Full Use of Dipmeter Data for Geocellular Property Modeling in the McMurray Formation, Alberta*

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Abstract

Dipmeter data has traditionally been used to assist interpretation of geologic structure, to infer depositional environments, and determine paleocurrent direction. However, dipmeter data is seldom used as direct conditioning for population of geocellular model properties. We discuss the preparation and use of dipmeter data for interpolation of Facies and Gamma Ray properties in a fluvial point bar deposit. Our example is from the McMurray Formation in Alberta, Canada.

Introduction

Dipmeter data in fluvial point bar deposits are noisy, containing signals from trough cross bedding, subaqueous dune foresets, slumping, mud clast conglomerates, and inclined heterolithic sediments (IHS). Trough cross bedding and dune foresets indicate paleocurrent direction, while the orientations of IHS beds contain information about the architecture of bar-scale lateral accretion packages. When populating geocellular model properties, it is these roughly co-planar, dipping IHS orientations that tell us how to correlate the beds between wells.

Methods and Discussion

We have developed a processing method that measures the variation of dipmeter orientations within a moving window, which allows isolation of the coherent bed orientation signal of the co-planar IHS beds. Once the dipmeter data has been high-graded, it can be upscaled into a model framework, interpolated throughout the model volume, and then used as a Locally Varying Azimuth to orient variograms/training images in the property modeling algorithms.

The workflow is as follows:

1. Create bed co-planarity "coherency" scores using moving depth windows in dipmeter data (Figure 1 and Figure 2).

2. Apply coherency score filtering and other criteria (e.g. exclude certain facies) to high-grade dipmeter readings for use in model conditioning (Figure 3 and Figure 4).
3. Supplemental bed dip data from geophysical survey interpretations can be added to the dataset (Figure 5).
4. Decompose the bed dip azimuths and dip angles into unit circle vectors dX, dY, and dZ as a strategy to avoid azimuth aliasing (Figure 6 and Figure 7).
5. Upscale the dX, dY, and dZ coherent bed orientation data into a model framework.
6. Interpolate dX, dY, and dZ through the geomodel framework using inverse distance squared weighting (Figure 8 and Figure 9).
7. Recombine unit circle vector properties into Dip Azimuth and Dip Angle (Figure 10).
8. Replicate upscaled core and wireline log data around the wells according to interpolated Dip Azimuths and Dip Angles to enhance local honoring of coherent bed orientation data (Figure 11 and Figure 12).
9. Perform property modeling using the bed orientation properties as Locally Varying Azimuth for steering variograms (Figure 13 and Figure 14).

Conclusions

1) Dipmeter co-planarity (or coherency) can be calculated as the standard deviation of dip angle and dip azimuth using moving windows;
2) Noisy data can be filtered out using the co-planarity statistic;
3) Filtered dip azimuth and dip angle data can be decomposed into unit circle vectors, the vectors interpolated between wells, and then recombined into angles again to avoid azimuth angle interpolation;
4) Dip azimuth can be used to steer variograms while interpolating model properties like Gamma Ray or Facies;
5) Upscaled point replication partially overcomes the minor axis variogram dip issue and the constant dip angle issue.

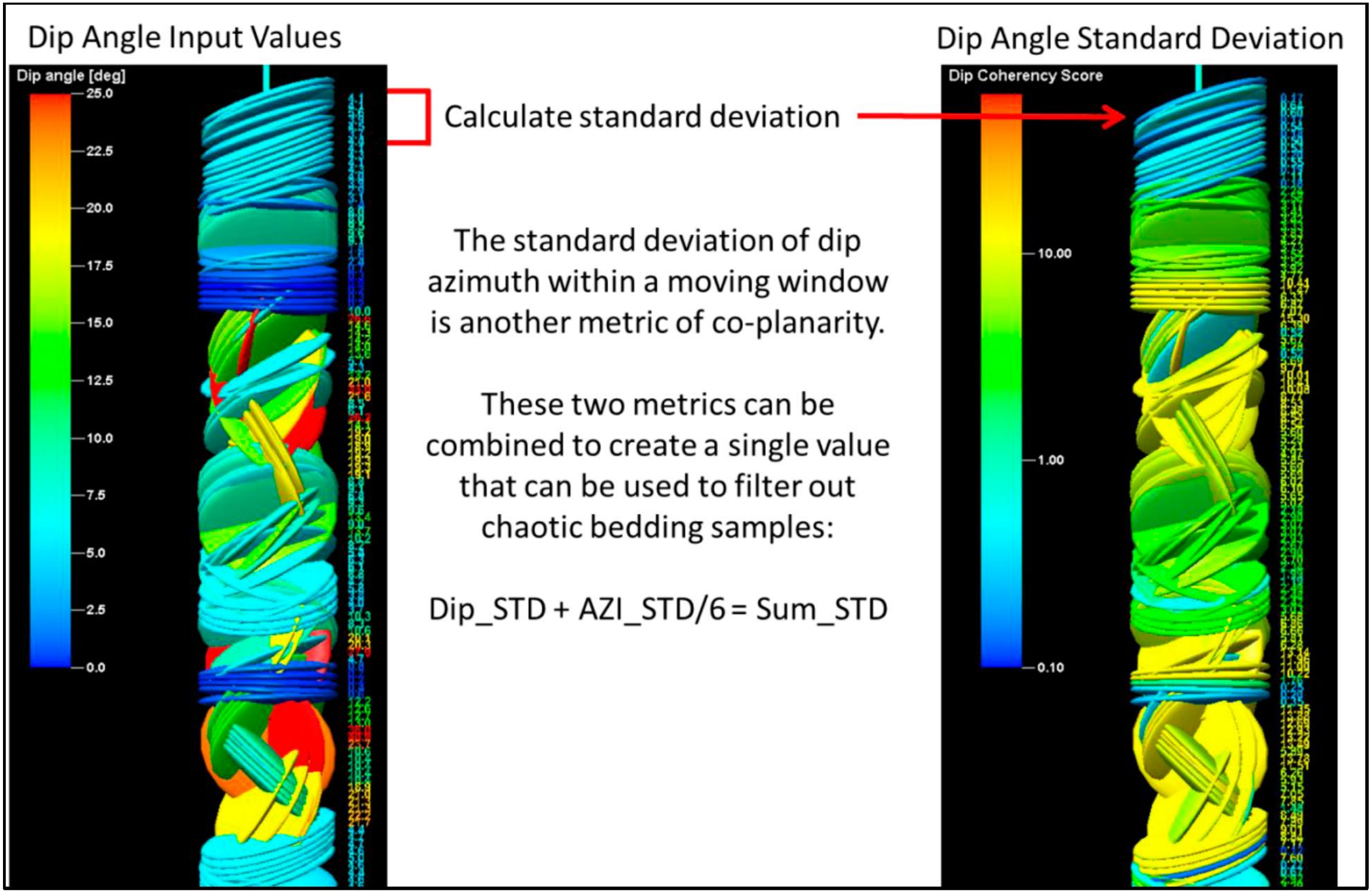

Figure 1. The standard deviation of dip angle and the standard deviation of dip azimuth within a moving window are co-planarity metrics. These can be combined together to create a single "Coherency Score" that can be used to filter out chaotic dipmeter readings, and presumably retaining co-planar IHS beds.

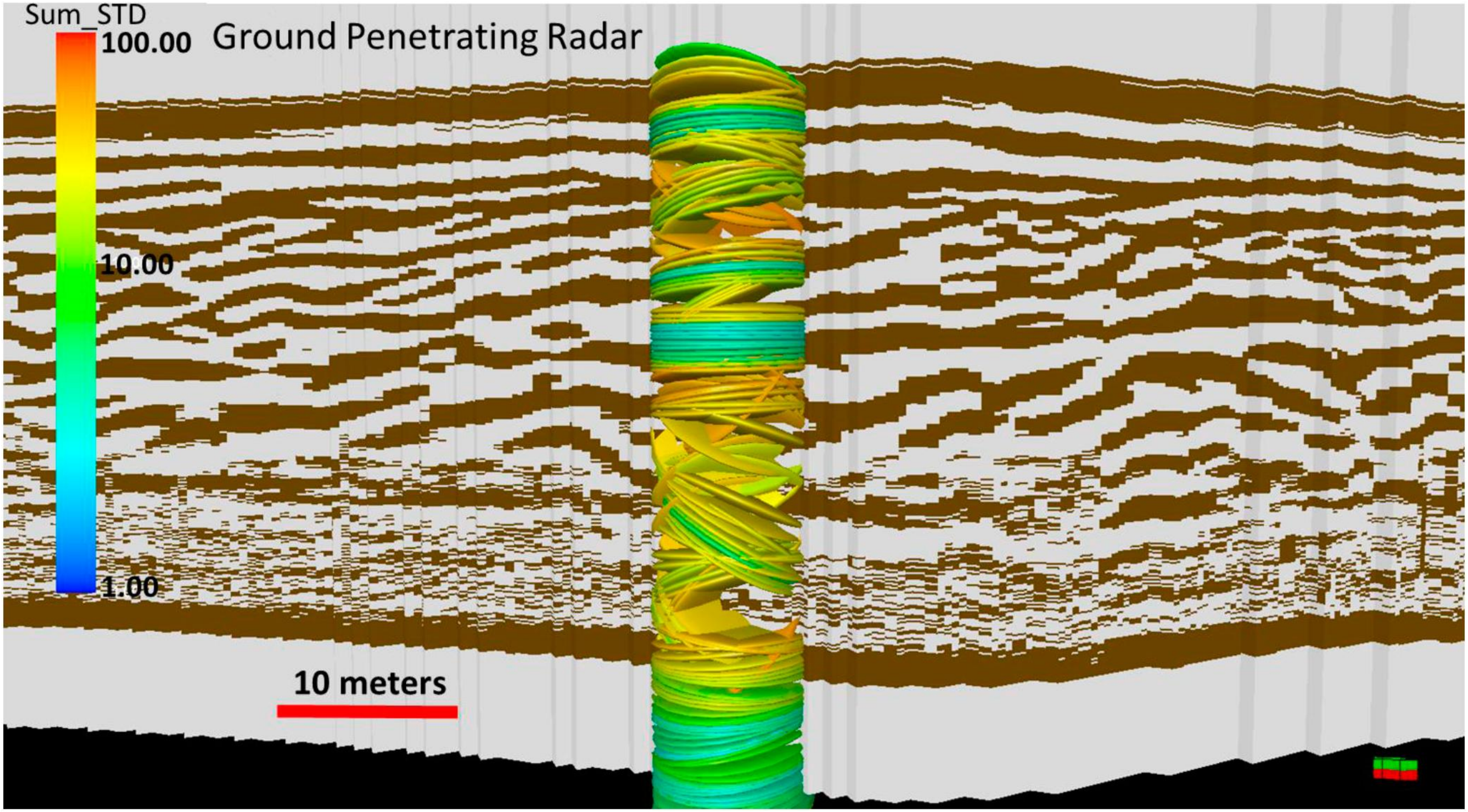

Figure 2. The degree of co-planarity, or "coherency" of dipmeter data can be measured. This dipmeter data is displayed as dipping discs colored by the coherency statistic. Only the blue and green colored samples represent the co-planar Inclined Heterolithic Strata (IHS) bed orientations as seen in the GPR line. The yellow and orange samples are noisy trough cross bedding, paleocurrent indicators, or slumps.

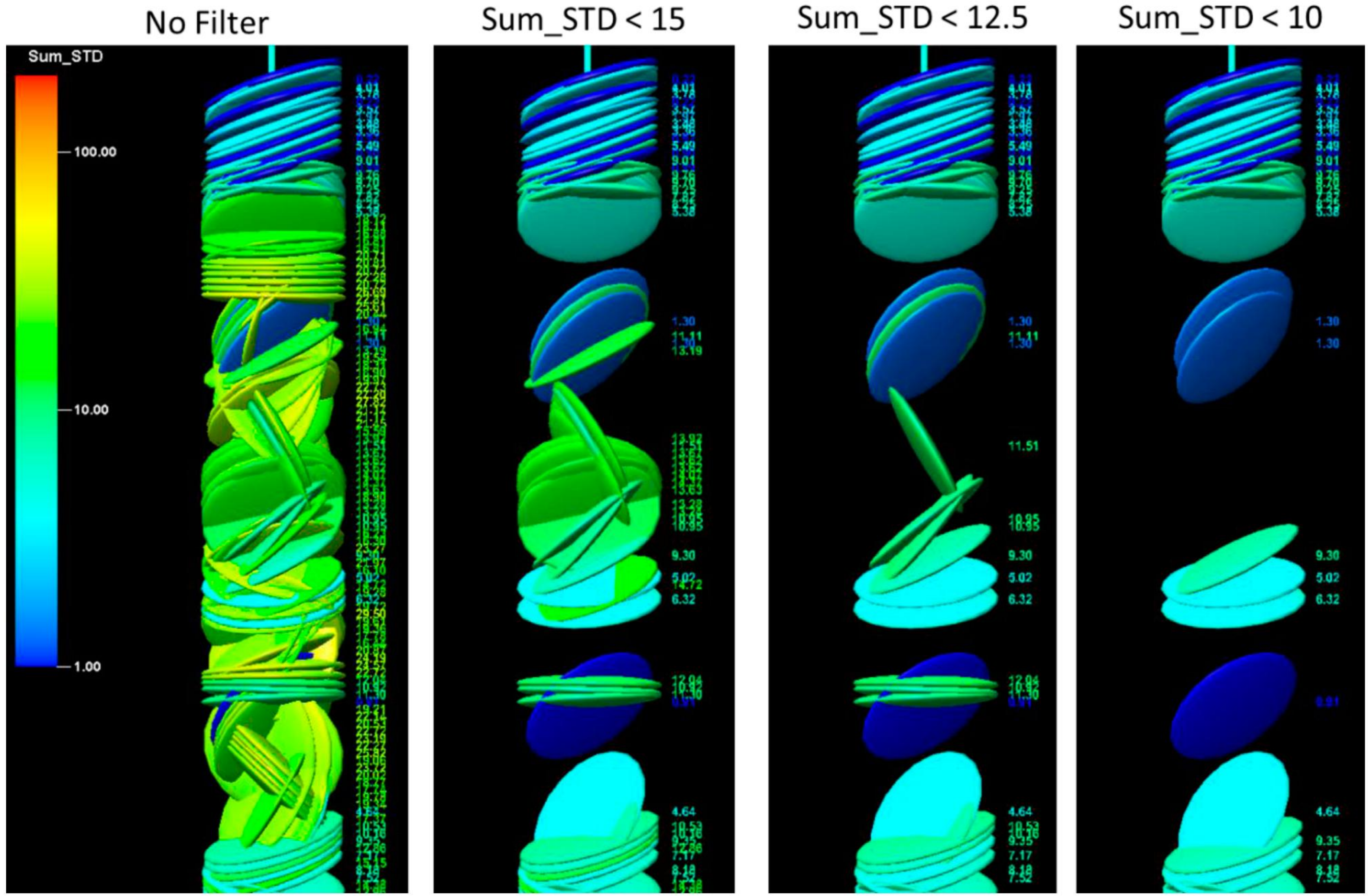

Figure 3. A coherency cutoff is found which eliminates the majority of non-IHS bedding. Additional filters can also be applied to eliminate samples with low gamma ray or trough crossbedding core descriptions.

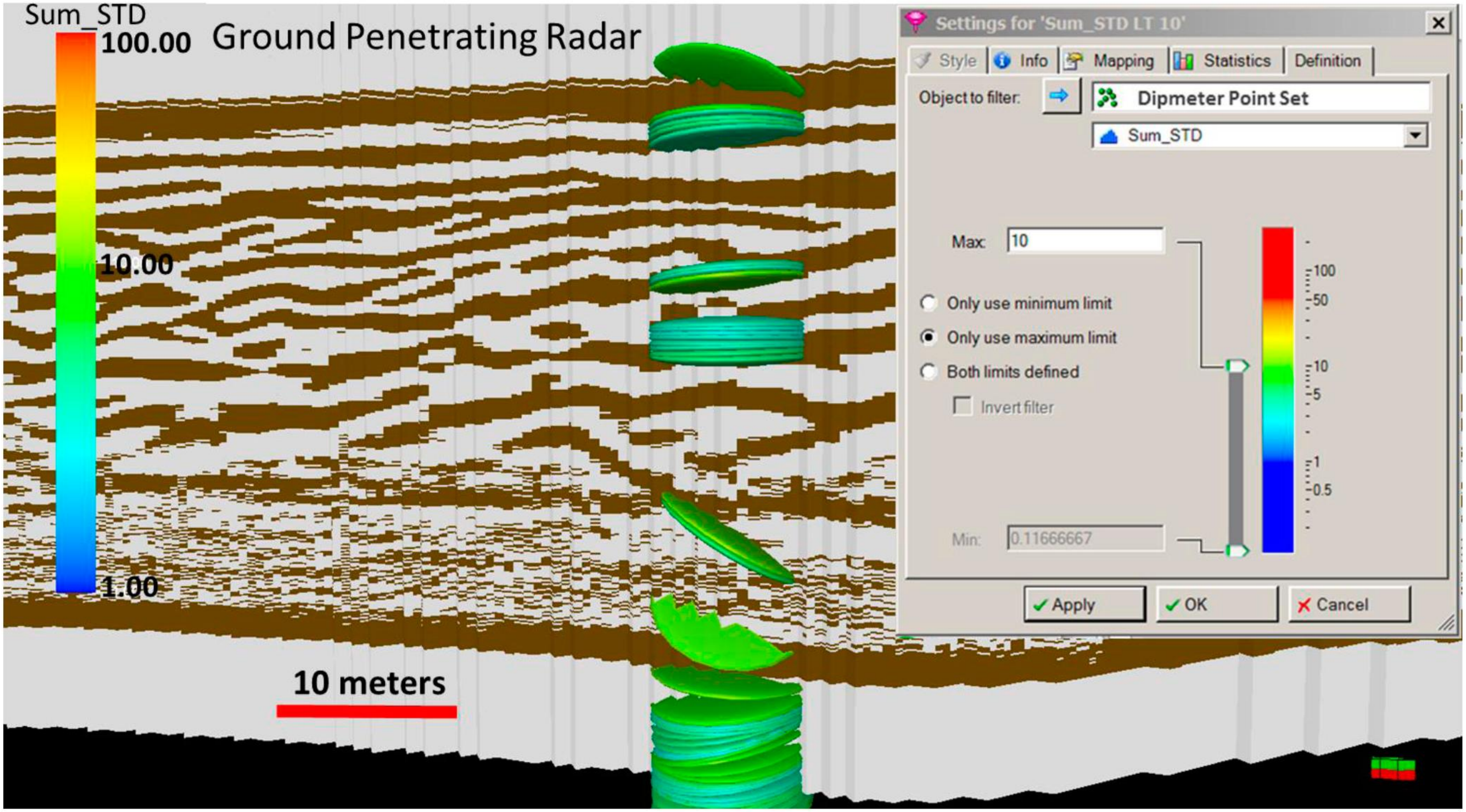

Figure 4. Filtered Dipmeter Coherency Scores - The dipmeter data has been filtered with a coherency score cutoff, thereby eliminating the noisy trough cross bedding, slumps, and most paleocurrent signals. A few very steep samples are retained that probably are dune foreset paleocurrent indicators. We will exclude these steeply dipping samples using a dip angle cutoff or facies filters in a separate step.

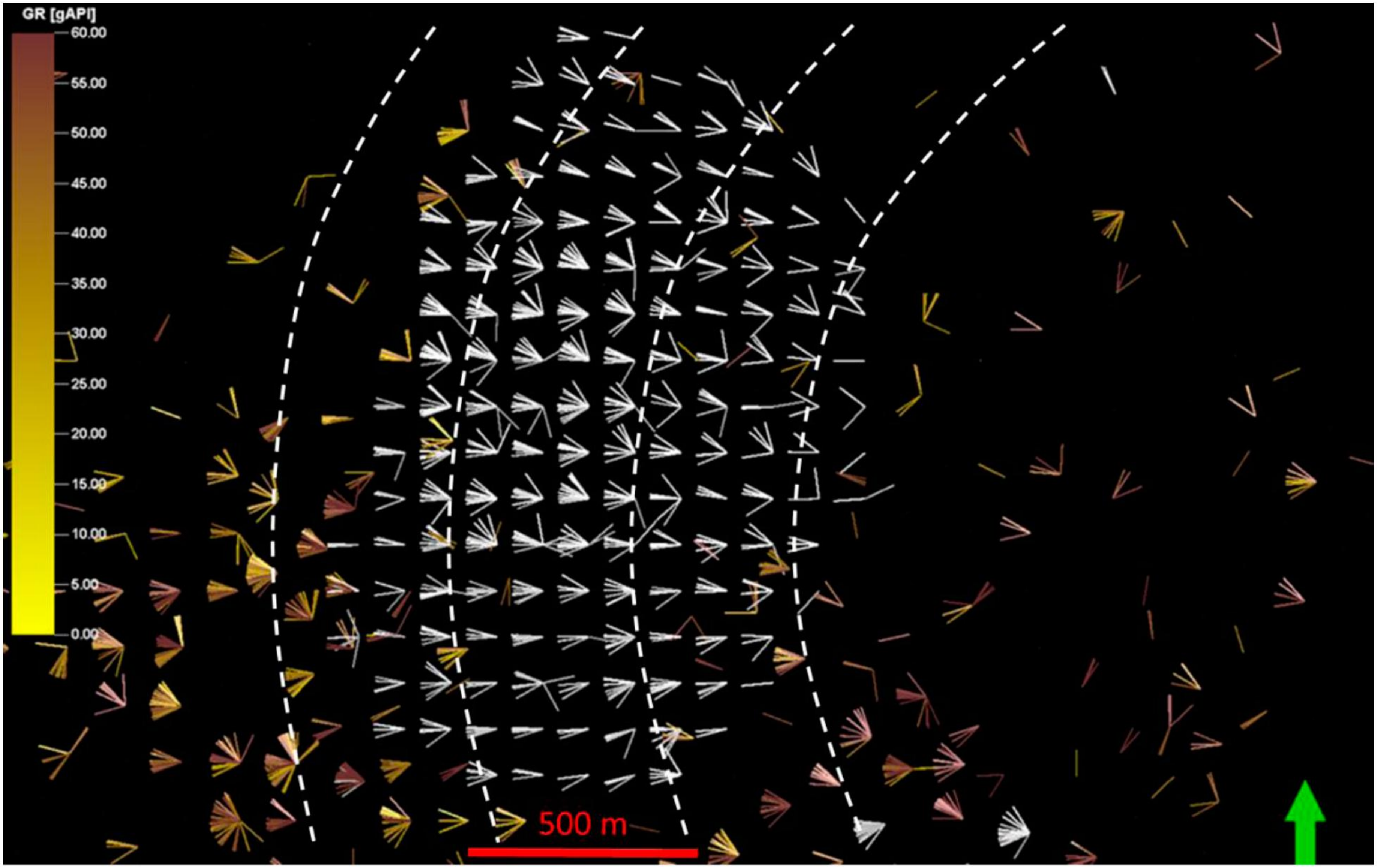

Figure 5. Dip-Stick display of filtered dipmeter data colored by Gamma Ray. Uncolored dip sticks are bed orientation data extracted at 100-meter spacing from surfaces interpreted from GPR and seismic data. We can interpret the radius of curvature of the point bar lateral accretion packages (dashed lines).

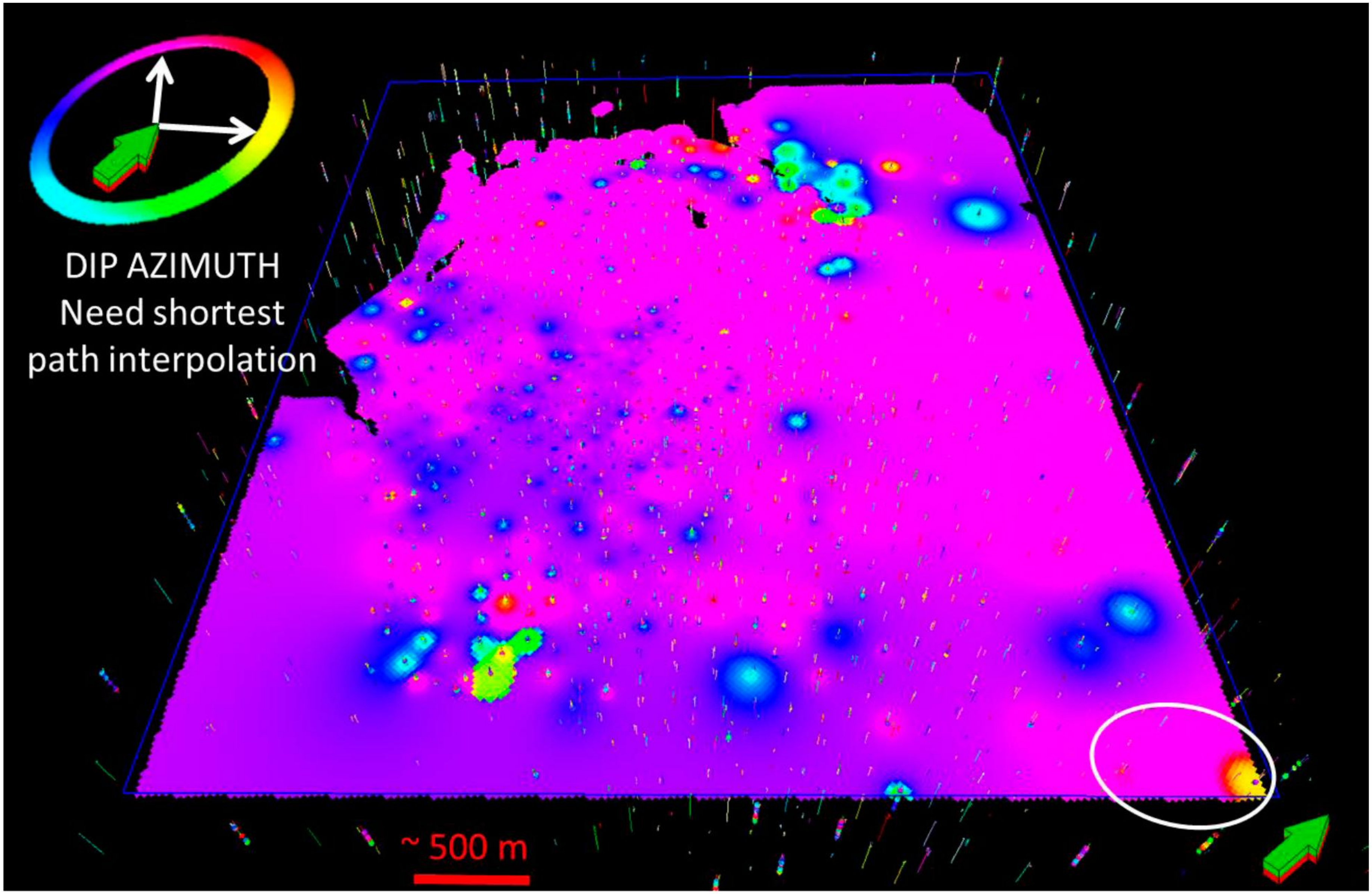

Figure 6. Dip azimuths must be interpolated through the geomodel framework for use as locally varying azimuths to steer the modeling variograms. The white circle indicates a region where interpolation of azimuths measured in degrees would produce incorrect intermediate values. Figure 7 explains this.

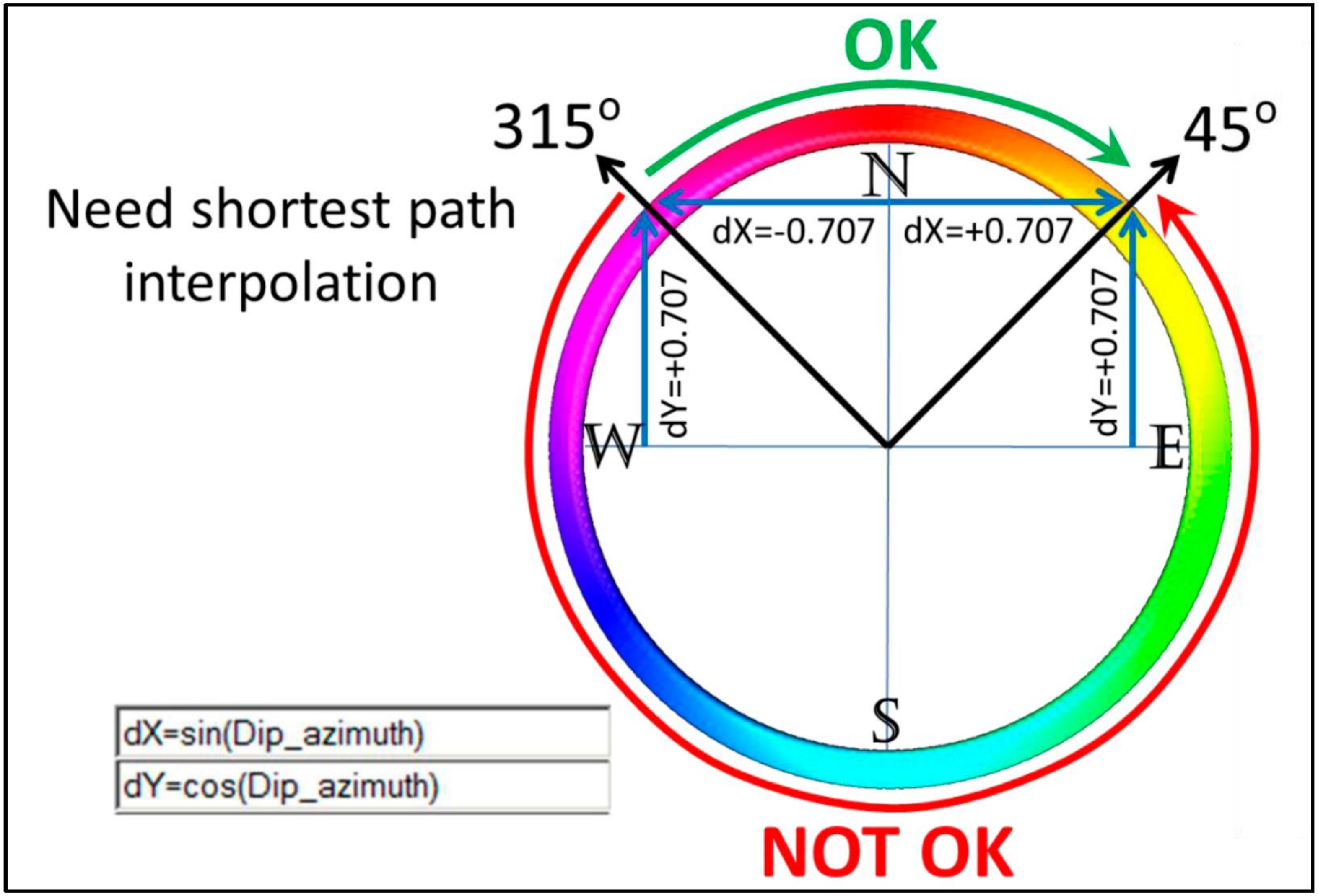

Figure 7. In the example from the circled region in Figure 6, we wish to ensure that interpolation takes the shortest route through due north between the wells with azimuths 315 and 45 degrees (green arrow "OK", pink to red to yellow), not the longest route (red arrow "NOT OK", pink to blue to cyan to green to yellow). Weight averaging the azimuth measured in degrees would result in a midpoint-interpolated value of 180 degrees (due south, "NOT OK"). We avoid this error by decomposing the degrees into unit circle vectors and then interpolating the unit vectors. Azimuth in degrees is reconstructed using the interpolated dX and dY model properties in the arctangent function. Because interpolated values of these weight-averaged dY well values are always positive in this example, the dip direction is always toward the north ("OK"). Equations assume trigonometry functions performed in degrees.

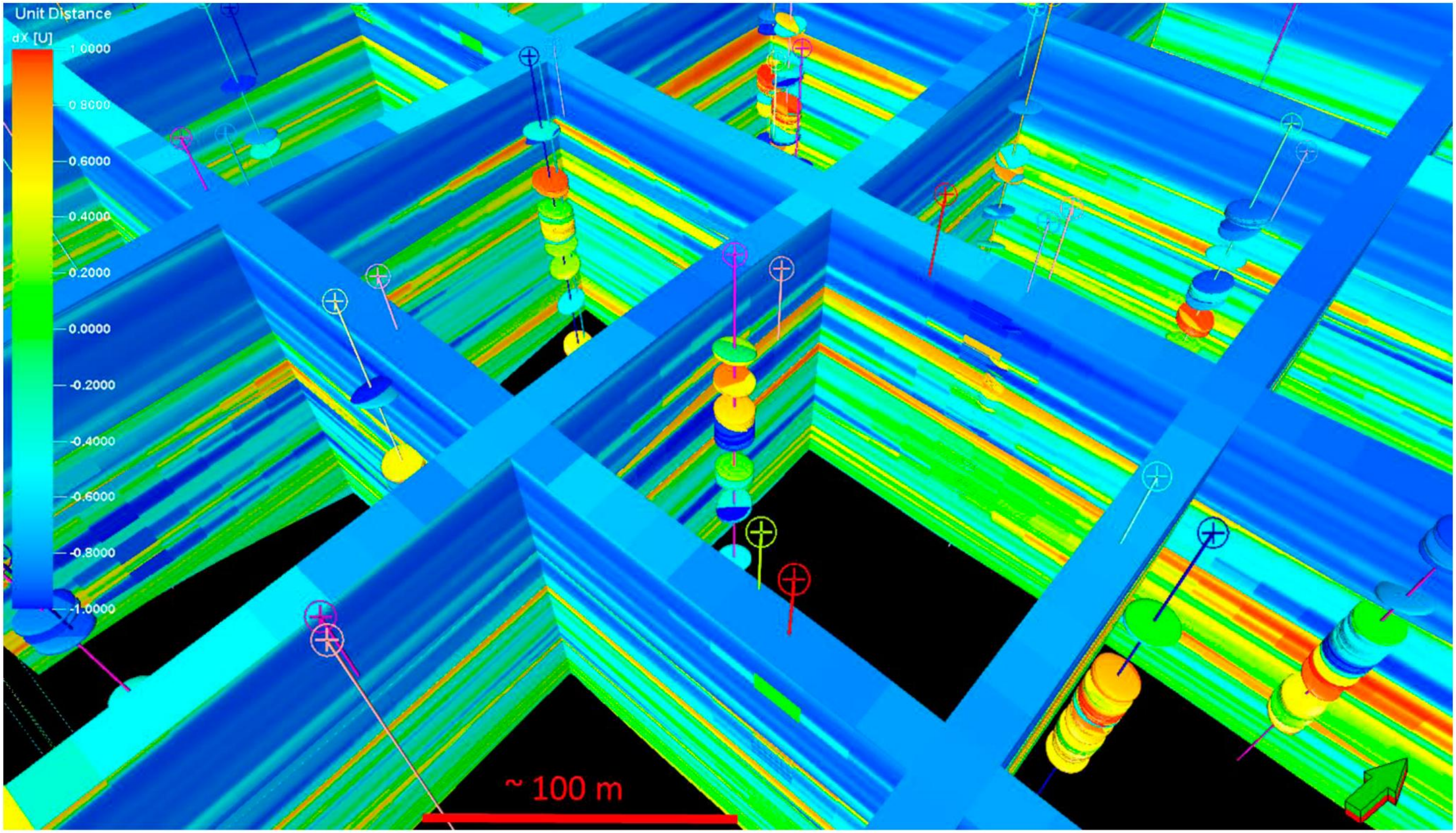

Figure 8. Unit vector dX upscaled and then interpolated between wells.

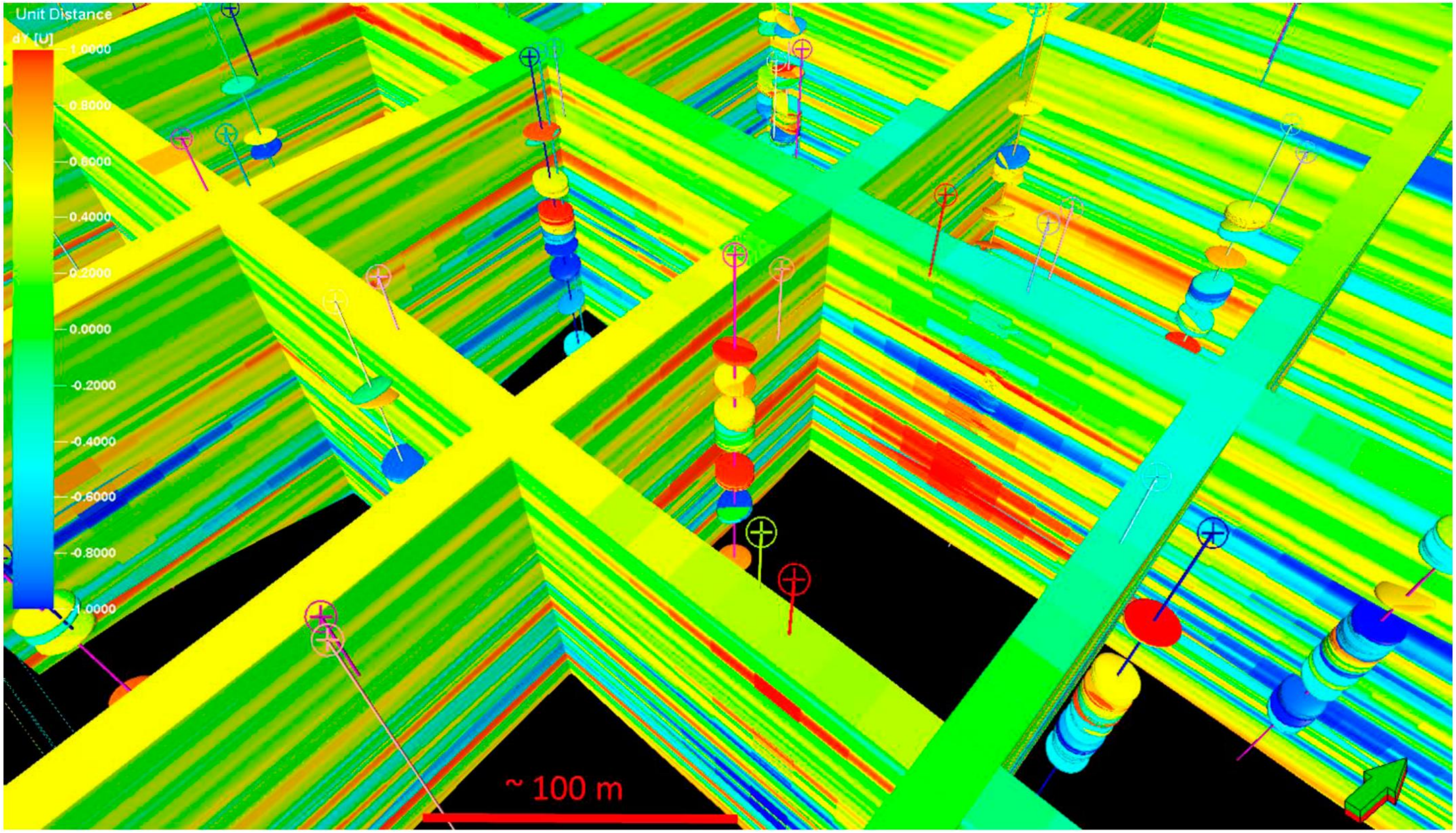

Figure 9. Unit vector dY upscaled and then interpolated between wells.

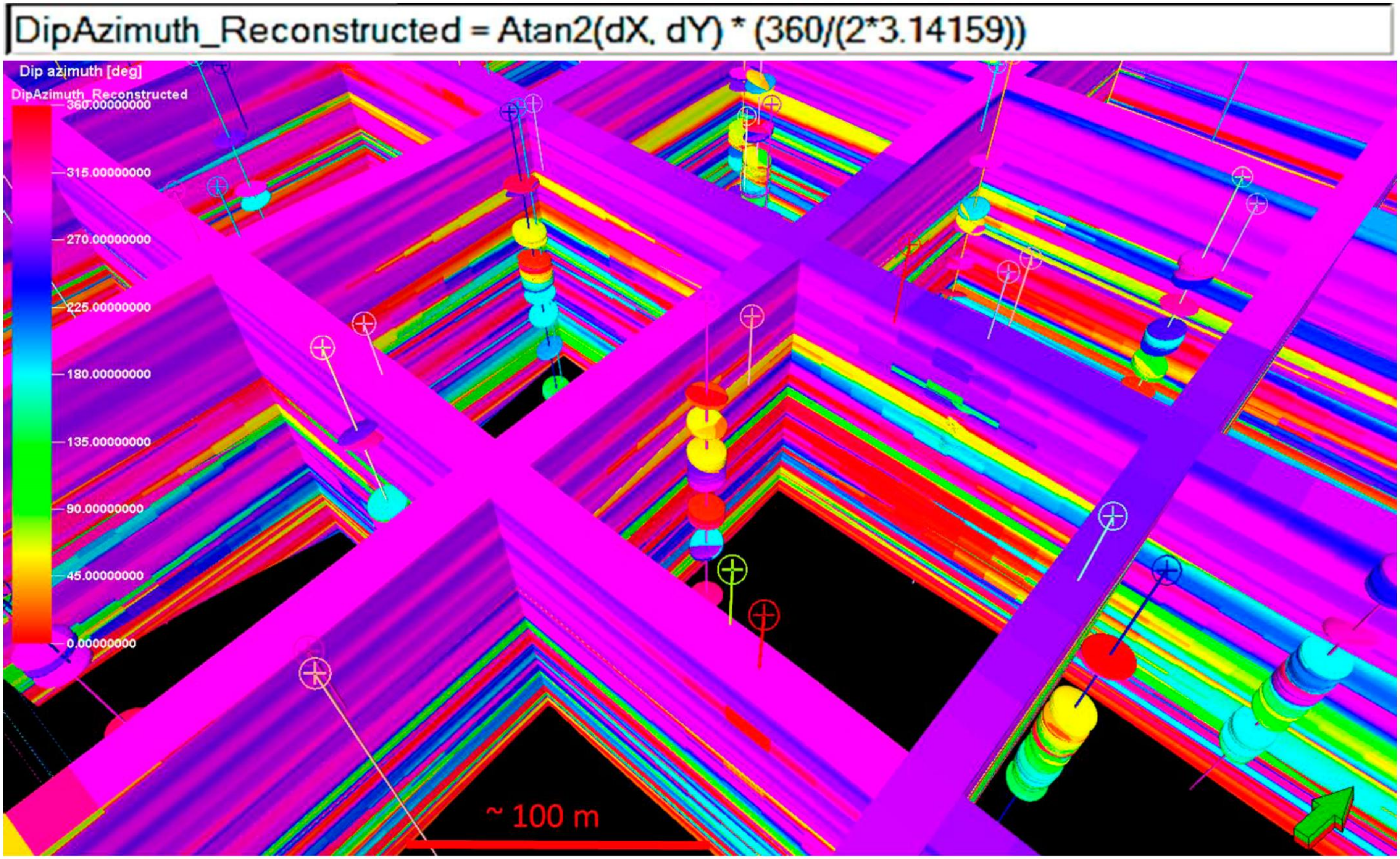

Figure 10. Dip Azimuth model property reconstructed from dX and dY using the arctangent function. Equation assumes trigonometry functions performed in radians.

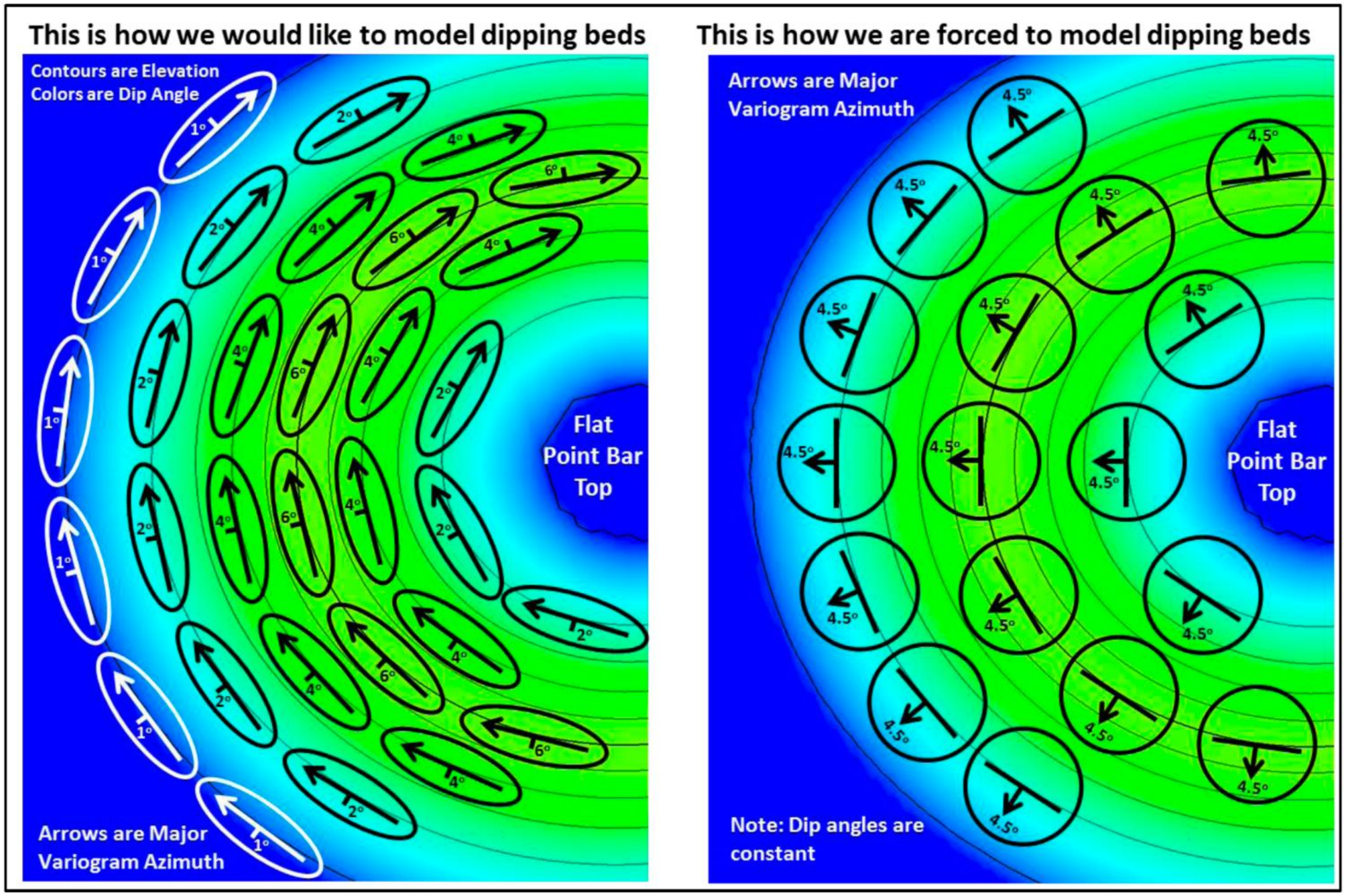

Figure 11. In a point bar, the direction of maximum correlation is horizontal and parallel to the paleocurrent direction (left image). In the dip direction, the correlation length should be shorter, resulting in a variogram shaped like an oval. Also, in cross section view the typical IHS bedding surface is sigmoidal, with the dip angle changing from flat in the uppermost point bar, to steepest in the middle point bar, and flat again in the lower point bar near the thalweg scour surface, so the oval-shaped variograms should dip down in the minor axis direction. The current geostatistical-modeling tool is limited to inclining the variogram only along the major (long) axis. Because we need to incline the variogram at right angles to the paleocurrent direction, and because by definition the minor range of a variogram must be less than or equal to the major range, we are forced to use an isotropic variogram with the "major" axis pointing toward the thalweg of the river system (right image). In addition, the geostatistical-modeling tool allows only the use of a constant dip angle, not a locally varying dip angle volume property. These limitations can be somewhat mitigated by replicating the well data in an array around the well according to the interpolated dipmeter orientations, thus expanding the region of influence of the wells (see Figure 12).

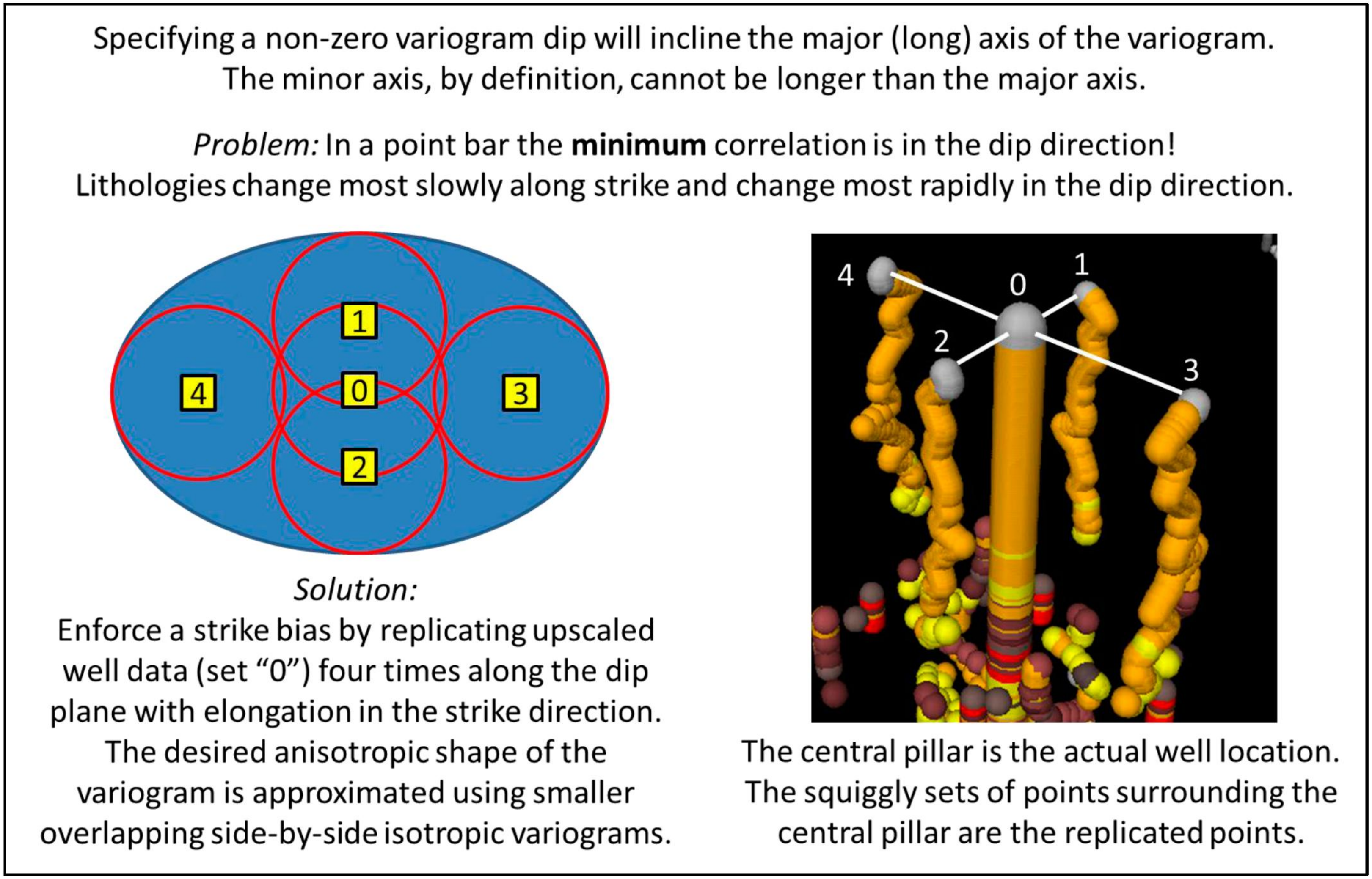

Figure 12. The bed orientations can be enforced by replicating the upscaled well data at four points (sets 1 - 4) around the true well location (set "0") along dip planes defined by the local interpolated dipmeter data. Replicated points along the strike direction (sets 3 and 4) have the same elevation as the true well points. Replicated points in the dip direction (sets 1 and 2) have different elevations that are calculated based on the local dip angle model property. To enforce a strike bias, the strike points are spaced farther from the true well location than the dip points, thus extending the influence of the well data in a plane defined by the local dip azimuth and dip angle model properties. Judiciously chosen isotropic variogram ranges that overlap replicated points will produce a model property that displays a fair approximation of a short-axis dipping variogram (see Figure 13). Replicating the well data at the true dip angle partially compensates for being restricted to specifying a single representative average dip angle to the geostatistical modeling dialog.

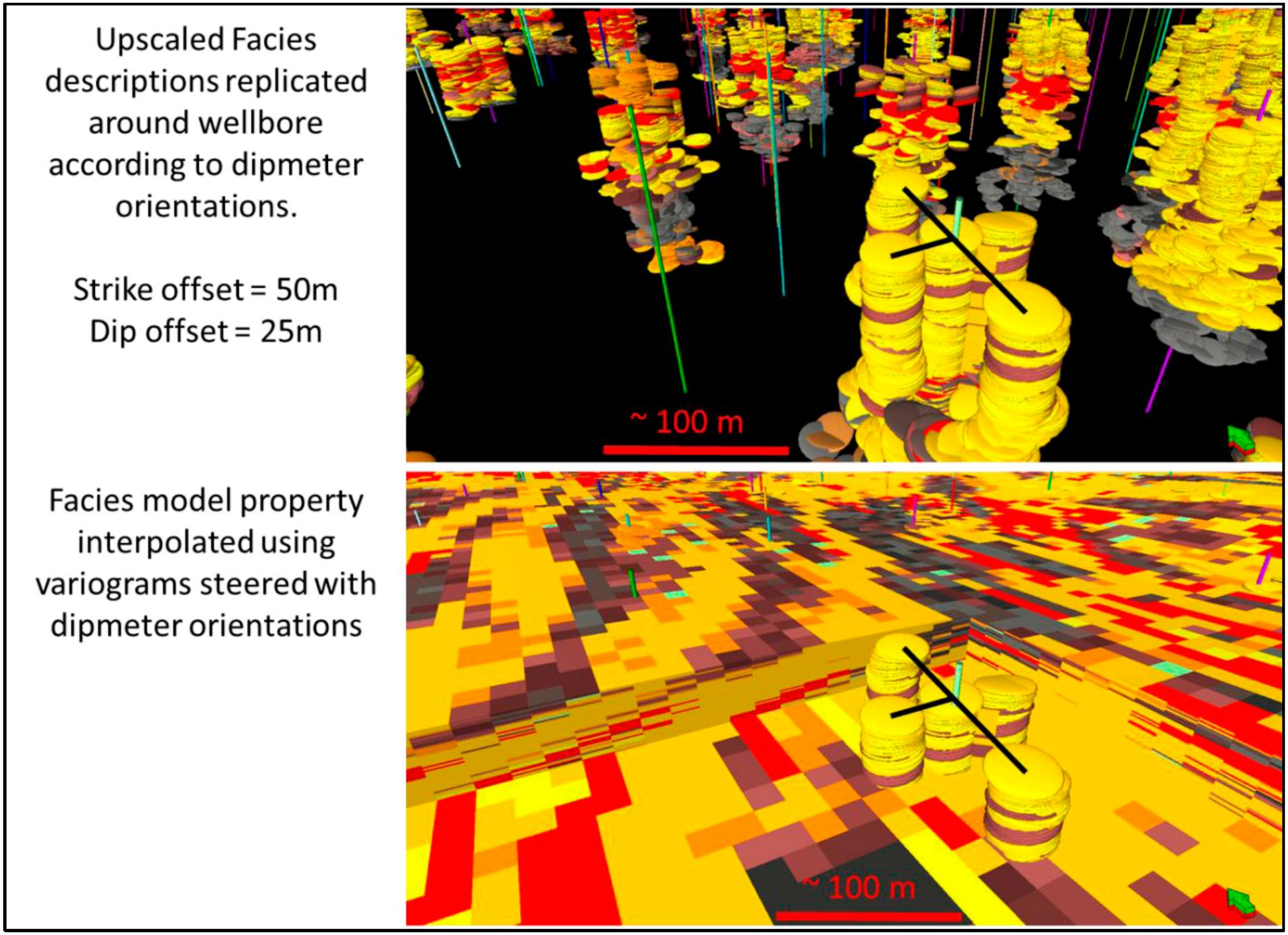

Figure 13. Log and core data is replicated around the well location with Strike Offset = 50m and Dip offset = 25m. This enforces dip direction and elongation in the paleocurrent direction.

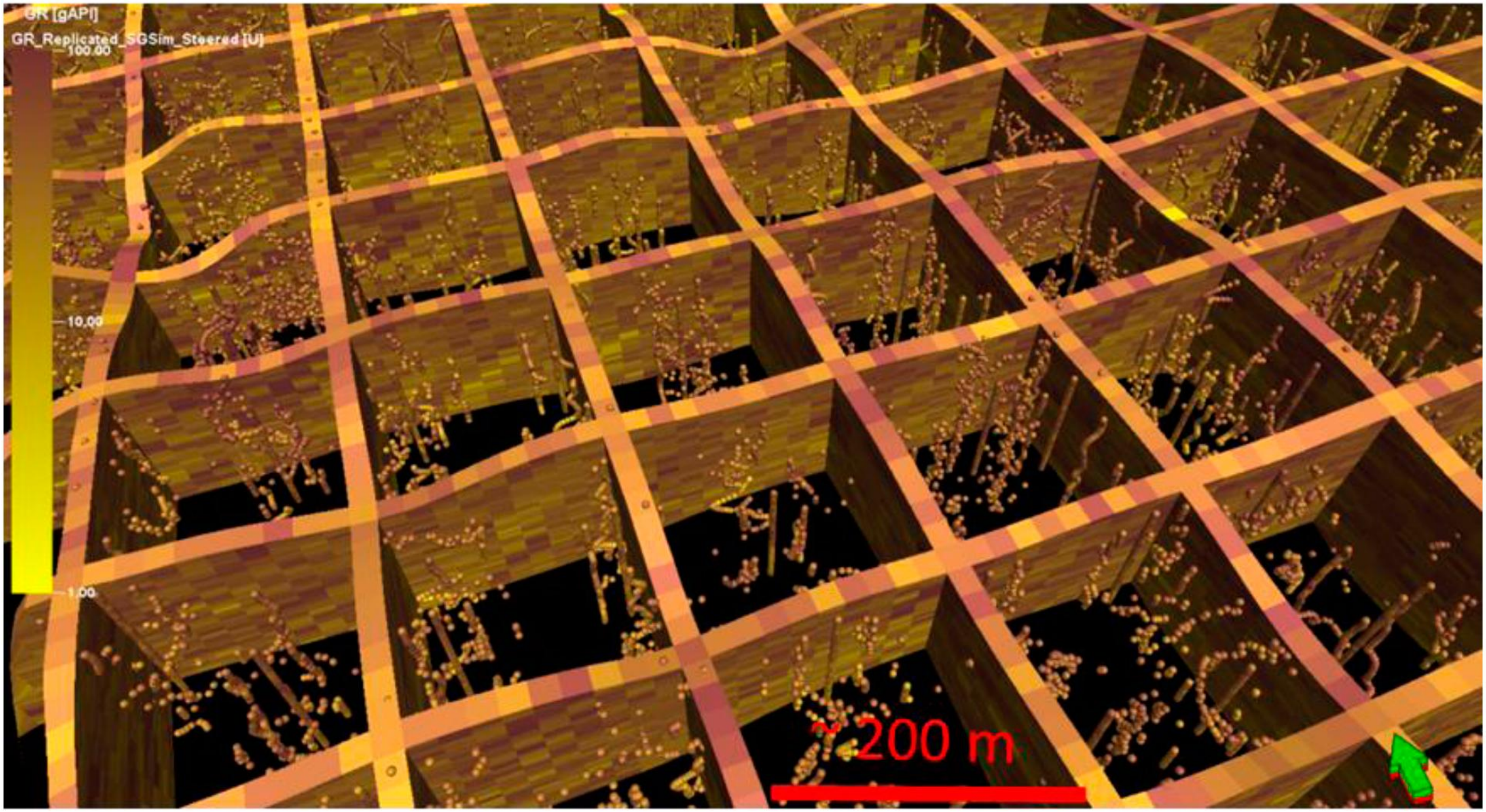

Figure 14. Fence diagram display of a Sequential Gaussian Gamma Ray realization using replicated well log data (small spheres) and dipping variograms. The well spacing required for resource characterization of heavy oil mining operations in McMurray point bars (~125 meters in this example) is approximately equal to the average correlation length of the depositional system.