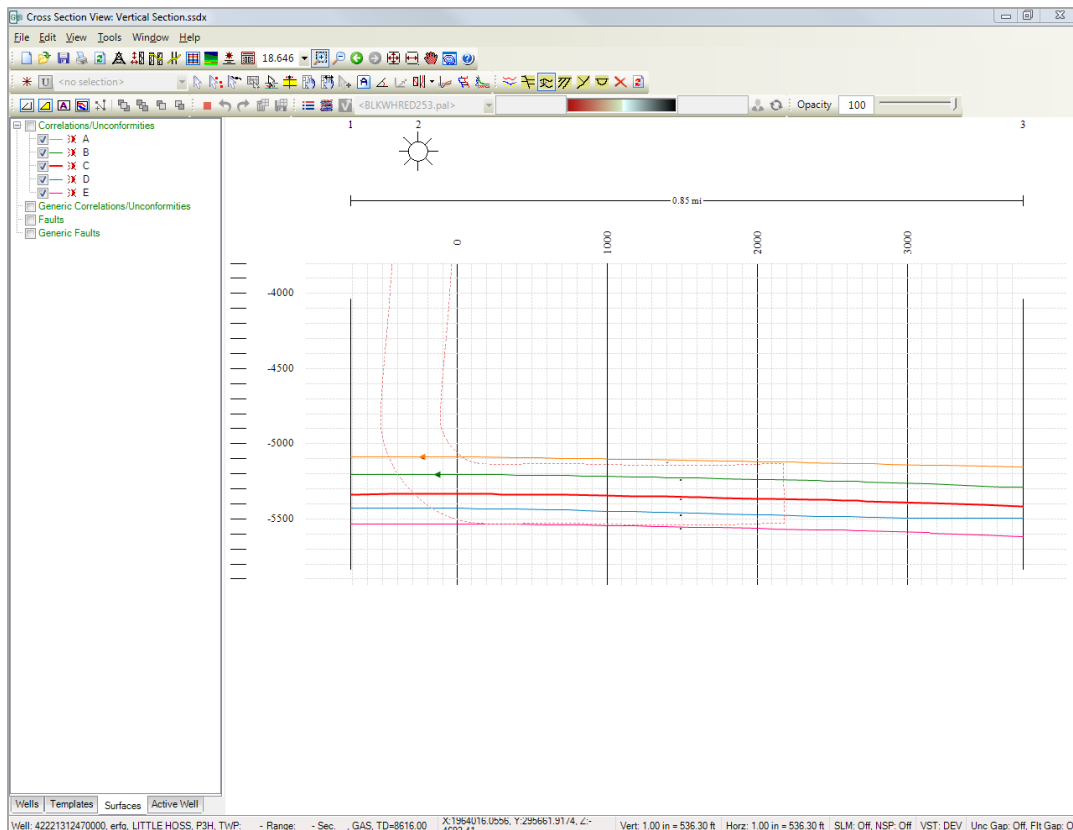



Figure 13: Cross Section displaying multiple surfaces modeled in GVERSE Geomodeling.


Step 8 – Selecting the well to be steered in Map View and creating a smartSTRAT Vertical Section

Create a smartSTRAT *vertical line of section* to geosteering your well to create a cross section that is parallel to, and coincident with, the lateral portion of the borehole. You can also set the well's surface location to zero. If the surface location of the well is set to zero, the horizontal distance away from the well, noted in the horizontal scale of the cross section, will represent the well's closure. The vertical section

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There are two methods for making a vertical line of section. It is recommended that you use the first method since it is the easiest and often the most accurate.

First method is to select the well in **Map View** by clicking the map symbol with the **Select**  tool, right-clicking, selecting the well's UWID (note that the well turns blue), right-clicking again, and selecting **Create Vertical smartSTRAT Section** from the drop-down menu. A line of section is instantly created along the length of the borehole that displays the horizontal well as a deviated well going from left to right. The line of section should include the portion of the well from the first maximum TVT to the TD of the well. The surface location of the well is automatically set to zero. In addition, the smartSTRAT module is automatically launched, and the **Options** dialog box is displayed. Select a favorite Prizm/

GVERSE Petrophysics template to display your LWD curve. Select the **Wells/Log**  tool to select the Prizm/GVERSE Petrophysics template. All existing templates will be available to select.

Second method is to draw a projected line of section over the lateral portion of the well in **Map View**. To make a projected line of section, select the **Cross Section >> Define Projected** menu option and click the cursor once at each end point of the lateral portion of the borehole (currently, smartSTRAT does not support a line of cross section with more than two points). Right-click, select **Select Wells**, and click on the well. Right-click again, and select **End Definition**.

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The well displays in the cross section window. If the well is difficult to select, simply make the line, right-click, select End Definition, and select the **Add Well**  tool in the **Wells** tab (lower left portion of the cross section) and select the well from a list of well names.

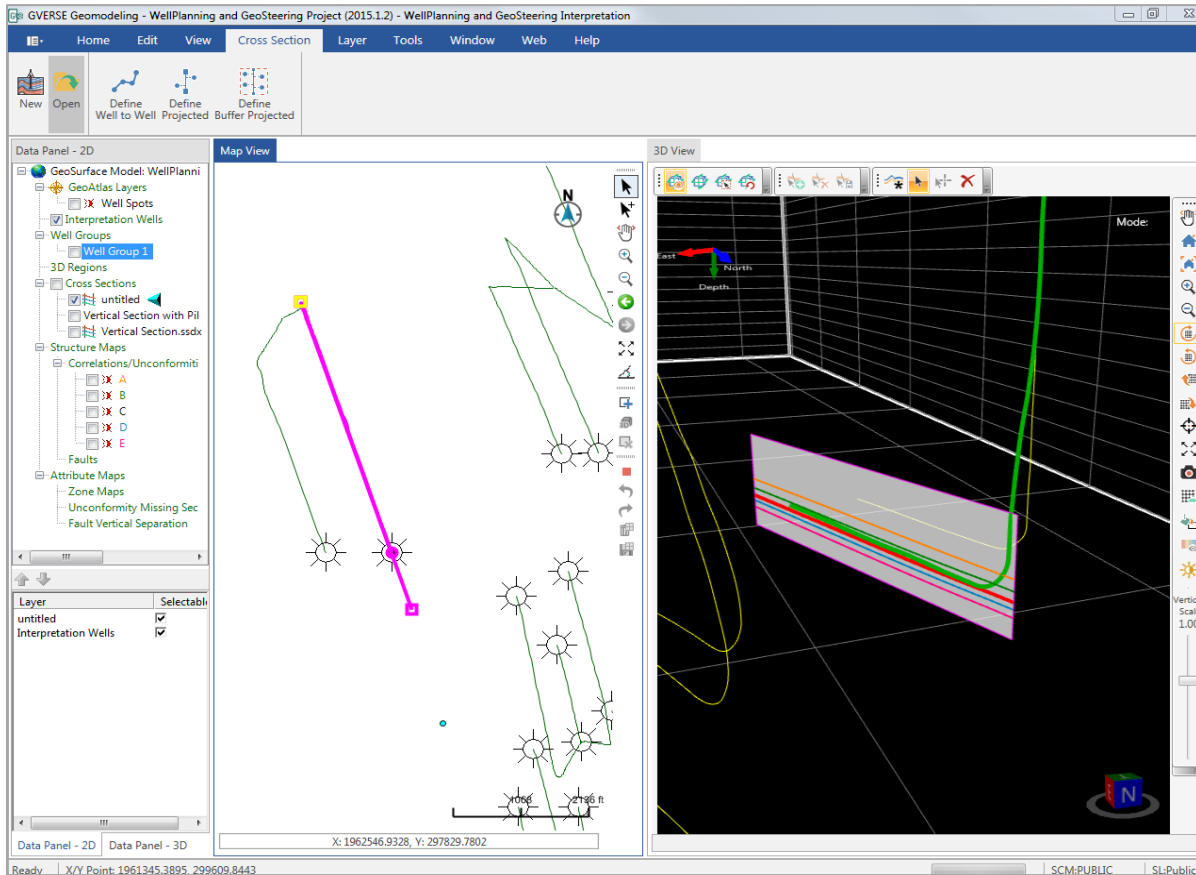


Figure 14: Projected cross section (magenta) drawn parallel to, and coincident with, the lateral portion of the horizontal well in Map View, in 3D view the cross section is automatically update on the fly

In the cross section, select the **Marginalia** tab, select the **Zero scale at Well's projected surface location** option, and make sure the well's **Unique Well ID** is listed in the drop-down box (this step is done automatically if you choose to use the **Create smartSTRAT Vertical Section** option).

Note: It is recommended that you turn on **Vertical** and **Horizontal** scales to assist in the geosteering workflow. It is recommended that you change the color of the grid to a light gray so that the scales do not interfere with the display of the wells and surfaces.

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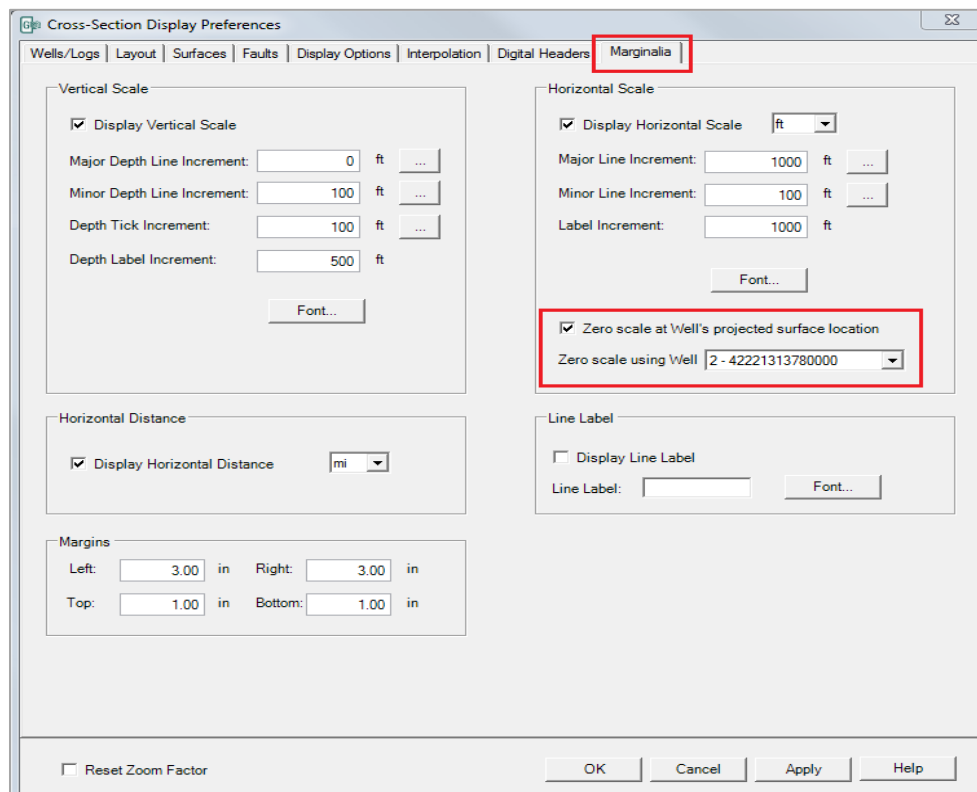




Figure 15: Marginalia tab - Location of options to set scales and to set the zero scale of the drilling well used in smartSTRAT.

Ensure that the wellbore displays from left to right; if it does not, select the **Reverse Order**  tool in the cross section **Wells** tab to flip the direction of the borehole. After you set up the cross section to reflect this change, select the **smartSTRAT**  tool.


Two points to remember when building a smartSTRAT cross section are to:

- Make sure the well goes from left to right.
- Only put one well in the geosteering cross section.

To see how local pilot holes correlate to this well, you can simply open other cross sections which include other wells in the area. Remember that since you are geosteering within a 3D geomodel, the surfaces that intersect your well come from the picks that are made in all the surrounding wells, so their actual presence in this cross section is not needed. In addition, offset wells can be added within the geosteering model itself, and are thus not added as a well in the cross section. You can open as many simultaneous cross sections as you need.

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Step 9 – Verifying the unique well ID of the well being geosteered, and selecting a 2D dip model surface in the Models tab of the Options dialog box

Open the cross section, and select the **smartSTRAT**  tool. Two panels display in addition to the Vertical Section (main cross section display). At the bottom is the **Horizontal** panel. It displays, in measured depth, the red LWD curve and the blue *predicted* curve (and a purple curve where the LWD and the predicted curve are identical). On the left side is the **Vertical** panel. It displays in TVT, the LWD curve (default blue), as well as the local and active type logs, which are the same in this default view. The type log curves can, at some TVT ranges, appear as multiple curves. The **smartSTRAT Options** dialog box also displays.

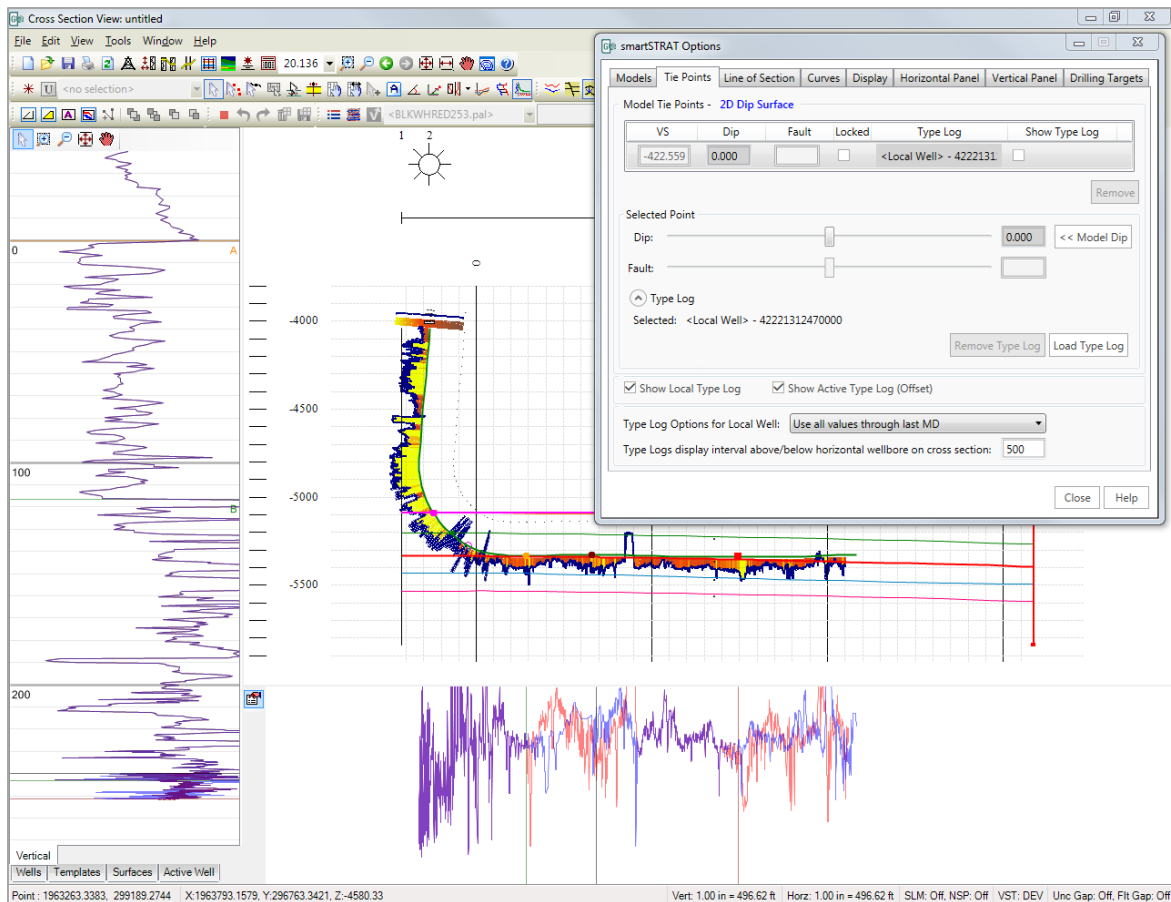


Figure 16: smartSTRAT displaying the Vertical and Horizontal panels, and the Options dialog box.

The **Options** dialog box is smartSTRAT’s control panel. This is where various options related to your geosteering model are selected, such as the surface assigned to control the initial 2D dip model.

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The **Models** tab displays the UWI for the well that is being geosteered. This is automatically input when you create your *smartSTRAT Vertical Section*, but it is always good to verify it is correct. The formation top used as the 2D dip surface is selected in the **Models** tab. The 2D dip surface should be based on a surface that is one of your better picked formation tops in the region.

Some important considerations about the selected 2D dip surface include:

- It must either be picked on the drilling well or project into it
- It should remain above the wellbore along the vertical section if possible, as smartSTRAT is optimized for this scenario
- It should be conformable with, and ideally generally parallel to, any target surfaces that it will control via GVERSE Geomodeling's conformance technology.

The 2D dip surface displays as a magenta-colored line in the cross section display when the 2D dip surface is selected in the **Models** tab. The 2D dip surface intersects the geosteered well at the location where the "Active Surface" was picked on, or projected into, that well and will initially be horizontal. You will see a solid triangle at the intersection of the wellbore and the "Active Surface" if the surface was picked in the well; if the surface is projecting into the well location, the triangle will be hollow and may not be at the correct position in the well, which would adversely affect the type log/predicted curve. It is usually advisable to pick the desired "Active Surface" in the drilling horizontal for this reason.

Note that the initially horizontal magenta 2D dip surface will typically diverge from GVERSE Geomodeling's modeled version of the "Active Surface", which is based on all available well and interwell control in the geomodel. The geosteering/correlation process involves the manipulation of the 2D dip surface (via dip adjustments and the addition of fault offsets) in order to match the LWD curve to the "predicted" curve. During this process, the 2D dip surface will usually more closely approximate the modeled surface.

Within the **Models** tab you can also open a previously saved steering/correlation exercise (often termed a GSX file) for the well in question, save the active version, and even email it to someone else who could then load your interpretation into their vertical section of the same well.

You can also add additional attempts at geosteering, or correlated, using a fresh 2D dip surface so that you can save all iterations of your correlation attempts. You can, for example, geosteer with one 2D dip surface and then choose another and save each correlation with a different *.gsx, or try different scenarios (e.g., one correlation with faults and one without).

Step 10 – Choosing the Type Log geosteering model in the Tie Points tab

The **Tie Points** tab lets you select the model that is used to create the *predicted* curve. To choose the model, click the **Type Log Options for Local Well** drop-down button. Notice the *predicted* curve might change shape when you choose different models.

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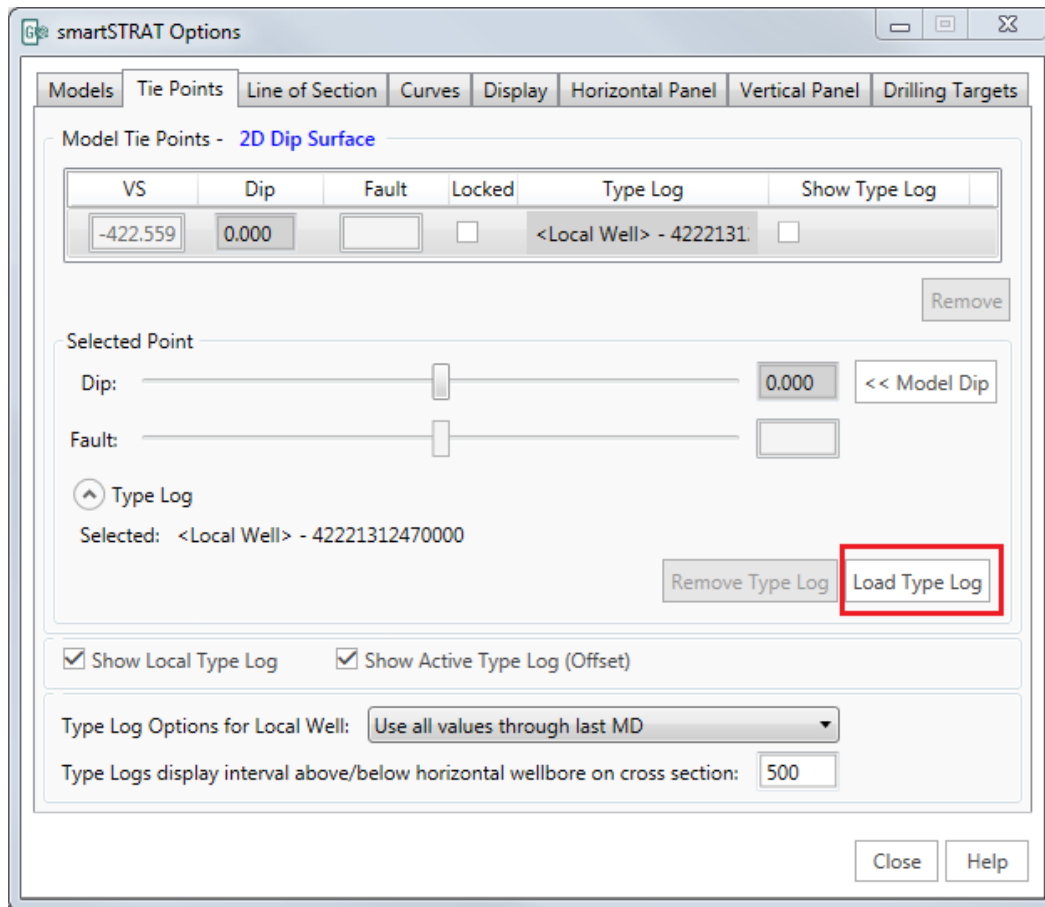


Figure 17: The Tie Points tab is used to choose the Type Log option, select and load a type log, move the dip slider to change the 2D dip surface, and insert fault offsets.

Step 11 – Selecting the LWD log curve type in the Curves Tab (default GR), and entering an appropriate scale

The **Curves** tab allows you to choose the specific LWD curve to be displayed in the **Horizontal** panel. This is often the GR curve, but if you are using a different type of curve, you can select it here. You can also adjust the GR scale in the **Horizontal** panel. It is very useful to look at your scale on the original log, and enter those values in the **Log Scale** field to optimize the use and appearance of the curves in the **Vertical** and **Horizontal** panels.

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Step 12 – Selecting the Display, Vertical, and Horizontal tabs to set the display parameters for the respective display panels

The **Display** tab controls the colors of the wellbore annotation in the projected cross section window. The most useful items to display are **Min Max TVTs** because they display the inflection points, or changes in dip along the lateral, relative to the 2D dip surface. The color of the 2D dip surface is magenta by default.

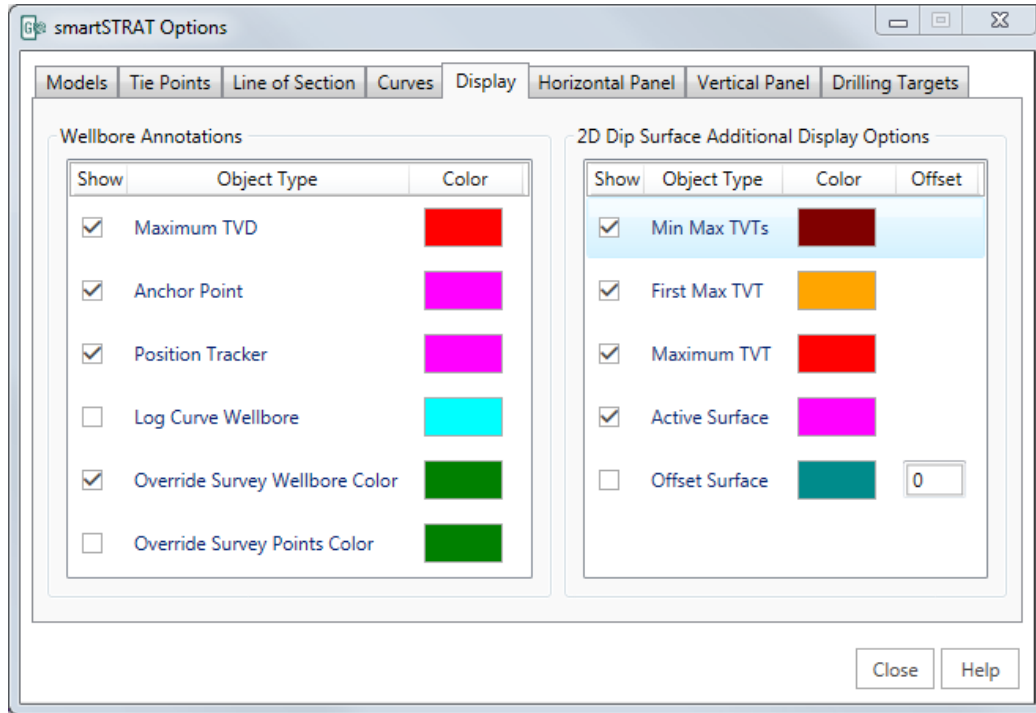


Figure 18: The Display tab determines the color and display of the objects in the main cross section.

The **Horizontal Panel** tab controls the colors of the **LWD Curve**, **Correlation Curve**, and **Predicted Curve** displayed in the **Horizontal** panel. The two most important curves are: the **Predicted Curve** which defaults to blue, and the **LWD** (usually a GR curve) which defaults to red. The **Correlation Curve** (which is green by default) is the goodness of fit between the “predicted” curve and the LWD curve. In addition, you can turn on various values associated with the cursor position. For example, you can turn on the LWD value at the position of the cursor.

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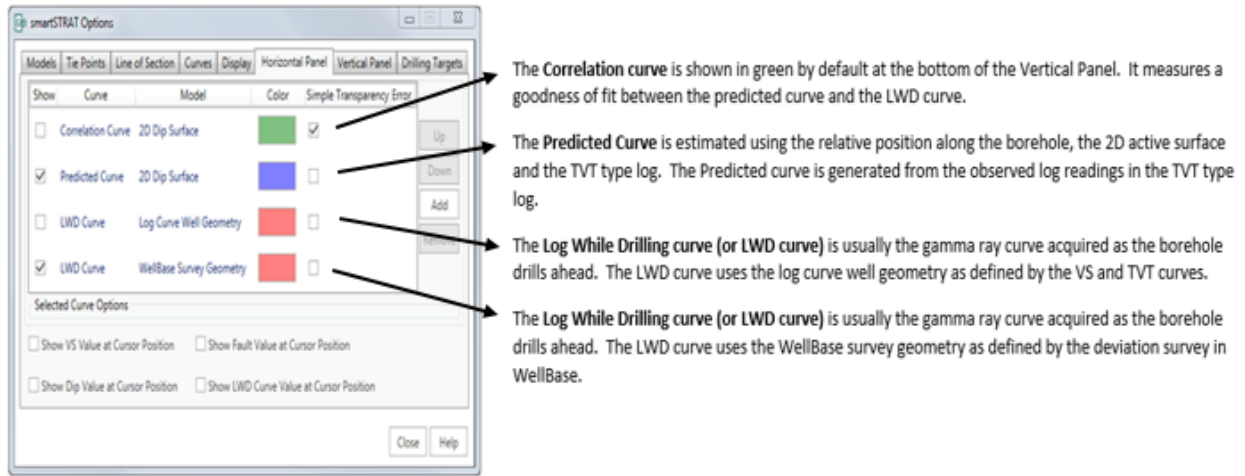


Figure 19: The Horizontal Panel controls the parameters of the curves displayed in the Horizontal Panel, most importantly the Predicted Curve and the LWD Curve.

The **Vertical Panel** tab lets you control the display parameters for the **Vertical** panel. You can set up the colors, control the transparency of the curves, set the units of the vertical scale, and show TVT and TVD values associated with the curves. Figure 20 below displays the definitions for each curve in the Vertical panel.

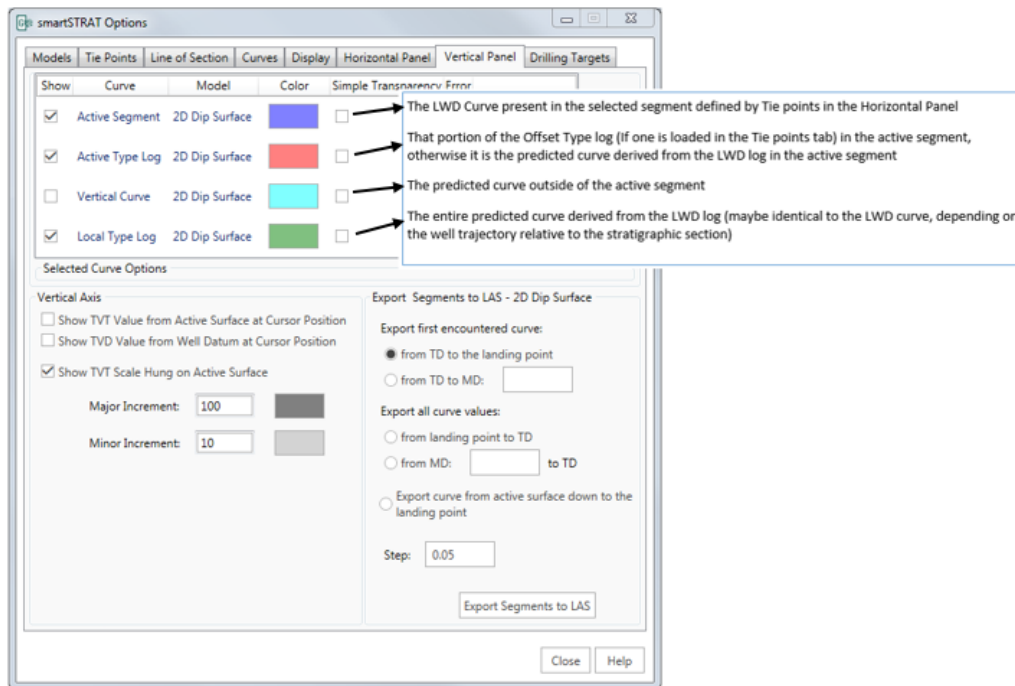


Figure 20: The Vertical Panel tab lets you control the parameters of the Vertical window panel. This diagram also describes the origin of the curves that are displayed in this tab.

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Step 13 – Selecting an offset well to use as a predicted curve if necessary

It is important to determine if you are going to use the drilling well, or an offset well to generate the type log/predicted curve. Note that the drilling well provides the best control, at least immediately after the well lands stratigraphically and proceeds back up-section. As the drill bit gets further away from the surface location and potentially nears another well, the type log can be changed from the “local” well to that new well without affecting any steering/correlation work already done uphole. It is important to note that the “local” well can only be used effectively as the type log if the well has bottomed stratigraphically, and is proceeding to drill generally up-section. If that is not the case, an offset type log must be used.

Offset wells are selected in the **Tie Points** tab. After selecting an offset well, the model uses the offset type log for all geosteering purposes and it becomes the “predicted curve”. While geosteering, you can actually alter between using the drilling log and an offset log in each tie point segment. To use an offset log, click [Load Type Log], select **Use Well TVD Type Log**, select a filter to narrow down your list of wells, or select **None**, and select from the list of wells.

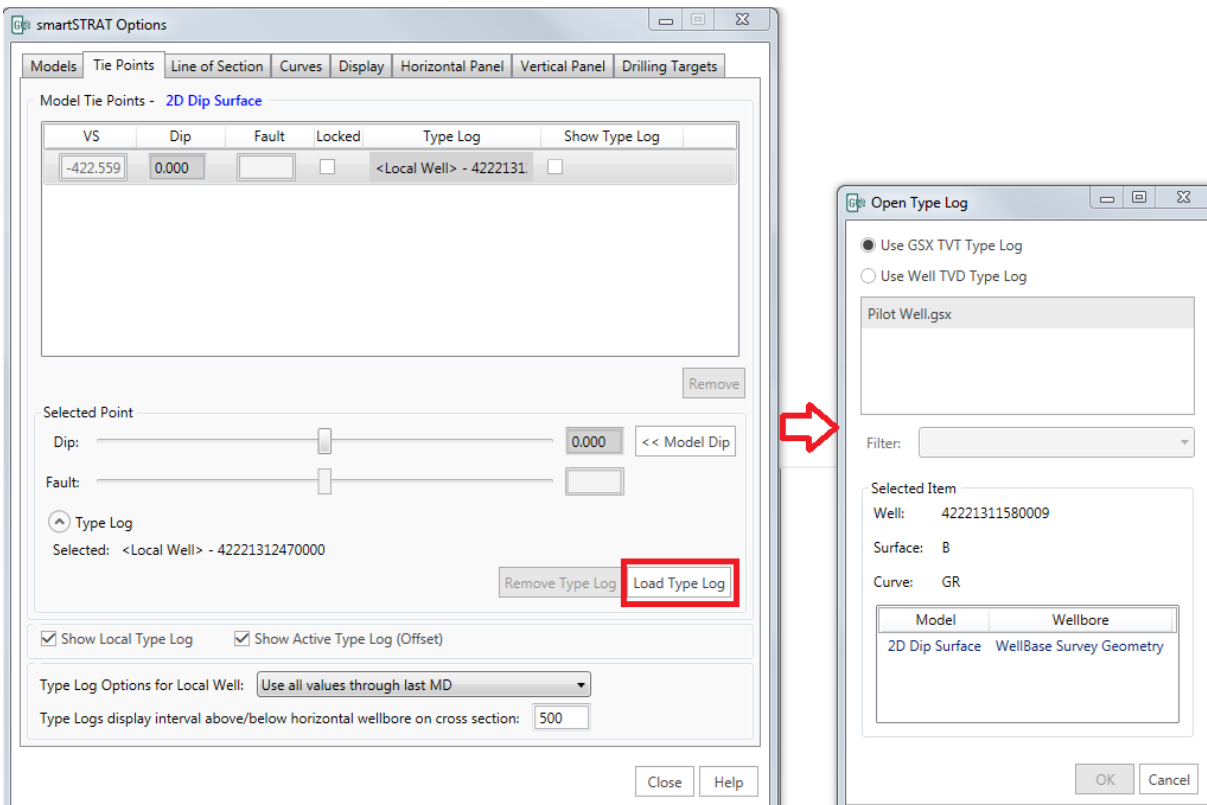


Figure 21: The Tie Points tab lets you change the dip angle on the 2D Dip Surface, load an offset well, and select the Type Log Options model for the Predicted Curve.

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After the offset log is selected, it will be listed in the **Tie Points** tab. You can edit various aspects of this well's curve display by making adjustments related to its scale, curve offset, and the normalization of the curve.

Note: When using an offset log, you can use the **Scale** slider bar to stretch and squeeze the log curve in both the **Vertical** and **Horizontal** panels to help you with your correlation. The slider bar for the offset well is located in the lower section under **Type Log**. Remember that when the offset well is used, its curve will become the "predicted curve".

Step 14 – Using the Tie Points tab to correlate curves in the Horizontal panel

As stated previously, the goal of the smartSTRAT geosteering module is to correlate the LWD curve to the "predicted" curve in order to verify the position of the borehole within the stratigraphic target zone, and geosteering the well. This involves a four step process where you:

1. Set up the model in the **Options** dialog box.
2. Correlate the curve in the **Horizontal** panel and pick tie points.
3. Fine-tune the correlations in the **Vertical** panel within the active segment chosen in the **Horizontal** panel.
4. Update the geologic model by matching your modeled surface with the 2D dip surface derived from your correlation.

The second tab in the **Options** dialog box is the **Tie Points** tab. The **Tie Points** tab lets you manipulate the slider bar to change the dip angle of the 2D dip surface until you correlate the LWD curve to the "predicted" curve. It is recommended that you click [Model Dip] when you start the correlation process to set the original dip of the magenta line, or 2D dip surface, to be equal to the dip of the equivalent geologic surface at the point it intersects the well bore path. You can also enter the thickness of the interval of the type log you wish to display in your cross section (should the option to display the type log at one or more tie points be selected).

In the **Horizontal** panel, a red LWD curve and a blue *predicted* curve are displayed by default. Use the information in the **Tie Points** tab and move the **Dip** slider until you see the curves match in the **Horizontal** panel. If you see the correlation between the predicted and LWD curves break down, simply double-click, or right-click and select **Add Tie Point** at that position, and proceed to alter the dip and/or add an offset in order to once again match the curves. The tie point will show up as a vertical cyan-colored line. To delete a tie point, select the tie point line, right-click, and select **Delete Selected Tie Point**. In addition, you can turn on several values related to the Horizontal panel display by using the right-click menu options.

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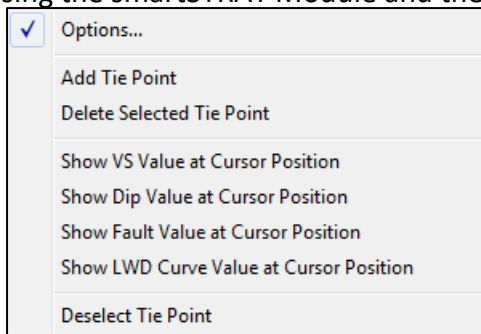


Figure 22: Right-click menu options in the Horizontal panel when a tie point is selected.

Note: It is strongly recommended that you view the GeoSteering Webinar located under Geology on the LMKR website (<http://www.lmkr.com/geographix-demos/demo.asp#>). The webinar reviews a live demo on how to correlate the curves.



If you suspect an offset needed to correlate the curves, slide the **Fault** slider to offset the 2D dip surface. The amount of offset will increase depending on how much you move the slider. The Fault slider does not become active until the first tie point is placed.

You can also use your keyboard's left and right arrow keys to change the dip of the 2D dip surface (if the **Dip** slider is active), or to increase the amount of fault offset (if the Fault slider is active). The up and down arrow keys can be used to move all the curves up and down in the **Horizontal** panel.

Note: The curves in the **Horizontal** panel will zoom in automatically if you zoom in on the main cross section window. The **Horizontal** panel can be increased in size vertically by selecting the line at the top of the panel and dragging it upwards.

Step 15 – Using the Vertical panel to refine correlations within the active segment (Optional)

The primary use of the **Vertical** panel is to fine-tune your correlations within the individual active segments set in the **Horizontal** panel, bounded by your tie points. After the tie points have been inserted into the **Horizontal** panel, you can click within the tie-point bounded segment and the contents of that active segment will display in the **Vertical** panel. Specifically, the LWD curve (**Active Segment**) and the *predicted* curve (**Active Type Log**) from that segment will be displayed in the Vertical panel. In addition, you can turn on the entire “predicted” curve derived from the LWD log (known as **the Local Type Log**), or the offset type log. If you are using an offset type log, it is possible to have both, it and the local type log, visible simultaneously.

You can zoom in using the **Zoom In**  tool (located at the top of the **Vertical** panel), select the **Select**  tool, and stretch and squeeze the curve until it is correlated. A colored circle displays at the selected point. As you drag the circle up and down, the curve will stretch and squeeze in both panels and adjust the correlation between tie points.

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 The most effective method of “fine-tuning” the correlation of a segment in this manner is to move the cursor along the segment in the **Horizontal** panel and observe in the **Vertical** panel whether the top or bottom of the segment is farthest toward the toe of the well. That is the point that should be selected and stretched/squeezed via the red dot. Offsets can be added by holding down the shift key while selecting the curve segment via the red dot, left-clicking, and dragging. This translates the entire segment up or down without stretching or squeezing it.

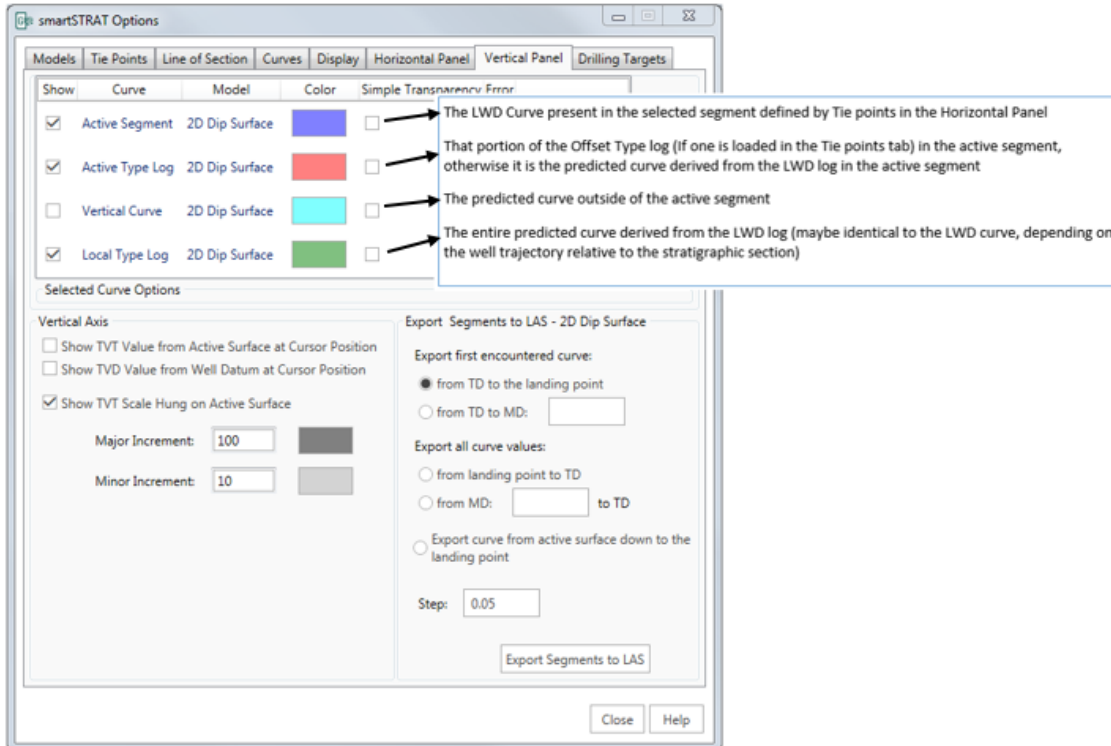


Figure 23: Description of the various curves that can be displayed in the Vertical panel.

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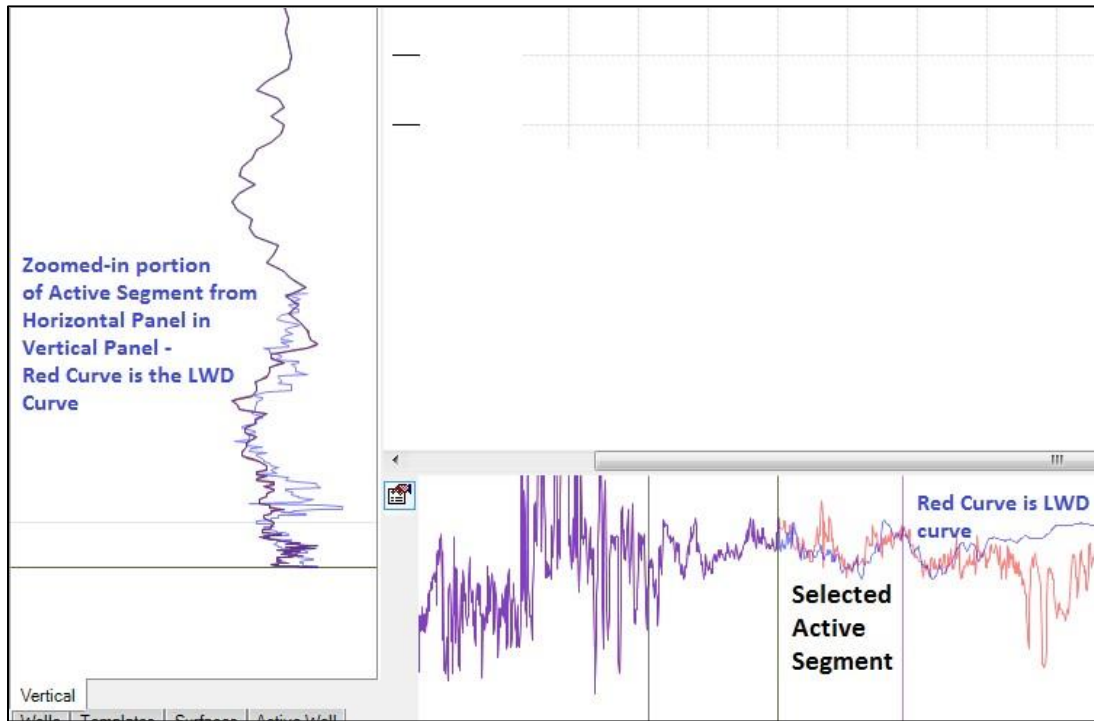


Figure 24: Diagram showing relationship between the Active Segment in the Horizontal panel and the display of its curves in the Vertical panel.

It is recommended that you change the color of the curves to reflect the colors of equivalent curves displayed in the **Horizontal** panel. The default blue curve is the TVT equivalent of the LWD curve, and the default red curve is the TVT equivalent of the “predicted” curve. Reversing these colors will make these curves easier to understand and correlate. This can be done in the **Vertical Panel** tab of the **Options** dialog box.

Note: The tools needed to manipulate the curves in the **Vertical** panel are located at the top of the Vertical panel (see Figure 25 below). These are, from left to right, the Select tool, the Zoom tool, the Zoom Out tool, the Full Extents tool, and the Pan tool. Use these to assist you in navigating exclusively within the Vertical panel.

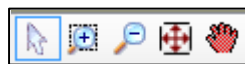




Figure 25: Tools located at the top of the Vertical panel.

Step 16 – Updating the geologic model

To update the GVERSE Geomodeling geologic model, you must adjust the original surface location of the 2D dip surface to match the final position of the magenta 2D dip surface. To edit and update the GVERSE Geomodeling surface, select the name of the surface on the left side of the cross section

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(Surfaces tab), select the **Add Surface Points**  tool, click on the 2D dip surface, and add as many interwell points as you feel is necessary to make the original surface match the magenta 2D dip surface. The surface will automatically adjust to this new location. These picks are interwell points and are stored in the database. However, their specific values are not visible in any WellBase tabs. These values can be queried and viewed in QueryBuilder. To delete an interwell point, you can select it with the **Select**  tool, and press the <Delete> key.

The interwell data points, picked in Cross Section view, can also be displayed and deleted in Map View. To display well and interwell data points in Map View, select the formation name in the data tree to the left of Map View, right-click and select **Edit Contour Options**, select the **Points** tab, and toggle on the **Interwell** points. Adjust the scale and font size to see them clearly. The formation top name must be toggled on in the data tree to view the individual formation's interwell picks. To delete the points, select the point, and press the <Delete> key. The data point will be deleted from the cross section and the map.

Step 17 – Saving the geosteering model and the tie points

To save the results of your geosteering attempts, select the **Models** tab, and click [Save] or [Save As]. When you choose to save your model, it will save all of your geosteering attempts, the tie points, the name of the **Type Log Option model**, and the 2D dip surface that was selected when you saved your geosteering model. If you created a cross section without using the automatic **Create SmartSTRAT Vertical Section** workflow, you will have to save your cross section as well as the model in order to fully duplicate your original correlation screen. It is not necessary to save your geosteering cross section if you simply made a cross section using the **Create smartSTRAT Vertical Section** workflow to create your original geosteering cross section.

Step 18 – Using the Drilling tab to send geosteering information to the driller

The last tab in the **Options** dialog box is the **Drilling Targets** tab. The **Drilling Targets** tab works in conjunction with the **Create Wellbore Target Lines**  tool, located in the GVERSE Geomodeling toolbar (cross section window). The **Drilling Targets** tab let you provide information to drillers, specifying the: direction, angle, and distance to a specific target ahead of the last position of the borehole. Use the **Create WellBore Target Line** tool to display the resulting line and target point.

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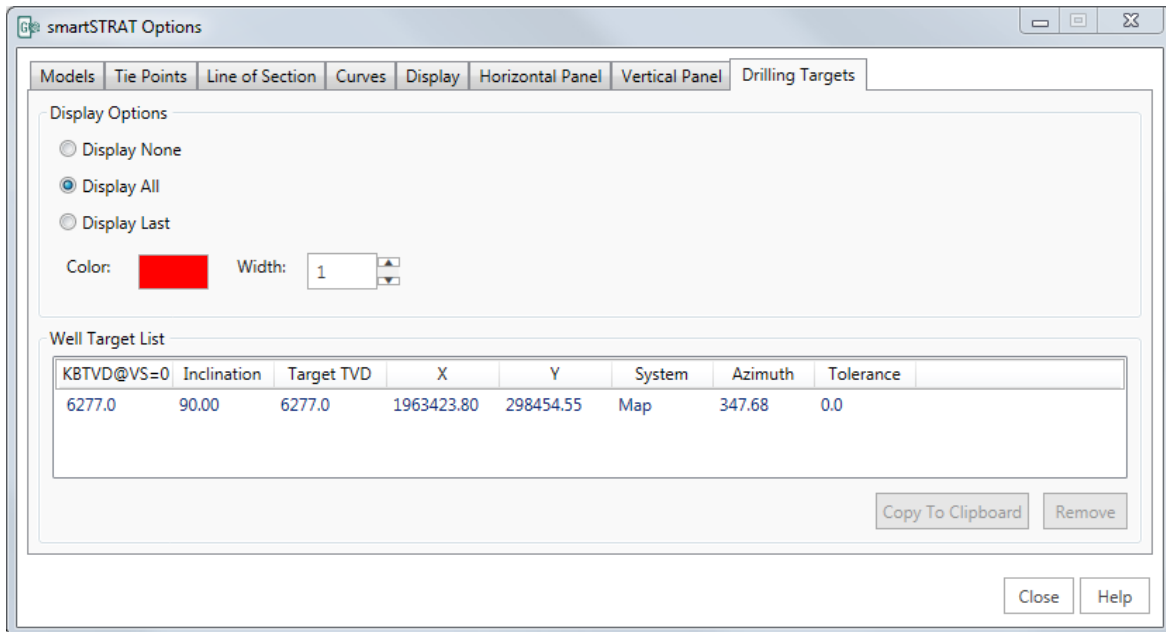


Figure 26: The Drilling Targets tab works in combination with the "Create Wellbore Target Line" tool to assist you in providing engineers with information on where to guide the borehole.

To use the **Create WellBore Target Line** tool, click and drag a line indicating the new target position ahead of the current wellbore. The resulting target line consists of two points, the point of origin (the point closest to the current TD), and the target point (the point farthest from the TD).

Drilling information for the target point is recorded and can instantly be copied to a clipboard by clicking **Copy to Clipboard**, and then pasted into an email or memo. If you need to delete the drilling target, select the related red square, and press the <Delete> key.

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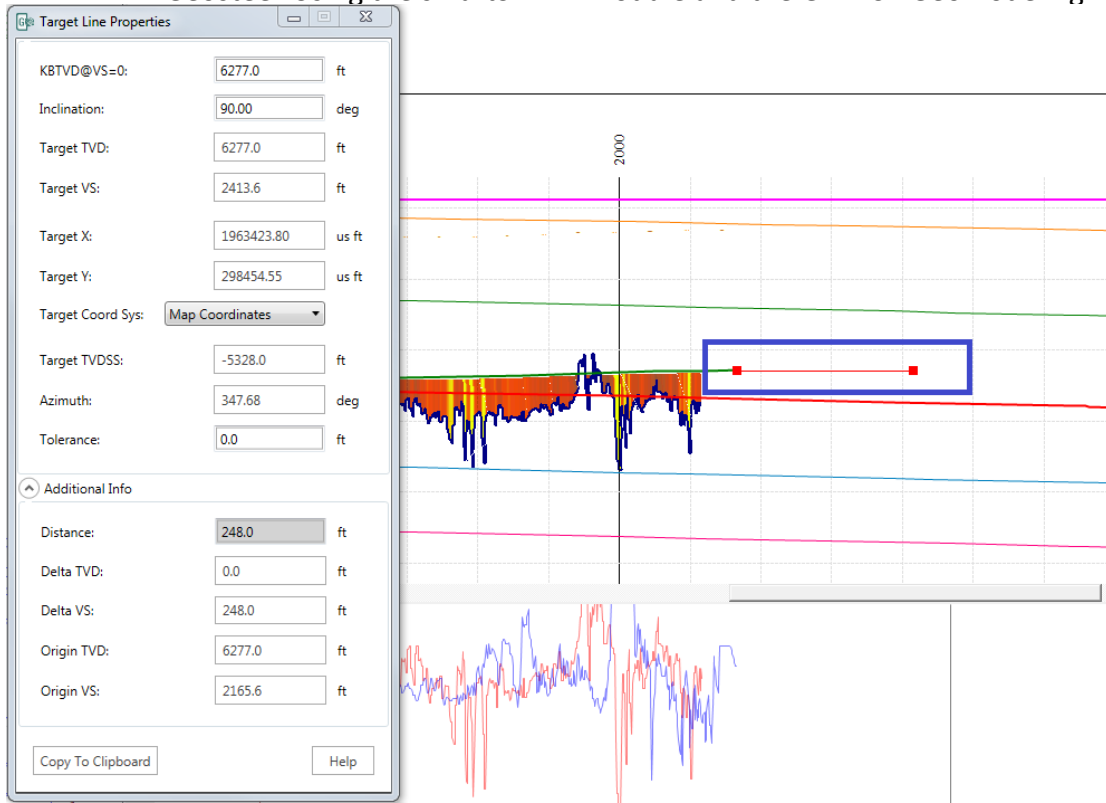


Figure 27: Using the Create Wellbore Target Line tool.

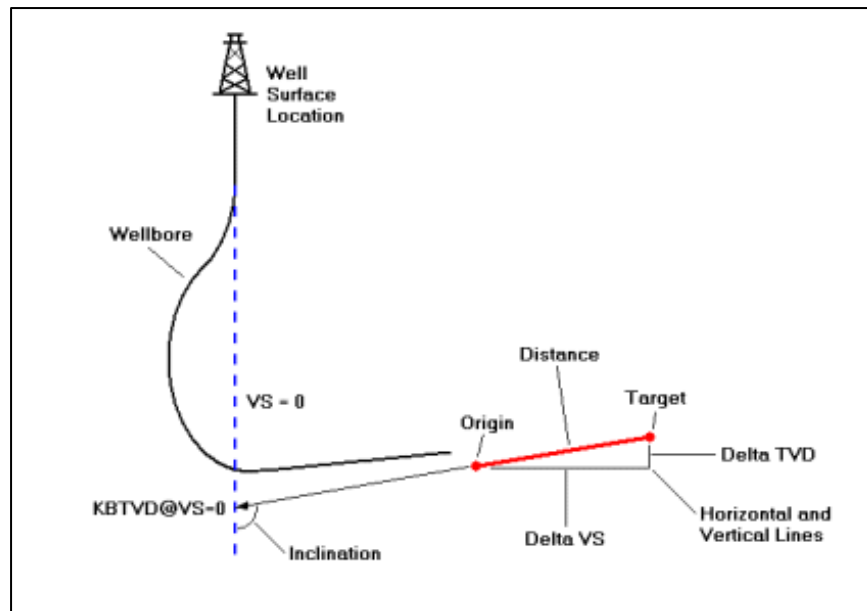


Figure 28: Description of variables generated by the Create Wellbore Target Line tool.

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Step 19 – Sending the results of your geosteering efforts to an onsite geologist

To send the results of your geosteering efforts to an onsite geologist, select the **Models** tab in the **Options** dialog box, and click **Email**. The .gsx file and the .ssd file (the GVERSE Geomodeling cross section file) will be emailed to the onsite geologist. He/she will have to place the .gsx file in the correct Project folder (located in ProjectExplorer), and copy and paste the .ssd file inside an Interpretation folder that contains the geosteered well.

Note: The GVERSE Geomodeling module must be closed to do this.

The geologist will then access the Interpretation, open the cross section from the list of cross sections, select the **Models** tab, and click [Load] to load the emailed .gsx file. The results of your geosteering efforts will display on the geologist's computer.

Conclusion

In conclusion, the iterative process of using smartSTRAT to geosteering is best learned by experimenting and utilizing the module many times. It will become second nature as you grow accustomed to the steps and the details of your geologic area. The key is to follow the overall guidelines outlined above, and to know the geology of your area. The more wells you geosteering in a particular region, the easier the correlations will get, as long as you remember to ensure:

- The 2D dip surface is picked in the well
- There is only one well in your cross section
- The drilling well is projected from left to right in your Vertical Section
- You correctly pick the curve related to your LWD log and use an appropriate LAS template.