A GRAVITY STUDY OF THE NORTHWESTERN BOUNDARY FAULT
OF THE SOUTHERN KAPUSKASING STRUCTURAL ZONE

by

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A thesis submitted in conformity with the requirements
for the degree of Master of Science
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M.Sc. Thesis by Bogdan Nitescu
Department of Geology, University of Toronto, 2000

ABSTRACT

The northwestern boundary of the Kapuskasing Structural Zone is formed by the Saganash Lake Fault, which was previously interpreted as a northwest dipping normal fault. A gravity study was initiated in the Little Missinaibi Lake – Racine Lake area with the purpose of determining the nature of this fault at its southern end. Gravity observations were made with a Lacoste-Romberg Model G gravity meter along a 40 km profile that is normal to the trace of the fault. The Bouguer gravity values show an increase of over 35 mgal across the fault, reflecting the presence of uplifted deep crust southeast of the Saganash Lake Fault. 2.5D gravity modeling suggests that at its southern end the Saganash Lake Fault is a reverse fault with a dip of 60°-70° SE and a depth extent of 10-15 km. This result supports the model of a pop-up structure for the southern Kapuskasing Structural Zone.
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1. INTRODUCTION

The Kapuskasing Structural Zone (KSZ) is a northeast-trending, fault-bounded, discontinuous belt of Archean high grade (granulite to upper amphibolite) metamorphic rocks, which cuts diagonally across the generally east-west subprovince structure of the south-central Superior Province, and extends 500 km southwestward from James Bay (Fig. 1-1). The high grade rocks within this discordant structure are characterized by high densities, high magnetic susceptibilities and high seismic velocities. The strong contrast in physical properties between the rocks of the KSZ and those in adjacent areas produces prominent gravity, magnetic and seismic anomalies. These geophysical anomalies attenuate in a region situated about 20 km west of Chapleau, which corresponds to the disappearance of the granulite to upper amphibolite rocks.

Various interpretations have been proposed for the KSZ. The early models included thinning of the granitic upper crust (Garland, 1950), mafic intrusions along a rift system (Innes et al., 1967), a horst (Bennett et al., 1967), an intercontinental suture (Wilson, 1968), a failed arm of a triple junction associated with the Keweenawan rift (Burke and Dewey, 1973), and a sinistral transcurrent fault zone (Watson, 1980). Based on evidence obtained from geological mapping, geobarometric measurements, and gravity modeling, Percival and Card (1983, 1985), and Percival and McGrath (1986) have interpreted the KSZ as an east-verging Proterozoic thrust fault system. In this model, a slab of deep crust was uplifted along the northwest-dipping Ivanhoe Lake Fault, which represents the southeastern boundary fault of the KSZ (Fig. 1-2). The thrust model was confirmed by the results of the seismic surveys conducted in KSZ under the auspices of Lithoprobe (Boland and Ellis, 1989; Percival et al., 1989; Geis et al., 1990; Clowes et al., 1992). On the basis of the configuration of the Matachewan dyke swarm, West and Ernst (1991) proposed a modification of the simple thrust model by inferring substantial Proterozoic dextral displacement.
Fig. 1-1: Regional geology of the Superior Province (after Portal, 1980).
Fig. 1-2. Geological map of the central Superior Province showing the fault-bounded blocks of the Kapuskasing Structural Zone (after Buranall et al., 1994).
The northwestern boundary fault of the central and southern KSZ is represented by the Saganash Lake Fault. In central KSZ the Saganash Lake Fault separates the Kapuskasing granulites from the amphibolite facies rocks of the Wawa Subprovince to the west, whereas in southern KSZ there is lithological and metamorphic continuity across the Saganash Lake Fault, the transition from amphibolite facies to granulite facies rocks being gradational (Fig. 1-2).

The geophysical data have led to contradictory interpretations regarding the nature and characteristics of the Saganash Lake Fault. On the basis of gravity and magnetic investigations in central and southern KSZ, Percival and Card (1983), Percival and McGrath (1986) and Atekwana et al. (1994) have suggested that Saganash Lake Fault is a northwest dipping normal fault formed as a collapse structure in response to crustal thickening which occurred during uplift along the Ivanhoe Lake Fault. Based on Lithoprobe seismic reflection data from the southern KSZ (Fig. 1-3), Manson and Halls (1997) suggested that Saganash Lake Fault dips to the southeast, so that the KSZ in the vicinity of Chapleau has the geometry of a pop-up structure bounded by inward-dipping reverse faults.

The different interpretations of the Saganash Lake Fault indicate the necessity of new geophysical investigations across this fault. The gravity study presented in this thesis was initiated with the purpose of providing a better understanding of the nature of Saganash Lake Fault at its southern end. The gravity measurements were conducted in the summer of 1998 along a profile crossing the fault in the region of gradational transition between the amphibolite grade rocks of Wawa Subprovince and the granulite grade rocks of southern KSZ. The study attempts to clarify two main problems concerning the southern Saganash Lake Fault: [1] the fault attitude and [2] the depth extent of the fault.

*The name of the fault is erroneous since the fault does not go through or nearby Saganash Lake, but it was used previously in the literature (e.g. Percival and McGrath, 1986; Bursnall et al., 1994; Percival and West, 1994).
Fig. 1-3. Lithoprobe regional seismic reflection data from southern KSZ suggesting that the Saganash Lake Fault dips to the SE. Seismic line locations are indicated on the map.
2. GEOLOGICAL BACKGROUND

2.1 Geological setting and structural framework of the Kapuskasing Structural Zone

The Superior Province of the Canadian Shield forms the core of the North American continent. It is the largest exposed Archean craton, and consists of igneous and metamorphic rocks with U-Pb zircon dates of 3.5-2.6 Ga (Percival and McGrath, 1986). The recent interpretations of the formation of the Superior Province suggest that it is the result of repeated plate tectonic interactions (Card, 1990; Williams, 1990; Williams et al., 1992). However, opinions non-supportive of a plate tectonic origin for the Archean crust were also expressed recently (Hamilton, 1998). The Superior Province was stabilized ca. 2.5 Ga ago, but its geological evolution continued in Proterozoic with a protracted period of faulting and dyke emplacement (Williams et al., 1992).

The southern Superior Province is composed of subparallel east-west trending granite-greenstone and metasedimentary subprovinces (Fig. 1-1). The granite-greenstone subprovinces are dominated by granitoid and gneissic rocks and contain supracrustal assemblages of mainly volcanic origin, which are metamorphosed to greenschist-amphibolite facies. The metasedimentary belts consist predominantly of metagreywackes and derived migmatite and granite. The subprovince boundaries are generally zones of complex tectonic interactions and some of them are marked by steep strike-slip faults (Clowes et al., 1992, Percival and West, 1994).

In south-central Superior Province the east-west trending Quetico and Opatica metasedimentary-plutonic subprovinces in the north, and Wawa and Abitibi granite-greenstone subprovinces in the south are separated by the northeast striking Kapuskasing Structural Zone (Fig. 1-2), characterized by high grade metamorphic rocks and positive gravity and aeromagnetic anomalies. Based on similar stratigraphic sequences, ages of rock units and the character of syn- and postvolcanic plutonic rocks, the Wawa and Abitibi subprovinces can
be correlated across the KSZ, this correlation indicating the intra-cratic character of the KSZ structure (Percival and Card, 1985, Percival and West, 1994). In Wawa Subprovince a continuous transition is observed from the low grade metavolcanic rocks of the Michipicoten belt, through amphibolite facies tonalitic gneiss and felsic plutons of the eastern Wawa Subprovince (Wawa Gneiss Domain), to granulite facies rocks of the KSZ, which are juxtaposed to the east against the low grade greenstone units and granitic intrusions of the Abitibi Subprovince. This transition is interpreted (Percival and Card, 1983, 1985) as representing an exposed oblique cross-section through the Archaean crust, the different metamorphic grades corresponding to different crustal levels: Michipicoten belt – upper crust, Wawa Gneiss Domain – middle crust, KSZ – lower crust.

On the basis of combined geological (distribution of high grade rocks) and geophysical (gravity and aeromagnetic anomalies) attributes, Percival and McGrath (1986) identified three distinct tectonic blocks within the KSZ. Although the KSZ is characterized by both gravity and aeromagnetic anomalies, the two types of anomalies are not perfectly coincident. Positive aeromagnetic and gravity anomalies are coextensive in southern and northern KSZ, whereas in the central KSZ the anomalies diverge by up to 45 km. The spatial distribution of the aeromagnetic anomaly coincides with the surface occurrence of granulite grade rocks. The aeromagnetic anomaly is moderate (250-500 nT) in southern KSZ and is strong (750-1000 nT) in central and northern KSZ. The gravity anomaly is strong (40-50 mgal) in both northern and southern KSZ, but is not continued in central KSZ. It deviates to the west of the central KSZ in a region of the Wawa Subprovince (Val Rita block) characterized by amphibolite facies rocks.

The northern block of the KSZ is the Fraserdale-Moosestone block, which is bounded by the Foxville fault to the west and by the Bad River fault to the east (Fig. 1-2). It consists mainly of granulite facies paragneiss and mafic gneiss with 8 to 10 kbar paleopressures, indicating about 13 km of uplift with respect to the lower-pressure rocks (4-5 kbar) of the Quetico belt. Based on gravity modeling, the block was interpreted as a pop-up structure (Percival and McGrath, 1986).
The central block of the KSZ is the Groundhog River block, which is separated from the northern Fraserdale-Moosonee block by a 65-km gap without granulites. The block is bounded by brittle faults to the east (Ivanhoe Lake Fault) and west (Saganash Lake Fault), and is characterized by an intense positive aeromagnetic anomaly and negligible gravity expression. The Groundhog River block consists of granulite facies mafic gneiss, tonalite gneiss and paragneiss. The estimates of the metamorphic paleopressure are in a range of 7 to 9 kbar (Percival and McGrath, 1986) implying at least 15 km of uplift along the Ivanhoe Lake Fault, which juxtaposes the Kapuskasing granulites against the low grade rocks of the Abitibi Subprovince. Based on potential field data, the Groundhog River block was interpreted as a thin (2-4 km thick) thrust wedge of granulite, bounded to the east by a west-dipping thrust fault and to the west by a west-dipping normal fault (Percival and McGrath, 1986; Atekwana et al., 1994).

The Chapleau block in southern KSZ is the largest part of the Kapuskasing structure. It is separated from the Groundhog River block by the Wabusimi River Fault (Fig. 1-2) and is bounded by the Ivanhoe Lake Fault to the southeast and the Saganash Lake Fault to the northwest. The northern part of the Chapleau block consists of northeast-striking belts of upper amphibolite to granulite facies paragneiss, mafic gneiss and tonalite gneiss similar to those of the Groundhog River block, and a layered anorthosite-gabbro intrusion, the Shawmere complex. The block broadens to the southwest and merges with the central Wawa Gneiss Domain along an irregular, north-trending, 10-km-wide zone east of Chapleau, which is defined by lithological, structural and metamorphic changes reflecting the transition to the amphibolite facies rocks of Wawa Subprovince (Fig. 1-2). Across this transition the estimated pressures of metamorphism decrease from 9-11 kbar in the Chapleau block granulites to 5-6 kbar in the Wawa Gneiss Domain (Percival and West, 1994). The source of the large gravity anomaly associated with the Chapleau block was modeled as a fault-bounded slab of dense rocks uplifted along the northwest-dipping Ivanhoe Lake Fault (Percival and Card, 1983, 1985; Percival and McGrath, 1986; Atekwana et al., 1994). This interpretation is supported by the
Lithoprobe seismic refraction and reflection data (Boland and Ellis, 1989; Percival et al., 1989; Geis et al., 1990).

A fourth uplifted block, the Pineal Lake block (Fig. 2-1), was recently discovered, based on changes observed in certain physical and petrological properties (paleomagnetic polarity, feldspar clouding intensity, feldspar hydrous alteration level) of the Proterozoic Matachewan dykes that indicate variations in their emplacement level (Halls and Zhang, 1995a, 1998; Zhang, 1999). The Pineal Lake block is 20 km sinistrally offset from the Chapleau block and extends 60 km to the southwest. It terminates to the west along a north-south fault (McEwan Lake Fault), which on the basis of gravity data was interpreted as a west-verging thrust having a depth extent of 5-7 km (Halls and Mound, 1998).

2.2 Rock units of central-eastern Wawa Gneiss Domain

The central-eastern Wawa Gneiss Domain consists of variably foliated tonalitic to granodioritic orthogneisses and plutons (mainly granitic and granodioritic) surrounding kilometre-scale belts of amphibolite to granulite grade mafic gneiss and paragneiss. The tonalitic gneiss is the predominant rock type in the central Wawa Gneiss Domain, making up approximately 65% of the exposed area (Moser, 1994). Near Chapleau, the tonalitic units extend from the Wawa Gneiss Domain into the KSZ. The oldest rocks of the Wawa Gneiss Domain are tonalitic gneiss components, dated by U-Pb on zircon at 2920 Ma (Moser et al., 1991; Percival and West, 1994). The distribution of these rocks is not known because they are indistinguishable petrographically from younger tonalitic gneisses in the area. The U-Pb age determinations show a wide range of ages for the tonalitic rocks of the Wawa Gneiss Domain, from 2820 Ma to 2680 Ma (Moser, 1994). In the units from southwestern Chapleau block, the metamorphism of tonalitic gneiss has produced leucosomal segregations with U-Pb zircon ages of 2660 and 2645 Ma (Moser, 1994). The bodies of plutonic rocks in Wawa Gneiss Domain have ages from 2690 to 2833 Ma (Percival and West, 1994).
Fig. 2-1. Geological maps showing the location of the Pineal Lake block (PB), which is offset sinistrally from the Chapleau block (CB) along the Nagasin Lake Fault (NLF). The block is bounded to the west by the McEwan Lake Fault (MLF). BLF, MRF and ACF refer to the Budd Lake Fault, Montreal River Fault and Agawa Canyon Fault.

a. The dots represent sites where paleomagnetic polarity data have been obtained. The red areas correspond to deep crustal levels where the Matachewan dykes have normal magnetic polarity. The blue and purple areas represent shallower crustal levels where the dykes have mostly reversed magnetic polarity.

b. The dots represent sites where feldspar clouding data have been obtained. The blue and green areas correspond to deep crustal levels where the Matachewan dykes have cloudy feldspars. The yellow areas represent shallower crustal levels where the dykes have clear feldspars.

The figures are modified after Halls and Zhang (1998) through the addition of new data and corrections for misplaced points (H.C. Halls, unpublished maps).
The area of the gravity study is located 30 km north of Chapleau, in the region of complex transition between the amphibolite grade rocks of the central-eastern Wawa Gneiss Domain and the granulites of the Chapleau block (Fig. 2-2). It extends from Little Missinaibi Lake in the northwest to Racine Lake in the southeast. In this area the tonalitic gneiss generally consists of hornblende-biotite-plagioclase-quartz ± K-feldspar assemblages. Mafic gneiss occurs as enclaves within the tonalitic gneiss at scales ranging from 1 m to several tens of meters, the abundance of the enclaves increasing eastwards (Moser, 1994). The mafic gneiss contains a dominant assemblage of fine-grained amphibole, plagioclase, and minor biotite and quartz. Southeast of the Saganash Lake Fault, there are two kilometre-scale bodies of mafic tonalite (15%-20% amphibole) cross-cutting the tonalitic gneiss. Also, an east-west trending, kilometre-scale belt of migmatitic paragneiss occurs southeast of the fault (Fig. 2-2). Northwest of the Saganash Lake Fault the gravity profile crosses the Windemere Batholith, which is a 15 km x 20 km complex of massive, leucocratic granitoid rocks including tonalite, granodiorite, and granite. In the whole area of study granitoid pegmatites are ubiquitous as centimetre- to metre-scale veins and dykes.

The central-eastern Wawa Gneiss domain is transected by north trending dykes belonging to the 2.45-Ga Matachewan swarm, which are clearly visible on the aeromagnetic map. The dykes are iron rich tholeiites often characterized by calcic plagioclase phenocrysts (Zhang, 1999). North-east trending dykes belonging to the 2.04-Ga Kapuskasing swarm occur southeast of the Saganash Lake Fault, and are also visible on the aeromagnetic map. Both types of dykes have predominant clinopyroxene and labradorite, with minor calcic amphibole, ilmenite, magnetite and quartz (Percival et al., 1994).

2.3 Uplift history of the Chapleau block

Constraints on the uplift history of the southern KSZ are provided by a variety of isotopic age data, the Matachewan and Kapuskasing dykes, and two sets of alkaline rock – carbonatite complexes which occur in spatial association with the KSZ.
Fig. 2-2. Geological map of the study area (after Moser, 1994).
The U-Pb geochronology suggests that the Kapuskasing rocks in southern Chappleau block remained at high temperature and significant depth until about 2500 Ma. The U-Pb zircon ages decrease with increasing paleodepth, from 2663 Ma near the western limit of the granulite facies to 2582 Ma in the east, and the U-Pb titanite ages decrease eastward from 2550 Ma at the amphibolite-granulite transition, to 2514-2493 Ma at the deepest structural levels within a few kilometres of the Ivanhoe Lake Fault Zone (Krogh, 1993; Percival and West, 1994).

$^{40}$Ar/$^{39}$Ar hornblende and biotite ages as old as 2500-2450 Ma from the deepest structural levels of the KSZ indicate that early uplift has occurred in this time interval, before the emplacement of the Matachewan dyke swarm at 2454 Ma (Percival and West, 1994). On the basis of the differences between the crystallization pressures of the Matachewan dykes and the metamorphic pressures of their country rocks in the Chappleau block, Percival et al. (1994) estimated that the pre-Matachewan uplift has a magnitude of 0-8 km.

There are several lines of evidence for uplift after the emplacement of the Matachewan dyke swarm: deformation of the Matachewan dyke swarm (Bates and Halls, 1991; West and Ernst, 1991), tilting and offset of the Kapuskasing dykes in the Ivanhoe Lake Fault Zone (Percival and West, 1994), paleomagnetic polarity reversals and mineralogical (feldspar clouding and hornblende Al content) variations in the Matachewan dykes indicating significant differences in the depth of emplacement across KSZ (Halls et al., 1994).

Geobarometric data on closely spaced Matachewan and Kapuskasing dykes suggest that some uplift (4-7 km) may have occurred in the interval 2.45-2.04 Ga between the emplacement of the Matachewan swarm and the emplacement of the Kapuskasing swarm (Percival et al., 1994). An episode of fault reactivation in this interval is also supported by ages in the range 2.2-2.3 Ga for micas close to the fault zones (Hanes et al., 1994).

The main uplift postdates the emplacement of the Kapuskasing dyke swarm and, based on the crystallization pressures of the Kapuskasing dykes exposed in KSZ, has a magnitude of 10-17 km (Percival et al., 1994). The Rb-Sr biotite ages in KSZ (Percival and
Peteman, 1994) decrease eastward from 2500 Ma in Wawa Gneiss Domain to 1930 Ma near Ivanhoe Lake Fault Zone, implying that temperatures in the deep crust remained above 280°C until 1930 Ma. This pattern suggests a post-1930-Ma uplift (Percival and West, 1994). The lower age bracket for the uplift is uncertain, but the 1.88-Ga Cargill alkaline rock – carbonatite complex emplaced on the Lepage fault in northern Wawa Gneiss Domain is only slightly offset, suggesting that the major KSZ deformation had occurred by this time (Percival and West, 1994). The deformation at ca. 1.9-1.85 Ga is probably the effect of an Early Proterozoic orogenic collision at the margins of the Superior Province, possibly the Trans-Hudson orogen (Manson and Halls, 1997) or the Penokean orogen (Percival and Peteman, 1994; Riller et al., 1999).

Late magmatic activity associated with the Kapuskasing structure is represented by the intrusion of alkaline rock – carbonatite complexes and lamprophyre dykes in the interval 1.14-1.01 Ga, and minor faulting at 1.1 Ga, which may be related to alkaline igneous activity, or to distant structural effects of the Grenville orogen (Percival and West, 1994).
3. GRAVITY DATA ACQUISITION AND PROCESSING

3.1 The gravity survey

The gravity survey was conducted along a logging road which crosses the Saganash Lake Fault about 30 km north of Chapleau (line AB on Fig. 3-1). In total, fifty-seven gravity stations were established, seven of which (stations 51-57) are situated on the shores of Racine Lake (Fig. 2-2) and have no road access. The gravity stations are spaced at distances of 0.3-1 km when projected on a straight line orthogonal to the strike of the fault. The gravity observations were made during a five-day period, with repeat measurements at the beginning and end of each day at Control Station 9002-84 of the Canadian Gravity Standardization Net located at Chapleau Airport, and having a gravity value of 980751.06 mgal.

The instrument used to measure the gravity differences between the gravity stations and the base station situated at Chapleau Airport was a Lacoste-Romberg Model G gravity meter loaned from the Geodetic Division of Geomatics Canada. The accuracy of the model G meter is 0.01 mgal. The gravity meter has a thermostat for temperature control and achieves drift rates of 0.5 mgal/month. Given this small drift rate, the largest source of errors in the field comes from the irregular drift produced by the vibrations and the various bumps encountered during the transport of the instrument. In order to reduce these unwanted effects, the meter was transported in a carrying case equipped with a shock-mounted cradle.

The drift control for the gravity survey was achieved by occupying the base station at the beginning and end of each survey day. For the road traverses excellent results were obtained, the largest closure error being only 0.03 mgal. In the case of the lake traverse, the gravity meter was transported by boat without the shock-mounted cradle and, as a result of the wave action, the irregular drift of the meter was larger, a closure error of 0.1 mgal being obtained.
Fig. 3-1. Shaded relief aeromagnetic map (total field intensity) of the southern KSZ showing the location of the gravity profile (line AB). The aeromagnetic expression of the Saganash Lake Fault (SLF) is clearly visible. Illumination azimuth: 295°. Illumination inclination: 29°.
3.2 The GPS survey

The reduction of the gravity observations requires the determination of the elevation and position (latitude) of each of the gravity stations. For this purpose a semi-kinematic differential GPS survey was conducted along the gravity profile. The GPS survey involved two Ashtech GPS receivers, one remaining permanently fixed at a base station and the other tracking the movement of the vehicle along the road. Both receivers acquired signals simultaneously from the same satellites and measured the (pseudo-)range to each satellite by multiplying the signal propagation time by the speed of light. A 2-3-minutes occupancy time at each of the road gravity stations with the mobile receiver ensured an increased accuracy as a result of the accumulation and averaging of several measurement epochs. The role of the stationary receiver was to provide error corrections (clock, orbit, propagation), improving thus considerably the accuracy of the measurements.

The elevations of the gravity stations located on the shores of Racine Lake in areas not accessible by land were measured in the field with respect to the water level using a simple ruler. For the determination of the absolute elevation of the lake level a lakeshore point situated at the water level and accessible by road was occupied with the GPS receiver. The positions (latitudes) of the lake stations were determined from the NTS 1:50000 map.

The accuracy of the GPS processed data (both elevations and horizontal positions) is estimated to be at the decimetre level. In the case of the stations located on the shores of the lake the uncertainty in their horizontal position is considered to be about 25 m.

In order to test the accuracy of the GPS-determined elevations a conventional survey using a Wild NA2 Universal Automatic level was undertaken along a segment of the gravity profile. The differences between the values of relative elevation obtained from the conventional survey and those provided by GPS were about 0.2 m (Fig. 3-2), confirming the estimated accuracy of the GPS results.

The elevations of all of the gravity stations are presented in Fig. 3-3.
Fig. 3.2: Comparison between the GPS elevations and the results of a conventional survey along a segment of the gravity profile.
Fig. 3-3: The elevation and the Bouger gravity values along the gravity profile.
3.3 The reduction of field observations

A series of reductions are made to the measured gravity values in order to obtain the Bouguer gravity values, which reflect only lateral density variations in the subsurface.

A preliminary sequence of operations is usually applied to the gravity meter readings, in order to derive the absolute gravity values in each of the gravity stations of a survey. First, the meter readings are converted from instrument units to gravity units (usually milligals) by multiplying them with a scale constant supplied by the manufacturer of the gravity meter. The values obtained are corrected for the tidal effects of the sun and moon, which are both time- and latitude-dependent and can have amplitudes of the order of 0.3 mgal. Also, based on the closure errors (differences obtained between readings taken at the base station, corrected for the tidal effects), a correction for the irregular drift is applied to the observations in each of the stations by linear interpolation. The values corrected for earth-tides and drift allow the determination of the gravity differences between each of the gravity stations and the base station, and the absolute value of gravity in each gravity station can be obtained if the absolute value is known for the base station.

The usual reduction procedure of the values of observed gravity attempts to account for the total mass of the Earth, the ellipsoidal shape of the Earth, the rotation of the Earth, the elevation of the observation point above the sea level and the attraction of the "normal" mass situated above sea level (Nettleton, 1976; Blakely, 1995; Simpson and Jachens, 1989). The Bouguer anomaly (BA) values are computed according to the following equation:

\[
BA = g_{\text{obs}} - (g_o + g_{FA} + g_B + g_T),
\]

where:
- \( g_{\text{obs}} \) is the observed gravity value corrected for drift and tidal effects.
- \( g_o \) is the latitude-dependent theoretical value of gravity at the surface of the reference ellipsoid. It accounts for the first three effects mentioned above.
• $g_{F_A}$ is the free air term. It adjusts the theoretical value of gravity at sea level to account for the elevation of the gravity station. The rate for the vertical decrease of gravity with increasing elevation is 0.3086 mgal/m, which represents the theoretical vertical gradient of gravity.

• $g_b = 0.04193 \cdot \sigma \cdot h$ is the Bouguer correction which accounts for the mass between the observation point and sea level by approximating it with an infinitely extended horizontal slab of density $\sigma$ and thickness $h$ equal to the height of the observation point above sea level. In most standardized gravity reduction operations, the density value used for the Bouguer correction is $\sigma = 2.67$ g/cm$^3$, which is considered to be an average crustal density. The purpose of the Bouguer correction is to adjust the theoretical value of gravity at the point of observation to include the effect of an idealized mass layer.

• $g_T$ is the terrain correction, which accounts for the departures of the Earth's surface from an idealized flat surface (as it was considered in the Bouguer correction).

The Bouguer anomaly as defined by Equation [1] represents the gravity effects of the subsurface geology at the point of measurement resulting from the difference between the gravity observed at that point and the gravity (also at the same point of observation) caused by a defined earth model. The Bouguer anomaly may also include effects caused by deficiencies in the earth model (the infinite horizontal layer considered for the Bouguer correction or the fact that the free-air and Bouguer adjustments use the sea level as the reference elevation rather than the surface of the ellipsoid).

The gravity observations considered in the study presented in this thesis were corrected for the tidal variations, irregular drift, latitude and elevation effects, using a software application (PCGRAV) provided by the Geodetic Survey Division of Geomatics Canada. For the calculation of the theoretical gravity, the PCGRAV application uses the Gravity Formula 1967, which yields theoretical gravity values on the surface of the reference ellipsoid defined by the Geodetic Reference System 1987 (Geomatics Canada, unpublished manuscript):
\[ g_0 (\psi) = 978031.85 \left[ 1.0 + 0.005278895 \sin^2(\psi) + 0.000023462 \sin^4(\psi) \right] \text{ (mgal)}, \]

where \( \psi \) is the station latitude in degrees.

The Bouguer correction was applied for the standard crustal density of 2.67 g/cm\(^3\). Given the small topographic irregularities in the area of study, terrain corrections were omitted, as they were negligible.

The Bouguer gravity profile (Fig.3-3) was produced by projecting the positions of the gravity stations on a straight line perpendicular to the strike of the fault, the orientation of the fault having been inferred from its aeromagnetic expression (Fig. 3-1).

3.4 Analysis of errors

The final uncertainty in the Bouguer gravity values was estimated by considering the various sources of error occurring in the process of gravity, elevation and position data acquisition, and also the errors caused by the assumptions made for the reduction of the gravity observations.

The irregular drift of the gravity meter caused an uncertainty in the Bouguer gravity values of maximum 0.03 mgal for the land stations (stations 1-50) and 0.1 mgal for the lake stations (stations 51-57).

For the standard crustal density value of 2.67 g/cm\(^3\), the elevation factor (the combined free-air and Bouguer corrections) has a value of 0.20 mgal/m. Therefore the uncertainty of about 0.25 m corresponding to the GPS-determined elevations translates into approximately a 0.05-mgal uncertainty in the Bouguer gravity.

The horizontal positions of the land stations were determined with the GPS and have decimetre accuracy. The horizontal positions of the lake stations were determined from the 1:500000 topographic map, and have an uncertainty of 25 m. Since at 48° latitude (the survey latitude) a variation of 100 m in the north-south direction produces a change of about 0.08
mgal in the theoretical value of gravity (Nettleton, 1978), the largest error in the value of the theoretical gravity term is less than 0.001 mgal for land stations and 0.02 mgal for lake stations.

The omission of terrain corrections in the case of a regional relief of less than 80 m over 20 km is estimated to have caused an error in the Bouguer gravity which is not greater than 0.1 mgal (Jones, 1973).

In summary, the maximum expected error for the Bouguer gravity is less than 0.2 mgal for the land stations and less than 0.3 mgal for the lake stations.

A topic which has to be addressed in a discussion of the errors in the final gravity values is that of the Bouguer density. As mentioned in a previous section, the Bouguer correction was applied for the standard density of 2.67 g/cm³. The density determinations based on the collected rock samples (Chapter 4) suggest a higher average surface density (2.73 g/cm³), but this result does not consider the less dense sediments of glacial origin occurring in the area of the gravity survey. However, due to the small variations in topography, the shape of the Bouguer anomaly curve computed for a Bouguer density of 2.73 g/cm³ is similar to the curve obtained for the standard density of 2.67 g/cm³ (Fig. 3-4). If one of the curves is translated over the other so that the points corresponding to the first station overlap, then the overlapping errors for the rest of the stations are less than 0.15 mgal. Based on the previous considerations and on the observation that the Bouguer anomaly computed for the standard Bouguer density shows little correlation with topography (Fig. 3-3), it can be considered that the density value of 2.67 g/cm³ was appropriate for the Bouguer correction, the error being negligible if compared to the amplitude (> 35 mgal) of the anomaly investigated.

3.5 Qualitative evaluation of the Bouguer anomaly

The Bouguer gravity values show an increase of over 35 mgal from the northwest to the southwest of the profile, which reflects the presence of uplifted dense crust southeast of Saganash Lake Fault. Due to the lack of access, the profile could not be continued beyond
Fig. 3-4. Comparison between the Bouguer gravity curves obtained for two different values of Bouguer density.
Lake Racine (Fig. 2-2) inside the KSZ and as a result, the top of the anomaly is not well defined. In order to remove this uncertainty, six previously established gravity stations situated southeast of Lake Racine on the direction of the profile were used to extend the gravity profile. The Bouguer gravity values corresponding to these stations were obtained from the federal gravity database. The extended gravity profile has a total length of 57 km and defines very well the gravity anomaly associated with the northwestern boundary fault of the Chapleau block (Fig. 3-5). It can be observed that the Bouguer gravity rises from the regional background gravity of approximately −65.5 mgal in Wawa Gneiss Domain to a maximum of about −28 mgal southeast of the Saganash Lake Fault, inside southern Chapleau block. The large amplitude of the anomaly indicates the existence of a significant mass contrast in the subsurface.

Another characteristic of the Bouguer anomaly curve is represented by the positive local anomalies of short lateral extent and low amplitude (less than 3 mgal) superimposed on the large anomaly associated with the Saganash Lake Fault. In order to remove these short wavelength anomalies, the Bouguer anomaly curve was smoothed graphically (Fig. 3-5). The smoothing procedure was unequivocal since most of the local anomalies are clearly distinguishable from the background gravity.

The aeromagnetic data indicate that in most of the cases these local gravity anomalies are observed in the stations situated in the vicinity of the Matachewan and Kapuskasing dykes which are crossed by the gravity profile (Fig. 3-6). Based on this observation it is inferred that the local anomalies are produced by dykes. In some cases the anomalies might include the effects of more than one dyke. For example, the residual anomaly observed in station 45 is very likely the sum of the gravity effects of both a Matachewan and a Kapuskasing dyke which intersect near this station. It can be noticed that the local anomalies observed northwest of the Saganash Lake Fault have larger amplitudes than those observed southeast of the Saganash Lake Fault (Fig. 3-5). This variation in the average amplitude of the local anomalies across the Saganash Lake Fault could be explained by (1) a variation of the density contrast between the dykes and the host rocks across the fault, and (2) a difference in the dyke thickness, the dykes
Fig. 3-5. The extended Bouger gravity profile, the smooth gravity curve and the local anomalies removed through smoothing.
Fig. 3-6. Shaded relief aeromagnetic map showing the positions of most of the gravity stations. Illumination azimuth: 295°. Illumination inclination: 22°. The yellow dots correspond to the stations where the local gravity anomalies have maximum amplitudes.
inside KSZ being thinner than those observed in Wawa Gneiss Domain (Ernst and Halls, 1983; Halls and Nitescu, field observations). In order to confirm the correlation observed between the local anomalies and the dykes crossed by the gravity profile, the gravity effects of several dyke models having parameters similar to those of the dykes from the study area were calculated using a 2.5D forward modeling program (Appendix B). The maximum amplitudes obtained for the computed dyke anomalies (0.5-1.8 mgal) are similar to the amplitudes of most of the local anomalies. However, the anomalies observed in stations 20 and 29 are too large (2.5-3.5 mgal) to be produced only by the dykes visible on the aeromagnetic image. These anomalies represent either the cumulated effect of a larger number of dykes, not all of them having a separate aeromagnetic expression, or include the effects of some unknown shallow density contrasts.
4. INTERPRETATION OF THE GRAVITY DATA

The objective of the gravity data interpretation is the determination of the mass distribution responsible for the observed gravity anomaly. A source of uncertainty in the interpretation of a gravity anomaly results from the inherent non-uniqueness (ambiguity) of the inverse problem for potential fields. An unlimited number of possible mass distributions can satisfy the observed gravity anomaly. In order to constrain the gravity model and to reduce the ambiguity it is essential to obtain independent information (density contrasts, geometry of the source, positions of contacts) from geological observations or other types of geophysical data.

4.1 Density determinations

In the area of the gravity survey the outcrops are scarce, most of the surface being covered by dense vegetation and surficial deposits of glacial origin. In order to investigate if there is any surface density contrast across Saganash Lake Fault, the densities of 48 rock samples collected from the outcrops occurring in the study area were determined. In terms of lithology, most of the samples from Wawa Gneiss Domain are tonalite-granodiorite gneisses and a few are massive granitoids from the Windermere batholith. Inside the Chapleau block the rock units sampled were of mafic tonalite and also tonalite-granodiorite gneiss. The macroscopic analysis of the rock samples and a study of 27 thin sections revealed that the rocks contain quartz, feldspar plagioclase, biotite and/or amphibole. Common accessory minerals are sphene and magnetite. Small amounts of potassium feldspar are present in some samples on both sides of the fault. No pyroxene or garnet was found in the samples collected. The granitoid and tonalite gneiss samples from Wawa Gneiss Domain contain 5%-10% amphibole and biotite, whereas the mafic tonalite and tonalite gneiss samples from the Chapleau block contain a larger proportion of mafic minerals (15%-20% amphibole and biotite), and are characterized by a coarser grain size. In the area of study there is no change
in the metamorphic grade of the rock units across the fault, all the rocks being in the middle amphibolite facies. Hydrous alteration products like sericite, epidote and chlorite are more evident in the rocks from Wawa Gneiss Domain, but they are also present in some samples from KSZ. The lower degree of hydrous alteration observed in the samples from southern KSZ indicates a deeper crustal level for the rocks situated southeast of the Saganash Lake Fault.

The density determinations comprised mass and volume measurements for each of the samples considered. The mass measurements were made with an Ohaus balance readable to 0.5 g. For the volume determinations a bucket having a downward dipping overflow pipe was used. Each sample was immersed in the bucket filled with water up to the pipe level, and the displaced amount of water was collected in a calibrated cylinder. In order to validate a volume determination, the same result had to be obtained in three measurements. The error in volume caused by the fluids trapped in closed pores is negligible due to the very small porosity (less than 0.1%) of the rock samples. The volume values are reliable to 2 cm³, which is the reading accuracy of the calibrated cylinder used to measure the volume of displaced water. The uncertainty in the density values is considered to be 0.02 g/cm³.

The results of the density determinations have brought direct evidence for the existence of a surface density contrast associated with the southern segment of Saganash Lake Fault (Fig. 4-1). The main causes of the contrast are considered to be the presence of an increased proportion of mafic minerals (5%-15% more biotite and amphibole) and a lower degree of hydrous alteration for the rocks situated southeast of the fault. The density histograms for the samples from Wawa Gneiss Domain and for those from the Chapleau block are presented in Fig. 4-2. It can be observed that most of the samples collected northwest of the fault have densities in a range between 2.62 and 2.73 g/cm³, with a peak at 2.68-2.69 g/cm³. This wide range is caused by both the heterogeneity of the tonalite gneiss (differences in biotite and amphibole content) and variations in the degree of hydrous alteration. In the case of the samples from southern KSZ, densities between 2.74 and 2.86 g/cm³ are observed for 75% of the samples. These samples show little or no hydrous alteration. The remaining 25%
Fig. 4-1. Density distribution map and density chart showing the location of the rock samples collected in the area of the gravity profile and their density.
Fig. 4-2. Density histograms for the samples from Wawa Gneiss Domain and southern KSZ.
of the samples are characterized by a higher degree of hydrous alteration and have densities in a range similar to that of the samples from Wawa Gneiss Domain.

The density determinations performed for the collected samples cannot lead to a precise estimate of the magnitude of the density contrast across the fault. This is due to a lack of precise knowledge of both the proportions of different rock types in the area and the proportions of rocks strongly affected by hydrous alteration. However, since the samples were collected from as many different locations along the gravity profile as possible, a simple density average could give an approximate estimate of the average surface density. The average density of the rock samples from Wawa Gneiss Domain is 2.69 g/cm$^3$ and for those from KSZ is 2.75 g/cm$^3$, suggesting a surface density contrast of 0.06 g/cm$^3$. This value of the surface density contrast could in fact underestimate the real surface density contrast, since it does not take into account the southeastward increase in abundance of the mafic gneiss enclaves within the tonalite gneiss. If a contact similar to the one observed at surface across northern Saganash Lake Fault between granulites of the northern Chapleau block and amphibolite facies gneisses of the Wawa Gneiss Domain is buried in southern KSZ, then the density contrast at depth is likely higher than that observed at surface across southern Saganash Lake Fault, where the rocks separated by the fault have the same metamorphic grade. Therefore, the value of the density contrast obtained from the density determinations has to be regarded as a lower limit for the average density contrast between Wawa Gneiss Domain and southern KSZ.

4.2 The source geometry and the position of the fault

An important constraint can be imposed on a gravity model if independent assumptions can be made about the geometry of the source. This requires an understanding of the geological features present in the subsurface. Usually, the construction of a model is based on two criteria: (1) the model has to be realistic and (2) the model should be kept as simple as possible. A complicated model having many details is not justified even if it gives a perfect
correspondence between calculated and observed gravity values, unless other geological or geophysical constraints can be brought to support an increased level of detail.

The model of a fault-bounded slab of uplifted deep crust for the KSZ, based on the Lithoprobe seismic surveys and the previous gravity interpretations (Percival and Card, 1985; Percival and McGrath, 1986; Atekwana et al., 1994; Percival and West, 1994), suggests a step structure geometry for the source of the gravity anomaly associated with the northwestern boundary of this structure in southern Chapleau block. Although the assumption of a truncated horizontal slab could be a simplification of the geological reality, such a model is suitable for the determination of the Saganash Lake Fault parameters, which constitute the purpose of this study. The possible average inclination of 8° NW (Percival and Card, 1985) for the slab of denser uplifted rocks is too small to produce a gravity effect significantly different from that of a horizontal slab, and would not require a change of the fault parameters in order to fit the observed anomaly.

The unequivocal determination of the fault attitude requires a precise specification of the position of the fault at the surface with respect to the gravity profile. By using the forward modeling capability it was determined that an unconstrained position of the fault can lead to equally acceptable step-structure models incorporating a normal, vertical or reverse fault. Since the attitude of the fault constitutes one of the main objectives of this study, the position of the trace of the fault represents the most critical constraint which has to be imposed on the model. Although the fault has no topographic expression, its position with respect to the gravity profile can be successfully determined from the analysis of the digitized federal-provincial aeromagnetic data. To enhance the short-wavelength, near-surface magnetic features a colour-draped shaded relief image of the total magnetic field intensity in the survey area was produced, the illumination direction and inclination being selected to best illustrate the position of the Saganash Lake Fault (Fig. 4-3). The aeromagnetic expression of the fault is revealed as a northeast-southwest linear region along which the Matachewan dykes are truncated and offset. By plotting on the aeromagnetic image the positions of the gravity stations, it can be
Fig. 4-3. Colour-draped shaded relief aeromagnetic map showing the position of the gravity stations with respect to the Saganash Lake Fault. Points A and B indicate the location of two Matachewan dyke samples for which different levels of feldspar clouding were observed. The colours indicate the intensity of the total field anomaly (red: low; purple: high). Illumination azimuth: 295°. Illumination inclination: 24°.
observed that the point of intersection between the gravity profile and the trace of the fault is situated in the vicinity of station 36, which corresponds to the point of maximum horizontal gradient of the magnetic anomaly associated with the fault. The uncertainty in the position of the fault is of ± 0.3 km about station 36.

A recently developed method which can be used in shield areas to constrain the position of the faults across which differential uplift occurred consists in the study of the feldspar clouding intensity in Proterozoic mafic dyke swarms (Halls and Zhang, 1995b; Zhang, 1998). The method is based on the observation that the cloudiness, which is caused in part by submicroscopic magnetite formed through exsolution of Fe from the feldspar structure during slow cooling, increases with the depth of dyke emplacement. Therefore, sudden variations in the level of clouding observed within a dyke swarm should coincide with the location of major faults across which differential uplift occurred. In the region of the gravity survey, two Matachewan dyke samples from the fault area (points A and B in Fig. 4-3) reveal a significant difference in the level of feldspar clouding (H.C. Halls, personal communication). The feldspar from the dyke sampled at point A is not clouded, whereas the dyke sampled at point B is characterized by clouded feldspar, which indicates a deeper level of emplacement. Based on this observation, it can be inferred that points A and B are separated by the Saganash Lake Fault, this result being confirmed by the aeromagnetic image. Due to the locations of the two sampling points, this method gives a poorer constraint for the position of the fault (uncertainty of 5.5 km) when compared to the result obtained from the aeromagnetic data. However, the observed variation in feldspar clouding across the southern Saganash Lake Fault demonstrates that the rocks separated by it correspond to different crustal levels, and confirms the potential of the method as a fault-mapping tool.

4.3 2.5D forward modeling

The forward modeling approach for the quantitative interpretation of the gravity data involves the direct calculation of the gravity effect of an initial model assumed for the source
body, and the comparison of the calculated and observed values. Then, the model parameters are adjusted and the whole process is repeated until a satisfactory level of agreement between the calculated and the observed anomaly is obtained.

The gravity anomaly observed across southern Saganash Lake Fault was interpreted using a 2.5D non-iterative modeling software produced by Karl Bouchard (Ecole Polytechnique, Montreal). The program can be used to calculate the gravity effects of horizontal bodies having an arbitrary polygonal cross-section and finite strike. In order to test the accuracy of the modeling program, the theoretical gravity effect of a two-dimensional vertical sheet was compared with the gravity effect calculated by the modeling software (Appendix A). The discrepancy at any point between the theoretical value of the gravity effect and that obtained with the modeling program was less than 0.2% of the theoretical effect at that point.

The geometry considered for the source of the gravity anomaly is that of a horizontal truncated plate (section 4.2). The parameters of the model are the depths to the top and bottom of the plate, the density contrast, the fault dip, the surface position of the fault with respect to the gravity profile and the strike and lateral (perpendicular to the strike) extent of the source body. The values for some of these parameters were determined from independent geological and geophysical data. Thus, the surface position of the fault was well constrained based on the aeromagnetic data. The strike length of the model was estimated from the Bouguer gravity map by considering the length of the gravity anomaly associated with the Chapleau block, and the lateral extent of the source body was obtained from the aeromagnetic map by considering the width of the KSZ in the survey area. It was also assumed, based on the existence of an observed surface density contrast, that the top of the anomalous body reaches the surface. The only parameters which had to be determined from the modeling of the anomaly were the dip of the fault, the depth extent of the anomalous body and the density contrast, which was not well constrained from the density determinations.
The modeling procedure consisted in fixing the surface position of the fault to coincide with the position of its aeromagnetic expression and determining the values of the fault dip and density contrast which produce the best agreements for various depths of the model. The preferred model was that in which a best fit was obtained for both the amplitude of the anomaly and the segment of steep gradient. Thus, the density contrast was varied until the calculated curve had an amplitude similar to the observed anomaly and the dip of the fault was changed until at least the point of steepest gradient on the calculated curve coincided with the point of steepest gradient on the observed curve. In a first stage, this procedure was performed for models having depth extents of 5, 10, 15, and 20 km (Fig. 4-4). For the models having depths of 5 km and 20 km the fit between the calculated and observed curves is poor (RMS error > 1 mgal). The best agreements (RMS errors of 0.5 mgal) were obtained for the models with depths of 10 and 15 km. These two models indicated density contrasts of 0.07 and 0.1 g/cm³ and a dip of 60°-70° to the SE. The range of dip values corresponds to the range of possible positions of the fault trace in the uncertainty interval (± 0.3 km about station 36).

The comparison of the observed anomaly with the gravity effects obtained for the four models suggests that the best fit to the observed anomaly should correspond to a model having a depth between 10 and 15 km (Fig. 4-5). The analysis of various models having depth extents between 10 and 15 km showed that the best fit (RMS error of 0.35 mgal) is obtained for a model characterized by a depth of 12 km, a density contrast of 0.085 g/cm³, and a dip of 60°-70° to the SE (Fig. 4-6).

All the models indicate that the Saganash Lake Fault is reverse. For any depth model, if the anomaly is modeled with a vertical or normal fault whose surface position is constrained by the aeromagnetic data, a significant offset between the calculated and the observed curve is produced (Fig. 4-7). In order to model the observed anomaly with a vertical or normal fault, the trace of the fault must be positioned southeast of station 39, which on a direction perpendicular to the trace is situated about 2 km away from the position indicated by the
Fig. 4-4. Interpretation of the Bouguer gravity data. The solid line shows the gravity effect corresponding to a 2.5D step model.

a. Depth extent of the step model: 5 km. Fault dip: 62° SE.

b. Depth extent of the step model: 10 km. Fault dip: 66° SE.

c. Depth extent of the step model: 15 km. Fault dip: 68° SE.

d. Depth extent of the step model: 20 km. Fault dip: 68° SE.
Fig. 4-5. Comparison of the observed Bouguer gravity with the gravity effects of the 2.5D step models having different depth extents.
Fig. 4-6. The best-fit 2.5D step model. Depth extent: 12 km. Fault dip: 66° SE.
Fig. 4-7. The gravity effect in the case of a vertical fault.
aeromagnetic data. This observation demonstrates that the gravity anomaly associated with southern Saganash Lake fault cannot be produced by a normal or vertical fault model.

4.4 The validity of the proposed gravity model

In order to be accepted as realistic, the gravity model has to produce not only a good fit between the calculated and observed curves, but it also has to be characterized by parameters which are compatible with other geological and geophysical observations.

The results of the forward modeling show that the gravity anomaly can be successfully modeled by a step model having a depth extent in the range 10-15 km, a density contrast of 0.07-0.1 g/cm³ and a fault dipping approximately 65° ± 5° to the SE. The depth extent and the density contrast ranges obtained for this model are consistent with the parameters of other geophysical models of the Chapleau block. The depth of the gravity model corresponds to the depth of the geophysical model presented by Boland and Ellis (1991) based on refraction and gravity data, as well as to the depth of the gravity model obtained by Atekwana et al. (1994). The lower limit of the density contrast range is slightly higher than the value of the surface density contrast. The higher values of the average density contrast obtained from gravity modeling confirm that the value of the surface density contrast based on density determinations underestimates the average density contrast across southern Saganash Lake Fault. The upper limit of the density range (0.1 g/cm³) is close to the density contrast of the gravity model presented by Percival and Card (1985) for northern Chapleau block (0.12 g/cm³).

The major disagreement between the gravity model presented in this study and the previous geophysical models concerns the attitude of the Saganash Lake fault. Independent information on the dipping direction of the fault bounding a truncated plate can be obtained from the horizontal gravity gradient curve if the position of the edge of the structure is known (Grauch and Cordell, 1987). Thus, for a horizontal slab truncated by a vertical margin the maximum gradient would be positioned above the edge, whereas in the case of a dipping
margin the point of maximum horizontal gradient would be displaced slightly towards the
dipping direction. The SE dip of the Saganash Lake fault suggested by gravity modeling (Fig.
4-6) is confirmed by the slight displacement towards SE of the maximum horizontal gradient of
gravity with respect to the surface position of the fault (Fig. 4-8).

The present study, which is based on a detailed gravity survey, has indicated that an
uncertainty of more than 2 km in the fault position would have led to equally acceptable
models of a normal, vertical or reverse fault. Therefore, an inaccurate positioning of the fault
and a larger spacing of gravity stations might explain the different dipping direction of the
Saganash Lake Fault obtained in previous gravity studies.
5. GEOLOGICAL IMPLICATIONS OF THE GRAVITY MODEL

6.1 An estimate of the components of displacement on southern Saganash Lake Fault

On the basis of the distortions and the offsets observed in the aeromagnetic pattern of the Matachewan dykes, West and Ernst (1991) have inferred that post-Matachewan dextral transcurrent deformation has occurred in the KSZ and surrounding area. The horizontal strain suffered by the KSZ is mainly a northeast-southwest trending band of dextral deformation, which in the northeast is concentrated along the boundary faults of northern and central KSZ (total horizontal offset 60-80 km) and in the southwest widens into an ~ 80-km wide zone of distributed strain. The western subswarm of the Matachewan dyke swarm shows an open Z-shaped bend as it crosses the Chapleau block, this distortion of the dyke swarm being attributed to a smooth, continuous pattern of shear strain. Although no major fault offset is revealed in southern KSZ, a small discontinuous transcurrent deformation occurred along southern Saganash Lake Fault, possibly accompanied by differential uplift. However, the lithological similarity observed across the fault suggests that the total vertical displacement is minimal in this area. In this section an attempt is made to estimate both the dextral strike slip and the vertical component of slip on southern Saganash Lake Fault.

The aeromagnetic data show that in the area of the gravity survey the Matachewan dykes are truncated and offset along Saganash Lake Fault. The amount of the strike offset can be determined only if at least one dyke can be correlated across the fault. The aeromagnetic pattern of the Matachewan dykes in the study area indicates that a group of six dykes on the northwestern side of the fault may correspond to a similar group of dykes on the southeastern side of the fault (Fig. 5-1). The possible correlation between the two groups of dykes is suggested by the relatively similar inter-dyke distances observed for corresponding pairs of dykes from each group. On the plausible assumption that the two groups of dykes represent the same group, which was truncated and offset along Saganash Lake Fault, the observed
Fig. 5-1. Colour-draped shaded relief aeromagnetic map showing a group of six dykes which are offset along the Seganash Lake Fault in the area of the gravity survey. The colours indicate the intensity of the total field anomaly (red: low; purple: high).

dextral strike separation of the dykes along the Saganash Lake Fault is approximately 5 km. This estimate agrees perfectly with the strike offset indicated for this segment of the fault on the map of the strain pattern produced by West and Ernst (1991).

The strike separation of the Matachewan dykes is not necessarily only the result of dextral strike-slip deformation. It is important to notice that if the Saganash Lake Fault is a SE-dipping reverse fault, as suggested by the gravity interpretation, any post-Matachewan dip-slip movement would cause a dextral strike separation of the Matachewan dykes (Fig. 5-2). The observed strike separation is likely the sum of two components: the strike offset produced by the post-Matachewan dip slip and the strike slip component of displacement. Therefore, the strike slip component cannot be assessed based on the observed strike offset of the Matachewan dykes, unless the amount of post-Matachewan differential uplift across the fault is known.

The post-Matachewan vertical component of slip on southern Saganash Lake Fault can be estimated on the basis of geobarometric and seismic data. The country rock paleopressures indicate a contrast of maximum 0.15 GPa across southern Saganash Lake Fault (Percival et al., 1994; Percival and West, 1994), which suggests a total differential uplift of 4-5 km. On the seismic section of the Lithoprobe reflection line 4 in Chapleau block (Fig. 1-1), the pairs of reflectors A-A’ and B-B’, which presumably represent offset segments of the same initial reflectors, indicate a total vertical component of displacement of 4 km, in perfect agreement with the geobarometric data. The differences between the country rock paleopressure and the emplacement pressure of the Matachewan dykes on both sides of the fault (Percival et al., 1994) suggest that the difference in the pre-Matachewan uplift suffered by western Wawa Gneiss Domain and the Chapleau block is between 0 and 1.5 km. This small difference could be explained by a 2° pre-Matachewan rotation suffered by the crustal slab uplifted along the Ivanhoe Lake Fault, its leading edge undergoing a larger amount of uplift. It is likely that the Saganash Lake Fault is a post-Matachewan feature, all the displacements observed along this fault being of post-Matachewan age. If this assumption is correct, then the
Fig. 5-2. Sketch showing that the strike offset of the Matachewan dykes is the sum of two components: the strike separation produced by the dip slip and the strike-slip component of displacement.
post-Matachewan vertical slip component on southern Saganash Lake Fault is in fact the total vertical slip inferred from geobarometric and seismic data. A differential uplift of 4-5 km would have produced a dextral strike separation of the Matachewan dykes of 1.5-3 km (Appendix C). Since the total observed strike offset of the Matachewan dykes along southern Saganash Lake Fault is of 5 km, the strike component of slip is approximately 2-3.5 km.

5.2 The cross-sectional geometry and the extent of the KSZ

The gravity model of the southern Saganash Lake Fault shows that at least in Chapleau block the northwestern boundary fault could not have formed as a collapse fault in response to uplift along Ivanhoe Lake Fault, as it was suggested in previous interpretations. It is likely that Saganash Lake Fault was initiated at a late stage during the compressive regime responsible for the main Kapuskasing uplift, which occurred at 1.9-1.85 Ga. The crustal shortening in Chapleau block was accommodated in the upper brittle crust through thrust duplication mainly along Ivanhoe Lake Fault crust, and to a much lesser extent, along Saganash Lake Fault. The development of the Saganash Lake Fault as a reverse fault parallel to the main thrust contributed to the accommodation of the upper crustal uplift caused by the thickening of the lower crust as a result of shortening, and of the isostatic uplift produced after erosion.

The differential uplift of about 4-5 km across southern Saganash Lake Fault has brought in contact rocks from different crustal levels, creating thus a density contrast which, based on the gravity interpretation, propagated to a depth of 10-15 km. If the fault extends beyond 10-15 km, then the lack of a significant density contrast below this depth could be explained either by a much smaller component of vertical displacement at this depth, or by a small density gradient in the middle to lower crust. The depth extent of the density contrast obtained from gravity modeling gives a minimum estimate for the extent of the Saganash Lake Fault. The seismic reflection data from the Chapleau block suggest that the main Kapuskasing thrust fault has a ramp and flat geometry, being situated at a depth of 10-12 km in the western
part of the Chapleau block (Geis et al., 1990). Based on this interpretation it is concluded that the Saganash Lake Fault may intersect the main detachment surface and may offset the dipping crustal slab of dense rocks uplifted along the Ivanhoe Lake Fault (Fig. 5-3).

The pop-up geometry inferred for both southern and northern KSZ raises the problem of the structure of central KSZ. The reverse character of southern Saganash Lake Fault and the smooth continuity of its aeromagnetic expression along southern and central KSZ, as well as recent aeromagnetic data modeling (Farrokhi, 1999) suggest that the fault may also have a reverse nature in Groundhog River block. If this is the case, then the convergence of the Saganash Lake Fault and Ivanhoe Lake Fault in the Groundhog River block area has probably led to the faulting of the tip of the uplifted slab of dense rocks and to its separation from the rest of the slab through uplift along a reverse Saganash Lake Fault (Fig. 5-4). The small thickness of the perched tip of dense rocks explains the lack of a gravity anomaly in Groundhog River block. Also, the compressive regime which led to the development of the Saganash Lake Fault, could have produced the uplift of the northwestern Val Rita block along a reverse Lepage Fault (Fig. 5-4). This would explain the large gravity anomaly observed in Val Rita block and the granulite occurrences at a few localities along the Lepage Fault. In order to confirm this possible model for the central KSZ, a reinterpretation of the gravity data, based on detailed sampling and accurate positioning of the fault traces, is necessary.

The results of the present gravity study confirm the cross-sectional similarity between the KSZ and the compressional belt with central uplift formed in Lake Superior through the inversion of the 1.1-Ga Midcontinent rift. Based on the observation that the inward-dipping boundary faults of southern KSZ are almost continuous along strike with the two main boundary faults that define the inversion of the Midcontinent rift in Lake Superior, Manson and Halls (1997) have suggested that the Lake Superior faults, whose last major phase of activity was during the Grenville Orogen (1.1 Ga), may represent reactivation of much older faults that belonged to an extended Kapuskasing structure (Fig. 5-5). It is difficult at this stage to assess the validity of this hypothesis, since a direct physical connection between the KSZ and the
Fig. 5-3. Schematic representation of the cross-sectional geometry of the Chapleau block. Between surface and a depth of approximately 1.5 km the fault juxtaposes amphibolite facies rocks from different depth levels creating a density contrast similar to that observed at surface. In the depth interval 1.5-7 km the fault brings in contact KSZ-type rocks with the amphibolite facies rocks of Wawa Gneiss Domain. The density contrast is probably close to that observed at surface across Saganash Lake Fault in central KSZ, where the amphibolite facies rocks of Wawa Gneiss Domain are in contact with KSZ granulites. Between 7 km and 12 km the fault separates KSZ-type rocks from different levels of the uplifted slab of dense rocks. The density contrast is probably lower than that in the interval 1.5-7 km. Below 12 km, the base of the NW segment of the uplifted slab is in contact with middle to lower crustal rocks and the density contrast attenuates.
Fig. 5-4. A possible model for the cross-sectional geometry of the Groundhog River and Val Rita blocks.
Fig. 5-6: Major crustal faults in the Midcontinent rift - Kapuskasing Structural Zone region (after Manson and Halls, 1997).
Midcontinent Rift has not been established between their northwestern boundaries. Although relatively deep gneisses with an Archean history similar to that of the rocks within the Chapleau block occur along the eastern shore of Lake Superior (Card, 1979; Corfu, 1987), evidence for a fault-bounded Proterozoic uplift is lacking in the region between the Pineal Lake block and Lake Superior. The absence of gravity and magnetic anomalies in this area and the minimal differential uplift inferred for the southern Chapleau block and for the Pineal Lake block suggest that the KSZ structure could end in fact at the north-south trending McEwan Lake Fault, which represents the western boundary of the Pineal Lake block. At present it is not known if the McEwan Lake Fault truncates the KSZ or represents the southerly continuation of the northern boundary fault of Pineal Lake block, which in turn is presumed to be the offset continuation of the Saganash Lake Fault.
6. SUMMARY AND CONCLUSIONS

The purpose of the study presented in this thesis was that of understanding the nature of the Saganash Lake Fault in southern KSZ, based on the modeling of gravity data. A total of 57 gravity stations were established along a profile which crosses approximately perpendicularly the trace of southern Saganash Lake Fault. For the determination of the elevations and positions of the gravity stations, a GPS survey was conducted along the gravity profile. The GPS measurements have a decimetre level accuracy, ensuring an uncertainty of less than 0.05 mgal in the Bouguer anomaly values. This excellent result confirms that the GPS technology is a reliable tool for the positioning of the gravity stations, which offers also the advantage of being much faster than the conventional surveying. The final uncertainty in the Bouguer gravity values due to the various sources of errors occurring in the processes of data acquisition and data reduction is less than 0.2 mgal.

An increase of over 35 mgal in the Bouguer anomaly values is observed from the northwest to the southwest of the gravity profile, reflecting the presence of uplifted dense crust southeast of Saganash Lake Fault. In order to model this gravity anomaly, two constraints were imposed on the gravity model. The geometry of the source was assumed to be that of a fault bounded horizontal slab, based on the previous gravity and seismic interpretations of the Chapleau block, and the surface position of the Saganash Lake Fault was specified precisely, based on the aeromagnetic expression of the fault. A 2.5D gravity modeling program was used for the interpretation of the gravity anomaly observed across southern Saganash Lake Fault. The gravity modeling results have indicated that the Saganash Lake Fault is reverse, having a dip of 60°-70° SE and a depth extent of 10-15 km.

Based on the fault parameters obtained from gravity modeling, the geobarometric and seismic data from the area of study, and the observed offset of the Matachewan dykes, it is
estimated that on southern Saganash Lake Fault the vertical component of slip is of 4-5 km, and the strike component of slip is of 2-3.5 km.

The similarity between the depth extent of the southern Saganash Lake Fault obtained from gravity modeling and the depth of the Kapuskasing thrust in western Chapleau block inferred from seismic reflection data, indicates that the Saganash Lake Fault fault might intersect and offset the main detachment surface along which the KSZ uplift occurred.

The reverse character of southern Saganash Lake Fault supports the model of a pop-up structure for the Chapleau block and indicates that in this region the Saganash Lake Fault cannot be interpreted as an extensional fault.
APPENDIX A

A TEST OF THE MODELING SOFTWARE
The theoretical gravity effect of a two-dimensional vertical sheet is compared with that calculated by the modeling program. The formula used for the calculation of the theoretical gravity effect of a two dimensional vertical sheet is (Nettleton, 1976):

\[ g(x) = 30.7 \cdot d \cdot t \cdot \{\log n - 0.5 \cdot \log \left[\frac{(1 + x^2/z^2)}{(1 + x^2/n^2 z^2)}\right]\} \]

where

- \(d\) – density of the vertical sheet in g/cm³
- \(t\) – the thickness of the vertical sheet in km; it has to be substantially less than the other dimensions
- \(z\) – the depth to the top of the vertical sheet
- \(n = h/z\), where \(h\) is the depth to the bottom of the vertical sheet
- \(x\) – the horizontal distance from the center of the vertical sheet

The characteristics of the vertical sheet are:

\(d = 0.1\) g/cm³; \(t = 0.5\) km; \(z = 2\) km; \(n = 4\)

The values of the theoretical effect and the values obtained with the modeling software are compared in the following table:

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It is observed that at any point, the difference between the two values is less than 0.2% of the theoretical effect.
APPENDIX B

DYKE MODELS
In order to estimate the gravity effects of the Proterozoic dykes crossed by the gravity profile, three dyke models were considered. The density values considered for the host rocks are based on the densities of the rock samples collected in the area of the gravity survey. The value used for the dyke density corresponds to the density of a dyke sample from Racine Lake area. The values of thickness considered are based on field observations. The model parameters and the maximum gravity effect obtained for each dyke model are presented below.

**MODEL 1 Dyke inside KSZ**

Thicknes: 20 m  
Depth extent: 10 km  
Dyke density: 3.1 g/cm³  
Host rock density: 2.85 g/cm³  
Maximum gravity effect: 0.5 mgal

**MODEL 2 Dyke in Wawa Gneiss Domain**

Thicknes: 30 m  
Depth extent: 10 km  
Dyke density: 3.1 g/cm³  
Host rock density: 2.7 g/cm³  
Maximum gravity effect: 1.2 mgal

**MODEL 3 The effect of two dykes in Wawa Gneiss Domain**

Two parallel dykes having parameters similar to those of the dyke model 2.  
Distance between dykes: 1 km  
Maximum gravity effect: 1.6 mgal
APPENDIX C

THE DETERMINATION OF THE STRIKE SEPARATION OF
THE MATACHEWAN DYKES CAUSED BY DIP SLIP
ON THE SAGANASH LAKE FAULT
If Saganash Lake Fault is reverse and dips to the SE, any dip slip movement on the fault plane would produce a dextral offset of a north-south trending Matachewan dyke, assumed to be vertical (Fig. 5-2).

The relation between the horizontal component of the dip slip (heave) and the vertical slip component is:

\[ H = \frac{V}{\tan d} \]

where

\( H \) – horizontal component of the dip slip

\( V \) – vertical component of slip

\( d \) – dip of the fault

The relation between the strike separation of a Matachewan dyke produced by the dip slip and the horizontal component of the dip slip is:

\[ S = \frac{H}{\tan i} \]

where

\( S \) – strike separation of the dyke

\( H \) – horizontal component of the dip slip

\( i \) – angle between the dyke and the fault measured in a horizontal plane

For

\[ \begin{align*}
V &= 4-5 \text{ km} \\
\theta &= 60^\circ-70^\circ \\
i &= 45^\circ
\end{align*} \]

It results

\[ S = 1.5-3 \text{ km} \]
APPENDIX D
DATA TABLES
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D – Distance from station number 1 on a direction orthogonal to the trace of the fault
E – Elevation
BA – Bouguer anomaly
* – Station from the federal gravity database
Table D2: Density values

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WGD – Wawa Gneiss Domain
CB – Chapleau Block
REFERENCES


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