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Strains developed in the hangingwalls of thrusts due to their slip/propagation rate: a dislocation model: discussion

C. R. Tippett

Shell Canada Resources Ltd., P.O. Box 100, Station M, Calgary, Alberta, T2P 2H5, Canada

P. B. Jones

International Tectonic Consultants (ITC) Ltd., 715-4th Street N.W., Calgary, Alberta, T2N 1P3, Canada

and

F. R. Frey

Shell Canada Resources Ltd., P.O. Box 100, Station M, Calgary, Alberta, T2P 2H5, Canada

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Abstract—Modern seismic data indicate that the sole fault of the Turner Valley thrust sheet does not lose displacement in an up-dip direction and that it does not crop out but rather flattens into the triangle zone on the eastern edge of the Rocky Mountain Foothills Belt. Well constrained balanced cross-sections drawn through this part of the belt do not incorporate significant folding related to the propagation of thrust faults.

The recent paper by Williams & Chapman (1983) clearly demonstrates the mode of thrust fault propagation in certain tectonic and lithological environments. We would like to offer several comments on this paper, first concerning their choice of the Turner Valley structure as a macroscopic example of this process and second on the question of structural style in the Canadian Rocky Mountain Foothills as it pertains to the general applicability of their model.

It is unfortunate that the authors chose the Turner Valley structure, which occurs at the foreland margin of the Canadian Cordillera, as an example of progressively decreasing bed offset along a thrust fault plane. The geological cross-section which they used (Williams & Chapman 1983, fig. 1) was adapted from Dahlstrom (1970), who in turn had adapted it from Gallup (1951), as they pointed out. That interpretation [reproduced here as Fig. 1 for comparison from Dahlstrom's (1969) companion paper], however, has long since been recognized as having been based on the incorrect correlation of a zone of disrupted strata at the surface with the Turner Valley sole fault at depth (Gallup 1951, p. 798). In fact, prior to the publication of Dahlstrom's papers, it had been suggested by Bally *et al.* (1966, plate 5—cross-section C–C′ and plate 6—seismic profile c–c′) that rather than being steep and appearing at the surface, the Turner Valley sole fault actually flattens to the east to become nearly parallel to bedding within strata of the Upper Cretaceous Edmonton Formation.

Although Bally *et al.*'s section is drawn approximately thirteen kilometres to the south of that of Gallup the difference in the interpreted geometric relationships is fundamental. Eastward slip along the W-dipping sole fault of the Turner Valley sheet was reinterpreted as being counterbalanced by one or more E-dipping underthrusts with the opposite sense of displacement. These latter faults underlie the eastern flank of the frontal triangle zone. One of these faults occurs on the Bally *et al.* (1966) line of section where it was originally mapped by Gallup (1951). It has a similar location relative to the Tertiary–Cretaceous contact as that observed by Gallup to the north. This interpretation was supported by Gordy & Frey (1975) whose modification of that cross-section (forming the basis for Fig. 2) is now accepted as a valid representation of the structural relationships within this frontal complex.

Zones of disrupted strata near the apex of the triangle zone on both lines of section (Figs. 1 and 2) are now interpreted as representing exposures of the upper detachment surface beneath which imbricates of older strata have been injected. The surface trace of this detachment is not geometrically constrained by the detailed geometry of the individual underlying thrust sheets, in particular the position of the leading edge of the Palaeozoic strata carried in the Turner Valley thrust sheet. Its outcrop pattern is, rather, a function of the aggregate stacking at depth combined with surface topography. Gallup (1951) correlated the Turner Valley sole fault with the outcrop of the upper detachment on his line of section because it was conceivable that a low-angle W-dipping fault could join the leading edge of the Mississippian carbonates with that outcrop zone. Farther south, for example at the location depicted in Fig. 2, however, the leading edge of the Palaeozoic

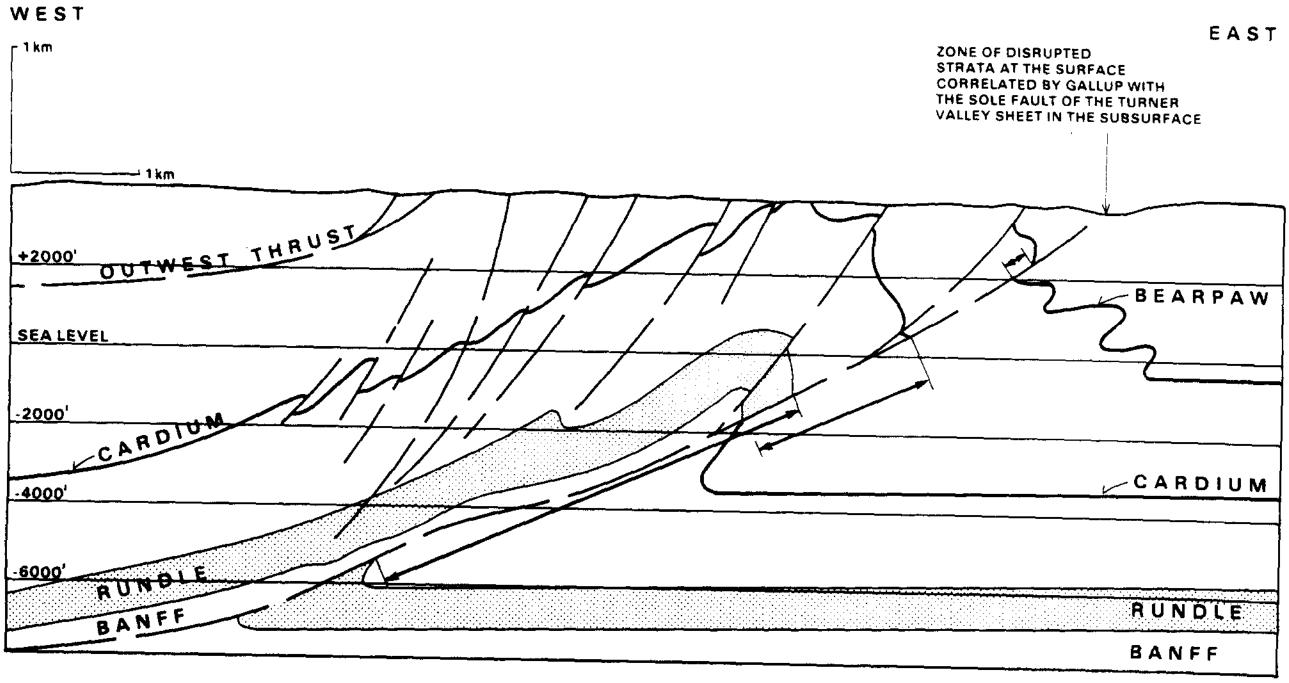

Fig. 1. The Turner Valley structure according to Dahlstrom (1969) as adapted from Gallup (1951, section B–B′, south branch of the Sheep River). Compare to Fig. 1 of Williams & Chapman (1983). Horizontal scale = vertical scale.

strata lies farther east with respect to the correlative zone of surface disruption making it unrealistic to join the two. Gallup's (1951) section A–A′ was drawn through the same part of the Turner Valley field as Fig. 2. It illustrates a sole fault that does not crop out and another fault with insignificant offset at a Palaeozoic level associated with the disrupted zone. Thus Gallup (1951) was forced to conclude that his Sheep River line of section (Fig. 1, section B–B′) was unique in including an outcrop of the sole fault even though similar zones of surface disruption occur on other transects through the triangle zone.

More recent seismic data has confirmed the importance of such zones of intercutaneous injection along much of the leading edge of the Rocky Mountain Foothills Belt as well as in other fold and thrust belts (Jones 1982, Teal 1984).

Our second comment deals with the applicability of the Williams & Chapman (1983) model to thrust belts in general, using the Canadian Rocky Mountain Foothills as an example.

The structural style of the southern part of the Foothills Belt is well known from the abundant seismic reflection data which has been recorded in the region. The deep-level structure is dominated by thick plates of Palaeozoic carbonate strata which have been emplaced along thrust faults, apparently with little internal deformation. Folds are more common in the overlying section which consists mainly of Mesozoic sandstones and shales, for example within the structure outlined by the Cretaceous Cardium Formation in Fig. 2. Even in this part of the stratigraphic succession, however, discrete thrust faults carrying relatively thick sections also dominate the imbricate zone.

Within the southern Foothills including Turner Valley, it has been found that cross-sections can be balanced reasonably using the assumption of constant offset along a given thrust fault, leading to the rules governing the summation of displacement. Examples of this type of section are those of Bally *et al.* (1966), Gordy & Frey (1975) and the Foothills and Front Ranges segments of Price & Fermor (1982). It is not necessary to resort to fault propagation-related hangingwall strain in order to balance these sections. Individual thrust faults are in effect visualized as having propagated instantaneously through the entire stratigraphic section over glide planes and ramps, as opposed to gradually working their way along as would be suggested by the model of Williams & Chapman (1983). This is not to say that the faulting was actually instantaneous but rather to state that however the initial (and subsequent) displacements occurred, the faults propagated rapidly in geological terms without imparting significant permanent strain other than intrastratal slip to the hangingwall rocks in order to accommodate hangingwall–footwall geometries. The rocks involved are not elastic on the geological time scale. Their behaviour is unlike that of a strained crystal lattice which given time may partially or fully recover. The present absence of folds which are not related to existing hangingwall–footwall relationships must therefore imply the absence of such folds at the time of fault formation. This is a major difference between our observations and those of Williams & Chapman (1983) as well as those of Boyer & Elliott (1982) regarding tip lines and fault propagation.

Rollovers of strata into fault planes such as that depicted by Gallup (1951) (Fig. 1) occur but are generally a consequence of the juxtaposition of, for example,

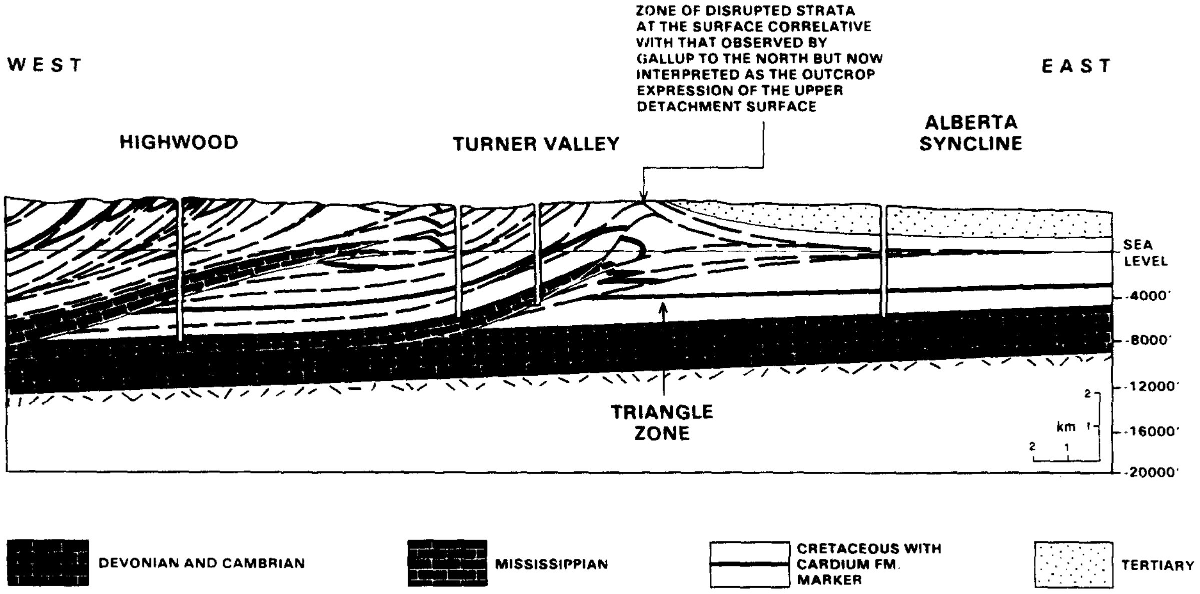

Fig. 2. The Turner Valley structure and corresponding triangle zone [slightly modified from Gordy & Frey (1975)] as adapted from Bally *et al.* (1966). This section is drawn where the Highwood River crosses the Turner Valley structure, approximately 13 km south of the section shown in Fig. 1. The sole fault of the Turner Valley Sheet flattens to the east where it merges with faults having the opposite sense of displacement. Horizontal scale = vertical scale.

a hangingwall glide zone (Banff)–steep ramp (Rundle) pair onto a planar (in this case inclined) footwall. Another classic example of this relationship was first recognized by Douglas (1950, pp. 79–97) to the south–southwest of the Turner Valley field in the gap of the Livingstone Range. Complications such as leading-edge imbrication, limited rotational effects (drag) and folding due to stacking beneath the thrust sheet of interest occur, but the general absence of corresponding footwall synclines to major hangingwall anticlines indicates that the latter do not form as a result of the propagation of thrusts by leading-edge folding. In this context the presence of folds at the lateral terminations of some thrust faults in the Front Ranges is puzzling.

In contrast to the structural style present in the southern part of the Canadian Rocky Mountain Foothills, the northern segment has a style much more compatible with the model described by Williams & Chapman (1983). As has been described by Thompson (1979, 1981), most major thrust faults in that region are blind and die out towards the northeast in a complex series of disharmonic hangingwall folds.

The change in structural style along strike in the Foothills and Front Ranges belts is a consequence of lithological changes in the stratigraphic sequence involved in deformation, specifically the contrast between thick Palaeozoic carbonate sequences to the south and laterally equivalent thick shale packages to the north (Thompson 1981). The rare development of a fold-dominated style within the southern segment where part of the Devonian section locally passes into a shale facies (Jones 1978) confirms that the change in style is lithologically induced rather than a consequence of a different tectonic setting or strain rate.

It is concluded that the model developed by Williams & Chapman (1983) is not universally applicable. It can realistically be applied to fold and thrust belts only where the bed thicknesses and ductility contrasts permit true buckling to occur. Those portions of fold and thrust belts, such as the Turner Valley area, where faults propagate through stratigraphic sequences without imparting significant strain to their hangingwalls behave in a fundamentally different manner.

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