Geologic Modeling for Highway Construction in ArcGIS

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Paper Abstract

Highway construction requires detailed attention to the geologic, chemical, and geotechnical environment, especially in the case of an interstate highway currently being constructed through the coal-bearing mountains of West Virginia, Virginia, and Kentucky. Since the road design involves excavating hundreds of feet of stratigraphic bedrock, the acid-producing strata and active and abandoned coal mines present particular challenges . Marshall Miller & Associates, Inc. (MM&A) was tasked with identifying potential geologic hazards and creating a baseline geologic model from core hole data. Using the Spatial Analyst extension to ArcGIS and a custom-built lithologic database, MM&A developed a detailed model of the lithologic sequence for use by the entire project team. This presentation will cover the development of the model and the production of exhibits and derivative products.

Paper

Highway construction in mountainous terrain involves extensive geotechnical investigation and a sound understanding of the geologic environment. The numerous cuts and fills that a mountain highway demands become even more challenging when the strata include mined coal seams, as is the case in southern Appalachia.

MM&A, a diversified engineering firm headquartered in Bluefield, Virginia, has used ArcGIS to assist in the creation of a digital geologic model for a major highway project in the Appalachian coalfields. The resulting model is used for a range of applications including design engineering, acid/base accounting, volumetric calculations, and geotechnical characterization of the project site. By customizing and extending the functionality of ArcGIS Spatial Analyst, MM&A's GIS staff has developed an efficient way to interpolate realistic surfaces, even with sparsely distributed data.

Sedimentary Logic

In general, sedimentary rock formations are created by the slow deposition of alternating layers of mud, silt, sand, the remains of plants and animals, or chemical precipitates over long periods of time. Within short distances, the thickness of the interval between one layer and another remains relatively consistent.
Folds, faults, and other structural anomalies can bend and distort the strata in the vertical dimension, but the thickness of each section typically remains fairly constant. What this means for the geologic model is that the structure of any given stratigraphic unit will correspond to overlying and underlying units in a predictable manner.

With a very dense and deep set of borehole data, it is possible to interpolate each stratigraphic layer independently and still derive a reasonable geologic model. Cost and time constraints, however, often allow for only a limited number of the boreholes that penetrate a few stratigraphic horizons at any single location, and each layer must somehow be derived from the underlying or overlying layer as well as its own handful of data points. Fortunately, in the present study, very detailed data was available for one of the layers comprising the geologic model.

The Datum

Abandoned and active coal mines across the project area can be a nuisance, but they also provide valuable geologic data. One coal mine in particular had a dense array of elevation measurements across it, and these data points were used to interpolate a detailed surface for that seam, hereafter referred to as S_1.

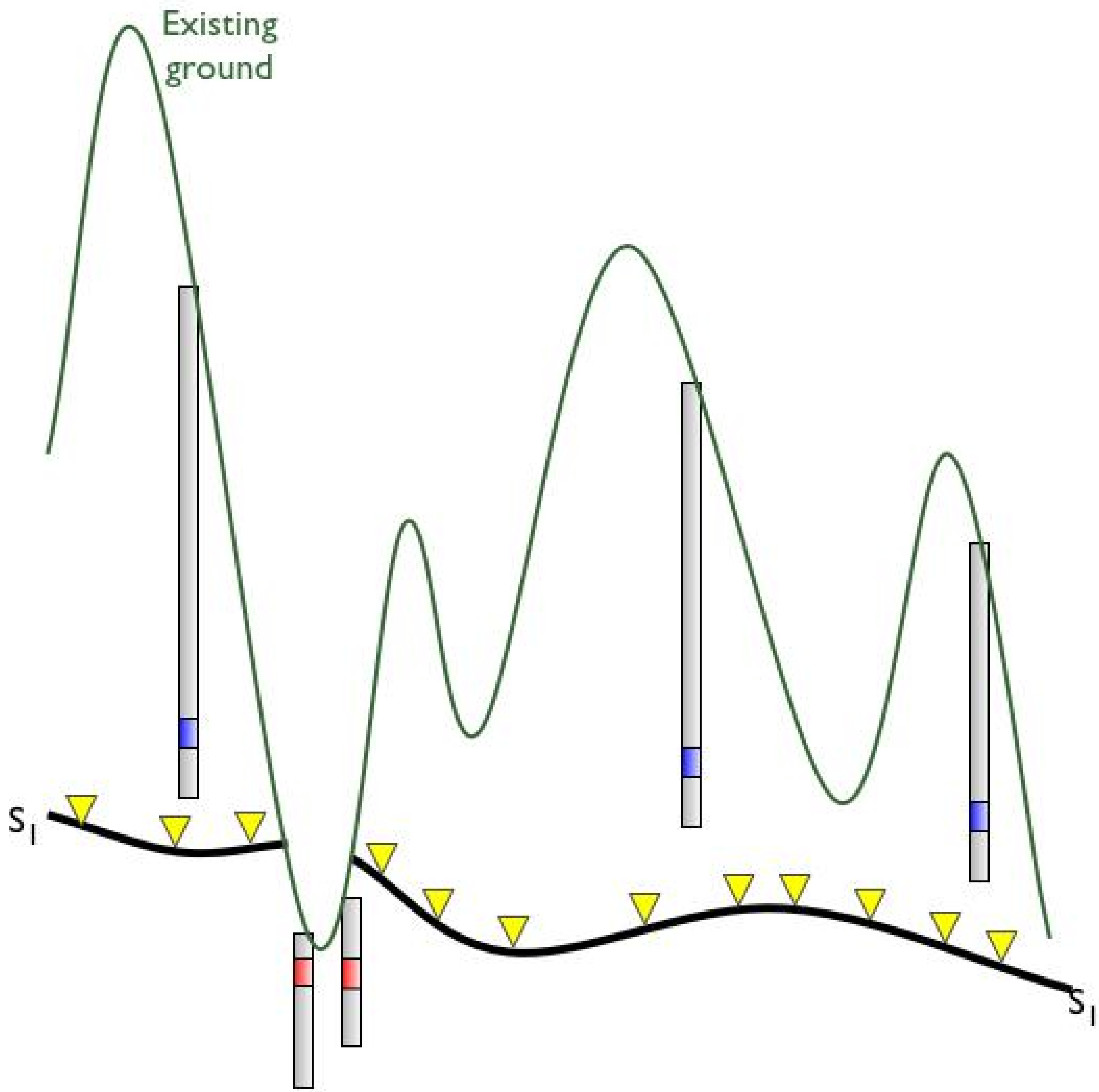

Fig. 1: A heavily-mined coal seam provides dense elevation data.

The detailed model of S_1 will define and constrain all of the deeper and shallower strata to be modeled, even if very few of the boreholes actually penetrate the datum coal seam. Using the datum as a baseline, every other layer, no matter how sparse its data points, can be tied to the detailed structure of the datum horizon.

Interpolation

Each hole drilled indicates the elevation of the penetrated strata within that hole, but sparse data points cannot depict the undulations of the entire geologic sequence.

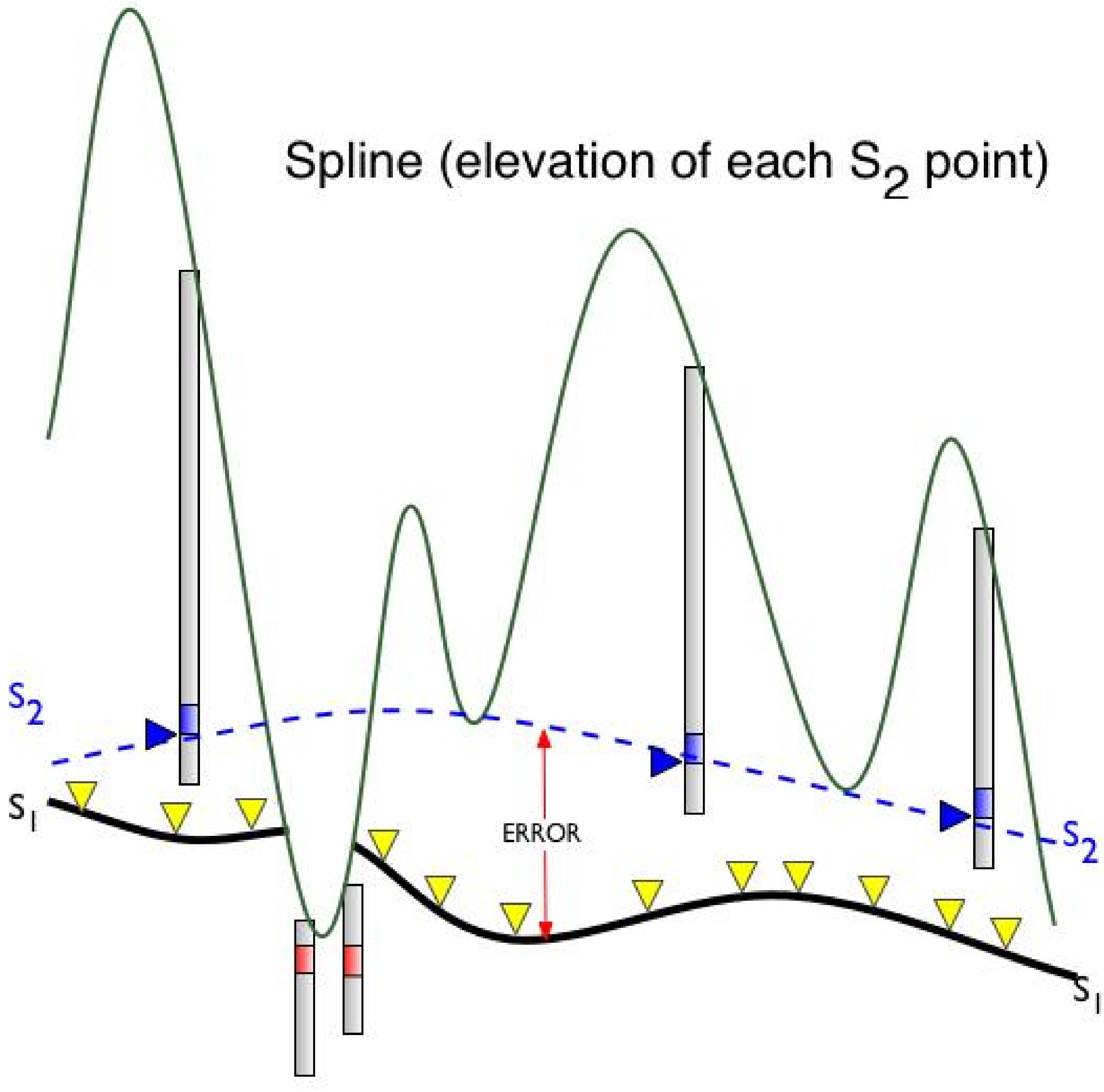

Fig. 2: Independent interpolation fails to reflect the regional structure.

Rather than interpolating each surface independently, it is necessary to interpolate the interval to the previously defined horizon. This iterative process begins with the first horizon above the datum S_1, and continues all the way up to the highest strata of interest.

For each horizon, all of the known base elevations are overlaid on the previous surface and the vertical distance to that surface is calculated as an attribute. Then, using the Inverse Distance interpolation method, a thickness interval is interpolated across the dataset. This interim thickness grid is added to the previous layer's elevation grid, and the resulting surface becomes the datum for the next iteration. For layers beneath the datum, the same process is used, but the interval thickness is subtracted from the previous seam's elevation.

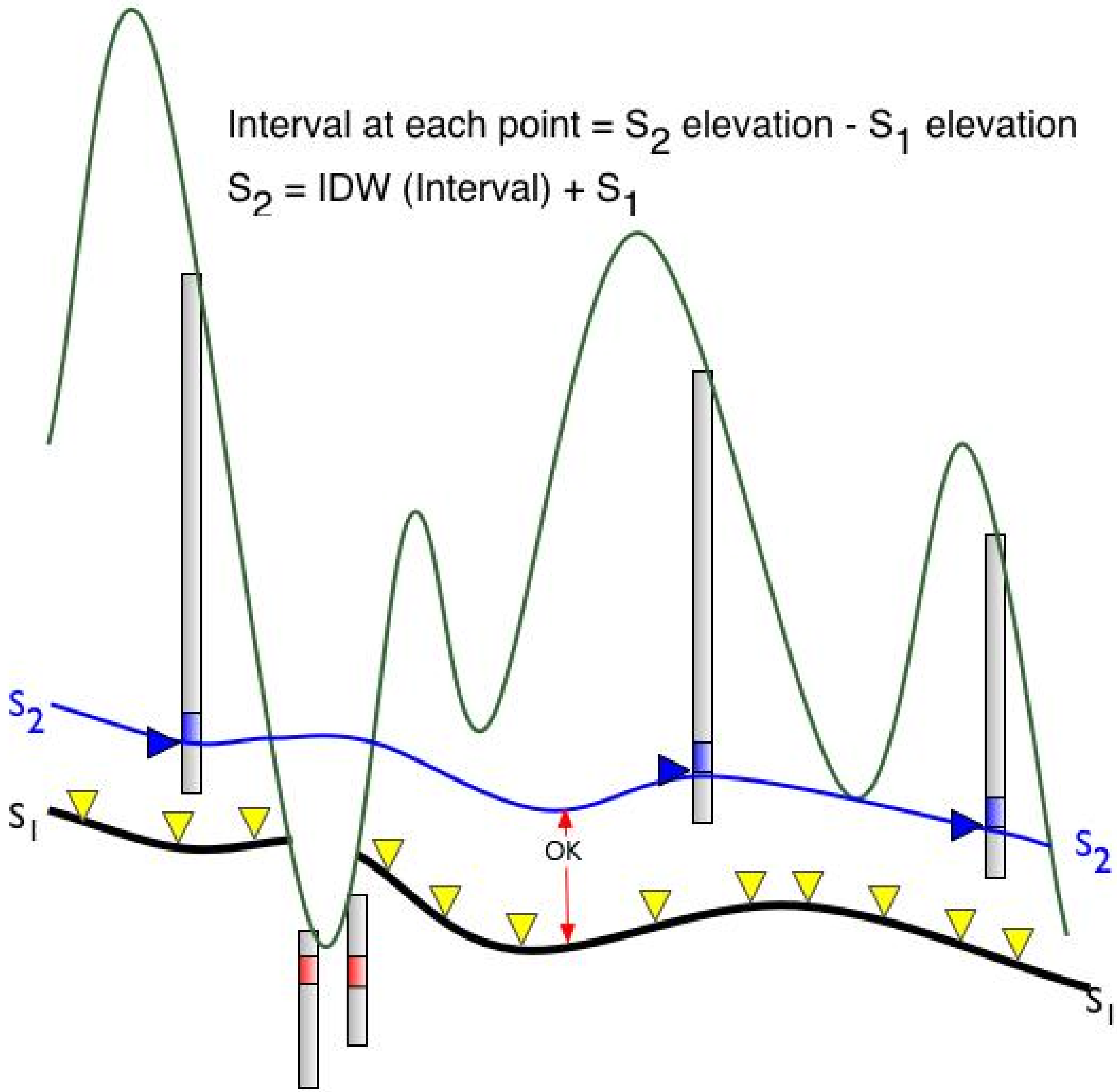

Fig. 3: Interpolating and adding the thickness (interval) grid results in a surface that follows the datum.

Potential Problems

Each layer is modeled with no awareness of the strata above it (or, in the case of a horizon below the datum, underlying it). In the example below, the far left borehole contains no valid elevation for the base of S_2, since the hole terminates before reaching the base of S_2. Meanwhile, the hole's proven top of S_2 appears deeper than the interpolated elevation for the base of that layer, which cannot be allowed in the model.

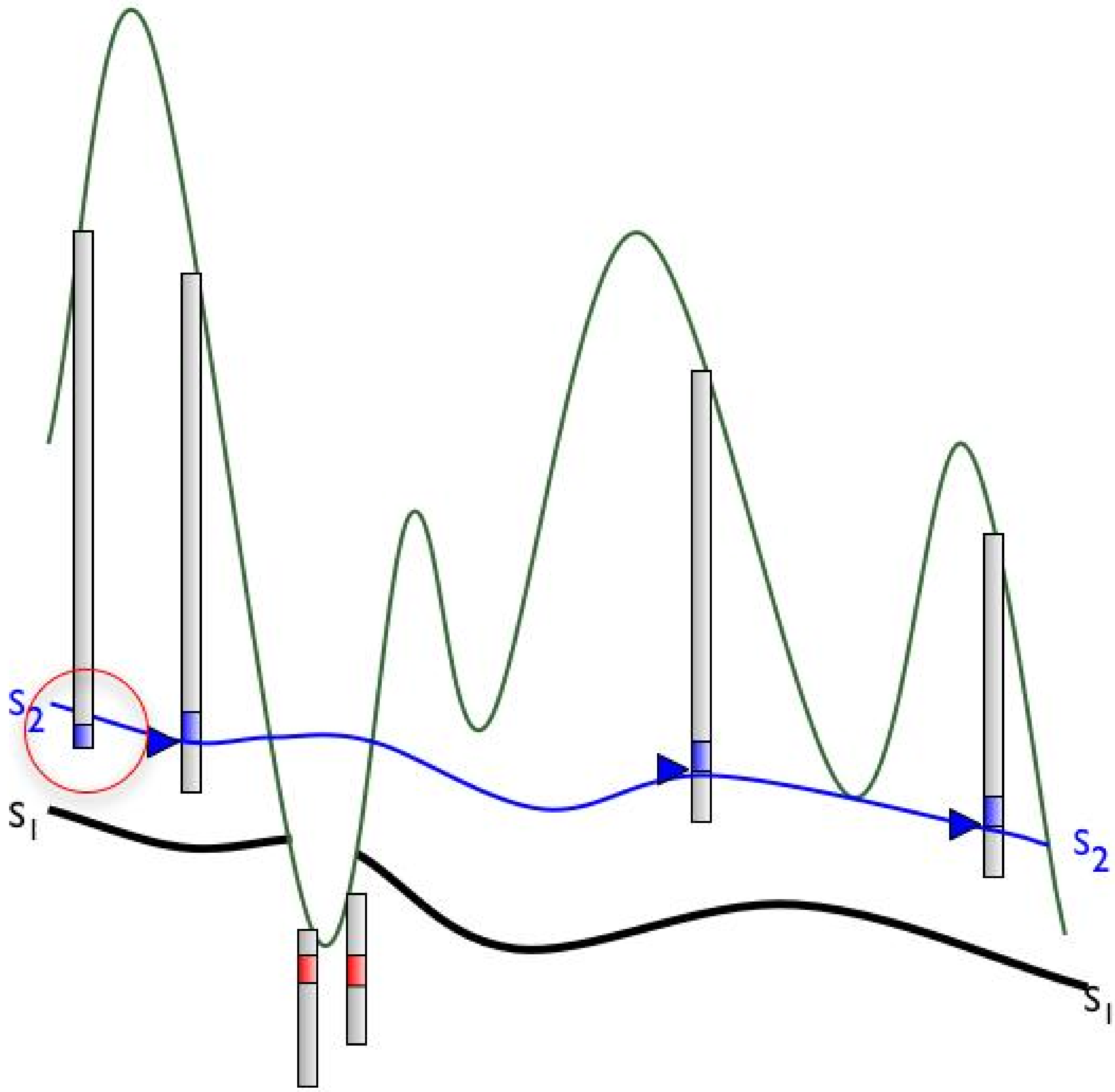

Fig. 4: A borehole shows the top of S_2 below its interpolated bottom elevation.

In these cases, a false data point was added below the terminating depth of the problematic borehole, forcing the deeper horizon to honor the overlying data (see below).

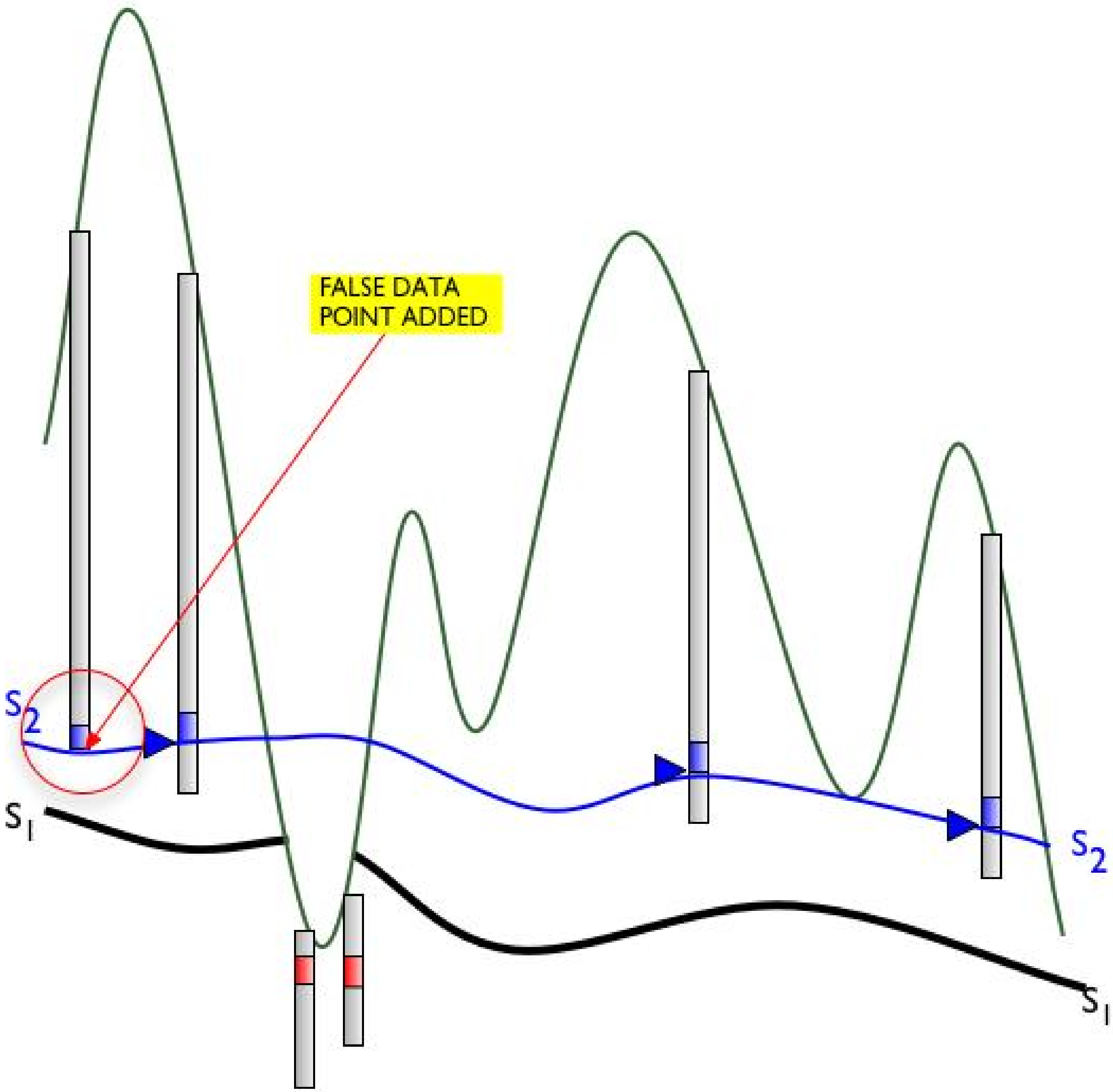

Fig. 5: S_2 has been adjusted to accommodate the overlying data.

After extending the model above and below the datum and confirming its geological reasonableness, each horizon's grid was converted to a TIN and the resulting mass points were exported to text files. This product was then used by various engineering teams to produce cross sections, cut and fill volumes, and other derivative works essential to the road project.

Author Information

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