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GRAVITY ANOMALIES AS INDICATORS OF GROUNDWATER RESERVES IN GLACIAL DEPOSITS

Final Report

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This study was conducted in terrain covered with glacial debris to determine the value of gravity measurements in the search for gravel deposits. The area used was a part of Ohio where there was considerable data available on the character of the glacial cover and the bedrock surface beneath. A residual gravity map was calculated for the area using 750 field stations. This map was compared to existing bedrock maps. The gravity low was over the Teays River Valley. Seismic

refraction verified these conclusions and defined the shape of this preglacial valley. Two-dimensional gravity model studies were then conducted to determine if the lows within the major low were caused by high concentrations of gravel. The model studies suggest strongly that gravel is related to the greatest lows.

The results indicate clearly that gravity exploration is the best first method of exploring for gravel in any area similar to the study area. Only about half of the field stations were necessary to find the gravel. Once gravity has been used to locate a gravel, other methods must be employed to quantitatively evaluate the prospect. The combination of gravity exploration for location followed by other methods for evaluation can greatly reduce the cost of exploration for gravel.

CONTENTS

INTRODUCTORY COMMENTS

This report consists of three parts--a resume of the research in non-technical language and two appendices that present the details of the study.[1] Appendix I contains the gravity data and the computer analyses of these data. It illustrates some methods of enhancement of field data to emphasize gravity variations due to shallow density changes, and it also describes the detail necessary to be able to delineate a buried valley and the gravels within it. Appendix II delineates the buried valley with seismic refraction, then uses two-dimensional gravity modeling to improve the knowledge of the material filling the valley. The reader is referred to these appendices for specific details of any part of the study.

Both of the appendices were done as partial fulfillment of requirements for advanced degrees at Wright State University. These students, Mr. Contrino and Mr. King, served as research assistants in this study under the direction of Dr. Richard. The theses are essentially unchanged, and each appendix, therefore, is relatively complete with duplication in places. Bibliographic references are found at the end of each appendix. This format allows the reader the opportunity to find the conclusion of the investigators quickly. If he then wants to check the validity of the results he can consult the appendices.

PURPOSE

The purpose of this study is to evaluate the premise that analysis of gravity field data provides an inexpensive method for locating large areas of well sorted gravel deposits. These deposits, which would be good groundwater reservoirs, lie in unconsolidated materials that exist in many geologic settings such as glacial terrain, intermontane basins, deltaic regions, and large alluviated valleys. Wherever the gravels have significantly different density from the surrounding material,

[1] Appendix I and II are included here only by title, abstract, and bibliography. Persons wishing to consult the full text of the appendices (including maps) are referred to copies of the Final Report in the STINFO Center, U.S. Army Engineer Topographic Laboratories, or in the Geology Department Library, Wright State University.

they should be locatable by measuring the acceleration due to gravity over the area. This study used terrain covered with glacial material as a model to test the reliability of gravity techniques and to compare the gravity method with other standard methods of exploration.

ACKNOWLEDGMENTS

The authors wish to thank the U.S. Army Engineer Topographic Laboratories and the Wright State University for support of the project. They wish to thank also the U.S. Army Topographic Command for loan of a gravity meter for the initial studies, the Ohio State Department of Natural Resources (Division of Water) for providing well log data and geologic maps, the U.S. Geological Survey (Water Resources Division) for seismic data from previous studies, and the consulting firm of Dames and Moore for providing area well log data. Gratitude is also expressed to petroleum and geophysical companies, especially Taylor Exploration and Gulf Research for giving Wright State seismic equipment necessary for the investigation.

LOCATION AND GEOLOGIC SETTING OF THE STUDY AREA

The area is in central Ohio and is covered by the following Geological Survey 7½-minute Topographic Quadrangle Maps: northern two-thirds of the Springfield, New Moorefield, and Donnelsville sheets, and essentially all of the Urbana East, Urbana West, Thackery, Kingscreek, Northville, and St. Paris sheets--an area of approximately 450 square miles. Springfield and Urbana are the only sizable cities. The Mad River valley between these two cities is developing rapidly with industry and housing. Because of this development there is a considerable amount of geologic data already available.

This area was selected because the geologic setting is ideal for testing the theory outlined above. Prior to glaciation, a major stream (the Teays) flowed northwest through the area in a valley having a maximum relief of 700 feet. The rocks cut by this stream system were resistant dolomites underlain by less resistant interbedded limestones and shale. As the glaciers advanced they dammed the river long enough for the valley to fill with low-energy, water-deposited sediments (deposits in still water carried in by tributary streams). Subsequently the glaciers covered these deposits. Some of the initial valley fill was removed by the ice, then the entire area was covered by unsorted, ice-deposited sediments.

During the retreat of the front of the ice sheet the topography was again modified. The streams fed by the melting glacier eroded to approximately 250 feet below the present level. Where this valley was cut in unconsolidated material it was as much as a mile wide but where it was cut into rock it was as little as 100 yards wide. As the glaciers waned, these streams were overloaded with debris and refilled the valleys they had cut with well sorted gravel. They continued to deposit gravel and built the broad, flat valleys of the Mad River and Buck Creek.

As the glaciers advanced and waned several times, the process outlined above was repeated. Younger streams may have recut older stream valleys or may have cut new ones that cut across the older valleys. Large gravel bodies are present where these channels were cut and refilled. This is particularly true where the valley was cut in unconsolidated material. Where it was cut into bedrock the valley was narrow and had less space available for gravel accumulation.

PAST METHODS OF EXPLORATION FOR GRAVELS

Exploration in this area has been limited to seismic exploration, some resistivity, analysis of existing water wells, ~~and some test drilling with various types of associated~~ logging. Appendix II summarizes the previous work. The seismic and drilling methods proved most successful. Seismic techniques delineated areas over the preglacial valley and the drilling determined the composition of the fill material. Both methods had to be used together because of the irregularity of the bedrock surface and the variation in composition of the fill. Some areas have over 450 feet of fill and no gravel.

Seismic studies are expensive, cover a small area and take considerable time. Drilling and sampling are also expensive and give information only on the hole drilled.

GRAVITY EXPLORATION FOR GRAVEL

This study has demonstrated that gravity exploration can locate areas of potential gravel deposits at low cost and can focus on sites for drilling and sampling. Appendix I gives the details of the technique and shows that gravity exploration is clearly the best and least expensive first exploration tool. It does not eliminate other exploration tools but focuses on areas where the probability of success is high. This eliminates random seismic exploration. Seismic studies are only needed for added definition of the deep alluvial sites. Drilling would be limited to the largest gravity low where the potential of gravel is highest. Appendix II essentially verifies the validity of the gravity method by using seismic depth determinations, well log data, and two-dimensional gravity modeling to verify the existence of gravel.

Absolute proof would require drilling the sites that have been modeled and sampling other potential gravel areas.

Four hundred and fifty square miles of glacial terrain in a setting similar to the study area can be explored for gravel sites in about fourteen man days and about one day of IBM 1130 computer time. This would produce a probability map similar to Figure 1. As the complexity of the geology increases and the size of the gravel deposit decreases, the time for the study increases and the results become more uncertain. The spacing of the data points in the field should be on an approximate grid about equal to the width of the valley or gravel deposit to be found. If the gravel is significantly thinner or closer in density to the surrounding material than in this study, all other controls such as latitude or elevation must be more accurate. Finally, as the complexity of geology increases the number of valid interpretations of the data increases. Considerable knowledge of local geology is then necessary for the correct evaluation of the data.

Some of the methods of analysis of the gravity data are described in Appendix I and II. In Appendix I, the regional or deep-seated density variations were removed subtracting a least square surface from the Bouguer anomaly. Deep-seated effects can also be removed with a mathematical derivative map. Appendix II studies the compositional variation of the material

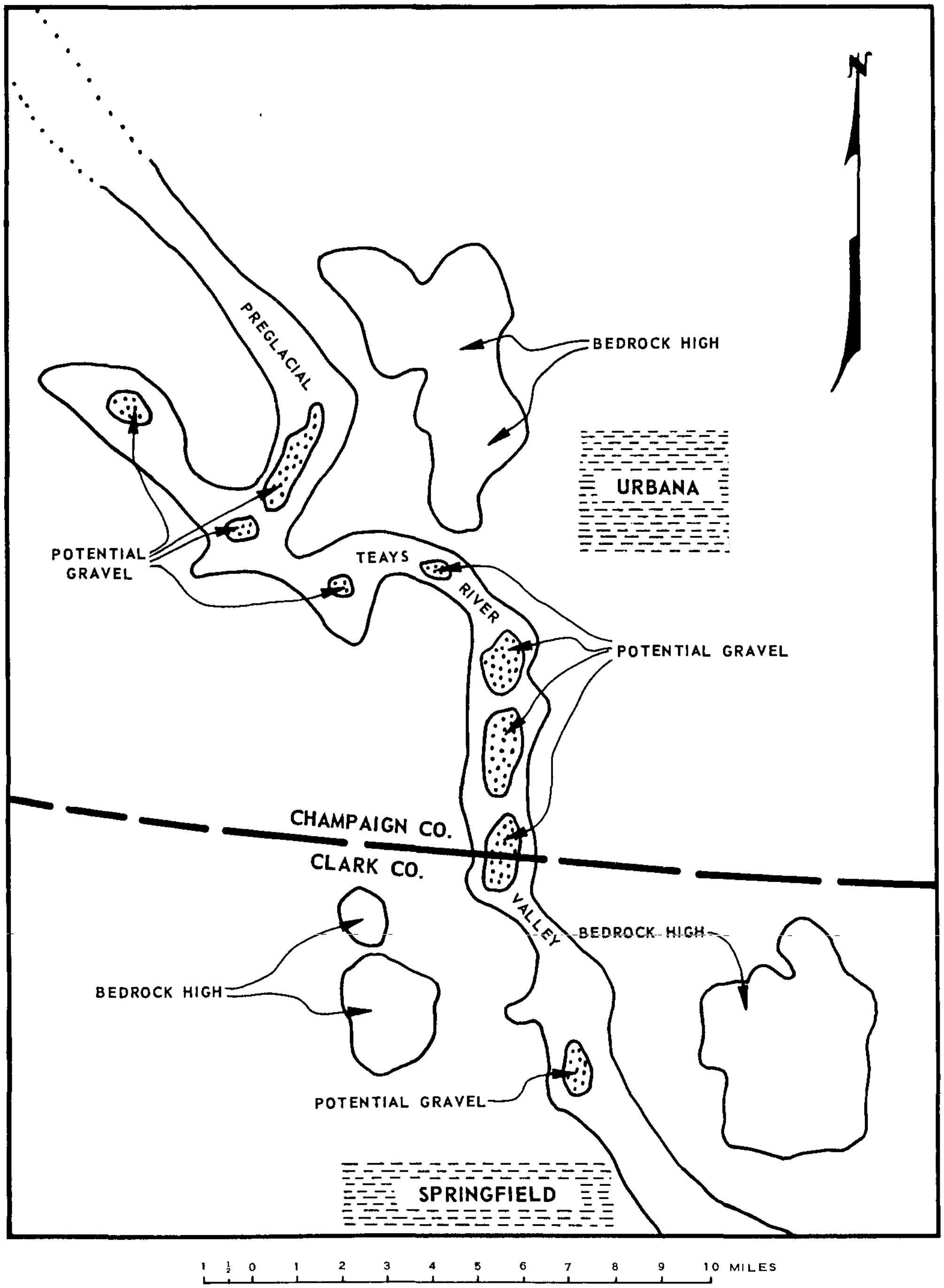

Figure 1. Map of a portion of Ohio showing the location of the Teays River Valley, potential gravel deposits, and bedrock high in the study area. These are sites located by gravity exploration.

using a polygon two-dimensional gravity model of the valley. The cross sectional shape of the valley was determined seismically to increase the validity of the density study. Two-dimensional analysis is only valid if the anomaly to be studied is long relative to its width. This requirement was reasonably well met in this study. If the two-dimensional aspect is not met then a three-dimensional analysis must be done. Computer programs are available for this type of study.

The two-dimensional modeling in this area improved our understanding of the distribution of sediments filling the ancestral valley. Gravity lows were explained best by increasing the thickness of the surface gravel. Certainly the fill is more complex than the model indicates but there is a high probability that the model approximates the real situation.

RESULTS OF THE STUDY

Where horizontal rocks are covered by glacial deposits of lower density, gravity studies can quickly and inexpensively delineate areas of greater thickness of glacial cover and sites within the glacial material of sizable gravel deposits (Figure 1). The gravel, because it has better sorting than the other overburden, is shown by a gravity low. The model studies (Appendix II) indicate the water-saturated gravel density to be 2.0, which is significantly lower than other near-surface materials. This is what produces the gravity low. As long as the other materials are reasonably uniform in density, the gravity lows, after deep seated effects have been removed, will be caused by either greater thickness of overburden or a higher percent of gravel. Seismic studies of the low can determine which of these variations caused the anomaly. In this study the two effects are superimposed. If there had not been a preglacial erosion system, analysis would have been easier.

An understanding of the geologic development is needed if two-dimensional modeling is going to be done. Many models can produce the observed anomaly and the geologic input is necessary to develop the correct model. Modeling can reduce the number of borings and analyses of samples required to completely define the gravel body.

Once the density contrast of the overburden to bedrock is known, analysis of gravity data can produce a map that relates directly to bedrock elevation. The residual gravity maps of the study area do not agree with existing bedrock maps that were constructed from well log data and some seismic data (see Appendix II). The seismic work of this study demonstrated that the gravity map was the most accurate indicator of this bedrock surface.

To do a gravity study of an area of 450 square miles looking for bodies one to two miles in diameter would take an experienced man about three weeks if he is able to use available elevation and latitude data. The resultant map would have the deep-seated effects removed and would show a series of gravity lows that would be sites of thick overburden or gravel. If smaller bodies were to be explored for, the station density and elevation and latitude control would have to be improved. This may require a survey crew, which would increase the cost. Even with this increased cost the gravity method would be several orders of magnitude less costly than any other.

CONCLUSIONS

Gravity exploration for large gravel deposits in areas covered by glacial terrain is better than any other exploration method because it focuses on all potential gravel sites in the area and gives an indication of the size of a body. Geologic knowledge of the area studied is necessary for good results. After the major deposits are located other techniques must be employed to totally define and evaluate the body.

Proof of the above statements would require drilling the gravel sites shown in Figure 1. If this technique were proved beyond any doubt for glacial cover, there is no reason why it could not be applied in areas such as deltas and intermontane basins.

Because a gravity study is so inexpensive in comparison to the other exploration methods, it should always be done as an initial phase of study of an area where large gravel deposits are needed for water supply or construction materials.

APPENDIX I

The Use of Computer Analysis in Interpreting Gravity Anomalies in Glacial Terrain

Presented in partial fulfillment of
the requirements for the M.S.T. Degree
at Wright State University

March 15, 1973

Prepared by

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ABSTRACT

This study is concerned with determining the validity and usefulness of coupling gravity data and high speed computer analysis to locate subsurface coarse-grained deposits in a glacial terrain.

Bouguer anomaly values were calculated for approximately 750 gravity stations in a 670-square-mile area directly north of Springfield, Ohio. Various data manipulation techniques were used to enhance the original data and six clearly distinguishable localized gravity lows were discovered within a larger gravity low. The large anomaly represented the buried preglacial Teays River which crossed the area, and the smaller anomalies were thought to represent well sorted, and hence less dense, gravel deposits.

In addition, variations in the station density were studied to determine the minimum effective density. It was concluded that a survey using station spacing of approximately the size of the expected anomaly, and removing the large regional gravity effects, was sufficient for clear definition of the anomalies.

In an efficiency analysis, it was further concluded that useful results could have been achieved with approximately three man weeks of gravity data collection and reduction time and less than eight hours of computer/plotter time.

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APPENDIX II

A Study of a Buried Valley in West Central Ohio Using Seismic Refraction and Two-Dimensional Gravity Model Studies

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science

Prepared by

Charles Thomas Contrino
B. S., University of Illinois, 1971

1973
Wright State University

ABSTRACT

A major buried preglacial valley trends in a northwesterly direction through Clark and Champaign Counties, Ohio. In the summer of 1971 and the spring and fall of 1972 a seismic refraction study was conducted to determine the areal extent and depth of the bedrock valley. Other depths from two previous refraction surveys and numerous well logs were added to these new data, and a bedrock contour map was constructed. This map was then compared to existing bedrock contour maps. These comparisons revealed one major discrepancy--the older maps failed to show the existence of a four-mile-long "meander" in the bedrock valley.

After the valley was defined, two-dimensional gravity models were constructed across the preglacial valley at four different sites. This was to examine reasonable density distributions within the material filling the valley and was done with the aid of a computer program written by Manik Talvani (1959). The input is a two-dimensional model comprised of generally three distinct bodies of fill and their respective densities. The bodies are glacial outwash, till and clay. The densities of the bodies were determined through sieve analysis, grain size correlation and literature research. The output is a mathematically calculated gravity anomaly which is then compared with a residual gravity profile. The initial comparison is good but is improved further with an introduction of an outwash-filled channel cut into the till body. This suggests that the most negative gravity anomaly over the valley reflects the position of the greatest thickness of the gravel.

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