A Case Study of Coal Resource Evaluation in the Canadian Rockies Using Digital Terrain Models

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BACKGROUND DESCRIPTION
The Problem

The purpose of this study was to evaluate the large-scale structure, and hence available reserves, of the Lower Cretaceous Luscarr Formation near Mountain Park, in the Foothills of Alberta.

Coal resource evaluation clearly requires information on the mineable tonnages, as well as the grade, of the coal strata. In open pit mining, the volume of coal economically extracted from a seam is directly related to the amount of overburden that must be removed in order to expose the coal. This may very conveniently be expressed as an "overburden ratio" map, a contour map of the ratio of the overburden thickness divided by the coal seam thickness at the same location. While the cutoff value for economic recovery varies due to many factors, it is relatively uncommon for coal with a ratio of greater than 10 to be economically mineable. The overburden ratio map may thus be of value in coal reserve estimation.

The construction of an overburden ratio map requires three components: a topographic model, a model of the top of the coal seam, and a model of its base. In this study the coal seam was fairly consistent in its thickness (about 30 feet) and therefore no model of the base of the coal seam was needed for thickness estimation. With this assumption, the problem became one of producing an overburden isopach, or thickness, map.

The Method
A wide variety of contouring programs have doubtless been used by geologists to construct isopach maps. Most of these programs require the generation, from the irregularly spaced data, of a regular grid of estimated values. The most common procedure would be to extract the thickness information directly from each sampling or drill hole location by subtracting the elevation of the bottom contact of the geological unit from the elevation of the top contact. The thickness values at each data point are then contoured by estimating the values at each node on a grid, and interpolating contour lines within each grid square.

While this approach produces a reasonable map where the geological unit is continuous, shortcomings become apparent when the stratum is absent in places. In particular, the zero thickness contour line is frequently implausible. This is the result of contouring a computer-generated grid with zero values in regions where the unit is absent and positive values elsewhere. The interpolated zero contour will therefore follow the grid square edges.

It is clear that the thickness "model" is inadequate and that zero thickness is not necessarily an adequate description of the absence of a geological unit in a particular location, especially if the absence is due to the erosion of pre-existing material. It is therefore more correct to consider an isopach as a map of the difference in elevation between two complete topographic models, one of the upper contact and the other of the lower contact of the geological unit. With this approach, negative values are legitimate and problems with the zero isopach line disappear.

DESCRIPTION OF THE METHOD
In the current application two models should be defined separately and used in combination to produce the overburden ratio map. These two models are the topographic surface model and the geological structure model.

The Topographic Model
In order to generate a topographic map, one needs to have access to both elevation data and a suitable combination of computer software and hardware to generate the model. Available hardware for this project included an Amdahl 470/V6 computer and a Calcomp plotter.

Figure 1 shows the topographic map generated for the study area. Available data were of three types — surveyed values at the site of drill holes; outcrop locations taken from air photos, with the elevations taken from topographic maps; and data regularly spaced on a coarse grid overlaid on the topographic maps. The quality of this data also clearly varied with its type. The surveyed data was accurate to within less than a foot and tended to be clustered in distribution. The outcrop data due to the nature of the field traverses, tended to occur as strings of surface-specific points (Peucker, 1972) along ridge and valley lines. Elevations were derived from contour maps with a contour interval and approximate accuracy of 5 feet, and a scale of 1:1,200. The grid data was derived from contour maps with a contour interval and approximate accuracy of 100 feet, the difficulty of point location at that scale, and the high relief of the terrain, an error of 500 feet in elevation estimates could occur.

The contouring or modelling system used was the TRIMAP package (Gold 1977, Gold et al. 1977) which operates by breaking the map area up into triangles with a data point at each vertex, estimating the slope at each data point if it is not initially known, and interpolating within each triangle in such a fashion that data point slopes and elevations are honored at the vertices. This is in itself a large potential advantage over gridding methods for contouring, where the necessity of overlaying a regular (and usually relatively coarse) grid over the map area and estimating the elevation at each node usually prevents the elevation, quite apart from the slope, from being correct at each data point. The triangulation approach also has advantages in the processing of strings of surface-specific data points so that they do, in fact, follow ridge or valley lines.
A final point concerns the resolution of the resulting map: unlike gridding techniques, the resolution is a direct function of data point density, since each triangle with data points at the vertices is divided into \( n^2 \) sub-triangles where \( n \) is a selectable resolution factor. Interpolated values are then estimated at the vertices of these sub-triangles for subsequent use in generating individual contour line segments. Unlike global gridding techniques, however, this resolution factor does not affect the pattern of the final map, but merely the smoothness of the interpolated contours.

**Problems Encountered**

The topographic surface was initially generated using the outcrop position data for the region directly surveyed, and, in addition, the gridded data to "pad out" regions of sparse information. Difficulties were immediately encountered. Occasionally, duplicate outcrop points derived from field work occurred, and these were sometimes assigned differing elevations. While gridding methods inevitably smooth the information used, the triangulation approach is normally required to honor each data point and is therefore relatively unforgiving. Errors in the input data are therefore readily detected by the presence of improbable peaks and cliffs on the resulting map; these points were eliminated manually, although, since one of the fundamental properties of the TRIMAP system is the ability to determine the triangle surrounding any arbitrary x-y location (Gold, 1977) and hence the data points forming the vertices, it would be straightforward to construct an interactive program to assist in data point editing.

A second difficulty that occurred was due to the inaccuracy of the background data collected on a grid. While helpful in regions of sparse outcrops, the values frequently showed large discrepancies from the outcrop data where these were present. Grid values were therefore eliminated from the final topographic map. As a general statement, great care must be taken when using data sets with widely varying accuracies.

**Structure Model**

The second surface to be modelled is the top contact of the coal seam under examination. This poses particular difficulties in that most of the data is obtained from outcrops and drill holes along one line — the intersection of the coal seam with the topographic surface. It is therefore necessary to estimate the geological structure (i.e., folding) of the originally flat-lying sedimentary rocks, so as to permit projection of the seam perpendicular to the "trace" of the coal. As in the topographic model, suitable mapping software and computer resources must be available. In addition, geological expertise is necessary to evaluate the geological structures, on the basis of the work of Charlesworth et. al. (1976) and Langenberg et. al. (1977), who discussed the criteria necessary in order to assume the presence of cylindrical folding within a domain — that is, under certain mathematical conditions, a particular portion of the coal seam may be satisfactorily described by a type of folding similar to a sheet of corrugated iron, linear in one direction and undulating perpendicular to this. If the orientation of the desired geological contact has been observed at several locations in the field, this linear direction, called the fold axis, may be determined by the mathematical techniques described in the previously mentioned references. A cross-section may then be constructed normal to this fold axis, and all data points projected onto this "profile."

The irregular folding of the coal seam in two portions of the map area is shown in the profiles of Figure 2. The domains are distinguished by being on opposite sides of a geological fault.

In the absence of satisfactory orientation data, it is possible to estimate a suitable fold axis in a trial and error fashion by examining the profiles generated for each estimate. If a suitable profile can be generated for each domain, it is a suitable description of the geological contact. However, it is described at a different orientation in space than the original map, being perpendicular to the estimated fold axis. Dummy data points may then be generated on the map and rotated into the coordinate system of the profile. Their elevations may then be estimated from the profile, and the resulting points transformed back into the map coordinate system. These values may then be contoured by the methods previously described for the topographic surface (Figure 3).

**Problems Encountered**

While a certain amount of effort was required to implement the methods described above, once implemented they worked very satisfactorily. While the need for skilled geological interpretation caused no concern in this project, it could have done so in other circumstances.
Figure 3. Surface of modelled geological contact of northern (upper) and southern (lower) fold domains (scale in feet). Heavy line shows current outcropping, with existing (non-eroded) strata indicated by shading.
Figure 4. Overburden ratio map of the coal seam in northern (upper) and southern (lower) fold domains (scale in feet). Heavy line indicates the fault of separating domains. Shaded zone indicates the part of the coal seam mineable between ratios of 0 and 10 (unless truncated by the fault).
The final step in the procedure consists of generating the overburden ratio map from the two distinct surface models. The procedure is straightforward: the elevations of the two surfaces must be evaluated at a series of map locations, the elevation of the top of the coal seam subtracted from the topographic surface, the resulting difference divided by the seam thickness, and a contour map produced of the result (Figure 4). These results may legitimately be negative where the coal has been eroded out, although normally only positive values would be contoured. On the basis of the local cutoff point for the overburden ratio, tonnages may readily be determined, either manually off the map or by further computer processing.

The structural modelling techniques used here are described by Charlesworth et al. (1976) and Langenberg et al. (1977). The TRIMAP contouring system is described in Gold (1977) and Gold et al. (1977).

RECENTS
While topographic maps may be produced by a variety of computer-based systems, the TRIMAP system had several potential advantages, including the honoring of all data point values (and slopes, if known) that made it particularly valuable for this project. This ability was convenient when a theoretical structural model was to be generated and placed in the map coordinate system for comparison with the topographic surface. This accurate model placement greatly contributed to the potential accuracy of overburden, and hence reserve, calculations. In particular, reasonable zero overburden thickness contours were readily produced.

In hindsight, the primary aspect of the project that would have been changed was the approach to data collection for the topographic model. More detailed editing of gridded and other data prior to model construction would have reduced project time. While in future projects it is doubtful if the density or accuracy of field-collected data would change significantly, efforts should certainly be made to extract greater topographic information from the best quality topographic maps available, and to collect it along breaks in slope of the topography.

Greater attention to this aspect would have increased the value of the zero overburden thickness contour as a display of the coal seam exposure. If sufficient detail is present, this trace alone, on a topographic map, may provide a valuable illustration of geological structure to the trained geologist.

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REFERENCES


