This is to certify that the

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Gravity Modelling of the western
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Soo-Meen Wee

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GRAVITY MODELLING OF THE WESTERN MARQUETTE AREA, MICHIGAN

by

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ABSTRACT

Gravity Modelling of The Western Marquette Area, Michigan.

by

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A gravity survey was conducted in the western Marquette district, Michigan, to delineate the relationship of the Proterozoic Marquette Supergroup rocks (Precambrian X) and Archean basement (Precambrian W) where the Republic and Marquette troughs join.

Three hundred and forty gravity stations were established in the area of 380 km^2.

Positive anomalies are associated with the Precambrian X, meta-sedimentary sequence which has a higher 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 method of Talwani et al.

Gravity model studies indicate that the Marquette trough is asymetrically shaped and steeply dipping at the north edge except in

the eastern part of 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.

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STRATIGRAPHIC NOMENCLATURE

Yd = Diabase of Keweenawan age

Xmus = Early Proterozoic, Baraga Group, Upper Slate member

Xmb = Early Proterozoic, Baraga Group, Bijiki Iron formation member

Xms = Early Proterozoic, Baraga Group, Lower Slate member

Xmd = Metadiabase

Xmcv= Early Proterozoic, Baraga Group, Clarksburg Volcanics member

Xmf = Early Proterozoic, Baraga Group, Strata near Fence Lake

Xfr = Early Proterozoic, Baraga Group, Fence River formation

Xhv = Early Proterozoic, Baraga Group, Hemlock formation

Xg = Early Proterozoic, Baraga Group, Goodrich Quartzite

Xn = Early Proterozoic, Menominee Group, Negaunee Iron formation

Xs = Early Proterozoic, Menominee Group, Siamo Slate

Xa = Early Proterozoic, Menominee Group, Ajibik Quartzite

Wg = Archean, Granitic rocks

1. Introduction

1.1. Purpose of the study

The western Marquette area is underlain by an elongate trough of Proterozoic (Precambrian X) metasediments of the Marquette supergroup which has a small offshoot known as the Republic trough. These troughs unconformably overlie Archean (Precambrian W) basement schists 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 occured prior to 2.5 Ga. Subsequent faulting of the basement developed during the Penokean orogeny.

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 1970s (Cannon and Klasner, 1974). These studies have provided valuable information about rock densities, particularly the significant density contrast existing between the Precambrian X sedimentry 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.

1.2. Study Area

1.2.1. Location and Topography

The area under investigation (Fig.1) lies within western Marquette and southeastern Baraga counties, Michigan. The survey area is bounded by 46°25' and 46°35' north latitude and by 87°55' and 88°10' west longitude, and includes parts of Townships 46, 47, 48, and 49 north, Ranges 29, 30, and 31 west.

The surface elevation rises 1800 feet above sea level in the north-western part of the study area and is 1500 feet at the southern end of Lake Michigamme. The elevation is never more than 300 feet above Lake Michigamme. A swamp covers a large area in the southern half of the study area.

1.2.2. General Geology

The area under investigation is composed of Precambrian rocks of three ages. The majority of the rocks are Precambrian W and Precambrian X (Fig. 2). The Precambrian W (lower Precambrian)

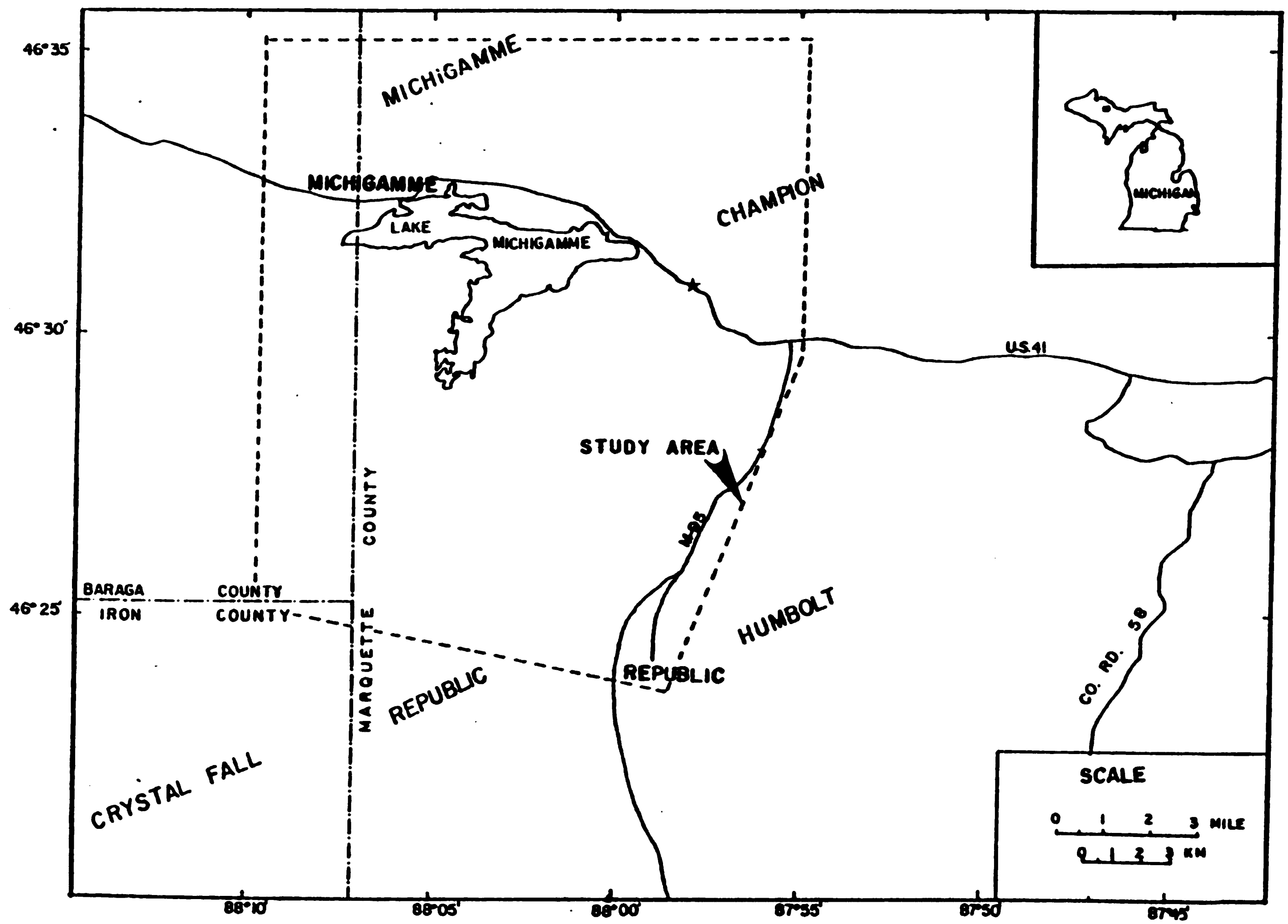

Figure 1. Index map. The study area is indicated by dashed line. Base station (Champion station) is marked by star.

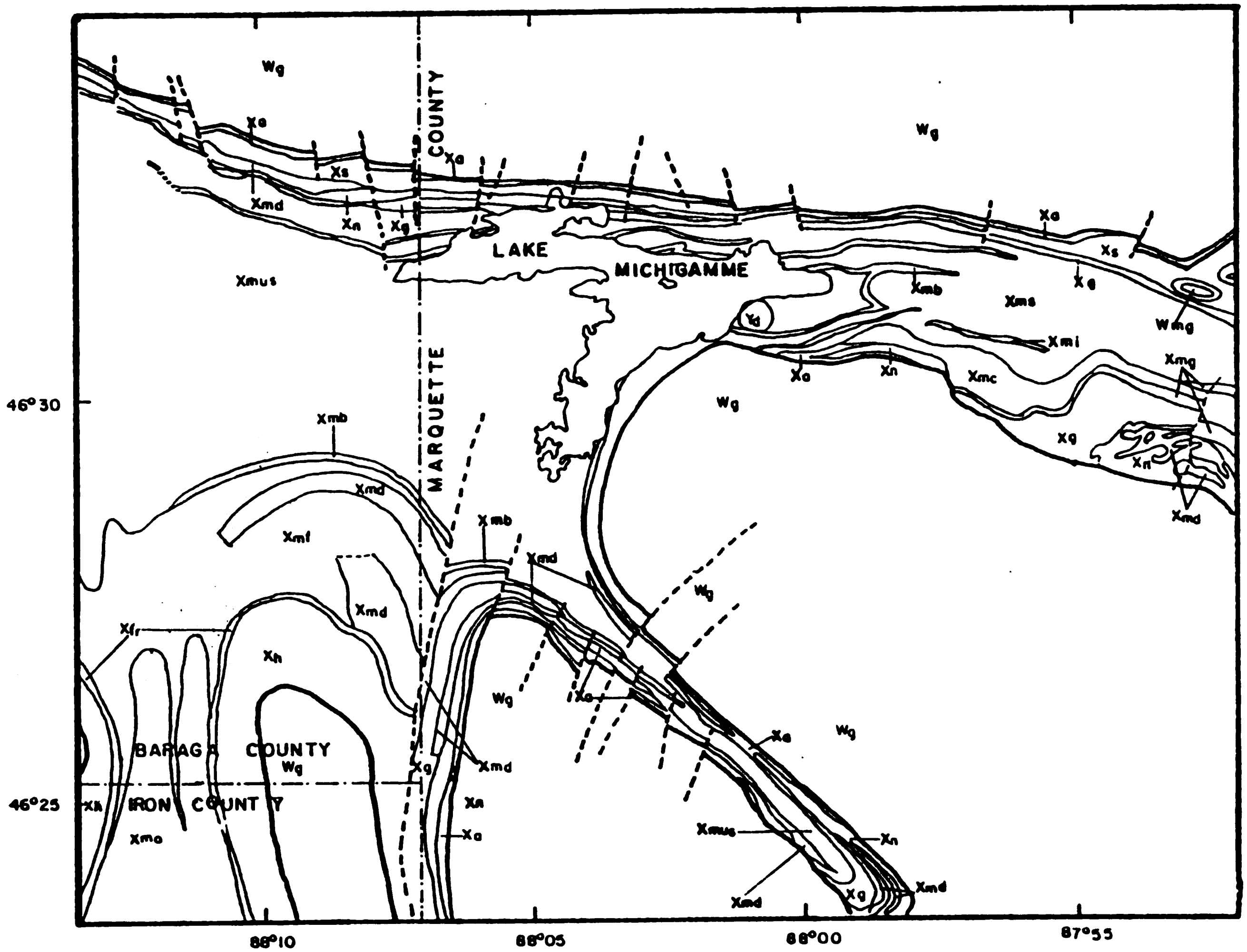

Figure 2. Geologic Map of the study area. Dashed lines indicate faults. Thick lines are boundary of Precambrian W and Precambrian X rocks. Abbreviations are given on page vii.

basement rocks, mostly granitic gneiss, are 2.5 billion years old or older by Rb-Sr dating (Cannon and Simmons, 1973), while the Marquette Range supergroup, a Precambrian X (middle Precambrian) 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 (Klasner and Cannon, 1978). 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 column of this area is shown in Table 1. The Menominee and Baraga groups of the Marquette Range supergroup are present in this study area. Previous geological investigators have shown that the Menominee and the Baraga groups 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 (Van Schmus,

Table 1

Stratigraphic column for western Marquette Range. (After Cannon and Klasner, 1972 and 1975)

SUPERGROUP, GROUP FORMATION, AND/OR MEMBER					DESCRIPTION
Upper Precambrian	Keweenawan		Intrusive diabase		Nonmetamorphosed diabase dikes and stocks.
Middle Precambrian			Pegmatite		Coarse-grained-microcline-quartz-muscovite rocks. Relatively rare.
			Metadiabase		Amphibolitic rock, much with relict diabase texture. Mostly as sills in middle Precambrian rocks and dikes in lower Precambrian rocks. Much is probably associated with rocks of the Clarksburg Volcanics Member of the Michigamme Formation.
	Marquette Range Supergroup	Baraga Group	Michigamme Formation	Upper slate member	Metapelite and metagraywacke with calc-silicate concretions. Also pyritic black slate.
				Bijiki iron-formation member	Mostly cherty silicate iron-formation. Some grunerite schist.
				Lower slate member	Metapelitic and metagraywacke with some pyritic carbonaceous slate.
				Strata near Fence Lake	Poorly exposed sequence of amphibolitic schist, graywacke, iron formation, conglomerate, and pyroclastic rocks.
			Fence River Formation		Banded iron silicate-magnetite iron-formation, commonly containing pelitic beds.
			Hemlock Formation		Largely basaltic rocks and less common felsic units and sedimentary beds. Contains flow and pyroclastic rocks.
			Goodrich Quartzite		Massive to banded protoquartzite with conglomerate near base.
			Local unconformity or disconformity		
		Menominee Group	Negaunee Iron-Formation		Mostly cherty silicate iron-formation with oxide iron-formation near top.
			Siamo Slate		Laminated metapelite
			Ajibik Quartzite		Banded to massive, light colored quartzite.
			Local unconformity or disconformity		
Lower Precambrian			Gneiss of northern and southern complexes		Complex of granitic and mafic gneiss, pegmatite and greenstone.

1976).

The Menominee group is a fining upward sequence with a basal quartzite overlain by laminated argillites, and chemical precipitates with local conglomerates (Klasner and Cannon, 1978). It was deposited unconformably on the Precambrian W basement rocks with mild tectonic disturbances during sedimentation (Van Schmus, 1976).

The Baraga group is composed of a greatly varied sequence of meta-sedimentary and metavolcanic rocks (Klasner and Klasner, 1975). It is the most extensive of four groups composing the Marquette Range superguoup (Cannon and Gair, 1970). 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 the development of a subduction zone resulting in compression of the basement and the overlying sediments (Cambray, 1977). An early tensional phase caused rupturing of the continental shelf which produced grabens and was followed by a compression phase which produced folds (Cambray,1977).

1.3 Previous Works

Numerous studies have been conducted concerning the extensive iron ore deposits in the vicinity of study area. In 1881, Rominger investigated iron bearing districts in Marquette area and analyzed the basic structure of the Marquette synclinorium (Boyum,1975). An analysis of the distribution of the rock types and contacts was performed by Van Hise and Bayley (1897).

Introduction of a new stratigraphic column by James (1958) initiated modern geological surveys of the area. Although this stratigraphic column is generally accepted, the name Marquette Range supergroup has been proposed to supplant the term Animikie Series by Cannon and Gair (1970) as shown in Table 2. This proposal is due to the failure to prove a correlation between the middle Precambrian rocks in the Marquette district of Michigan and the type area of the Huronian. The geology of the southern parts of the Marquette district were also investigated (Cannon and Simmons, 1973). The tectonic events and depositional history of Early

Table 2

Stratigraphic sections of Precambrian rocks in parts of northern Michigan.

			Marquette Range	Iron River-Crystal Falls District	Menominee Range	Gogebic Range
Upper Precambrian	Keweenawan		Intrusive diabase	Intrusive diabase	Intrusive diabase	Volcanic, intrusive, and sedimentary rock
Middle Precambrian	Marquette Range Supergroup	Paint River Group		Fortune Lakes Slate Stambaugh Formation Hiawatha Graywacke Riverton Iron-Formation Dunn Creek Slate		
		Baraga Group	Michigamme Slate Upper Iron-Formation Member Clarksburg Volcanics Member Greenwood Iron-Formation Member Goodrich Quartzite	Badwater Greenstone Michigamme Slate Amasa Formation Hemlock Formation	Badwater Greenstone Michigamme Slate •	
			LOCAL UNCONFORMITY OR DISCONFORMITY		UNCONFORMITY	UNCONFORMITY
		Menominee Group	Negaunee Iron-Formation Siamo Slate Ajibik Quartzite		Vulcan Iron-Formation Felch Formation	Ironwood Iron-Formation Palms Quartzite
			UNCONFORMITY OR DISCONFORMITY		UNCONFORMITY	UNCONFORMITY
		Chocolay Group	Wewe Slate Kona Dolomite Mesnard Quartzite Enchantment Lake Formation	Saunders Formation	Randville Dolomite Sturgeon Quartzite Fern Creek Formation	Bad River Dolomite Sunday Quartzite
			UNCONFORMITY	UNCONFORMITY(?)	UNCONFORMITY	UNCONFORMITY
Lower Precambrian			Gneiss Greenstone	Greenstone (stratigraphic position uncertain)	Gneiss	Gneiss Granite

Compiled from Leith and others, 1935, Table facing p. 10; James, 1958, p. 30; and Gair and Thaden, 1968, Table 1; and Cannon and Gair, 1970, Figure 2.

Proterozoic strata in Michigan were studied by Van Schmus (1976).

Klasner (1978) investigated deformation and associated metamorphism in the western Marquette range related to the Penokean orogeny.

Geophysical studies were conducted by Cannon and Klasner (1974) and are the only detailed gravity work concerning the study area. They contributed to the interpretation of subsurface geology by determining the depth of some parts of the elongated troughs, and providing rock densities. Their general method is used for the present study. A magnetic and gravity survey, with additional density determinations, of the Witch Lake area was performed by Cannon and Klasner (1976), and a bedrock geologic map of southern part of the Diorite and Champion 7 1/2 minute quadrangles, with cross-sectional interpretations of the Marquette trough based on gravity data, was published (Cannon and Klasner, 1977).

Subsequently, the bedrock geologic map of the southern part of the Michigamme and Three Lake quadrangles, Marquette and Baraga counties, based on a gravity and magnetic survey, was published (Klasner and Cannon, 1978).

Aeromagnetic maps of some parts of Marquette area have been published by Case and Gair (1965) and of parts of the Witch Lake quadrangle by Cannon and Klasner (1976).

Gibb (1967) contributed to the determination of the density of the Precambrian rocks exposed in northern Manitoba.

2. Field Work

2.1 Gravity Survey and Instrumentation

The survey was carried out during the periods of July 5-July 14,1984.

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 (Model No. FA 112) and read directely from topographic maps. This altimeter is marked in units of ten feet. A second Wallace 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 several loops with their lengths varying from 8 to 20 kilometers (Fig.3). The station spacing varied according to the amount of

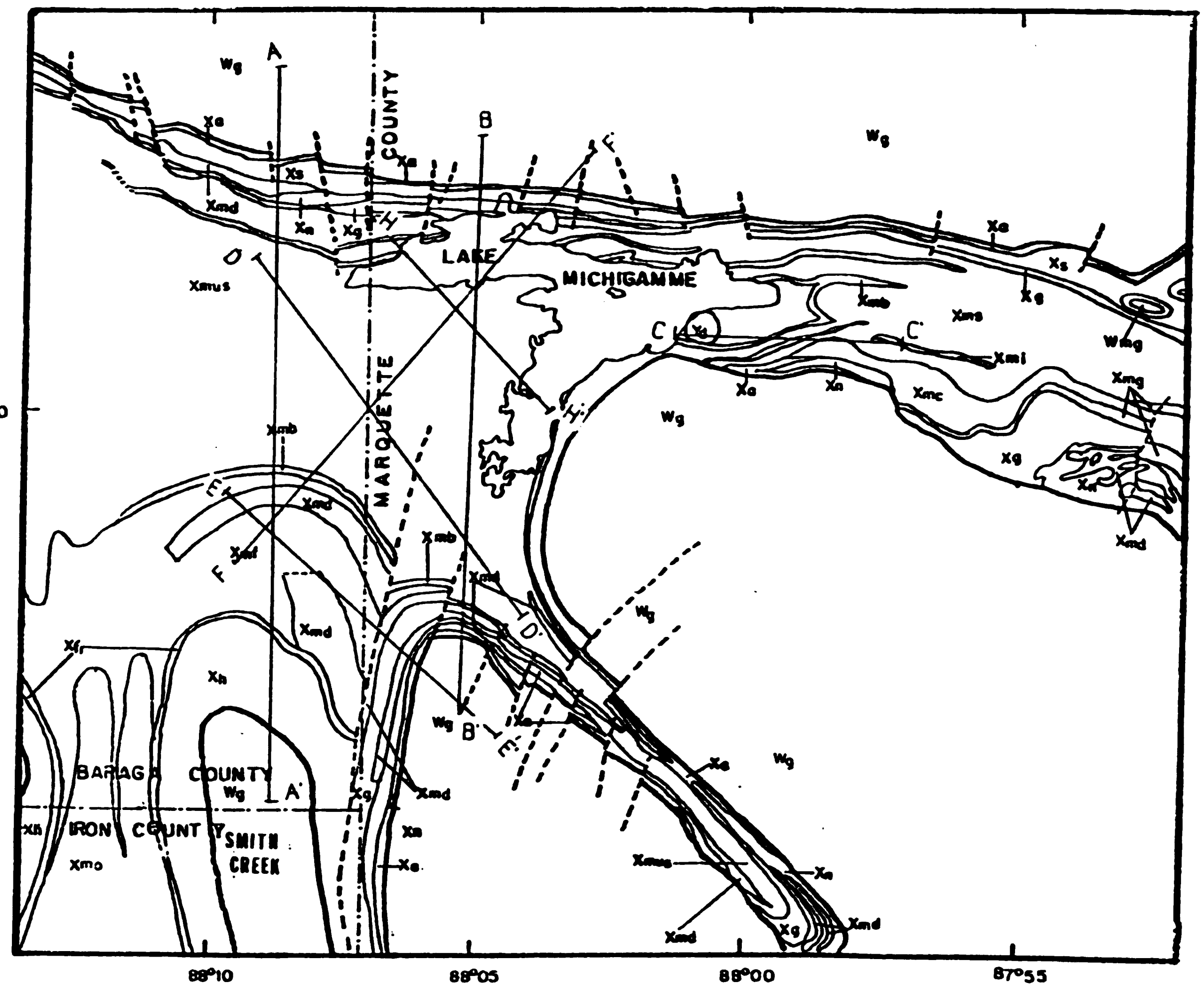

Figure 3. Geologic Map showing location of modelled gravity profiles. Symbols as in figure 2.

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 following sources of data.

1. U.S.G.S. 7 1/2 minute (Witch Lake NE, Michigamme, and Three Lakes) quadrangles, and U.S.G.S. 15 minute (Witch Lake) quadrangles. The 15 minute quadrangle was blown-up to 1: 24,000 photographically.
2. Michigan Department of Natural Resources airphotoes of the Witch Lake quadrangle taken on August 14, 1978, provided by the Michigan D.N.R field office in Ishpeming, which were traced and expanded to 1: 24,000.
3. Mead Paper Co. timber classification maps provided by Mead Paper, Co., Champion Office. These maps are at an approximate scale of 10cm = 1 mile. These were photo reduced to 1: 24,000.
4. Mead Paper Co. Field Maps at 8"=1mile drawn for road construction. These maps were also photo-reduced to 1:24,000, but accuracy proved often to be in error by up to 1/8 mile (660').

5. Mead Paper Co. logging maps at 1"=1320'. These were at best schematic diagrams.

In addition to the above maps, a pace and compass survey was run in section 5 and odometer-topography-bearing survey were performed in section 14 and for line P. All locations were plotted onto U.S.G.S. topographic maps.

2.2. Accuracy of Horizontal Coordinates

Latitude and longitude coordinates were determined for each station from U.S.G.S. topographic maps (scale, 1:24,000). 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. All stations north of Lake Michigamme and south of US-41 are probably very accurate.

The largest potential errors seemed to be on line V, particularly stations V26 through V32. The possible mislocations in line V are ±75 m to 150 m with some exceptions.

2.3. Elevation Control

Elevations of all the stations were established by using two Wallace and Tiernan altimeters, one metal, and one wood cased. The metal cased altimeter drifted considerably more than wooden one (Paddock,1982), 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 elevations, therefore, is estimated to be ± 5 feet and no case exceed ±10 feet, resulting in error of ± 0.21 milligal.

3. Data Reduction

3.1. Gravity

Observed gravimeter readings were drift-corrected based on drift curves (Fig.4 and Fig.5) for lines J, K, V, and W which had high frequency instrumental drift due to climatic conditions. Other lines were corrected assumming linear drift within each loop. The readings were then converted to milligals using the calibration constant of the gravimeter. This process produced the observed gravity values listed in Appendix B.

Drift rates are listed in Table 3.

Table 3

Drift Rate

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)

3.2. Elevation Correction

The elevation, or free-air, correction takes into account the

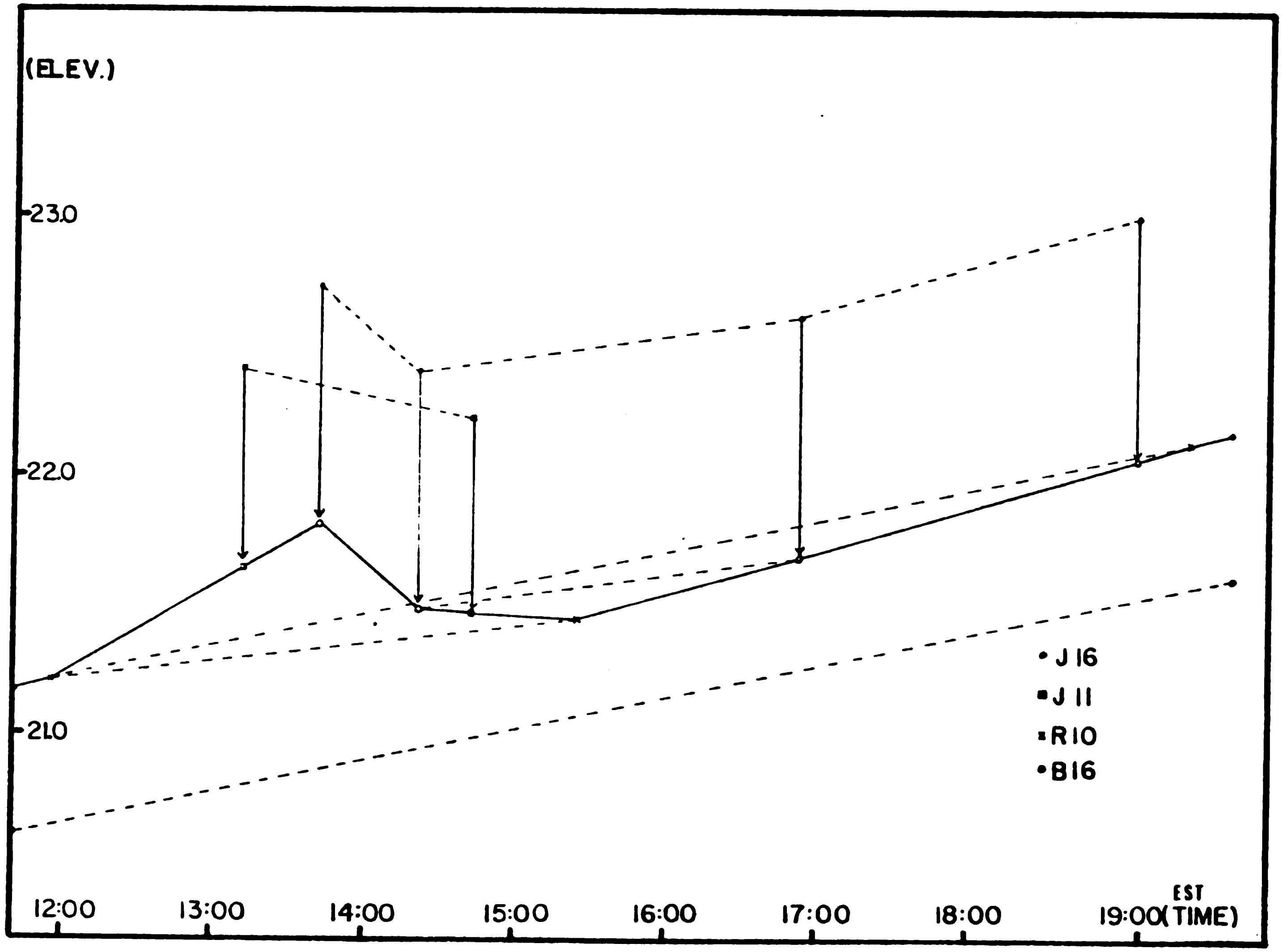

Figure 4. Altimeter(W) drift for J and K loops. Dashed lines represent altitude drift curve of the each station. Solid line represents the composite drift curve used for J and K loops. Elevation marked in units of ten feet.

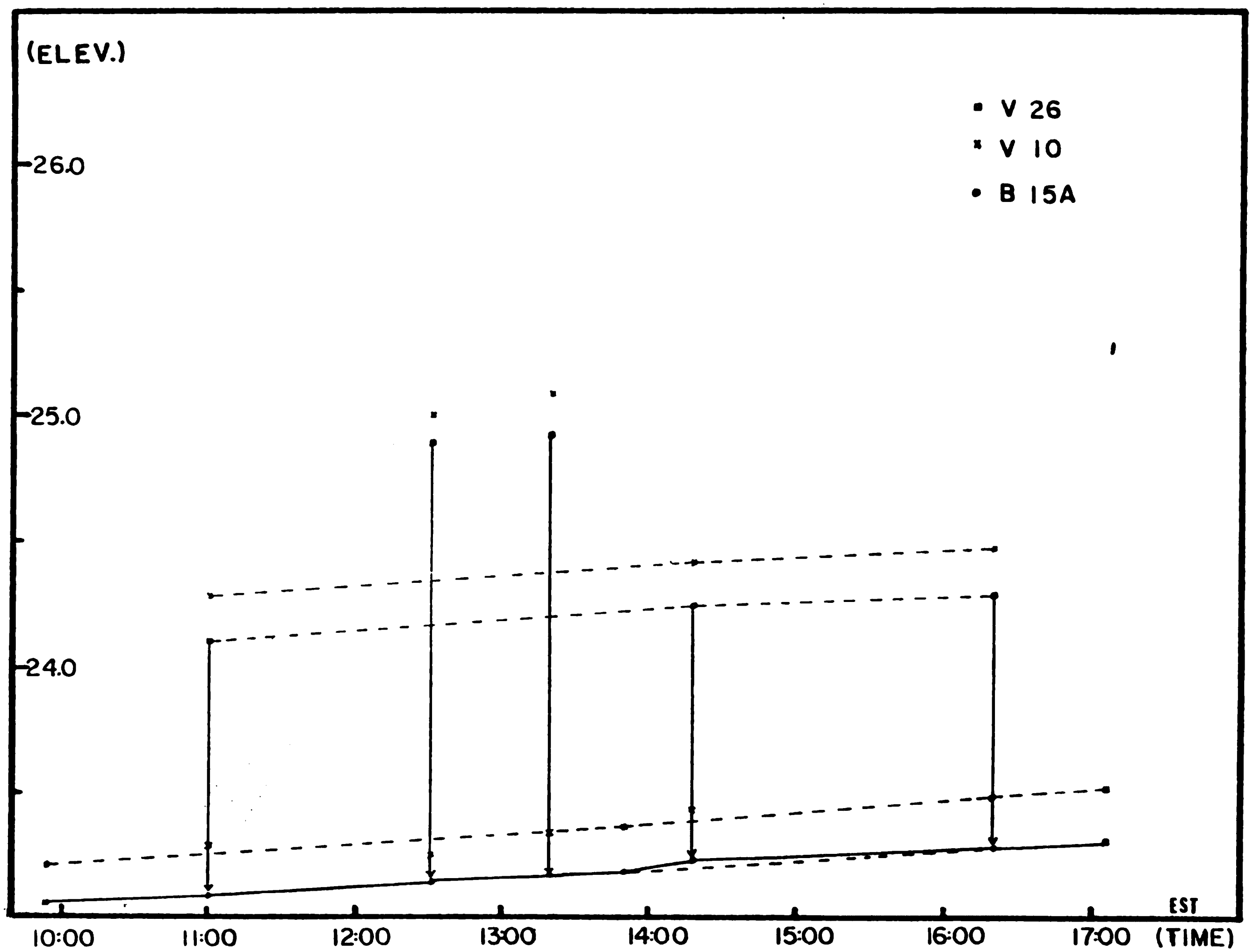

Figure 5. Altimeter(W) drift for V and W loops. Dashed lines represent altitude drift curve of the each station. Solid line represents the composite drift curve used for V and W loops. Elevation marked in units of ten feet.

vertical decrease of gravity with an increase in elevation with following formula (Telford et al., 1976).

$$dg_{fa}/dR_e = -2GM_e/R_e^3 \approx -2g/R_{eq} \approx -0.09406 \text{ mgal/ft} = -0.3080 \text{ mgal/m}$$

M_e : mass of Earth

R_e :Radius of the Earth at latitude ø

G : Gravitational constant

R_{eq} : equatorial radius

Gravity data were reduced to base station level (the elevation of the platform at Champion railroad station, 1598 feet) using a correction factor of 0.09406 mgal per foot (0.3080 mgal per meter).

3.3. Mass Correction

The Bouguer correction takes into account of the vertical increase of the gravity with an increase in elevation due to the attraction of the material between the datum and each station. This correction is calculated from the following formula (Telford et al., 1976)

$$dg_b/dR_e \approx dg_b/dR_{eq} = 2\pi G\rho \text{ mgal/ft} = 0.01277\ \rho \text{ mgal/ft}$$

$$= 0.04188\ \rho \text{ mgal/meter}$$

p : material density (g/cm^3)

R_e: Radius of the Earth at latitude ø

R_{eq}: equatorial radius

Elevation values for each stations are listed in Appendix B.

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.

3.4. Latitude Correction

The latitude correction takes into account those gravity changes that are attributable to latitudinal differences, such as the increase in gravity from the equator to the poles. For stationary gravimeters, the value of the Earth's gravitational attraction varies with latitude due to the effect of the centrifugal accleration by the following formula (Telford et al., 1976).

$$g = g_0 - W^2 R_a \cos^2 \varnothing$$

g : observed gravity measured with stationary gravimeter

g_0 : Earth gravitational field at pole

ϕ : latitude

W : angular velocity

R_a : Equatorial Radius of Earth

The gravity data were normalized to the latitude of the 46°30'00", which is close to Champion station, and was selected as the base latitude. The latitude corrections were made by using following formula.

The 1967 International Fomula for gravity variation with latitude is (Nettleton, 1976) :

$$g\ (cm/sec^2) = 978.0490\ (1 + A \sin^2\phi + B \sin^2 2\phi)$$

$$A = 5.2884 * 10^{-3}$$

$$B = -5.9 * 10^{-6}$$

ϕ : latitude

Observed gravity values were then adjusted for the above corrections to obtain the Bouguer gravity anomalies according to the following:

Bouguer gravity anomaly = observed gravity

+ free-air correction

+ Bouguer correction

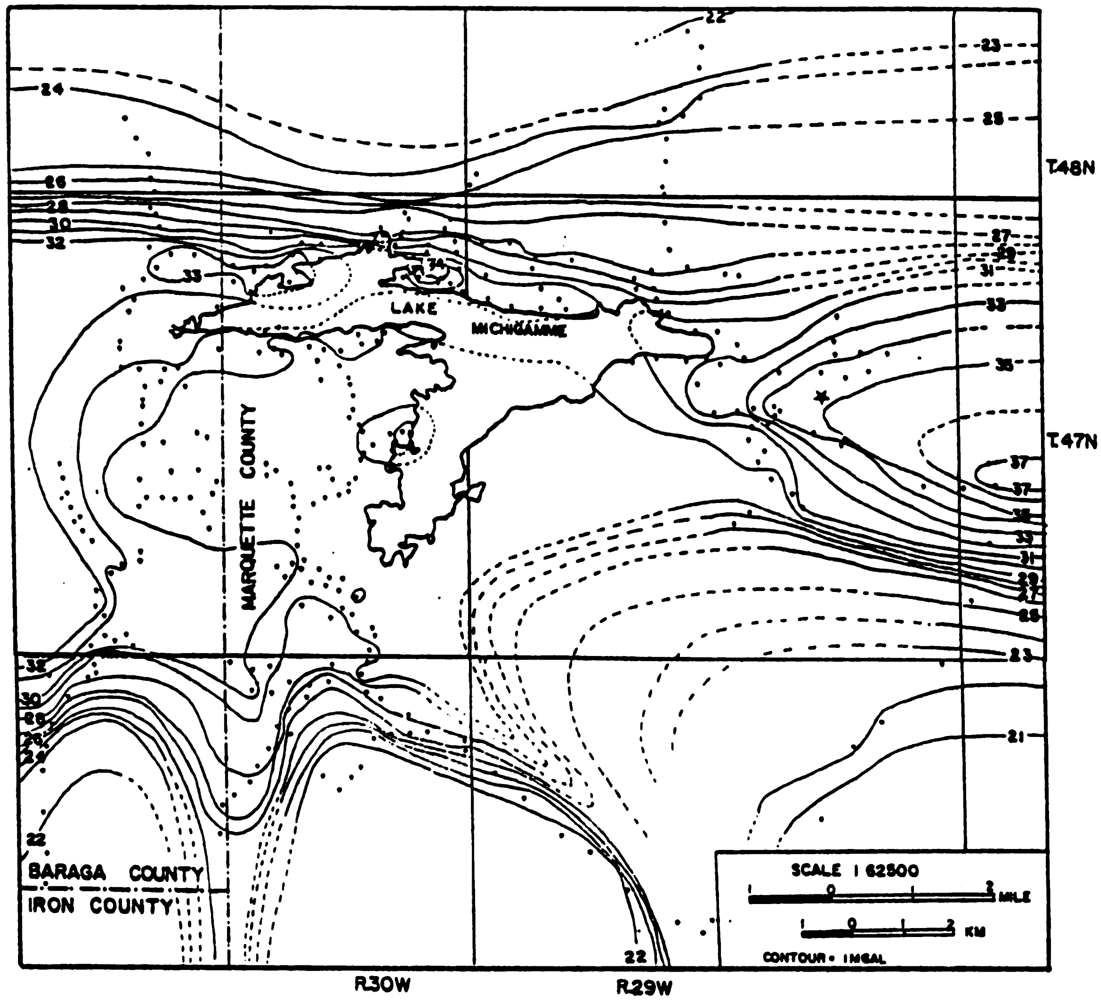

Figure 6(a). Bouguer Gravity map of the study area. In unsurveyed areas, the contour lines are marked with a dashed line. Base station (Champion station) is marked by star.

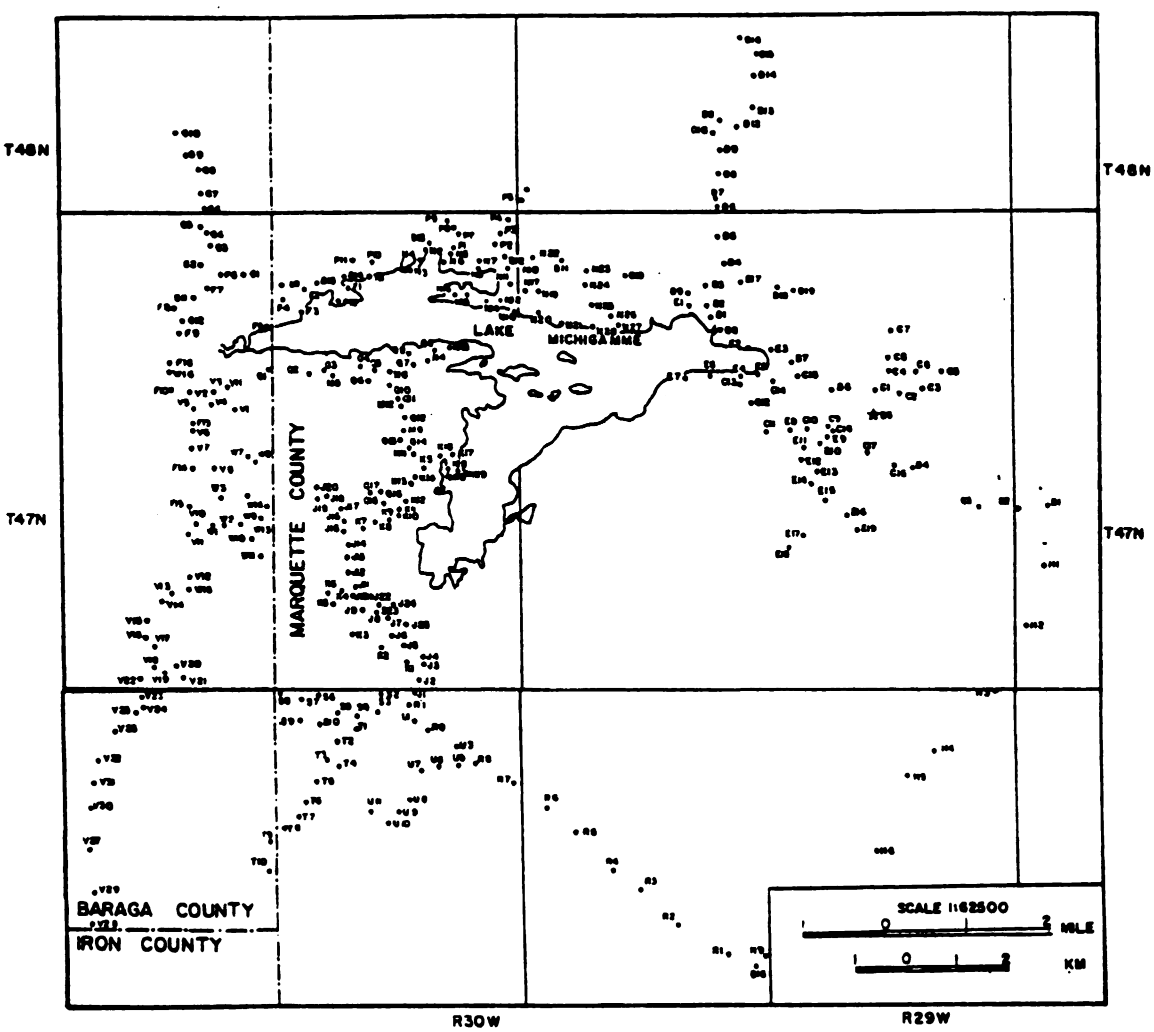

Figure 6(b). Station locations of the study area. Base station (Champion station) is marked by star.

+ latitude correction

- base station gravity

The Bouguer gravity anomaly map and the locations of the gravity stations are shown in Figures 6a and 6b.

3.5. Error Analysis

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 fomula (Nettleton, 1976):

$$g_{F,B} = (0.09406 - 0.01278 \, p) \, h$$

$g_{F,B}$: combined correction for Bouguer and free-air anomaly

p : 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 + 30 m which result in an error of ± 0.02 mgal except in line V. In line V, there is maximum mislocation of stations of ± 150 m, probably considerably less than that, which results in an error of ± 0.11 mgal.

An incorrect value of the subsurface material density causes an error in the mass correction. An error in the density of 0.1 g/cm^3 causes an error of 0.001 mgal per foot (Nettleton, 1976):

$$\partial g = 0.0127 \, \partial p \, h \quad mgal/ft$$

∂g : gravity error

$\partial\rho$: density error (g/cm^3)

h : elevation (ft)

In this study, an error in the density of $0.1 g/cm^3$ 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 10 m, with a till density of $2.0 g/cm^3$ (Paddock, 1982), will cause an error of ± 0.28 mgal. Assumming that above factors are independent, possible errors in this survey are listed in Table 4.

Table 4

Error Sources

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 ft	11 ft	1.12 ft	± 3.52 ft	± 0.21
Errors in Latitude	-	0.00 m	150 m	-	-	±0.11
Probable Error						± 0.24

4. Interpretation of Gravity Data

4.1. Procedure

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, seven gravity profiles were considered from the area (Fig.3): 1) two north-south oriented; 2) one east-west oriented; 3) three northwest-southeast oriented; 4) the one oriented from northwest to southeast.

The gravity data were interpreted in a step by step manner. First, the overall structural trends were 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) using a program by Paddock (1982). Computation was performed using a CDC Cyber 750 computer. The assumption of two dimensionality is justified because most anomalies are horizontally linear having greater lengths then widths (Oray, 1971) except of profile C-C'. Some minor e.rrors may also be encountered in profile F-F' and southern parts of profile B-B'.

Models were also required to match every point where separate profiles crossed. One of the most important causes of error in the model studies is the density determination for each rock unit. The density of the rock units were fixed as shown in Table 5 except the Negaunee and Goodrich formation. Densities of the Negaunee and Goodrich formations were varied depending on the percentage of iron content which was determined by previous workers.

4.2. 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 Figure 6a shows the results of reducing the observed gravity. Figure 6a 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 figure 6a, 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 diabase dike. In the unsurveyed areas, gravity contour lines are dashed and based on geologic maps and other available information.

4.3. 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', E-E', F-F'

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 subsurface complexity between the rock units is unknown. 3) The gravity stations were not measured on the cross-section but projected to them.

Observed and calculated gravity can be equally well matched in more than one way by varying the thicknesses of subsurface rock units and densities as shown in Figures 9,11,17,20. They give good correlations between the observed and calculated gravity values.

However,they were not adopted in this study because they provide an unreasonable model considering that the Marquette trough was formed in two phases: tension, with sedimentation, followed by a compressional phase. However, these models indicate that the basement uplift caused during the early depositional period.

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 as shown in Tables 5 and 6.

Profile A-A'

Figure 7 illustrates a geological model of profile A-A', which is oriented north to south and extends from 0.5 mile west of Nelligan Lake to 1 mile southwest of St. Johns Lake in the western Marquette district, Michigan.

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 calculated gravity in the southern part. Therefore, I analyzed the cause of failure and then remodelled this

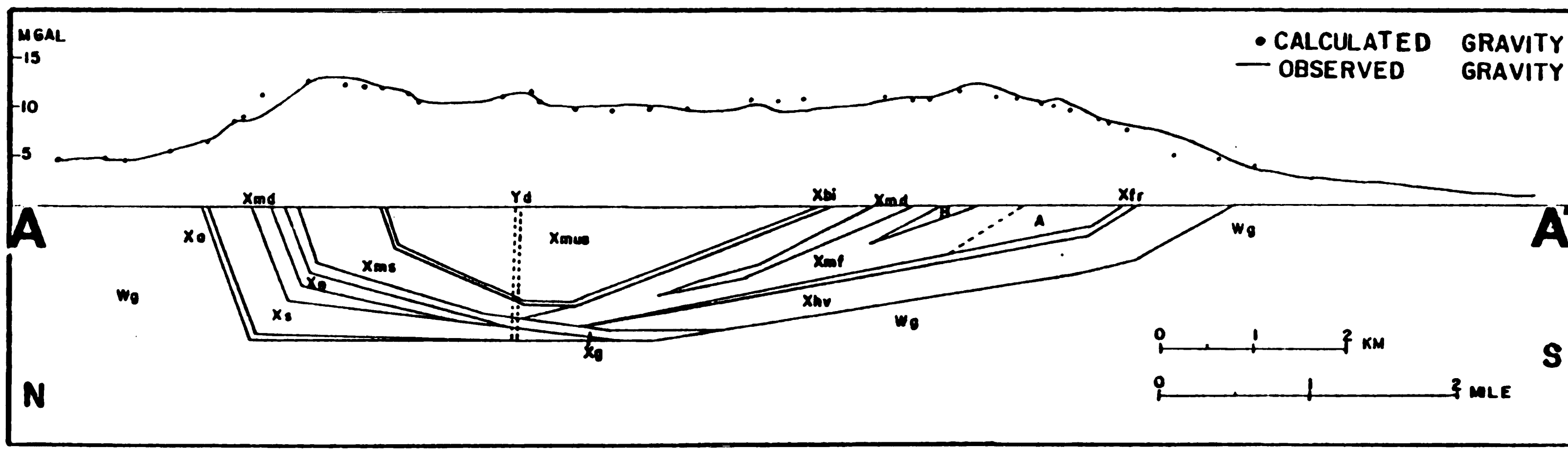

Figure 7. Gravity profile(I) measured along section A-A' showing observed gravity (solid line) and calculated gravity (points). Abbreviations are given on page vii. No vertical exaggeration.

Table 5

DENSITY DATA

Formation	No	Range (gm/cm^3)	$\bar{p}$ (gm/cm^3)	Source	
Undivided, Granitic rocks	944	2.50-2.78	2.64	Gibb(1967)	Granite: 2.64(Sheriff et al., 1982)
Granitic Gneiss	458	2.50-2.78	2.65	Gibb(1967)	Granite: 2.667(Daly, 1960) (Mass): 2.621 (Mass): 2.624 range: 2.621-2.667 $\bar{p}$ = 2.64 Granitic gneiss: 2.65(Cannon and Klasner, 1974)
Ajibik Quartzite	4	2.50-2.73	2.65	Cannon & Klasner (1974)	Qartzite: 2.60(Sheriff et al., 1982) Quartzite: (Montana): 2.647(Daly et al., 1960) (Cheshire): 2.643 range: 2.60-2.647 $\bar{p}$ = 2.63
Siamo Slate	3	2.57-2.84	2.73	Cannon & Klasner (1974)	Fortune Lake Slate: 2.84(Paddock, 1982) Dune Creek Slate: 2.77(Bacon & Wyble, 1952) Slate(Penn): 2.78(Daly et al., 1960) range: 2.67-2.84 $\bar{p}$ = 2.77

Negaunee Iron Formation	10	2.97-3.83	3.56	Cannon & Klasner (1974)	Density of iron formation can be determinded from percent Fe. Boyum(1964) stated that the average iron content of Negaunee Iron formation is 26 to 31 %. Using Curve from Hinze(1966) relatively percent Fe to density showed range from 3.2 to 3.7 (Cannon & Klasner, 1974).
	21	2.97-3.92	3.47	Cannon & Klasner	
	31	2.97-3.92	3.50	Total average	
Goodrich Quartzite Black to dirty gray Qtz	1	2.72	2.72	Cannon & Klasner (1974)	$\overline{p}$ = 2.63(General Quartzite)
Iron formation	3	3.08-3.59	3.24		
			2.85	Composition of dirty Quartzite and 20% of iron formation(Cannon & Klasner)	
Michigamme Formation					Michigamme Slate: 2.99(Leney, 1966)
Upper Slate member	5	2.73-3.03	2.84	Cannon & Klasner (1974)	Michigamme Formation: 2.89 (Cannon & Klasner, 1974)
Lower Slate Member	7	2.64-2.79	2.72	Cannon & Klasner (1976)	Michigamme Formation: 2.72 (Cannon & Klasner, 1976)
	12	2.64-3.03	2.77	Total average	
Bijiki Iron Formation	1	3.09	3.09	Cannon & Klasner (1974)	According to composition Graywacke: 2.65(Sheriff et al., 1982) Slate: 2.79(Sheriff et al.,1982) Hormblended schist, mica schist: 2.73(Gibb, 1967)

$\bar{p} = 2.72$

Fence river Formation	4	2.91-3.81	3.18	Cannon & Klasner (1976)	
Starta near Fence Lake					Density of Iron formation was taken same as Bijiki because
Schist			2.64	Sheriff et al.,1982	according to W.F. Cannon et al
Graywacke			2.65	Sheriff et al.,1982	(1975), "Starta near Fence
Staurolite Schist			2.74	Cannon & Klasner (1974)	Lake" is considered part of Michigamme Formation.
Hornblanded, Mica Schist			2.73	Gibbs(1967)	
Amphibolite			3.01	Gibbs(1967)	
Iron Formation	6		2.81	Total average	
			2.82	Cannon & Klasner(1976)	
Hemlock Formation					Other volcanics in the vicinity of Northern Wisconsine.
Mafic	6	2.82-3.11	2.96	Cannon & Klasner (1976)	"Siliceous rock" of Jenkins (pembine area): 2.75
Felsic	4	2.55-2.74	2.67		Andesitic fragmental volcanics (Pembine area): 2.95
	10	2.55-3.11	2.84	Total average	Hager Rlyolite(at Thunder Mt.): 2.78 Waupee water-laid ash(high falls area): 2.75 Rhyolite Porphyry(Nashville Quad.): 2.65 Quinnesec felsic wolcanics: 2.77 Serpentinized basalt(Pembine area): 2.80 (Carlson, 1974) range: 2.65-2.95 $\bar{p} = 2.76$

Table 6

Thicknesses of Formations of the Menominee and Barage Groups

Formation	Thickness(m)	Range	Source	Location
Ajibik	180-380		Boyum, 1975	
	80-150	80-380	Cannon & Klasner, 1977 Klasner & Cannon, 1978	East of Lake Michigamme, north edge of Marquette trough
Siamo	180-380		Boyum, 1975	
	150-360	150-380	Cannon & Klasner, 1977	East of Lake Michigamme
Negaunee	max 1300		Boyum, 1975	Negaunee-Ishpeming area
	70-170	variable	Cannon & Klasner, 1977 Klasner & Cannon, 1978	Western part of the Mar-quett trough
Goodrich	max 460		Boyum, 1975	west of Ishpeming
	50-220	50-460	Klasner & Cannon, 1978	Marquette trough
Michigamme	600-1200		Klasner & Cannon, 1978	western Marquette district
	800 602		Trow, 1979 Trow, 1979	Dead River basin East Baraga basin
	1800		James et al., 1968	Eastern Iron county
Mafic Intrusive	0-210	variable	Boyum, 1975	

Hemlock(early)	300	Bayley, 1959	
(middle)	700		Eastern Iron county
(upper)	3300		
Greenwood Iron	150-365	Boyum, 1975	

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 are due to Precambrian X sedimentary rocks which have an average density of 0.22 g/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 Menominee group, which occurs on the northern edge of the Marquette trough, pinches out a few kilometers from the north edge of the Marquette trough (Klasner and Cannon, 1978). 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 (2.85 g/cm^3) because of the high percentage of iron formation in it (Cannon and Klasner,1974). The Hemlock formation apparantly lies directly on pre-Baraga group rocks. The Fence River formation, which is an iron rich chemical precipitate, 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 figures 7,8,9) 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 continuation of the metadiabase sill which occurs near the area but is not shown on the geologic map within the " strata near Fence Lake " could also cause this deviation. High magnetic and gravity values over unit B (Figure 7) suggests it is an iron formation, which is one of the materials composing the "strata near Fence Lake". Cannon and Klasner (1976) suggest that the observed and calculated gravity in the southern part of the district correlate poorly because the nature and density of the rocks are not well known and lack a two dimensional configuration of their structure. In constructing their density model, the density contrast for the "strata near Fence Lake " and the Hemlock formation were major unknowns. The density constrast of the Hemlock formation varies from near zero for felsic volcanic rocks to about 0.30 g/cm^3 for mafic volcanic rocks (Cannon and Klasner, 1976). In this profile, the low gravity values suggest that the Hemlock formation here has a large felsic component (Cannon and Klasner, 1976).

An Alternate model to Profile A-A

Figure 8 illustrates an alternate model for profile A-A'. This model assumes that a fault exists between the north edge of the Marquette trough and the Smith Creek uplift.

Figure 9 also shows good correlation between the observed and calculated gravity. This model was made with the assumption that the Menominee group rocks were terminated at the uplifted block. This model indicates that the uplift occured during the early depositional period. However, the compressional phase occured after sedimentation. Thus, with respect to the time of compression, the existance of the uplifted basement block makes this model geologically unlikely.

Profile B-B'

Figure 10 illustrates a geological model of profile B-B', which is oriented northeast to southwest and extends of 14 km through the Marquette trough into the Republic trough. A large positive anomaly

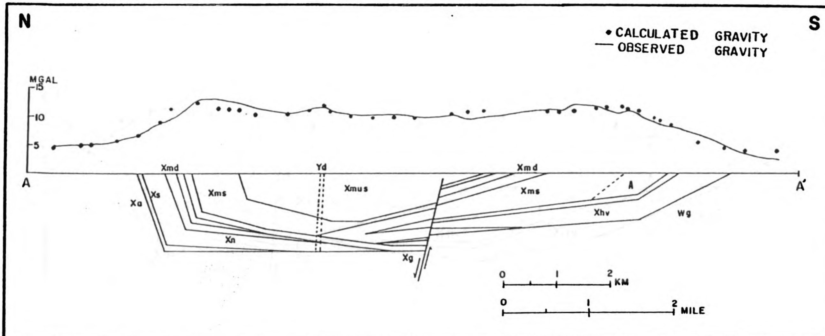

Figure 8. Alternated gravity profile measured along section A-A' showing observed gravity (solid line) and calculated gravity (points). Abbreviations are given on page vii. No vertical exaggeration.

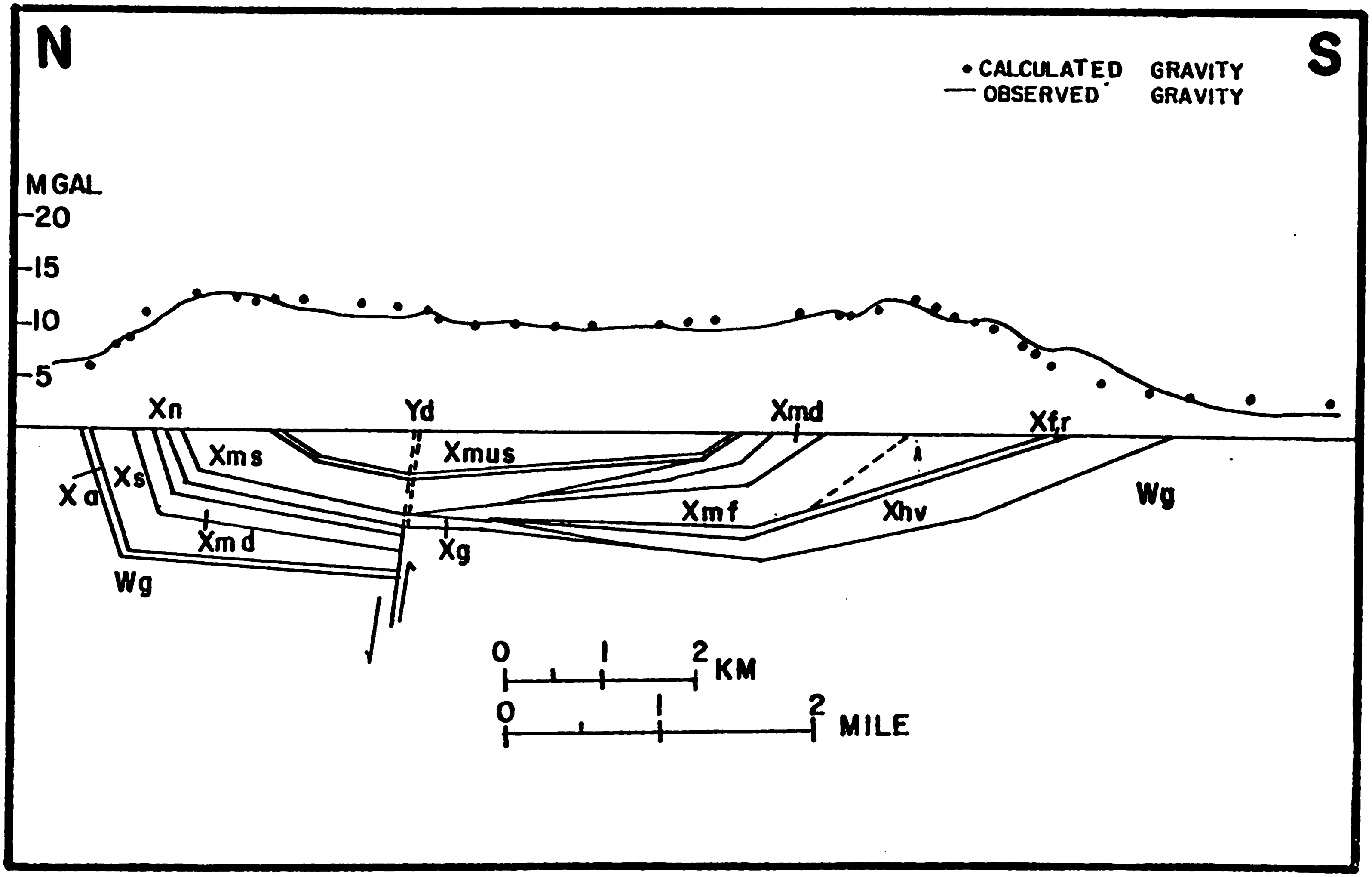

Figure 9. Gravity profile(II) measured along section A-A' showing observed gravity (solid line) and calculated gravity (points). Abbreviations are given on page vii. No vertical exaggeration.

exists at the north edge of the Marquette trough and a very flat positive anomaly extends across the area to the south. 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 exists which has a depth to basement of 2 km.

The sedimentary sequence overlying the basement block was downfolded during the development of the graben during the Penokean orogeny (Klasner and Cannon, 1978). The thickness of the sedimentary strata is very uniform while the southernmost metadiabase sill probably thins to the north.

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 0.13 g/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):

$$\partial h = \partial g / 2\pi G \rho$$

∂g : anomaly contrast

G : gravitational constant

p : density contrast

The small, 1 mgal, irregularities in the gravity values could be caused by minor differences in surface material over very limited areas or folding in the Michigamme formation, particularly in the Bijiki iron formation. The folding was caused by compression of the developing graben during the Penokean orogeny. The irregularites also may be due to errors in elevation, mislocation of the stations and/or till distribution. The Menominee group rocks pinch out to the south from the north edge of the marquette trough. The upper slate member (Xmus) has a maximum thickness of approximately of 1500 meters in the center of the sedimentary basin and the lower slate member (Xms) becomes thinner to the south. The Goodrich quartzite covers the entire area of this profile.

Figure 11 shows a good example of the ambiguity of gravity modelling in that the observed and calculated gravity can be equally well matched in more than one way by varying the thickness of the subsurface rock units and densities. This model indicates that the uplift occured during the early deposional period. However, the

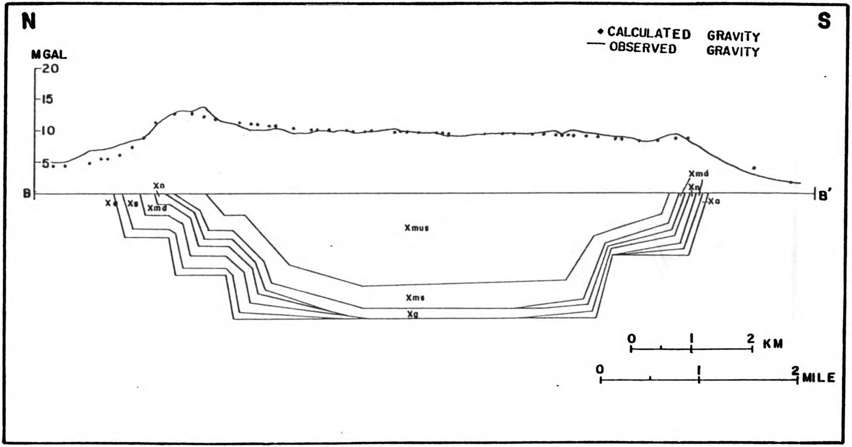

Figure 10. Gravity profile(I) measured along section B-B' showing observed gravity (solid line) and calculated gravity (points). Abbreviations are given on page vii. No vertical exaggeration.

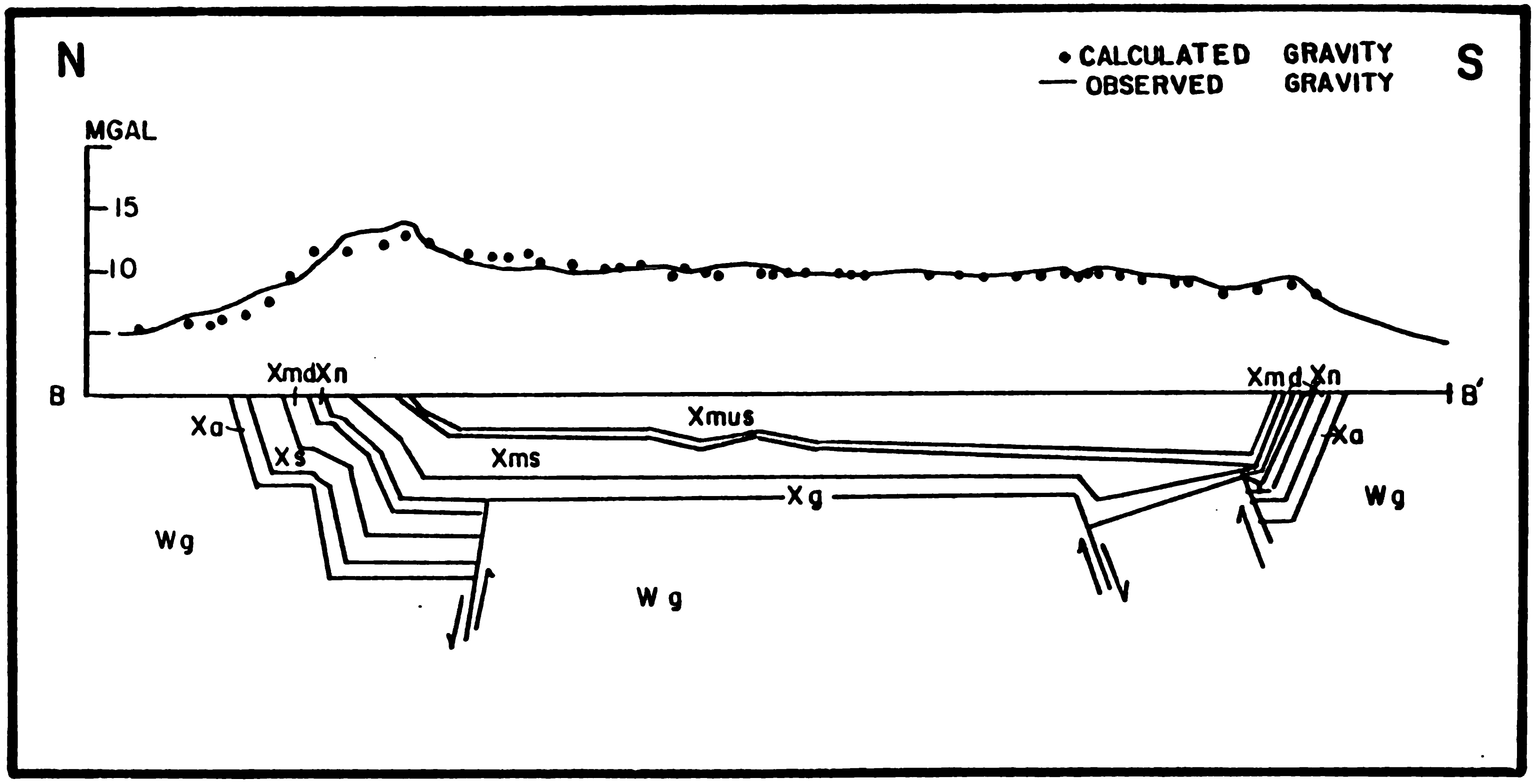

Figure 11. Gravity profile(II) measured along section B-B' showing observed gravity (solid line) and calculated gravity (points). Abbreviations are given on page vii. No vertical exaggeration.

compressional phase occured after sedimentation. Thus, with respect to the time of compression, the existence of uplifted block makes this model geologically unlikely.

Profile C-C'

Profile C-C', is oriented east-west and extends from the eastern end of the Lake Michigamme in sec. 26, T. 48 N., R. 30W., through the eastern part of Champion. Due to the orientation of this profile with respect to the strike of the Marquette trough, two dimensional modelling may result in computed gravity values with substantial errors. Therefore, this profile was modelled using published information by previous workers (Cannon and Klasner, 1977) on strata thicknesses

. Figure 12 illustrates a possible geological for profile C-C'. The gravity anomalies are relatively variable in the profile region. The positive anomaly in the eastern part is associated with the thick lower slate member, the Clarksburg volcanics, and existance of the iron formation. The lower slate member becomes thinner to the west. A Keweenawan diabase stock (Michigamme intrusion) is observed with a diameter of 300 meters and a thickness of 1350 meters. According to Phillips (1979), a vertical stock was the best model

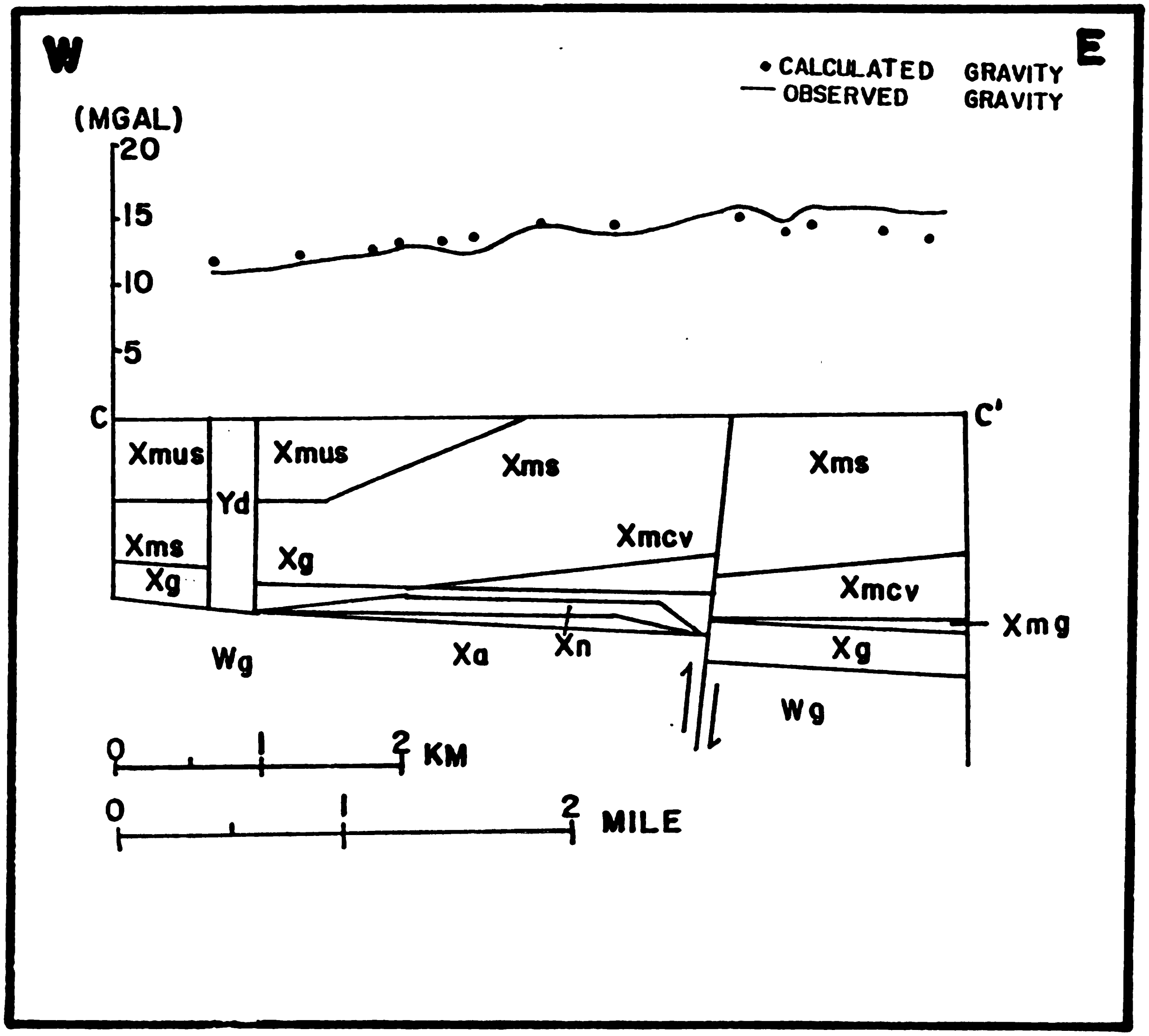

Figure 12. Gravity profile measured along section C-C'. Abbreviations are given on page vii. No vertical exaggeration.

based on his remanent magnetization study. However, the observed gravity anomalies do not correlate well over the stock in my model. This is due to the projection of gravity stations,which were not measured over the Michigamme stock.

In the eastern part, there is a reverse fault with a vertical displacement of approximately 200 meters. The Ajibik quartzite and Siamo slate covers all of the area in northern edge of the Marquette trough, however, the Siamo disappears in cross-section in C-C'.

The stratigraphic section changes abruptly across the fault in the eastern part of the profile. West of the fault, the Negaunee iron formation is thick, the Goodrich quartzite is very thin, the Clarksburg volcanic members are relatively thin, and the Greenwood iron formation is absent. On the contrary, to the east, the Negaunee iron formation is absent, and the Goodrich quartzite and Greenwood iron formation are relatively thick. The Clarksburg volcanics gradually thicken to the east and reaches a maximum thickness (500 m) in the Humbolt area. The Goodrich quartzite has a variable thickness and a maximum thickness of 460 meters in the Humbolt area (Cannon and Klasner, 1974). The Clarksburg volcanics and Greenwood iron formation, now considered members of the Michigamme formation (James, 1958), lie between the Goodrich quartzite and the lower slate member of the Michigamme formation. They have a stratigraphic position and lithology analagous to the Fence River formation and the "strata near Fence Lake" (Cannon and Klasner, 1975), however, are not continuous with these latter units at the surface. Clearly, lateral facies changes occur within distances of a few kilometers to a few tens of kilometers, resulting in many units of only local extent (Cannon and Klasner, 1975).

The faulting may have occurred during the sedimentation of the younger Michigamme formation. This may be inferred from the geologic map in which the fault does not appear to have cut the youngest units of the Michigamme formation.

Profile D-D'

Figure 13 illustrates a geological model of profile D-D', which is oriented northwest to southeast and extends west of the Michigamme Lake through sec. 17, T.47N., R.30W., where the Michigan River trough, the Republic trough and south edge of the Marquette trough intersect.

The gravity anomalies over this area are relatively flat contrary to

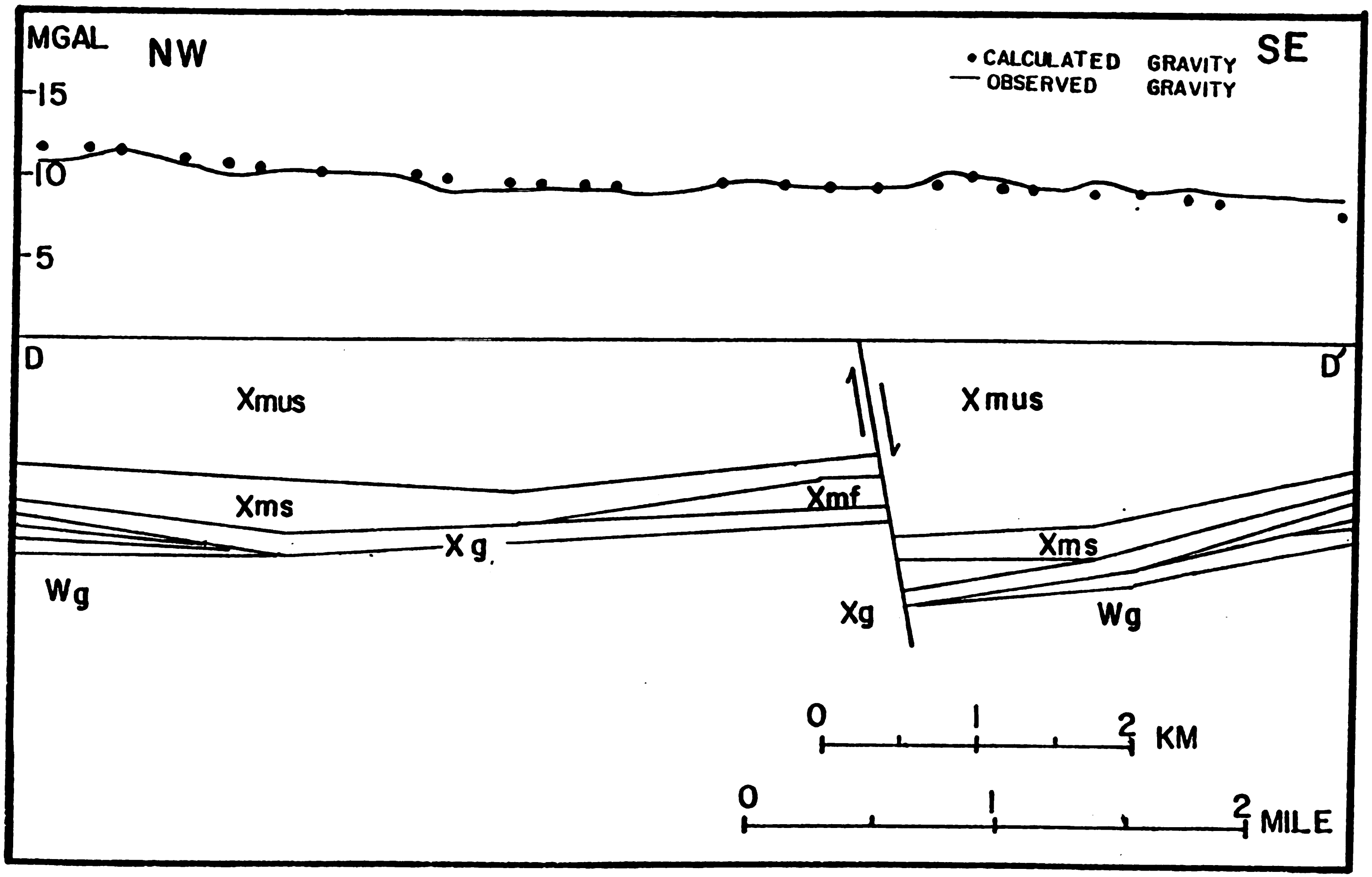

Figure 13. Gravity profile measured along section D-D'. Abbreviations are given on page vii. No vertical exaggeration.

expectations that the junction of the two troughs might be structurally complex. The model was constructed based on stratigraphic thickness from geologic map (Cannon and Klasner, 1976, 1977), information from one drillhole (Cannon and Klasner, 1976), and previous models (author's profile A-A' and B-B' and Klasner and Cannon, 1978) near this area. This model assumms that the Menominee group pinches out to the south as claimed by Klasner and Cannon (1978).

" The Ajibik, Siamo, and possibly the Negaunee pinch out to the south, so that the entire Menominee group is absent and rocks of the Baraga group lie directly on basement gneiss (Cannon and Klasner, 1975). It is not clear whether the pinch out is due to original sediment distribution or is a result of erosion prior to deposition of the Baraga group."

In the west, a few kilometers from the end of the profile, where a drillhole intersects about 10 meters of quartzite above the Negaunee iron formation (Klasner and Cannon, 1978). This supports the conclusion of my models that the Goodrich quartzite lies directly on the basement block and covers the entire area. The " strata near Fence Lake " exist only north of the Smith Creek uplift (Fig.3) and west of the Michigan River Trough fault, which has a vertical displacement of approximately 500 m. This local extent of the "strata near Fence Lake" can be explained as the result of facies changes (Cannon and Klasner, 1975) in the Michigamme formation. The fault was inferred from geologic map (Cannon and Klasner, 1976). The lower slate member becomes thinner to the southeast and only the Bijiki iron formation, which is considered as part of the lower Michigamme formation, exists in the southeast of the study area.

Profile E-E'

Figure 14 illustrates a geological model of the profile E-E', 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 14). West of the fault, the 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 "starta near Fence Lake". Cannon and Klasner(1975) also support this possibility.

"The Hemlock formation, Fence River formation, and "strata near Fence Lake", which compose this part of the section, are absent and may pass by lateral facies change within distances of a few kilometers into the quartzite and slate. This abrupt change is difficult to explain solely by facies changes, even when allowing for substantial later offset along the fault. However, if the fault was active during sedimention, a west-facing scarp may have prevented eastward spreading of volcanic rocks."

The other possiblity is that the faults are not contemporaneous

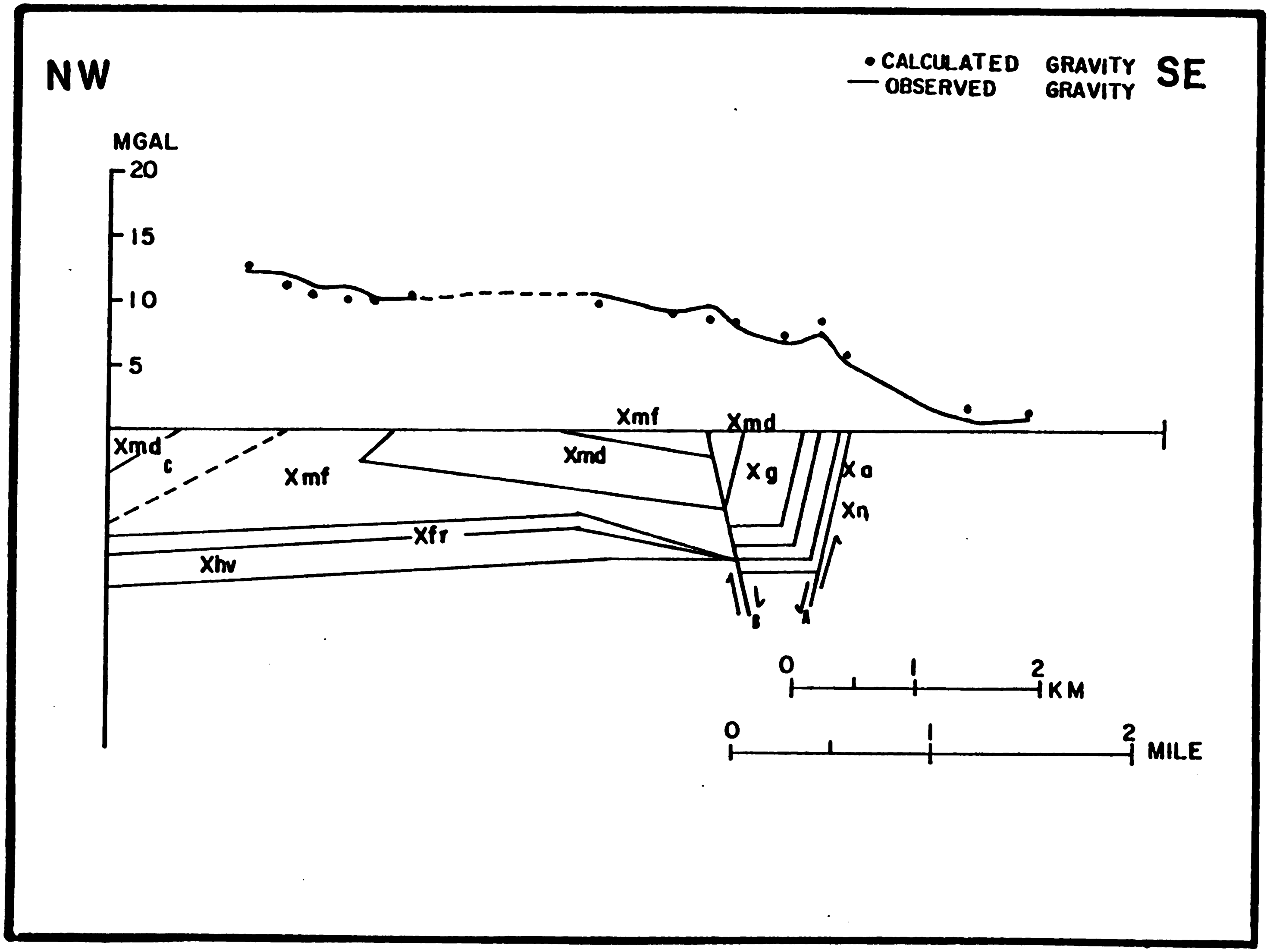

Figure 14. Gravity profile measured along section E-E'. Abbreviations are given on page vii. No vertical exaggeration.

and sediment pinches out in a different direction. In this model, fault A developed in the basement, upthrowing the right side block. Either faulting occured concomitant with sedimentation or after sedimentation but before lithification of the sediments. The sediment would then overlie the basement with an angular unconformity, and slope off the upthrown block onto the downthrown block. This model predicts 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 of faulting (B on Fig.14) cut the sediment in the downthrown block, and eroded down to the present surface. However, the geometry suggests that faulting occured in one episode.

The Hemlock and Fence River formations occur with uniform thickness. In the western part of this section, the unit west of the dotted line (C on figure) is considered to be an iron formation. This is one of the formation composing the "strata near Fence Lake", and is based on high magnetic anomalies seen in the magnetic survey performed by Cannon and Klasner(1976).

<u>An alternate model to Profile E-E'</u>

Figure 15 illustrates an alternate geological model to profile

E-E'. This model was made based on the hypothesis that the metadiabase sill, which is exposed at sec.24, T.47N, R.30W, continues to the west.

Profile F-F'

Figure 16 illustrates a geologic model of Profile F-F', which is oriented southwest to northeast. Long wavelength positive anomalies exist 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 the 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 (Cannon and Klasner, 1975).

Figure 17 shows the good correlation between the observed and calculated gravity. However, it is a geologically unlikely model for this area. This model showes that the uplift caused during the early depositional period. However, the compressional phase occured after

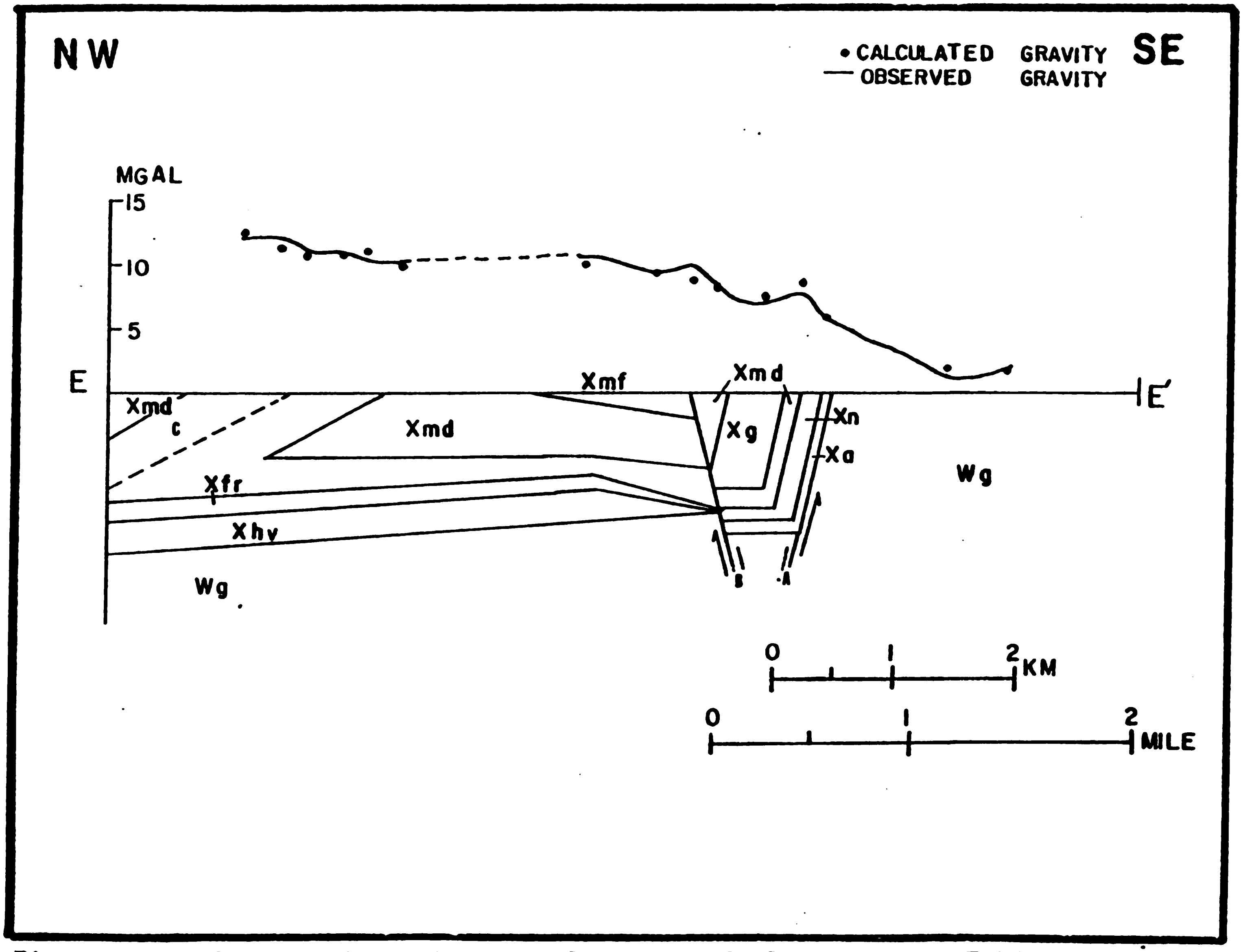

Figure 15. Alternated gravity profile measured along section E-E'. Abbreviations are given on page vii. No vertical exaggeration.

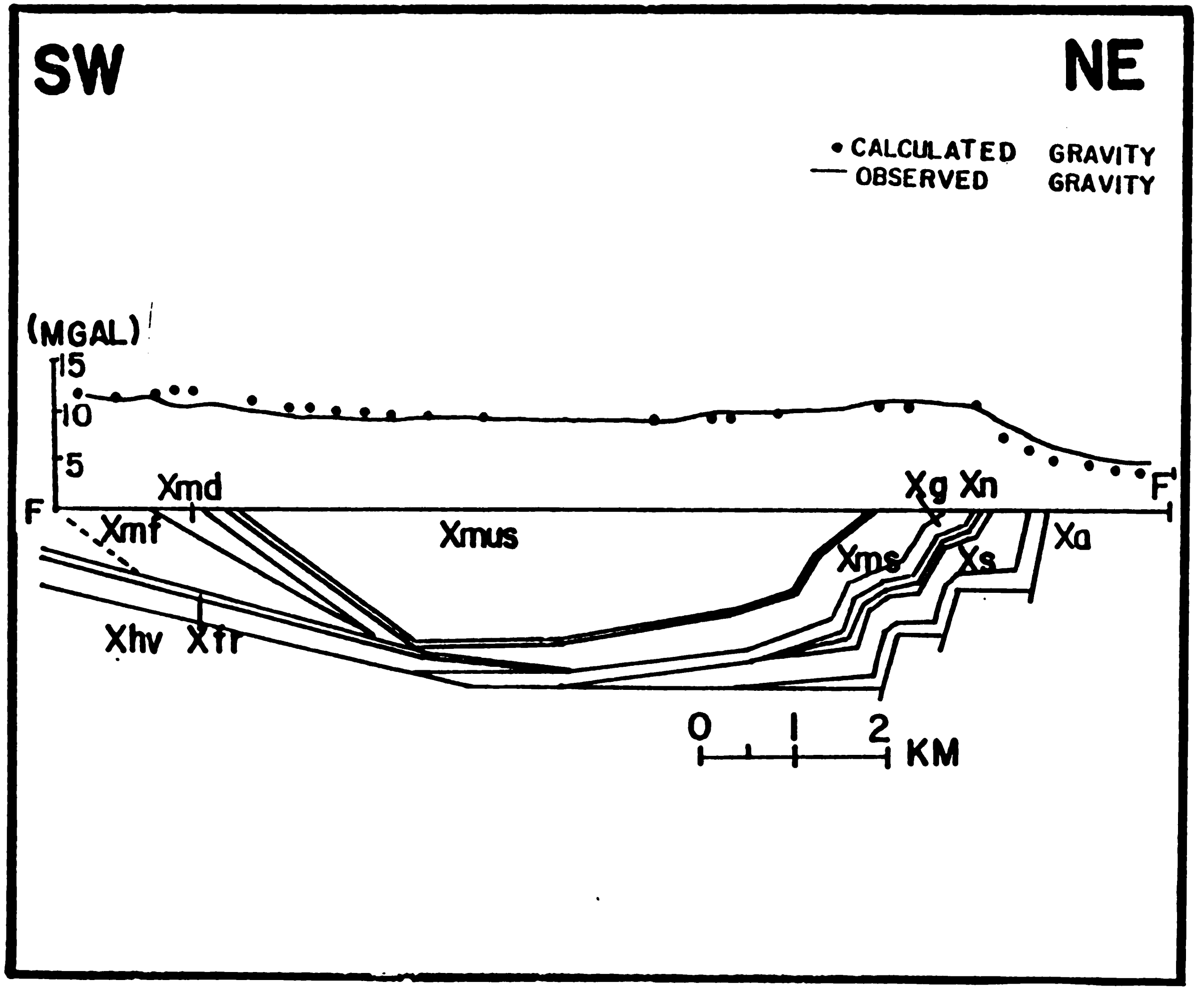

Figure 16. Gravity profile(I) measured along section F-F' showing observed gravity (solid line) and calculated gravity (points). Abbreviations are given on page vii. No vertical exaggeration.

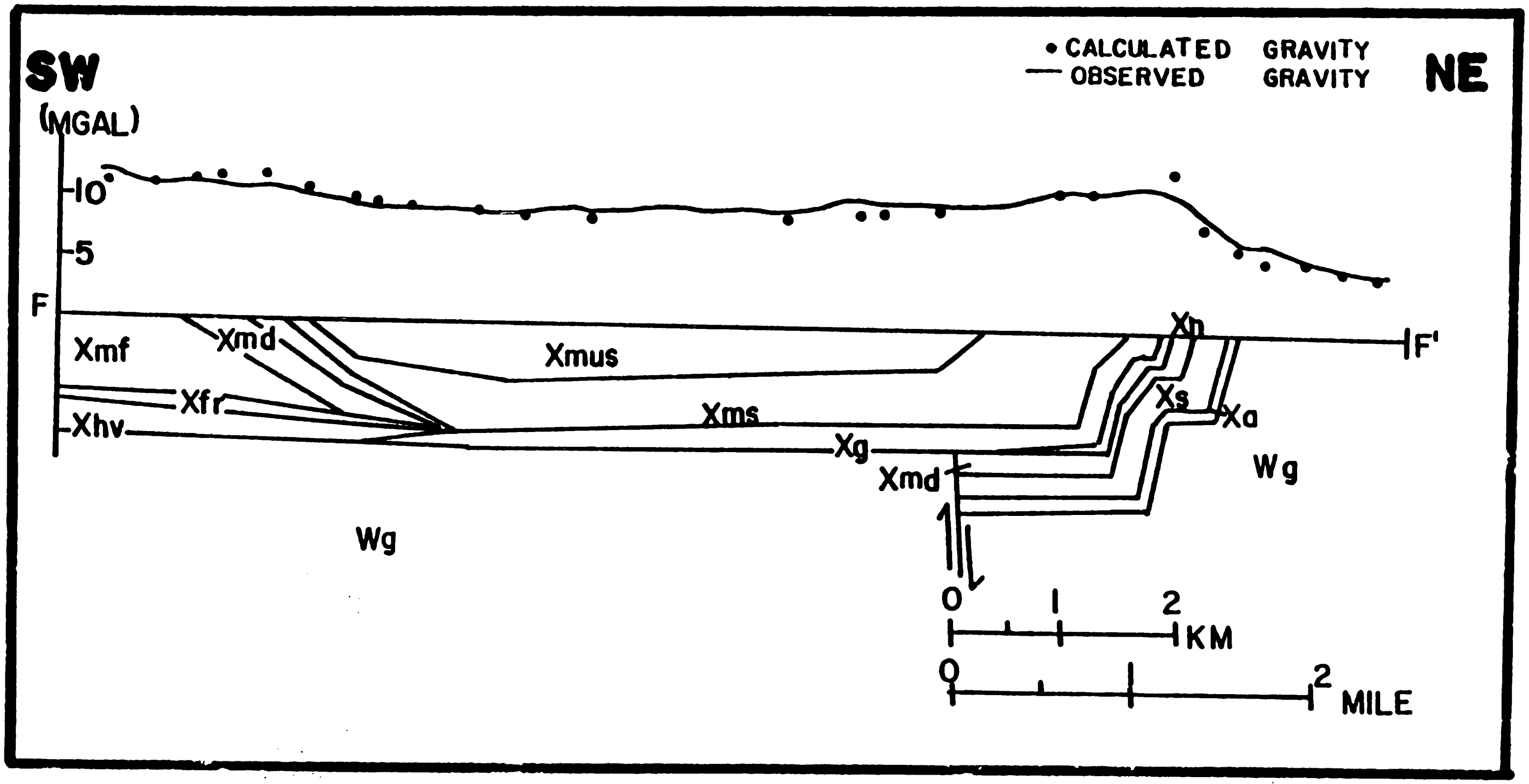

Figure 17. Gravity profile(II) measured along section F-F' showing observed gravity (solid line) and calculated gravity (points). Abbreviations are given on page vii. No vertical exaggeration.

sedimention. Thus, with respect to the time of compression, the existence of the uplifted basement block makes this model geologically unlikely.

An Alternate model to profile F-F'

Figure 18 illustrates an alternate geological model to profile F-F'. This model assumes the Michigan River trough fault continues further north, thus giving a better correlation between the observed and calculated gravity values compared to the previous model. However, gravity data over the fault area were insufficient to confirm the existence of the fault.

Profile H-H'

Figure 19 illustrates a geological model of profile H-H', which is oriented northeast to southwest and extends from Michigamme to Dutchman Point in sec.4, T.48N, R.30W. The positive anomaly of the northwestern part of the profile H-H' (Fig.19) is dominated by the Precambrian X sediment with a thickness of 1750 m. The gravity values across the broad sedimentary basin are relatively flat. The Goodrich quartzite overlies the basement rocks and has a uniform

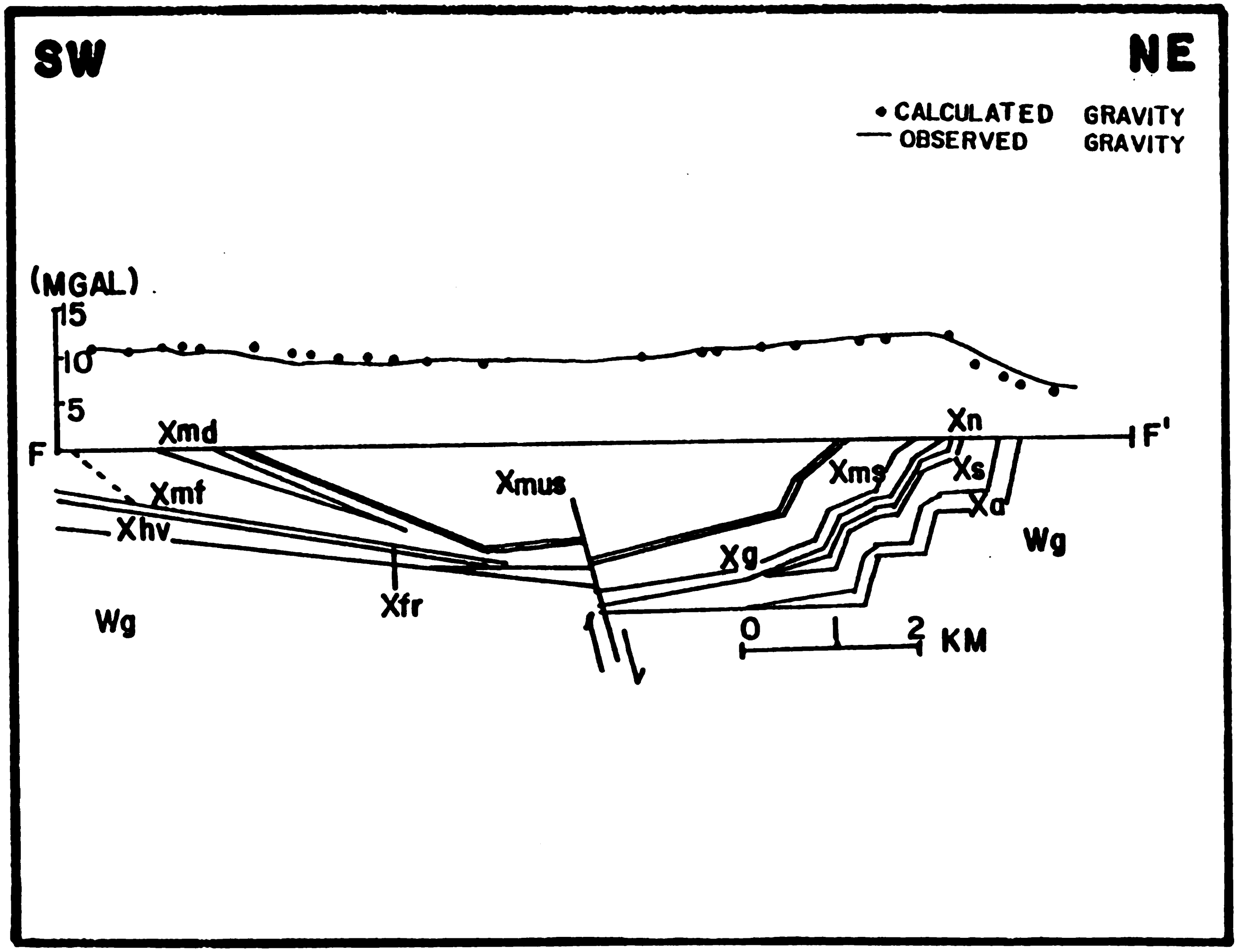

Figure 18. Alternated gravity profile measured along section F-F' showing observed gravity (solid line) and calculated gravity (points). Abbreviations are given on page vii. No vertical exaggeration.

thickness (for determination of the thickness of the Goodrich quartzite refer to the Klasner and Cannon's cross section, 1978). The Menominee group rocks pinch out to the south.

The positive anomalies in the southeastern part (Fig.19) are considered to be small Keweenawan diabase stocks or dikes (shown in Fig 20). The assumption of Keweenawan diabase dikes or stocks was inferred from the Bouguer gravity map shown in Fig.6. The Bouguer gravity map shows the small circular shape of a positive anomaly in the area.

The correlation between the observed and calculated gravity is not well matched in the northwestern part (toward H on the profile) because the profile is oblique to the northern edge of the Marquette trough. Thus, the observed thicknesses of the beds does not represent the true thicknesses.

Figure 20 showes another model which shows good correlation between the observed and calculated gravity. This model indicates that the uplift occured during the early depositional period. However, the compressional phase occured after sedimentation. Thus, with respect to the time of compression, the existence of the uplifted basement block makes this model geologically unlikely.

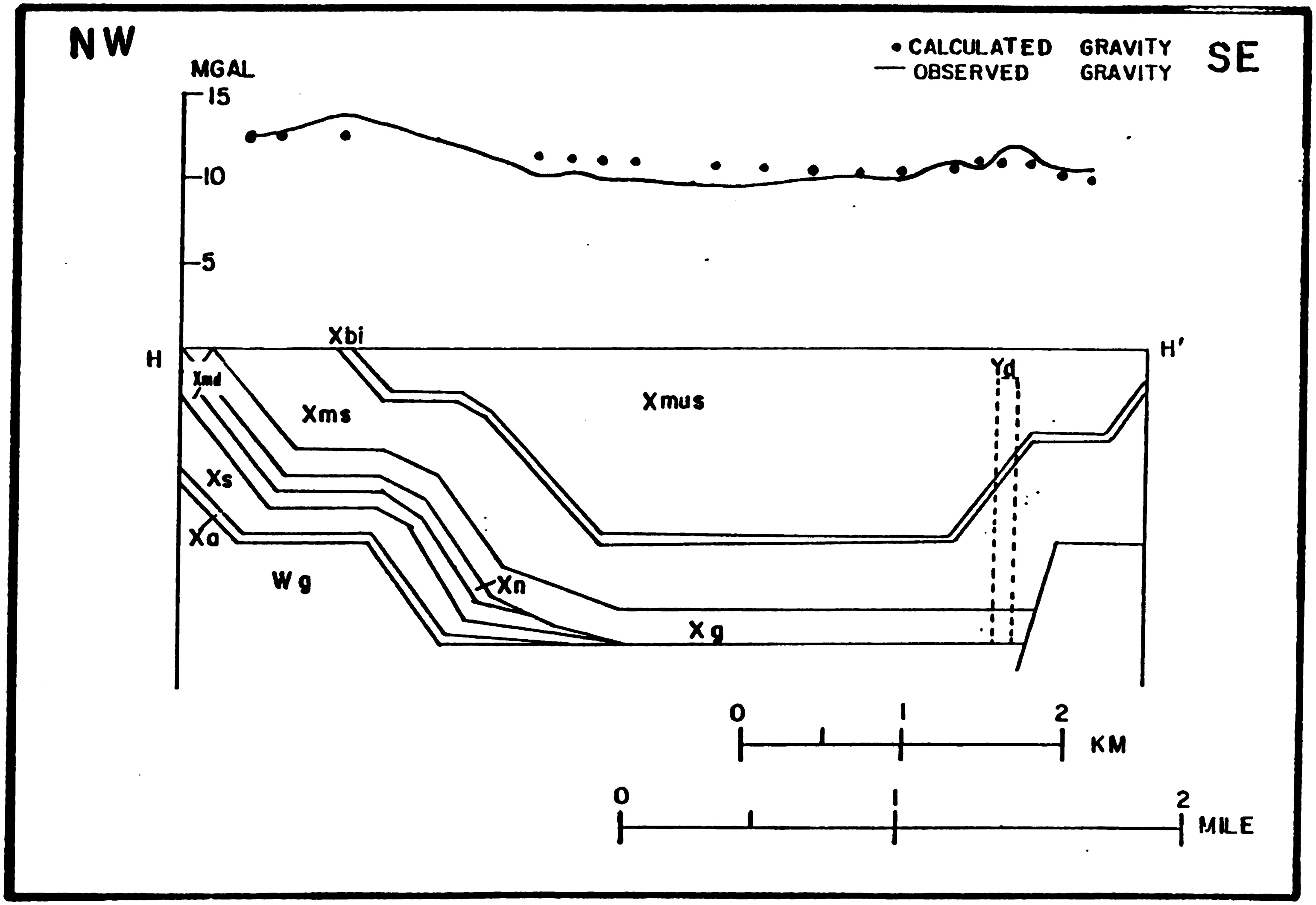

Figure 19. Gravity profile measured along section H-H' showing observed gravity (solid line) and calculated gravity (points). Abbreviations are given on page vii. No vertical exaggeration.

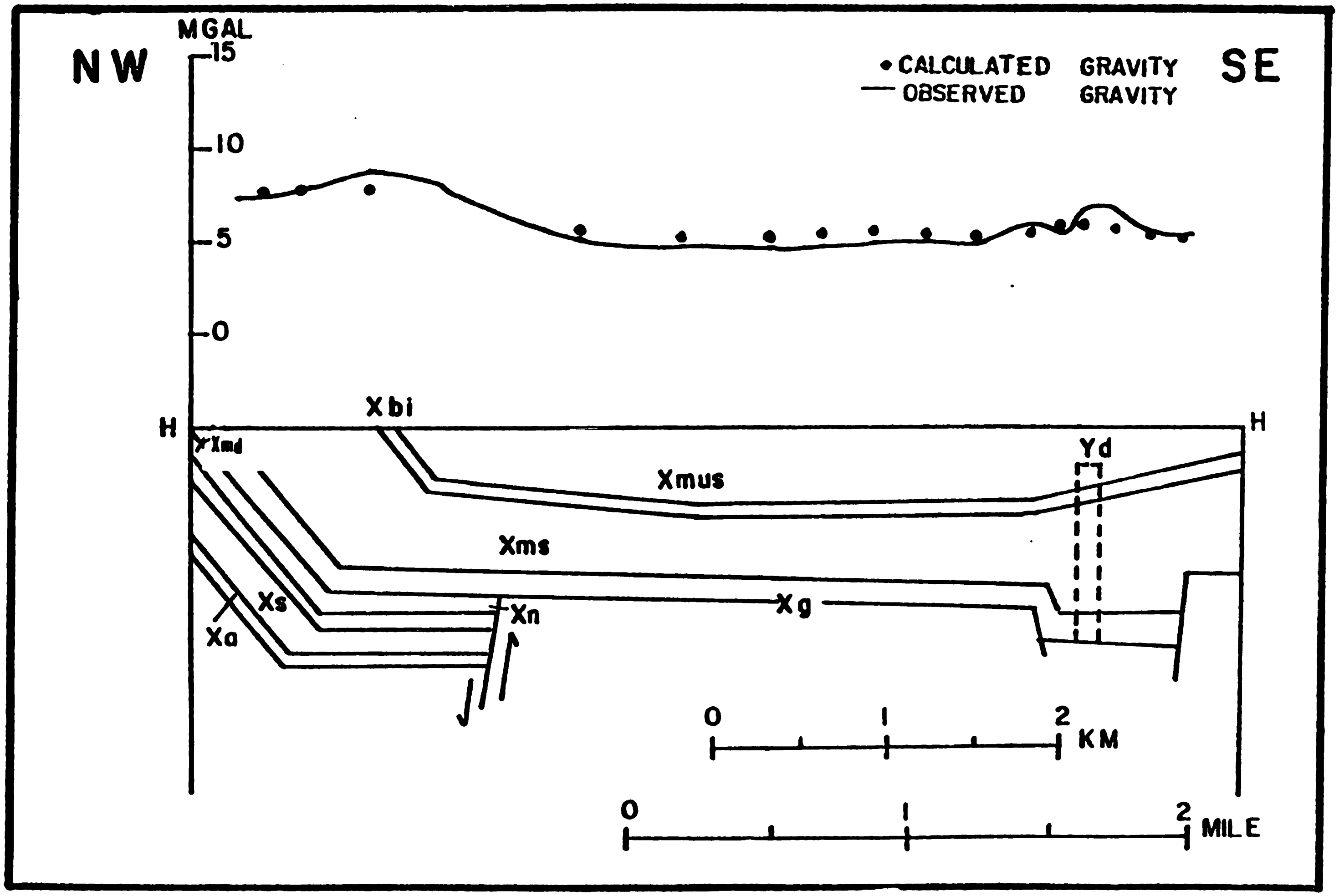

Figure 20. Gravity profile(II) measured along section H-H' showing observed gravity (solid line) and calculated gravity (points). Abbreviations are given on page vii. No vertical exaggeration.

4.4. Summary of the results

The gravity models considered in this study were constructed using all the available information including published geologic maps (Cannon and Klasner, 1976, 1977; Klasner and Cannon, 1978) and the Bouguer gravity map (shown in Fig. 6).

A synthesis of the results fron 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 (Klasner and Cannon, 1978). The reason of the pinch out is unknown. It may be due either to the original sediment distribution or to the weathering and erosion which has partly or totally removed the Menominee group(Cannon and Klasner, 1974) 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 (Cannon and Klasner, 1975). 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 changes of thickness. It is not clear whether the thickness variations 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 and the Wilson Creek uplift. A few kilometers north of the Smith Creek uplift, the Goodrich quartzite and Hemlock formation occur together and pinch out in opposite directions. According to previous worker, the Goodrich underlies the Hemlock and it could be at least in part contemporaneous with the Goodrich or the lower slate member of the Michigamme (Cannon and Klasner,1975). 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 centeral volcaic area, centered west or south of the Amasa uplift (Cannon and Klasner, 1975).

Figure 21 shows the thickness of the sedimentary rocks (depth to basement) and the distribution of the faults in the study area.

However, because the model is based on several assumptions, the contour lines and the postulated faults are tentative.

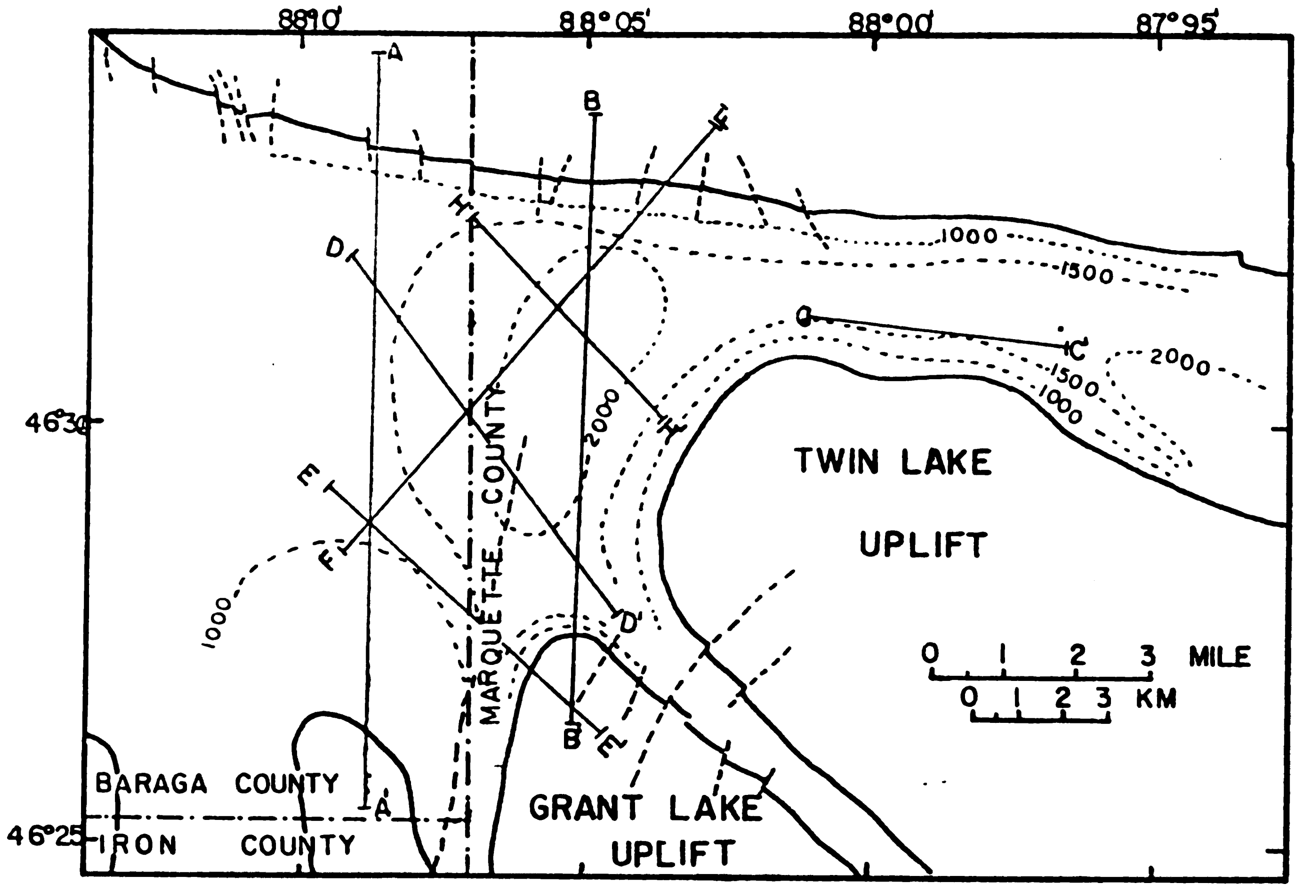

Figure 21. Thickness of the sedimentary rocks and distribution of faults. Dashed lines indicate faults. Thick solid lines indicate boundary of Precambrian X and Precambrian W rocks. Contour interval = 500m.

5. Conclusion and Recommendations

This study of the western Marquette area of the northern Peninsula of Michigan presents an interpretation of the subsurface structural features of the junction 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, and Klasner and Cannon, 1978) gave much different results compared to the author's in the thickness of the Michigamme formation. Cannon and Klasner (1976) 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 1900 m west of Lake Michigamme. The thickness difference between the profile A-A' and profile B-B' (Fig. 3) 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 what Cannon and Klasner inferred (1976). This gives a better correlation between the observed and calculated gravity in section F-F'.

The result of the present modelling study suggests the following: Distribution of the Menominee group rocks (particularly 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 study 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.

For more accurate interperations, the following are recommended.

1) Deep drilling core data will be necessary to define subsurface complexity, particularly in the rocks whose density contrast is very small compared to basement rocks (Ajibik, Goodrich), or in the area where the existence of the fault would be expected.

2) Outcrops are very scarce in the western Marquette area. Thus, geological boundaries are poorly known. In order to determine the boundary of the iron formation in the "strata near Fence Lake", a magnetic survey is desirable. Gravity, as well as magnetic surveys can also delimit the position of the Keweenawan diabase.

3) More accurate density determinations will be necessary. Incorrect density determinations gives rise to many errors in the modelling. Particularly, the density of the Negaunee and Goodrich are variable for the reasons previously mentioned. Therefore,detailed density determinations, especially in these formations, may be able to provide more accurate results.

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APPENDIX A

STATION	STATION LOCATION
B1	On the front yard of Mitch's motel at the junction of US-41 and M-95
B2	0.5 mile west from B1 along the US-41, under the FN/US-41 sign
B3	1 mile west from B1 along the US-41, under the FNO/US-41 sign
B4	At the apex of sharp curve of US-41, 0.8 mile west from junction of FNO/US-41
B5	At the railroad crossing which located junction of US-41 and AF Rd
B6	At platform of train station in Champion
B6	Junction of AB/US-41
B7	Old enterance(no longer used) of Van Riper Park which located 1.5 mile northwest from Champion station along the US-41
B8	0.5 mile west from the B7, just before bridge, under the sign of "River Campground"
B9	0.5 mile northwest from B8 along the US-41, under of "Champion Timberland" sign
B10	0.7 mile northwest from B9 along the US-41
B11	0.5 mile west from B10 along the US-41
B12	In the front yard of the Woodland united methodist church
B13	1 mile west from B12, at the junction of US-41 and dirt road just under "DO NOT PASS" sign

B14 In front yard of Mt. Shasta bar, in Michigamme

B15 Juncton of Max St. and Railroad St. in Michigamme

B15A New Michigamme basestation. NW corner of junction of Max St. and railroad

B16 Junction of M-95 and LG, just pass bridge in Michigamme

H1 0.8 mile south from junction of US-41 and M-95, just pass the railroad, under of "SPEED LIMIT" sign

H2 0.9 mile south from H1 along M-95, under the "Lief Erickson Highway" sign

H3 0.7 mile south from H2 along the M-95

H4 Just before junction of old railroad trace and M-95

H5 At the entrance of right side of dirt road, 0.7 mile from H4 along the M-95

H6 0.6 mile south from Granite Lake along M-95

H7 At the entrance of the way to Republic on M-95

H8 0.5 mile south from H7 along M-95

H9 Just before bridge over the Michigamme river on M-95

R1 0.5 mile northwest from junction of M-95/LG in the front yard of private house

R2 1 mile west along the LG from junction of M-95/LG, just before small wood bridge

R3 At the enterance of private road, 0.5 mile north west from R2

R4 0.5 mile northwest from R3

R5 Junction of left side dirt road and LG St.

R6 Junction of left side dirt road and LG St., 0.5 mile from R5

R7 Entrance of right side dirt road on the LG St.

R8 At the cross road, 0.5 mile NW from R7

R9 0.8 mile to NW from R8, at the entrance of dirt road on right side

R10 Near the US BM 1550. Under the LGA/LG sign

M1 Junction of Mesnard St. and Main St.

M2 0.5 mile south from M1 along the Mesnard St., just before bridge

M3 Junction of Spruce Rd. and Cardinal Rd.

M4 At the entrance of private road, center of north edge of sec.31

M5 0.6 mile east from M4

M6 0.7 mile east from M5, at right side of dirt cross road

M7 Center of sec.32

M8 1.1 mile south from M6, near swamp

M9 NW1/4,NW1/4, of sec.4, T47N, R30W

M10 West side hill of Dutchmen's Point, at the parking lot of privite house

M11 0.4 mile west from M9

M12 Center of sec. 32

M13 Entrance of private road "Cardinal point members"

F1 East end of Black Rd.

F2 Junction of Brook St and Main St., opposite side of US Post Office

F3 South end of Brook St, in front of Philomena Office

F4 Junction of Lake St. and Mesnard St.

F5 Corner of Mesnard St., under the "Swie's" sign plate

F6 Junction of M-95 and Spruce Rd, just before railroad crossing

F7 Junction of imperial Hts and Spruce Rd

F8 Junction of Spruce Rd and Fence Lake Rd and Petticoat Lake Rd

F9 0.5 mile south of F8

F10 In front of "Mikkola" house where the junction of Koskela Rd and Spruce Rd

F11 Junction of Jokela Rd and Spruce Rd

F12 Junction of Kead Rd and Spruce Rd

F13 0.5 mile south from F12

F14 Junction of Kead Rd and Smith Rd

F15 Junction of Kead Rd and Koivula Rd

F16 0.4 mile north from F10 along Spruce Rd

I1 0.5 mile west from F15 along M-95 just under "Imperial Hight Rd" road sign

I2 Enterance of dirt road in sec.24, north side of M-95

I3	0.3 mile from I2, at curve in road
I4	Corner of the road in sec.24
I5	Under the high tension wire, in sec.24
I6	On the section line between sec.24 and sec.13
I7	0.2 mile north from I6, at topographic. high
I8	0.4 mile north from I7, at the road junction
I9	West of the section line between sec.14 and sec.13
I10	On the section line between sec.11 and sec14 at BM 1693
I11	At the corner of Imperial Hight in sec.25
I12	At road junction, east of Bass Lake in sec.25
C1	Junction of AF Rd and AH in Champion
C2	0.4 mile east from C1
C3	0.3 mile east from C2, in front of private house
C4	Fork of the road AF/AG and Gibson Rd
C5	East end of the road from C4, under the mail box in front of the private house
C6	0.3 mile west from C5
C7	North end of the road from C4, the top of the hill
C8	0.3 mile south from C7
C9	Junction of AJ/EM
C10	Junction of ELM and Main St.

C11	Intersection of railroad and AJ St.
C12	0.3 mile NNW from C11 in sec.36
C13	Junction of IAJ/IKE
C14	North west corner of sec.31 ,T47N, R29W
C15	At parking lot in the gate of Park
C16	Junction of FBB/FFB
C17	On the forest boundary between sec.32 and sec.5
C18	Junction of AJ/AS
R1	South side of bridge at the center of NE1/4, of sec.20,T47N,R3
J1	N1/2,NE1/4, of sec.20,T47N,R30W
J2	SE1/4,SE1/4, ofsec.17,T47N,R30W. Elev. 1561
J3	At pipeline junction at SE1/4, of sec.17, T47N, R30W
J4	Apex of curve on the road at SE1/4, of sec. 17, T47N, R30W
J5	SW1/4, SW1/4, ofsec.17, T47N, R30W
J6	SE1/4,NW1/4, of sec. 17, T47N, R30W
J7	Center of junction at NE1/4,NW1/4, of sec.17, T45N, R30W
J8	Road junction at N1/2,NW1/4, of sec.17, T47N, R30W
J9	On the section line between sec.5 and sec.17
J10	At crest of hill where road change direction between sec.7 and sec.8

J11 New road junction at SW1/4, of sec.6, T47N, R30W

J12 Curve in road at SW1/4, of sec.7, T47n, R30W

J13 Road junction at curve S1/2,NE1/4, of sec.7, T47N, R30W

J14 NE1/4, of sec.7, T47N, R30W

J15 N1/2,NE1/4, of sec.7, T47N, R30w

J16 SE1/4,SE1/4, of sec.6, T47N, R30W

J17 Bottom of deep gully at SE1/4, of sec.6, T47N, R30W

J18 NW1/4,SW1/4, of sec.6, T47N, R30W

J19 300 feet N20E of lake at SW1/4, of sec.6, T47N,R30W

J20 End of the road, center of sec.6, T47N, R30W

J21 West end of Spruce. sec.6, T47N,R30W

J22 Bottom of gully at SW1/4, of sec.6, T47N, R30W

J23 Curve in Road. Just pass crest at S1/2,SW1/4, of sec.6, T47N, R30W

J24 S1/2,SW1/4, of sec.6, T47N, R30W

J25 Curve on new road at NE1/4, of sec.17, T47N,R30W

K1 Bottom of gully. N40E of lake at SE1/4, sec.17, T47N, R30W

K2 Bottom of gully before pipeline at S1/2,NW1/4, of sec.17, T47N, R30W

K3 Fork in road at the section line between sec.18 and sec.17

K4 Junction of loop at N1/2,SE1/4, of sec.7

K5	Junction of loop at S1/2, SE1/4, of sec.7
K6	Swamp bottom at SE1/4, of sec.7, T47N, R30W
K7	SW1/4,SW1/4, of sec.5, T47N, R30W
K8	SW1/4,SW1/4, of sec.5, T47N, R30W
K9	Topographic. low on east side at SW1/4, of sec. 5
K10	Topographic. high. center of S1/2, of sec.5
K11	SE1/4, of sec.5
K12	Topographic. high. NW1/4,SE1/4, of sec.5
K13	Road junction. near crest. NE1/4, of sec.5, T47N, R30W
K14	Road junction. SW1/4 NE1/4, of sec.5
K15	Center of NE1/4, of Sec 5
K16	Dutchman's Pt. road at NE1/4,NE1/4, of sec.5
K17	Sharp curve which turn to south at NW1/4 NW1/4, of sec.4
K18	Curve to left. NW1/4, of sec.4
K19	Dutchman's Point . at NW1/4 of sec.4
K20	Cross road at SW1/4, of sec.5
E1	Road junction. just before railroad NW1/4, of sec.25
E2	0.4 mile east from road junction. SE1/4, of sec.25
E3	Junction of US-41 and dirt road SW1/4, of sec.30

E4 IAJ/IE at NE1/4, of sec.36

E5 Parking lot circle at NE1/4,NE1/4, of sec.36

E6 0.3 mile west from E4

E7 West end of IAJ Rd

E8 0.3 mile from railroad. At left side of JCT of dirt road. sec 31, T48N, R29W

E9 Road junction. center of, SE1/4, of sec.31, T48N, R29W

E10 Road junction. SW1/4, SE1/4, of sec.31, T48N, R29W

E11 50m north from FG/FKL, sec.6, T47N, R29W

E12 Junction of FG and Fish Lake Rd. NW1/4, of sec.6, T47N, R29W

E13 Sharp curve at NE1/4, of sec.6, T47N, R29W

E14 Center of, of sec.6, T47N,R29W

E15 NW1/4,SW1/4, of sec.6

E16 Road junction. At SW1/4 of sec.6

E17 0.1 mile SE from Egg Lake at NW1/4, of sec.7

D1 At 607/US-41. Just pass the bridge at NW1/4, of sec.25, T48N,R30W

D2 At the corner of 607/US-41. 0.15 mile north from D1

D3 Under the power line at SW1/4, of sec.24

D4 Right side of the road junction 607/IDA. Near the BM 1572 at SW1/4, of sec.24

D5 Curve of the Peshekee River. Under "NO PASSING ZONE" sign

D6	Under the "MARQUETTE 607 COUNTY" sign plate
D7	Road intersection, SW1/4, of sec.13
D8	Just pass narrow bridge, near the BM 1572 at center of sec.13
D9	0.4 mile north from D8
D10	Road intersection S1/2,SW1/4, of sec.12
D11	At sharp curve to right. near the BM 1593. SW1/4. of sec.12
D12	Sharp curve to left. SE1/4, of sec.12
D13	Sharp curve to right. SE1/4. of sec.12
D14	Sharp curve to left. NE1/4, of sec.12
D15	SE1/4 SE1/4, of sec.1
D16	Just before the narrow bridge. Road intersection near the BM 1613 at SW1/4, of sec.1
N1	Curve to west of US-41. SW1/4 of sec.1
N2	Road junction at NE1/4, of sec.20 Elev.1573
N3	End of Pink road, at SE1/4, of sec.20
N4	0.1 mile NE from N3. SE1/4, of sec.20
N5	Orange Rd/Railroad at NW1/4, of sec.21, T48N, R30W
N6	Curve in road at SW1/4 of sec.21
N7	Road junction at SE1/4, of sec.21
N8	Road junction, 0.1 mile south from N7

N9 0.1 mile east from N7, at road intersection

N10 Cross road, south of railroad track at SE1/4, of sec.21

N11 Junction IB/IC at SE1/4,SE1/4, of sec.21

N12 NE1/4,NE1/4, of sec. 21

N13 N1/2,NE1/4, of sec.28. Elev. 1600

N14 N1/2,SW1/4, of sec.28

N15 0.1 mile west from N14

N16 West end of road. 0.1 mile west from N15

N17 Road junction, on the section line between sec.22 and sec.27. Elev. 1580

N18 South end of road, SW1/4, of sec.27

N19 Sharp curve to south, 0.1 mile east from N17

N20 Road junction, 0.2 mile south from N19, NW1/4, of sec.27

N21 North shore of Lake Michigamme, center of sec.27

N22 0.2 mile east from B12 along US-41. SW1/4, of sec.22

N23 0.8 mile east from N22 along US-41. SW1/4, of sec.22

N24 Railroad cross on Green road at S1/2,SE1/4, of sec.22

N25 Curve in road at NE1/4, of sec.27

N26 Topographic high on curve at NW1/4, of sec.26

N27 Cross road, 0.1 mile SSE from N26

N28 0.2 mile south from N26

N29	Road junction
P1	Logging road junction, just off US-41, NW1/4, of sec.21, T48N, R30W
P2	Curve in road, S1/2,NE1/4, of sec.21
P3	0.1 mile NNE from P2
P4	Topographic high. West of Mud Lake
P5	Curve in road, SW1/4, of sec.15
P6	0.1 mile NNE from P5, road junction, SW1/4, of sec.15
P7	Road curve,NW1/4, of sec.21
P8	Road junction, front of cliff
P9	End of logging road. 0.1 mile NNW from P7
P10	Junction of logging road and US-41
P11	Section line between sec.19 and sec.20
P12	Crest of road, NE1/4,NE1/4, of sec.30
Q1	North of section line between sec.36 and sec.25, T48N, R31W
Q2	N1/2,NW1/4, of sec.31, T48N, R30W
Q3	N1/2,NE1/4, of sec.31
Q4	SW1/4 SW1/4, of sec.29
Q5	Road cross on the section line between sec.29 and sec.32
Q6	0.1 mile south from Q5, NW1/4, of sec.32

Q7 SE1/4, of sec.32

Q8 SW1/4, of sec.28. Elev. 1632

Q9 0.1 mile NNE from Q7

Q10 Sharp curve in road, 0.1 mile south from road junction

Q11 0.1 mile SSE from Q10, NE1/4, of sec.32

Q12 On curve, SE1/4, of sec.32

Q13 0.2 mile south from Q12

Q14 Section line between sec.32, T48N, R30W and sec.5, T47N, R30W

Q15 N1/2,SW1/4, of sec.5, T47N, R30W

Q16 S1/2,NW1/4, of sec.5

Q17 0.1 mile west from Q16

S1 0.1 mile SSE from road junction, SE1/4, SE1/4, of sec.21

S2 Under power line, NE1/2, NW1/4, of sec.20

S3 Road junction, S1/2, NW1/4, of sec.20

S4 Road curve to west, SW1/4, NW1/4, of sec.20

S5 Road cross, S1/2, NE1/4, of sec.19. Elev. [illegible]573

S6 Road cross, NW1/4, NE1/4, of sec.19

S7 0.1 mile west from S6, N1/2, NW1/4, of sec.19

S8 End of logging road, NW1/4, NW1/4, of sec.19

S9 SE1/4, NW1/4, of sec.19

S10	Curve in road, SW1/4, NE1/4, of sec.19
T1	Topographic.Low, east of sectionlinebetween sec.19 and sec.20
T2	Topographic. High. N1/2, SE1/4, of sec.19
T3	Road junction, SW1/4, SE1/4, of sec.19. Elev. 1615
T4	0.3 mile SE from T3. SE1/4, SE1/4, of sec.19
T5	Curve to west, NE1/4, of sec.30
T6	Center of sec30. Elev.1617
T7	0.1 mile SSW from T6
T8	Before hill, N1/2, SW1/4, of sec.30
T9	Junction of road, near the BM 1679, SE1/4, SE1/4, of sec.25, T47N, R31W
T10	0.2 mile south from T9, S1/2, NE1/4, of sec.36, T47n, R31W
T11	On the section line
U1	Curve in road, S1/2, NE1/4, of sec.20
U2	Curve to right pass Brown, N1/2, SE1/4, of sec.20
U3	Center SW1/4, of sec.21
U4	Road junction, SW1/4, of sec.21. Elev. 1546
U5	0.1 mile west from U4, S1/2, SW1/4, of sec.21
U6	SW1/4, SW1/4, SW1/4, of sec.21
U7	0.1 mile west from U6, south side of section line between sec.20 and sec.29

U8	Topographic high, just before curve to west, S1/2,NE1/4, of sec.29
U9	Center of sec.29
U10	0.1 mile SW from U9
U11	0.2 mile west from U9
V1	Road curve to east, center, of sec.36, T48N, R31W
V2	150 feet west of road curve to south of sec.36
V3	SW corner of road, NW1/4, of sec.36
V4	0.1 mile south from V3, at the curve to west
V5	On the section line between sec.35 and sec.36. Elev. 1695
V6	Topographic Low. 0.2 mile south from V5
V7	At the corner of sec.35,36, T48N, R31W, and sec.1,2, T47N, R31W. Elev.1681
V8	East end of logging road, SE1/4, NW1/4, of sec.1, T47N, R31W
V9	Junction of Spruce River, on the section line between sec.1 and sec.2
V10	Road curve, SW1/4,SW1/4,SW1/4, of sec.1
V11	Road junction, center of pipe line, north end of section line between sec.11 and sec.12
V12	0.5 mile south from V11, at the road junction
V13	Curve in road, 0.2 mile SW from V12 at center,, SE1/4, of sec.11

V14	0.1 mile SW from V3, at S1/2, SE1/4, of sec. 11
V15	Just before curve, NE1/2, NW1/4, of sec. 14
V16	Junction on curve, 0.2 mile south from V15
V17	Center, of sec.14
V18	Junction of road, NW1/4, SE1/4, of sec.14
V19	Junction of road, 0.1 mile EES from V18, SE1/4, of sec.14
V20	Junction of old road, NE1/4, SE1/4, of sec.14
V21	South end of logging road, SE1/4,SE1/4, of sec.14
V22	SE1/4, SW1/4, of sec.14
V23	0.2 mile south from V22, NE1/4, NW1/4, of sec.23
V24	road curve to SW, SE1/4NW1/4, of sec.23
V25	Last curve into straight, NW1/4, NW1/4, of sec.23
V26	Topographic high before curve, NW1/4, NW1/4, SW1/4, of sec.23
V27	Road junction with Cannse and Klane, just south of section line between sec.27 and sec.34
V28	Bottom of swamp, SW1/4,SE1/4, of sec.34
V29	Road junction 0.4 mile north from V28
V30	Curve in road, 0.5 mile north from V27, SE1/4, of sec.27
V31	Topographic low middle of swamp, NE1/4, of sec.27
V32	Topographic high south side of curve, SE1/4, SE1/4, of sec.22

W1	Curve to east, SW1/4, SW1/4, of sec.1
W2	Road junction, 0.1 mile east from W1
W3	Road junction. South of bridge, NE1/4, SW1/4, of sec.1
W4	SW1/4, NE1/4, of sec.1
W5	Junction of circle, NW1/4, NW1/4, of sec.1
W6	Junction of T, NE1/4,NE1/4, of sec.1
W7	0.1 mile west from W6, NW1/4, NE1/4, of sec.1
W8	North east end of the loop, NE1/4, of sec.1
W9	curve to SSE, SW1/4, SE1/4, of sec.1
W10	Junction with new road to north near swamp, NE1/4, of sec.12
W11	Curve to left, on topographic. high, S1/2, NE1/4, of sec.12
W12	Junction of road to north, SW1/4, NW1/4, of sec.7
W13	Topographic. high., SE1/4, SE1/4, SE1/4, of sec.1
W14	North end of logging road, NE1/4, SE1/4, of sec.1
W15	At curve to east, on the section line between sec.11 and sec.12

APPENDIX B

STA	ELEV.(ft)	OBSER. GRAV. (mgal)	LAT.	FREE.AIR. (mgal)	BOUG.	GRAVITY (mgal)
B0	1598	35.88	-1.24	0.00	0.00	34.64
B1	1553	39.81	0.25	-4.23	1.54	37.37
B2	1565.5	37.62	0.32	-3.06	1.11	35.99
B3	1612.5	33.53	0.30	1.36	-0.50	34.69
B4	1638.5	33.62	-0.35	3.81	-1.39	35.69
B5	1600	35.90	-1.24	0.19	-0.07	34.78
B6	1594	34.88	-1.64	0.38	0.14	33.00
B7	1578	34.92	-2.07	-1.88	0.69	31.66
B8	1559.5	35.11	2.61	-3.62	1.32	30.20
B9	1579.5	32.46	3.20	-1.74	0.63	28.15
B10	1594	33.11	3.37	-0.38	0.14	29.50
B11	1590.5	33.28	-3.73	-0.71	0.26	29.10
B12	1581	34.94	-3.83	-1.60	0.58	30.09
B13	1576.5	33.02	-3.97	-2.03	0.74	27.77
B14	1567.5	38.70	-3.45	-2.87	1.04	33.42
B15	1570	37.93	4.01	-2.63	0.96	32.25
B15A	1569	37.86	-4.01	-2.73	0.99	32.11

STA	ELEV.(ft)	OBSER. GRAV.	LAT	FREEAIR.	BOUG.	GRAV.
B16	1505	24.82	8.06	-8.75	3.19	27.32
H1	1594	31.52	1.23	-0.38	0.14	32.51
H2	1628.5	21.80	2.23	2.87	-1.04	25.86
H3	1608.5	19.64	2.23	0.99	-0.36	22.50
H4	1564.5	19.62	4.35	-3.15	1.15	21.97
H5	1568	19.02	4.94	-2.82	1.03	22.17
H6	1569.5	16.55	6.02	-2.68	0.98	20.87
H7	1570.5	15.54	6.75	-2.59	0.94	20.64
H8	1577.5	14.86	7.27	-1.93	0.70	20.90
H9	1526	20.42	7.80	-6.77	2.47	23.92
R1	1504	22.01	7.78	-8.84	3.22	24.17
R2	1496	21.24	7.27	-9.59	3.49	22.41
R3	1493	20.92	6.67	-9.88	3.60	21.31
R4	1496	21.36	6.37	-9.59	3.49	21.63
R5	1498	23.12	5.73	-9.41	3.23	22.87
R6	1515	24.45	5.28	-7.81	2.84	24.76
R7	1533	24.84	4.90	-6.11	2.23	25.85
R8	1544	25.41	4.50	-5.08	1.85	26.68
R9	1549	26.05	3.99	-4.61	1.68	27.11

STA	ELEV.	OBSER.GRAV.	LAT.	FREEAIR	BOUG.	GRAV.
R10	1555	26.77	3.67	-4.51	1.64	27.57
M1	1641	33.29	-3.34	4.04	-1.47	32.52
M2	1554	35.93	-2.43	-4.14	1.51	30.87
M3	1655	29.41	-2.01	5.36	-1.95	30.81
M4	1646.5	27.69	-1.91	4.56	-1.66	28.68
M5	1656	28.81	-1.86	5.46	-1.99	30.42
M6	1593	32.57	-1.91	-0.47	0.17	30.42
M8	1603	30.58	-0.89	0.47	-0.17	29.99
M9	1565.5	33.21	-0.50	-3.06	1.11	30.76
M10	1558.5	32.75	-0.28	-3.72	1.35	30.10
M12	1604	30.13	-0.55	0.56	-0.21	29.93
M12	1675	26.83	-1.34	7.24	-2.64	30.09
M13	1602	32.43	-2.31	0.38	-0.14	30.36
M14	1587	32.83	-2.09	-1.03	0.38	30.09
F1	1565	38.29	-3.25	-3.10	1.13	33.07
F2	1611	35.56	-3.25	1.22	-0.45	33.08
F3	1568.5	38.53	-2.89	-2.77	1.01	33.88
F4	1663.5	31.99	-3.08	6.16	-2.24	32.83
F5	1637.5	32.23	-2.64	3.72	-1.35	31.96

STA	ELEV.	OBSER.GRAV.	LAT.	FREEAIR	BOUG.	GRAV.
F6	1603.5	36.27	-3.53	0.52	-0.19	33.07
F7	1600	36.01	-3.30	0.91	-0.07	32.83
F8	1618	34.04	-2.94	1.88	-0.69	32.29
F9	1688	27.90	-2.51	8.47	-3.08	30.78
F10	1692.5	27.58	-1.59	8.89	-3.24	31.67
F11	1688.5	27.40	-1.60	8.51	-3.10	31.21
F12	1709.5	25.55	-1.54	10.49	-3.82	30.68
F13	1688	26.06	-1.03	8.47	-3.08	30.42
F14	1660	26.39	-0.25	5.83	-2.12	29.85
F15	1644	27.05	0.31	4.33	-1.58	30.11
F16	1679.5	28.11	-1.99	7.67	-2.79	31.00
I1	1609	35.93	-3.52	1.03	-0.38	33.06
I2	1608	35.95	-3.65	0.94	-0.34	32.90
I3	1631.5	31.33	-4.01	3.10	-1.15	29.27
I4	1640	30.32	-4.20	3.95	-1.54	28.53
I5	1642	30.33	-4.22	4.14	-1.51	28.74
I6	1645	28.38	-4.56	4.42	-1.61	26.63
I7	1694	24.92	-4.88	9.03	-3.29	25.78
I8	1680	25.13	-5.29	7.71	-2.81	24.74

STA	ELEV.	OBSER.GRAV.	LAT.	FREEAIR	BOUG.	GRAV.
I9	1688	25.00	-5.49	8.47	-3.08	24.90
I10	1688	25.07	-5.84	8.47	-3.08	24.62
I11	1599	35.76	-3.10	0.09	-0.03	32.72
I12	1650	31.24	-2.72	4.89	-1.78	31.64
C1	1675	31.97	-1.62	7.24	-2.64	34.95
C2	1713	29.61	-1.56	10.82	-3.94	34.93
C3	1776	25.41	-1.66	16.74	-6.10	34.39
C4	1708	29.05	-1.91	10.35	-3.77	33.72
C5	1799	24.05	-1.93	18.91	-6.88	34.15
C6	1760	26.23	-1.94	15.24	-5.55	33.98
C7	1777.5	24.59	-2.62	16.88	-6.15	32.70
C8	1716	28.29	-2.17	11.10	-4.04	33.08
C9	1732	27.26	-1.05	12.60	-4.59	34.22
C10	1746.5	25.99	-0.96	13.97	-5.09	33.91
C11	1716	26.67	-0.89	11.10	-4.04	32.84
C12	1609	33.03	-1.43	1.03	-0.38	32.25
C13	1589.5	34.00	-1.68	-0.80	0.29	31.81
C14	1580	35.32	-1.74	-1.69	0.65	32.54
C15	1585	34.28	-1.86	-1.22	0.45	31.65

STA	ELEV.	OBSER.GRAV.	LAT	FREEAIR	BOUG.	GRAV.
C16	1681.5	29.02	-0.35	7.85	-2.86	33.66
C17	1707	28.10	-0.58	10.25	-3.73	34.04
C18	1715.5	28.54	-0.96	11.05	-4.02	34.61
R'1	1532	29.67	3.55	-6.21	2.26	29.27
J1	1550	28.27	3.34	-4.51	1.64	28.74
J2	1570	26.84	3.18	-2.64	0.96	28.35
J3	1577.5	27.48	2.89	-1.93	0.70	29.14
J4	1574	28.01	2.79	-2.26	0.82	29.36
J5	1581	27.85	2.57	-1.60	0.58	29.40
J6	1591.5	27.68	2.39	-0.61	0.22	29.68
J7	1604	27.48	2.09	0.56	-0.21	29.92
J8	1615	27.00	2.01	1.60	-0.56	29.36
J9	1634.5	25.26	1.99	3.43	-1.25	29.43
J10	1642	25.16	1.76	4.14	-1.51	29.55
J11	1635	25.67	1.62	3.48	-1.27	29.50
J12	1622.5	26.79	1.38	2.30	-0.84	29.63
J13	1618	27.10	1.15	1.88	-0.69	29.44
J14	1640	26.24	0.93	3.95	-1.44	29.68
J15	1650	25.67	0.71	4.89	-1.78	29.49

STA	ELEV	OBSER.GRAV.	LAT	FREEAIR	BOUG	GRAV.
J16	1654	25.60	0.58	5.27	-1.92	29.53
J17	1647	26.24	0.28	4.61	-1.68	29.45
J18	1649	25.81	0.12	4.80	-1.75	28.98
J19	1654.5	25.36	0.16	5.31	-1.94	28.89
J20	1653.5	25.88	-0.04	5.22	-1.90	29.16
J21	1641	26.58	0.51	4.04	-1.47	29.66
J22	1623	26.50	1.71	2.35	-0.86	29.70
J23	1625	26.22	1.89	2.54	-0.92	29.73
J24	1605.5	27.56	1.87	0.71	-0.26	29.88
J25	1590	28.34	2.16	-0.75	0.27	30.02
K1	1558	28.69	2.79	-3.76	1.37	29.09
K2	1584	27.24	2.59	-1.32	0.48	28.99
K3	1616.5	25.46	2.37	1.74	-0.63	28.94
K4	1653.5	25.47	1.72	5.22	-1.90	30.51
K5	1661	24.85	1.88	5.93	-2.16	30.50
K6	1635	26.68	1.70	3.48	-1.27	30.59
K7	1674	24.14	0.61	7.15	-2.60	29.30
K8	1706	21.76	0.55	10.16	-3.70	28.77
K9	1662	24.90	0.51	6.02	-2.19	29.24

STA	ELEV	OBSER.GRAV.	LAT	FREEAIR	BOUG.	GRAV.
K10	1653.5	25.51	0.40	5.22	-1.90	29.23
K11	1632	27.28	0.30	3.20	-1.16	29.62
K12	1607	28.90	0.10	0.85	-0.31	29.54
K13	1605.5	29.24	-0.02	0.71	-0.26	29.59
K14	1598	30.29	-0.18	0.00	0.00	30.11
K15	1599	30.61	-0.25	0.09	-0.03	30.42
K16	1597.5	31.35	-0.41	-0.05	0.02	30.91
K17	1571.5	33.73	-0.51	-2.49	0.91	31.64
K18	1571	33.59	-0.28	-2.54	0.92	31.69
K19	1603	29.98	-0.20	0.47	-0.17	30.08
K20	1576	31.28	-0.74	-2.07	0.75	30.70
E1	1561	35.18	-3.04	-3.62	1.32	29.84
E2	1554	36.63	-2.33	-4.19	1.52	31.63
E3	1554	36.20	-2.31	-4.19	1.52	31.22
E4	1559	35.46	-1.84	-3.95	1.44	31.11
E5	1553	36.32	-1.88	-4.42	1.61	31.63
E6	1560	35.22	-1.84	-3.57	1.30	31.11
E7	1596	32.48	-1.78	-0.19	0.07	30.58
E8	1716	25.88	-0.93	11.10	-4.04	32.01

STA	ELEV.	OBSER.GRAV.	LAT.	FREEAIR.	BOUG.	GRAV.
E9	1711.5	28.79	-0.89	10.68	-3.89	34.69
E10	1708	26.90	-0.75	10.35	-3.77	32.73
E11	1690	26.98	-0.67	8.65	-3.15	31.81
E12	1689.5	25.57	-0.41	8.61	-3.13	30.64
E13	1635	28.85	-0.28	3.48	-1.27	30.78
E14	1633.5	28.31	-0.08	3.34	-1.22	30.35
E15	1623	28.05	0.20	2.35	-0.86	29.74
E16	1616.5	29.08	0.43	1.74	-0.63	30.62
E17	1625.5	25.84	0.75	2.59	-0.94	28.24
E18	1647	23.82	0.93	4.61	-1.68	27.68
E19	1609.5	30.30	0.65	1.08	-0.39	31.64
D1	1577	33.51	-2.80	-1.98	0.72	29.45
D2	1578	33.14	-2.99	-1.88	0.69	28.96
D3	1576	32.33	-3.34	-2.07	0.75	27.67
D4	1572	32.61	-3.70	-2.45	0.89	27.35
D5	1567	32.30	-4.13	-2.92	1.06	27.35
D6	1570	32.16	-4.62	-2.63	0.96	25.87
D7	1578	32.07	-4.74	-1.88	0.69	26.14
D8	1583	31.72	-5.21	-1.41	0.51	25.61

STA	ELEV.(ft)	OBSER.GRAV.	LAT	FREEAIR	BOUG.	GRAV.
D9	1601	30.64	-5.61	0.28	-0.10	25.21
D10	1589	30.23	-5.86	-0.85	0.31	23.83
D11	1593	30.28	-6.02	-0.47	0.17	23.96
D12	1604	30.01	-6.01	0.56	-0.21	24.35
D13	1597	30.86	-6.34	-0.09	0.03	24.46
D14	1607	29.02	-6.79	0.85	-0.31	22.77
D15	1614	28.49	-7.19	1.50	-0.55	22.25
D16	1617	28.32	-7.45	1.79	-0.65	22.01
D17	1565.5	30.70	-3.35	-3.06	1.11	25.40
D18	1562.5	34.31	-3.28	-3.34	1.22	28.91
D19	1567	33.88	-3.25	-2.95	1.06	28.77
N1	1598	36.24	-3.53	0.00	0.00	32.71
N2	1571	33.00	-3.95	-2.54	0.92	27.43
N3	1570	36.24	-3.55	-2.63	0.96	31.02
N4	1569	34.37	-3.70	-2.73	0.99	28.93
N5	1577.5	33.53	-3.87	-1.93	0.70	28.43
N6	1573	35.10	-3.71	-2.35	0.86	29.90
N7	1591	33.26	-3.85	-0.66	0.24	28.99
N8	1626.5	32.74	-3.65	2.68	-0.98	30.79

STA	ELEV(ft)	OBSER.GRAV.	LAT.	FREEAIR	BOUG.	GRAV.
N9	1586.5	33.85	-3.83	-1.08	0.39	29.33
N10	1580	34.57	-3.70	-1.69	0.62	29.80
N11	1582	35.88	-3.34	-1.50	0.55	31.59
N12	1568.5	37.19	-3.10	-2.77	1.01	32.33
N13	1598	34.96	-2.97	0.00	0.00	31.99
N14	1642.5	34.87	-3.20	4.19	-1.52	34.34
N15	15.83	35.41	-3.18	-1.41	0.51	31.33
N16	1554	37.01	-3.10	-4.14	1.51	31.28
N17	1573	35.10	-3.22	-2.35	0.86	30.39
N18	1548.5	36.95	-2.90	-4.66	1.70	31.09
N19	1558	35.75	-3.22	-3.76	1.37	30.14
N20	1564	35.99	-2.87	-3.20	1.16	31.08
N21	1602.5	34.39	-2.71	0.42	-0.15	31.95
N22	1568.5	33.45	-3.20	-2.77	1.01	28.49
N23	1568.5	33.63	-3.62	-2.77	1.01	28.25
N24	1566.5	34.91	-3.34	-2.96	1.08	29.69
N25	1586.5	34.95	-2.97	-1.08	0.39	31.29
N26	1607	33.69	-2.80	0.85	-0.31	31.43
N27	1591.5	34.29	-2.67	-0.61	0.22	31.23

STA	ELEV.(ft)	OBSER.GRAV.	LAT.	FREEAIR	BOUG.	GRAV.
N28	1597	34.20	-2.71	-0.09	0.03	31.43
N29	1563	33.34	-3.95	-3.29	1.20	27.34
P1	1578.5	32.76	-3.95	-1.83	0.67	27.65
P2	1596.5	31.28	-4.01	-0.14	0.05	27.18
P3	1634.5	28.89	-4.20	3.43	-1.25	26.87
P4	1676	25.59	-4.45	7.34	-2.67	25.81
P5	1667.5	25.55	-4.74	6.54	-2.38	24.97
P6	1670	25.55	-4.91	6.77	-2.47	24.94
P7	1643	28.63	-4.17	4.23	-1.54	27.15
P8	1682.5	25.99	-4.26	7.95	-2.89	26.79
P9	1707	24.88	-4.40	10.25	-3.73	27.00
P10	1631	32.44	-3.73	3.10	-1.13	30.68
P11	1622	32.83	-3.71	2.26	-0.82	30.56
P12	1597.5	36.11	-3.06	-0.05	0.02	33.02
Q1	1647.5	29.34	-1.87	4.66	-1.70	30.40
Q2	1660	28.26	-1.85	5.83	-2.12	30.12
Q3	1655	28.31	-1.85	5.36	-1.95	29.87
Q4	1602	31.59	-1.91	0.38	-0.14	29.92
Q5	1609	31.11	-1.87	1.03	-0.38	29.89

STA	ELEV.(FT)	OBSER.GRAV.	LAT.	FREEAIR	BOUG	GRAV.
Q5	1556.5	30.34	-1.73	-3.90	1.42	26.13
Q6	1556.5	30.34	-1.73	-3.90	1.42	26.13
Q7	1583.5	32.87	-1.98	-1.36	0.50	30.03
Q8	1630	30.20	-2.20	3.01	-1.10	29.91
Q9	1583.5	33.09	-2.15	-1.36	0.50	30.08
Q10	1636.5	28.89	-1.66	3.62	-1.32	29.53
Q11	1656.5	27.78	-1.41	5.50	-2.00	29.87
Q12	1663.5	27.20	-1.17	6.16	-2.24	29.95
Q13	1608	29.66	-0.76	0.94	-0.34	29.50
Q14	1604	29.99	-0.62	0.56	-0.21	29.72
Q15	1654.5	24.99	0.23	5.31	-1.94	28.59
Q16	1660	24.18	0.08	5.83	-2.12	27.95
Q17	1673	23.63	0.08	7.05	-2.57	28.19
S1	1517	26.75	4.60	-7.62	2.77	26.50
S2	1528	29.24	3.35	-6.58	2.40	28.41
S3	1560	25.57	3.61	-3.57	1.30	26.91
S4	1566	25.29	3.70	-3.01	1.10	27.08
S5	1567	26.34	3.64	-2.92	1.06	28.12
S6	1611	25.55	3.37	1.22	-0.45	29.69

STA	ELEV.(ft)	OBSER.GRAV.	LAT.	FREEAIR	BOUG	GRAV.
S7	1632	23.83	3.44	3.20	-1.16	29.31
S8	1649	24.22	3.35	4.80	-1.75	30.62
S9	1607	25.79	3.76	0.85	-0.31	30.09
S10	1560	26.67	3.80	-3.57	1.30	28.20
T1	1564	24.45	3.91	-3.20	1.16	26.32
T2	1642	20.24	4.05	4.14	-1.51	26.92
T3	1606	23.04	4.38	0.75	-0.27	27.90
T4	1596	20.99	4.54	-0.19	0.07	25.41
T5	1605	23.40	4.75	0.66	-0.24	28.57
T6	1610	22.24	5.09	1.13	-0.41	28.05
T7	1585	23.27	5.37	-1.22	0.45	27.87
T8	1624	20.13	5.51	2.45	-0.89	27.20
T9	1664	17.41	5.74	6.21	-2.26	27.10
T10	1657	1598	6.21	5.55	-2.02	25.72
T11	1540	28.39	---	-5.46	1.99	----
U1	1560	25.83	3.78	-3.57	1.30	27.34
U2	1548	26.46	3.93	-4.70	1.71	27.40
U3	1551	25.59	4.23	-4.42	1.61	27.01
U4	1547	25.43	4.42	-4.80	1.75	26.80

STA	ELEV.(ft)	OBSER.GRAV.	LAT.	FREEAIR.	BOUG	GRAV.
U5	1603	22.11	4.44	0.47	-0.17	26.85
U6	1636	18.68	4.52	3.57	-1.30	25.47
U7	1677	13.50	4.58	7.43	-2.71	22.80
U8	1649	13.71	5.09	4.80	-1.75	21.85
U9	1671	11.96	5.28	6.87	-2.50	21.61
U10	17.02	9.46	5.41	9.78	-3.56	21.09
U11	1721	8.41	5.24	11.57	-4.21	21.01
V1	1701	24.65	-1.23	9.69	-3.53	29.58
V2	1659	26.63	-1.23	5.74	-2.09	29.05
V3	1674	27.28	-1.56	7.15	-2.60	30.27
V4	1692	25.92	-1.29	8.84	-3.22	30.25
V5	1692	25.72	-1.26	8.84	-3.22	30.08
V6	1680	26.26	-0.92	7.71	-2.81	30.24
V7	1681	25.83	-0.57	7.81	-2.84	30.23
V8	1651	26.77	-0.25	4.99	-1.82	29.69
V9	1640	27.35	0.27	3.95	-1.44	30.13
V10	1670	24.66	0.57	6.77	-2.47	29.53
V11	1702	22.83	0.77	9.78	-3.56	29.82
V12	1762	19.52	1.48	15.43	-5.62	30.81

STA	ELEV.(ft)	OBSER.GRAV.	LAT.	FREEAIR.	BOUG	GRAV.
V13	1754	20.09	1.71	14.67	-5.34	31.13
V14	1752	19.81	1.88	14.49	-5.27	30.91
V15	1739	21.63	2.14	13.26	-4.83	32.20
V16	1749	20.59	2.45	14.20	-5.17	32.07
V17	1758	18.90	2.61	15.05	-5.48	31.08
V18	1769	17.77	2.90	16.08	-5.86	30.89
V19	1763	18.08	2.96	15.52	-5.65	30.91
V20	1756	18.06	2.87	14.86	-5.41	30.38
V21	1754	17.98	3.08	14.67	-5.34	30.39
V22	1765	17.19	3.09	15.71	-5.72	30.27
V23	1764	15.47	3.37	15.61	-5.69	28.76
V24	1754	15.46	3.49	14.67	-5.34	28.30
V25	1744	15.99	3.64	13.73	-5.00	28.36
V26	1745	14.29	4.00	13.83	-5.03	27.09
V27	1750	07.45	5.90	14.30	-5.21	22.44
V28	1707	8.15	6.63	10.25	-3.73	21.30
V30	1744	8.71	5.22	13.73	-5.00	22.66
V31	1733	10.60	4.76	12.70	-4.62	23.44
V32	1750	11.34	4.45	14.30	-5.21	24.88

STA	ELEV.(ft)	OBSER.GRAV.	LAT.	FREEAIR.	BOUG	GRAV
W1	1670.5	24.49	0.57	6.82	-2.48	29.40
W2	1672.5	24.13	0.59	7.01	-2.55	29.18
W3	1640.5	26.90	0.19	4.00	-1.46	29.63
W4	1641.5	26.71	0.09	4.09	-1.49	29.40
W5	1644	26.83	-0.21	4.33	-1.58	29.37
W6	1658	25.81	-0.39	5.64	-2.06	29.00
W7	1659	25.73	-0.43	5.74	-2.09	28.95
W8	1647.5	26.42	-0.14	4.66	-1.70	29.24
W9	1649.5	25.72	0.57	4.84	-1.76	29.37
W10	1649.5	25.42	0.83	4.84	-1.76	29.33
W11	1664	24.23	1.13	6.21	-2.26	29.31
W12	1657	24.48	1.14	5.55	-2.02	29.15
W13	1663	24.68	0.47	6.11	-2.23	29.03
W14	1646	25.98	0.29	4.51	-1.64	29.14
W15	1729.5	21.33	1.16	12.37	-4.50	30.36
W16	1687.5	27.84	-1.87	8.42	-3.07	31.32