Measuring Minor Structures in Borehole Image Logs

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Summary

Borehole image logs can be used to draw detailed cross-sections of the same mesoscopic (sub-seismic scale) fold-and-fault structures that are frequently seen in outcrop. Similarly, outcrop measurements of mesoscopic structures can be used to generate synthetic borehole image logs by drawing a scaled cross-section and intersecting that cross-section with imaginary wellbores. These translations were done on a set of outcrops in the Alberta Rocky Mountains and Foothills and were successfully compared to same-scaled structures from a borehole image log drilled in northeast British Columbia, Canada. This comparison shows that the minor fold and fault structures in subsurface logs are the same as those in outcrop; they are measurable and can be sketched in cross-section. The cross-sections derived from borehole image logs can be used to infer the sense of motion on adjacent major faults, the sense of motion for bedding plane slip and the vergence direction for minor structures, even when such information is unclear from the overall dip patterns.

Method

To better understand how mesoscopic-scale minor fold and fault structures would appear when observed by a borehole image log, careful line-drawing cross-sections were generated from minor fold structures measured from outcrops in Alberta. The cross-sections were then intersected from various angles with imaginary cylindrical boreholes that are parallel to the plane of section. Then, those imaginary boreholes were used to determine how the observed bedding would intersect the cylinder and then the imaginary cylinder was unrolled to make a synthetic borehole image log. The method for translating between cross-sectional view and synthetic borehole view follows fairly simple rules that are easily reproducible, similar to how a cross-section can be reliably projected from surface and subsurface dip data. By reproducing this method, a set of examples was generated so that the complex structures seen in subsurface logs could be referenced through analogy and thus we can understand what types and what scales of structures can be measured accurately in image logs. An example showing the results of this translation is shown in Figure 1.

The procedure for measuring mesoscopic structures in borehole image logs is also not particularly difficult when compared to standard borehole image log interpretation. Borehole image interpretation uses computer programs to fit sinusoidal traces to the predominantly planar features that are common in these logs, such as fractures or bedding. The interpretation software takes the known borehole orientation, caliper measurements, and sinusoid position, apparent dip and rotational azimuth and calculates a true dip and dip azimuth for each interpreted event. The process is similar for measuring mesoscopic structures except that

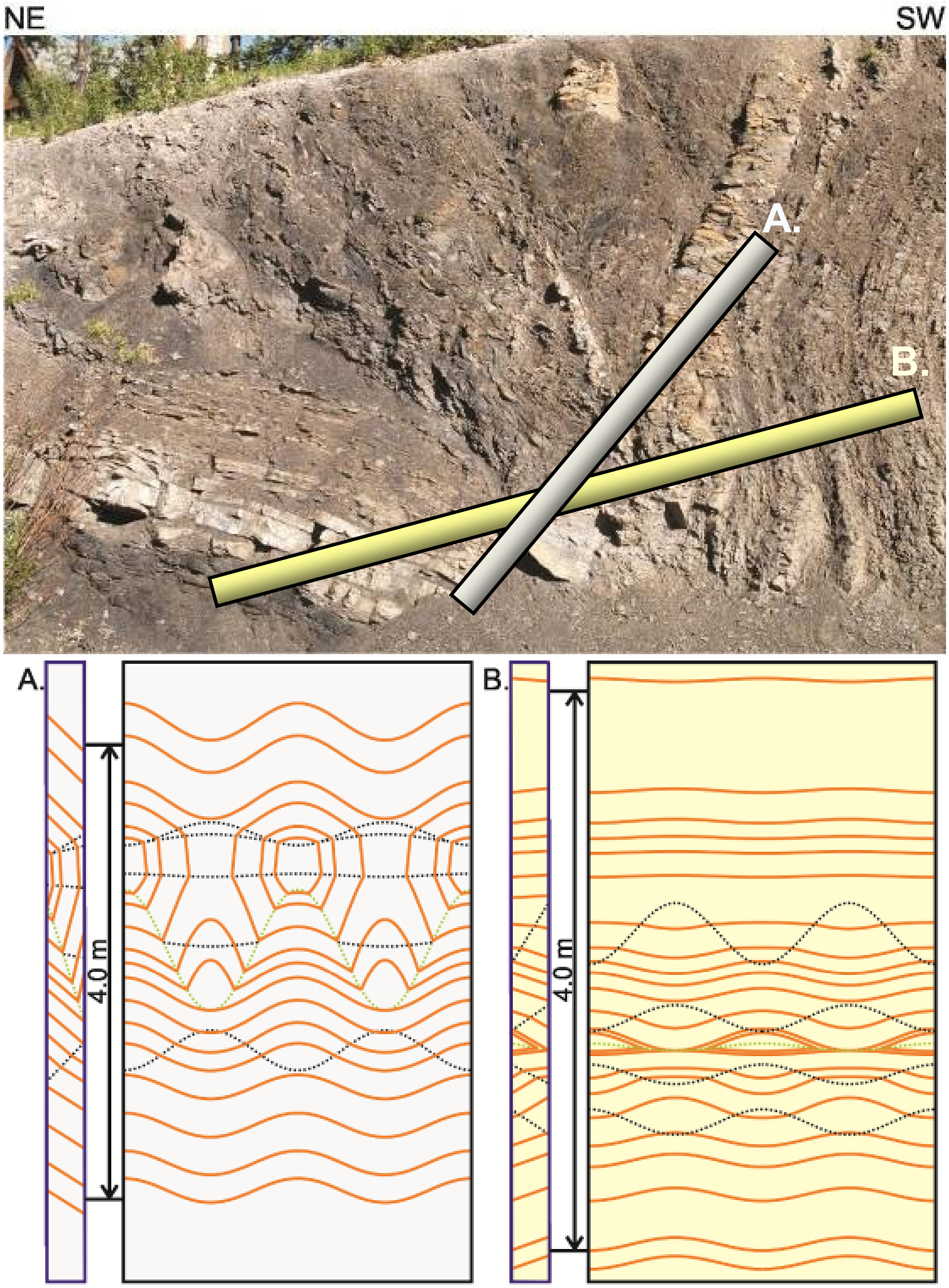

Figure 1: Canmore minor fold outcrop and synthetic borehole images

Minor folds such as this one from the Kootenay Formation (structurally below the Rundle Thrust in the town of Canmore, Alberta) are often seen in outcrop and are used to infer sense of structural vergence as well as corroborating structural trends among other uses. By drawing careful cross-sections, it is possible to intersect those sections with imaginary wellbores to deduce what the corresponding borehole image log would look like. This exercise produces the complex and interesting synthetic borehole image logs shown below the section. In these examples, bedding planes are shown in orange and the dip domain boundaries from the original cross-section are shown in dotted black and green lines.

the measured features are not planar and can be observed to bend within the area of the wellbore. Typically, mesoscopic structures have lateral extents in the axial direction that are wider than the cylinder of the borehole (i.e. the fold plunges do not change rapidly enough to be visible in wellbores that are between 10 and 50 cm in diameter). This means that they will be observed twice in each borehole image log and there will be a plane of symmetry in the bedding features. By using this plane of symmetry, one can fit sinusoidal trace segments along a curved surface to approximate the bending bedding planes as a series of short plane segments. Those planes can then be translated from the cylindrical (sinusoidal) space of the borehole into a cross-sectional view where the structural geometry is easier to understand. A result of this procedure is reproduced for a simple fold in Figure 2 and a much more complicated structure in Figure 3.

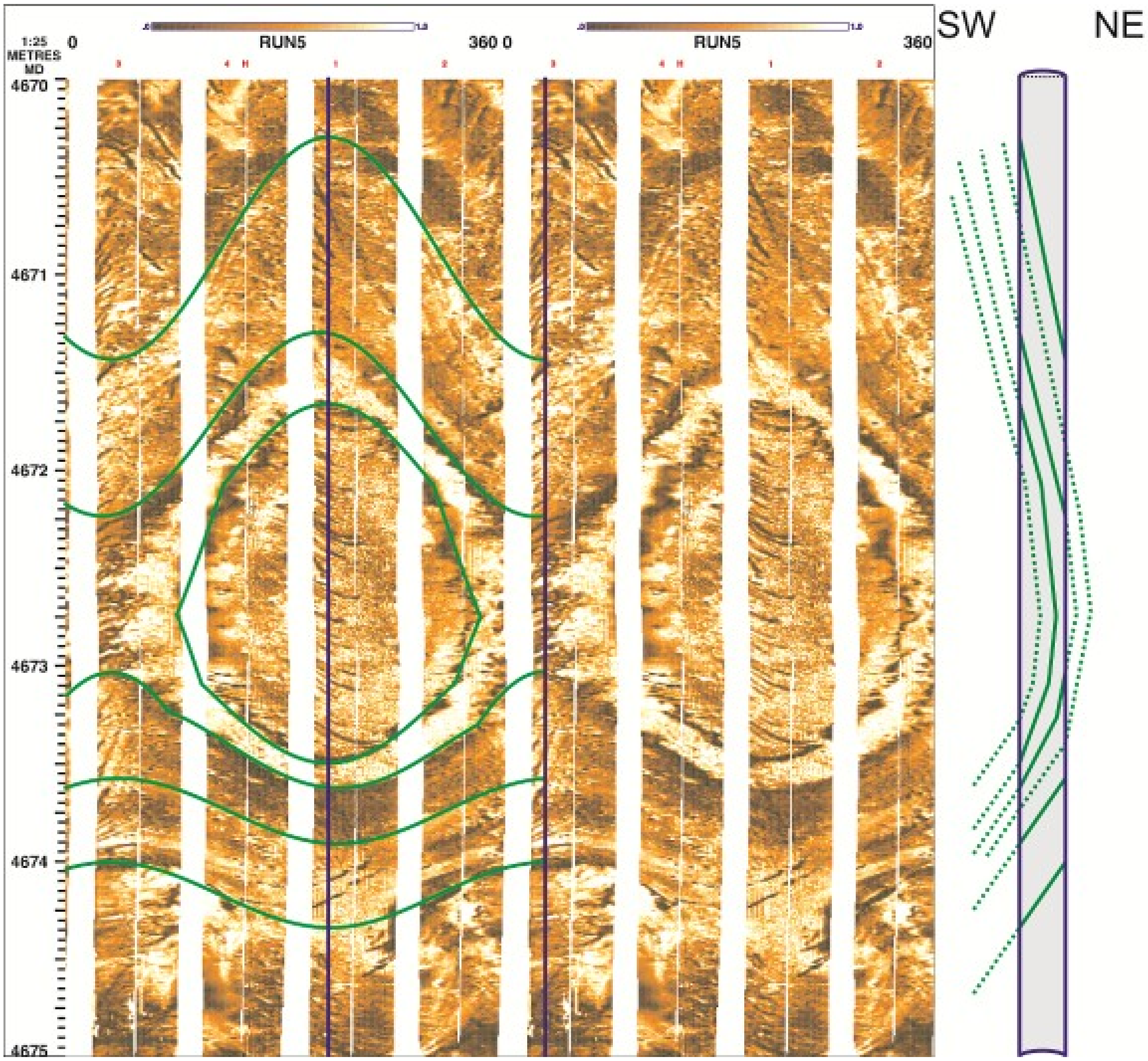

Figure 2: Simple minor fold in a borehole image log
This interval shows an uncomplicated open fold structure with a near-horizontal fold hinge where the bedding is delineated by a pair of bedding-parallel stylolites (the dark, wavy egg-shaped features in the centre of the image, traced with green sinusoid and line segments) riming a light coloured resistive bed. Because the borehole intersection is at a very small angle to bedding that is near-vertical in dip, this image is identical to how an image would look if a horizontal well intersected an open fold with a vertical hinge plane. The accompanying cross-section on the right is derived directly from the sinusoid segments and is an unexaggerated structral cross-section. In the image, there are two vertical black lines (about one quarter and one half of the way from the left edge). These lines represent the plane of section and are positioned so they are 180 degrees apart and intersect the peaks and troughs of the bedding sinusoids so the resulting section is in the orientation of maximum apparent dip.

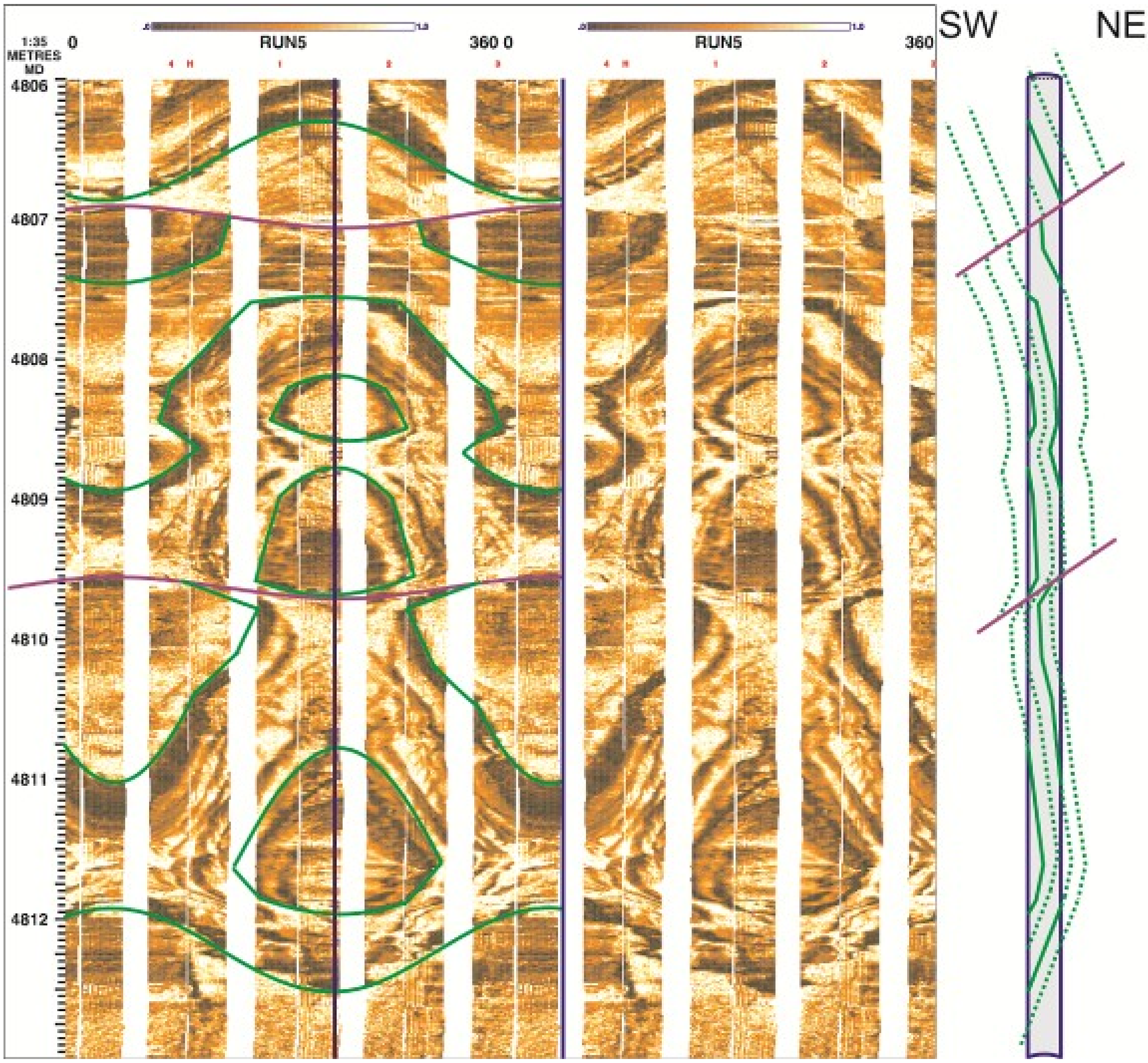

Figure 3: Complex minor folds and faults in a borehole image log
This interval shows a a set of undulating folds and fault-bound blocks. The fault planes in this case (the purple sinusoids and lines at 4807 and 4809.6 metres) are resistive features implying that they have been healed or are full of resistive fault gouge. While the folding in this image is not very large in scale (amplitudes in the range of 15 centimetres), the bedding drag adjacent to the faults implies that the fault plane vergence is clockwise, and we can conclude that the steeply dipping bedding panel was likely thrust into this position before the smaller faults were formed.

Conclusions

The key novel result of this study is the development of a method to convert complex borehole image logs to a cross-section, revealing important details like the vergence direction of mesoscopic folds and faults. By looking at a variety of these structures in the subsurface and comparing to those derived from outcrop analogues, a catalogue of mesoscopic structures in real and synthetic borehole images was produced to help visualize these complex structures in the strange cylindrical geometry of the borehole.

Acknowledgements

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