Fitting Deterministic Arcuate Map View/Sigmoidal Cross Section Surfaces to IHS Beds in Fluvial Point Bars*

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Abstract

The geocellular models most faithful to the formation architecture are those in which the cell layers are parallel to bedding. Achieving this in fluvial point bar deposits is difficult because bedding in the heterolithic upper point bar is neither parallel to the point bar's scour base nor to the overlying seal beds. In general, the upper point bar bed geometry is sigmoidal in cross section and arcuate in map view. This shape can be described with the following algorithm:

(1) Ps = (SQRT ((Xc - Xs)^2 + (Yc - Ys)^2) - R) / W
(2) IF Ps < 0 THEN Zs = UpperZ
(3) ELSE IF Ps > 1 THEN Zs = LowerZ
(4) ELSE Zs = UpperZ+ (0.5 x cos (3.14159 x Ps) - 0.5) * (UpperZ-LowerZ)

where:

Ps = normalized position of the sample point on the sigmoidal slope
Xs = sample location X coordinate
Ys = sample location Y coordinate
- * Xc = circular planform shape centroid X coordinate
- * Yc = circular planform shape centroid Y coordinate
- * R = circular planform shape radius to top of sigmoid slope
- * W = width of sigmoid from top of slope to base of slope

Zs = calculated elevation of sample
- * UpperZ = elevation of top of sigmoid slope
- * LowerZ = elevation of base of sigmoid slope

* = term in sigmoid shape equation (Figure 1)

Discussion

The geocellular models most faithful to the formation architecture are those in which the cell layers are parallel to bedding. Achieving this in fluvial point bar deposits is difficult because bedding in the heterolithic upper point bar is neither parallel to the point bar's scour base nor to the overlying seal beds. In general, the upper point bar bed geometry is sigmoidal in cross section and arcuate in map view (Figure 2). The dip angle of the sigmoidal surface at any location can be determined as the first derivative of the above function. In addition, the down-dip azimuth can be calculated as the angle between any sample point and the shape centroid relative to due North. To determine dip azimuth and dip angle at well pick locations, the picks elevations (Figure 3) may be gridded (Figure 4), local dip azimuth and dip angle calculated (Figure 5), and then the dip angle and dip azimuths can be reverse-interpolated from the grid (Figure 6).

The algorithm of Equations 1 through 4 is optimized to the surface elevation picks in wells and/or geophysical data using a spreadsheet that iteratively modifies the six equation parameters of the mathematically defined surface (denoted with asterisks) until an objective function of fit to the real data is minimized (Figure 7). The objective function is a weighted summation of elevation estimation error, dip angle estimation error, and dip azimuth estimation error.

After the best-fit equation terms are determined, the same algorithm is used to assign elevation values to the nodes of a surface elevation grid (Figure 8). These surfaces can then be flexed to match well data and/or geophysical interpretations and then used as zone boundaries, as layer orientation guides for the geocellular framework, or to help correlate between widely spaced wells (Figure 9).

A cut-bank surface is constructed using the same algorithm, except the UpperZ and LowerZ elevations are reversed and the radius is adjusted to match the thalweg position of the point bar surface (Figure 10).

Conclusions

This method has been successfully applied to a Brazos River (Texas) modern point bar with time-lapse aerial photos to aid in correlation (Figure 1) and dense borehole coverage, and also applied on two heavy oil reservoirs in Alberta, one with 3D seismic and the other with ground penetrating radar.

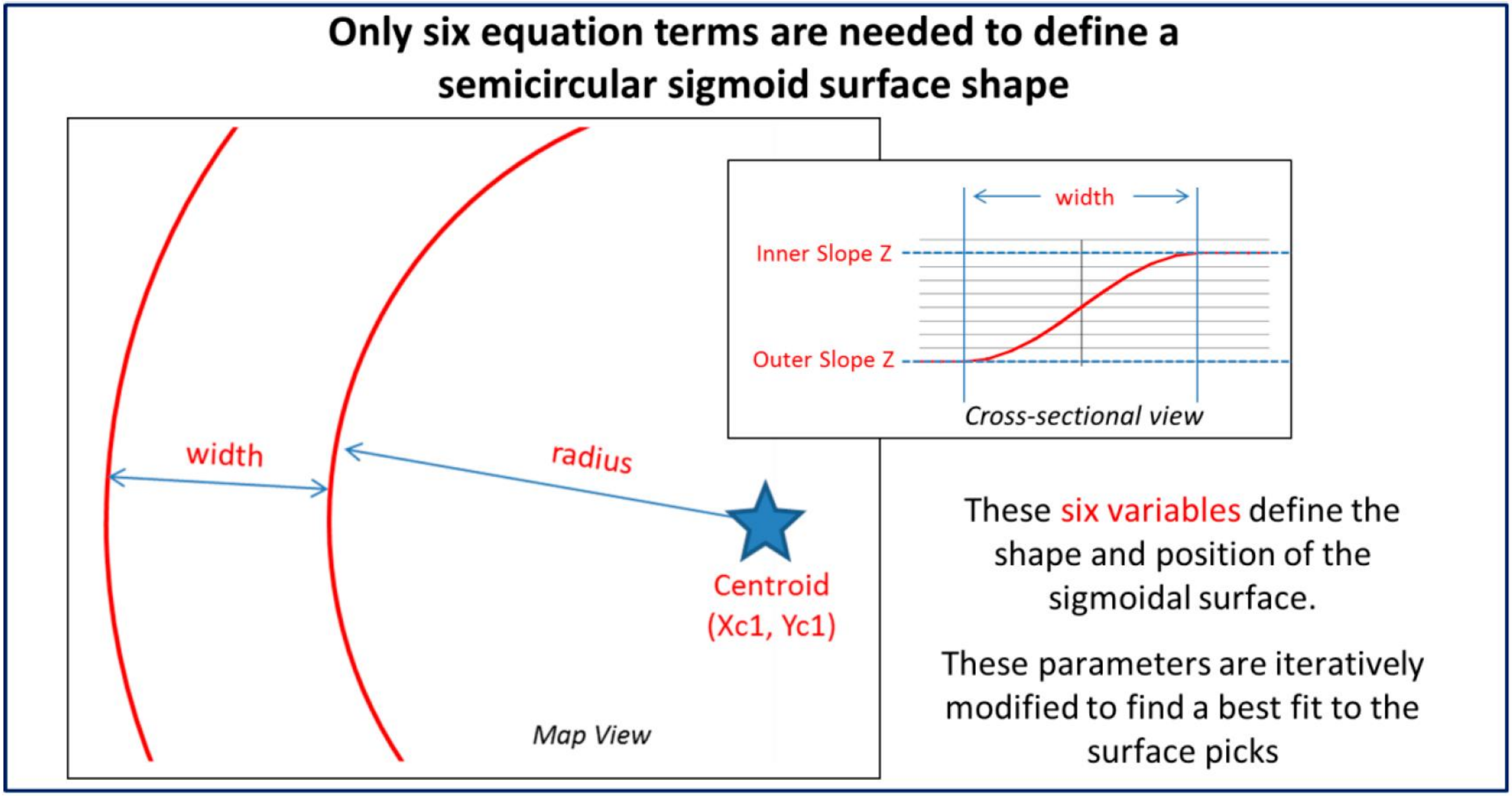

Figure 1. Six equation variables describe a surface that is arcuate in map view and sigmoidal in cross section view. We optimize these variables to obtain a best-fit surface to a set of X-Y-Z points. The fit can also be influenced by local dip azimuth and dip angle, if those properties are available.

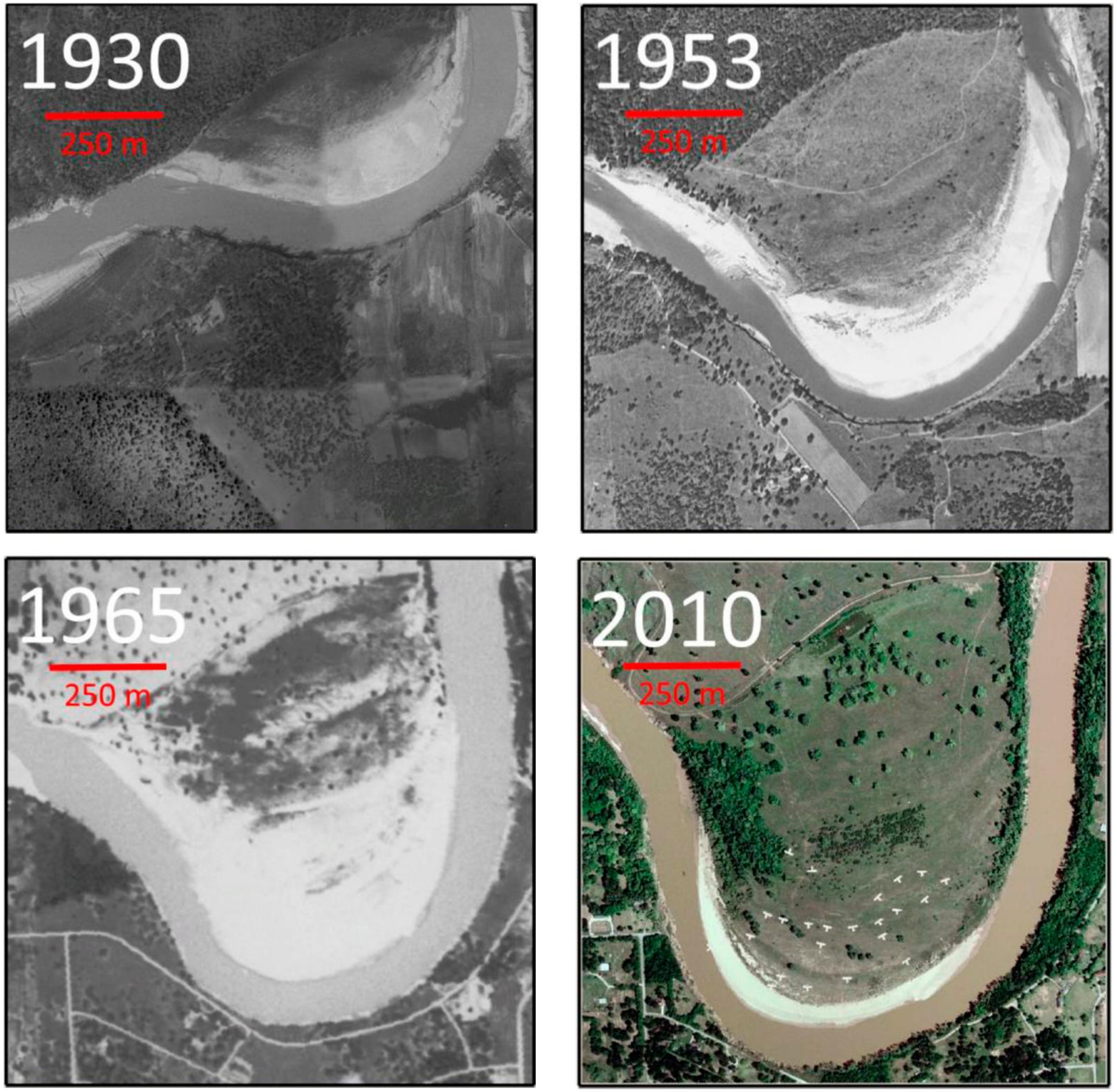

Figure 2. The significant lateral accretion surfaces of this point bar on the Brazos River (Texas) can be correlated between wells using geophysical data and aerial photos, which document the positions through time.

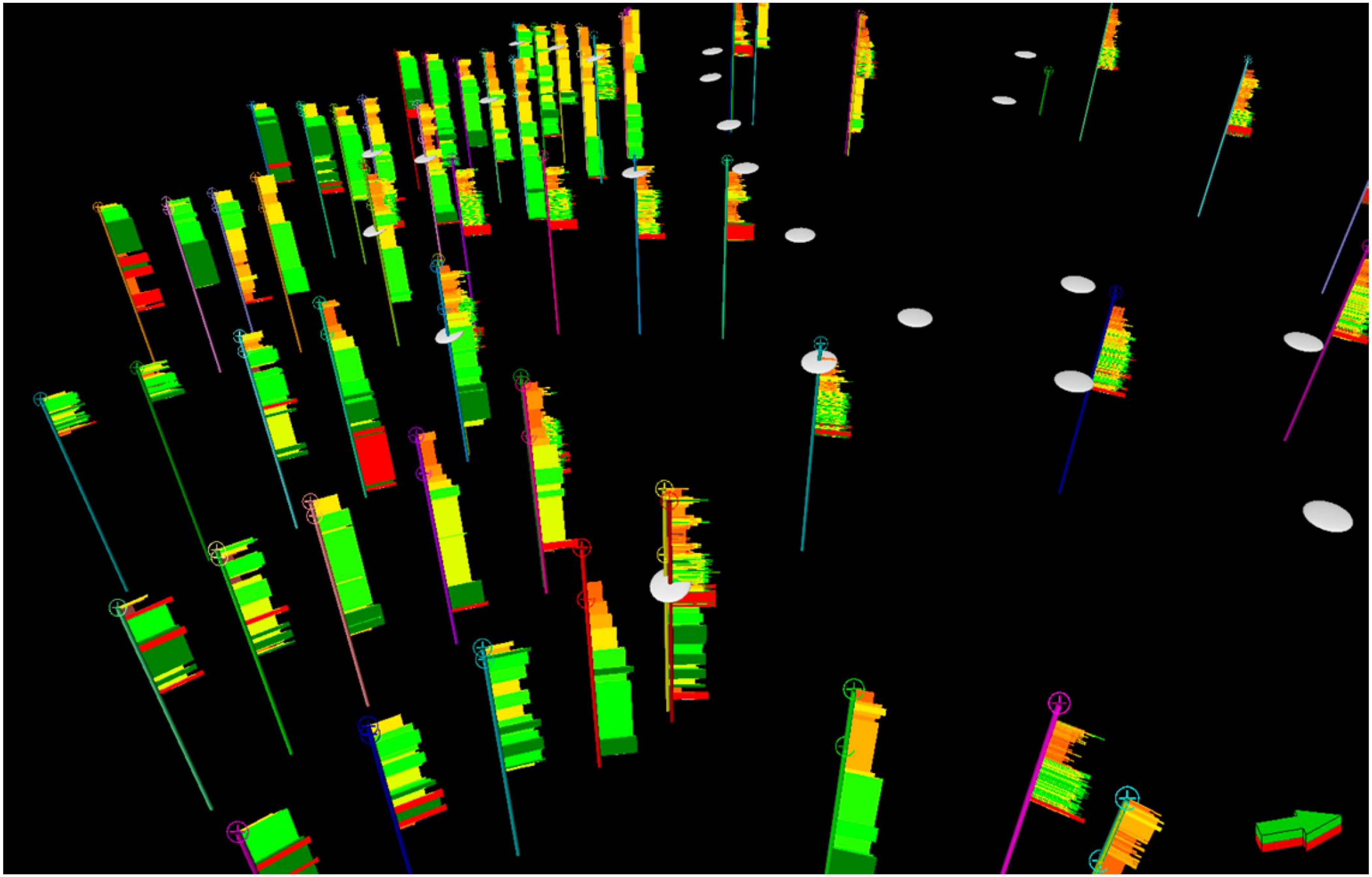

Figure 3. Step 1 – Make interpretation points (discs, with X-Y-Z) from wells and/or geophysical data.

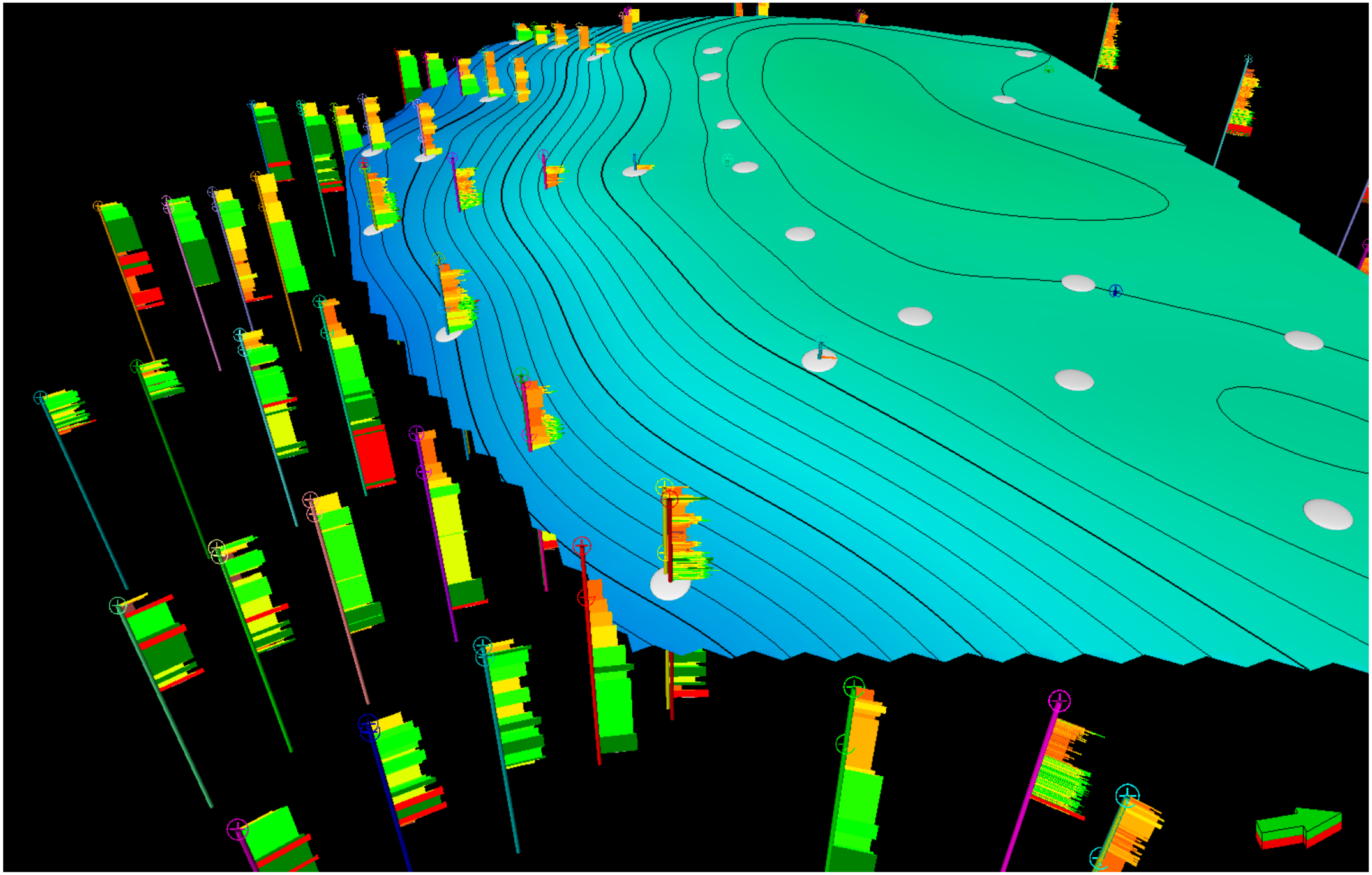

Figure 4. Step 2 - Interpolate the surface elevations between the interpretation points

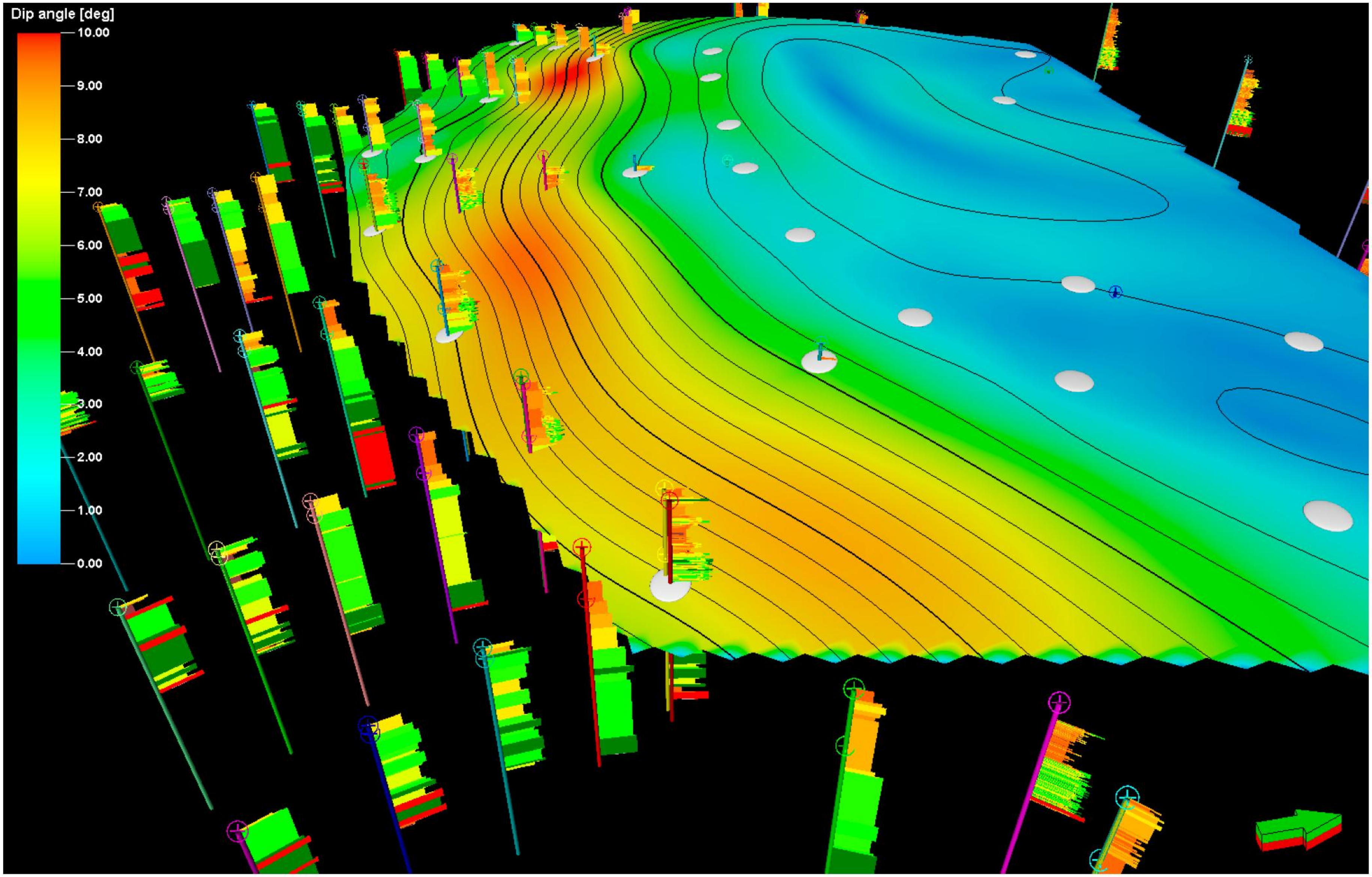

Figure 5. Step 3 - Create Dip Azimuth and Dip Angle from the gridded surface. Dip angle shown.

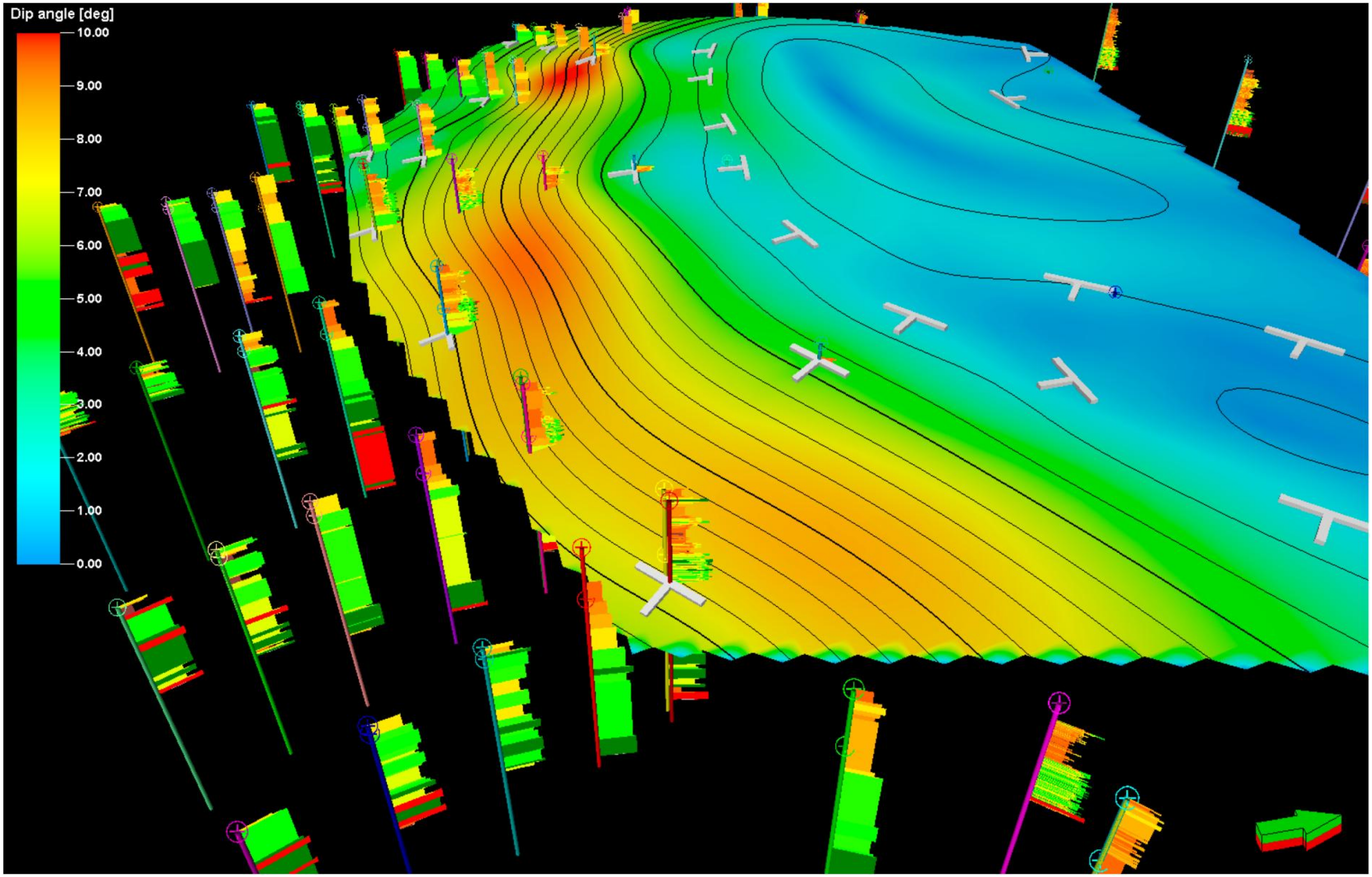

Figure 6. Step 4 - Read Dip Azimuth and Dip Angle onto the pick set.

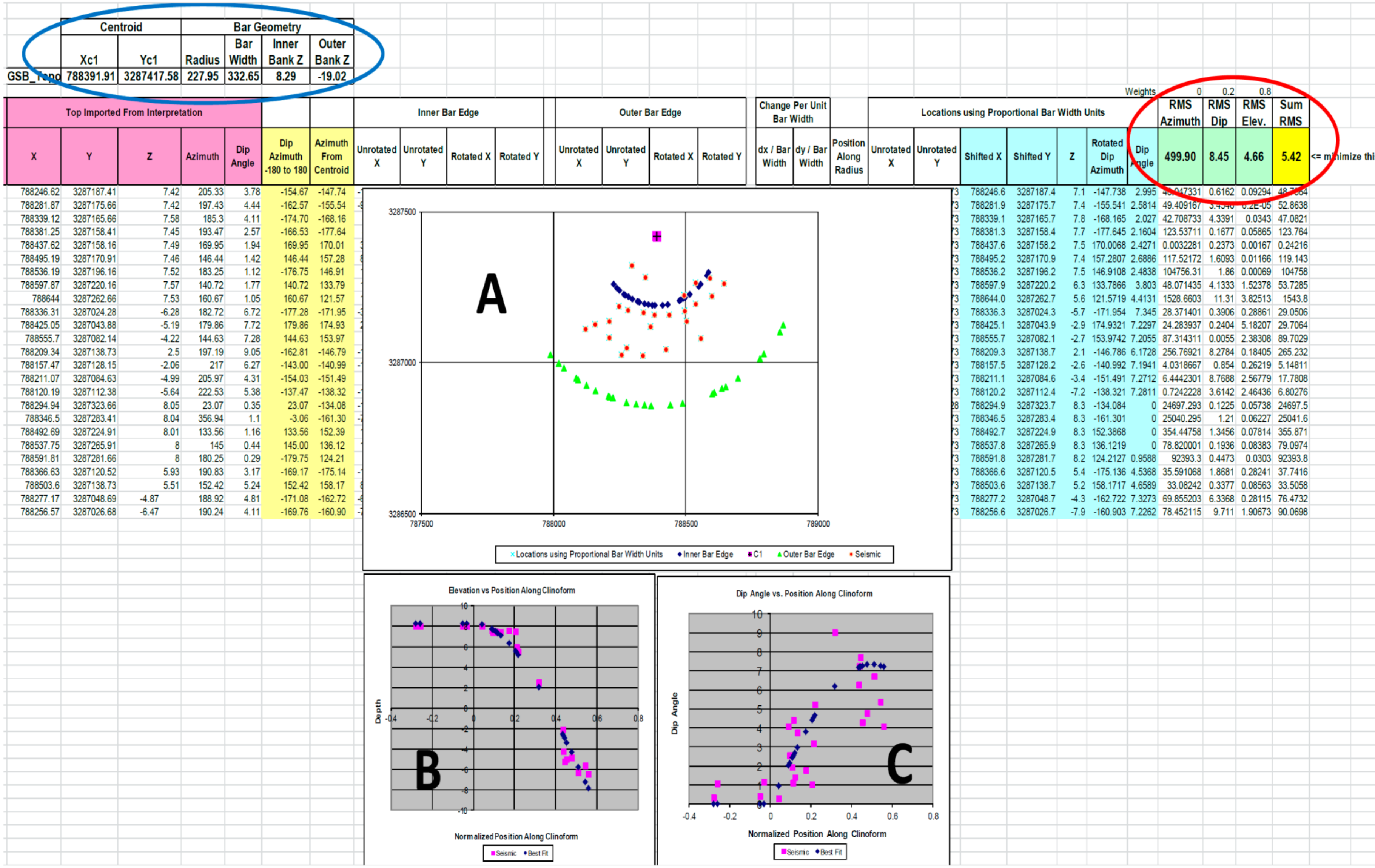

Figure 7. Step 5 - Copy the interpreted points into a spreadsheet and fit a mathematical arcuate sigmoid surface to them. This spreadsheet does a best-fit optimization by minimizing the Root Mean Square Error (RMSE) to an input set of points by changing the centroid position, radius, width, inner and outer slope depth parameters (blue circle). Graphs A, B, and C visualize the effects of the shape parameters. RMS Error statistics (red circle) are the objective functions optimized by SOLVER when it iteratively changes the shape parameters.

Workflow to Generate Calculated Sigmoidal Surface

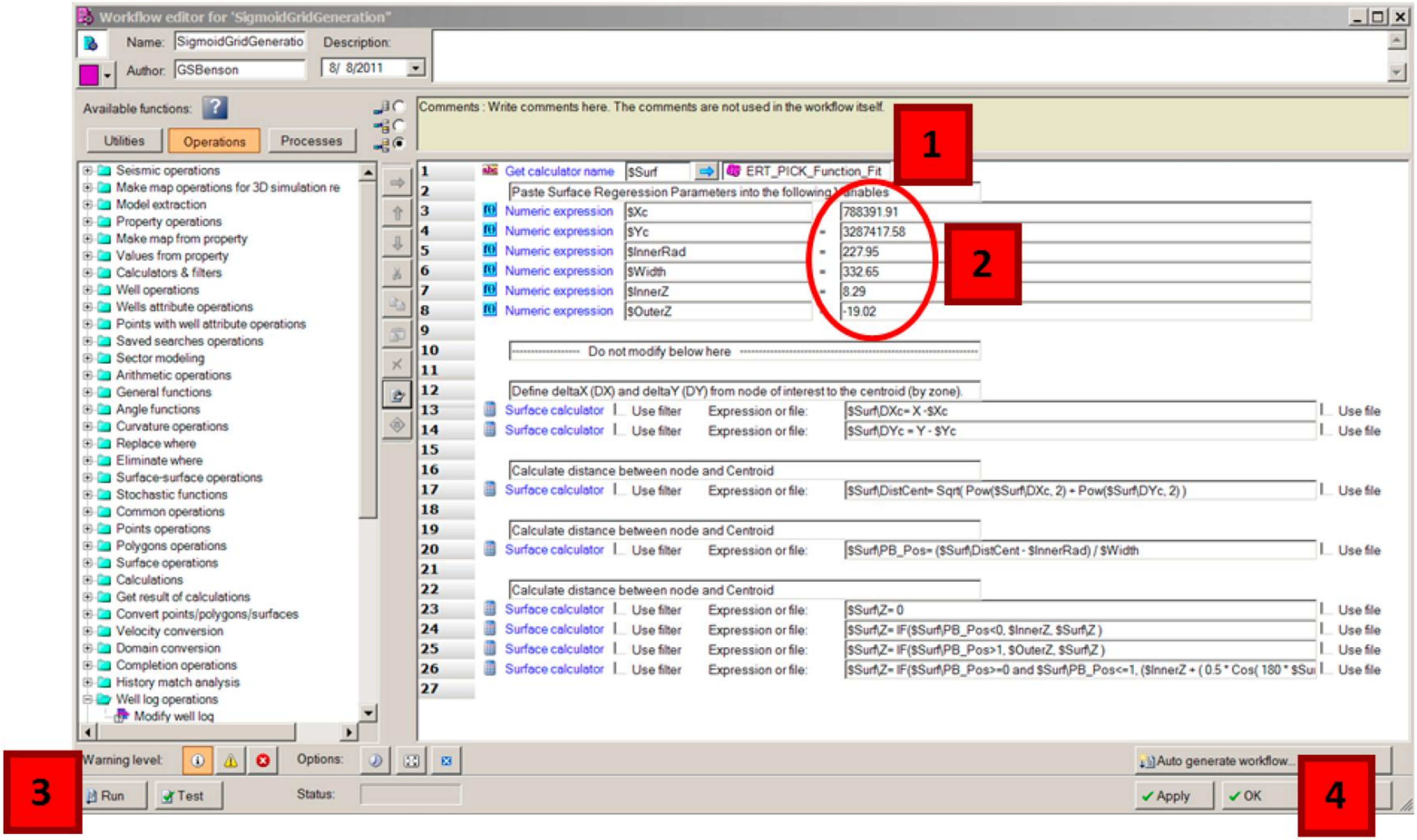

Figure 8. Step 6 - Create the calculated surface in the modeling tool using the 6 optimized arcuate sigmoid equation parameters.

1. Make a copy of an existing sigmoid surface and enter it into the workflow by using the blue arrow to “shoot it in”
2. Enter in the six optimized values for Xc, Yc, Inner Radius, Width, InnerZ, and OuterZ from the Excel spreadsheet
3. Click “Run” to generate the surface.
4. Click “Ok” to save the changes and to close the window.

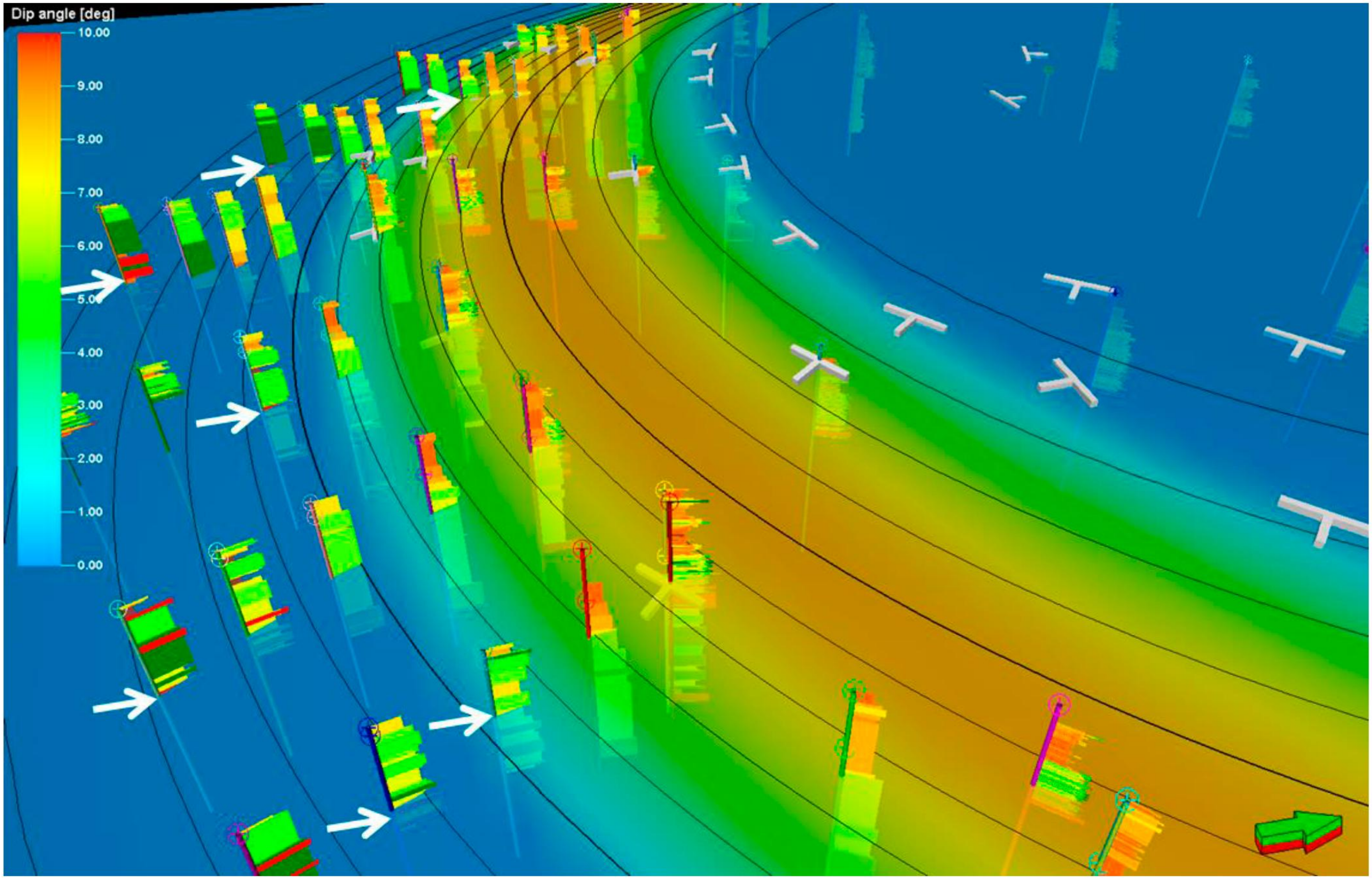

Figure 9. Step 7 - Correlation in fluvial point bars is particularly challenging because the lateral accretion surfaces are curved and inclined at variable angles. The traditional datumed well section correlation technique fails because, aside from the scour base, there is no originally horizontal surface upon which a well section can be datumed. An equation-based surface that has been fit to the picks can be used to extend the arcuate and sigmoidal lateral accretion trends beyond the existing picks (strike/dip symbols). This surface serves as a guide to identify candidates for additional correlative surface picks in the surrounding wells (arrows) along the best-fit curviplanar timeline. We repeat Steps 1 through 7 until the surface correlations can be extended no further.

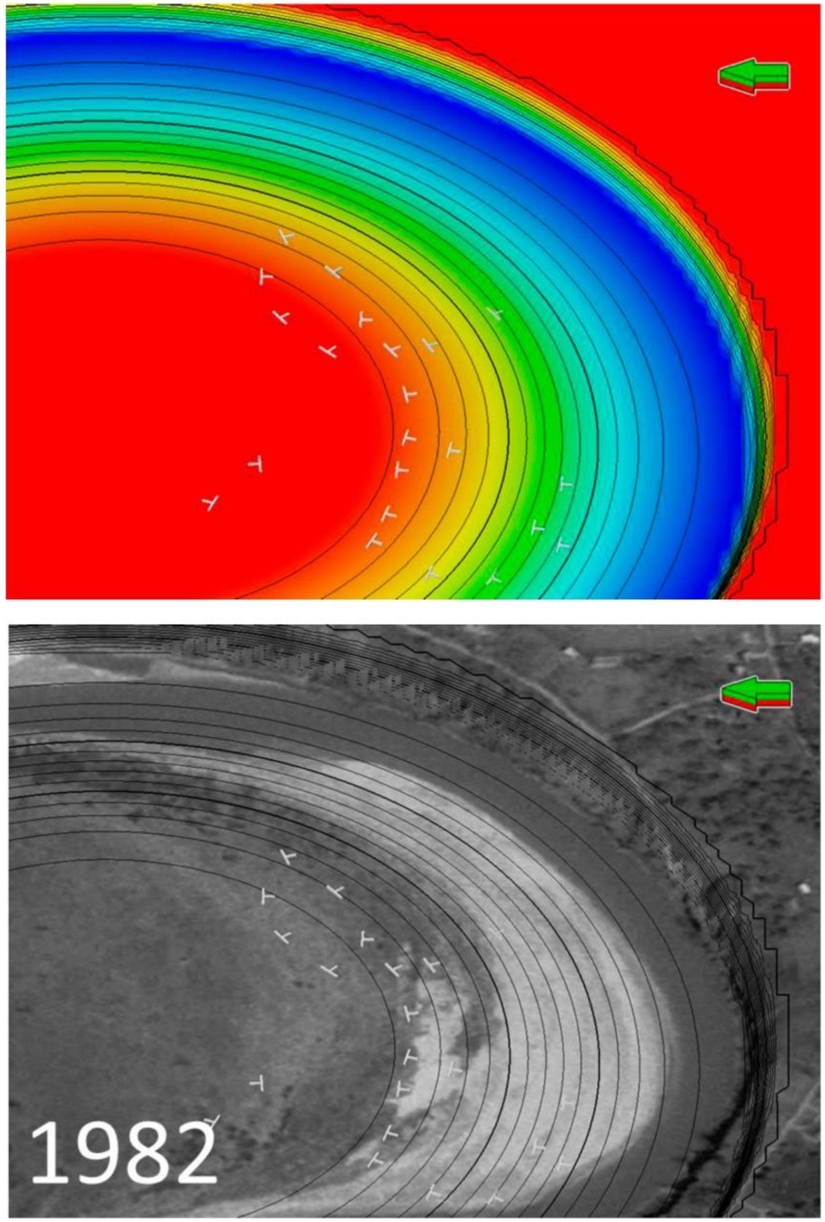

Figure 10. A concave outer cut-bank shape can also be generated using the same workflow by reversing the UpperZ and LowerZ elevations, adjusting the radius to locate the lower elevation at the channel thalweg, and making the sigmoid width much narrower. This function-generated arcuate sigmoid example is a good approximation of the 1982 point bar topography.