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Interpretation of Subsurface Structure by 2-D Gravity Modeling Study

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ABSTRACT: A gravity survey was conducted in the western Marquette district, Michigan, to delineate the subsurface structure and the relationship of the Proterozoic Marquette Range Supergroup rocks (Precambrian X) and Archean basement (Precambrian W) where the Republic, Michigan River, and Marquette troughs join. In order to accomplish these purposes, three hundred and forty gravity stations were established in the area of 380 km^2. Positive anomalies are associated with the Precambria X, metasedimentary sequence which has a higer density with respect to the Precambrian W, basement rocks. The dominant positive gravity anomalies follow the axes of the three troughs which are filled with Precambrian X rocks. Subsurface structure was modelled by using the Talwani method. Gravity model studies indicate that the Marquette trough is asymetrically shaped and steeply dipping at the north edge except in the eastern part of the study area. The interpretive results obtained from two dimensional model studies suggest that the basement structure of the study area is relatively flat, and that the troughs were formed contemporaneously.

INTRODUCTION

The western Marquette area is underlain by an elongate trough of Proterozoic (Precambrian X) metasediments of the Marquette Range Supergroup (MRS) which has small off shoots known as the Republic trough and Michigan River trough. These troughs unconformably overlie Archean (Precambrian W) basement granite and gneisses. At the junction of the Marquette trough, the Republic trough, and the Michigan River trough, the complex structural and stratigraphical patterns of Precambrian X rocks may be related to previous deformations of the basement structure which ouccured prior to 2.5 Ga. Subsequent faulting of the basement developed during the Penokean orogeny which occured about 1.9 Ga ago.

The surface geology of the study area is well known as a result of many investigations which delimited the extensive iron ore deposits in the supergroup section. However, geophysical investigations have only been conducted in a limited area and started only in the 1970's (Cannon and Klasner, 1974). These studies have provided valuable information about rock densities, particularly the significant density contrast existing between the Precambrian X sedimentary sequence and the basement rocks. However, there are insufficient data to allow for estimates of the depth, structure, and cross-sectional configuration of the western Marquette area. In the present investigation the subsurface geology of the western Marquette area was modelled based on gravity measurements.

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GENERAL GEOLOGY

The area under investigation is composed of Precambrian rocks of three ages (Fig. 1). The majority of the rocks are Precambrian W and Precambrian X. The Precambrian W basement rocks, mostly granitic gneiss, are 2.5 billion years old or older by Rb-Sr dating (Cannon and Simmons, 1973), while the MRS, a Precambrian X sedimentary sequence is about 2.0 billion years old (Cannon and Klasner, 1974). Keweenawan rocks (Precambrian Y) exist only in outcrops on an island in lake Michigamme and forms a circular stock and very small dikes which trend approximatly east-west. The basement rocks are unconformably overlain by Precambrian X rocks which were deposited during an extensive period of sedimentation with minor volcanic activity. The contact between Precambrian W and Precambrian X rocks was originally an unconformity, but it became a zone of major slippage as the sedimentary rocks were down folded into the developing graben (Klasner and Cannon, 1978).

The general stratigraphic colum of this area is shown in Table 1. The Menominee and Baraga groups of the MRS are present in this study area. Previous geological investigators have shown that the Menominee and the Baraga group had different depositional environments. The former was deposited in shallow water, while the latter was deposited in a deep water eugeosynclinal environment resulting from rapid subsidence of the depositional basin. The Menominee group is a fining upward sequence with a basal quartzite overlain by laminated argillites, and chemical precipitates with local conglomerates. It was deposited unconformably on the Precambrain W basement rocks with mild tectonic disturbances during sedimentation (Van Schums, 1976).

The Baraga group is composed of a greatly varied sequence of metasedimentary and metavolcanic rocks. It is the most extensive of four groups composing the MRS. In the study area, it is composed of the Goodrich quartzite, Hemlock formation, Fence River formation, Strata near Fence Lake, and the Michigamme formation. The last covers the large area in this study area. The Strata near Fence Lake is considered to be part of the Michigamme formation (Cannon and Klasner, 1975).

Regional metamorphism, ranging from sillimanite to staurolite grade, recrystallized the rocks at approximatly the same time as deformation (Cannon and Klasner, 1977). Deformation in the trough is attributed to the Penokean Orogeny (Cannon, 1973), which occured about 1.9 Ga ago, and is related to development of arc-continent collision resulting in compression of the basement and the overlying sediments. An early tensional phase caused rupturing of the continental shelf which produced grabens and was followed by a compressional phase which produced folds (Cambray, 1977).

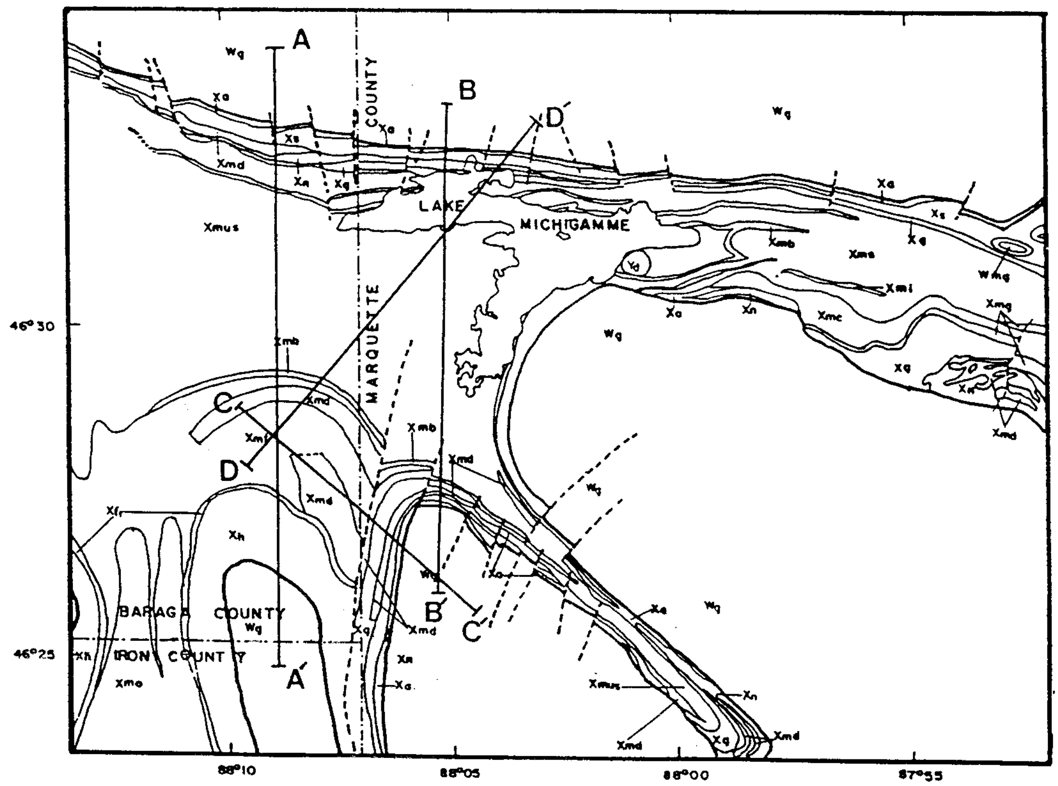

Fig. 1. Geologic map of the study area and locations of modelled gravity profiles. Dashed lines indicate faults, thick lines are boundary of Precambrian W and Precambrian X rocks. Abbreviations are given in Table 1.

Table 1. Stratigraphy of the study area.

Precambrian Y		Diabasic Dike (Yd)
(late Proterozic)	Baraga Group	(ρ = 2.82 g/cm^3, N=4)
		Upper Slate member (Xmus) (ρ = 2.84 g/cm^3, N=5)
		Bijiki iorn formation member (Xmb) (ρ = 3.09 g/cm^3, N=1)
		Lower Slate member (Xms) (ρ =2.72 g/cm^3, N=7)
Precambrian X	Baraga Group	Metadiabasic Dike (Xmd) (ρ =2.96 g/cm^3, N=6)
		Clarksburg Volcanics member (Xmcv) (ρ =2.84 g/cm^3, N=10)
		Strata near Fence lake (Xmf) (ρ =2.81 g/cm^3, N=6)
		Fence River formation (Xfr) (ρ =3.18 g/cm^3, N=4)
		Goodrich quartzite (Xg) (ρ =2.85 g/cm^3, N=4)
		Negaunee Iron formation (Xn) (ρ =3.50 g/cm^3, N=31)
	Menominee	Suamo slate (Xs) (ρ =2.73 g/cm^3, N=3)
		Ajibik Quartzite (Xa) (ρ =.2.63 g/cm^3, N=4)
Precambrian W (Archean)		Granitic rocks (Wg) (ρ =2.65 g/cm^3, N=458)

FIELD WORK

The gravity observations of this survey were taken with a LaCoste Romberg geodetic-quality gravity meter number, G-180, which has a range of 7000 milligals with an accuracy of ± 0.01 milligal. Elevation was controlled using a Wallace and Tiernan altimeter and read directly from topographic maps. This altimeter is marked in units of ten feet. A second Wallce and Tiernan altimeter was used in conjuction with the first one to reduce possible errors and to enhance accuracy. Four base stations were used in order to determine instrumental drift by reoccupation. The magnitude of the drift was checked at least once every four hours and yielded a mean drift curve, without respect to sign, of 0.018 milligal per hour with a standard deviation of ±0.021 milligal per hour.

Three hundred and forty stations were measured in this study along serveral loops with their lengths varying from 8 to 20 kilometers. The station spacing varied according to the amount of resolution desired and varied from 100 m to 1 km. The existing road network did not provide as good a coverage of the area as desired. However, the survey covered a large area in which logging roads provided access. Most of these road do not appear on U.S.G.S. topographic maps and have been built in the last decade. In order to minimize the location error, station locations were determined by using the topographic maps, air photoes (provided by Michigan D. N.R.), timber classification maps, and photo-reduced logging maps (provided by Mead Paper Co.). In addition to the above maps, a pace and compass survey, and odometer-topography-bearing survey were performed in some sections.

Accuracy of Horizontal Coordinates

Latitude and longitude cordinates were determined for each stations from U.S.G.S. topographic maps (scale, 1:24000). Stations were located at road intersections or at recognizable locations whenever possible. The location error for most stations at such intersections does not exceed ±150 m with very few exceptions.

Elevation Control

Elevations of all the stations were established by using two Wallace and Tiernan altimeter, one metal, and one wood cased. The metal cased altimeter drifted considerably more than wooden one, especially in direct sunlight because of ground temperature.

Only two bench marks were actually found during the survey, 1596 feet (station N10) along the Soo trackage south of the Mud Lake, and 1679 feet (station T10) northeast of St. Johns Lake. When culturally identifiable locations were unavailable, gravity stations were located at topographically identifiable features, such as in the center of depressions or on the crests of gentle hills.

The accuracy of these eleviations, therefore, is estimated to be ±5 feet and no case exceed ± 10 feet, resulting in error of ±0.21 milligal.

DATA REDUCTION

Observed gravimeter readings were drift-corrected based on drift curves (Fig. 2) for lines which had high frequently instrumental drift due to climatic conditions. Other lines were corrected assuming linear drift within each loop. The readings were then converted to milligals using the calibration constant of the gravimeter. Drift

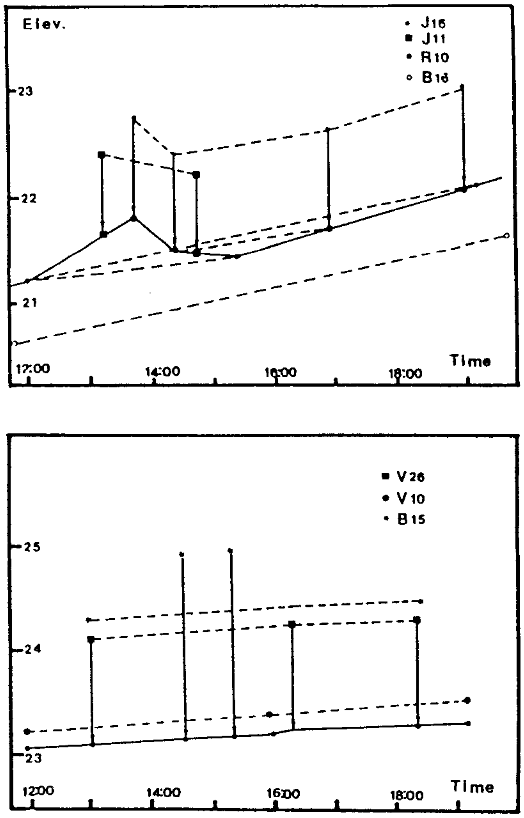

Fig. 2. Altimeter drift for loops which had high frequency instrumental drift. Dashed lines represent altitude drift curve of the each station. Solid line represent the composite drift curve. Elevation marked in units of ten feet.

rates are listed in Table 2.

Observed gravity values were then adjusted for the elevation, mass, and latitude corretions (formula developed by Telford et al., 1976) to obtain the Bouguer gravity anomalies. No correction was made for the terrain effect, since the topographic relief in the survey area was small enough to make the terrain correction negligible.

Table 2. Drift Rates.

Drift Rate	No	min/hour	max/hour	mean	St.Dev
Gravimeter	18	0.00	0.03	0.018	± 0.021
Altimeter *M	14	0.01	0.17	0.08	± 0.05
*W	14	0.01	0.17	0.08	± 0.05

(*M : Metal cased altimeter, W:Wooden altimeter)

In making the gravity reductions, the potential sources of error may stem from the survey procedure itself. These errors can be divided into following four possibilities.

A. Errors in reading the gravimeter.
B. Errors in elevation determination.
C. Errors in latitude determination.
D. Errors caused by incorrect assumed values of density of subsurface material.

The magnitude of the above errors can be estimated in the following manner.

An estimate of the accuracy of the gravimeter readings can be obtained by multiple readings at some stations. The standard deviation for these repeated gravity observation is ±0.02 mgal. Elevation errors within the study area can be determined by comparing topographic map values with those measured by the altimeter. Twenty six stations of known elevation (e.g., road intersections, bridges) were selected for this comparison. The standard deviation for these errors is ±3.25 feet which produces the error ±0.21 mgal according to the following combined formula (Nettleton, 1976):

$$g_{f,B} = (0.09406 - 0.01278\,\rho)\,h$$

$g_{f,B}$: combined correction for Bougner and free-air anomaly
ρ : rock density (g/cm^3) h : relief (ft)

Errors in the latitude correction depend on the accuracy of the latitude determinations. The latitude errors of the most stations do not exceed ±30m which result in an error of ±0.02 mgal. An incorrect value of the subsurface material density causes an error in the mass correction. An error in the density of 0.1g/cm² causes an error of 0.001 magal per foot (Nettleton, 1976):

$$\partial g = 0.0127\ \partial\rho\ h \text{ magl/ft}$$

∂g: gravity error
$\partial\rho$: density error (g/cm^3)
h: elevation(ft)

In this study, and error in the density of 0. 1g/cm^3 will cause an error of 0.013 mgal per 10 feet. The largest density contrast in the geologic column is between glacial deposits and the bedrock. Therefore, the distribution of till significantly influences the gravitational field. However, no data were available about the till thickness in this area. Deviations in the till thickness of 10m, with a till density of 2.0 g/cm^3 (Paddock, 1982), will cause an error of ±0.28 mgal. Assuming that above factors are independant, possible errors in this survey are listed in Table 3.

Table 3. Error Analysis.

Error Sources	No	Min	Max	Mean	St.Dev.	mgal
Errors in Reading	8	0.00	0.05	0.019	± 0.02	± 0.02
Errors in Elevation	24	0.00	11	1.12	± 3.52	± 0.21
Errors in Latitude	-	0.00m	150m	-		± 0.11
Probable Error						± 0.24

INTERPRETATION OF GRAVITY DATA

Interpretation of gravity data has been carried out using all available data, including published geological information, measured Bouguer gravity, and rock density data determined by previous workers. In the present study, four gravity profiles were considered from the area. The gravity data were interpreted in step by step manner. First, the overall structural trends were

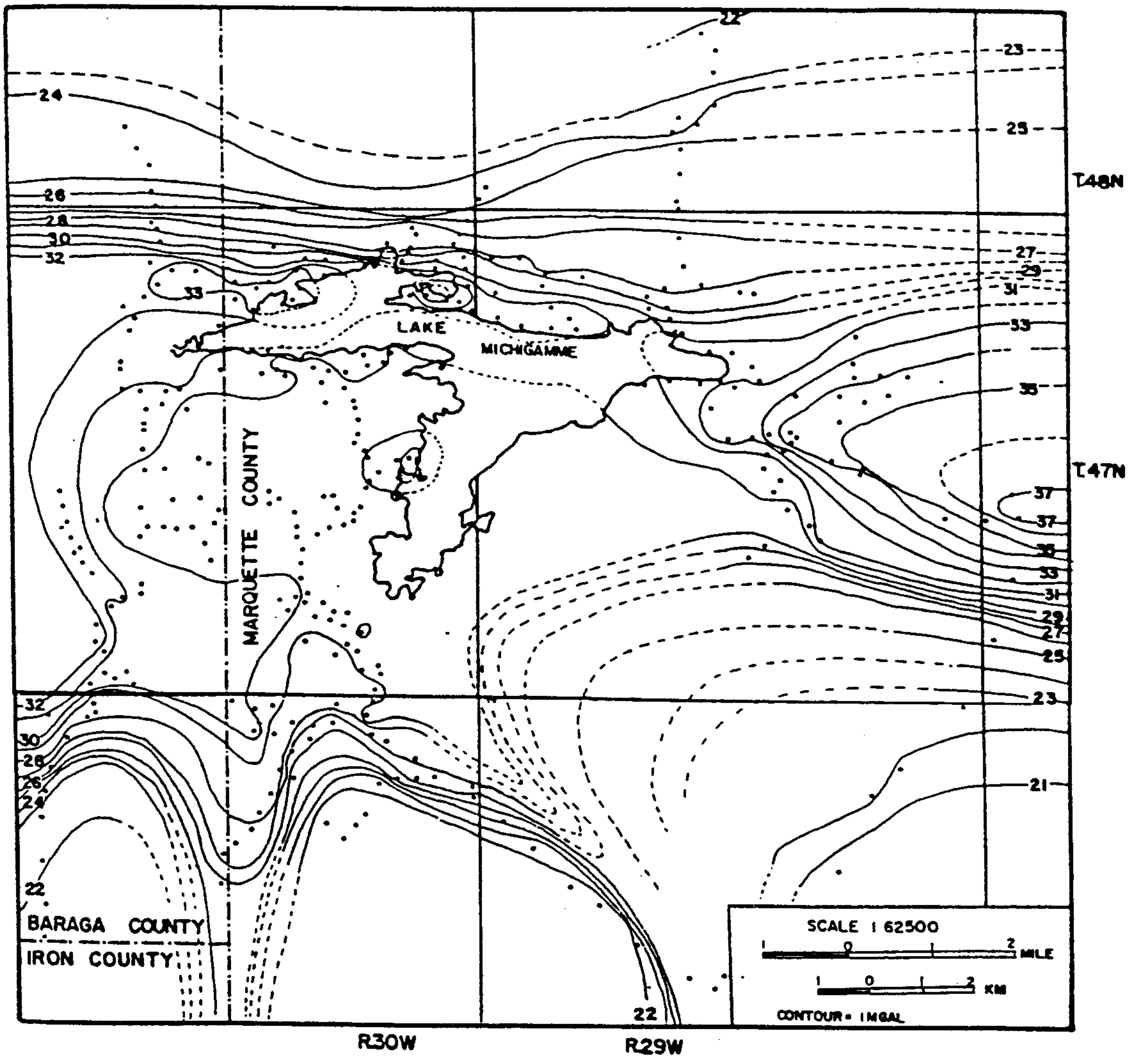

Fig. 3. Bouguer gravity map of the study area. In unsurved areas, the contour lines are marked with a dashjed line. Base station is marked by star.

determined from the Bouguer gravity map. Several geological models were made for each profile based on all the available information. Then the best one was chosen after computation. Gravity models were calculated for the two dimensional subsurface geological models using the method of Talwani et al. (1959). Computation was performed using a CDC Cyber 750 computer.

The assumption of the two dimensionality is justified because most anomalies are horizontally linear having greater lengths then widths (Oray, 1971). Models were also required to match every point where separate profiles crossed.

Interpretation of the Bouguer Gravity Map

The major purpose of the interpretation of the Bouguer gravity map is to determine the general structural trends throughout the area by using a qualitative approach concerning the gradient, the shape of the anomaly and anomaly values. The Bouguer gravity map shown in Fig. 3 shows the results of reducing the observed gravity. Fig. 3 shows three major directions of the anomalies. The major trend is oriented east-west and two branches with north-south and northwest to southeast directions occure in the southern part of the present area. These anomalies coincided with the existence of three troughs which are filled with Precambrian X sediments with higher densities than that of the basement rocks. In the east-central part of the area, the anomaly is assymetric with steeper gradients on the south side compared to the north side.

In the southern part of Fig. 3, there are two branches of positive anomalies, one stretching north-south and the other northwest-southeast. Both have a very narrow width and a relatively steep gradient. The gradient may be attributed to either the steep dip of the troughs' 'limbs or by the existence of iron formation on both limbs of the troughs. The Michigan River trough, however, is most likely to be a fault monocline, with iron formation present only on one limb on the basis of detailed geologic mapping and magnetic surveys by Cannon and Klasner (1974, 1976).

In the southern part of this map, gravity lows are associated with the Smith Creek uplift, Grant Lake uplift and the Twin Lake uplift which are composed of Precambrian W granitic gneiss ($2.64 g/cm^3$). The elliptically shaped high positive anomaly present in the northeastern part of T. 47N, R. 30W appears to be due to a large exposure of the Negaunee iron formation. The circular shaped positive anomaly in the center of this map, may suggest the possibility of the existance of the Keweenawan diabasic dike. In the unsurveyed area, gravity contour lines are dashed and based on geologic maps and other available information.

Modelling

The purpose of modelling is to delineate the complexity of Precambrian rocks based on measured gravity values and all the aforementioned information. The magnetic survey data of Cannon and Klasner (1976) were used for reference in some parts of profiles A-A', C-C', and D-D'.

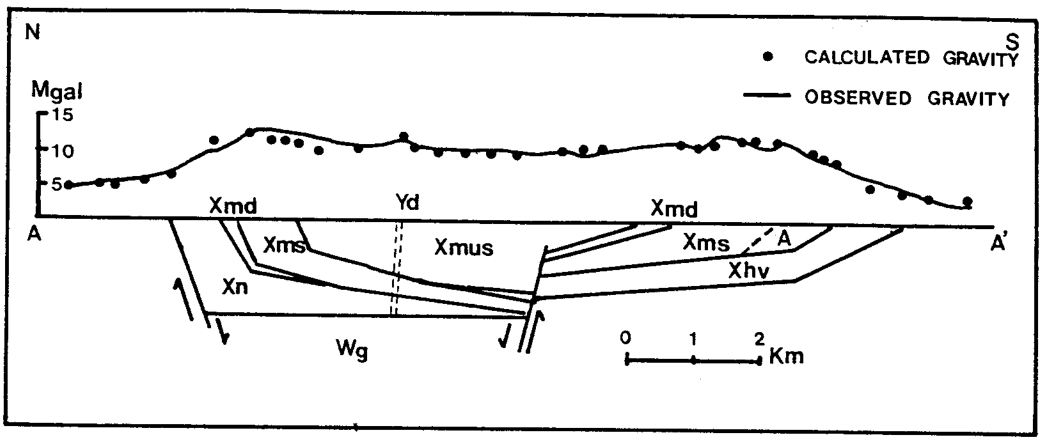

Fig. 4. Gravity profile measured along section A-A' showing observed gravity (solid line) and calculated gravity (points). Abbreviations are give in Table 1. No vertical exaggeration..

The results of the present study, however, may not be unique for several reasons. 1) The physical properties of the rock units (especially density) are not uniform and change in horizontally and vertically. For example, the Goodrich quartzite has an average density of 2.73 g/cm^3. However, it changes up to 2.85 g/cm^3 in the north edge of the Marquette trough because it contains a high percentage of iron formation (Cannon and Klasner, 1974). The density of the Negaunee iron formation is also variable, and may vary with depth.2) The gravity stations were not measured on the cross-section but projected to them. Thus, to reduce the above mentioned ambiguities and to enhance the accuracy of the model, densities and thickness of the formations were varied within a limited range based on previous studies (Gibb, 1967; Cannon and Klasner, 1974; Paddock, 1982;) and drillhole data (Boyum, 1975; Klasner and Cannon, 1978; Trow, 1979).

Profile A-A'

This model assumes that a fault exists between the north edge of the Marquette trough and the Smith Creek uplift (Figure 4). The ends of the profile were modeled from the geophysical investigations of Cannon and Klasner (1974, 1976). Their model matches the observed and calculated gravity in the northern end relatively well, but fails to show a good correlation between the observed and caluclated gravity in the southern part. Therefore, I analyzed the cause of failure and then remodelled this profile. One reason for poor correlation of their model is the variable density of the Strata near Fence Lake, which are composed of materials of various densities and occurs in a very limited area; this suggestion is supported by very irregular magnetic and gravity anomalies (Cannon and Klasner, 1976). The positive anomalies seen in the profile area due to Precambrian X sedimentary rocks which have an average density of 0. 22g/cm^3 (Cannon and Klasner, 1974) more than that of Precambrian W basement rocks. The small, sharp positive anomaly superimposed on the long wavelength positive anomaly across the Marquette trough suggests the possibility of the existence of Keweenawan diabase dike with a roughly east-west trend. The Goodrich quartzite thins out to the south and lies directly on the basement block. The density of the Goodrich quartzite at the north edge of the Marquette trough is relatively high(2.85g/cm) because of the high percentage of iron formation in it (Cannon and Klasner, 1974). The Hemlock formation apparently lies directly on pre-Baraga group rocks. The Fence River formation, which is an blankets the Hemlock volcanic rocks and appear to be approximately coextensive (Cannon and Klasner, 1975).

In this model, the block which is marked by the dotted line in the southern part (A on figure) has low magnetic and high gravity values. Presence of the low magnetic and high gravity values may have two possible causes. One possibility is the effect of the amphibolitic schist in the Strata near Fence Lake. Secondly, a continu-

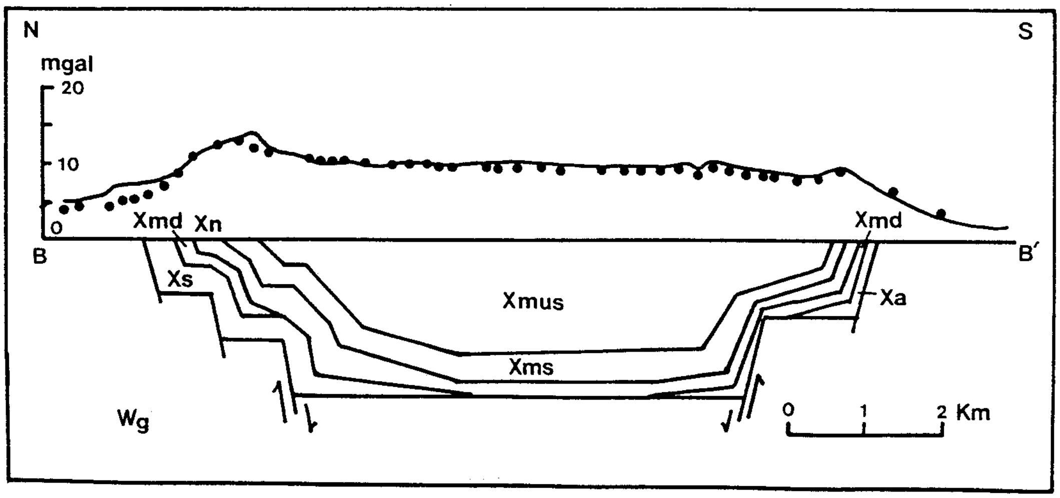

Fig. 5. Gravity profile measured along section B-B' showing observed gravity (solid line) and calculated gravity (points). Abbreviations are given in Table 1. No vertical exaggeration.

ation of the metadiabase sill which occurs near the area but is not shown on the geologic map within the area could also cause this deviation.

Profile B-B'

A large positive anomaly exists at the north edge of the Marquette trough and a very flat positive anomaly extends across the area to the south (Fig. 5). Of several geological models attempted, a graben structure gives the best correlation between the observed and calculated gravity in the northern part of the Marquette trough on this profile. Between the northern edge of the Marquette trough (B on profile) and the Republic trough (B' on profile), a deep broad sedimentary basin exsits which has a depth to basement of 2 km.

The anomaly has a difference of 10 milligal between the center and the ends of the profile. The average density contrast between the sedimentary rocks and basement rocks is 0.13g/cm^3. These are used to give a depth to basement of approximately 1850 meters under the flat-lying sediments according to the following formula (Bacon and Wyble, 1952):

$h = g/2\pi\ G\rho$
g: anomaly contrast
G: gravitational constant
ρ: density contrast

The small, 1 mgal, irregularities in the gravity values could be caused by minor differences in surface material over very limite areas or folding in the Michigamme formation, particulary in the Bijiki iron formation. The folding was caused by compression during the Penokean orogeny. The irregularities also may be due to errors in elevation, mislocation of the stations and/or till north edge of the Marquette trough.

Profile C-C '

Fig. 6 illustrates a geological model of the profile C-C', which is oriented northwest to southeast and extends 8 km in length. The positive anomalies decrease to the southeast. Two small short wavelength positive anomalies are caused by the existence of the iron formation and metadiabase which are located at both edges of the Michigan River trough. These positive anomalies allow an estimate of the depth to basement of the Michigan River trough of 1100 meters. The Negaunee and Ajibik formations have a uniform thickness east of the fault (B in figure). West of the fault, Ajibik, Negaunee and Goodrich are absent and the Hemlock formation overlies the Precambrian W basement rocks. This is considered to be a lateral facies change of the Michigamme formation to the Strata near Fence Lake. The other possibility is that the faults are not contemporaneous and sediment pinches out in a different direction. In this model, fault A developed in the basement, upthrowing the right side of the block. Either faulting occured concomitant with sedimentation but before lithification of the sediments. The sediment would then overlie the basement

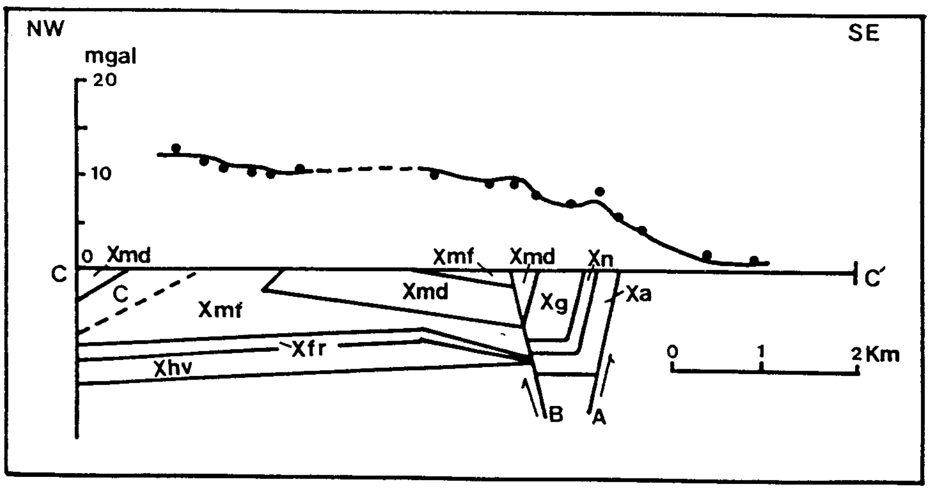

Fig. 6. Gravity profile measured along section C-C' showing observed gravity (solid line) and calculated gravity (points). Abbreviations are given in Table 1. No vertical exaggeration.

with an angular unconformity, and slope off the pinching out of the Ajibik, Negaunee, and Goodrich formation to the west, while the Hemlock and Fence River formation, and the Strata near Fence Lake were deposited from the west. Then the second period faulting (B on Fig. 6) cut the sediment in the downthrown block, and eroded down to the present surface. However, the geometry suggests that faulting occured in one episode.

In the western part of this section, the unit west of the dotted line (C on Fig.) is considered to be an iron formation. This is one of the formation composing the Strata near Fence Lake, and is based on high anomalies seen in the magnetic survey performed by Cannon and Klasner (1976).

Profile D-D'

Fig. 7 illustrates a geologic model of profile D-D', which is oriented soutwest to northeast. Long wavelength positive anomalies exists at both ends of the section, while it is fairly flat in the middle. The graben structure at the northern end yields the best correlation between the observed and the calculated gravity values among several geological models. The lower slate member is very thick in the northeastern part of this section, while it is very thin on tht opposite side. The Goodrich quartzite overlies Precambrian W basement rocks and becomes thinner to the southeast and pinches out near the southern edge of Lake Michigamme. The Hemlock and Fence River formations pinch out to the north and are coextensive.

Summary of the Results

A synthesis of the results from the modelling study interpretes the following two major distribution patterns of the overall rock units. The Menominee group rocks are restricted to within a few kilometers north edge of the Marquette trough, the Republic trough, and east flank of the Michigan River trough. The Ajibik quartzite, Siamo slate and probably the Negaunee iron formation pinch out to the south within a few kilometers of the north edge of Marquette trough. The reason of the pinch out is unknown. It maybe due either to the original sediment distribution or to the weathering and erosion which has partly or totally removed the Menominee group prior to the deposition of the Baraga group.

The Baraga group is composed of a varied sequence of metasedimentary and metavolcanic rocks. Detailed mapping by previous workers reveal many changes within the stratigraphic column from area to area. The oldest unit of the Baraga group is the Goodrich quartzite which overlies the Precambrian W basement rocks over a large area with a various thickness are due to the original sediment distribution or to erosion before the deposition of the Michigamme formation. The distribution of the Strata near Fence Lake appears to be confined to the north flank of Smith Creek uplift. The Hemlock, which is present a few kilometers southwest of the study area, apprently forms a broad apron, as much as a kilometer thick along the periphery of a cen-

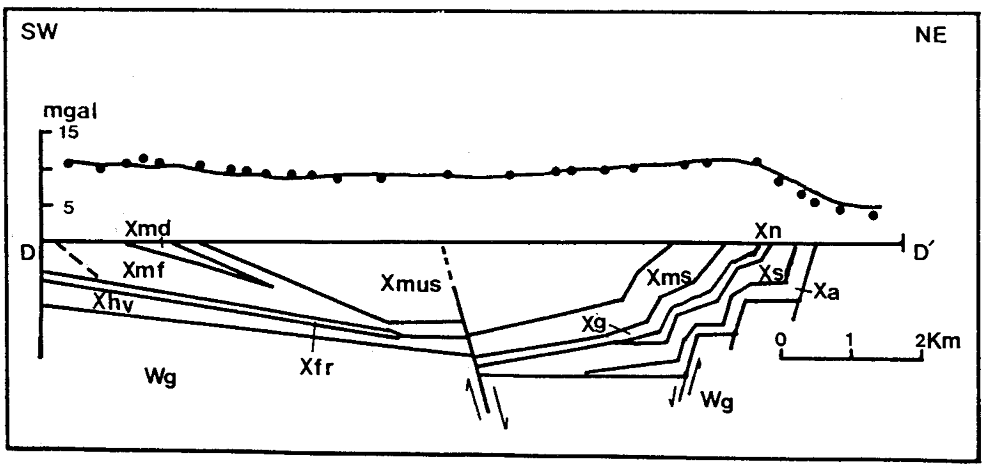

Fig. 7. Gravity profile measured along section D-D' showing observed gravity (solid line) and calculated gravity (points). Abbreviations are given in Table 1. No vertical exaggeration.

tral volcanic area, centered west or south of the Amasa uplift.

CONCLUSION

This study present an interpretation of the subsurface structural features of the juction of the Marquette trough, Republic trough and the Michigan River trough based on gravity data. The modelling revealed that some current views do not fit the observed and calculated gravity. For example, previous models of a cross section west of Lake Michigamme (Cannon and Klasner, 1974,; Klasenr and Cannon, 1978) gave much different results compared to the author's in the thickness of the Michigamme formation. They suggested an uniform thickness of Menominee group rocks and a thickness of Michigamme formation of less than 600 meters, while author's results suggest the Menominee group rocks pinch out to the south and the Michigamme formation has a thickness of 1000 to 1900m west of Lake Michigamme. The thickness difference between the profile A-A' and profile B-B' can be explained only if the basement is folded or faulted upwards. However, deformation of the supergroup rocks of this type is not seen on the surface exposures. Therefore, the Michigan River trough fault is proposed to continue a few kilometers north of that Cannon and Klasner inferred (1976). This gives a better correlation between the observed and calculated gravity.

The result of the present modelling study suggests the following:

Distribution of the Menominee group rocks (particulary in the Siamo slate) are limited within a few kilometers from north edge in the Marquette trough. The upper slate member becomes thicker to the west. The lower slate member becomes thinner to the west and south direction and eventually pinches out. The Bijiki iron formation exists only in the southwest part of the Marquette trough in this area. Separate episodes of faulting would result in vertical displacement of the basement blocks relative to one another. Contrary to expectations, the basement structure of the study area appears to be a relatively flat, broad sedimentary basin, suggesting that the elongated troughs might have formed contemporaneously. This study, however, is subject to the previously mentioned errors. The conclusions presented here, thus, serve only as a first order approximation.

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중력탐사를 이용한 2차원 Modelling study에 의한 지질구조 해석

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요약: 본 연구에서는 북부 미시간지역에 분포하는 세개의 troughes (Marquette, Republic, and Michigan River troughes)가 만나는 지역의 tectonic evolution을 해석하기 위한 stress의 방향 및 변성퇴적암류의 분포를 이해하는데 도움을 주기위하여, 중력탐사를 통하여 연구지역의 기반암구조 및 이를 피복하고 있는 변성퇴적암과의 관계를 해석하였다. 연구지역은 시생대 기반암(Precambrian W)을 원생대의 변성퇴적암이 부정합으로 덮고 있으며, 이들 암석군들은 현저한 밀도의 차이를 보여 본역의 지각구조를 설명하는데 있어서 중력탐사가 효과적이다. 380 km^2에 걸친 연구지역에 340개의 중력기점을 설정하여 측정된 중력은 표준중력 보정과정을 통하여 중력이상도를 작성하였다. Trough내에 퇴적되어 있는 변성퇴적암류를 따라 positive anomaly가 세 trough들의 축을 따라 나타난다. 각 trough들의 지하구조는 Talwani 방법에 의하여 modelling되었으며, 이들의 심도 또한 계산되었다. 그 결과로 Marquette trough는 비대칭형으로 남쪽사면에 비하여 북쪽사면이 급경사를 이루고 있다. 세 trough가 합류하는 지점의 기반암구조는 대체로 평평하며, 이것으로 미루어 이 trough들이 거의 동시에 생성되었음을 시사해준다.