COAL RESOURCE EVALUATION IN DEFORMED SEQUENCES, USING DIGITAL TERRAIN MODELS

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ABSTRACT

A common task in coal exploration is evaluating reserves by estimating some form of isopach map. Available machine-contouring packages, because of their gridding/contouring sequence, are generally unsatisfactory for this purpose. A different approach considers an isopach map as the difference between two complete digital models of the upper and lower surfaces involved. In addition, whereas a topographic surface can be modelled directly from a topographic map, an outcropping geological surface can be modelled best by using a structural cross section and the fold axis. These methods lead to realistic maps and are illustrated by means of data from the Mountain Park coalfield in the Rocky Mountain Foothills of west-central Alberta.

INTRODUCTION

To evaluate the coal resources of a property, the recoverable tonnage of each seam should be estimated. In open-pit mining this tonnage is directly related to the thicknesses of the coal seam and the overlying overburden. The recoverable tonnage can be found by using an “overburden ratio” map, which is a contour map of the ratio of the overburden thickness to the apparent vertical thickness of the coal seam. The input data required to produce such a map consist of three components; namely, models for the configurations of the topographic surface and the top and bottom of the seam. The area underlain by recoverable coal is outlined on an overburden-ratio map by the zero contour and the “cut-off contour whose value, although dependent on various factors, is usually about 10. Tonnages may be determined manually, by using the overburden-ratio map and the isopach map of the coal seam, or numerically, by means of further elementary computer processing. Where a seam’s thickness and dip are constant, overburden-ratio maps are equivalent to overburden-thickness isopach maps, except that the thicknesses are divided by a constant equal to the apparent vertical thickness of the seam.

Two problems arise when using conventional isopach computer packages to prepare an overburden-ratio map. The first stems from the inadequacy of the input model describing the configuration of the coal seam where the distribution of data points is limited: only in a property with a large number of uniformly spaced drillholes will such a model be realistic. The second problem has to do with the method many packages use to calculate thickness. This method generates a regular grid of estimated elevations of each surface from an input of irregularly spaced elevations, subtracts the estimated elevations of the two surfaces at each grid point, and uses the resulting grid of estimated elevation differences as input to the contouring procedure. Although this approach produces a reasonable map where the geological unit is continuous, shortcomings become apparent where it is not, as is the case, for

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example, where a coal seam crops out in a property. In such a case, where the grid of estimated thicknesses contains zero values, the zero contour, so important in calculating recoverable resources, assumes an unrealistic rectilinear pattern because it lends to follow the boundaries of the grid squares. For the two reasons cited above, the conceptual model used by available isopach computer packages is likely to be inadequate in many instances.

The problem is thus how to develop a computer-based method for constructing isopach maps that will produce a realistic model of a coal seam from sparse, irregularly spaced input data, and that will draw a smoother, more realistic zero contour (i.e., model the edges of the seam more plausibly). One such method is described below. In the final part of this paper the method is applied in part of the Mountain Park coalfield of west central Alberta.

THE METHOD

General Principles

One reason why most contouring packages give unsatisfactory overburden-ratio maps is because zero thickness is not necessarily the best way of describing the absence of a geological unit, especially where this absence is caused by erosion. The approach we follow is to consider an isopach map as the difference in elevation between complete models of the two surfaces involved. Viewed in this light, the model for, say, the top of a coal seam cropping out in a property should consist of both eroded and uneroded segments. With this approach, negative values are legitimate and problems with the zero isopach disappear.

The first step is to model the topographic and geologic surfaces from inputs of irregularly spaced elevations. The method of modelling we prefer divides the map-area into triangles, with an input elevation at each apex, and estimates the slope at each apex if it is not initially known (Gold, 1977; Gold et al., 1977). The apices of all triangles are then used as input to the contouring process. A major advantage of this system over normal gridding methods is that it does away with the necessity of having a regular and usually coarse grid of derived data points, at each of which the estimated elevation, to say nothing of the slope, is likely to be inadequate. Nevertheless, although we regard the “triangulation” method of modelling surfaces as superior to normal gridding methods, for the purposes of preparing overburden-ratio maps the latter may be used if preferred.

The next step consists of using the component models to generate two isopach maps, one for the overburden on top of the coal seam and the other for the coal seam itself. For each isopach map this is carried out by estimating the elevations of the two surfaces involved at a series of map locations covering the entire area, and subtracting one series of elevations from the other. The overburden-ratio map is derived by dividing the series of overburden thicknesses by the series of apparent seam thicknesses measured vertically, and contouring the resulting series of values. In those areas where the seam has been eroded, its modelled elevations are greater than those of the topographic surface, and contours on the resulting overburden-ratio map have negative values; these contours can easily be suppressed in the final map.

Modelling the Topographic Surface

To model the topographic surface, its elevation should be sampled at a series of points whose spacing depends on the relief and required accuracy. Care should be taken to have elevations along conspicuous breaks in slope. The best way of obtaining such a sample is to use a detailed, accurate topographic map with a contour interval of 25 ft (7.5 m) or less.

Modelling a Geological Surface

Complete models for the upper and lower surfaces of a coal seam cropping out in an area are more difficult to construct, in that most input data points are either outcrops or nearby shallow drillhole intersections; and, of course, no elevations are available for the eroded segment of the seam. In order to estimate the configuration of the seam throughout the
property, its configuration along the outcrop has to be estimated from the available elevations and then projected into the remainder of the area. Before looking at how this is done, let us examine the rationale of the procedure.

Studies the world over indicate that layers such as coal seams in deformed sedimentary terrains like the Canadian Rocky Mountains can be compared to sheets of corrugated metal, the axes of the corrugations being parallel to what is known as the fold axis. Whereas the orientations of strata vary considerable when traced across the corrugations, they tend to remain remarkably constant when followed parallel to them. Some areas, known as domains, are structurally simple in that they contain just one set of corrugations or cylindrical folds with a single fold axis. In other areas, the folding is more complex and can be thought of in terms of corrugated sheets that are not planar but gently warped. Even here, however, the warped sheets can be treated as a series of planar segments welded together, each segment with an orientation slightly different from that of its neighbours, but with corrugations that are continuous with those in adjacent sheets. Thus, if a property consists of a single structural domain with one fold axis B, a series of closely spaced points along or near the outcrop of the coal seam can be projected parallel to B, to produce a complete three-dimensional model of the seam. Where two or more domains are present, the procedure is similar and only slightly more complicated (Langenberg et al., 1977).

The first step in constructing the complete model or structure-contour map for, say, the top of a coal seam is to divide the area into as small a number of domains as possible and determine the orientation of the fold axis in each. This can be done by using the orientations of bedding at outcrops (Charlesworth et al., 1976), or by trial and error by using the coordinates of points on the top of the coal seam (Kilby and Charlesworth, 1980).

Once the fold axis B has been found, the second step is to take the known points on top of the seam in the associated domain and project them parallel to B onto a vertical plane perpendicular to the trend of B. The projected points on this plane are then used to interpolate a complete structural cross section of the seam top. The three-dimensional model for the top of the seam can be thought of in terms of a series of lines parallel to B, drawn through closely spaced points on this cross section.

The third step is to take each point used to model the topographic surface and find the distance it is above or below the three-dimensional model for the top of the coal seam. This is done by projecting each "topographic" point parallel to the fold axis onto the plane of the structural cross section, and determining the vertical distance between the projected topographic point and the trace of the seam top. This vertical distance is then subtracted from or added to the elevation of the topographic point, to generate a new point for the model of the top of the seam. The resulting set of points provides a complete digital model for the seam top throughout the domain. Where more than one domain is present, the models for the various domains are grouped, to give a complete model for the entire property. All the above procedures can be carried out by the computer.

EXAMPLE FROM THE MOUNTAIN PARK COALFIELD

The method described above was applied in one area of the Mountain Park coalfield in the Rocky Mountain Foothills, 320 km west of Edmonton, Alberta (Fig. 1). The major aspects of the geology of the coalfield have been described by Kilby (1978). The coal seam studied was the Kennedy (Jewel) seam in the Lower Cretaceous Luscar Formation. Because the seam's thickness remains essentially constant at about 11 m and the dips are fairly uniform, the problem of preparing an overburden-ratio map could be reduced to constructing an overburden isopach map for the seam. To do this, models for the topographic surface and the top of the coal seam were generated.

Computerized data on the topographic surface near Mountain Park were available in the form of outcrop and drillhole-collar coordinates. The collar coordinates had been surveyed.
and were accurate to about 0.1 m. Outcrops had been located initially on aerial photographs and subsequently transferred to topographic maps from which the coordinates were obtained. The area studied was covered by a 1:10,000 topographic map with a contour interval of 10ft (3 m), so the coordinates of outcrops falling within this area are accurate to about 10ft (3 m). Although the drillholes tend to be clustered close to the outcrop of the Kennedy seam and most outcrops occur along traverses following valley bottoms and ridge crests, the two sets of coordinates represented the topographic surface in the study area fairly adequately. Had the overburden-ratio maps reproduced below actually been used to estimate tonnages rather than illustrate a method of constructing the maps, a more accurate topographic model would have been obtained by adding points obtained directly from the 1:10,000 map.

In the area studied, the Kennedy seam is repeated by the Drummond Creek thrust faults (Fig. 1). Although little is known about the panel between the thrusts, the seam in the foot-wall and hanging-wall panels of the fault system has been intersected by numerous drillholes, and the adjacent Luscar strata are fairly well exposed. These panels can be shown to be cylindrically folded, with fold-axis orientations of 135° 15’ in the foot wall and 140° 15’ in the hanging wall. Points on top of the coal seam obtained from outcrops and drillhole intersections were then projected onto vertical planes with strikes of 45° for the foot wall and 50° for the hanging-wall panels (Fig. 2).

Cross sections showing the complete configuration of the coal seam in each domain were then obtained by drawing the “best-fit” line through the points on these projections. Each point comprising the topographic model was then projected parallel to the appropriate fold axis onto these cross sections, to determine how far it is above or below the modelled seam top in the two panels. These distances were used to generate two new data sets modelling the top of the coal seam in the foot-wall and hanging-wall panels of the fault.
Fig. 2. Plots of outcrops and intersections between the Kennedy seam and drillholes in the study area, projected parallel to the fold axis B onto vertical planes perpendicular to B. a) Plot for the foot-wall panel of the Drummond Creek thrusts, where B is 145°15'. b) Plot for the hanging-wall panel, where B is 150°15'. No vertical exaggeration.
Fig. 3. Structure-contour models (or the top of the Kennedy seam in the foot wall (a) and hanging wall (b) panels of the Drummond Creek thrusts. The slight variation in configuration of the structure contours in each domain is caused by the irregular spacing of points used as input to the contouring process. Structure-contour interval: 500 ft. (150 m).
Fig. 4. Overburden-ratio maps for the Kennedy seam in the foot-wall (a) and hanging-wall (b) panels of the Drummond Creek thrusts. The shaded areas estimate the area underlain by coal recoverable by open-pit mining.
system. The structure-contour maps of Figure 3 were derived by triangulation methods from these data sets. Finally, the differences in elevation between the topographic-surface model and the two geological models were divided by 11 (the seam’s apparent vertical thickness), to obtain the overburden-ratio models/contoured versions of which are shown in Figure 4.

REFERENCES