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Mapping Formation-Top Offsets in Southwest Alberta, Canada: Methodology and Results

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Summary

Introduction

Recently, the AGS seismicity monitoring network has detected a cluster of earthquakes in southwestern Alberta, which may be related to fault reactivation potentially induced by hydraulic fracturing (Schultz et al., in prep.).This observation hightlights a need to better understand the regional bedrock structure.

The structural framework of southern Alberta includes three major domains; from west to east these are: 1) the Rocky Mountain fold-and-thrust belt, 2) the Alberta Syncline and 3) the Sweetgrass Arch (Lerand, 1983). In the southern Alberta Plains, deformation structures including faults have also been reported more than 100 km to the east of the triangle zone (Russell and Landes, 1940; Irish, 1968; Skuce et al.,1992; Wright et al., 1994; Hiebert and Spratt, 1996; Lemieux, 1999; Zaitlin et al., 2011). This study presents the results of subsurface bedrock offset mapping in southwestern Alberta, using well log data and geostatistical analysis. A bedrock offset is herein defined as any vertical displacement of a formation top or bedrock horizon; a linear offset represents a potential fault. Three horizons, the Basal Fish Scale Zone (BFSZ), the top of Milk River Formation and the Lower Bearpaw flooding surface, were selected and numerous linear offset structures were recognized and highlighted from these three surfaces. Some of the mapped offsets coincide with previously reported faults in various studies, and suggest basement control.

Method

After deposition, sedimentary units may undergo regional compaction, regional deformation, and local structural disturbances. Consequently, the present-day elevation of a stratigraphic unit top represents the result of the combined effects of both the regional and local processes.

In this study, the objective is to highlight and separate the offsets caused by local structural features from the combined effects of regional processes. The methodology used in this study was developed by Mei (2009) and allows recognition of metre-scale formation-top offsets that are below the detection or resolution limits of conventional seismic surveys. In this method, a smooth surface is modelled to include the regional effect and, then, the deviations of data points from this surface are calculated and used to interpolate a residual surface. Marine bedrock surfaces were preferred for mapping formation-top offsets because they remained smooth after regional compaction and deformation; they become disturbed only after they are offset by local structural features. As a result, local structures can be highlighted in the residual surface generated after removal of the regional effects.

Examples

Numerous linear offsets have been recognized and they appear to strike NW-SE, except in the southeast portion of the study area where the linear offsets strike NNW-SSE (Fig. 1). In addition, this NW-SE structural fabric appears to be crosscut and possibly displaced by a number of NE trending lineaments/zones.

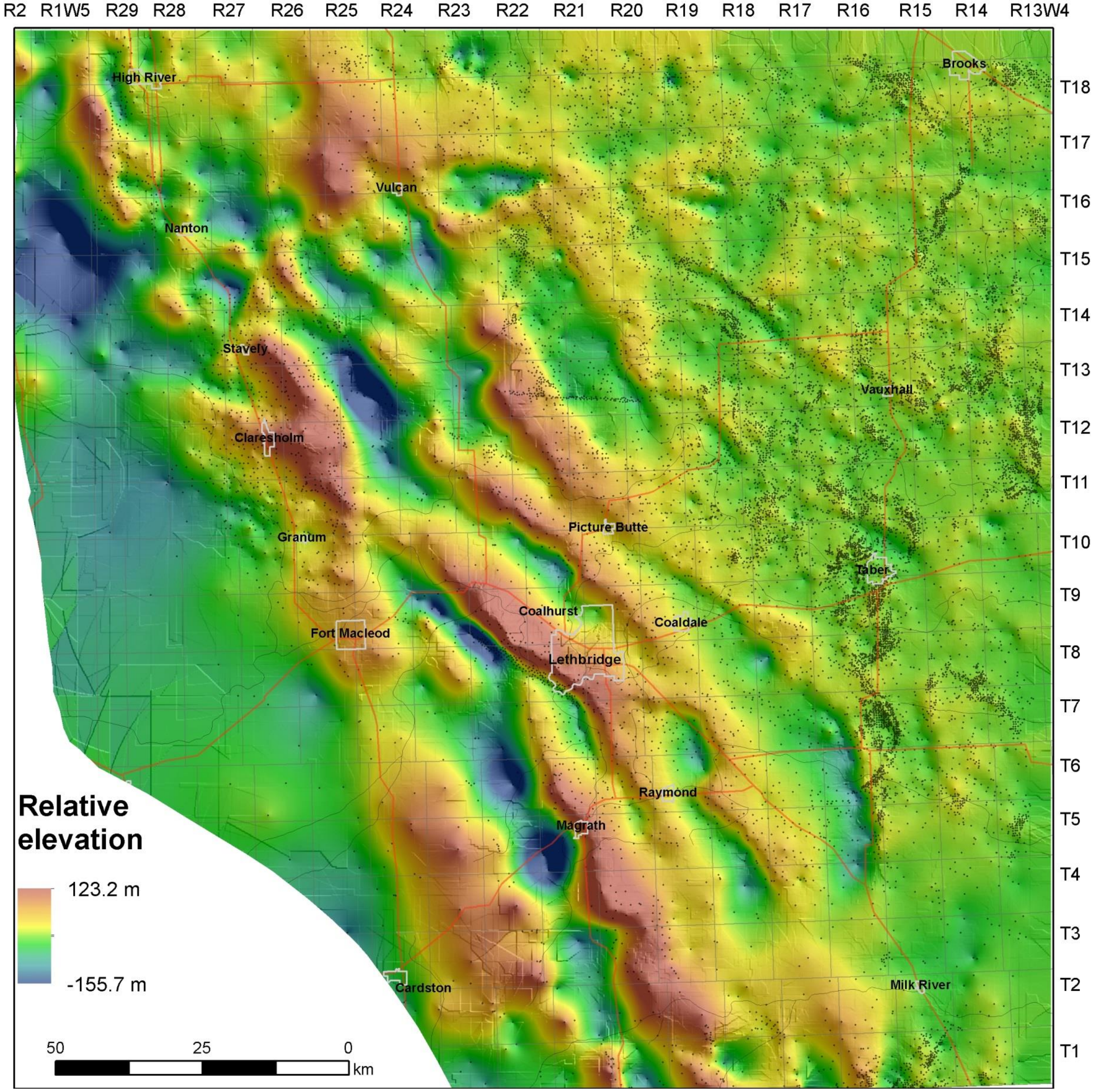

Figure 1. Residual map of the Basal Fish Scale Zone surface in the study area. Red lines indicate roads and grey dots are control wells and can be seen more clearly when zoomed in. The southwest margin of the map is clipped at the approximate eastern limit of the deformation belt.

Some of the offsets mapped in this study coincide with previously reported faults (Fig. 2). These faults were identified at isolated riverbank outcrops and locations along the seismic reflection lines of the Lithoprobe Southern Alberta Lithospheric Transect (Boerner et al., 1997); our offset maps have revealed the orientation and extent of these faults.

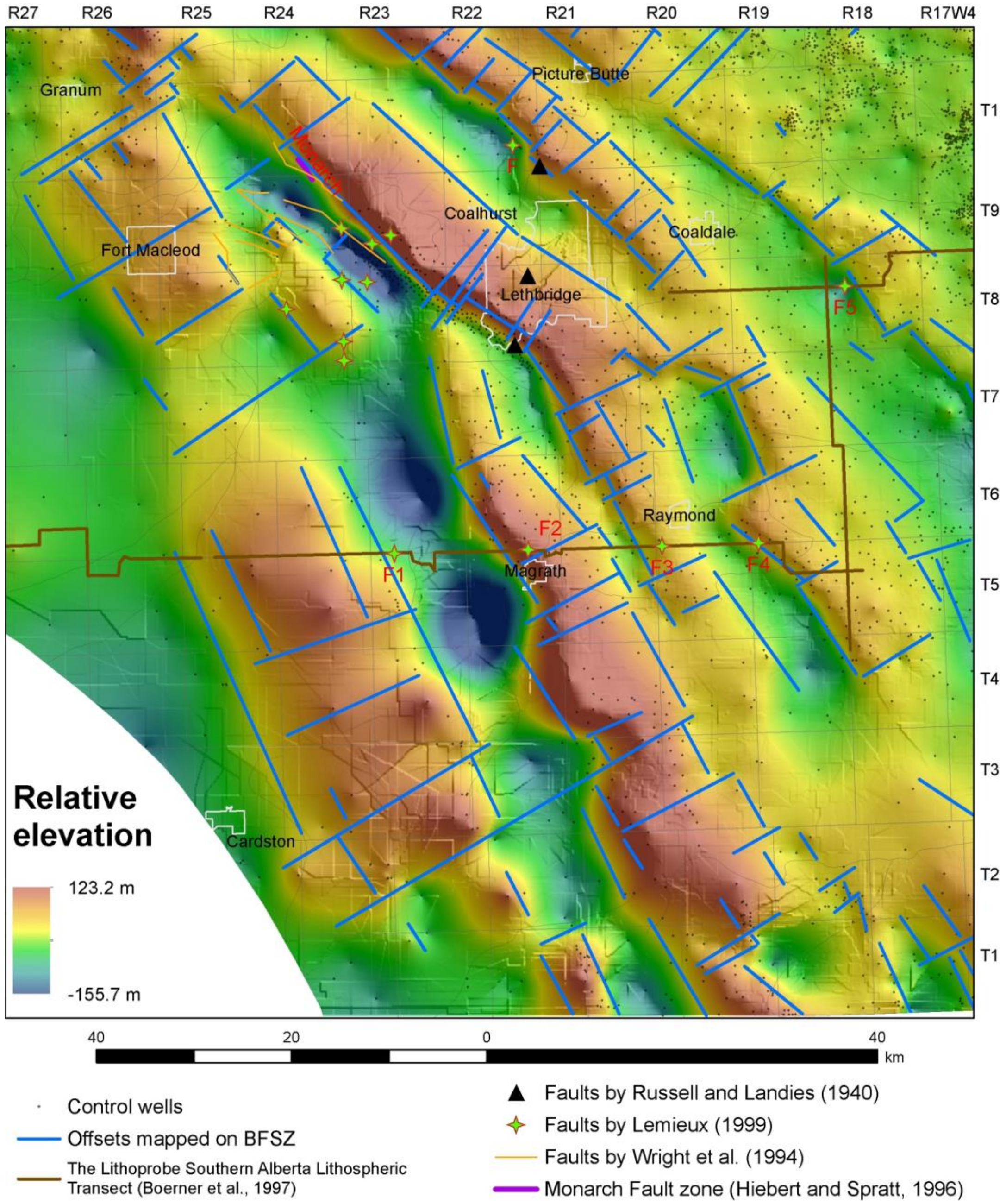

Figure 2. Comparison of mapped offsets with previously reported faults. The background is the residual map of BFSZ. The southwest margin of the map is clipped at the approximate eastern limit of the deformation belt.

Comparison of the offset linements with the gravity and magnetic lineaments interpreted from potential-field maps of the basement indicates that the trends of our offset lineaments mimic the grain of the potential field maps and locally coincide with the gravity and/or magnetic lineaments (Figure 3). Note that the Vulcan Low, as defined by the magnetic data and to a large extent by gravity data, coicides with a wide, ENE trending zone in the northwest of the study area, where the offset lineaments apear to be interupted and possibly displaced (compare Fig. 1 and Fig. 3), suggesting a basement control on the development of structures in the sedimentary cover. Another observation is the trend change in our offset lineaments from southeasterly near and north of Lethbridge, to south-southeasterly south of Lethbridge, which suggests a change in the local stress field that roughly coresponds to the change in the orientation of the adjacent fold-and-thrust belt. This change may have been accommodated by a small-displacement strike-slip fault zone as suggested by our northeasterly trending offset lineaments (Fig. 2).

In some instances our offset lineaments partly overlap or are located very close to basement-inferred faults. Good examples as indicated on Figure 3 are F1, which partly overlaps with one of the gravity lineaments and F2, which is close and has the same orientation as a magnetic lineament inferred in the basement; also, our southeasterly trending offset lineament that corresponds to the Monarch Fault is underlined by an obvious gravity lineament west of Lethbridge. This suggests that these offset lineaments may in fact represent deeply rooted faults. The partial (incomplete) spatial overlap between lineaments inferred in the basement and those mapped in the sedimentary cover may be due partly to the inherent approximation/ imprecision in tracing lineaments on potential field maps and partly to the refraction of faults through ductile shale layers.

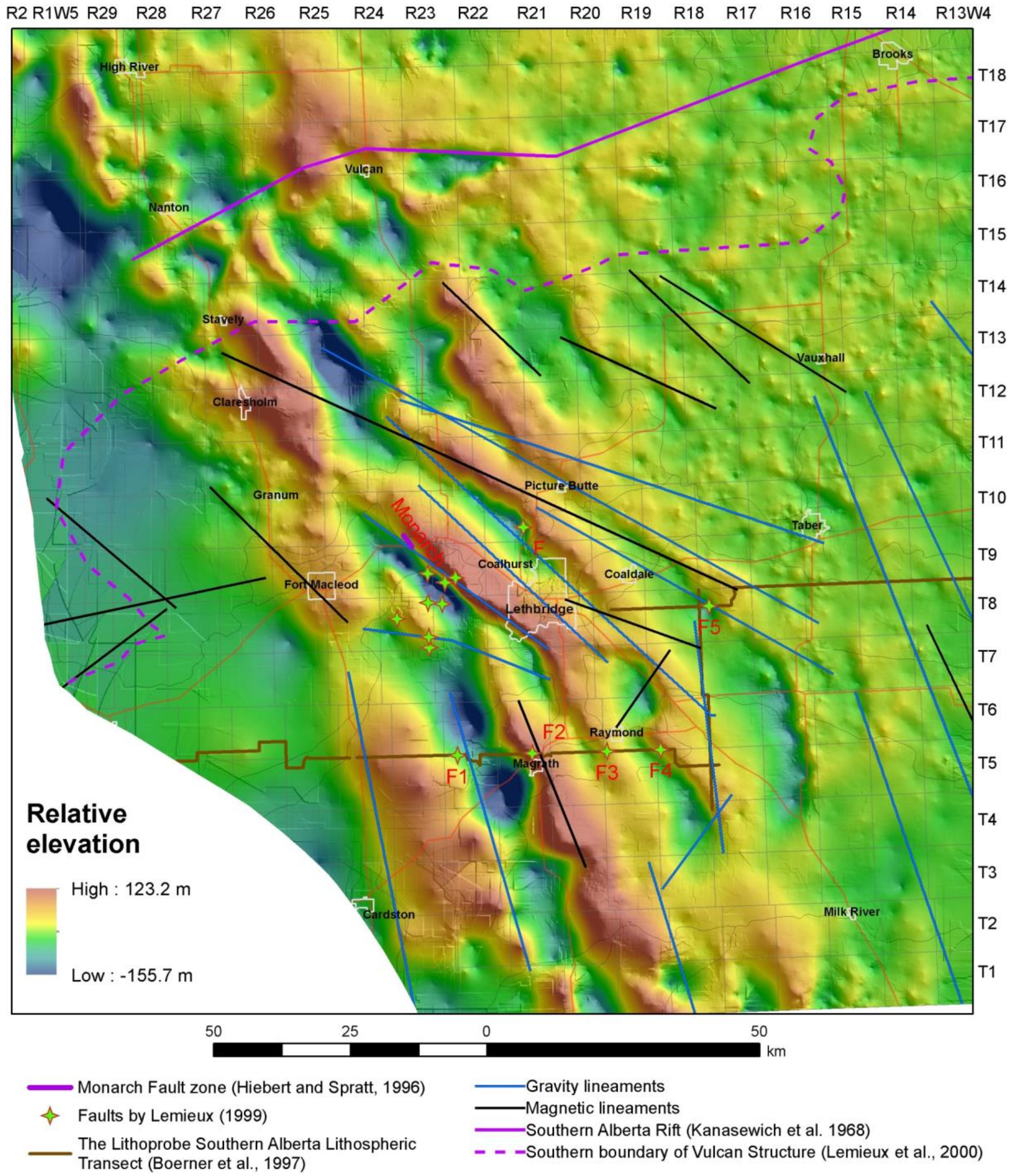

Figure 3. Comparison of mapped offset lineaments in the stratigraphic cover with the basement lineaments. The background is the residual map of BFSZ and the southwest margin of the map is clipped at the approximate eastern limit of the deformation belt.

Conclusions

Numerous linear structures have been recognized in the southern Alberta Plains, 50-140 km east of the Foothills triangle zone. These structures trend southeasterly in the study area north of Lethbridge; they trend south-southeasterly in the area south of Lethbridge. This pattern mimicks the basement grain/fabric inferred from magnetic and/or gravity maps of the Archean Medicine Hat Block. Some of the offset lineaments overlap with faults previously identified in isolated loactions, which significantly impoves our understanding of the orientation and extent of these faults. In addition, our offset lineaments map revealed numerous, previously unrecognized structures. The orientation patterns appear to be disturbed by the Vulcan Low basement structure and by a northeasterly trending zone just south of Lethbridge, suggesting both basement control and influence of the Cordilleran stress field. Offset lineaments that partialy overlap with geophysically detected or inferred basement faults make a strong case for their interpretation as reactivation faults, deeply rooted into the basement.

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