A Geophysical Investigation of a Possible Astrobleme in Southwestern Michigan

Suhas L. Ghatge

Western Michigan University

Follow this and additional works at: https://scholarworks.wmich.edu/masters_theses

Part of the Geophysics and Seismology Commons

Recommended Citation


https://scholarworks.wmich.edu/masters_theses/1498

This Masters Thesis-Open Access is brought to you for free and open access by the Graduate College at ScholarWorks at WMU. It has been accepted for inclusion in Master's Theses by an authorized administrator of ScholarWorks at WMU. For more information, please contact maira.bundza@wmich.edu.
A GEOPHYSICAL INVESTIGATION OF A POSSIBLE ASTROBLEME IN SOUTHWESTERN MICHIGAN

by
Suhas L. Ghatge

A Thesis
Submitted to the
Faculty of The Graduate College
in Partial Fulfillment
of the requirements for the
Degree of Master of Science
Department of Geology

Western Michigan University
Kalamazoo, Michigan
April 1984
A GEOPHYSICAL INVESTIGATION OF A POSSIBLE ASTROBLEME IN SOUTHWESTERN MICHIGAN

Suhas L. Ghatge, M.S.
Western Michigan University, 1984

A circular pattern to the oil production in Calvin Township, Cass County, Michigan, absence of about 1200 feet of Ordovician sediments and uplift indicated by a deep drill hole in the center of the productive area and absence of anomalies on the regional gravity and magnetic maps led to detailed gravity and magnetic surveys over this structure to delineate it and provide information regarding its genesis.

The Bouguer gravity and magnetic anomaly maps show no anomaly associated with the structure. The 28-mile wavelength second harmonic residual gravity and magnetic maps show linear features in the area. Two dimensional gravity modeling of the NNW-SSE trending linear feature over the area of circular production is interpreted as upthrusting involving the basement rocks. The NNW-SSE trending Jefferson field appears to be truncated by NE-SW trending faults.

The lack of a circular gravity anomaly and the lack of direct geologic evidence in support of the impact origin leaves the question of genesis open.
ACKNOWLEDGEMENTS

This project would not have been possible without the funds from the Western Michigan University Graduate College Research Grants and the support of Dr. William Sauck who organized and developed many of the ideas in this investigation. I would like to thank him for his help. I would also like to thank Dr. Straw, Dr. Grace and Dr. Harrison for ideas, recommendations and information. I am also thankful to Mr. Florencio Mata of Hosking Geophysical for suggesting this problem and Mr. Ron DeHaas of Michigan Petroleum Geologists Inc. and Mr. Robert Mannes of Mannes Oil Corp. for providing some geologic and geophysical information. Special thanks are extended to Mr. Douglas Daniels of the Michigan Department of Natural Resources for providing time for discussions and for making available geological information on the area. Thanks are also extended to the Department of Geology, Albion College, for providing their Magnetometer and to the Computer Center at Western Michigan University for the computer time.

Last, but not the least, I would like to express my deepest appreciation and thanks to my wife Gauri who helped me in my data collection and during the process of writing this report. Her care and patience were important and vital during all aspects of the survey.

Suhas L. Ghatge
INFORMATION TO USERS

This reproduction was made from a copy of a document sent to us for microfilming. While the most advanced technology has been used to photograph and reproduce this document, the quality of the reproduction is heavily dependent upon the quality of the material submitted.

The following explanation of techniques is provided to help clarify markings or notations which may appear on this reproduction.

1. The sign or “target” for pages apparently lacking from the document photographed is “Missing Page(s)”. If it was possible to obtain the missing page(s) or section, they are spliced into the film along with adjacent pages. This may have necessitated cutting through an image and duplicating adjacent pages to assure complete continuity.

2. When an image on the film is obliterated with a round black mark, it is an indication of either blurred copy because of movement during exposure, duplicate copy, or copyrighted materials that should not have been filmed. For blurred pages, a good image of the page can be found in the adjacent frame. If copyrighted materials were deleted, a target note will appear listing the pages in the adjacent frame.

3. When a map, drawing or chart, etc., is part of the material being photographed, a definite method of “sectioning” the material has been followed. It is customary to begin filming at the upper left hand corner of a large sheet and to continue from left to right in equal sections with small overlaps. If necessary, sectioning is continued again—beginning below the first row and continuing on until complete.

4. For illustrations that cannot be satisfactorily reproduced by xerographic means, photographic prints can be purchased at additional cost and inserted into your xerographic copy. These prints are available upon request from the Dissertations Customer Services Department.

5. Some pages in any document may have indistinct print. In all cases the best available copy has been filmed.
GHATGE, SUHAS LAXMAN

A GEOPHYSICAL INVESTIGATION OF A POSSIBLE ASTROBLEME IN SOUTHWESTERN MICHIGAN

WESTERN MICHIGAN UNIVERSITY M.S. 1984

University Microfilms International 300 N. Zeeb Road, Ann Arbor, MI 48106
PLEASE NOTE:

In all cases this material has been filmed in the best possible way from the available copy. Problems encountered with this document have been identified here with a check mark ✓.

1. Glossy photographs or pages
2. Colored illustrations, paper or print
3. Photographs with dark background
4. Illustrations are poor copy
5. Pages with black marks, not original copy
6. Print shows through as there is text on both sides of page
7. Indistinct, broken or small print on several pages ✓
8. Print exceeds margin requirements ✓
9. Tightly bound copy with print lost in spine
10. Computer printout pages with indistinct print ✓
11. Page(s) ___________ lacking when material received, and not available from school or author.
12. Page(s) ___________ seem to be missing in numbering only as text follows.
13. Two pages numbered ___________. Text follows.
14. Curling and wrinkled pages
15. Other

University Microfilms International

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
TABLE OF CONTENTS

ACKNOWLEDGEMENTS ................................................................. ii
LIST OF FIGURES ................................................................. v
LIST OF PLATES ................................................................. vi

Chapter

I. INTRODUCTION ................................................................. 1
   Objective ........................................................................... 1
   Location ........................................................................... 7
   Physiography .................................................................... 7
   Approach .......................................................................... 7

II. GEOLOGY ................................................................. 9
   Regional Geology ........................................................... 9
   Local Geology ............................................................... 15

III. GRAVITY AND MAGNETIC SURVEYS OVER ASTROBLEMES . . 17

IV. FIELD METHODS ............................................................. 27
   Gravity Survey ............................................................... 27
   Magnetic Survey .......................................................... 28

V. DATA REDUCTION AND PLOTTING ..................................... 30
   Gravity Data Reduction .................................................. 30
   Magnetic Data Reduction .............................................. 31
   Data Plotting ............................................................... 32
LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Location Map of the Survey Area</td>
<td>2</td>
</tr>
<tr>
<td>2. Oil Field Location Map of Calvin Township, Cass County, Michigan</td>
<td>3</td>
</tr>
<tr>
<td>4. Total Magnetic Intensity Map of the Southern Peninsula of Michigan</td>
<td>6</td>
</tr>
<tr>
<td>5. Structure in the Vicinity of the Michigan Basin</td>
<td>10</td>
</tr>
<tr>
<td>6. Stratigraphic Succession in Michigan</td>
<td>11</td>
</tr>
<tr>
<td>7. Basement Surface Configuration Map of the Southern Peninsula of Michigan</td>
<td>13</td>
</tr>
<tr>
<td>8. Interpreted Regional Basement Lithology, Southern Peninsula of Michigan</td>
<td>14</td>
</tr>
<tr>
<td>9. A. Bouguer Anomaly Map, Gosses Bluff, Australia</td>
<td>18</td>
</tr>
<tr>
<td>B. Residual Anomaly Map, Gosses Bluff, Australia</td>
<td>18</td>
</tr>
<tr>
<td>10. A. Total Magnetic Intensity Anomalies, Ries, Germany</td>
<td>20</td>
</tr>
<tr>
<td>B. Residual Gravity Field, Ries, Germany</td>
<td>20</td>
</tr>
<tr>
<td>11. Bouguer Anomaly Map, Flynn Creek Crater, Tennessee</td>
<td>24</td>
</tr>
<tr>
<td>12. Total Intensity Magnetic Anomaly Map, Flynn Creek Crater, Tennessee</td>
<td>25</td>
</tr>
<tr>
<td>13. Borehole Section Across the Structure in Calvin Twp.</td>
<td>41</td>
</tr>
<tr>
<td>14. Residual Gravity Profile A-A' and 2-D Gravity Upthrust Model Profile</td>
<td>43</td>
</tr>
</tbody>
</table>
LIST OF PLATES

Plate

I. Bouguer Gravity Anomaly Map, South-central Cass County, Michigan

II. Total Magnetic Intensity Anomaly Map of South-central Cass Co., Michigan

III. First Harmonic Residual Gravity Map, Wavelength = 16 Miles; South-central Cass Co., Michigan

IV. First Harmonic Residual Gravity Map, Wavelength = 28 Miles; South-central Cass Co., Michigan

V. Second Harmonic Residual Gravity Map, Wavelength = 28 Miles; South-central Cass Co., Michigan


VII. First Harmonic Residual Gravity Map, Wavelength = 42 Miles; South-central Cass Co., Michigan

VIII. Residual Magnetic Map; South-central Cass Co., Michigan
CHAPTER I

INTRODUCTION

Objective

The discovery of oil in the Traverse limestone of Middle Devonian age in the Calvin Township, Cass County of Michigan (Fig. 1), led to the development of the Calvin-28 oil field located in sections 27, 28, 29, 32, 33 and 34, T14W, R7S of Cass County, Michigan. The production was found to be in a circular pattern with a diameter 1.5 miles which led to the drilling of deep holes in the center and on the edge of the circular producing area (Fig. 2). In the deep hole at the center of the production (Hawkes-Adams 1-28) there is an indication from the well logs of the absence of about 1200 feet of Ordovician sediments as a result of uplift and erosion during Late Ordovician time. Lawson 1-28, the deep hole on the edge of the production, is 0.75 miles northeast of the Hawkes-Adams 1-28. The Lawson 1-28 cut at least two thrust faults that duplicate portions of the Trenton and Black River Formations. The Utica Shale was not encountered and the dips are very disoriented below the faults as indicated by dipmeter log. The Hawkes-Adams 1-28 deep test did not encounter the sequence from the Upper Munising Formation to the Utica Shale (DeHaas, personal communication, 1983). DeHaas suggested that the Eau Claire was uplifted over 1400 feet probably due to a large thrust fault. He described the structure as
Figure 1. Location map of the survey area.
Figure 2. Oil Field location map of Calvin twp., Cass Co., Michigan. (from Oil & Gas News.)
being similar to cryptoexplosive structures in midcontinental United States. The Kentland structure in Indiana (Gutschick, 1971), the Versailles structure (Black, 1964), Jeptha Knob (Seeger, 1966) in Kentucky, the Glasford structure in Illinois (Buschbach and Ryan, 1963) and the Serpent Mound structure in Ohio (Bucher, 1963) are some midcontinent features that have been referred to as cryptoexplosive structures. The Lawson 1-28 has an Ordovician section which according to DeHaas (personal communication, 1983) is similar to that exposed at the Kentland structure in Indiana and the Glasford structure, Illinois, which have been considered to be possible astroblemes.

Seismic surveys have been conducted in Cass County, but the confidential nature of these investigations has resulted in a paucity of published information on the applicability of seismic methods to delineate the location and structure of the production. Florencio Mata (personal communication, 1982) described the structure responsible for the production as being probably due to the presence of a possible astrobleme of Upper Ordovician age which could account for the absence of about 1200 feet of Lower Ordovician sediments and the central uplift of the subsequent sediments. Seismic sections across the area were described by him as being similar to those across structures in the Williston Basin that have been considered to be astroblemes (Sawatzky, 1975).

The above information and the absence of anomalies in the area on the Regional Bouguer Gravity Anomaly and Total Magnetic Intensity Anomaly Maps of the Southern Peninsula of Michigan (Figures 3 and 4) prepared by Hinze and Merritt (1969) and Hinze et al., (1971) gave the
Figure 3. Bouguer Gravity Anomaly Map of the Southern Peninsula of Michigan (from Hinze et al., 1971).
Figure 4. Total Magnetic Intensity Map of the Southern Peninsula of Michigan (from Hinze et al., 1971).
necessary impetus for conducting detailed gravity and magnetic investigations in the area.

Location

The area under investigation includes portions of the Penn, Calvin, Porter, Jefferson, Mason and Ontwa Townships in Cass County of southwestern Michigan (Fig. 1). The study area is about 12 miles by 14 miles, and lies between latitude 41° 45'N and 41° 56'N and longitude 85° 49'W and 86° 6'W. It is covered by portions of the Vandalia and Cassopolis quadrangles, 15-minute series, Michigan-Indiana (USGS Maps).

Physiography

The area has numerous lakes and swamps with relief mainly due to the uneven disposition of the glacial material forming a rolling surface, smooth rounded slopes, knobs and ridges of sand and gravel. This is characteristic of topography in glaciated areas. The elevation ranges from 700 feet to 1100 feet. The northwestern part of the area is relatively flat and under agricultural cultivation.

Approach

The gravity observations in the field were carried out using the Worden Prospector gravimeter and the field data was corrected with latitude and elevation factors to determine the Bouguer gravity anomalies. Sea-level was assumed as the datum, the density used as 2.67 gm/cc and the formula used as the International Gravity Formula.
of 1930. The Bouguer gravity anomalies were analyzed using Double Fourier Series to remove the regional and obtain residual gravity values. The Bouguer gravity values from 178 stations were analyzed for residual values.

Magnetic field observations were taken at 159 stations using two Geometrics Proton Precession Magnetometers (Model G816). One magnetometer was used as the mobile field unit while the other was used as the stationary base station unit to correct the field data for the diurnal variations to obtain total magnetic field intensities. Pipelines, well casings, fences and other ferromagnetics were avoided as much as possible.
CHAPTER II

GEOLOGY

Regional Geology

The Michigan Basin is located in the midwestern portion of the large North American craton. The structural basin is surrounded by major geologic features which define the basin framework (Cohee and Landes, 1958). The Precambrian rocks of the Lake Superior Syncline form the northern boundary of the basin. The Wisconsin Arch forms the western boundary, the Kankakee Arch in Indiana and the Findlay Arch in northwestern Ohio form the southern boundary and the Algonquin Axis, probably fault controlled (Fisher, 1969), forms the Eastern boundary of the basin (Fig. 5).

The sedimentary rocks of the basin dip in a northeasterly direction toward the center of the structural basin at a rate of 25 to 60 feet per mile (Ells, 1969). The Paleozoic rocks in southwestern Michigan (Fig. 6) comprise of a thick sequence which includes Cambrian sandstone sequence, a carbonate, sand and evaporite sequence of Lower Ordovician to Middle Devonian age, an Upper Devonian-Mississippian sequence of sandstone, carbonate, anhydrite and shale.

The dominant trend in major folds and faults in the Michigan Basin is NW-SE (Newcombe, 1933; Pirtle, 1932). This NW-SE trend direction was confirmed by the regional gravity and magnetic data of Hinze and
Figure 5.--Structure in the Vicinity of the Michigan Basin. (from Ells, 1969)

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
## Stratigraphic Succession in Michigan

<table>
<thead>
<tr>
<th>Era</th>
<th>System</th>
<th>Series</th>
<th>Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Paleozoic</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ordovician</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silurian</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Devonian</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carboniferous</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permian</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mesozoic</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Triassic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jurassic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cretaceous</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cenozoic</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paleogene</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neogene</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quaternary</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Suggested Reading:

- [Stratigraphic Succession in Michigan](#) (Figure 6)

---

**Figure 6. Stratigraphic succession in Michigan.**

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Based on the 19 poorly distributed basement drill holes and depths interpreted from a total magnetic intensity map, Hinze and Merritt (1969) depicted the basement surface configuration (Fig. 7). The Precambrian basement surface was depicted by Hinze and Merritt (1969) as a uniform and oval depression, with a maximum depth of 15,000 feet below sea level near the center of Bay County. Figure 8 depicts the interpreted regional basement lithology in the southern peninsula of Michigan (Kellogg, 1971). The few existing drillholes penetrated granite, granite gneiss, granite regolith, mafic gneiss and some metasediments. The mid-Michigan anomaly on the gravity anomaly map (Fig. 3) prepared by Hinze et al. (1971) is probably due to mafic rocks. The anomaly has also been interpreted as having its source in a Keweenawan paleorift zone expressed locally as a basalt trough, and generally as a disturbance of the deep crustal layers by intrusion and upwarp (Hinze & Merritt, 1969). Hinze et al. (1971) suggested that the broad negative gravity anomaly associated with the basin reflects the lower density of the sedimentary rocks in comparison to the underlying basement rocks and that the gravity anomalies derived from bedrock topography and sedimentary structures such as reefs and fracture zones have short wavelengths and positive and negative amplitudes of less than 1 milligal and commonly less than 0.5 milligals.

The magnetic anomalies are primarily the effect of gross basin configuration, basement topography and intrabasement lithologic variations (Hinze et al., 1971).
Figure 7. Basement surface configuration map of the Southern Peninsula of Michigan (from Hinze & Merritt, 1969).
Figure 8. --Basement Province Map of the Southern Peninsula of Michigan. (from Kellogg, 1971)
Local Geology

The area under investigation is a portion of the southwestern flank of the Michigan basin. The Paleozoic sequence overlying the Precambrian basement consists of the Mt. Simon Sandstone, the Eau Claire, the Dresbach, the Franconian and Trempealeau Formations of Cambrian age; the Prairie du Chien Group, St. Peter Sandstone, Black River Group, Trenton Group and Cincinnatian Series of Ordovician age; the Cataract Group and Clinton Formation, Niagaran Series, Salina Series and Bass Island Groups of Silurian age; Sylvania Sandstone, Detroit River Group, Dundee Limestone, Traverse Limestone and Traverse Formation of Devonian age and the bedrock subcrooming under the glacial drift is the Antrim Shale or the Ellsworth Shale of early Mississippian age (Fig. 6). The regional dips in the area range from 19 feet per mile for the Traverse Formation to 48 feet per mile for the Niagaran Series in a 14.5 mile long section from section 35 of Jefferson Township to section 26 of Volinia Township of Cass County, Michigan (Doug Daniels, personal communication, 1983). The Utica Shale, Trenton, Black River, Prairie du Chien, Upper Trempealeau and Upper Munising formations were not encoun­tered in the Hawkes-Adams 1-28 in section 28 of the Calvin Township. Rocks of the Cincinnatian Series directly overlay the Cambrian Trempealeau Formation. The entire sequence appears to have been uplifted. The Lawson 1-28 in section 28 of the Calvin Township encountered two thrust faults and the Black River Formation has been duplicated due to this faulting. The Utica Shale is missing. The dips below the faults, indicated by dipmeter log, are highly irregular ranging from 10 to 70 degrees towards the east and northeast with
fracturing and fragmentation (DeHaas, personal communication, 1983). The Gordon Smith 1-20 deep well in section 20, Calvin Township, encountered an unusually thick Glenwood-St. Peter Sandstone sequence and the Trempealeau-Praire du Chien sequence appears to be missing (DeHaas, personal communication, 1983). The Jefferson field which is to the west of the Calvin Field in Jefferson Township has a NNW-SSE trend to the production which is probably fault controlled. Newcombe (1933) and Hinze and Merritt (1969) have noted this trend direction in the Michigan Basin. Other deep wells in the area show a normal sequence of Paleozoic sediments in the area with dips toward the Basin depocenter in Midland County.

The Precambrian basement in the area is probably granite gneiss and metasediments (Fig. 8) as determined from deep holes and magnetic and gravity maps (Kellogg, 1971). Depth determinations carried out by Kellogg (1971) on the basis of magnetic data show that the average depth to basement in Cass County ranges from 3495 feet to 3740 feet below mean sea-level. He determined the depths from the straight slope methods and Peters' half slope method. The nearest basement drill-hole is in section 10, Berrien County, and it encountered the Precambrian metasediments at a depth of 3800 feet below sea-level. The basement configuration map (Fig. 7) shows the generalized depth of the basement for the region.
CHAPTER III

GRAVITY AND MAGNETIC SURVEYS OVER ASTROBLEMES

The term astrobleme, from the Greek roots meaning 'star wound', refers to ancient scars left in the earth's crust by meteorites (Dietz, 1968). McCall (1977, 1979), French and Short (1968), Silver and Schultz (1982) and Middlehurst and Kuiper (1963) have edited and commented on various publications concerning possible Astroblemes or cryptoexplosion structures in the world. McCall (1977, 1979) has classified cryptoexplosive structures-astroblemes on the basis of evidence or proof of their genesis. McCall (1979) has cited unique indicators of impact explosions: shatter cones, the high pressure polymorphs of silica, coesite and stishovite, shock lamellations, diaplectic glasses, impactites and impact melts and breccias.

A number of these astroblemes have been geophysically investigated. The results of the gravity and magnetic studies of some of these cryptoexplosion structures-astroblemes are described below. These structures are of class IV A of McCall (1979) where these structures are either deeply eroded or buried or complex and do not display an immediately apparent physiographic form of meteorite craters. All are possible meteorite impact-explosion structures and display some form of shock metamorphism or brecciation.

The Bouguer gravity map of the Gosses Bluff impact structure (Fig. 9A) in Australia shows low values. The residual gravity map (Fig. 9B) indicates a residual gravity low, circular and centered on
Figure 9. a) Bouguer Anomaly map, Gosses Bluff, Australia.
   b) Residual Anomaly map, Gosses Bluff, Australia.
   (from Milton et al., 1972)
the Bluff. The first regional aeromagnetic survey showed no anomaly for Gosses Bluff. A later survey, however, showed a local anomaly of -75 gammas and a detailed ground magnetic survey at the base of the south wall of the Bluff reveal two anomalies (Milton et al., 1972).

The Bouguer anomaly map around Lake Lappajarvi Basin in Finland indicates a negative anomaly of 5 to 10 milligals over the basin which is 10 to 17 miles diameter. The presence of shock-induced deformations, transformations and fusion indicate that this feature is due to meteoric impact sometime between Precambrian and Pleistocene times (Engelhardt, 1972), probably late Cretaceous age according to Grieve (1982).

The Ries structure, southern Germany, has a diameter of 24 kilometers and with a centrosymmetrical residual negative gravity anomaly that is thought to be due to filling of the crater by breccias and Mesozoic sediments (Fig. 10A). The total intensity of geomagnetic field near Ries shows moderate negative anomalies due to the presence of suevite in the sediments (Fig. 10B). The Ries structure has been dated as upper Tortonian age (late Miocene) (Dennis, 1971).

The Steinheim Basin, Germany, has a diameter of 2.2 miles and slight negative gravity anomaly that is due to the presence of sediments, breccias and brecciated bedrock in the center part of the feature. The magnetic field shows a small positive anomaly 2 miles south-southeast of the center. This structure has a central uplift. The topography, central uplift with shatter cones and breccias indicate an impact origin at about the same age as the Ries structure, that is, late Miocene (Engelhardt, 1972).
Figure 10. a) Residual Gravity Field, Ries, Germany
b) Total Magnetic Intensity Anomalies, Ries, Germany
(from Dennis, 1971).
The Popigay meteorite crater, U.S.S.R., shows negative gravitational and magnetic anomalies caused by the lower density of shattered and re-fused rocks and their weak magnetization. The feature has a central uplift, explosion breccia, suevite, and shatter cones which indicate an impact origin during the Neogene (Miocene) age (Masaytis et al., 1971).

The negative gravity anomaly field in the Deep Bay Crater of Saskatchewan, Canada, with a diameter of 8.5 miles shows deformation of the rocks underlying waters of Deep Bay in the form of intense fracturing and fragmentation (Innes, 1964; Innes et al., 1964). The negative anomaly forms a circular pattern concentric with the feature with amplitude of gravity variation of about 20 milligals near the center of the bay. The Aeromagnetic map of the Geological Survey of Canada shows small and uniform variation in intensity over the central portion of the crater not exceeding 190 gammas with uniform gradients no larger than 50 gammas as compared to the surroundings (Beals et al., 1963). The date of formation of the crater is indicated at 100 ± 50 M years (Grieve, 1982).

Magnetic field anomalies of low intensity in the 18-mile diameter Carswell structure in Canada are characteristic of impact craters due to blanketing effect of brecciated and highly shocked material underlying the crater floors. The greatest magnetic disturbance is interpreted as an indication of central uplift. The gravity map shows a negative gravity anomaly and is described as due to a dolomite ring. The higher gravity anomalies in the center are due to the central uplift of the uneroded impact breccia (Innes, 1964).
The Lake Wanapitei structure, Canada, probably formed in late Paleozoic or Mesozoic time and is described as showing a relatively uniform featureless magnetic field. The Bouguer gravity anomaly map indicates a local, circular gravity depression of about 15 milligals (Dence & Popolar, 1972). Grieve (1982) gave the age of the crater at $37 \pm 2$ M years.

The gravity interpretation in the Sudbury area, Canada, has failed to produce evidence in support of the meteorite impact hypothesis for the origin of the Sudbury structure because the features associated with this structure are not well preserved and it cannot be properly studied. The residual gravity map shows a nearly circular anomaly over the Sudbury structure and the regional magnetic map shows an oval positive anomaly (Popolar, 1972).

Gravity observations of the Brent Crater, Canada (Beals et al., 1963; Millman et al., 1960), and Holleford Crater of Precambrian age in Canada (Beals, 1960; Beals et al., 1963) indicate the presence of circular negative gravity anomalies associated with both these craters. These anomalies have been interpreted as being due to sediments filling the craters and the presence of crushed and fragmented rock due to meteorite impact and explosion (Innes, 1961). The aeromagnetic survey over Brent Crater shows marked contrast between intensities observed within and outside the rim of the crater. An aeromagnetic survey over the Holleford crater shows uniform variation of contours indicating absence of an anomaly (Beals et al., 1963).

A gravity survey over the Nicholson Lake area of Canada shows a disturbance of the gravity field at Nicholson Lake. Removal of the
regional' gave an approximately circular negative residual anomaly with a central low of 7.5 milligals (Dence et al., 1968).

Gravity surveys over the Clearwater Lakes (Dence et al., 1965) and West Hawk Lake crater (Dence et al., 1968) in Canada indicate negative anomalies of the kind expected for craters underlain by large volumes of breccia and shattered rock.

No closed gravity anomalies (Fig. 11) and no large magnetic anomalies (Fig. 12) are associated with the Flynn Creek Crater, Tennessee. It was probably formed during the Devonian period and has a diameter of 2.2 miles with a large central hill, highly deformed rim strata and a breccia lens within the crater (Roddy, 1968).

The Wells Creek structure, Tennessee, was formed in Late Mississipian or Early Pennsylvanian age. It has been described as showing regional gravity lows trending down both the east and the west sides of the structure and regional gravity highs bound the structure to the north and the south with a small central gravity high that is due to a central uplift of more than 2500 feet (Stearns et al., 1968).

The Versailles structure in Kentucky has a diameter of about 1 mile and gravity and magnetic surveys of it show no anomalies. Apparently there are no anomalous densities or magnetizations associated with this structure indicating that basement rocks are not involved in the deformation (Seeger, 1972).

The gravity survey over the Kentland structure, Indiana, shows an encircling outer positive anomaly interpreted as a ring anticline with an inner negative anomaly due to a ring syncline and a central positive
Figure 11. Bouguer Anomaly Map, Flynn Creek Crater, Tennessee (from Roddy, 1968).

Contour interval: 1 milligal.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
Contour interval: 25 gammas.

Figure 12. Total Intensity Magnetic Anomaly Map, Flynn Creek Crater, Tennessee. (from Roddy, 1968)
anomaly over the central uplift, this is used to interpret basement uplift of 2000 to 3000 feet and hence involvement of the basement rocks in the structure. Because there is no significant magnetic anomaly directly associated with the structure, it is interpreted as a basement uplift rather than an igneous intrusion (Tudor, 1971). Shock metamorphic structures and shatter cones have been observed at Kentland (Gutschick, 1971).
CHAPTER IV

FIELD METHODS

The Gravity Survey

The Worden Prospector gravimeter capable of being read to the nearest .01 milligal (1 milligal = 0.001 cm/sec²) was used in this study. The gravimeter is capable of measuring variations as minute as one unit in 100,000,000 of the earth's total gravity field.

Survey Procedure

Gravity readings were taken along all available roads at approximately 1-mile intervals. Coverage was extended at the center of the area of interest by using gravity readings at 1/4-mile intervals. Accuracy of the gravimeter readings was maintained by taking repeated observations at each station until duplication was obtained within 0.2 scale divisions. The calibration constant of the Worden gravimeter of 0.09706 milligal/division was used throughout the survey. Survey stations were established at selected benchmarks, spot elevations at road intersections or section boundaries. Station elevations were taken from USGS topographic maps (Cassopolis and Vandalia Quadrangles) and the local station elevations were interpolated from the topographic maps having 10-foot contour intervals. Interpolation error is estimated to be ±1 foot relative to the contour lines. However, USGS map
specifications normally suggest that at least 90% of the elevations interpolated from the contour lines shall be correct within one-half the contour interval. The primary base station established by the Michigan State University is 4 miles due west of Cassapolis on the Pokagon Highway at the intersection with Old Mills Road on the northern edge of the road. The observed gravity at this station is 980284.18 milligals and the elevation is 920 feet.

Magnetic Survey

Instrumentation

Two Geometrics Proton Precession Magnetometers (Model G816) were used in this survey. The instrument is accurate within ±1 gamma over a range of 20,000 to 90,000 gammas and measures the total intensity of the earth's magnetic field. One was used as a field or mobile magnetometer and the other the base magnetometer. Usage was kept the same throughout the survey.

Survey Procedure

The general location of most magnetic stations coincide with the gravity stations. The magnetic stations were located so as to be free from magnetic effects of steel fences, pipelines, iron and steel structures, etc. Whenever a site free from extraneous magnetic fields was unavailable near a gravity station, another station was located. At each station three readings were taken at a separation of 5 feet with the third reading taken at a right angle offset or L pattern.
This method was used to aid in the evaluation of magnetic effects of surface formations and to check for any surface disturbances. If three readings did not check within 20 gammas, more readings were taken at 5-foot intervals until the desired consistency was obtained. In cases where the inconsistency persisted, the station was abandoned.
CHAPTER V

DATA REDUCTION AND PLOTTING

Gravity Data Reduction

Data reduction was performed using a gravity reduction program to calculate the Bouguer gravity anomalies. Secondary base stations were established on Calvin Center Road at various road intersections by loops tying them with the primary base station. The gravimeter readings at each station were converted to observed gravity by first correcting for instrumental drift from base station readings repeated every 2 hours. Then the difference between base station and field station were multiplied by the meter constant (0.09706) and added to the base station observed gravity to obtain the station observed gravity.

For latitude corrections, the station coordinates were taken from the topographic sheets. The margin of error in latitude was ± 0.025 min. The theoretical gravity at sea-level at each station was determined from the International Gravity Formula of 1930 which is \( G = 978049 \left(1 + 0.0052884 \sin^2 \phi - 0.0000059 \sin^2 (2\phi)\right) \) gals where \( G \) is the sea-level gravity at latitude \( \phi \). The free-air correction compensates for the normal vertical gradient of gravity by applying a correction factor to the difference in elevation between the station and a reference datum, in this case the sea-level. The mass correction accounts for the gravity acceleration due to a mass of material between

30
sea-level and station elevation. The effect of the elevation of the station above sea-level is determined by calculating the free-air and Bouguer reductions. The free-air effect is 0.09406 milligals/foot. The Bouguer correction factor is 0.01277*Sigma milligals/foot where Sigma is the mean density of the included rock mass. The Bouguer correction is applied in the opposite sense to free-air, that is, it is subtracted when the station is above the datum plane and vice versa (Dobrin, 1976; Telford et al., 1976). A density of 2.67 gm/cc was used in these corrections.

The terrain correction accounts for the deviation of topography from a horizontal surface. Terrain corrections were not calculated for this survey due to the gentle topography.

The Bouguer gravity anomaly was calculated using the corrections given above. The equation (Dobrin, 1976) used in the calculations is:
Bouguer gravity anomaly = observed gravity - theoretical sea-level gravity + free-air correction - Bouguer correction.

Magnetic Data Reduction

The magnetic data were corrected to take into account the daily variations of the earth's magnetic field. These variations or drift in magnetic field called diurnal variations were obtained by taking repeated readings at the base station at 3-minute intervals. The base station was located at the public access site on the western bank of Paradise Lake in section 3 of Calvin Township of Cass County, Michigan. The station readings were corrected to an arbitrary base field of 58,000 gammas. This was done by subtracting the total field at the base
station from the base field (58,000 gammas) and the result was added to
the total field of the station.

Data Plotting

The Bouguer gravity anomalies and the total magnetic field data
were plotted on the California Computer Products (CALCOMP) 906 Drum
Plotter, using the Fortran Computer Program MAPNUM.FOR written by Dr.
William Sauck, Department of Geology, Western Michigan University. The
plot shows the station location and gravity or magnetic value at that
station. The data were then manually contoured and the Bouguer Anomaly
Map (Plate I) and the Total Magnetic Intensity Map (Plate II) of
south-central Cass County was produced.
CHAPTER VI

INTERPRETATION

Data Analysis

Gravity Data

The Bouguer gravity anomalies were analyzed using the Double Fourier Series Analysis Fortran Program (James, 1966). This program computed the residual values for the gravity data by subtracting the computed values from the observed Bouguer anomalies. The computed gravity values were computed using Double Fourier series of the first harmonic with wavelengths of 16, 28 and 42 miles. These values were used as they are equal or larger than the dimensions of the control area. Otherwise there is a repetition of trends outside the control area. James (1966) suggested that if there was some periodicity on data the wavelength may be estimated and multiplied by successive integers and the program run using a variety of fundamental wavelengths choosing from them on the basis of the reduction in sum of squares due to removal of the trend. Residuals were also calculated with wavelength of 28 miles for the second harmonic. The second harmonic surface with 28 miles fundamental wavelength was the best trend surface fit (98.5%). The first harmonic surface with wavelength of 16 miles gave a trend surface fit of about 88% to the observed Bouguer surface. The first harmonic surfaces with wavelengths of 28 and 42 miles gave fits of 95.8% and 96.7%, respectively,
to the observed Bouguer surface. The second harmonic gravity trend surface with 28-mile wavelength (Plate VI) has the best fit to the Bouguer surface and hence probably best describes the regional for the area under investigation. The residual values were then plotted and contoured as mentioned earlier to give residual gravity maps with different wavelengths and harmonics (Plates III to VII).

Magnetic Data

The total magnetic intensity data were analyzed using the Double Fourier Series Analysis program like the gravity data using the second harmonics with fundamental wavelength of 28 miles. The residual values obtained were plotted using the CALCOMP plotter and hand contoured to produce the residual magnetic map (Plate VIII).

Map Interpretation

A representation of geologic conditions may be provided by gravity and magnetic anomaly maps. These maps illustrate the difference between observed and theoretical values of a force field caused by horizontal or lateral variations in physical properties of the underlying rock formations. The physical property is density in the case of the gravity maps, and magnetic susceptibility and remanent magnetism in the case of the magnetic maps. The sum of all departures from the horizontally homogeneous earth conditions gives the anomaly values. Hinze et al. (1971) suggested that short wavelengths and low amplitude anomalies in the Michigan Basin are caused by the density contrasts within the glacial drift and long wavelength anomalies of variable amplitude are
produced by regional facies changes within the sediments, deep crustal or upper mantle density contrasts, and variable thickness of crustal layers. Bedrock topography and sedimentary structures have short wavelength and positive or negative amplitude gravity anomalies typically less than 1 milligal. Relief of the basement surface produces gravity anomalies of varying wavelength and amplitude. Intra-basement lithologic variations produce the largest amplitude anomalies (Hinze et al., 1971).

Magnetic anomalies produced by basement lithology are more pronounced than in the case of gravity. Hinze et al. (1971) suggested that the magnetic effect of basement topography is an order of magnitude less than the effect of basement lithology. According to these authors the major gravity and magnetic anomalies within the Michigan Basin are produced by variations in the intrabasement lithologies.

The Bouguer gravity anomaly map for south-central Cass County (Plate I) shows mainly the gravity due to a regional source which has long wavelength. This map, contoured at 1 milligal intervals, does not show any local anomaly closures, probably because of the strong regional feature which dominates. The contours in this map are similar to the contours for the area on the Regional Bouguer Gravity Anomaly Map of the Southern Peninsula of Michigan (Fig. 3). The absence of closures on this map could possibly indicate the lack of involvement of the basement in the structure under investigation. However, the lower density of the Mt. Simon Sandstone may be opposing some of the basement effects. Because of the presence of a strong regional anomaly, various attempts were made to remove it so that local residual anomalies could be studied. Residual values are the component of gravity having a local source and shorter
wavelength (Dobrin, 1976). The first harmonic residual gravity map with wavelength of 16 miles (Plate III) and 88% fit shows a circular to subcircular negative anomaly surrounding a central positive. The central positive is located around section 31 of Calvin Township and has a magnitude of 2.2 milligals. An annular gravity low surrounds this high and positive residuals occur to the north and the east. This is similar to anomalies expected over astroblemes but the regional from which the residual was obtained is a poor fit to the data. Hence, this circular feature is an artifact of the processing, a result of trying to force-fit a small wavelength to the regional. The eastern positive anomaly is also present on the other residual maps and coincides with a positive magnetic anomaly. Some of the higher negative or positive values along the edges may be due to edge effects.

The first harmonic residual gravity anomaly maps (Plates IV & VII) with wavelengths of 28 and 42 miles appear to be similar in configuration. This is because the trend surface representing the regional are similar and the reduction of the sum of squares are very close. These residual maps and the second harmonic residual anomaly map with wavelength of 28 miles (Plate V) show four gravity highs and six gravity lows bounded by linear features. A linear negative anomaly in Ontwa Township may be due to an edge effect as this becomes a positive in the second harmonic residual gravity map using wavelength of 28 miles (Plate V). These positive and negative anomalies are generally separated by linear trending gradients. A linear feature appears to be trending N-S near the eastern edge of the central positive and negative gravity anomalies (Plates IV & VII). But this trend is NNW-SSE in the
second harmonic residual map with wavelength of 28 miles (Plate V) whose trend surface (Plate VI) probably best represents the regional gravity contours. Other linear features (discontinuities) trend NW-SE and NE-SW conforming with the general trend of anticlines and faults in the Michigan Basin (Newcombe, 1933; Pirtle, 1932; and Hinze & Merritt, 1969). The Jefferson field in Jefferson Township has a NNW-SSE trend which is in close proximity to a linear trend in the residual gravity maps. This trend is pronounced in the 28-mile wavelength second harmonic residual map (Plate V). The Jefferson field appears to be truncated on the north and south by NE-SW trending linear features. In the center of the study area just north of the central positive there is a small linear feature trending E-W which appears to cause displacement between the negative anomaly in the north and positive anomaly to the south of the feature.

The high positive residual anomaly observed in the southeastern portion of the area represented by the first harmonic residual gravity maps (Plates III, IV & VII) appears to have been shifted by about a mile to the west on the second harmonic residual map with wavelength of 28 miles (Plate V).

The central positive gravity anomaly is not associated with the anomalous Hawkes-Adams deep test but is about 2 miles to the west of the well. There is a linear-trending feature over the Hawkes-Adams and Lawson deep tests which has a NNW-SSE trend, indicating a possible faulted area which might account for the uplifted sediments in the Hawkes-Adams deep test. The structural map on top of the traverse limestone in Calvin Township also suggests that the structural high
is 1 mile west of the Hawkes-Adams test. The Lawson deep test encountered two faults and steeply dipping beds below the faults.

The total field magnetic intensity map (Plate II) shows one high positive anomaly towards the southeastern corner of the map in sections 31 and 32 of north Porter Township. This anomaly is also observed on the regional magnetic map of the southern peninsula of Michigan (Fig. 4). This anomaly coincides with the gravity high observed in the residual gravity maps of the area (Plates III, IV, V & VII), thus suggesting an intrabasement lithologic variation. No anomalous closures are observed over the area of known structural deformation. The variation in contours is also smooth. NNW-SSE trending linear features are observed on the magnetic residual map (Plate VIII) east and west of the area of interest coinciding with the trends in the same direction observed on the residual gravity map (Plate V).

The linear features and anomalies are probably caused by a horst-graben type of structure in the area. The positive anomalies indicate the horsts and the negative anomalies the grabens which are bounded by faults trending NNW-SSE, NW-SE, E-W and NE-SW as indicated by the linear features on the residual gravity map (Plate V). Such horst and graben type of feature has been observed in astroblèmes like the Wells Creek structure in Tennessee as described by Stearns et al., (1968). The negative residual gravity anomaly in sections 19, 20, 29 and 30 in Calvin Township in the center of the map (Plate V) may be due to the abnormally thick Glenwood-St. Peter Sandstone which was encountered in the Gordon Smith 1-20 deep test.

Two possible hypotheses to explain the cause of the uplift and faulting are:
1. The uplift may have been a result of either delayed isostatic adjustment or prompt rebound due to meteoric impact. Older faults may have been rejuvenated by the impact to produce the horst-graben feature and the general rectilinear fault block pattern of the area; and

2. The area could have been a focal point of regional stress. The presence of parallel left lateral strike-slip faults causing shearing within the central block could have resulted in upthrusting as explained by Lees (1954) and Quennell (1957) for the faults and folds near the Dead Sea. Lowell (1972) experimented with Clay and produced strike-slip movement with a component of shortening across the fault zone. A zone of en-echelon fractures were formed at a small angle to displacement but the material moving up out of the fault zone formed a welt bounded by thrusts on both sides and a series of en-echelon folds.

Gravity Modeling

The low density of the Mt. Simon Sandstone overlying the Precambrian basement could be masking the uplifted denser Precambrian basement, and thus reducing the Bouguer gravity anomaly to the small values observed. Modeling was done in an attempt to determine the cause of the positive anomaly and the NNW-SSE trending linear feature on the residual gravity map (Plate V). Three-dimensional vertical cylinder and two-dimensional fault models were used to model the profile A-A' obtained from the second harmonic residual gravity values using wavelength of 28 miles (Plate V). The density values for the layers were obtained from the bulk density logs of the Hawkes-Adams and Lawson deep tests. The Precambrian basement was assumed to have a density of 2.7 gm/cc, the Eau
Claire a density of 2.55 gm/cc, the Mt. Simon a density of 2.45 gm/cc and the other overlying sediments were assigned a density of 2.67 gm/cc which is an average density for these sediments as per the logs.

The modeling was started from the top of the Eau Claire as the significant lateral density variations were downward from this formation. Each formation was modeled separately and a composite anomaly was added to account for the total effect. The model gravity values were calculated by Fortran programs (Appendix A) using the formulas in Telford et al., (1976).

The vertical cylinder with diameter 2 miles model showed a negative gravity effect over the cylinder which was not the observed response. Different density contrasts were used to attempt a match but to no avail. Hence the vertical-cylinder model was discarded. The thicknesses and depths of the layers in the cylinder were taken from the well logs of the Hawkes-Adams 1-28 deep test and those of the Lawson 1-28 deep hole were used to represent the normal section (Fig. 13).

The normal fault model showed a small positive anomaly with a steep negative slope which was again not the observed effect.

The thrust-fault model was prepared after studying the geologic cross section of the deep holes between Hawkes-Adams 1-28, Lawson 1-28, the Gemberling 1-36 and Haldeman 1-31 in Calvin Township (Fig. 13). The depths to the top of each faulted layer were taken from the well logs. The model was prepared using fault plane dips of 30 degrees and 45 degrees towards the southwest. The models clearly showed steeply descending gravity values towards the east and high gravity values to the west which was the observed effect. The 45 degree upthrust fault matches
Figure 13. Borehole Section across the structure in Calvin twp., Cass Co., Michigan.
more closely the residual gravity profile (Fig. 14). Hence the NNW-SSE trending linear feature may well be a thrust fault involving the basement in the uplift. The other linear features may also represent faults, either thrust or normal, causing a horst-graben type of structure in the area. There are apparently strike-slip cross faults truncating the horst-graben feature and thus limiting them in their strike extent. The result is an assemblage of fault blocks which are roughly equi-dimensional prisms.
Figure 14. Residual Gravity Profile A-A' and 2-D Gravity Upthrust Model Profile.
Due to the lack of core samples from the deeper parts of the section, there is a lack of direct geologic evidence such as shatter cones, brecciation, presence of coesite, etc., to support an impact origin for this feature. The interpretation of the genesis of the uplift and the absence of Ordovician sediments is inconclusive from the gravity and magnetic surveys. Thrust faulting in the central uplift and erosion of the sediments has been observed in most proven astroblemes or impact craters. The presence of shock metamorphism and brecciation have also been observed in all astroblemes. Astroblemes that have been investigated by gravity and magnetic methods have shown circular negative gravity anomalies with a central positive gravity anomaly if a central uplift is present. Magnetic anomalies are rarely associated with known astroblemes. Most astroblemes that have a circular negative gravity anomaly are near-surface features or have not been deeply eroded. Structures like the Flynn Creek Crater in Tennessee do not have any gravity anomaly closures associated with the structure even at the level of 1 milligal on the Bouguer gravity map like the structure studied in this project. As there was no significant circular Bouguer gravity anomaly associated with the Cass County structure, residual values were calculated. The circular-subcircular anomaly with a central positive anomaly observed on the first harmonic residual gravity
map with wavelength of 16 miles may not represent the actual geology as the trend surface produced by this wavelength does not represent the regional. A NNW-SSE trending linear feature with a positive closure to its west was observed on the first harmonic residual gravity maps with wavelengths of 28 and 42 miles. It can also be seen on the second harmonic residual map with wavelength of 28 miles. The other linear features which bound the positive gravity anomaly trend E-W, NW-SE and NE-SW may also be faults. The NNW-SSE trending Jefferson field appears to be truncated by NE-SW trending strike-slip faults. A residual gravity positive is located in the southeast section of the area and which is coincident with a magnetic high which could be interpreted as being effects of variations in basement lithology.

Two- and three-dimensional modeling was performed to try to match the residual profile across the NNW-SSE trending linear feature over the circular production area observed on the second harmonic residual map with wavelength of 28 miles. The thrust-fault, normal-fault and the vertical-cylinder models were used and the best fit obtained was from the thrust-fault model which shows the steep slope northeast of a high positive similar to that of the gravity profile. The vertical-cylinder and normal-fault models did not match the residual profile. Hence the uplift could be due to a thrust fault involving the Precambrian basement. The fault could have been active until the Late Ordovician and the uplifted sediments could have been eventually eroded away. The Hawkes-Adams and Lawson deep tests in section 28 of Calvin Township could be on the flanks of the uplifted portion and the center of the uplifted portion is 1 mile to the west.
The genesis of the uplift still remains a question, as there is no magnetic anomaly associated with the uplift. A central gravity positive, representing the central uplift, and linear trending features, representing faults, are present on the second harmonic residual gravity map with fundamental wavelength of 28 miles, probably forming horst-graben type of structures similar to structures in proven astroblemes. Another possible hypothesis to explain the uplift and faulting is that parallel left-lateral strike-slip faults could cause shears within a central block to produce upthrusts. With the lack of conclusive geologic evidence in support of the impact theory, the structure should be called a crypto-explosion structure until more evidence is available.
APPENDIX A

GRAVITY MODELING PROGRAM

PROGRAM GRMOD

C THIS PROGRAM (ON FILE GRMOD.FOR[20030,200303]) CALLS A VARIETY OF
C SUBROUTINES WRITTEN BY STUDENTS OF GL562 CLASS, (WMU, FALL,
C 1983). THESE SUBROUTINES CALCULATE A GRAVITY PROFILE OVER VARIOUS
C 2-D AND 3-D BODIES. THE PARAMETERS AND GRAVITY ARRAY ARE PASSED BACK
C TO THE MAIN PROGRAM, WHERE THEY ARE DISPLAYED ON THE LINE PRINTER.
C ALL LINEAR DIMENSIONS ARE IN FEET. DIP ANGLES ARE MEASURED CW
C ABOUT THE CENTER POINT (26).
C MAIN PROGRAM WRITTEN BY W.A. SAUCK FOR DEC1099/ OCT./ 1983.

REAL GRAV(51), TITLE(16), LENGXI(20), XI(20)
COMMON FIG(51,25)
DATA DASH/VERT/ DDT/PLUS/BLANK/AST/ RATIO/"-"/"!"/"."/"*"/
+ "*",*66666667/
OPEN(UNIT=6, DEVICE='DSK', FILE='GRVMOD.DAT', PROTECTION='155)
10 WRITE(5,1000)
1000 FORMAT(2X,'ENTER: 1 FOR SPHERE',/15X,'5 FOR DIPPING SHEET/',
+ //10X, '2 FOR DIPPING ROD',/10X, '6 FOR HORIZ. THIN SHEET/',
+ //10X, '3 FOR HORIZ. ROD',/11X, '7 FOR THICK PRISM/',
+ //10X, '4 FOR THICK VERT. CYL',/5X, '8 FOR DIPPING FAULT/',
+ //10X, '9 TO TOGGLE TABULAR OUTPUT ON/OFF',/5X, '-9 TO STOP')
READ(5,1100,ERR=10) ITYPE
1100 FORMAT(I)
IF(ITYPE.LE.9) GO TO 999
IF(ITYPE.GT.9) GO TO 10
IF(ITYPE.LT.9) GO TO 15
IF(ITAB) 12/12/13
12 ITAB=1
GO TO 10
13 ITAB=0
GO TO 10
15 WRITE(5,1200)
1200 FORMAT(2X,'ENTER UP TO 80 CHARACTERS OF TITLE')
READ(5,1300) TITLE
1300 FORMAT(16A5)
C------ END OF MAIN PROGRAM INPUT. ERASE SUBSURFACE CROSS-SECTION.
30 DO 25 I=1,51
25 fig(i,j)=BLANK
WRITE(6,1310) TITLE
1310 FORMAT('1',2C2X,16A5)
GO TO(100,200,300,400,500,600,700,800)/ITYPE
C CALL SPHERE(DEPTH,RADIUS,DENS,DX,GRAV)
XINCH=DX*6.
WRITE(6,1400) DEPTH,RADIUS,DENS,XINCH
1400 FORMAT(5X,"DEPTH TO CENTER OF SPHERE="/F7.1/," RADIUS="/F7.1/
+ ", DENSITY CONTRAST="/F5.2/, SCALE:"/F7.1," FT.")
C--NOTE USE OF TRUNCATION FOR CONVERSION TO INTEGER; NEXT 3 LINES, ETC.
110 IDEP=0.5 + DEPTH*RATIO/DX
IRADX=0.5 + RADIUS/DX
IRADZ=0.5 + RATIO*RADIUS/DX
IF (IDEP.GT.24) GO TO 120
I=25-IDEP
FIGC26/I)=PLUS
IF (RADIUS.LT.DX) GO TO 900
J=26-IRADX
FIG(J,I)=DASH
J=26+IRADX
FIG(J,I)=DASH
I=I+IRADZ
FIGC26/I)=VERT
I=I-IRADZ+2
IF (I.LT.1) GO TO 900
FIGC26/I)=VERT
GO TO 900
120 FIGC26/I)=AST
GO TO 900
C--

200 CALL DIPROD(DEPTH,RADIUS,LENGTH,DIP,DENS,DX,GRAV)
XINCH=DX*6.
WRITE(6,1500) DEPTH,RADIUS,LENGTH,DIP,DENS,XINCH
1500 FORMAT(5X,"DEPTH TO TOP OF ROD="/F7.1/," RADIUS="/F7.1/
+ ", LENGTH="/F7.1/, DIP="/F6.1/, DENSITY CONTRAST="
+ /F5.2/, SCALE:"/F7.1," FT.")
IX0=26
210 IDEP=0.5 + DEPTH*RATIO/DX
IF (IDEP.GT.24) GO TO 240
DBOT=DEPTH+LENGTH*SIN(CIP*0.01745329)
IBOT=0.5 + OBOT*RATIO/DX
DO 220 I=IDEP,25
ISUB=I
CALL DIAG(DIP, IX, FX, ISUB)
REM=FX-IX
IF (REM.LE.0.25) GO TO 216
IF (REM.GE.0.75) GO TO 215
GO TO 220
215 IX=IX+1
216 II=IXO-IX
IF (II.LT.1 .OR. II .GT. 51) GO TO 225
FIGCII-25-I)=AST
220 CONTINUE
225 GO TO 900
C-- BODY BELOW BOTTOM OF FIGURE --

240 CALL DIAG(DIP, IX, FX, IDEP)
II=IXO-(FX+0.5)
FIGCII-1)=AST
GO TO 900

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
GO TO 900

C ------------

300 CALL HORROD(DEPTH,RADIUS,LENG,Y,DENS,DX,GRAV)
XINCH=DX*6.
LENG=LENG*2.
WRITE(6,1600) DEPTH,RADIUS,LENG,Y,DENS,XINCH
1600 FORMAT(5X,'DEPTH TO CENTER=',F7.1,' RADIUS=',F7.1,
+ ' LENGTH=',F7.1,' Y OFFSET=',F7.1,'/5X,' 
+ ' DENSITY CONTRAST=',F5.2,' SCALE:1''=',F7.1,' FT. ')
GO TO 110

C ------------

400 CALL VERCYL(DEPTH,RADIUS,LENG,OENS,OX,GRAV)
DB=DEPTH+LENG
XINCH=DX*6.
WRITE(6,1700) DEPTH,RADIUS,DB,DENS,XINCH
1700 FORMAT(5X,'DEPTH TO TOP=',F7.1,' RADIUS=',F7.1,
+ ' DEPTH TO BOTTOM=',F7.1,'/5X,' DENSITY CONTRAST=',F5.2,
+ ' SCALE:1''=',F7.1,' FT. ')
IDEP=0.5 + DEPTH*RATIO/DX
IRADX=0.5 +RADIUS/DX
ISOT=C.5 + DB*RATIO/DX
I=25-IDEP
J=26-IRADX
K=25-ISOT
L=26+IRADX
IF(IDEP.GT.24) GO TO 420
IF(K.LT.0) K=1
DO 410 M=K/I
FIG(J,M)=DASH
FIG(L,M)=DASH
410 FIG(K,M)=DASH
IF(K.EQ.1) GO TO 420
DO 415 M=J,L
FIG(M,I)=VERT
415 FIG(M,K)=VERT
GO TO 900
420 DO 422 M=J,L
422 FIG(M,1)=AST
GO TO 900

C ------------

500 CALL OSHET(DEPTH,THICK,LENG,DIP,DENS,DX,GRAV)
XINCH=DX*6.
WRITE(6,1800) DEPTH,THICK,LENG,DIP,DENS,XINCH
1800 FORMAT(5X,'DEPTH TO TOP=',F7.1,' THICKNESS=',
+ ' LENGTH=',F7.1,' DIP=',F6.1,' DENSITY CONTRAST=',
+ ' SCALE:1''=',F7.1,' FT. ')
IDEP=0.5 + DEPTH*RATIO/DX
CALL DIAG(DIP,IX,FX,IDE)
IXO=26 + X
GO TO 210

C ------------

600 CALL HSHET(DEPTH,THICK,LENG,DENS,DX,GRAV)
XINCH=DX*6.
WRITE(6,1900) DEPTH,THICK,LENG,DENS,XINCH
1900 FORMAT(5X,'DEPTH TO CENTER=',F7.1,' THICKNESS=',F7.1,
+ ' LENGTH=',F7.1,' DENSITY CONTRAST=',F5.2,}

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
FIG(M,1)=AST

CONTINUE
GO TO 900

C

CALL FAULT(DEPTH1,DEPTH3,THICK,DIP,DENS,DX,GRAV)
XINCH=DX*6.
WRITE(6,2100)DEPTH1,DEPTH3,THICK,DIP,DENS,XINCH
2100 FORMAT(5X,'DEPTH TO RIGHT SIDE=','F7.1',' DEPTH TO ' + + 'LEFT SIDE=','F7.1',' THICKNESS=','F7.1',' DIP=',' + + 'F7.1',' DENSITY CONTRAST=','F5.2',' SCALE: 1"=',' + + F7.1',' FT. ')
DEPTH2=DEPTH1+THICK
DEPTH4=DEPTH3+THICK
CALL GETDIA(DEPTH1,VERT,AST,DIP,RATIO,DX,1)
CALL GETDIA(DEPTH2,VERT,AST,DIP,RATIO,DX,1)
CALL GETDIA(DEPTH3,VERT,AST,DIP,RATIO,DX,1)
CALL GETDIA(DEPTH4,VERT,AST,DIP,RATIO,DX,-1)
GO TO 900

C

WRITE(5,3001)(GRAV(I),I=1,9/32)

C-----PREVIEW CALCULATED PROFILE; GIVE CHANCE TO RESTART.
3001 FORMAT(2X,'THE CENTRAL 14 GRAV VALUES ARE SHOWN BELOW',/ + + 14F6.2,' ENTER: 0 TO CONTINUE, 1 TO START OVER')
READ(5,1100,ERR=900)NGO
IF(NGO,LT.1)GO TO 910
GO TO 30
910 WRITE(5,3003)
3003 FORMAT(2X,'ENTER OPTIONAL MINIMUM AND MAXIMUM SCALE VALUES ', + + 'FOR PLOT','/4X,'ZEROS CAUSES GRAPH TO FILL ENTIRE SCALE ', + + 'RANGE WITH YOUR PLOT.')
READ(5,3004,ERR=900)GMIN,GMAX
3004 FORMAT(2F)

C-----SEND RESULTS TO BE PLOTTED ON LINE PRINTER.
CALL GRAPH(GRAV,51,GMIN,GMAX)
 IF(ITAB.EQ.0)GO TO 920

C-----PRINT OPTIONAL OUTPUT TABLE. ------------------------
WRITE(6,3005)(I,GRAV(I),I=1,51)
3005 FORMAT(1H1,'/12X','I',6X,'GRAV',/51(10X,I3,'F10.3,/) + + 10X, '+ 3 TO END')
READ(5,1100)NGO
GO TO(10,15,999),NGC
999 WRITE(5,3002)
3002 FORMAT(2X,'YOUR OUTPUT IS ON FILE GRVMDAT')
STOP
END

SUBROUTINE GETDIA(DEPTH,VERT,AST,DIP,RATIO,DX,ISW)
C-----USED FOR REPETITIVE CALLS TO DIAG FROM "FAULT" FIGURE DRAWING
C-----TSW +1 DRAWS HORIZ LINE FROM FAULT TO RIGHT EDGE.
C-----TSW -1 DRAWS HORIZ LINE FROM FAULT TO LEFT EDGE OF FIGURE.
COMMON FIG(51,25)
IDEP=DEPTH*RATIO/DX
+ "SCALE: 1" = "F 7.1" FT.
IDEP = 0.5 + DEPTH * RATIO / DX
ITHIK = 0.5 + THICK * RATIO / (2. * OX)
ILEN = 0.5 + LENG / DX
IF (ILEN.GT.25) ILEN = 25
IX = 26 + ILEN
IF (IDEP.GT.24) GO TO 620
IT = 25 - IDEP + ITHIK
IB = 25 - IDEP - ITHIK
DO 610 M = 26, IX
FIG(M, IT) = VERT
610 FIG(M, IB) = VERT
DO 615 M = IB, IT
IF (ILEN.LT.25) FIG(IX, M) = DASH
615 FIG(26, M) = DASH
GO TO 900
620 DO 630 M = 26, IX
630 FIG(M, 1) = AST
GO TO 900
C ---
700 CALL PRISM(DEPTH, DEPTH2, WIDTH, DIP, DENS, DX, GRAV)
XINCH = DX * 6.
WRITE (6, 2000) DEPTH, DEPTH2, WIDTH, DIP, DENS, XINCH
2000 FORMAT (5X, "DEPTH TO TOP = " , F8.1, "/", "DEPTH TO BOTTOM = " ,
+ "F 8.1", "/", "WIDTH = " , F8.1, "", "DIP = " , F6.1, "", "DENSITY CONTRAST = " ,
+ "F 5.2", SCALE: 1" = "F 7.1" FT.")
IDEP = DEPTH * RATIO / DX
I = 25 - IDEP
IDEP2 = DEPTH2 * RATIO / DX
IWIDTH = WIDTH / OX
IF (IDEP.GT.24) GO TO 720
CALL DIAG(DIP, IX, FX, IDEP)
IXL = 26 - IX
IF (IXL.LT.1 .OR. IXL .GT. 51) GO TO 711
IXR = IXL + IWIDTH
DO 710 M = IXL, IXR
IF (M .LT. 1 .OR. M .GT. 51) GO TO 710
FIG(M, I) = VERT
710 CONTINUE
711 IF (IDEP2.GT.24) GO TO 720
CALL DIAG(DIP, IX, FX, IDEP2)
I = 25 - IDEP2
IXL = 26 - IX
IXR = IXL + IWIDTH
DO 715 M = IXL, IXR
IF (M .LT. 1 .OR. M .GT. 51) GO TO 715
FIG(M, I) = VERT
715 CONTINUE
GO TO 900
720 CALL DIAG(DIP, IX, FX, 25.)
IXL = 26 - IX
IXR = IXL + IWIDTH
C-------------- BOTTOM EDGE OF DRAWING OR CROSS-SECTION --------------
DO 725 M = IXL, IXR
IF (M .LT. 1 .OR. M .GT. 51) GO TO 725

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
SUBROUTINE DIA G C D I P /I X /F X /I D E P )
C - - - - - - - - - - - - - - - - - - - - - - - - -RETURNS IX AND DX GIVEN A DIP AND DEPTH (FOR DRAWING FIGURE).
IF (D I P .G T .8 5 .0 .A N D .D I P .L T .9 5 .0 ) G O  T O  5 0
IF (D I P .G T .1 7 8 .0 ) G O  TC 4 0
I F (D I P .L T . 2 . C) G O  T O  4 5
D X  = 0 .6 *F L O A T (I D E P )/T A N (D I P *0 .0 1 7 4 5 3 2 )
I X  = 0
R E T U R N
4 0
D X  = 2 5 .
I X  = 2 5
R E T U R N
4 5
D X  = -2 5 .
I X  = -2 5
R E T U R N
5 0
D X  = 0 .
I X  = 0
R E T U R N
E N D

SUBROUTINE SPHER ERECZ/A/ 0 / S/ G )
C
A U T H O R S : J O E L W A L T E R A N D D A V E R A P P
G E O L . 5 6 2 , F A L L , ' 8 3 .
C
— EQUATION 2 . 4 0 A , T E L F O R D —
C
C
C
C
C
C
C
O F 5 1 L O C AT I O N S
C
C**** V A R I A B L E D I C T I O N A R Y ****
C
Z - T H E D E P T H T O T H E C E N T E R O F T H E S P H E R E
C
A - R A D I U S O F T H E S P H E R E

THE STATION SPACING
THE DENSITY CONTRAST
ARRAY CONTAINING THE CALCULATED STATION GRAVITY
DENSITY CONTRAST * RAD. OF SPHERE **3, A CONSTANT
DEPTH TO THE CENTER OF THE SPHERE SQUARED
THE DISTANCE FROM THE POINT IMMEDIATELY ABOVE THE CENT:
ARRAY INDICES

C**** DECLARATIONS ****

REAL Z, A, X, O, G(51), DA3, Z2, S
INTEGER I, J

INPUT PARAMETERS

WRITE(5, 100)
100 FORMAT(// "WHAT IS DEPTH TO CENTER OF SPHERE----->", $)
READ(5, 101, ERR=5) Z
101 FORMAT(F)
IF(Z.LT.1.) GO TO 5

WRITE(5, 110)
110 FORMAT(// "WHAT IS THE RADIUS OF THE SPHERE----->", $)
READ(5, 101, ERR=6) A
IF(A.LT.1.) GO TO 6
IF(Z.GE.A) GO TO 7
WRITE(5, 115)
115 FORMAT(2X, 'ERROR! RADIUS GREATER THAN DEPTH')
GO TO 5

WRITE(5, 120)
120 FORMAT(// "WHAT IS THE STATION SPACING----->", $)
READ(5, 101, ERR=7) S
IF(S.LT.0.001) S=A/3.

WRITE(5, 130)
130 FORMAT(// "WHAT IS THE DENSITY CONTRAST----->", $)
READ(5, 101, ERR=8) D

C CALCULATION OF CONSTANTS

DA3=D*(A**3.)
Z2=Z**2.
J=26
X=0.0

C LOAD ARRAY G

DO 10 I = 26, 51
   G(I) = 8.53E-3*(DA3/(Z2*((1.0+(X**2.)/Z2)**1.5)))
   G(J)=G(I)
   X=X+S
   J=J-1
10 CONTINUE
RETURN
SUBROUTINE DIPROD (Z,R,L,ALPHA,SIGMA,DELX,G)

C

CALCULATES THE GRAVITY EFFECT CAUSED BY THIN DIPPING ROD.

WRITTEN BY: BEN WOODLIFF
JEFF HAWKINS
GEOPHYSICS 562
FALL 1983

DIPROD:
SUBROUTINE TO APPLY EQUATION 2.41A, APPLIED GEOPHYSICS, TELFORD, 1976. SUBROUTINE TO COMPUTE THE GRAVITY EFFECT OF 51-EQUIDISTANT STATIONS LOCATED ABOVE A MASS HAVING THE GEOMETRY OF A DIPPING ROD. THE OPERATOR OF THE PROGRAM WILL BE ABLE TO SELECT THE PARAMETERS OF THE DIPPING ROD BY TYPING IN THE DATA DIRECTLY TO THE COMPUTER TERMINAL.
THE SUBROUTINE IS DESIGNED TO CHECK FOR INPUT ERRORS AND WILL NOT ACCEPT ANY DATA THAT IS OUT-OF-RANGE.

PARAMETERS
.INPUT FROM MAIN: NONE
.RETURNED TO MAIN: G(51) - ARRAY OF 51 GRAVITY POINTS
ALPHA - ROD DIP ANGLE IN DEGREES
R - RADIUS OF ROD IN FEET
Z - DEPTH OF ROD IN FEET
L - ROD LENGTH IN FEET
SIGMA - DENSITY CONTRAST
DELX - STATION SPACING IN FEET

DECLARATION

REAL G(51) ARRAY OF 51 GRAVITY DATA POINTS
ALPHA ROD DIP ANGLE IN DEGREES
ALRAD ROD DIP ANGLE ALPHA IN RADIANS
AREA CROSSECTIONAL AREA OF THE ROD
R ROD RADIUS
X CURRENT HORIZONTAL DISTANCE FROM ZERO
DELX INTERVAL OF STATION SPACING
Z DEPTH TO TOP OF ROD
L ROD LENGTH
SIGMA DENSITY CONTRAST
C XNUM1 TEMPORARY VARIABLE FOR EQUATION
C XNUM2 " " " "
C XDEN1 " " " "
C XDEN2 " " " "
C TERM1 " " " "
C TERM2 " " " "
C XTERM VALUE OF EQUATION AT "X"
C CONST CONSTANT MULTIPLIER

INTEGER I LOOP INDEX COUNTER
J STATION NUMBER COUNTER

REAL G(51)/ALPHA/ALRAD/AREA/R/Z/SIGMA/L/X/DELX
REAL XNUM1/XNUM2/XDEN1/XDEN2/TERM1/TERM2/XTERM/CONST
INTEGER I/J

READ IN DATA FROM OPERATOR

WRITE(5,500)
FORMAT( "///10X," TYPE IN VALUES FOR THE FOLLOWING: "///)
C
1 WRITE(5,510)
510 FORMAT( "/ENTER: ROD DIP ANGLE (ALPHA) IN DEGREES: "/,$)
READ(5,700/ERR=1) ALPHA
CHECK FOR ANGLE BETWEEN 0-180 DEG.
IF((ALPHA.LE.0.0).OR.(ALPHA.GE.180))GOT01
C
2 WRITE(5,520)
520 FORMAT( "/ENTER: ROD RADIUS (R) IN FEET: "/,$)
READ(5,700/ERR=2) R
CHECK FOR NEGATIVE RADIUS
IF(R.LE.0.0) GOTO2
C
3 WRITE(5,530)
530 FORMAT( "/ENTER: DEPTH TO TOP OF ROD (Z) IN FEET: "/,$)
READ(5,700/ERR=3) Z
C
4 WRITE(5,540)
540 FORMAT( "/ENTER: DENSITY CONTRAST (SIGMA): "/,$)
READ(5,700/ERR=4) SIGMA
C
5 WRITE(5,550)
550 FORMAT( "/ENTER ROD LENGTH (L) IN FEET: "/,$)
READ(5,700/ERR=5) L
CHECK FOR NEGATIVE ROD LENGTH
IF(L.LE.0.0)GOT05
C
6 WRITE(5,560)
560 FORMAT( "/ENTER: STATION SPACING (DELX) IN FEET: "/,$)
READ(5,700,ERR=6)DELX
C    CHECK FOR NEGATIVE STATION SPACING
    IF(DELX.LE.0.C)GOTO6
C
700  FORMAT(F)
C    COMPUTE ALRAD, RADIANT VALUE OF ANGLE ALPHA
C    ALRAD=ALPHA*C.017453293
C    COMPUTE AREA, CROSSECTIONAL AREA OF ROD
C    AREA=3.141592654*R**2
C    *** BEGIN : CALCULATION OF GRAVITY DATA ***
C
J=-26
DO 100 I=1,51
   J=J+1
   X=FLOAT(J)*DELX
   IF(X.EQ.0.) X=0.0001*CEILX
C
C    CHECK FOR ALPHA=90 (VERTICAL ROD)
C    IF(ALPHA.NE.90.)GOTO3C
C
   ELSE:
   (SPECIAL CASE: VERTICAL ROD)
   CONST=0.00203*SIGMA*AREA
   TERM1=1.0/(Z**2.0 + X**2.0)**0.5
   TERM2=1.0/((Z+L)**2.0 + X**2.0)**0.5
   GOTO40
C
30   CONTINUE
C
   CONST=0.00203*SIGMA*AREA/X*SIN(ALRAD)
   XNUM1=X+Z*(1.0/TAN(ALRAD))
   XDEN1=(Z**2.0/(SIN(ALRAD)))**2.0+2*X*Z/TAN(ALRAD)
       +X**2.0)**0.5
C
   TERM1=XNUM1/XDEN1
C
   XNUM2=X+Z*(1.0/TAN(ALRAD))+L*COS(ALRAD)
   XDEN2=((L+Z/SIN(ALRAD)))**2.0+X**2.0+2.0*X*
       (L*COS(ALRAD)+Z/TAN(ALRAD)))**0.5
C
   TERM2=XNUM2/XDEN2
C
40   CONTINUE
C
   XTERM=TERM1-TERM2
C
   G(I)=CONST*XTERM
C
100  CONTINUE

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
SUBROUTINE HCRROD (Z, R, L, Y, RHC, DX, G)
C
 THE GRAVITY EFFECT OF A BURIED HORIZONTAL ROD

--- FROM EQUATION 2.42A, TELFORD ---
C
WRITTEN BY J. PORTER AND MARK CALDWELL / OCT. 1983 / WMU
C
THIS SUBROUTINE WILL CALCULATE THE VERTICAL COMPONENT OF
C GRAVITY OVER A BURIED HORIZONTAL ROD. THE ROD IS
C ASSUMED TO BE PARALLEL TO THE Y-AXIS AND CENTERED
C UNDER THE X-AXIS AT A DEPTH Z. THE USER MAY SPECIFY
C LENGTH, RADIUS, DENSITY CONTRAST AND DEPTH OF BURIAL
C OF THE ROD. BY INPUTTING SPECIFIED VALUES FOR X AND Y
C IN FEET, THE USER MAY GENERATE THE PREDICTED GRAVITY
C EFFECT AT ANY POINT ON THE SURFACE. DISTANCES ARE IN
C FEET AND G IS IN MGALS.
C
*******VARIABLE DICTIONARY**************
C
K1=G*PI=CONSTANT=6.387 EXP -3
C R=RADIUS OF ROD
C RHO=DENSITY CONTRAST
C Z=DEPTH TO CENTER OF BURIED ROD
C Y=HORIZONTAL DISTANCE (PARALLEL) FROM CENTER OF ROD
C L=LENGTH OF ROD
C DX=STATION SPACING
C G=OUTPUT=VERTICAL COMPONENT OF GRAVITY (MGAL)
C
*************VARIABLE DECLARATION*************
C
REAL R, RHO, Z, DX, Y, L, G(51), K1, K2, K3, X
INTEGER I, M
EPS = 1.0E-4
C
ENTER THE PARAMETERS
C
20 WRITE(5, 200)
200 FORMAT(' TYPE A VALUE FOR Y, (Y=C @ LEFT END OF ROD)----> ', $
READ(5, 900, ERR=20) Y
30 WRITE(5, 300)
300 FORMAT(' TYPE A VALUE FOR Z----> ', $
READ(5, 900, ERR=50) Z
IF(Z.LT.0) GO TO 30
IF(Z.LT.R) GO TO 30
C
60 WRITE(5,100)
100 FORMAT('TYPE A VALUE FOR DX ---> ',S)
     READ(5,900,ERR=60)DX
     IF(DX.LT.EPS) DX = ((2.*Z)/25.)
70 WRITE(5,400)
400 FORMAT('TYPE A VALUE FOR THE DENSITY CONTRAST ---> ',S)
     READ(5,900,ERR=70)RHC
80 WRITE(5,600)
600 FORMAT('TYPE A VALUE FOR THE HALF-LENGTH OF THE ROD ---> ',S)
     READ(5,900,ERR=80)L
     IF(L.LE.EPS) GO TO 8C
900 FORMAT(F)

C INITIALIZATIONS

M = 26
K1 = .006387 * RHO * Z
X = 0
YML= Y - L
YPL= Y + L
YPL2 = YPL**2.0
YML2 = YML**2.0

C NOW GENERATE THE OUTPUT IN A LOOP

C DO 10 I=26/51
  R1 = (X**2.0+Z**2.0)
  G(I) = ((K1*(R**2.0))/R1)*((YPL/(YPL2+R1)**0.5) -
  + (YML/(YML2+R1)**0.5))
  G(M) = G(I)
  X = X + DX
  M = M-1
10 CONTINUE
C
RETURN
END

SUBROUTINE VERCYL(Z,R,L,SIGMA,DX,GRAV)
C JAMES KONNIE AND STEVE WIGGER
C --- USES EQUATIONS 2.45A AND 2.45B, TELFORD, TWICE
C SUBTRACTING THE EFFECTS OF 2 INFINITE VERT. CYLINDERS
C AT DEPTHS Z(1) AND Z(2).
C GEOLOGY 562 FALL/83
C LAB ASSIGNMENT C4, DUE OCT. 13/1983
C THIS SUBROUTINE GIVES
C THE GRAVITY EFFECT OF A THICK VERTICAL CYLINDER IN THE
C SUBSTRATUM ALONG AN X COORDINATE AXIS.
C VARIABLE DICTIONARY
C R: HORIZONTAL RADIUS OF CYLINDER
C Z(1): DEPTH TO CENTER TOP OF CYLINDER
C Z(2): DEPTH TO BOTTOM OF CYLINDER
C SIGMA: DENSITY CONTRAST
C L: LENGTH OF CYLINDER

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
C X: LOCATION ALONG X AXIS
C A: CONSTANT VALUE 2*(PI)*R*SIGMA
C GRAV: GRAVITY EFFECT
C
REAL R, SIGMA, L, G, P(6), GRAV(51), TEMP(51/2), Z(2), S(2), U(2),
+ B(2), C(2)
11 WRITE(5, 110)
110 FORMAT('ENTER: RADIUS')
READ(5,120,ERR=11)R
120 FORMAT(F)
12 WRITE(5, 130)
130 FORMAT('ENTER: DEPTH TO TOP OF CYLINDER')
READ(5,120,ERR=12)Z(1)
13 WRITE(5, 140)
140 FORMAT('ENTER: DENSITY CONTRAST')
READ(5,120,ERR=13)SIGMA
14 WRITE(5, 150)
150 FORMAT('ENTER: LENGTH')
READ(5,120,ERR=14)L
IF(L.LE.0.0) GO TO 14
Z(2)= Z(1) + L
15 WRITE(5, 160)
160 FORMAT('ENTER: DELTA X')
READ(5,120,ERR=15)DX
IF(DX.LT.0.0001) DX=R/5.
C
C CALCULATE ARRAY GRAV(X)
A=0.01277*R*SIGMA
X=0
DO 20 J=1/2
DO 10 I=26/51
S(J)=(X**2+Z(J)**2)**0.5
U(J)=Z(J)/S(J)
B(J)=S(J)/R
C(J)=R/S(J)
P(1)=U(J)
P(2)=1.5*U(J)**2-0.5
P(4)=4.375*U(J)**4-3.75*U(J)**2+1.375
P(6)=14.4375*U(J)**6-19.6875U(J)**4+6.5625*U(J)**2-1.3125
IF(Z(J).LE.S(J).AND.S(J).LE.R) GO TO 300
IF(S(J).GT. R .AND. R.GT. Z(J)) GO TO 400
IF(Z(J).GT. R) GO TO 400
C EQUATION FOR SMALL X OR SMALL R. (TELFORD, EQ. 2.45A)
300 TEMP(I,J)=A*((1.-B(J)*P(1))+(0.5*B(J)**2*P(2))-
+ (Q.125*B(J)**4*P(4))+(0.0625*B(J)**6*P(6))
GO TO 500
C EQUATION FOR LARGE X. (TELFORD, EQ. 2.45B)
400 TEMP(I,J)=A*(Q.5*C(J))-Q.125*C(J)**3*P(2)+(Q.0625*C(J)**5*P(4))
+ -(Q.0390625*C(J)**7*P(6))
500 X=X+DX
10 CONTINUE
X=0.0
20 CONTINUE
DO 30 I=26/51
GRAV(I)=TEMP(I,1)-TEMP(I,2)
IF(I.GT.25) GRAV(52-I)=GRAV(I)
SUBROUTINE DSHEET(DEPTH, THICK, LENG, DIP, DENS, DX, GRAV)

*** DSHEET SUBROUTINE DESCRIPTION ***

--- USES EQUATION 2.46A, TELFORD ---

WRITTEN BY R. LEVISA AND J. ZAPATA, OCT., 1983 FOR GL562

THIS SUBROUTINE WILL CALCULATE 51 DIFFERENT GRAVITY VALUES
FOR A THIN DIPPING SHEET. ALL INPUTS WILL BE IN DEGREES
AND FEET. LISTED ARE THE FOLLOWING PARAMETERS:

DEPTH - DEPTH OF BODY FROM SURFACE
THICK - THICKNESS OF BODY
LENG - LENGTH OF BODY
DENS - DENSITY CONTRAST
DX - CHANGE IN HORIZONTAL DISTANCE

REAL DEPTH, THICK, LENG, DIP, DENS, DX, X,
A, B, C, D, D1, D2, E, L, GRAV(51)
INTEGER N

DATA RAD/0.01745329/

WRITE(5,1400)
1400 FORMAT(1H ,29HPLEASE ENTER DEPTH, THICK, LENG)
READ(5,1500,ERR=10) DEPTH, THICK, LENG
1500 FORMAT(3F)
10 IF (DEPTH .LE. 0.0) GO TO 10
11 IF (THICK .LE. 0.0) GO TO 10
12 IF (LENG .LE. 0.0) GO TO 10
CONTINUE

WRITE(5,1600)
1600 FORMAT(1H ,25HPLEASE ENTER DIP AND DENS)
READ(5,1700,ERR=20) DIP, DENS
1700 FORMAT(2F)
20 IF (DIP .LT. 0.0) OR (DIP .GT. 180.0) GO TO 20
CONTINUE

WRITE(5,1800)
1800 FORMAT(1H ,15HPLEASE ENTER DX)
READ(5,1900,ERR=30) DX
1900 FORMAT(F)

IF USER ENTERS 0 OR A NEGATIVE VALUE FOR DX
THEN THE PROGRAM WILL PROVIDE DX

IF (DX .GT. 0.0) GO TO 2100

DX = ((3.0/2.0)*LENG)/25.0
2100 CONTINUE

X =-26.*DX
DO 51 N=1,51,1
A = 0.00447*DENS*THICK
B = ((DEPTH+LENG+sin(DIP*rad))**2+(X+LENG*cos(DIP*rad))**2)/
   (X**2+DEPTH**2)
C = 0.5*sin(DIP*rad)*alog10(3)
D1 = (DEPTH*sin(DIP*rad)+LENG+(X)*cos(DIP*rad))
D2 = ((X)*sin(DIP*rad)-DEPTH*cos(DIP*rad))
D = atan(D1/D2)
E = atan(((DEPTH*sin(DIP*rad)+(X)*cos(DIP*rad)))/
   ((X)*sin(DIP*rad)-DEPTH*cos(DIP*rad)))
L = cos(DIP*rad)*(D - E)
GRAN(N) = A*(C-L)
X = X+DX
51 CONTINUE
RETURN
END

C*******************************************************************************
C**                                                                                   
C**                                    SUBROUTINE HSHEET                      
C**                                                                                   
C************************************************************************************
C AUTHORS: DAVE COOK  , ANN NEVERO
C       USES EQUATION 2.47A, TELFORD
C THIS FORTRAN PROGRAM CALCULATES THE GRAVITY EFFECT OF
C A HORIZONTAL THIN SHEET OF VARIABLE LENGTH AND GIVEN THICKNESS
C VARIABLE DICTIONARY
C
C REAL    Z-VERTICAL DEPTH TO CENTER OF SHEET OR SLAB
C      T-SLAB THICKNESS
C    SIGMA-DENSITY CONTRAST
C     DX-DISTANCE BETWEEN POINTS
C      X-DISTANCE FROM ZERO PT.[LENGTH IN FT.]
C        L-LENGTH OF THE SHEET[FEET], MEASURED TO RIGHT FROM ORIG.
C      G(  )-GRAVITY AT A GIVEN PT.
C
C INTEGER PNT-THE PT. IN QUESTION
C       I-LOCATION OF POINT ON X
C
C SUBROUTINE HSHEET(Z,T,L,SIGMA,DX,X,G)
C
C REAL Z,T,SIGMA,DX,X,G(51),PI,L
C INTEGER PNT,I
C
C INITIALIZE VARIABLES
C
C PNT = -25
C PI = 3.1415927
C I = 0
C
C INPUT THE DEPTH
C
C 10 WRITE(5,100)
C 100 FORMAT(2X,'WHAT IS THE DEPTH TO CENTER OF SHEET?')
READ (5, 200, ERR = 10) Z

200 FORMAT(F)
20 WRITE (5, 300)
300 FORMAT(2X, 'WHAT IS THE SLAB THICKNESS?')
READ (5, 200, ERR = 20) T
IF (Z.GT.2.0*T) GO TO 400
WRITE (5, 350)
350 FORMAT(2X, 'ERROR! DEPTH < 2*THICKNESS!')
GO TO 10
400 WRITE (5, 500)
500 FORMAT(2X, 'WHAT IS THE DENSITY CONTRAST?')
READ (5, 200, ERR = 40C) SIGMA
30 WRITE (5, 600)
600 FORMAT(2X, 'WHAT IS THE X-LENGTH OF THE SHEET?')
READ (5, 200, ERR = 30) L
40 WRITE (5, 700)
700 FORMAT(2X, 'WHAT IS THE DISTANCE BETWEEN POINTS?')
READ (5, 200, ERR = 40) DX
IF (DX.LT.0.0001) DX = 2.0*Z/25.0
50 IF (PNT.GT.25) GO TO 70
X = PNT*DX
I = I + 1
PNT = PNT + 1
G(I) = 0.0047*SIGMA*T*(ATAN((L-X)/Z)+ATAN(X/Z))
GO TO 50
70 RETURN
END

C///\///\///\///\///\///\///\///\///\///\///\///\///\///\///\///\///\///\///\///

SUBROUTINE PRISM(DT, DB, B, ALPHA, DS, DX, GRAV)
C ** GEOLOGY 562 - GRAVITY AND MAGNETICS.**
C AUTHORS: DEMETRE VALINDORAS & WILLIAM MORSE.
C*** THIS SUBROUTINE CALCULATES THE THEORETICAL GRAVITY
C FOR A CENTRAL STATION AND 25 STATIONS ON EITHER SIDE
C OF THE CENTRAL STATION.
C --- USES EQUATION 2.49A, TELFORD ---
C THE VARIABLES ARE DECLARED EXPLICITLY ONLY IF THEY
C ARE SIGNIFICANT. THEY ARE NOT DECLARED BUT USED
C IMPLICITLY IF THEY ARE ONLY INTERMEDIATE OR CONTROL
C VARIABLES. A LIST OF THE VARIABLES FOLLOWS:
C DT: DEPTH TO THE TOP OF THE PRISM
C DB: DEPTH TO THE BOTTOM OF THE PRISM.
C B: WIDTH OF THE PRISM
C ALPHA: ANGLE OF DIP OF THE PRISM. (MEASURED CCW)
C DS: DENSITY CONTRAST OF THE PRISM
C DX: STATION SPACING ON THE SURFACE. IF A VALUE
C OF 0.0001 OR LESS IS INPUT THEN THE SPACING
C IS CALCULATED ACCORDING TO: DX=8/6
C PI: THE CONSTANT PI.
C ALPHAR: ALPHA IN RADIANS.
C X(51): ARRAY CONTAINING THE STATION DISTANCES FROM
C THE CENTRAL STATION. NEGATIVE DISTANCES ARE
C TO THE LEFT OF THE CENTRAL STATION, POSITIVE
TO THE RIGHT. DISTANCES ARE IN FEET.

THE REST OF THE VARIABLES ARE SELF EXPLANATORY.

INTEGER I

REAL DT, DB, B, ALPHA, DS, DX, PI, ALPHAR, X(51), GRAV(51)

& SINA, COSA, SIN2A, COTA, CONST

DATA PI /3.1415926536/

WRITE(5,1000)

1000 FORMAT(//2X, 'INPUT DEPTH TO TOP & BOTTOM OF PRISM: 'S)

READ(5,1005, ERR=10) DT, DB

1005 FORMAT(2F)

11 WRITE(5,1010)

1010 FORMAT(//2X, 'INPUT WIDTH OF PRISM & ANGLE OF DIP: 'S)

READ(5,1005, ERR=11) B, ALPHA

15 WRITE(5,1015)

1015 FORMAT(//2X, 'INPUT DENSITY CONTRAST & DELTA X: 'S)

READ(5,1005, ERR=15) DS, DX

1700 IF (DX.LT.0.0001) DX=B/6.

ALPHAR=PI*ALPHA/180.
SINA=SIN(ALPHAR)
COSA=COS(ALPHAR)
SIN2A=SINA**2
COTA=COSA/SINA
CONST=0.00407*DS
DB2=DB**2
DT2=DT**2

DO 1200 I=1,51
X(I)=(I-26)*DX
XIMB=X(I)-B

FR1=(DB2+(X(I)+DB*COTA)**2)/(DB2+(XIMB+DS*COTA)**2)
FR2=(DT2+(XIMB+DT*COTA)**2)/(DT2+(X(I)+DT*COTA)**2)
LOG1=ALOG10(FR1*FR2)
FR3=(DB2+(XIMB+DS*COTA)**2)/(DT2+(XIMB+DT*COTA)**2)
LOG2=ALOG10(FR3)
OCC1=ATAN((XIMB)/DB+COTA)
OCC2=ATAN((XIMB)/DT+COTA)
OCC3=ATAN(X(I)/DB+COTA)
OCC4=ATAN(X(I)/DT+COTA)

G1=X(I)*SIN2A*0.5*LOG1+B*SIN2A*0.5*LOG2
G2=X(I)*SINA*COSA*(OCC1-OCC3-OCC2+OCC4)
G3=B*SINA*COSA*(OCC1-OCC2)-DB*(OCC1-OCC3)
G4=DT*(OCC2-OCC4)

GRAV(I)=CONST*(G1-G2+G3-G4)

1200 CONTINUE

RETURN

END
C***************************************************************
C SUBROUTINE FAULT
C Author: Saiful Bahri Baharom
C GEOPHYSICS 522 GRAVITY AND MAGNETIC METHODS
C***************************************************************
C THIS IS A SUBROUTINE TO CALCULATE THE GRAVITY EFFECT
C OF A FAULT AT VARIOUS POINTS. THE INFORMATION NEEDED
C TO DO THIS ARE:
C 1) THE THICKNESS OF THE 3EO
C 2) THE DEPTH TO THE RIGHT SIDE
C 3) THE DEPTH TO THE LEFT SIDE
C 4) THE ANGLE OF DIP OF THE FAULT (MEASURED CCW FROM LEFT)
C 5) THE AVERAGE DENSITY OF THE ROCK
C 6) THE INCREMENT DESIRED FOR THE X-AXIS
C--- THE ROUTINE IS BASED ON EQUATION 2.51A OF TELFORD ---
C***************************************************************
C DEARATION CF VARIABLES
SUBROUTINE FAULT (Z1,Z3,THIK,DIP,DENS,DX,GRAV)
REAL B,Q1,Q2,Q3,Q4,Y1,Y2,Y3,Y4,F1,F2,F3,F4,PI,X,Z2,Z4
REAL GRAVC51)
INTEGER I
DATA PI/RAD/3.1415926,0.01745329/
C***************************************************************
C INPUT OF DATA: THICKNESS/ DEPTH TO RIGHT SIDE/ DEPTH TO
C THE LEFT SIDE/ DIP ANGLE/ AVERAGE DENSITY
C AND THE X-AXIS INCREMENT.
C 5 WRITE (5/10)
10 FORMAT(2X,'ENTER THICKNESS, DEPTH TO RIGHT SIDE, DEPTH TO
+ LEFT SIDE')
20 READ (5,20,ERR=5) THIK,Z1,Z3
20 FORMAT(3F)
IF(THIK.LT.(0.01))GO TO 5
IF(Z1.LT.(0.01))GO TO 5
IF(Z3.LT.(0.01))GO TO 5
25 WRITE (5,30)
30 FORMAT(2X,'ENTER DIP ANGLE/ AVERAGE DENSITY/ X-INCREMENT')
40 READ (5,40,ERR=25) DIP,DENS,DX
40 FORMAT(3F)
IF(DIP.LT.(0.00001))GO TO 25
IF(DIP.GT.(180.0))GO TO 25
RDIP = DIP * RAD
IF (DX.LT.(0.000001)) DX = Z3 / 5.0
Z2 = Z1 + THICK
Z4 = Z3 + THICK

C

C*******************************************************************************
C
C LOOP FOR CALCULATING THE GRAVITY VALUES AT VARIOUS POINTS
C
DO 50 I=1,51
   X = (I - 26) * CX
   IF (I.EQ.26) GO TO 45
   B = (PI / 2. - ROIP)
   Q1 = ATAN(X / Z1 + SIN(B)/COS(B))
   Q2 = ATAN(X / Z2 + SIN(B)/COS(B))
   Q3 = ATAN(X / Z3 + SIN(B)/COS(B))
   Q4 = ATAN(X / Z4 + SIN(B)/COS(B))
   Y1 = (Q1 - B)
   Y2 = (Q2 - B)
   Y3 = (Q3 - B)
   Y4 = (Q4 - B)
   F1 = Y1 * (COS(Y1) / SIN(Y1)) - ALOG10(ABS(SIN(Y1)))
   F2 = Y2 * (COS(Y2) / SIN(Y2)) - ALOG10(ABS(SIN(Y2)))
   F3 = Y3 * (COS(Y3) / SIN(Y3)) - ALOG10(ABS(SIN(Y3)))
   F4 = Y4 * (COS(Y4) / SIN(Y4)) - ALOG10(ABS(SIN(Y4)))
   GRAV(I) = 0.00407 * DENS * (PI * THIK + X * C0S(B)) **2 * (F2 - F1 - F4 + F3)
   IF (ABS(X).LT.0.00001) GRAV(I) = 0.00407 * DENS * PI * THIK
45 CONTINUE
SUBTRACT THE BACKGROUND CONSTANT GRAV DUE TO THE ENTIRE SLAB.
GRAV(I) = GRAV(I) - C.01277 * DENS * THIK
50 CONTINUE
RETURN
END

C*******************************************************************************
C
SUBROUTINE GRAPH(Y,N, AMIN / AMAX)
C--MODIFIED FOR WMU DEC 1969 IN OCT., 1983.
C--PLOTS VALUES OF Y FOR EACH OF N VALUES OF X. (N) IS SIZE OF Y ARRAY.
C--SUBROUTINE CALCULATES MIN AND MAX VALUES OF Y UNLESS THEY ARE
C--SUPPLIED AS NON-ZERO VALUES BY CALLING ROUTINE.
DIMENSION Y(51), CHAR(81)
COMMON FIG(51,25)
DATA BLANK/PL, AST,DOT,1H,1H*,1H*,1H, / 
200 FORMAT(53X/"GRAVITY ANOMALY"/17X/5(10X,F10.4)/34X,1H:/ 
14(19X,1H:/))
300 FORMAT(6X,22("---")
400 FORMAT("",/25A1,"..",/81A1,1H:)
   IF(AMIN.NE.0. AND, AMAX.NE.0.) GO TO 11
   YMIN=Y(1)
   YMAX=Y(1)
   DO 10 I=1,N
   IF(YMIN.LT.Y(I)) GO TO 5
   IF(YMAX.GT.Y(I)) GO TO 6
   10 CONTINUE
   YMAX=Y(I)
   YMIN=Y(I)
11 RETURN
END

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
YMIN = Y(I)
GO TO 10
5 IF(YMAX.GT.Y(I)) GO TO 10
YMAX = Y(I)
10 CONTINUE
   IF (ABS(AMIN).LE.0.000001) GO TO 12
   YMIN = AMIN
11 IF (ABS(AMAX).LE.0.000001) GO TO 14
   YMAX = AMAX
12 YRANGE = YMAX - YMIN
   SF = 30./YRANGE
   Y1Q = YMIN + YRANGE/4.
   Y2Q = YMIN + YRANGE/2.
   YTQ = YMIN + .75*YRANGE
   WRITE(6,200) YMIN, Y1Q, Y2Q, YTQ, YMAX
   WRITE(6,300)
   DO 20 IJ = 1, N
      15 CHAR(K) = BLANK
      IF (IJ - (IJ/3)*3) 151, 152, 151
151 CHAR(21) = DOT
      CHAR(41) = DOT
      CHAR(61) = DOT
      C-- NEXT 5 STMTS PUT VERTICAL LINES AT UNIFORM INTERVALS GIVEN ON
      C-- NEXT CARD.
152 IF (IJ - (IJ/18)*18) 16, 16, 18
      16 CHAR(1) = PL
         DO 17 K = 1, 71, 10
         CHAR(K) = DOT
      17 CHAR(K+5) = PL
      18 I = (Y(IJ) - YMIN)*SF + 1.5
      C-- NEXT 2 CARDS ALLOW + OR - 100 PERCENT ERROR IN ESTIMATING
      C-- AMIN AND AMAX.
      IF (I.GT.81) I = I - 80
      IF (I.LT.1) I = I + 80
      19 CHAR(I) = AST
      20 WRITE(6,400) (FIG(IJ,II), II = 1, 25), CHAR
         WRITE(6,300)
      RETURN
END
### APPENDIX B

#### GRAVITY DATA

<table>
<thead>
<tr>
<th>STN.</th>
<th>LATITUDE</th>
<th>LONGITUDE</th>
<th>ELEV.</th>
<th>OBS. GRAV.</th>
<th>FR. AIR BOUG. AN.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>41 53.83</td>
<td>85 56.00</td>
<td>868.0</td>
<td>980276.665</td>
<td>8.413</td>
</tr>
<tr>
<td>A</td>
<td>41 53.83</td>
<td>85 56.00</td>
<td>868.0</td>
<td>980276.660</td>
<td>8.410</td>
</tr>
<tr>
<td>A</td>
<td>41 53.80</td>
<td>85 55.13</td>
<td>871.0</td>
<td>980276.032</td>
<td>8.106</td>
</tr>
<tr>
<td>AE1</td>
<td>41 53.88</td>
<td>85 54.83</td>
<td>877.0</td>
<td>980276.184</td>
<td>8.702</td>
</tr>
<tr>
<td>AE2</td>
<td>41 53.55</td>
<td>85 53.68</td>
<td>883.0</td>
<td>980275.294</td>
<td>8.871</td>
</tr>
<tr>
<td>AE3</td>
<td>41 53.53</td>
<td>85 53.08</td>
<td>913.0</td>
<td>980273.619</td>
<td>10.049</td>
</tr>
<tr>
<td>AE4</td>
<td>41 53.60</td>
<td>85 52.50</td>
<td>918.0</td>
<td>980273.565</td>
<td>10.359</td>
</tr>
<tr>
<td>AE5</td>
<td>41 53.85</td>
<td>85 52.00</td>
<td>926.0</td>
<td>980273.521</td>
<td>10.724</td>
</tr>
<tr>
<td>AE6</td>
<td>41 53.30</td>
<td>85 52.00</td>
<td>917.0</td>
<td>980273.485</td>
<td>10.635</td>
</tr>
<tr>
<td>AN1</td>
<td>41 54.68</td>
<td>85 56.00</td>
<td>870.0</td>
<td>980278.066</td>
<td>8.731</td>
</tr>
<tr>
<td>AN10</td>
<td>41 54.10</td>
<td>85 54.85</td>
<td>877.0</td>
<td>980278.640</td>
<td>9.335</td>
</tr>
<tr>
<td>AN11</td>
<td>41 54.68</td>
<td>85 54.85</td>
<td>858.0</td>
<td>980279.112</td>
<td>8.648</td>
</tr>
<tr>
<td>AN12</td>
<td>41 54.25</td>
<td>85 54.83</td>
<td>881.0</td>
<td>980276.777</td>
<td>9.120</td>
</tr>
<tr>
<td>AN13</td>
<td>41 54.15</td>
<td>85 52.50</td>
<td>911.0</td>
<td>980275.170</td>
<td>10.483</td>
</tr>
<tr>
<td>AN2</td>
<td>41 55.10</td>
<td>85 56.00</td>
<td>890.0</td>
<td>980277.681</td>
<td>9.600</td>
</tr>
<tr>
<td>AN3</td>
<td>41 55.10</td>
<td>85 57.15</td>
<td>881.0</td>
<td>980278.323</td>
<td>9.396</td>
</tr>
<tr>
<td>AN4</td>
<td>41 55.10</td>
<td>85 58.30</td>
<td>891.0</td>
<td>980277.555</td>
<td>9.567</td>
</tr>
<tr>
<td>AN5</td>
<td>41 55.55</td>
<td>85 58.30</td>
<td>902.0</td>
<td>980277.251</td>
<td>9.624</td>
</tr>
<tr>
<td>AN6</td>
<td>41 55.55</td>
<td>85 57.15</td>
<td>892.0</td>
<td>980278.710</td>
<td>10.143</td>
</tr>
<tr>
<td>AN7</td>
<td>41 55.55</td>
<td>85 56.50</td>
<td>893.0</td>
<td>980278.440</td>
<td>9.967</td>
</tr>
<tr>
<td>AN8</td>
<td>41 55.53</td>
<td>85 54.25</td>
<td>887.0</td>
<td>980278.970</td>
<td>9.963</td>
</tr>
<tr>
<td>AN9</td>
<td>41 55.55</td>
<td>85 54.85</td>
<td>878.0</td>
<td>980279.797</td>
<td>9.913</td>
</tr>
<tr>
<td>AW1</td>
<td>41 53.83</td>
<td>85 58.28</td>
<td>875.0</td>
<td>980275.610</td>
<td>8.017</td>
</tr>
<tr>
<td>AW2</td>
<td>41 53.85</td>
<td>85 0.65</td>
<td>932.0</td>
<td>980273.404</td>
<td>8.319</td>
</tr>
<tr>
<td>B</td>
<td>41 53.00</td>
<td>85 56.00</td>
<td>854.0</td>
<td>980275.590</td>
<td>7.261</td>
</tr>
<tr>
<td>B</td>
<td>41 53.00</td>
<td>85 56.00</td>
<td>854.0</td>
<td>980275.582</td>
<td>7.253</td>
</tr>
<tr>
<td>B</td>
<td>41 53.00</td>
<td>85 56.00</td>
<td>854.0</td>
<td>980275.629</td>
<td>7.300</td>
</tr>
<tr>
<td>BE1</td>
<td>41 53.18</td>
<td>85 55.10</td>
<td>863.0</td>
<td>980276.212</td>
<td>8.461</td>
</tr>
<tr>
<td>BE2</td>
<td>41 52.95</td>
<td>85 53.68</td>
<td>881.0</td>
<td>980274.225</td>
<td>8.511</td>
</tr>
<tr>
<td>BE3</td>
<td>41 52.90</td>
<td>85 52.85</td>
<td>913.0</td>
<td>980272.456</td>
<td>9.826</td>
</tr>
<tr>
<td>BE4</td>
<td>41 52.90</td>
<td>85 52.50</td>
<td>915.0</td>
<td>980272.368</td>
<td>9.926</td>
</tr>
<tr>
<td>BE5</td>
<td>41 52.90</td>
<td>85 52.00</td>
<td>918.0</td>
<td>980272.538</td>
<td>10.378</td>
</tr>
<tr>
<td>BW1</td>
<td>41 52.98</td>
<td>85 57.15</td>
<td>863.0</td>
<td>980274.655</td>
<td>7.203</td>
</tr>
<tr>
<td>BW2</td>
<td>41 52.98</td>
<td>85 58.30</td>
<td>845.0</td>
<td>980273.975</td>
<td>6.711</td>
</tr>
<tr>
<td>BW3</td>
<td>41 53.00</td>
<td>85 0.65</td>
<td>892.0</td>
<td>980271.902</td>
<td>7.147</td>
</tr>
<tr>
<td>BW4</td>
<td>41 53.00</td>
<td>85 1.80</td>
<td>892.0</td>
<td>980272.221</td>
<td>7.466</td>
</tr>
<tr>
<td>C</td>
<td>41 51.65</td>
<td>85 56.05</td>
<td>868.0</td>
<td>980271.225</td>
<td>6.231</td>
</tr>
<tr>
<td>C</td>
<td>41 51.65</td>
<td>85 56.05</td>
<td>868.0</td>
<td>980271.553</td>
<td>6.560</td>
</tr>
<tr>
<td>C</td>
<td>41 51.65</td>
<td>85 56.05</td>
<td>868.0</td>
<td>980271.574</td>
<td>6.581</td>
</tr>
<tr>
<td>CE1</td>
<td>41 51.65</td>
<td>85 55.15</td>
<td>897.0</td>
<td>980269.635</td>
<td>7.369</td>
</tr>
<tr>
<td>CE2</td>
<td>41 51.63</td>
<td>85 54.58</td>
<td>893.0</td>
<td>980270.175</td>
<td>7.562</td>
</tr>
<tr>
<td>CE3</td>
<td>41 51.63</td>
<td>85 54.00</td>
<td>889.0</td>
<td>980270.893</td>
<td>7.903</td>
</tr>
</tbody>
</table>

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
<p>| | | | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CE4</td>
<td>41</td>
<td>51.60</td>
<td>85</td>
<td>52.85</td>
<td>848.0</td>
<td>980273.541</td>
<td>6.740</td>
<td>-22.173</td>
<td></td>
</tr>
<tr>
<td>CE5</td>
<td>41</td>
<td>51.15</td>
<td>85</td>
<td>51.10</td>
<td>910.0</td>
<td>980270.742</td>
<td>10.447</td>
<td>-20.580</td>
<td></td>
</tr>
<tr>
<td>CE6</td>
<td>41</td>
<td>51.60</td>
<td>85</td>
<td>51.10</td>
<td>913.0</td>
<td>980271.513</td>
<td>10.826</td>
<td>-20.303</td>
<td></td>
</tr>
<tr>
<td>CN</td>
<td>41</td>
<td>52.28</td>
<td>85</td>
<td>56.00</td>
<td>854.0</td>
<td>980273.946</td>
<td>6.694</td>
<td>-22.424</td>
<td></td>
</tr>
<tr>
<td>CN1</td>
<td>41</td>
<td>52.28</td>
<td>85</td>
<td>55.13</td>
<td>862.0</td>
<td>980272.628</td>
<td>7.129</td>
<td>-22.262</td>
<td></td>
</tr>
<tr>
<td>CN2</td>
<td>41</td>
<td>52.25</td>
<td>85</td>
<td>54.00</td>
<td>904.0</td>
<td>980270.833</td>
<td>8.329</td>
<td>-22.494</td>
<td></td>
</tr>
<tr>
<td>CN3</td>
<td>41</td>
<td>52.25</td>
<td>85</td>
<td>52.83</td>
<td>901.0</td>
<td>980271.467</td>
<td>8.861</td>
<td>-22.040</td>
<td></td>
</tr>
<tr>
<td>CN4</td>
<td>41</td>
<td>52.03</td>
<td>85</td>
<td>51.10</td>
<td>920.0</td>
<td>980271.450</td>
<td>10.780</td>
<td>-20.588</td>
<td></td>
</tr>
<tr>
<td>CNW1</td>
<td>41</td>
<td>52.33</td>
<td>85</td>
<td>57.33</td>
<td>849.0</td>
<td>980273.846</td>
<td>6.694</td>
<td>-22.424</td>
<td></td>
</tr>
<tr>
<td>CNW2</td>
<td>41</td>
<td>52.68</td>
<td>85</td>
<td>58.90</td>
<td>862.0</td>
<td>980271.302</td>
<td>10.447</td>
<td>-22.262</td>
<td></td>
</tr>
<tr>
<td>CNW3</td>
<td>41</td>
<td>52.15</td>
<td>85</td>
<td>51.00</td>
<td>856.0</td>
<td>980271.467</td>
<td>8.861</td>
<td>-22.040</td>
<td></td>
</tr>
<tr>
<td>CNW4</td>
<td>41</td>
<td>52.18</td>
<td>85</td>
<td>1.75</td>
<td>864.0</td>
<td>980269.089</td>
<td>4.271</td>
<td>-25.187</td>
<td></td>
</tr>
<tr>
<td>CNW5</td>
<td>41</td>
<td>51.33</td>
<td>85</td>
<td>0.30</td>
<td>832.0</td>
<td>980271.570</td>
<td>3.669</td>
<td>-24.699</td>
<td></td>
</tr>
<tr>
<td>CNW6</td>
<td>41</td>
<td>52.15</td>
<td>85</td>
<td>0.05</td>
<td>864.0</td>
<td>980271.940</td>
<td>4.484</td>
<td>-26.202</td>
<td></td>
</tr>
<tr>
<td>CSW1</td>
<td>41</td>
<td>51.20</td>
<td>85</td>
<td>56.05</td>
<td>839.0</td>
<td>980271.733</td>
<td>4.685</td>
<td>-23.922</td>
<td></td>
</tr>
<tr>
<td>CSW2</td>
<td>41</td>
<td>50.30</td>
<td>85</td>
<td>56.05</td>
<td>924.0</td>
<td>980263.673</td>
<td>5.964</td>
<td>-25.541</td>
<td></td>
</tr>
<tr>
<td>CSW3</td>
<td>41</td>
<td>50.45</td>
<td>85</td>
<td>56.08</td>
<td>911.0</td>
<td>980261.911</td>
<td>4.251</td>
<td>-25.919</td>
<td></td>
</tr>
<tr>
<td>CSW4</td>
<td>41</td>
<td>50.50</td>
<td>85</td>
<td>57.53</td>
<td>880.0</td>
<td>980261.940</td>
<td>4.484</td>
<td>-26.202</td>
<td></td>
</tr>
<tr>
<td>CSW5</td>
<td>41</td>
<td>50.25</td>
<td>85</td>
<td>56.68</td>
<td>900.0</td>
<td>980261.670</td>
<td>3.274</td>
<td>-27.412</td>
<td></td>
</tr>
<tr>
<td>CSW6</td>
<td>41</td>
<td>50.15</td>
<td>85</td>
<td>0.05</td>
<td>864.0</td>
<td>980261.450</td>
<td>4.659</td>
<td>-25.857</td>
<td></td>
</tr>
<tr>
<td>CSW7</td>
<td>41</td>
<td>50.33</td>
<td>85</td>
<td>57.20</td>
<td>937.0</td>
<td>980261.320</td>
<td>6.789</td>
<td>-25.159</td>
<td></td>
</tr>
<tr>
<td>CSW8</td>
<td>41</td>
<td>51.20</td>
<td>85</td>
<td>58.35</td>
<td>842.0</td>
<td>980272.104</td>
<td>5.338</td>
<td>-23.371</td>
<td></td>
</tr>
<tr>
<td>CSW9</td>
<td>41</td>
<td>50.33</td>
<td>85</td>
<td>50.35</td>
<td>900.0</td>
<td>980261.450</td>
<td>4.659</td>
<td>-25.857</td>
<td></td>
</tr>
<tr>
<td>CSW1</td>
<td>41</td>
<td>51.70</td>
<td>85</td>
<td>57.15</td>
<td>839.0</td>
<td>980272.395</td>
<td>4.598</td>
<td>-24.009</td>
<td></td>
</tr>
<tr>
<td>CSW2</td>
<td>41</td>
<td>50.30</td>
<td>85</td>
<td>58.33</td>
<td>831.0</td>
<td>980273.312</td>
<td>4.763</td>
<td>-23.571</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>41</td>
<td>50.80</td>
<td>85</td>
<td>56.05</td>
<td>880.0</td>
<td>980267.654</td>
<td>5.060</td>
<td>-24.945</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>41</td>
<td>50.80</td>
<td>85</td>
<td>56.05</td>
<td>880.0</td>
<td>980267.864</td>
<td>5.270</td>
<td>-24.735</td>
<td></td>
</tr>
<tr>
<td>DE1</td>
<td>41</td>
<td>50.55</td>
<td>85</td>
<td>54.90</td>
<td>914.0</td>
<td>980265.479</td>
<td>6.456</td>
<td>-24.708</td>
<td></td>
</tr>
<tr>
<td>DE2</td>
<td>41</td>
<td>50.53</td>
<td>85</td>
<td>53.73</td>
<td>924.0</td>
<td>980266.107</td>
<td>8.055</td>
<td>-25.450</td>
<td></td>
</tr>
<tr>
<td>DE3</td>
<td>41</td>
<td>50.53</td>
<td>85</td>
<td>52.85</td>
<td>935.0</td>
<td>980266.222</td>
<td>9.204</td>
<td>-25.676</td>
<td></td>
</tr>
<tr>
<td>DW1</td>
<td>41</td>
<td>50.78</td>
<td>85</td>
<td>57.18</td>
<td>904.0</td>
<td>980266.052</td>
<td>5.745</td>
<td>-25.078</td>
<td></td>
</tr>
<tr>
<td>DW2</td>
<td>41</td>
<td>50.80</td>
<td>85</td>
<td>58.35</td>
<td>851.0</td>
<td>980269.471</td>
<td>4.148</td>
<td>-24.867</td>
<td></td>
</tr>
<tr>
<td>DW3</td>
<td>41</td>
<td>50.78</td>
<td>85</td>
<td>59.40</td>
<td>842.0</td>
<td>980269.944</td>
<td>3.806</td>
<td>-24.903</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>41</td>
<td>49.90</td>
<td>85</td>
<td>56.05</td>
<td>943.0</td>
<td>980261.402</td>
<td>6.079</td>
<td>-26.073</td>
<td></td>
</tr>
<tr>
<td>EE1</td>
<td>41</td>
<td>49.90</td>
<td>85</td>
<td>56.05</td>
<td>943.0</td>
<td>980261.420</td>
<td>6.097</td>
<td>-26.056</td>
<td></td>
</tr>
<tr>
<td>EE2</td>
<td>41</td>
<td>49.90</td>
<td>85</td>
<td>56.05</td>
<td>943.0</td>
<td>980261.468</td>
<td>6.145</td>
<td>-26.008</td>
<td></td>
</tr>
<tr>
<td>EE3</td>
<td>41</td>
<td>49.90</td>
<td>85</td>
<td>56.05</td>
<td>943.0</td>
<td>980261.537</td>
<td>6.214</td>
<td>-25.939</td>
<td></td>
</tr>
<tr>
<td>EE4</td>
<td>41</td>
<td>49.90</td>
<td>85</td>
<td>54.90</td>
<td>936.0</td>
<td>980262.346</td>
<td>6.384</td>
<td>-25.550</td>
<td></td>
</tr>
<tr>
<td>EE5</td>
<td>41</td>
<td>49.90</td>
<td>85</td>
<td>54.90</td>
<td>936.0</td>
<td>980262.497</td>
<td>6.516</td>
<td>-25.398</td>
<td></td>
</tr>
<tr>
<td>EE6</td>
<td>41</td>
<td>49.90</td>
<td>85</td>
<td>53.75</td>
<td>911.0</td>
<td>980265.351</td>
<td>7.018</td>
<td>-24.044</td>
<td></td>
</tr>
<tr>
<td>EE7</td>
<td>41</td>
<td>49.90</td>
<td>85</td>
<td>53.75</td>
<td>911.0</td>
<td>980265.292</td>
<td>6.959</td>
<td>-24.102</td>
<td></td>
</tr>
<tr>
<td>ES1</td>
<td>41</td>
<td>49.43</td>
<td>85</td>
<td>54.93</td>
<td>908.0</td>
<td>980263.067</td>
<td>5.154</td>
<td>-25.805</td>
<td></td>
</tr>
<tr>
<td>ES2</td>
<td>41</td>
<td>49.43</td>
<td>85</td>
<td>53.75</td>
<td>888.0</td>
<td>980265.318</td>
<td>6.024</td>
<td>-24.253</td>
<td></td>
</tr>
</tbody>
</table>
E 49.43 85 52.58 895.0 980268.166 9.030 -21.486
W 49.90 85 56.63 955.0 980260.582 6.388 -26.174
E 49.90 85 56.63 955.0 980260.621 6.427 -26.135
W 49.90 85 56.35 936.0 980261.729 5.747 -26.167
E 49.90 85 56.95 945.0 980261.395 6.260 -25.961
W 49.90 85 57.50 910.0 980263.438 5.012 -26.016
E 49.90 85 58.80 912.0 980262.979 4.696 -26.399
W 49.90 85 58.68 875.0 980265.407 3.613 -26.221
E 49.90 85 59.20 828.0 980268.500 2.285 -25.946
W 49.70 85 59.00 850.0 980265.934 2.162 -26.819
E 49.50 85 59.00 847.0 980267.212 3.457 -25.422
W 49.30 85 59.00 822.0 980267.756 1.948 -26.079
E 49.08 85 58.75 840.0 980266.200 2.414 -26.226
W 49.90 85 57.20 915.0 980263.304 5.347 -23.851
E 49.90 85 57.20 915.0 980263.188 5.230 -23.967
W 49.05 85 58.15 842.0 980265.328 1.774 -26.934
E 49.05 85 57.65 882.0 980262.932 3.141 -26.932
W 49.28 85 58.40 855.0 980265.403 2.729 -26.423
E 49.70 85 58.40 880.0 980264.273 3.323 -26.681
W 49.70 85 56.65 930.0 980261.820 5.573 -26.136
E 49.70 85 56.05 910.0 980262.793 4.665 -26.362
W 48.83 85 56.08 874.0 980262.771 2.556 -27.244
E 49.25 85 56.05 903.0 980261.748 3.822 -27.035
W 49.90 85 57.80 919.0 980262.959 5.379 -25.955
E 49.90 85 57.80 919.0 980262.968 5.388 -25.946
W 49.90 85 58.35 893.0 980263.820 4.227 -26.392
E 49.90 85 58.35 898.0 980263.881 4.287 -26.331
W 49.90 85 58.95 862.0 980266.104 3.163 -26.228
E 49.90 85 58.95 862.0 980266.127 3.186 -26.205
W 49.90 85 59.38 816.0 980269.335 1.991 -25.831
E 49.90 85 59.38 816.0 980269.365 2.021 -25.801
W 50.35 86 0.33 806.0 980270.313 1.437 -26.045
E 50.43 86 1.30 836.0 980269.190 2.935 -25.570
W 49.83 86 1.80 828.0 980267.830 1.795 -26.436
F 48.60 85 56.10 867.0 980262.694 2.165 -27.396
F 48.60 85 56.10 867.0 980262.749 2.160 -27.341
F 48.60 85 56.10 867.0 980262.904 2.375 -27.186
F 48.60 85 56.10 867.0 980262.557 2.027 -27.534
F 48.60 85 56.10 867.0 980262.811 2.281 -27.280
F 48.60 85 56.10 867.0 980262.631 3.230 -26.740
F 48.60 85 54.90 879.0 980264.319 5.766 -24.512
F 48.60 85 53.75 888.0 980264.319 5.766 -24.512
F 48.60 85 52.80 897.0 980265.915 8.203 -22.376
F 48.60 85 51.95 878.0 980268.171 8.677 -21.259
F 48.55 85 50.88 871.0 980269.512 9.434 -20.264
F 48.55 85 50.05 775.0 980277.257 8.149 -18.275
F 48.33 85 56.70 883.0 980262.041 2.673 -27.434
F 49.05 85 57.53 371.0 980263.985 3.159 -26.538
F 49.05 85 57.95 864.0 980264.130 2.646 -26.813
F 49.08 85 59.00 803.0 980267.545 0.273 -27.101
F 49.08 86 0.05 807.0 980267.002 0.111 -27.404
F 49.05 86 1.75 817.0 980266.635 0.729 -27.127
F 49.15 85 56.13 853.0 980262.598 1.425 -27.659
G 49.15 85 56.13 853.0 980262.643 1.470 -27.614
G 49.15 85 56.13 853.0 980262.729 1.557 -27.527
G 49.15 85 56.13 853.0 980262.547 1.374 -27.710

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
BIBLIOGRAPHY


Bucher, W. H. Cryptoexplosion structures caused from within or without the earth (Astroblemes or Gleoblemes?). Am. J. Sc., 1963, 261, 567-649.


Innes, M. J. S., Recent advances in meteorite crater research at the Dominion Observatory, Ottawa, Canada, Meteoritics, 1964, 2, 219-241.


Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.


EXPLANATION
Contour Interval: 1.0 milligal
MSU Network Base Station
Instrument: Worden Prospector
I.G.F. 1930
Density: 2.67 gm/cc
Survey Date: Jan. 1983 to July
Station Location
Oil Field

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
EXPLANATION

Contour Interval: 1.0 milligal

MSU Network Base Station

Instrument: Worden Prospector

L.G.F. 1930

Density: 2.67 g/cc

Survey Date: Jan. 1983 to July 1983

Station Location

Oil Field
COUNTY, MICHIGAN.

**EXPLANATION**

Contour Interval: 25 gammas

Base Station

Instrument: Proton Precession Magnetometer (Geometrica G-816)

Survey Date: July 1983 to Aug. 1983.

- Declination: 1.8°
- Inclination: 71°

**Map Features**

- Oil Field
- Contour lines indicating variations in magnetic anomalies

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
Contour Interval: 25 gammas

Base Station

Instrument: Proton Precession Magnetometer (Geometrics G-816)

Survey Date: July 1983 to Aug. 1983.

Oil Field
Declination: 1.8°
Inclination: 71°
FIRST HARMONIC RESIDUAL GRAVITY

16 MILES; SOUTH-CENTRAL CAS
GREEVITY MAP, WAVELENGTH-
CAL CASS COUNTY, MICHIGAN.

EXPLANATION
Contour Interval: 0.5 m
Instrument: Worden Pro
Density: 2.67 gm/cc
Survey Date: Jan. 1983
Oil Field

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
EXPLANATION

Contour Interval: 0.5 milligals

MSU Network Base Station

Instrument: Worden Prospector

I.G.F. 1930

Density: 2.67 gm/cc

Survey Date: Jan. 1983 to July 1983

Station Location

Oil Field

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
FIRST HARMONIC RESIDUAL GRAVITY MAP

SOUTH-CENTRAL CASS COUNTY
EXPLANATION
Contour Interval: 0.25 millilgal
\( \oplus \) MSU Network Base Station
Instrument: Worden Prospector
I.G.F. 1930
Density: 2.67 gm/cc
Survey Date: Jan. 1983 to
Station Location
Oil Field

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
EXPLANATION

Contour Interval: 0.25 milligals

MSU Network Base Station

Instrument: Worden Prospector

I.G.F. 1930

Density: 2.67 gm/cc

Survey Date: Jan. 1983 to July 1983

Station Location

Oil Field
SECOND HARMONIC RESIDUAL GRAVITY MILES; SOUTH-CENTRAL CASS

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
SECOND HARMONIC TREND SURFACE

LENGTH = 28 MILES; SOUTH-CENTRAL MICHIGAN.
FACE GRAVITY MAP WAVE-ITRAL CASS COUNTY,

EXPLANATION

Contour Interval: 1.0 milligals
∇ MSU Network Base Station
Instrument: Worden Prospector
I.G.F. 1930
Density: 2.67 gm/cc
Survey Date: Jan. 1983 to July

Oil Field

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
EXPLANATION

Contour Interval: 1.0 milligals
⊕ MSU Network Base Station
Instrument: Worden Prospector
I.G.F. 1930
Density: 2.67 gm/cc
Survey Date: Jan. 1983 to July 1983
Station Location
Oil Field
GRAVITY MAP, WAVELENGTH
AL CASS COUNTY, MICHIGAN

EXPLANATION
Contour Interval: 0.5 milligals
MSU Network Base Station
Instrument: Worden Prospector
I.G.F. 1930
Density: 2.67 gm/cc
Survey Date: Jan. 1983 to Jul.
Station Location

Oil Field

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
Explanations:

Contour Interval: 0.5 milligals

MSU Network Base Station

Instrument: Worden Prospector

Density: 2.67 gm/cc

Survey Date: Jan, 1983 to July 1983

Station Location: Oil Field

Legend:

- 41°50'
- 41°55'

Map Area:

+ Birch Lake
- Sawhead Lake

Scale: 0.5 mile

Credit:

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
MAP, SOUTH-CENTRAL MICHIGAN.

EXPLANATION
Contour Interval: 25 gammas
Base Station
Instrument: Proton Precession Magnetometer
(Geometrics G-616)
Survey Date: July 1983 to Aug. 1983.

- Oil Field
Declination: 1-8°
Inclination: 71°
PLATE VIII

EXPLANATION
Contour Interval: 25 gammas
Base Station
Instrument: Proton Precession Magnetometer (Geometrics G-816)
Survey Date: July 1983 to Aug. 1983.
Oil Field
Declination: 1.8°
Inclination: 71°

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.