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# Aeromagnetic interpretation of basement structure using over 3,000 control wells, central Alberta: a case history

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## Summary

High-resolution aeromagnetic data over central Alberta, from 55° to 57° N and 117° to 114.25° W (Figure 1), is interpreted to map the depth-to-magnetic basement and basement structure. Over 3,000 wells, penetrating Precambrian and Granite Wash rocks are used for interpretation control.

The basement slopes down to the southwest from about 750 m to over 2,000 m bsl. Dominant basement structures are series of north-south trending inter-connected grabens and half grabens. These structures are interpreted to act as control for deposition of Granite Wash sediments as well as influencing structural and facies development on overlying sediments, particularly economically important Devonian and Carboniferous rocks.

The southeastern flank of the Peace River Arch, a broad southwest plunging Paleozoic basement structure, subcrops throughout the northern part of the study area. The arch was topographically elevated from Cambrian to Late Devonian, then collapsed forming an embayment in Latest Devonian, and was a major structural element of the Western Canada foreland basin throughout Mesozoic time. This interpretation suggests that the basement expression of the southeast flank of the Peace River Arch is subtle, with a gentle gradient.


## Geology

The present Canadian Shield configuration was formed between 2.0 and 1.8 Ga (Ross and Stephenson, 1989). The western shield is composed of Archean and Proterozoic micro-continents sutured along roughly north-south Proterozoic orogenic belts. The survey area is located over the Buffalo Head Terrane, an Early Proterozoic micro-continent. This granitic crust is essentially undeformed since the Mid-Precambrian Hudsonian Orogeny at 1650 Ma (Cant, 1989).

The Peace River Arch is asymmetric with a steeper northern side (O'Connell et al., 1990). In Early Carboniferous time several inter-linked graben structures, with relief of up to 60, formed over its crest. The arch moved upward and downward possibly due to thrust loading in the Cordillera, and affected sedimentation up to Cretaceous time (Cant, 1989).

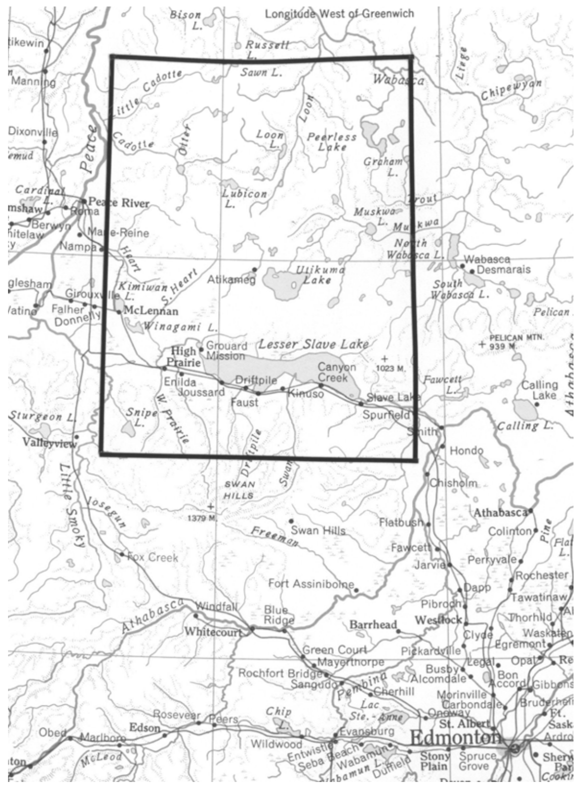


**Figure 1** Study area.

Workers disagree regarding the location of the arch's exact boundaries, but its southern limit appears to coincide with the Chinchaga magnetic low, a probable internal shear zone within the basement. O'Connell et al. (1990) report that theories for the origin of the Peace River Arch cover a spectrum of ideas from totally tectonic flexural, to completely thermal, formation.

Sedimentary deposition began in Cambrian time and throughout the Paleozoic Era mostly marine carbonate platforms, reefs, and sands were deposited in the aeromagnetic survey area. Mesozoic and Cenozoic sedimentation changed, due to the Columbian Orogeny, with mostly terrigenous clastic deposition (Poulton, 1989).

Cambrian to Lower Ordovician interior platform sediments overlie crystalline basement (Aitken, 1989) in the survey area. Unconformably overlying Lower Ordovician sediments transgressive reefs, carbonate platforms and foredeeps were deposited throughout Devonian time (Moore, 1989). Basal siliciclastics, derived from the Peace River Arch, are wide spread suggesting the possibility of greater relief for the arch in Devonian time.

Latest Devonian and earliest Mississippian sediments consist of carbonate platform and ramp deposits as well as evaporites and siliciclastics (O'Connell, 1994). During this time the survey area was situated in the Peace River Embayment, which was part of a larger downwarped and downfaulted western margin of ancestral North America called the Prophet Trough (Richards, 1989). The Peace River Embayment is thought to have formed in response to transtensional forces, related to sinistral transcurrent faulting, and the collapse of the Peace River Arch.

O'Connell (1994) suggests that basement reactivation, expressed by north-south grabens filled with Granite Wash sediments, is roughly parallel the Ksituan-Chinchaga basement contact and that the distribution of dolomite within the Devonian Wabamun Formation also trends parallel to basement contact. Hence, the Granite Wash lithozone is confined to graben structures and varies from 0 to 20 m in thickness over crest of the arch in the study area (O'Connell et al., 1990). East of the arch, Granite Wash forms narrow elongated bodies of fluvial and shallow marine deposits.

**Petroleum Geology**

Important structural controls in the Western Canada Sedimentary Basin are crustal folds, folds due to differential compaction, folds due to salt dissolution, and faults (Osadetz, 1989). Salt dissolution folds are most spectacular and several are associated with the Middle Devonian Elk Point Group, a thick evaporitic succession. Crustal folds are the largest and most prominent and provide fundamental control on petroleum accumulation. Bending due to differential compaction are economically the most important and include drape paleotopography over carbonate and reef buildups. Bending folds, parallel to, and over the Peace River Arch are thought to be differentially compacted over fault blocks related to Laramide compression. Interior platform conventional petroleum resources are stratigraphically entrapped. In the survey area normal faults that cut crystalline basement are important for helping to define Granite Wash, Devonian and Carboniferous plays.

**Method**

Werner depth estimation (Werner, 1953) is a mathematical process that automatically calculates depth locations, dip directions, and magnetic susceptibility of magnetized sources from anomalies sampled along profile data. Werner is similar to other computer-aided depth estimation techniques; that is, they are fundamentally 'brute-force' methods that automate earlier graphical 'slope' methods (Åm, 1972). For all depth estimation methods, the horizontal distance of the slope of the anomaly over its source body is considered to be proportional to the depth of that source.

Caveats associated with using Werner (or any other profile-based depth estimation technique) are: profiles are two-dimensional, anomaly shapes, and relative positions of profiles and anomalies. Taking these caveats into account, and interpreting depths in a consistent manner is the best approach. Even though depth estimation is ± 7 to 10% accurate, as long as consistency is maintained, the end product will show the relative relief of structures. This type of analysis is labor and time intensive, however it is the best method for interpreting the basement surface, and producing a geologic map of that surface.

**Data**

Almost 75,000 line km of high resolution aeromagnetic data, covering 31,750 $km^2$, were acquired in 1997 over central Alberta. W5M townships 70 to 90 and Ranges 3 to 18 are covered by east-west survey lines (traverses) and north-south tie lines, with 600 and 1800 m spacing respectively. Aircraft elevation was 120 m, draped above ground level, and positioning was accomplished by differential GPS navigation.

Precambrian and Granite Wash TDs were used to constrain the interpretation, totaling 3,647 control points. Since Granite Wash thickness varies, mostly between 0 and 20 m, and since magnetic depth estimate resolution is greater than 20 m, Granite Wash well TDs are included as basement control.

**Results**

In general, magnetic basement should coincide with crystalline basement. A total of 5,482 depth estimates were interpreted along almost 500 magnetic anomaly profiles. With extensive well control calibration of Werner depth estimates is refined, however this control is not evenly spaced throughout the area and a map, contoured from wells alone, does not reflect basement structuring throughout the survey area.

Overall the basement dips from the northeast corner of the area to the southwest corner, or from about 750 m to just over 2000 m bsl. Roughly north-south trending grabens and half-grabens are interpreted throughout the area, especially along the crest of the Peace River Arch. Several basement fault splays indicate a complex tectonic history;

hence the subtle basement expression of the arch is somewhat masked.

The northwest-southeast oriented partition between the eastern and western blocks of the Peace River Arch (O'Connell et al., 1990) correlates with a zone of short, intersecting basement faults. North of this interpreted fault zone numerous basement structures are mapped with major structures generally oriented north-south. South of this zone, basement faulting is patchy with variable fault intensity. Changes in regional structure and basement lithology may be reflected in this variability of basement structuring.

Trotter's (1989) Precambrian surface map (O'Connell, 1994) is similar to the depth-to-magnetic basement contours interpreted here; and to gridded Precambrian and Granite Wash TDs. An important and significant feature of basement interpretations derived from Werner profile analysis is the ability to accurately map basement faults. Mapped basement faults, in turn, provide: precise locations of structural boundaries that affect overlying sediments, the ability to infer directions of regional compression and/or extension, bases for constructing balanced cross sections, and improved insight for understanding a region's evolution and geologic history.

**Conclusion**

Classic petroleum targets related to an interpreted depth-to-magnetic basement surface are anticlines formed by basement structuring and differential compaction over existing basement highs. Additional first order targets in the survey area are grabens and half-grabens that act as conduits for accumulation of Granite Wash sediments. Stratigraphic plays related to basement structures are pinch-outs of Devonian strata produced by active basement structures or by differential compaction over basement highs.

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