Update on CBM Modeling Methodology

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A method for modeling multiple thin coal seams containing coal-bed methane (CBM) using a volume function was introduced previously. This note presents the advances and changes in the methodology, as well as further post-processing utilities. The method of modeling coal seams using a volume function has demonstrated favorable results in both geologic realism and computational efficiency. The main focus in the intervening time period has been to increase geologic accuracy while maintaining computational efficiency. To accomplish this, changes have been made to both the data preparation process and the modeling algorithm. These changes include improved log interpretation, removal of the indicator calculation step, dynamic vertical search, and variable volume function cutoff. Additionally, further methods of post-processing the model have been developed including the calculation of geo-objects and determination of connected volume. This note will not include a thorough review of the volume function modeling method. For this, the reader is referred to the Centre for Computational Geostatistics (CCG) Report 9: pg 108-1.

Review of Volume Function Method

The volume function method of modeling geologic phenomena aims to precisely locate facies boundaries. The method is limited to two distinct facies: 'net' and 'non-net.' Multiple stratigraphic facies must be modeled one at a time. The limit of two distinct facies makes the method particularly amenable to modeling coal. The method is able to take raw well data, create a volume function variable, and model this volume function in three dimensions.

The first step in the methodology, after the appropriate wells have been gathered, is to create the volume function data. This is done by applying a cutoff(s) to the log data to locate facies boundary elevations at the well locations. One or more logs may be used to determine the boundary elevations. Once the boundary elevations have been located, the volume function can be calculated. The term 'volume function' (VF) is defined as the distance to the nearest interface where the interface is defined as the surface separating two distinct domains. The VF distance can be negative or positive depending on whether the location is inside or outside a given facies. The surface is defined by all locations within the accumulation limits where the VF is valued at zero (McLennan, 2007). The calculation of the VF creates a three-dimensional VF dataset. The total thickness of coal is also determined from the logs for each well creating a two-dimensional thickness dataset.

The modeling algorithm uses both the thickness and the VF in the determination of boundary elevations. The following takes place at an aerial location: the thickness is estimated using global kriging (Neufeld, 2005), the column of VF values are estimated and the resulting thickness determined, the two thicknesses are compared and the VF cutoff adjusted until the thicknesses agree, the resulting boundary elevations are recorded. This is performed at every location and results in a model of boundary elevations. This boundary elevation model can be plotted using `pickselplt` and gridded using `grid_picks` for use with more conventional cell-based geostatistial software.

Updates to the Modeling Process

As mentioned, advances in both geologic realism and computational efficiency have been achieved. The improvements relating to VF calculation, VF modeling, and post-processing are described.

One improvement has been the addition of flexibility regarding log interpretation. The early version of the process took into account only one log, namely, the gamma ray log, in the determination of facies boundary elevations. This was deemed insufficient for practical use. As such, the method whereby facies boundary elevations are determined has been expanded to enable the consideration of multiple well logs. These logs, as well as their cutoffs, are specified by the user. As many as 15 logs can be used to determine the boundary elevations. This flexibility allows boundary elevations to be determined for any geological layer; it is not limited to coal.

To determine a facies boundary elevation, at each sample elevation the value of each log is compared to its cutoff. If every log is on the 'net' side of its cutoff, that location is considered 'net.' A boundary elevation occurs between two sample elevations where the facies changes from 'net' to 'non-net', or vice versa. The elevation is precisely determined by linearly interpolating using the log(s) that changed from 'non-net' to 'net' (or vice versa) (see Figure 1).

Another improvement to the modeling process is the removal of the 'indicator calculation' step. Previously, an indicator would be calculated from the well log and this indicator would then be used to calculate the VF. This not only added an extra step to the process, but also eliminated the ability to precisely locate the boundary elevations by linear interpolation. The VF is now calculated directly from the boundary elevations taken straight from the well logs in one step. This change has improved both geologic realism and computational efficiency by removing an unnecessary calculation step and more precisely locating the geologic boundaries. The program `vf_any` (previously `faci_dist`) has been created to do this. It has been set up to calculate the VF directly from a raw well log. The user inputs parameters which assist the program in interpreting the header of the log, extracting information such as Unique Well Identifier (UWI) and collar elevation. This program outputs a file containing the 3-D VF data as well as a file containing 2-D thickness data.

The VF modeling process is only suitable for naturally stratigraphic or stratigraphically transformed data. Experience has shown that a suitable choice of datum can have a significant impact on the quality of the final model. Experience has also shown that it may be desirable to model within a certain stratigraphic zone. To enable these abilities, the `vf_any` program has the option of creating zonal data and straightening using some datum. The first option writes out only the VF data that falls within a zone as well as the thickness of the geology of interest within the zone. This zonal data can then be used as input to the modeling program to model strictly within the desired zone. The second option adjusts the elevations of the data such that the elevation is zero at the datum surface.

In the early stages of zonal modeling, artifacts were observed at the top and bottom edges of the model. Further investigation revealed that these artifacts were due to two factors: decreasing VF values towards the zone boundary and zonal VF data not reaching the zone boundary. To correct these issues, the `vf_any` program was modified to write out improved zonal data. To ensure that the VF data reaches the extents of the zone, the user specifies a minimum VF value. The VF data is then extended until this minimum value is reached. This ensures that the VF data will extend well past the top and bottom of the zone (Figure 2). The other modification that improves zonal VF data is the adjustment of the VF data to be always increasing towards a zone boundary. There are instances where a coal seam in an adjacent zone may be causing the VF data to be decreasing as it leaves the zone. This issue has been corrected by finding the local VF maxima closest to the zone boundary and increasing the VF data towards the zone boundary as shown in Figure 3. These modifications have eliminated the artifacts that previously arose when modeling by stratigraphic zone.

Two improvements have been made to the VF modeling program `coal_picks`: a variable VF cutoff and a dynamic vertical search.

The vertical search is an important parameter. It was previously specified as a standard deviation and the number of standard deviations. This allowed the data to be weighted according to a normal distribution based on their elevation relative to the location being estimated. It was observed that too large a vertical search would clump the coal together instead of matching the data as it should (see Figure 4). Best results were obtained using a small vertical search. It was also desired to have the vertical search determined automatically. Different data-dependent parameters were experimented with including minimum seam separation distance, maximum seam thickness, and minimum seam thickness. These values can be calculated for each well and then modeled the same as total thickness is modeled. Experiments showed that the minimum seam thickness value gave the best modeling results as this was the narrowest of the three experimental parameters. As such, the program now models the minimum seam thickness at every aerial location and uses this value as the vertical search standard deviation. Twice this value (two standard deviations) is used as the vertical search limit. The data are weighted based on their elevation relative to the location being estimated.

Another observed shortcoming with the models was the missing thin seams as seen in Figure 5. The wells show that there should be coal at locations where none has been modeled, while the thick seams have been inflated. This inflated thickness should be showing up as the missing thin seams. Investigating this issue revealed that local VF minima were greater than the value of the VF cutoff where thin seams should have been located. Since the cutoff was lower, no seam was modeled there. This is shown in Figure 6 along with the implemented remedy. To fix this problem, the cutoff is found which identifies the greatest number of seams. The cutoff is then reduced until the thicknesses match. If a seam would be missed by reducing the cutoff, the cutoff is not changed for that seam, thus retaining the seam at that location. When the thicknesses match, the thin seams are now retained as shown in Figure 7. This modification and the dynamic vertical search are implemented in `coal_picks_vc`.

Post-Processing

Being able to use and extract results from the model is an important step. The plotting program `pickselplt` and the gridding program `grid_picks` have not been changed, other than to fix a few known bugs. The advances in post-processing relate primarily to connected volume determination. This is the process whereby the volume of coal that is connected to a well is determined for different well densities. The first step in this process is to run the `geo_obj` (Deutsch, 1998) program on the gridded proportion model produced by `grid_picks`. The `geo_obj` program determines which geological modeling cells are connected in three dimensions. These connected three-dimensional bodies are called geo-objects. Once the geo-object model is created, it is sampled at varying well densities (Figure 8). The geo-objects are then categorized according to the number of times they are intersected by a well. There are three categories, or types. Type I are those geo-objects that are intersected more than once, Type II are intersected once, and Type III are not intersected. Types I & II taken together constitute the connected volume. Each type is divided by the total volume of coal to get the connected fraction for each. The connected fraction is then plotted vs. well density to observe how connected the model is (Figure 9). This is useful for determining the number of wells needed to exploit the resource.

Conclusion

Modeling using a volume function is a promising method for building models of stratigraphic phenomena such as coal. These advances discussed further improve the method in both geologic realism and computational efficiency.

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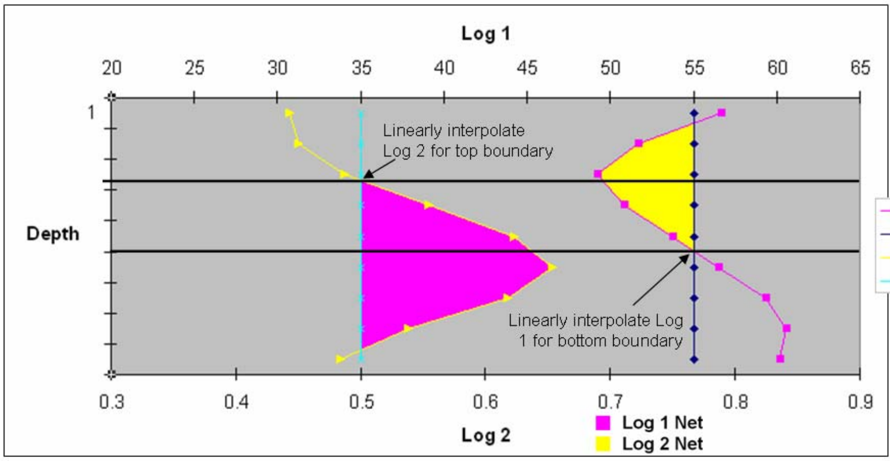

Figure 1: Multi-log facies boundary elevation determination.

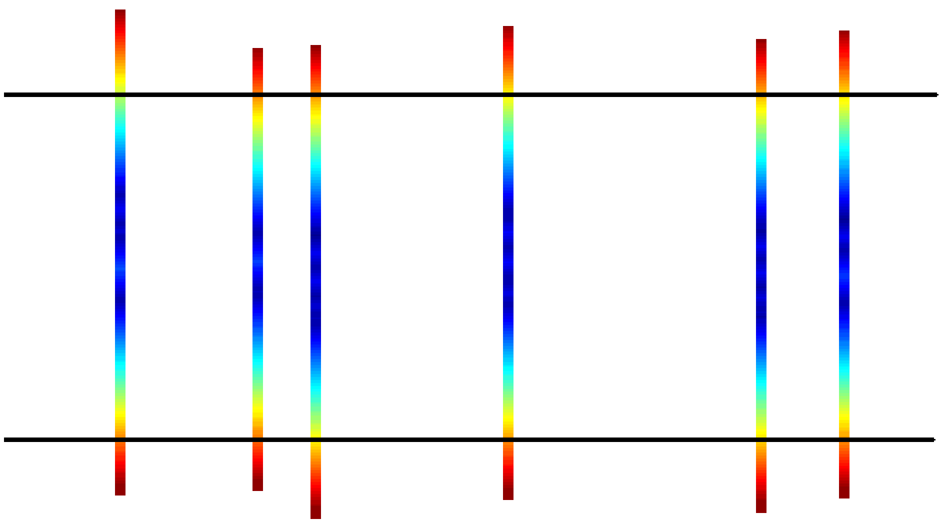

Figure 2: Artifacts are eliminated when the VF data extends past the top and bottom of the zone.

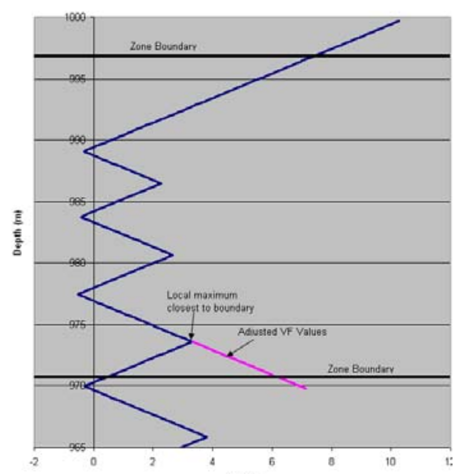

Figure 3: VF values are adjusted to be increasing towards the zone boundary and are extended past the zone boundary until the minimum VF threshold is reached.

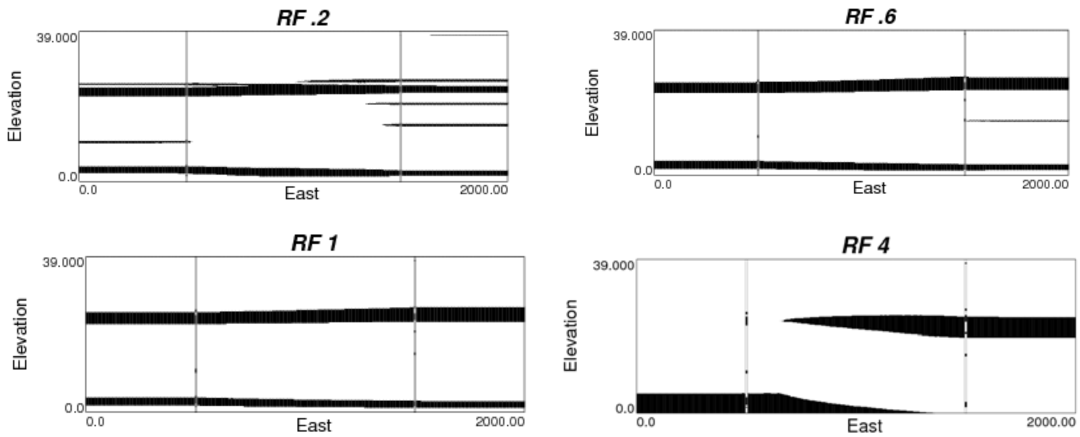

Figure 4: Differences in model due to different vertical search (same slice for each).

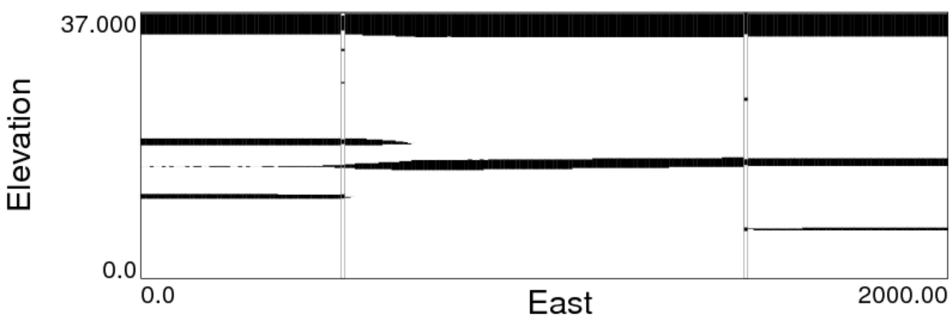

Figure 5: Thin seams being missed and coal ending abruptly at well.

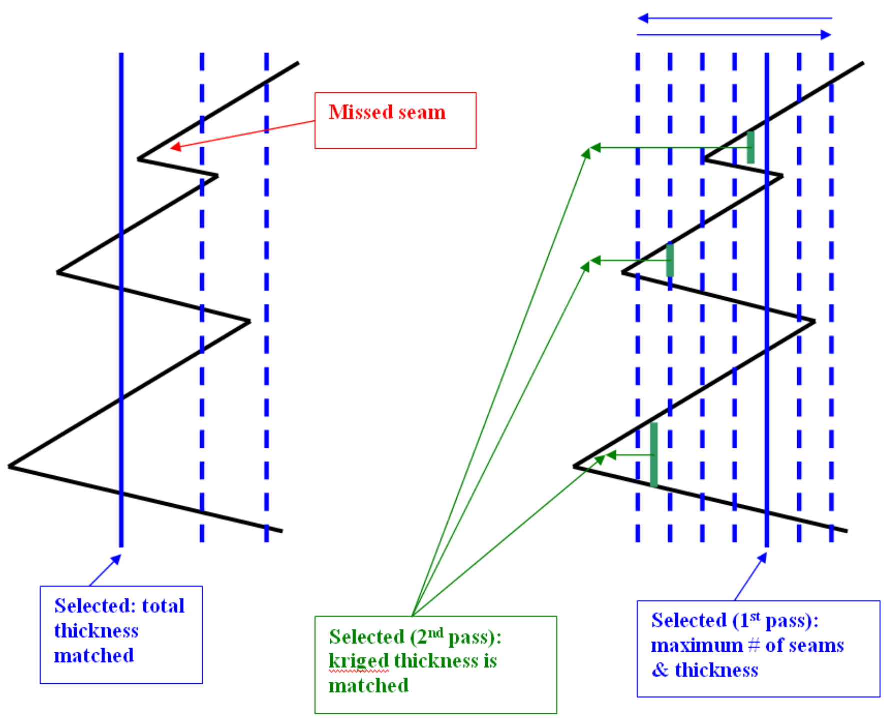

Figure 6: Variable VF cutoff keeps the thin seams from being missed.

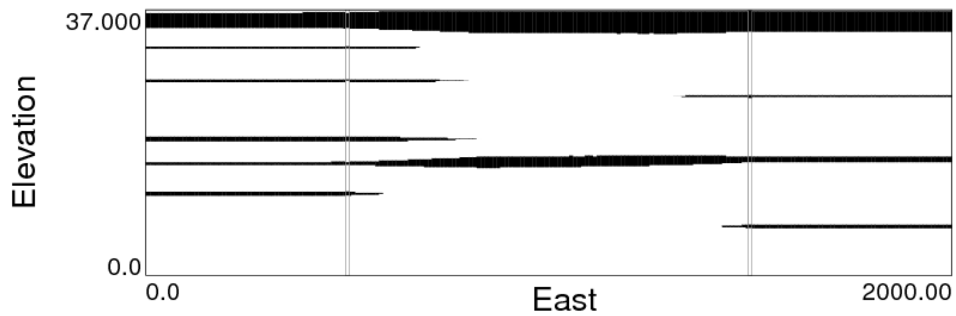

Figure 7: Thin seams are retained when variable VF cutoff used.

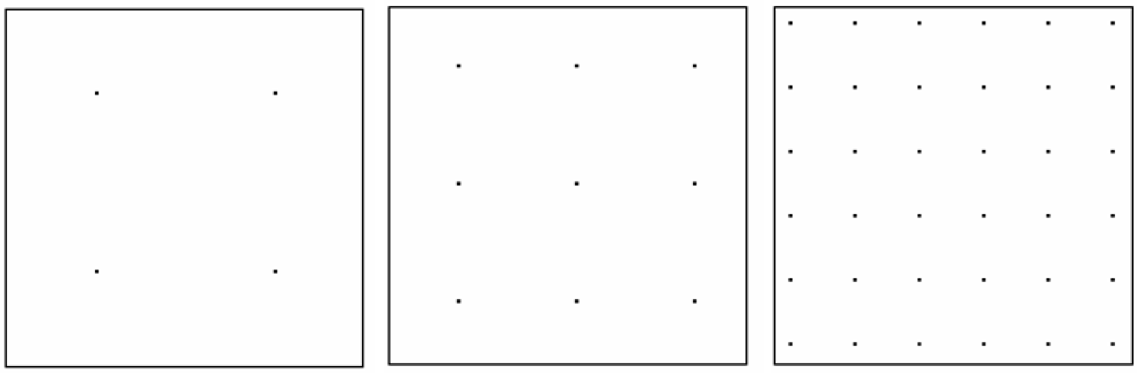

Figure 8: Various well densities used to determine connected volume.

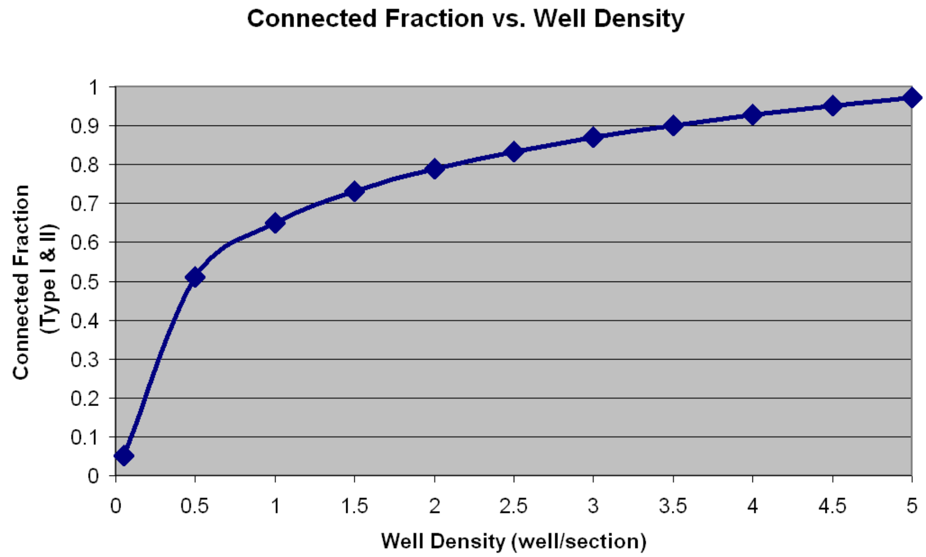

Figure 9: Graph of connected fraction vs. well density.