Modelling of High-resolution Gravity Data Near the McArthur River Uranium Deposit, Athabasca Basin

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Abstract

Preliminary modelling of gravity data collected at 50 or 100 m station-spacing along a 27.2 km traverse near the unconformity-associated McArthur River uranium deposit, Athabasca Basin has been completed. The range of terrain-corrected Bouguer anomalies (reduction density = 2.00 g/cm^3) in a derived gravity profile is approximately 2.9 mGal. A relatively long wavelength gravity high (>2500 m wide, +1.75 mGal amplitude) and low (6000 m to 1.15 mGal) dominate the southern part of the profile. The northern part is characterized by less extreme variations in gravity, and most anomalies have smaller wavelengths and amplitudes, generally about 500 m (or less) and <0.5 mGal, respectively. Several others have longer wavelengths (up to ~1800 m), but similar amplitudes. A conspicuous 3000 m wide, 1 mGal amplitude positive anomaly occurs at the northern end of the profile. Modelling of anomalies is constrained by magnetic data, drill-hole logs and density information, and reflection seismic data. Long wavelength anomalies are attributed to variations in basement density and offset of the basement unconformity, the principal high being modelled in terms of a quartzite ridge. The shortest wavelength anomalies are explained by variations in overburden thickness, support for which is provided by drill holes. Thickened overburden may be indicative of faulting within the sandstone, which is locally weakened and more susceptible to glacial scouring. Intermediate wavelength anomalies are explained by alteration within the Athabasca Sandstone, manifested as relatively high density sandstone silicification, particularly above quartzite ridges. Desilicification is present, but limited. Identification of such alteration zones is critical to uranium exploration, since they are associated with mineralizing fluids, and because silicification/desilicification patterns are important to exploration from a fluid flow perspective.

Keywords: *geophysics, gravity, McArthur River, uranium, Athabasca Basin, Bouguer anomaly, Athabasca Sandstone.*

1. Introduction

Sandstones of the Athabasca Basin (Figure 1), together with the regolithic rocks at the basal unconformity and underlying basement, form a rich repository for unconformity-associated uranium deposits. At times they have provided approximately one-third of world uranium production (Matthews *et al.*, 1997). Polymetallic (U-Ni-Co-As) deposits are coincident with the unconformity, whereas monometallic (U) varieties are generally below it, and rarely above (Ruzicka, 1995). Most deposits are near the eastern margin of the basin. Earlier discoveries were at depths of less than 200 m, whereas later ones were considerably deeper. The McArthur River deposit lies at a depth of approximately 550 m. Because of the burial factor, geophysics has been extensively employed in uranium exploration. Major deposits are associated with faults focused on conductive basement graphitic units, hence electromagnetic techniques have been widely applied. They have also been used to detect alteration zones that invariably accompany mineralization. Alteration zones typically undergo a change of density, thereby inviting investigation by gravity surveys. Structural controls on mineralization might also produce gravity signatures. At “BJ Lake”, for example, faulted quartzite-pelite contacts bounding paleotopographic highs may have provided conduits for mineralizing fluids (Marlatt *et al.*, 1992). In general, the amplitudes of gravity anomalies of relevance to uranium exploration are relatively small. The maximum amplitudes of gravity anomalies to be expected for several geological situations are:

1) faults offsetting the sandstone-basement unconformity: 0. 5 to 1 mGal (Matthews *et al.*,1997),
2) ridges of quartzite and paleotopographic high/low combinations: 0.5 to 2 mGal (Matthews *et al.*, 1997), and
3) alteration zones: 0.4 to 1 mGal (Hasegawa *et al.*, 1990).

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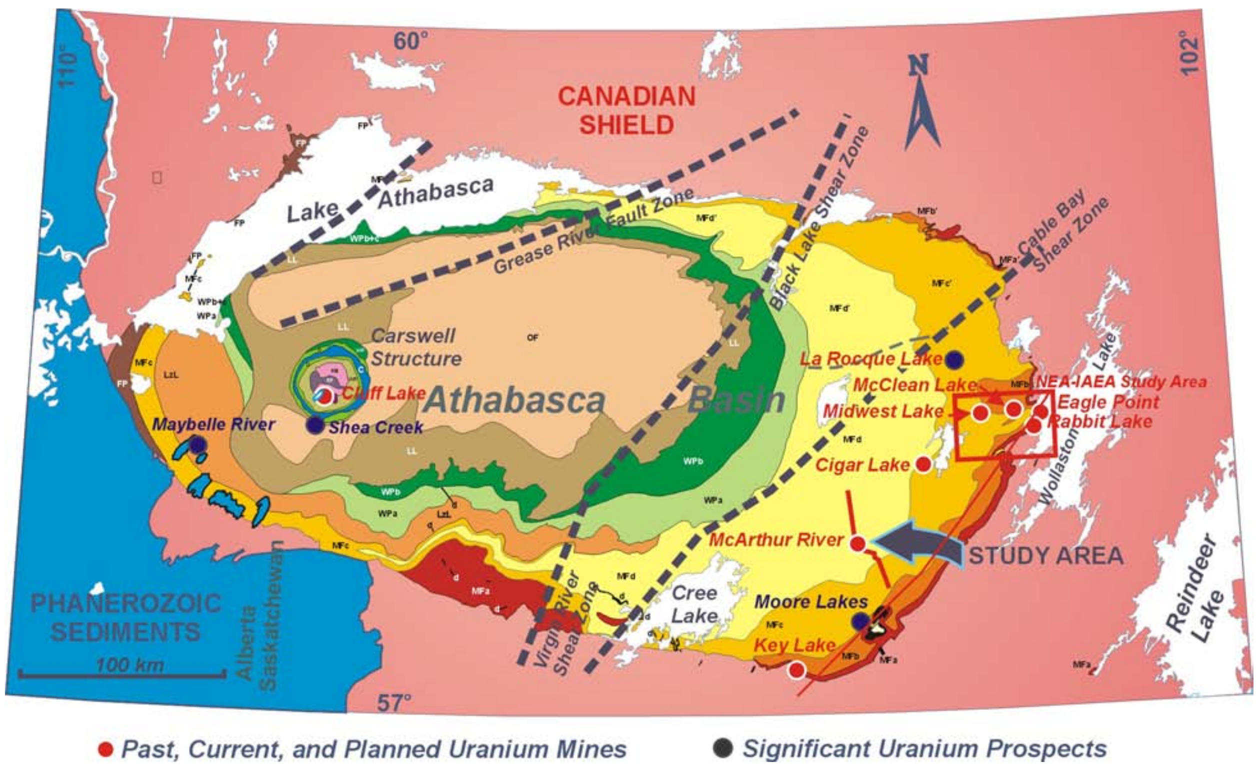

Figure 1 - Geological map of Athabasca Basin and the location of the gravity survey (after Ramaekers** et al.**, (2001) indicating locations of significant uranium deposits.

The gravity anomalies described by Hasegawa *et al.* (1990) were negative, as the mineralization-related alteration surveyed formed a region of decreased density, and a single associated gravity low. However, alteration at McArthur River has resulted in both increases and decreases in density related to silicification and desilicification of the Athabasca Sandstone, respectively. Alteration in the sandstone is generally enhanced over quartzite units in the basement. The McArthur River P2 North deposit is estimated to contain >260 million pounds of U_3O_8 (McGill *et al*., 1993). It is 500 to 570 m deep, hosted by silicified Athabasca Group sandstone and basement pelites. It is structurally controlled by the conductive southeastward-dipping, graphitic P2 thrust fault, which has upthrown basement on the south side by as much as 80 m. The fault is outlined at depth by electromagnetic surveys. The basement rocks comprise a pelite and quartzite sequence. The patterns of silicification/desilicification are important guidelines for exploration and are potentially detectable by gravity surveys, as are possibly fault-bounded paleotopographic highs whose margins may have been loci for mineralizing fluid flow. In the illustrated section (Figure 2) along line 76+50N (modified from Marlatt *et al.* (1992) and McGill *et al.* (1993)) quartzitic units produce gravity highs, one of which (to the east) is regarded as a paleotopographic basement ridge.

This EXTECH IV study examines a high-resolution gravity profile near the 76+50N line, which trends at and crosses the mineralized trend of the McArthur River deposit. Seismic reflection and electromagnetic surveys have also been carried out along the line of the gravity traverse.

2. Gravity Survey

The EXTECH IV high-resolution gravity traverse extends over a 27.2 km long, north-northwest-trending path just west of the McArthur River P2 North deposit. Station spacing is 50 or 100 metres, and 383 observations were made. The terrain is covered by glacial overburden that presents a hummocky surface dominated by northeast-trending drumlins. Maximum variation in relief along the traverse is about 70 m.

It would be beneficial to examine the detailed survey within the context of a well-defined surrounding gravity field, but unfortunately available regional gravity coverage is very sparse with stations generally 15 to 20 km apart. Much of the company data around the deposit is proprietary and unavailable, and is not incorporated into the illustrated gravity map (Figure 3). Ideally, a situation similar to that at the Midwest Lake deposit, for example, would be desired. There, much of the area has been covered by gravity observations spaced 1 or 2 km apart and, over the deposit itself, values on a 122 x 61 m grid are accessible (Sobczak, 1983). The McArthur River high-resolution gravity traverse sits on a gentle north-northwest-trending saddle that is superposed on a broad east-northeast-trending gravity high.

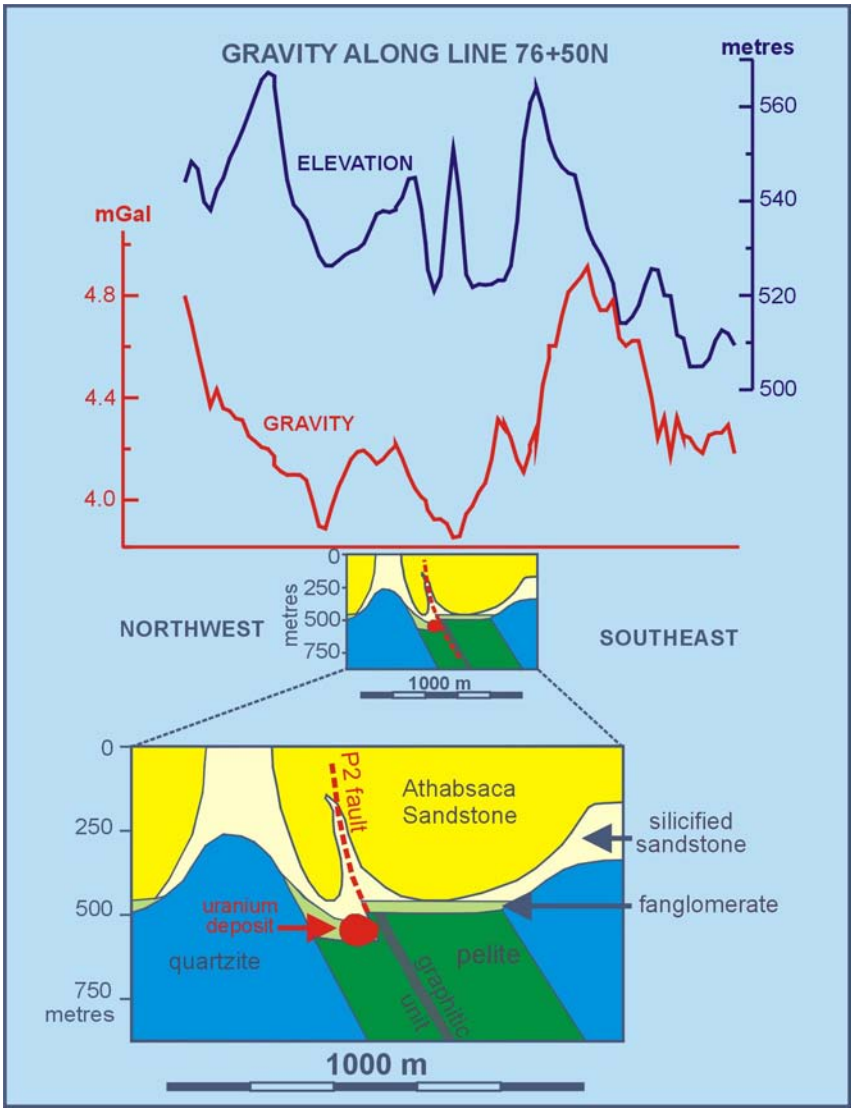

Figure 2 - Geological section along line 76+50N (modified from Marlatt** et al. **(1992) and McGill** et al. **(1993)). Note association of quartzite units with gravity highs. The unit to the southeast is interpreted to be a paleotopographic basement ridge.

3. Reduction of Gravity Data

Theoretically, most variations in a map of Bouguer gravity anomalies reflect density changes within the Earth's crust. Gravity observations made at the Earth's surface, however, also include the effects of latitudinal position and elevation, as well as variations relating to instrumental drift and Earth tides. These are eliminated in the process of deriving Bouguer anomalies. The correction for elevation includes two parts: a correction for height above datum (usually sea level), called the Free-Air correction, and a correction to remove the attraction of the slab of rock between the observation point and datum, known as the Bouguer correction. The density assigned to the slab should be that of the underlying rock, otherwise the Bouguer correction might be too large or too small. Because detailed density information is generally unavailable, a uniform density representing an estimated mean density of the near-surface rocks is commonly used. A mean crustal value of 2.67 g/cm^3 is widely adopted by many national surveys. A density of 2.00 g/cm^3 has been used in the case of the McArthur River high-resolution survey, because the surface topography is built of glacial overburden, a typical density of which is about 2.00 g/cm^3. The difference in the Bouguer anomaly obtained with 2.00 and 2.67 g/cm^3 is illustrated in Figure 4, and may be as large as 1 mGal.

The formula for the Bouguer correction presumes a slab of rock bounded by parallel planes, one of which coincides with sea level and the other passing through the observation point. In reality, however, the surface of the terrain is uneven with parts both above and below the gravity station. The 70 m of relief along the traverse represents fairly rugged topography in the context of this present gravity study, as gravity anomalies of just a few tenths of a mGal amplitude may be important in the search for uranium. Survey terrain corrections have been computed using a density of 2.00g/cm^3. A plot of terrain corrections along the traverse is shown in Figure 5. Although most are less than 0.1 mGal, many range from 0.1 to 0.35 mGal.

4. Modelling of Gravity Anomalies

The interpretation of the high-resolution gravity profile has used various constraints, one of which is information obtained from aeromagnetic maps. A map of the total magnetic field based on data from the Canadian Aeromagnetic Database was used. The data were collected along flight lines spaced 805 m apart at an elevation of 305 m. These data were originally collected in analogue format, but were later digitized. Since the Athabasca Sandstone itself is

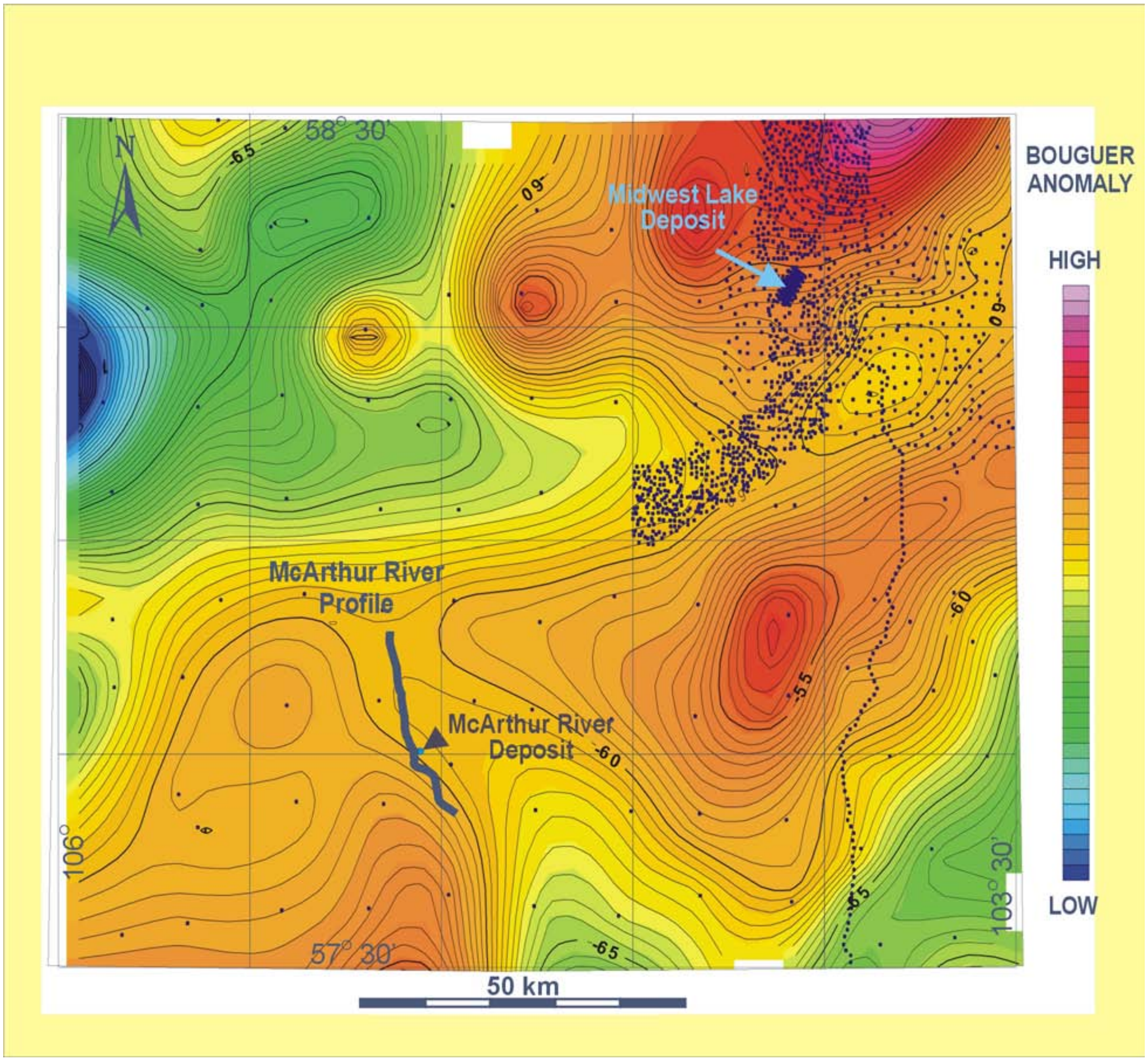

Figure 3 - Location of high-resolution gravity traverse on gravity map of region surrounding the McArthur River deposit. Station locations are indicated by dots. Contour interval=0.5 mGal.

essentially non-magnetic, the patterns and intensities of magnetic anomalies provide one of the few means of investigating the structure and composition of the underlying basement, both of which are of critical interest in the search for uranium deposits. The magnetic field works very well as a tool for differentiating the "first order" components of the basement, i.e., distinguishing metasedimentary rocks from the igneous varieties.

Magnetic susceptibilities measured on basement rocks (Annesley and Madore, 1993) illustrate the contrast in magnetic properties between granitoid rocks (susceptibility k = 0 to 20 SI x 10^{-3}), at one extreme, and metasedimentary pelitic, psammitic and calc-silicate gneisses (k = 0 to 4 SI x 10^{-3}), at the other. The susceptibility of meta-quartzites ranges from 0 to 0.2 SI x 10^{-3}. On the basis of these measurements, magnetic lows would be expected over metasedimentary regions, which host uranium, and magnetic highs over granitoid areas. This expectation is not as clear-cut in the area of the gravity traverse, because some magnetic highs occur over metasedimentary units. Clearly, a database of magnetic properties from the specific area under study would assist interpretation of magnetic anomalies.

Maps of the vertical gradient of the total magnetic field focus anomalies related to relatively shallow structures and, at the same time, eliminate longer wavelength signatures. A vertical gradient map was also used to interpret basement structure and contacts.

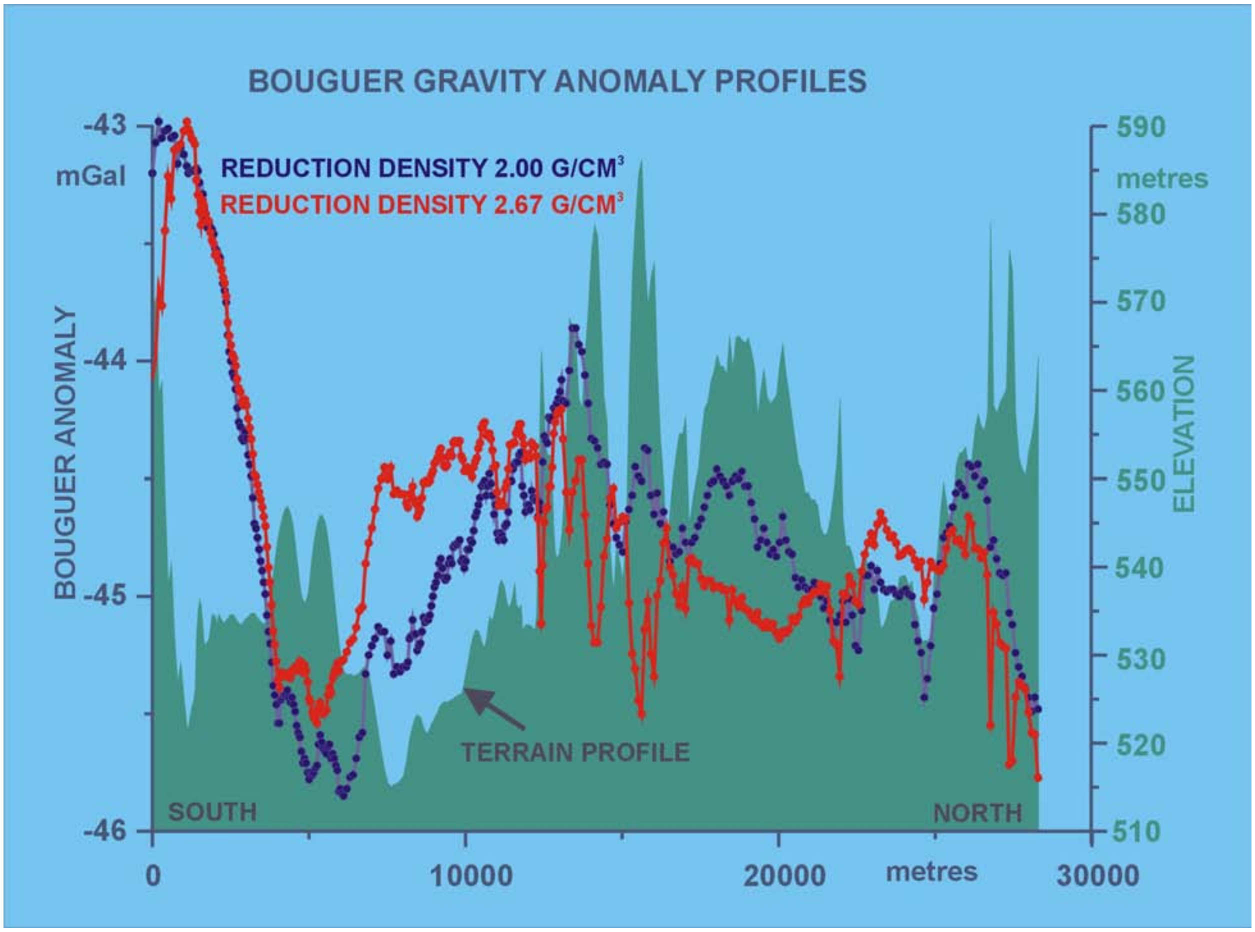

Figure 4 - Bouguer gravity anomaly profiles along the high-resolution gravity traverse derived using reduction densities of 2.00 and 2.67 g/cm³.

A gravity model which focuses on different parts of the vertical section is shown in Figures 6, 7, and 8. The model is composed of 2¾D prisms, elongate parallel to strike, which represent individual bodies. The real geological situation, however, should probably be regarded as 3D, since some magnetic trends indicate structure does not always parallel strike and there may be along-strike variations in density. A nice feature of the modelling package is that it allows the topographic relief to be included in the model.

The range of Bouguer anomalies along the profile is approximately 2.9 mGal. A prominent long wavelength gravity high (+1.75 mGal amplitude) is at the south end of the profile, flanked by a low (-1.15 mGal), ~6000 m wide, to the north. North of the low, variations in gravity are less extreme, but the general level of the field is disrupted by a significant number of small and intermediate wavelength (200 to 1800 m) anomalies, whose amplitudes are less than 0.5 mGal.

Gravity anomalies represent the sum effect of density variations at various depths and of different magnitudes. Models are, therefore, non-unique, but achieve more credibility when independent constraints are available. In this study, magnetic data, drill-hole logs, densities based on drill core information, and preliminary reflection seismic data provided constraints. A model showing the combined gravity effects of variations in basement geology, sandstone silicification/desilicification, and overburden thickness is shown in Figure 6.

The short wavelength (generally <500 m) gravity anomalies are attributed mainly to variations in overburden thickness (Figure 7). Several drill holes close to the gravity traverse have provided information on depth to the sandstone, and these have been projected to the line of the gravity profile. The depth to bedrock varies between 20 to 120 m. This variation has a profound influence on the gravity profile producing the short wavelength "sawtooth" noise observed along the profile. Drumlins have been observed to cover topographical lows or highs, making a big difference in the observed gravity pattern over these features. Changes in the density of the material within the overburden may have a minor effect on the gravity response, but this was not considered in the modelling.

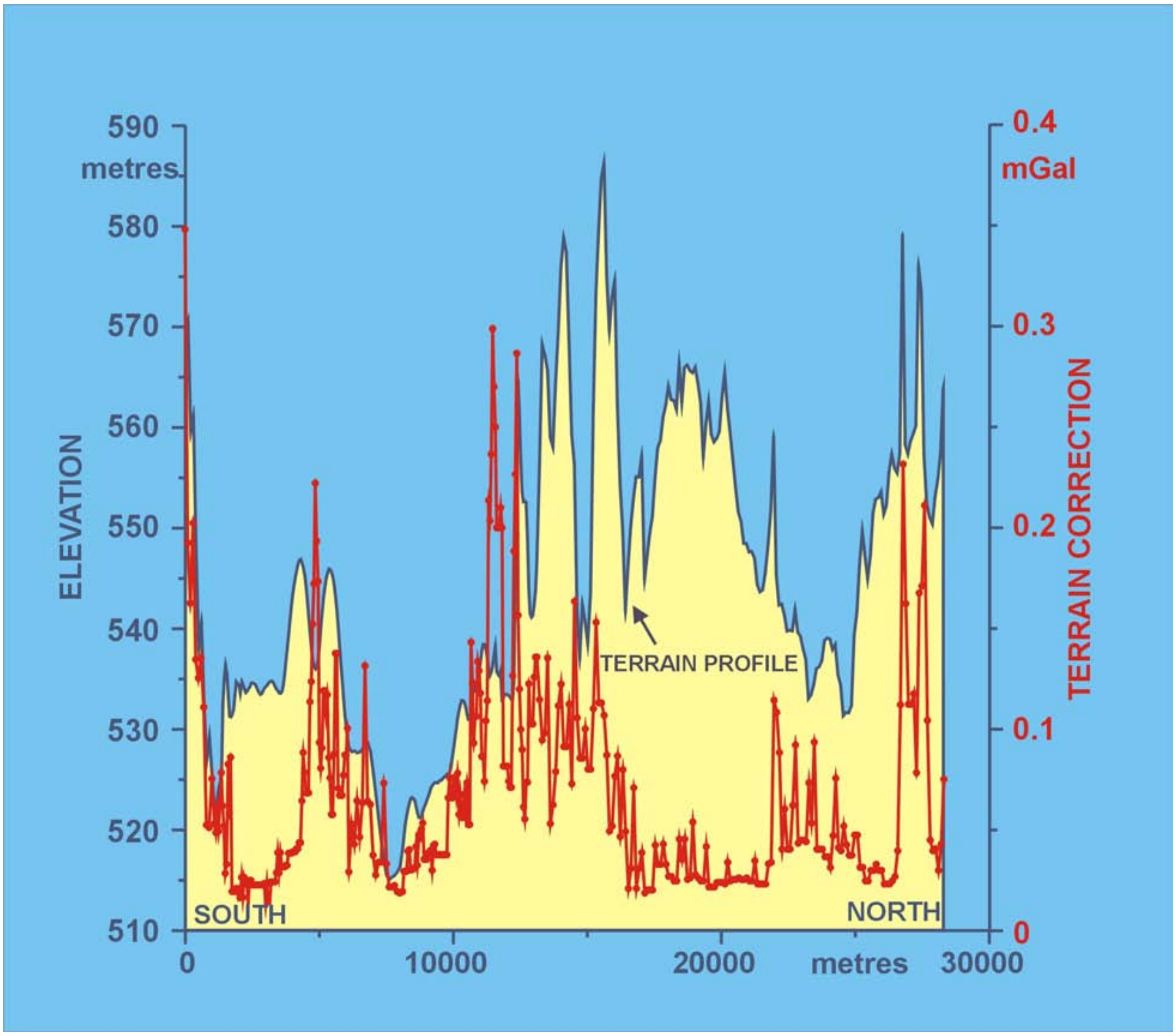

Figure 5 - Terrain corrections along the high-resolution gravity traverse.

Sharp, short wavelength anomalies, though primarily a manifestation of changes in overburden thickness, nevertheless are indicative of structure within the sandstone. Faulting and fracturing, as well fluid movement within these discontinuities, weakens the sandstone. Subsequent glacial scouring plucks boulders out of, or preferentially erodes, these planes of weakness to significant depths; surrounding competent rock remains relatively unaffected. The eroded hollows fill with lower density till creating distinct, short wavelength, negative gravity anomalies.

Intermediate wavelength (500 to 1800 m) anomalies are interpreted to be generally the result of alteration patterns in the sandstone (Figure 8) or either variations in the density of shallow basement, or shallow basement offsets. This is a reasonable conclusion because, in general, the basement beneath this profile is deeper than 500 m. Near the southern end of the profile, the top of one of the quartzite units is interpreted to come within 200 m of surface. The large amplitude gravity high in this area is, therefore, interpreted to be the result of basement paleotopography related to this quartzite ridge.

The long wavelength (>2500 m) gravity anomalies are attributed to a combination of variations in the density of the basement and offset of the unconformity at the base of the Athabasca Sandstone. Historically, gravity was used to map such features in order to prioritize drill targets along strike-extensive conductor trends. Recognition of prospective basement host rocks together with a structural trap is a key component in any exploration play. The largest gravity anomalies probably signify a coincidental basement offset and change in basement lithology.

There is significant alteration of the sandstone in the McArthur River area, a pattern that is likely to continue beneath the entire profile. Much of this alteration is related to sandstone silicification, particularly above quartzite

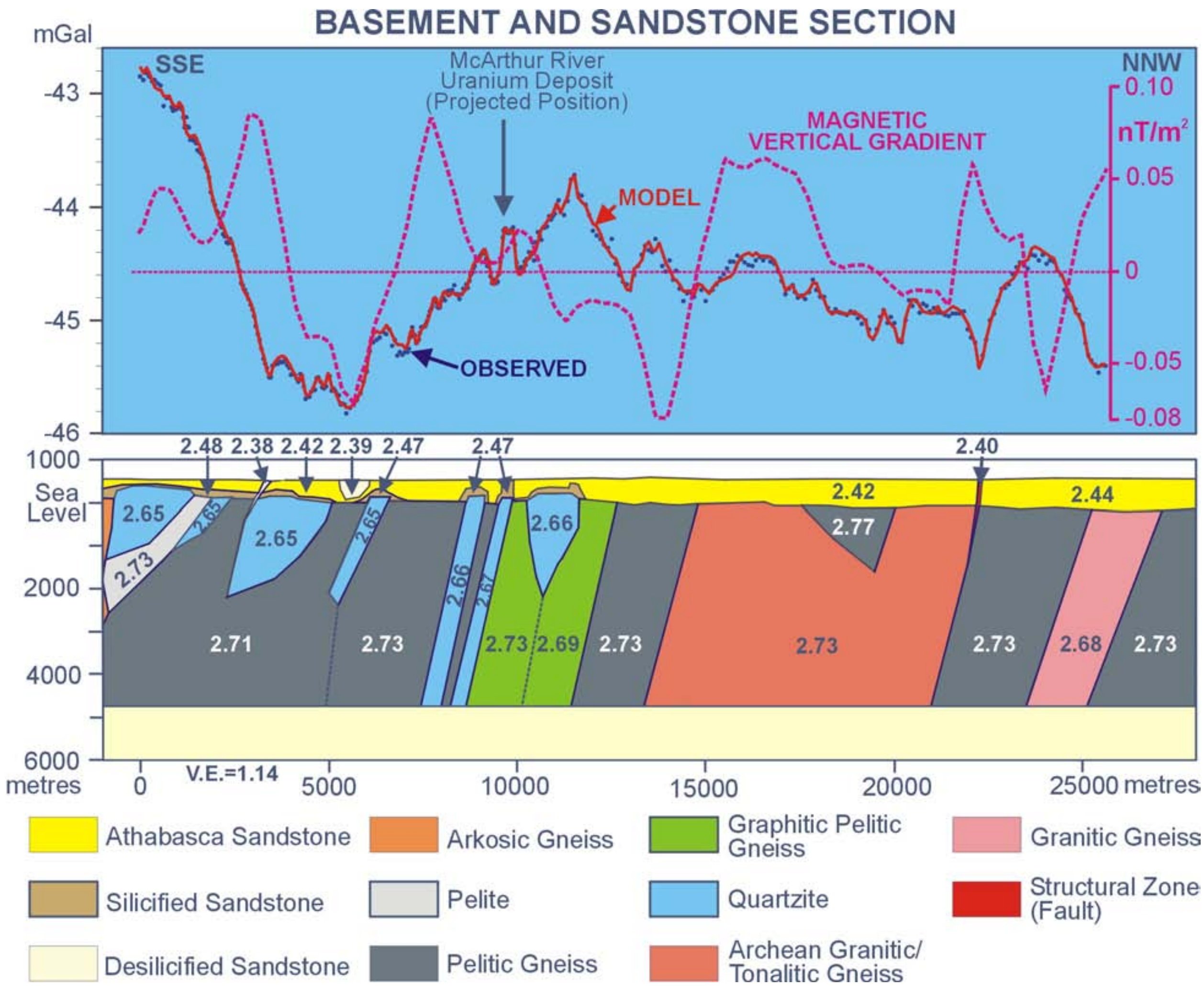

Figure 6 - Observed and modelled gravity profiles along the high-resolution gravity traverse. Densities (g/cm^3) of modelled geological units are indicated. Overburden layer is too thin to display at this scale.

ridges. The alteration portrayed in the model is basically related to higher density silicified zones as shown. Desilicification is just as important, but is not well represented in the gravity model. A better understanding of these types of alteration is required, since silicification/desilicification patterns are becoming more important to exploration from a fluid flow perspective.

It is important to note that even though drill holes are shown to penetrate the zones of silicification, they do not necessarily encounter silicification, as they are projected onto the profile line. It must also be remembered that there are three main potential contributors to the observed anomalies: changes in overburden thickness, basement offsets/highs, and sandstone alteration. The geometries of any one of these can change significantly, depending on how modelling proceeds. The model is as good as the constraints used to develop it.

5. Conclusions

The high-resolution gravity survey has defined several small, yet distinct gravity anomalies that may have significance for uranium exploration. They are modelled in terms of basement relief (some probably fault-controlled), changes in overburden thickness (may be indicative of underlying faults), and silicification/desilicification in the Athabasca Sandstone. The association of all of these features with uranium mineralization is well documented, hence segments of this profile hold potential for further investigation. They may well have potential for exploration, as some of the silicified/desilicified zones proposed from gravity modelling lie along strike from the McArthur River deposit, which itself is associated with intense silicification.

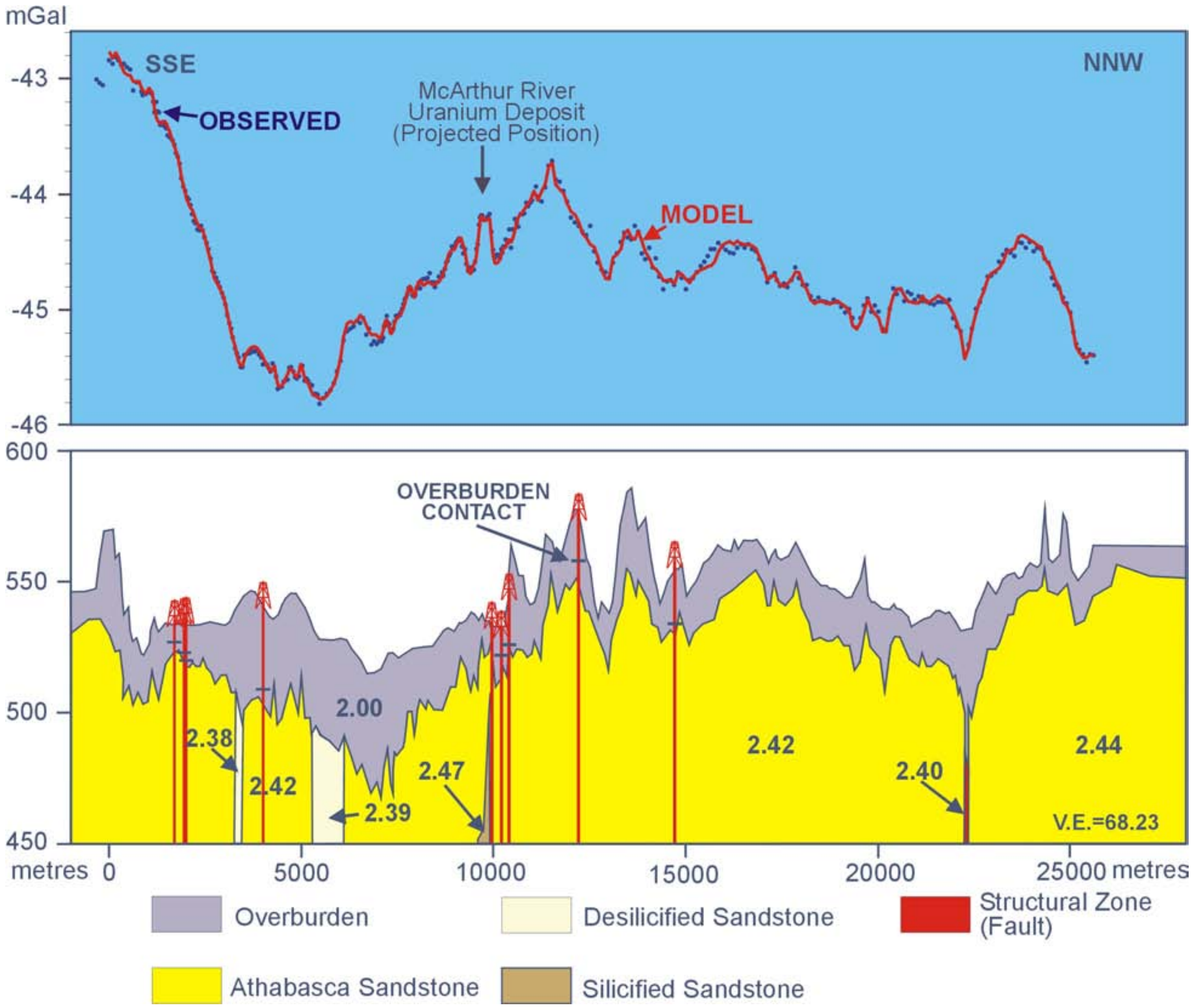

Figure 7 - Modelled overburden section. Tick marks on drill holes indicate depth of overburden/sandstone contact. Drill-hole information has been extrapolated from locations close to the traverse, hence tick marks do not necessarily coincide precisely with the modelled base of the overburden.

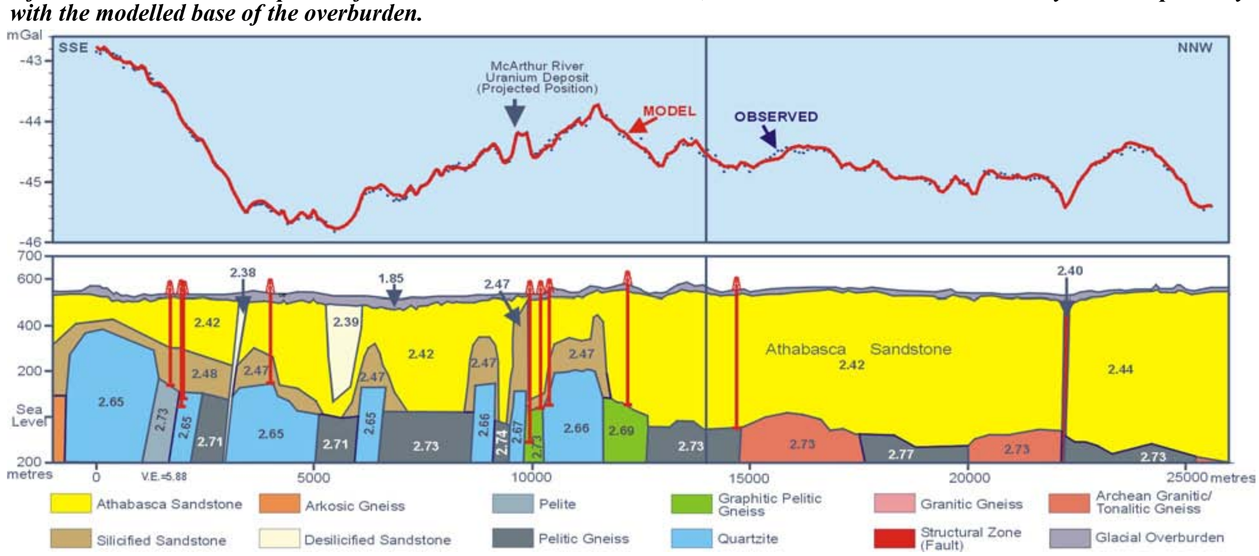

Figure 8 - Section of high-resolution gravity model highlighting regions of silicification/desilicification within the Athabasca Sandstone, and relief on the Precambrian basement.

Studies of the P2 North deposit indicate that the silicification event pre-dated hydrothermal alteration associated with the main phase of mineralization. It is further suggested that silica-rich fluids were associated with mineralizing fluids in the early stages of ore formation. The identification of silicified zones is, therefore, of considerable importance for exploration. This study indicates that gravity may contribute to the identification of these zones. The model presented here is still regarded as preliminary, and hopefully will be enhanced when it is further constrained by results of electromagnetic and reflection seismic studies along the same traverse. The gravity model portrays basement units as having steep contacts, whereas seismic interpretation indicates that dips are significantly more gentle, and directed towards the southeast. Overburden depths derived from the seismic data will also be examined, along with information provided by modelling of electromagnetic data. Studies on recently acquired gravity data adjacent to the traverse are also planned, which should also help consolidate the integrated model.

6. Acknowledgments

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