Gravity Modeling in Western Vilas County, Northern Wisconsin

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ABSTRACT

The geology of Vilas county consists of Precambrian bedrock covered by thick glacial till. Outcrop and drill-hole data are rare; hence the geology must be inferred from surrounding areas and from geophysical surveys. Maps by the Wisconsin Geological and Natural History Survey and the Minnesota Geological Survey in 1982 have the same general features but the details do not match. Using the Bouguer gravity of western Vilas county, three subsurface geology profiles were derived based on the two maps, and differences in interpretations were discovered. The Wisconsin Survey map shows a much broader dome of Early or Middle Precambrian gneiss, north of the Niagara fault, than actually exists. The Minnesota Survey map places the dome in the metavolcanic region. Neither map contains a structure that would account for the high gravity to the southwest. Additional information about the bedrock is needed before the geology of Vilas county is completely understood.

INTRODUCTION

Gravity measurements from western Vilas county in north-central Wisconsin, near the Upper Michigan border, were used to model the subsurface structure in this region (fig. 1). Bedrock exposures are few, averaging about one small outcrop per township (LaBerge and Mudrey, 1979), so that geological field mapping methods cannot be applied. The geology must be inferred by using geophysical surveys to extrapolate from outcrops in surrounding areas and to interpolate between drill-holes. A gravity investigation can locate subsurface geological features and perhaps determine their depths and dimensions.

The field area was surveyed in the summer of 1982 with a LaCoste & Romberg Model G gravity meter. The gravity stations were chosen from 7.5- and 15-minute topographic maps at sites where spot and spirit level elevations were given. Additional data were provided by C.P. Ervin of Northern Illinois University and M.G. Mudrey, Jr. of the Wisconsin Geological and Natural History Survey. There are a total of 834 gravity stations, some of which were combined since their locations coincided, for a net of 730 observation sites. These measurements cover the western part of Vilas county. This area is bounded by latitude 46°15' N on the north, by latitude 45°48' N on the south, by longitude 89°18' W on the east, and by longitude 90°0' W on the west, and covers approximately 2,700 square km.

The Precambrian bedrock is overlain by glacial till (Attig, 1985). The topography is almost entirely the result of glaciation, although bedrock controls some of the larger features, such as kettle chains and belts of outwash and ground moraine. The average elevation is roughly 490 m above sea level. Local relief greater than 15 m is rare, but it can reach 45 m near terminal moraines and drumlins.

PREVIOUS GEOPHYSICAL WORK

Numerous gravity and seismic studies have been undertaken in the Great Lakes region; however, most of these studies have been primarily concerned with distinguishing the Late Precambrian sequence from Early and Middle Precambrian rock, usually considered as one lithologic unit (Thiel, 1955; Bacon, 1966; Mooney and others, 1970; Cohen and Meyer, 1966; Ocola and Meyer, 1973; White, 1966). The regional seismic surveys indicate that the crustal thickness in northern Wisconsin is about 36 km, creating an average regional Bouguer anomaly of -40 mGal from an isostatically compensated crustal column (Cohen and Meyer, 1966).

Sternberg (1977) discovered an interesting feature of the region, the Flambeau anomaly, from resistivity data. This 20-km wide band of high conductivity within the earth's crust extends to the east from about latitude 46° N, longitude 91° 20' W for at least 170 km (Daneshvar, 1977; Sternberg and

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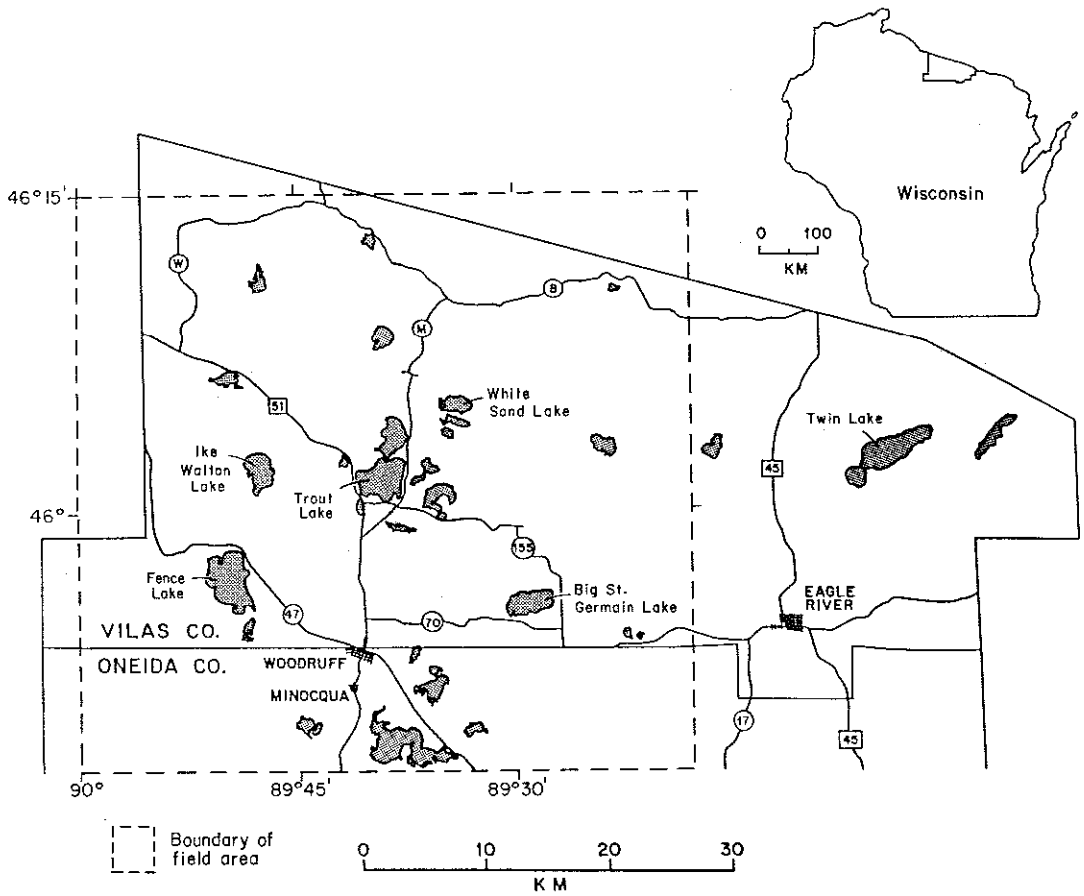

Figure 1. Location of the field area in northern Wisconsin. The dashed lines show the location of the field area with respect to Vilas county (solid lines).

Clay, 1977). The northern boundary of the anomaly lies roughly along an inferred east-west contact between an Early Precambrian gneiss terrane to the south and a younger Early Precambrian greenstone-granite terrane to the north (Sims, 1976). Daneshvar (1977) surveyed north-central Wisconsin from 90° W to 89°W and found that the Flambeau anomaly extends to at least 89° W through the Trout Lake region of Vilas county.

Several gravity surveys have been conducted in northern Wisconsin, but few have attempted to model the subsurface in any detail. Koo (1976) analyzed two north-south gravity traverses and concluded that a density contrast of 0.05-0.10 g cm^{-3} accounts for the 20 mGal gravity high over the Flambeau anomaly. Fredricks (1975) studied the gravity of eastern Vilas county, found a single elliptical anomaly, and concluded that an extremely high density contrast (1.28 g cm^{-3}) is needed to model the feature. The Niagara fault separates two distinct crustal terranes: mafic intrusives are found north of the fault but are absent to the south. Davis (1977) obtained a gravity profile perpendicular to the strike of the Niagara fault and determined that two different basement terranes of contrasting density account for the measurements. This interpretation has been accepted by Greenberg and Brown (1983), but Mudrey and Ervin (1986, verbal communication) see no distinctive gravity pattern to justify this theory and instead consider mafic intrusives north of the fault to be the cause of the gravity high. Carlson (1974) studied the gravity field of northeastern Wisconsin and was able to distinguish several different units of the Middle Precambrian (granites, greenstones, and gneisses). His analysis of a profile across the Niagara fault led him to conclude that mafic intrusives, as well as the two terranes postulated by Davis, overly granitic gneiss.

GEOLOGIC SETTING

Little is known about the bedrock geology of Vilas county because of the thick layer of glacial sediment

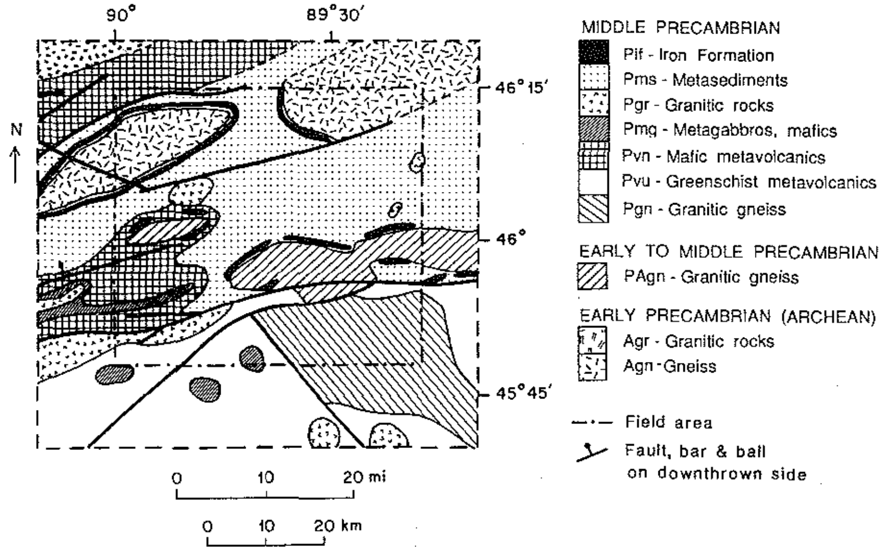

Figure 2. Geologic map of western Vilas county and adjacent areas, according to the Wisconsin Geological and Natural History Survey (Mudrey and others, 1982).

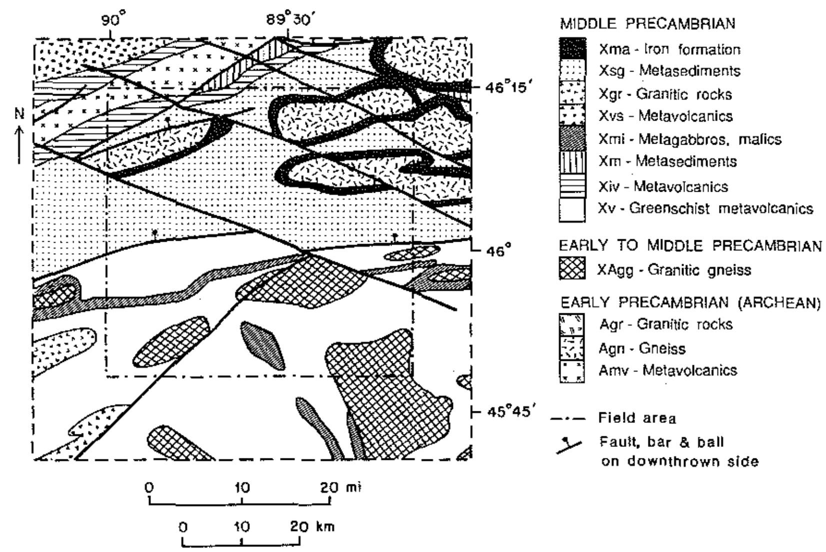

Figure 3. Geologic map of western Vilas county and adjacent areas, according to the Minnesota Geological Survey (Morey and others, 1982).

overlying the Precambrian units. Most available information comes from geophysical data, exploration drill-hole logs, and extrapolation from surrounding areas where exposures are more common. Attig (1985) found only two bedrock exposures in the county, one of which is composed of white quartz and gray extrusive rocks. The other, also reported by Thwaites (1929), consists of coarse gray and pink granite intruded by pegmatite dikes. Drill holes penetrate granite, quartzite, slate, iron formation, schist, and gneiss (Dutton and Bradley, 1970). All of the bedrock is probably either Early or Middle Precambrian in age.

According to Attig (1985), the bedrock elevation in Vilas county ranges from 413 m above sea level in the south-central region to 512 m in the north-central and southeast areas. The two known Precambrian outcrops both occur at an elevation of 512 m, and nearby well logs show at least 50 m of local relief. Because of the scarcity of data, the bedrock elevation may vary considerably between contours. In general, elevation decreases from the north and northeast to the south and southwest. The Precambrian bedrock is covered by unconsolidated glacial drift ranging from 0 to 85 m thick. There is no simple relationship between the elevation of Precambrian bedrock and the thickness of the overlying unconsolidated sediment. The thickest overburden in eastern Vilas county (82 m) covers a relatively high bedrock surface, while the thick sediment in the south-central area (85 m) is underlain by the lowest Precambrian surface. The glacial features in western Vilas county consist chiefly of outwash, recessional moraines, and drumlins (Attig, 1985). Both the moraines and the outwash are heavily pitted by steep-sided kettles.

There are two very different 1982 maps of the bedrock geology of Vilas county, one published by the Wisconsin Geological and Natural History Survey and the other by the Minnesota Geological Survey (fig. 2 and 3; tables 1 and 2). Both maps have the same general characteristics, for example, Middle

Table 1. Descriptions of Early and Middle Precambrian rocks in northern Wisconsin. Symbols refer to the Wisconsin Geological and Natural History Survey (WGNHS) and the Minnesota Geological Survey (MGS) maps (from Mudrey and others, 1982; Morey and others, 1982).

WGNHS SYMBOL	MGS SYMBOL	ROCK DESCRIPTION
MIDDLE PRECAMBRIAN INTRUSIVES:		
Pgr	Xgr	Intermediate to granitic rocks
Pgn	XAgg	Banded and migmatitic gneiss with subordinate amphibolite and biotite schist
MIDDLE PRECAMBRIAN METAMORPHICS:		
Pif	Xma	Magnetic iron formation, known or inferred from magnetic surveys
Pms	Xsg	Metasedimentary rocks—metagraywacke, slate, quartzite, meta-conglomerate, and marble—with some iron formation and metavolcanics
Pmg	Xmi	Metamorphosed mafic intrusives
Pvn	Xiv, Xm	Mafic metavolcanic rocks with subordinate felsic metavolcanics and metasedimentary rocks
Pvu	Xv, Xvs	Mafic metavolcanics with lesser felsic metavolcanic rocks
EARLY PRECAMBRIAN METAMORPHICS:		
PAgn	XAgg	Metamorphic rocks of Early or Middle Precambrian age. Includes gneiss, biotite schist, and amphibolite
Agr	Agr, Amv	Metamorphosed mafic to intermediate rocks
Agn	Agn	Quartzofeldspathic gneiss, migmatite and, minor amphibolite

Precambrian metasediments intruded by mantled gneiss domes to the north, and Middle Precambrian metavolcanics intruded by Early Precambrian mafic rocks to the south. The boundary between these two units is the Niagara fault (Dutton, 1971, and Greenberg and Brown, 1983). A 15-20 km wide band of Early Precambrian greenstone-granite terrane northwest of Vilas county is present on both maps, but the details of the two maps differ as to the location and extent of faults and geologic boundaries.

The Minnesota Survey map, compiled by Morey and others (1982), shows an extensive fault system throughout the region, which truncates many features such as the gneiss domes. South of the Niagara fault, the region is intruded by Early or Middle Precambrian mafic plutons. The Early or Middle Precambrian gneiss body in the center of the map is about 10 x 20 km at the surface of the bedrock.

According to the Wisconsin Survey map (Mudrey and others, 1982), there are fewer recognized faults in this area. The intrusives south of the Niagara fault are Middle Precambrian units. To the north, the geology is much more complicated. For example, the western region consists of mafics, gneiss, and granite (instead of simply metasediments as in the Morey diagram), and is substantiated by drill-hole data. The Early or Middle Precambrian gneiss structure is much longer in the east-west direction, based upon the presence of the mantling iron formation (Greenberg, 1986, verbal communication).

The differences between the two maps can be traced to the data from which they were created. The Minnesota Survey map was constructed predominantly from aeromagnetic measurements (Greenberg, 1986, verbal communication). The Wisconsin Survey map, however, used gravity and magnetic information, some drill-hole data not used by the Minnesota Survey, and, although outcrops are few, boulders in the glacial till were found to be indicative of the bedrock units to within a few kilometers. The gravity data will be used to determine the relative accuracy of the bedrock maps.

COLLECTION OF DATA

The gravity data consist of measurements taken during the summer of 1982, using a LaCoste & Romberg Model G geodetic meter (number G-19), and data provided by C.P. Ervin, of Northern Illinois University, and M.G. Mudrey, Jr., of the Wisconsin Geological and Natural History Survey (fig. 4). The data pro-vided by the Wisconsin Survey are a composite from four different gravity studies that took place from 1972 to 1978 (Ervin and others, 1983). Most of these measurements were obtained with LaCoste & Romberg meters, but a small part of northwestern Vilas County was surveyed with a Worden meter. These readings have been corrected to the 1971 Inter-national Standardization Net (ISN-71).

The station spacing was kept to about 1.6 km along each traverse, but station sites were necessarily limited to places of known elevation accessible by reasonably passable roads. The entire gravity net was tied to the base station at Rhinelander, which has an absolute gravity of 980555.21 $\pm$ 0.05 mGal (Ervin, 1983).

The station elevations were obtained from 7.5- and 15-minute quadrangle topographic maps (contour interval = 10 ft) acquired from the Wisconsin Geological and Natural History Survey. The stations were located at U.S. Geological Survey and U.S. Coast and Geodetic Survey bench marks, and road corners where spot and spirit level elevations were given.

DATA REDUCTION

By reoccupying the base station every two to three hours, the drift and tidal effects were eliminated with a simple linear interpolation between readings. The Geodetic Reference System (GRS-67) formula was used for the latitude reduction. The latitude, free-air, and Bouguer reductions were calculated using a density of 2.67 g cm^{-3}. The bedrock of western Vilas county is believed to be mafic metavolcanic and metasedimentary rock, with several large denser Early Precambrian gneiss bodies (Morey and others, 1982). However, this density value has been used for most gravity studies in northern Wisconsin (Fredricks, 1975; Koo, 1976) because core samples and density determinations are few and may not represent the entire region.

The 730 gravity station locations were converted to Cartesian coordinates by a Lambert projection, using a computer program supplied by C.P. Ervin of Northern Illinois University. The density of measurements ranges from about 7 points in the center of the region to 33 points per 50 km^2 in the southwest. The Bouguer gravity values were contoured manually, using a linear interpolation between the two nearest data points, and visually smoothed (fig. 5).

Error Analysis

The accuracy of the measured gravity values is listed in table 3. The latitude reduction error ($\pm$ 0.08 mGal) was calculated using a $\pm$ 0.05 minute uncertainty in the latitude measurement. The Wisconsin gravity network base station values are reliable to within $\pm$ 0.05 mGal. The terrain correction for an area of similar topography was estimated by Carlson (1974) to be $\pm$ 0.25 mGal. The error of $\pm$ 0.02 mGal in the free-air correction comes from neglecting the higher order elevation terms. The net error is $\pm$ 0.62 mGal.

No error limits were provided with the data supplied by C.P. Ervin and the Wisconsin Geological and Natural History Survey. However, many sites coincided with those of the 1982 survey, and these were used to test the data's reliability. From 86 overlapping or nearby points, the absolute value of the Bouguer gravity discrepancies is 0.30 mGal, with a standard deviation of 0.24 mGal, which is well within the accuracy limits.

Table 2. Correlation of rock units between the Wisconsin Geological and Natural History Survey (WGNHS) map and the Minnesota Geological Survey (MGS) map (from Mudrey and others, 1982; Morey and others, 1982). Ages of rock units are in billions of years (G.a.).

WGNHS MAP	MGS MAP	AGE (G.a.)
Pif	Xma	1.90–1.80
Pms	Xsg	1.90–1.80
Pgr	Xgr	1.90–1.80
Pmg	Xmi	1.90–1.80
Pvn	Xiv, Xm	1.90–1.80
Pvu	Xv, Xvs	1.90–1.80
Pgn	XAgg	1.90–1.80
PAgn	XAgg	3.00(?)–1.80(?)
Agr	Agr, Amv	2.75–2.60
Agn	Agn	3.00(?)–2.75

GRAVITY DATA ANALYSIS

Density Values

The densities of the Precambrian rocks of northern Wisconsin are found in many sources, some of them unpublished. Most of these values, listed in table 4, are from Chandler (Open-file report, Minnesota Geological Survey). Additional data were obtained from Carlson (1974), Klasner and Cannon (1974), Klasner and others (1985), and Ocola and Meyer (1973). Densities range from 2.64 to 3.10 g cm^{-3}.

Gravity Modeling Algorithm

The Bouguer gravity was modeled using both two- and two-and-one-half-dimensional algorithms developed by Talwani and others (1959) and by Cady (1980). The two-dimensional structure has infinite strike-length perpendicular to the profile, which defines the x-axis. The mass is truncated in the $\pm$ y-direction in the two-and-one-half-dimensional method. The gravitational attraction is then a function of the coordinates of the vertices of the polygon.

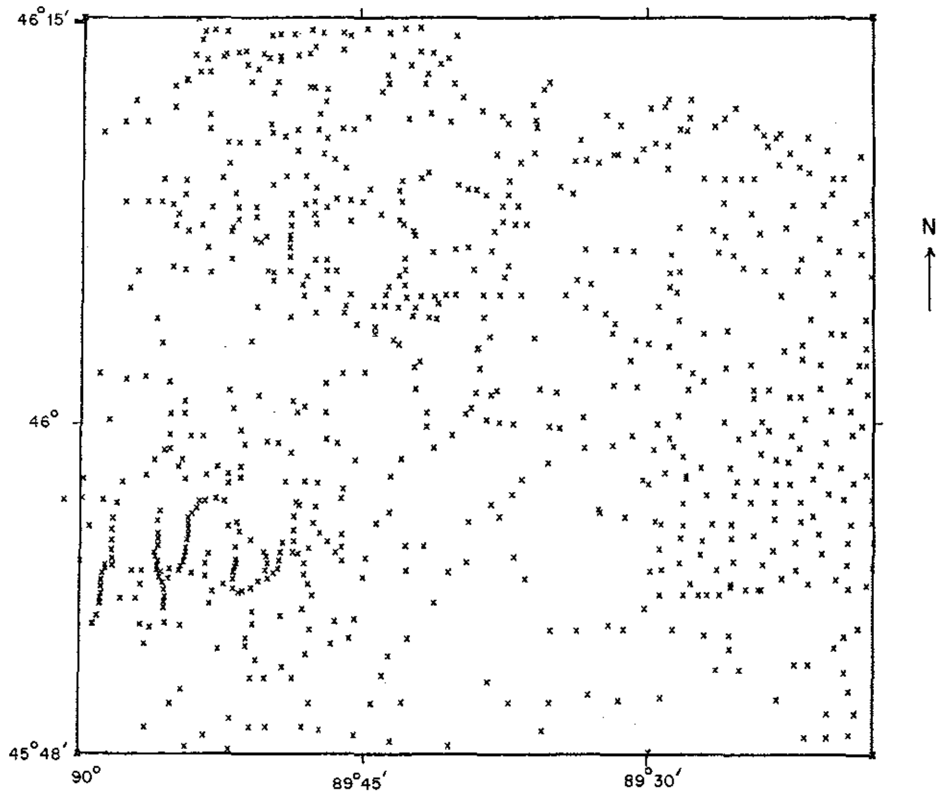

Figure 4. Locations of gravity stations in western Vilas county; the 730 measurements are scattered irregularly throughout the region. The southwest corner of the map is at latitude 45° 48.0' N, longitude 90° 00.0' W.

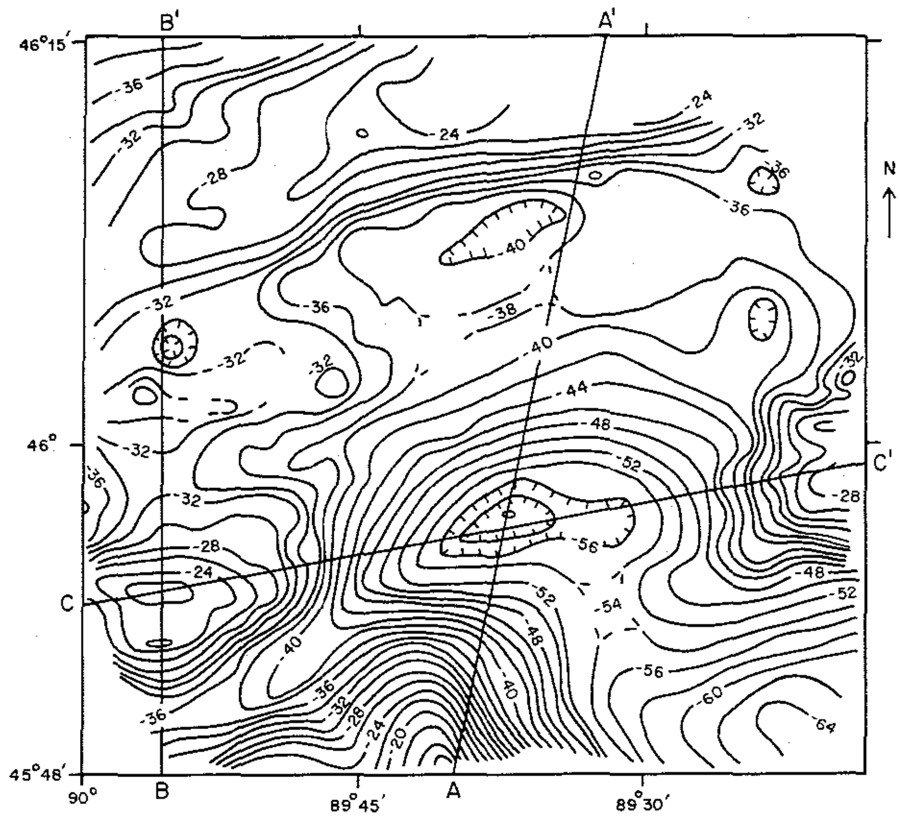

Figure 5. Bouguer gravity map of western Vilas county in northern Wisconsin, showing the three profiles AA', BB', and CC'. Gravity data are manually contoured and visually smoothed. The southwest corner of the map is at latitude 45° 48.0' N, longitude 90° 00.0' W. Contour Interval = 2.0 mGal.

Table 3. Sources and magnitudes of error, in mGal, in Bouguer gravity values collected during 1982. The latitude error assumes an uncertainty of ± 0.05 minutes in latitude. Meter readings were accurate to within ± 0.05 mGal; hence errors are the same for the observed station value, the main base station reading at Rhinelander, and the local base station reading. The absolute gravity at the Rhinelander base station was 980555.21 ± 0.05 mGal with respect to the 1971 International Gravity Standardization Net (Ervin, 1983). The terrain correction of ± 0.25 mGal was estimated by Carlson (1974) for the area east of Vilas county, where the topography is similar. The free-air and Bouguer correction errors assume that altitudes are accurate to ± 0.30 m.

SOURCE	ERROR (mGAL)
Latitude	± 0.08
Observed Station Value	± 0.05
Main Base Station Reading	± 0.05
Local Base Station Reading	± 0.05
Absolute Base Station Value	± 0.05
Terrain Correction	± 0.25
Free-air Correction	± 0.09
Bouguer Correction	± 0.03
Total Error	± 0.62 mGal

Three curves bisecting the major anomalies were selected for modeling (fig. 5). Profile AA' trends roughly north-south and transects both the high (-12 mGal) anomaly of the south-central region and the low (-60 mGal) feature in the central area. Profile BB' transects the positive (-22 mGal) anomaly to the southwest and the relatively low (-36 mGal) region due north. Profile CC' trends nearly east-west, crossing AA' at the -60 mGal area and BB' at the -22 mGal structure.

Each profile was first corrected for the glacial till layer and the greater bedrock density. Next, the regional gravity of -40 mGal was subtracted (Cohen and Meyer, 1966). Finally, the approximate boundaries of the geologic units were obtained from the bedrock maps, and polygons were selected to match the gravity curves. Since profile CC' crosses the other two, it was used as a constraint on both AA' and BB'. The fitting process was repeated until the polygons matched in both directions. Two models were derived for each profile: one based on the Wisconsin Geological and Natural History Survey (WGNHS) map, and the other on the Minnesota Geological Survey (MGS) map. Since outcrop and drill-hole data are scarce, the maps were used only as approximate guides to the bedrock surface. For the remainder of this work, all bedrock symbols correspond to those of the WGNHS map.

The average density of observations is about one reading for every 4 km^2 area, ranging from 0.5 readings to 2.6 readings per 4 km^2. Since the iron formation (Pif) typically occurs in long narrow bands about 0.1 km wide (Ervin, 1988, written communication), and is on the order of 0.2 km deep (Dutton, 1971), the gravity measurements cannot detect it except as high frequency noise. For example, a gravity profile bisecting a unit of iron formation 0.1 km wide, 0.2 km deep, and 10 km long will have an anomaly of +1.2 mGal directly over the iron formation, with a half-width of 0.07 km. Thus the iron formation cannot be accurately modeled with this data set.

Till-Bedrock Correction

The Bouguer density of 2.67 g cm^{-3} used to compute Bouguer anomalies is inaccurate since the till, which averages 40 m thick, has a density of 2.0 g cm^{-3}, and the average bedrock density is 2.74 g cm^{-3} (Ocola and Meyer, 1973; Woollard, 1962). A till-bedrock correction was applied to each profile to compensate for these effects. Estimates of the till thickness and bedrock elevation were obtained beneath each profile from Attig (1985). The effects of the till and denser bedrock were then stripped from the Bouguer values. For example, the bedrock beneath profile AA' is very irregular, and the till thickness ranges from 85 m at the southern end to 5 m at the northern end. Figure 6 shows the cross-sectional view below AA', the till correction, bedrock correction, and the net correction along the profile. Since the till surface is relatively flat, the bedrock correction is essentially the negative of the till correction, but with a lower amplitude. Near the thickest till, the correction is as much as +1.0 mGal. As the till thins, the bedrock correction dominates, and an extremum of -1.4 mGal occurs. The net correction for profile BB' is always negative and ranges from -0.5 to -0.1 mGal. Profile CC' crosses a broad basin of till; its correction ranges from -0.5 to +0.5 mGal.

Comparison of Gravity Models Based on the WGNHS and MGS Maps

The two-and-one-half-dimensional algorithm was used to derive structures that matched the observed

Table 4. Average densities (in g cm^{-3}) of Early and Middle Precambrian rock units in northern Wisconsin. The symbols refer to the Wisconsin Geological and Natural History Survey bedrock map. The references are: 1 – Chandler, 1986, written communication; 2 – Carlson (1974); 3 – Klasner and Cannon (1974); 4 – Klasner and others, (1985); 5 – Ocola and Meyer (1973).

ROCK TYPE	SYMBOL	DENSITY	REF.
QUATERNARY:			
Glacial Till	–	2.00	5
MIDDLE PRECAMBRIAN:			
Iron Formation	Pif	3.03	1
Metasedimentary Rocks	Pms	2.79	1
Granitic Rocks	Pgr	2.67	1
Mafic Metaplutons	Pmg	3.10	2
Mafic Metavolcanics	Pvn	2.92	4
Greenschist Metavolcanics	Pvu	2.91	3,4,5
Granitic Gneiss	Pgn	2.67	1,2
EARLY PRECAMBRIAN:			
Granitic Rocks	Agr, PAgn	2.64	1
Metasedimentary Rocks	–	2.74	1
Granitic Gneiss	Agn	2.64	1
Felsic Gneiss	Agn	2.89	1

gravity, using the WGNHS and MGS maps as guides to the subsurface geology. Figures 7-12 show the model cross sections and observed and calculated gravity fields. All gravity values were computed at the surface of the till, approx 500 m above sea level.

Using the WGNHS map, the gravity of profile AA' was calculated by placing the bodies of finite strike-length - mafic intrusives (Pmg), granitic gneiss (Pgn), Early or Middle Precambrian gneiss (PAgn), and Early Precambrian gneiss (Agn) - in infinitely broad units of either greenschist metavolcanics (Pvu) to the south or metasediments (Pms) to the north. The metavolcanic-metasedimentary boundary (the Niagara fault) was placed in the middle of the PAgn body. As shown by figure 7, a gravity maximum of -12 mGal at the southern end of profile AA' is modeled by a deep (approx 3.5 km) mafic intrusive body (Pmg), with a strike-length of ± 3 km (that is, 3 km both east and west of AA'). The Pgn unit is only 1.3 km thick and extends from 4 km west of AA' to 30 km east of AA'. The Early or Middle Precambrian dome centered at 18 km lowers the field to -60 mGal and is about 8 km deep, becoming wider with depth. The dashed line on the cross section within the PAgn unit indicates that polygons of different strike-length (that is, different extent perpendicular to the profile) were used in the model. The felsic Early Precambrian gneiss (Agn) at the northern end of the profile is about 2.7 km deep, ranging from 4 km west to 10 km east of AA'. The greenschist metavolcanic layer is 1.1 km thick, and the metasediments range from 0.7 to 1.6 km thick.

Using the MGS map, the cross section beneath profile AA' is roughly the same as for the WGNHS profile, but the location of the greenschist metavolcanic (Pvu) and metasediment (Pms) boundary is further north (fig. 8). This makes a significant change in the Early or Middle Precambrian gneiss dome. Since the dome is now surrounded by higher density material, it must be much larger in order to decrease the gravity field to -60 mGal. Its uppermost portion, however, is very narrow because of the sharp drop in gravity directly over the dome's center.

Profile BB' has a considerably more complex sequence of bedrock units, based upon recent drill-hole data in the southwest region (Greenberg, 1986, verbal communication). Figure 9 illustrates the cross section as well as the observed and modeled gravity based on the WGNHS map. Although not shown on the diagram, the gravity was modeled by encircling the mafic plutons (Pmg) with mafic metavolcanics (Pvn) 1.4 km thick. Also, the Pvn unit was surrounded by metasediments (Pms). In this model, the mafic body (Pmg) had to be widened from 2 km in the north-south direction (as shown on the WGNHS map) to about 6 km to account for the broad gravity maximum of -23 mGal. The gravity over the Pmg unit ranges from -24.0 to -22.2 mGal, with a slight dip in the middle. A small unit of Middle Precambrian granite centered over this anomaly may account for the gravity drop but is entirely speculative. However, this interpretation corresponds with another structure just west of Vilas county mapped from drill-hole data (Greenberg, 1986, verbal communication). The 1.8 mGal fluctuation may easily be due to an undetected increase in the thickness of the glacial sediments. At 30 km, the lowered gravity (-33 mGal) is shown on the WGNHS map to be the result of another Early or Middle Precambrian dome, but this is not supported by the gravity: even a relatively shallow (approximately 3 km) and narrow dome decreases the field by almost 10 mGal below the observed values. Thin granitic masses, similar to those mapped throughout the region, may account for the lowered gravity. The lowest gravity, -36 mGal at 30 km, is above the metasediment (Pms) layer, 1.3 km thick and infinite in strike. The gravity increases 10 mGal at about 35 km over the denser Early Precambrian gneiss (Agn). At the northern extreme of BB', the rapid decrease in gravity is probably due to the large body of Early Precambrian granite (Agr) located just north of Vilas county.

The cross section for profile BB' based on the MGS map is almost exactly the same as that for the WGNHS profile (fig. 10). The MGS map does not distinguish between greenschist (Pvu) and mafic (Pvn) metavolcanics, and the density difference between these rocks is only 0.01 g cm^{-3}; hence the models for this area are the same. A step-like boundary between the mafic unit (Pmg) and the greenschist metavolcanic unit fits the gravity better than the sloping contact of the WGNHS profile. The major difference is the location of the metavolcanic-metasediment contact of the Niagara fault, which is about 13 km further north on this diagram. Since the metasediment has a relatively low density, it contributes little to the gravity at the southern end of BB', and the southern boundary cannot be determined.

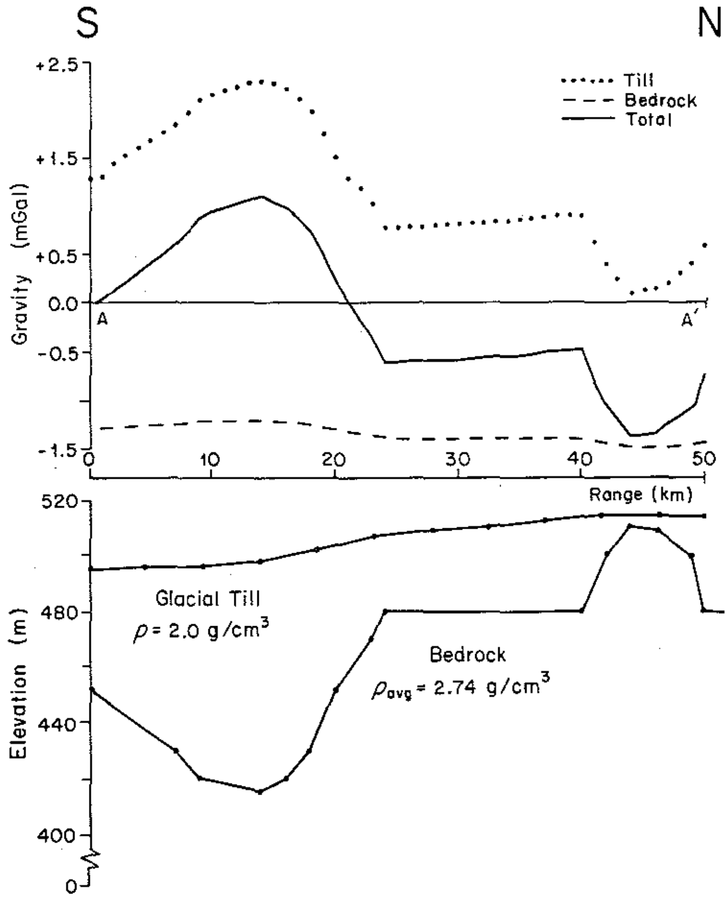

Figure 6. Till-bedrock correction for profile AA'. The dotted line represents the correction term for the till layer, and the dashed line is the bedrock layer. The solid curve shows the values to be added to the Bouguer gravity to strip these layers from the observed field.

Profile CC' crosses both the -60 mGal dome of AA' and the -23 mGal feature of BB' (fig. 11). The bodies of Early or Middle Precambrian gneiss (PAgn) and mafic plutons (Pmg) have been translated into their corresponding two-and-one-half-dimensional polygons in the east-west direction. From the WGNHS map, the Pmg body is very narrow (approx 0.8 km) in the north-south direction at the extreme western edge of the profile. (The eastern boundary of the narrowest part is marked by dashed lines on fig. 11.) From the gravity model, the unit widens around the intersection of BB' and CC', then narrows once more. Not shown but included in the model is the surrounding mafic metavolcanics (Pvn). Further east, the sequence rapidly changes from metavolcanics to metasediments (Pms), followed by the dome of Early or Middle Precambrian gneiss (PAgn). This model differs from that shown on the WGNHS map in that the dome must end at about 43 km from the western end of CC' because of the increase in gravity from -60 to -30 mGal. On the map, the dome ends at about the eastern edge of Vilas county, but the gravity becomes 30 mGal less than the observed values using this model. Since the feature is mantled by iron formation, the increase in gravity may be due to another unit of mafic rocks (Pmg) within metavolcanics (Pvn), similar to those found at the western end of the profile. The gravity may have other causes, such as underlying material or a change in the dome's shape. In this example, the Pvn unit is 9 km wide and the Pmg rock is about 5 km wide.

Profile CC' based on the MGS data does not match the WGNHS diagram because the greenschist metavolcanic (Pvu) material is found along its entire length. Hence, as shown by figure 12, the Early or

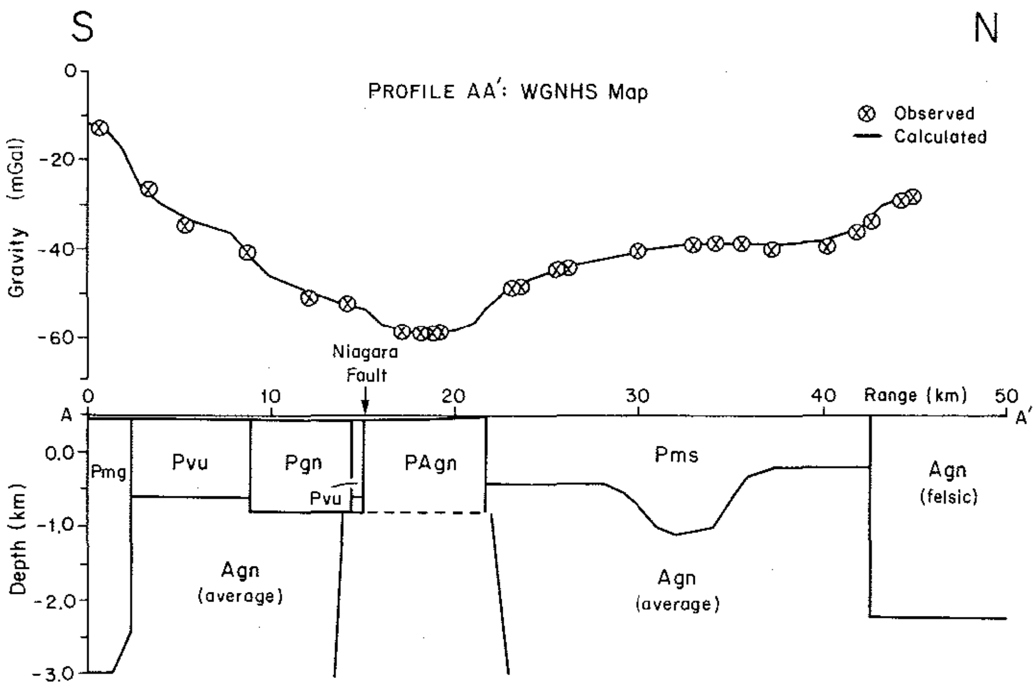

Figure 7. Observed (X···X) and calculated (—) gravity, in mGal, along profile AA', according to the WGNHS map. The axes of the cross section are in kilometers.

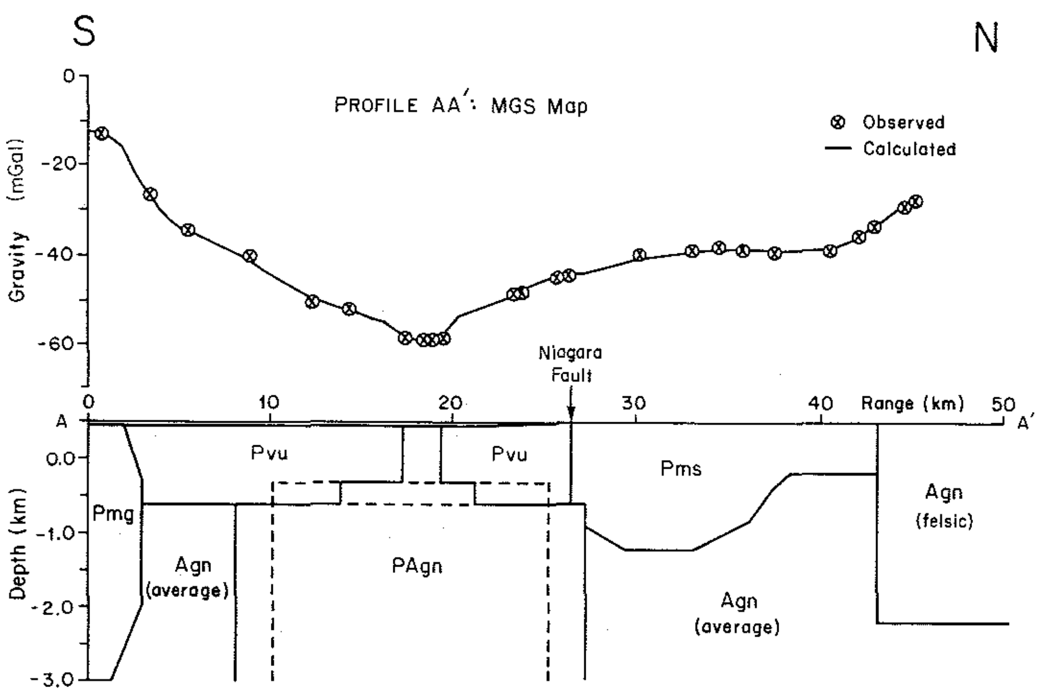

Figure 8. Observed (X···X) and calculated (—) gravity, in mGal, along profile AA', according to the MGS map. The axes of the cross section are in kilometers.

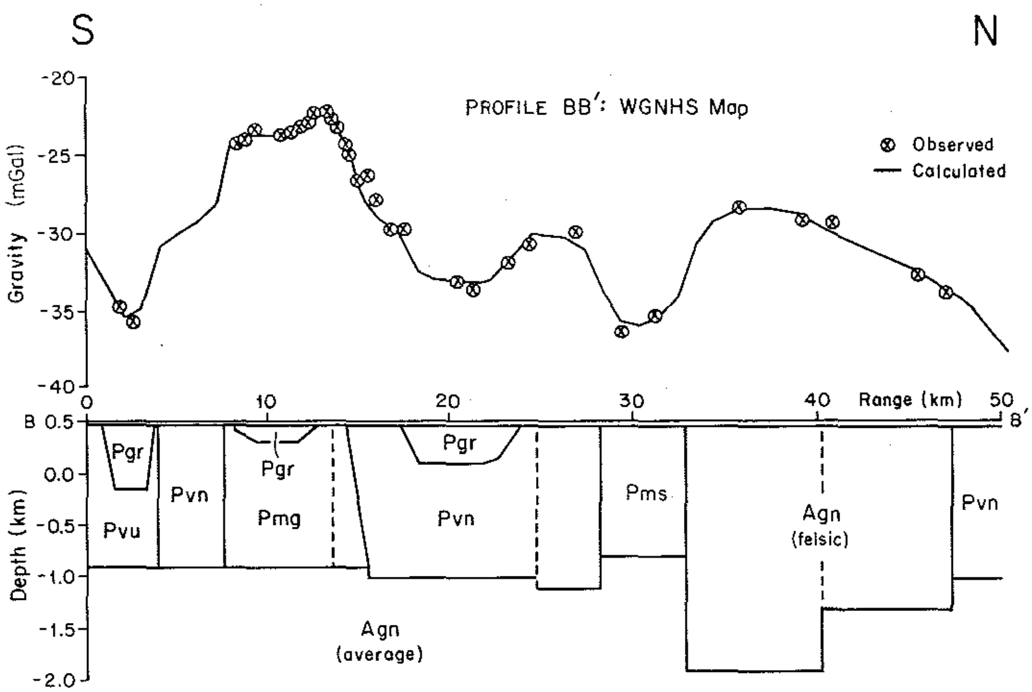

Figure 9. Observed (X···X) and calculated (—) gravity, in mGal, along profile BB', according to the WGNHS map. The axes of the cross section are in kilometers.

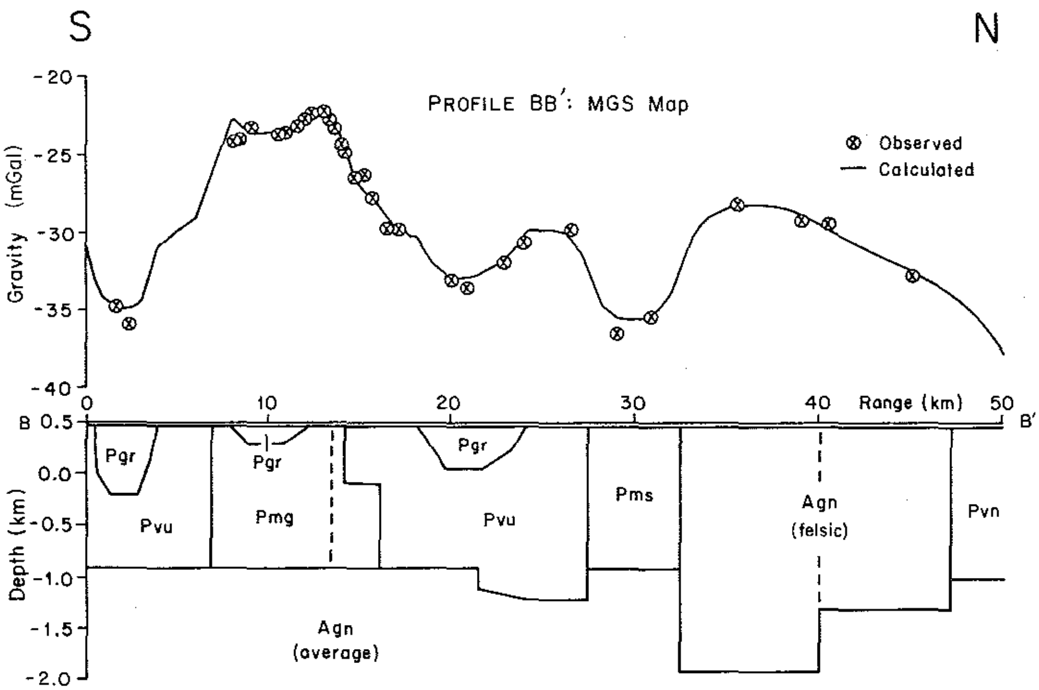

Figure 10. Observed (X···X) and calculated (—) gravity, in mGal, along profile BB', according to the MGS map. The axes of the cross section are in kilometers.

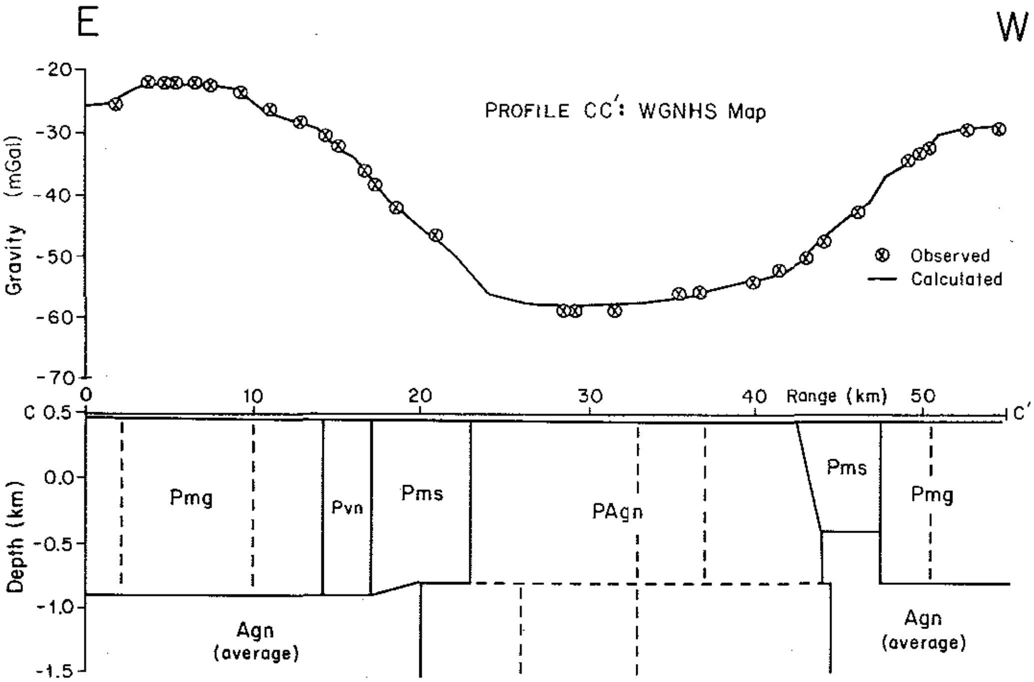

Figure 11. Observed (X···X) and calculated (—) gravity, in mGal, along profile CC', according to the WGNHS map. The axes of the cross section are in kilometers.

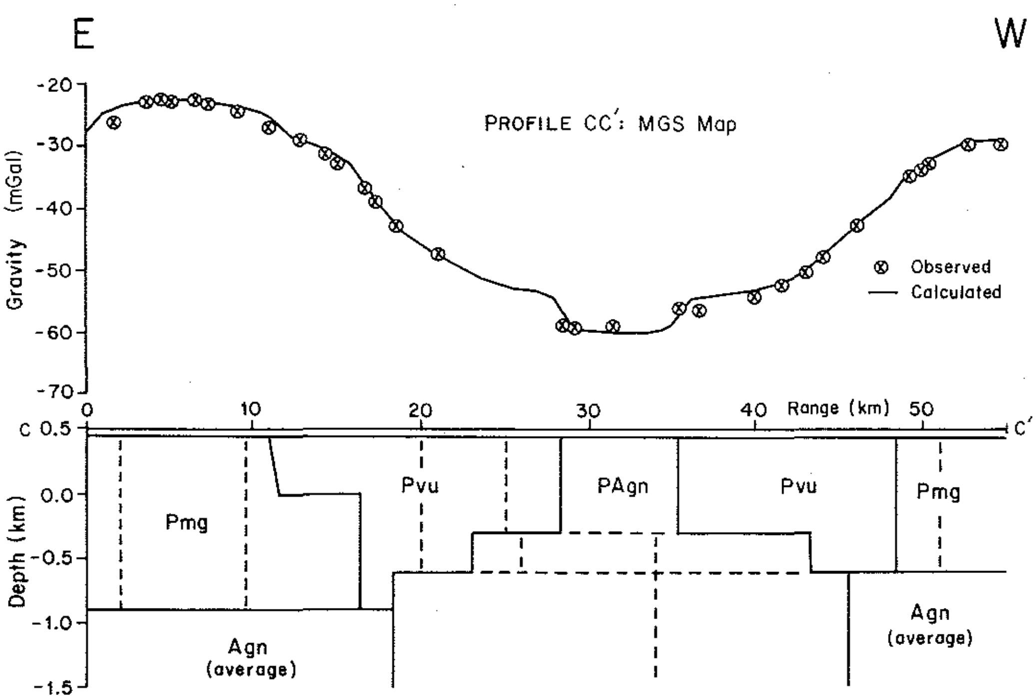

Figure 12. Observed (X···X) and calculated (—) gravity, in mGal, along profile CC', according to the MGS map. The axes of the cross section are in kilometers.

Middle Precambrian dome must be quite large yet narrow at the surface.

Figures 13 and 14 are three-dimensional views of the Early or Middle Precambrian dome models. From the WGNHS map (fig. 13), the structure is narrower on the eastern end to correspond with the gradually increasing gravity. The total depth is 8 km, the east-west length is a maximum of 26 km at the base, and the base in the north-south direction is 9 km long. A rough estimate of the total mass of the dome is approx 4×10^{15} kg. In the MGS model (fig. 14), if the total depth is held at 8 km, the dome must be very wide and broad. Its maximum length along profile AA' (the north-south direction) is 18 km. Beneath profile CC', the base of the dome is 32 km long, and the net mass is approx 9×10^{15} kg, double that of the dome from the WGNHS models.

CONCLUSIONS

The variation in thickness of the overlying till and in the elevation of the bedrock surface may have a significant effect on the residual gravity. If the till-bedrock interface is fairly flat, the effect may be less than 0.5 mGal. However, when the interface is highly irregular, the effect is negative over low and positive over high bedrock and can easily range from -1.4 to +1.0 mGal, which will greatly alter a gravity model. By modeling the subsurface as two-and-one-half-dimensional polygons, one can effectively strip this layer from the gravity field.

Because of the greater amount of bore-hole data used in the WGNHS map, the bedrock surface should be generally more reliable than that of the MGS map. For example, the mafic metavolcanics (Pvn) in the southwestern region are not shown on the MGS diagram, and the Niagara fault, the contact between the greenschist metavolcanics (Pvu) and the metasedimentary units (Pms), is further north. Since Pvn only occurs in association with metasediments, this is also evidence for the more southern boundary hypothesized by the Wisconsin Survey, which in turn supports the smaller version of the Early or Middle Precambrian gneiss (PAgn) dome. However, the large eastward extent of the dome is unsupported by the gravity field. A more consistent interpretation is another unit of metavolcanics (Pvn) surrounding mafic intrusives, since this is also mantled by iron formation and thus consistent with the magnetics of the region.

The Early Precambrian gneiss (Agn) domes must be relatively dense in character since they increase the gravity field. The small PAgn body in western Vilas county, as shown on the WGNHS diagram, is not supported by drill-hole data (Greenberg, 1986, verbal communication), and the lowered gravity may more likely be the result of granitic (Pgr) bedrock. In the southwestern area, neither map shows a feature large

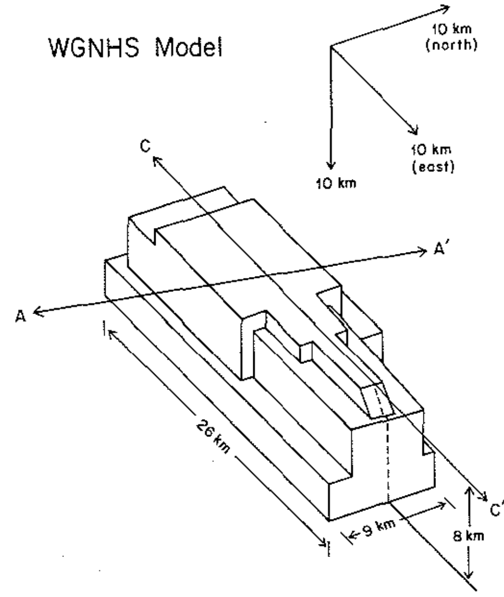

Figure 13. Early or Middle Precambrian gneiss dome in three dimensions, from the Wisconsin Geological and Natural History Survey gravity models.

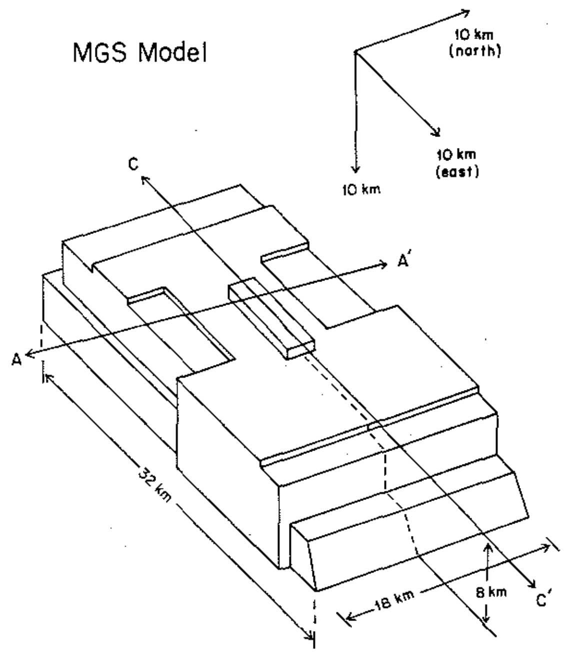

Figure 14. Early or Middle Precambrian gneiss dome in three dimensions, from the Minnesota Geological Survey gravity models.

enough to account for the high (-22 mGal) gravity. A mafic intrusive, about 7 km wide in the north-south direction and 15 km long in the east-west direction, matches the observed field. The exact location of the southern boundary of this body cannot be determined from the gravity because there are few measurements in this region.

The anomalous masses on either side of the Niagara fault prevent a determination of the fault's strike and dip from the gravity data. The changes in gravity from these bodies are much greater than the fluctuation due to the fault, and the fault's gravity field cannot be reliably separated from the total field. Also, the extent of the iron formation cannot be determined because the spatial wavelength of these long narrow features is much shorter than the measurement separation.

Northern Wisconsin, and particularly Vilas county, has few outcrops because of the thick glacial till, and drill-hole data are also scarce. The interpretation of the gravity field thus required several assumptions based upon the geology of the region surrounding the field area. Additional information, particularly concerning the density of the upper crust, may change the parameters determined from this analysis.

ACKNOWLEDGMENTS

This study was undertaken as part of a Ph.D. thesis at the University of Wisconsin-Madison. I thank my advisor, C.S. Clay, and the members of my thesis committee, C.R. Bentley, H.F. Wang, J.S. Steinhart, and C.J. Bowser, for their guidance and support during the course of this study. This study could not have been completed without the data provided by J.K. Greenberg and M.G. Mudrey, Jr. of the Wisconsin Geological and Natural History Survey, by C.P. Ervin at Northern Illinois University, and by V. Chandler of the Minnesota Geological Survey. The Center for Limnology was also very generous with its facilities at the Trout Lake Biological Station in Vilas county.

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