Geophysical Investigations in the Tri-State Zinc and Lead Mining District

By

J. J. JAKOSKY, R. M. DREYER
and C. H. WILSON

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CONTENTS

PAGE

Foreword 9
Introduction 11
  Purpose of the investigation 11
  Acknowledgments 12
  Previous geophysical investigations in the Tri-State area 13
Geography 16
  Location of the area 16
  Topography 16
  Zinc and lead production in the Tri-State district 17
Geology 17
  General geologic setting 17
  Method of selecting areas for geophysical investigations 21
  Geologic description of the areas studied in geophysical investigations .. 23
    Neutral area 24
    Mullen area 25
    Jarrett area 25
    Walton area 27
    Karcher area 29
    Swalley area 29
    Greenback area 31
    McBee-Martin area 32
Geophysical Survey 33
  Instruments, field procedure, and presentation of data 33
    Introduction 33
    Magnetic survey 34
      Instruments 34
      Field procedure 34
      Correction of field measurements 35
        Temperature corrections 35
        Diurnal corrections 37
        Latitude and longitude corrections 37
        Datum correction 37
      Accuracy of data 37
      Presentation of data 38
    Gravity survey 38
      Instruments 38
      Field procedure 38
      Computation and correction of field measurements 38
        Calibration of the instrument 39
        Elevation correction 39
        Latitude correction 39
        Regional gradient 39

PAGE
Accuracy of data 39
Presentation of data 40
Natural potential survey 40
Instruments 40
Field procedure 40
Computation and correction of field measurements 41
Accuracy of data 42
Presentation of data 42
Resistivity survey 42
Instruments and measurement technique 42
Field procedure 44
Computation of field measurements 45
Factors influencing interpretation 46
Presentation of data 47
Geothermal survey 49
Instruments and equipment 49
Field procedure 49
Computation and correction of field measurements 50
Accuracy of data 51
Presentation of data 51
Geochemical survey 51
Instruments and procedure 51
Discussion of elements 55
Relation between spectral intensity and sample composition .. 60
Accuracy of data 62
Sources of analytical error 62
Errors due to variations in arcing conditions 62
Errors due to variations in visual determination of spectral intensity 63
Errors due to impurities in the electrodes 64
Errors due to interfering lines 65
Errors due to contamination of samples 65
Errors due to sampling 66
Errors due to variations in method of developing spectrograms 66
Errors due to variations in exposure time 66
Validity of readings 66
Validity of soil analyses 66
Mullen area 74
Walton area 74
Karcher area 75
Swalley area 75
Greenback area 75
Validity of Cherokee shale analyses 75
Validity of Mississippian limestone analyses 75
Presentation of data 77

PAGE
Geological basis for geophysical interpretations 77
Magnetic anomalies 77
Gravity anomalies 79
Natural potential anomalies 79
Resistivity anomalies 80
Geothermal anomalies 82
Geochemical anomalies 82
Geophysical interpretations and geological correlations 82
Geological correlations in different areas 82
Regional survey 82
Magnetic survey 83
Gravity survey 84
Comparison and correlation of magnetic and gravity results 84
Geochemical survey 84
Shale samples 84
Limestone samples 87
Shale and limestone samples 88
Neutral area 89
Magnetic survey 90
Gravity survey 90
Natural potential survey 90
Resistivity survey 90
Profile 90
Depth stations 90
Geothermal survey 91
Geochemical survey 91
Conclusions 91
Mullen area 92
Magnetic survey 94
Gravity survey 95
Natural potential survey 96
Resistivity survey 96
Profiles 96
Depth stations 97
Geothermal survey 98
Geochemical survey 100
Jarrett area 100
Walton area 103
Magnetic survey 103
Gravity survey 106
Natural potential survey 107
Resistivity survey 109
Profiles 109
Depth stations 113
Geothermal survey 113
Geochemical survey 117
Summary 117

PAGE
Karcher area 119
Magnetic survey 119
Gravity survey 119
Natural potential survey 120
Resistivity survey 120
Profiles 122, 123, 124
Depth stations 125
Geothermal survey 128
Geochemical survey 126
Summary 130
Swalley area 132
Gravity survey 133
Resistivity survey 133
Geochemical survey 135
Greenback area 135
Gravity survey 135
Resistivity survey 137
Geothermal survey 138
Geochemical survey 138
McBee-Martin area 139
Results of gravity, resistivity, and temperature measurements 139
Summary and coördination of geophysical results 140
Factors influencing interpretations 140
Regional magnetic and gravity investigations 141
Investigations in local areas 142
Magnetic survey 142
Gravity survey 142
Natural potential survey 143
Resistivity survey 144
Geothermal survey 145
Geochemical survey 146
Conclusions 146
Evaluation of geophysical prospecting as an aid to ore exploration in the
Regional geological implications of geophysical results 148
Tri-State district 150
References 151

ILLUSTRATIONS

PLATE PAGE

1. *A*. Magnetometer and operator in field; *B*. Field set-up for measuring natural earth potentials 36
2. *A*. Field set-up for measuring earth resistivity; *B*. Thermometer bridge and resistance thermometer set-up for temperature measurements 43

FIGURE

1. Regional map of northwestern part of Tri-State mining district........ 23
2. Map showing contours on the top of the limestone, mineralized zones, and traverse lines in the Mullen area........ 24
3. Map showing contours on the top of the limestone and traverse lines in the Jarrett area 26
4. Map showing contours on the top of the limestone, topography, mineralized zone, and traverse lines in the Walton area........ 27
5. Map showing contours on the top of the limestone, topography, mineralized zone, and traverse lines in the Karcher area........ 28
6. Map showing contours on the top of the limestone, mineralized zone, and traverse lines in the Swalley area........ 30
7. Map showing contours on the top of the limestone, mineralized zone, and traverse lines in the Greenback area........ 31
8. Map showing mineralized zone and traverse lines in the McBee-Martin area 32
9. Isodynamic contour map near Baxter Springs, Kansas........ 34
10. Map showing isanomalic gravity contours in an area near Baxter Springs, Kansas 35
11. Anomaly caused by electrically conductive zone crossed by resistivity traverse 48
12. Geochemical profiles for drill holes showing ore mineralization........ 52
13. Geochemical profiles for nonmineralized drill holes........ 53
14. Vertical distribution of lead in drill holes........ 54
15. Vertical distribution of zinc in drill holes........ 56
16. Profiles along a traverse in the Neutral area........ 89
17. Resistivity depth profiles in the Neutral area........ 91
18. Profiles along traverse 1-1′ in the Mullen area........ 93
19. Profiles along traverse 11-11′ in the Mullen area........ 94
20. Profiles along traverse 111-111′ in the Mullen area........ 95
21. Map showing natural potential contours in the Mullen area........ 98
22. Resistivity depth profiles and indicated structure in the Mullen area... 99
23. Profiles along traverse 1-1′ and 11-11′ in the Jarrett area........ 101
24. Profiles along traverse 111-111′ in the Walton area........ 102
25. Profiles along traverse IV-IV′ in the Walton area........ 103
26. Profiles along traverse V-V′ in the Walton area........ 104
27. Profiles along VII-VII′ in the Walton area........ 105
28. Profiles along traverse VIII-VIII′ in the Walton area........ 106
29. Profiles along traverse IX-IX′ in the Walton area........ 107
30. Profiles along traverse X-X′ in the Walton area........ 107
31. Map showing magnetic contours in the Walton area........ 108
32. Map showing gravity contours in the Walton area........ 111
33. Map showing natural potential contours in the Walton area........ 112
34. Map showing temperature contours in the Walton area........ 114
35. Map showing areal distribution of cobalt in the soil of the Walton area, 115

PAGE
36. Resistivity depth profiles in the Walton area........................ 116
37. Profiles along traverse 11-11′ in the Karcher area.................... 122
38. Profiles along traverse IV-IV′ in the Karcher area.................... 123
39. Profiles along traverse V-V′ in the Karcher area..................... 124
40. Resistivity profile along traverse VII-VII′ in the Karcher area........ 125
41. Map showing magnetic contours in the Karcher area................. 125
42. Map showing gravity contours in the Karcher area................... 127
43. Map showing natural potential contours in the Karcher area.......... 127
44. Map showing temperature contours in the Karcher area.............. 128
45. Resistivity depth profiles in the Karcher area........................ 128
46. *A*. Map showing the areal distribution of cobalt in the soil of the Karcher area; *B*. Map showing the areal distribution of manganese in the soil of the Karcher area.................................. 129
47. Profiles along traverse 1-1′ in the Swalley area....................... 131
48. Profiles along traverse II-II′ in the Swalley area..................... 132
49. Resistivity depth profiles in the Swalley area......................... 133
50. Map showing the areal distribution of manganese in the soil of the Swalley area 134
51. Profiles along traverse 1-1′ in the Greenback area..................... 136
52. Profiles along traverse IV-IV′ in the Greenback area................. 137
53. Resistivity depth profiles in the Greenback area...................... 138
54. Profiles along traverse 1-1′ in the McBee-Martin area................. 140
55. Profiles along traverse 11-11′ in the McBee-Martin area.............. 143

TABLES

TABLE
1. List of elements and spectral lines used in the spectrographic analyses, 55
2. Comparison of spectral intensity values for three samples which were arced four times 63
3. Spectral intensity variations in samples read ten days apart........... 64
4. Results of check readings on soil samples.......................... 67
5. Table comparing total variation of spectral intensities with analytical errors for each element—Mullen area............................ 68
6. Table comparing total variation of spectral intensities with analytical errors for each element—Walton area............................ 69
7. Table comparing total variation of spectral intensities with analytical errors for each element—Karcher area.........................70–71
8. Table comparing total variation of spectral intensities with analytical errors for each element—Swalley area........................... 72
9. Table comparing total variation of spectral intensities with analytical errors for each element—Greenback area...................... 73- 74
10. Table showing variations in spectral intensity obtained by arcing Cherokee shale samples sixteen times............................... 76
11. List of elements indicated in the limestone samples.................. 76
12. Drill holes from which shale and limestone samples were obtained.... 85
13. Average spectral line intensities of elements in the Cherokee shale.... 86
14. Resistivity depth correlations—Walton area......................... 113
15. Magnitude of geophysical anomalies—Walton area.................. 117
16. Resistivity depth correlations—Karcher area......................... 126
17. Magnitude of geophysical anomalies—Karcher area.................. 130

FOREWORD

For many years the area known as the Tri-State Zinc and Lead Mining District, comprising territory in southwestern Missouri, southeastern Kansas, and northeastern Oklahoma, has been the most important zinc-producing area, not only of the United States, but in the world. A very large tonnage of lead is obtained annually from this district also, together with some cadmium and great quantities of the prominently siliceous residue of mining operations which is known as chat. Earliest developments were in the Missouri part of the field, centering around Joplin, Webb City, Granby, and Oronogo; considerable ore was produced also just west of the Missouri boundary, near Galena, Kansas. In 1915, great bodies of ore were discovered at Picher, Oklahoma, and this led to intensive exploration and development in many square miles of northeastern Oklahoma and in areas around Baxter Springs and Treece, Kansas. Large demands for zinc and lead during World War I were readily met by exploitation of the rich, newly discovered ore bodies in the Tri-State area.

The zinc and lead situation in World War II, especially in regard to production from the Tri-State zinc and lead mining district, is like the earlier war period in its stimulus to the output of ore, but the situation is materially different now as regards the known reserves of readily mined ore bodies. Naturally, the huge quantities of zinc and lead sulphides that have been brought to the surface from Tri-State mines and shipped to smelters constitute a depletion of great magnitude. Continuation of mining operations and prolongation of prosperous economic conditions that are incident to production of zinc and lead call for additions to the known reserves of unmined ore. Explorations must be greatly extended and intensified. If new techniques in exploratory work can be developed, they may be a critical factor in the efforts to find large new quantities of valuable ore. Especially if new techniques in the search for zinc and lead ore offer advantages in speed and economy, they are to be rated as having increased importance and desirability.

RAYMOND C. MOORE, *State Geologist and Director,*
State Geological Survey of Kansas.

GEOPHYSICAL INVESTIGATIONS IN THE TRI-STATE ZINC AND LEAD MINING DISTRICT

By J. J. Jakosky, R. M. Dreyer, and Clyde Wilson

INTRODUCTION

Purpose of the Investigation

Early in 1941 the University of Kansas Engineering Experiment Station and the State Geological Survey of Kansas were invited, by several governmental agencies, to investigate the feasibility of using geophysical methods as a guide to ore prospecting in the Tri-State zinc and lead mining district of Kansas, Oklahoma, and Missouri. The increased demand for zinc and lead in the production of war materials made it appear desirable to attempt to develop some geophysical method or combination of methods which would be more rapid and less expensive than the present method of exploration by churn drilling now commonly employed in the Tri-State district.

Arrangements were completed between the State Geological Survey and the University Engineering Experiment Station. These organizations then approached the Tri-State Zinc and Lead Ore Producers' Association to ascertain whether the operators in the district thought it advisable to investigate the potentialities of geophysical prospecting in that area. The project was looked upon with such favor by the Ore Producers' Association that the Association offered to underwrite half the cost of the project. A subsequent grant was obtained from the Kansas Industrial Development Commission for the spectographic analysis.

The purpose of the geophysical investigation, therefore, was to determine some geophysical technique or combination of techniques which could be utilized for ore prospecting in the Tri-State district. In order to simplify the initial experimental work all of the geophysical investigations were made over areas where, as the result of intensive drilling, the geologic conditions and mode of ore occurrence were already known. In each area there was an attempt to correlate the various geophysical anomalies with known geologic conditions. No attempt was made to prospect areas which had not been explored by drilling.

During the course of the investigation, the following types of geophysical surveys were conducted: electrical resistivity, geothermal, geochemical, gravity, natural earth potential, and magnetic. Seismic work was contemplated, originally, as a part of the project. The difficulty and expense of applying seismic methods to these areas, however, as compared with the results that theoretically might be expected, made it appear advisable to defer this work until a later date.

Acknowledgments

Few geophysical projects can be successful without the full cooperation of the ore producers and operators. From the beginning of the project, all of the producers and operators in the Tri-State district gave most generously of their advice and assistance; and to their help is due, in no small measure, the relatively rapid completion of the project. Mr. Evan Just, Secretary of the Tri-State Zinc and Lead Ore Producers' Association, helped the writers continuously throughout the duration of the project. Mr. George M. Fowler gave the writers ready access to the tremendous fund of geologic data which he has developed during his many years of geologic study in the Tri-State district.

It would be impossible to mention separately each of the companies and their engineers who have freely given their advice and use of their established facilities. The Eagle-Picher Mining and Smelting Company gave assistance on numerous occasions; for this assistance, the writers wish to thank Mr. George W. Potter, Mr. D. C. MacKallor, Mr. R. K. Stroup, and Mr. E. W. McMullen. Thanks are also due to Federal Mining and Smelting Company—especially to Mr. Chester Scott, Mr. L. G. Johnson, and Mr. I. V. Korts. The help of Mr. John Inman and Mr. W. F. Netzeband of the American Zinc, Lead, and Smelting Company is likewise acknowledged.

We wish to acknowledge the courtesy of International Geophysics, Inc., of Los Angeles, in releasing for work on this project their past Chief Engineer, Mr. C. H. Wilson.

The gravity surveys published as a part of this report were conducted by the Mott-Smith Corporation, Houston, Texas. The kindness of the Mott-Smith Corporation in running the gravity work on a research basis is greatly appreciated. In this connection, we wish to thank Mr. E. V. McCollum, of the Mott-Smith Corporation, who arranged for his company to do this work. We also take pleasure in acknowledging the help of Mr. Julian Hawes, who ably supervised the gravity field work for the Mott-Smith Corporation.

The spectroscopic analyses were made in the Department of Physics, Kansas State College, by permission of President F. D. Farrell and Dr. A. B. Cardwell, Chairman of the Department of

Physics. This work was done under the able supervision of Professor J. Howard McMillen, the Department of Physics, Kansas State College. An industrial fellowship of the University of Kansas, which was awarded by the Kansas Industrial Development Commission to Mr. Maurice Wallace, gave financial assistance for spectroscopic studies.

We wish especially to acknowledge the able assistance of the technical crew, including Mr. Maurice Wallace, assisting with geologic studies and with the geochemical and geothermal surveys; Mr. Arthur Bowsher, assisting with resistivity and natural potential surveys; and Mr. Stuart Bunn, surveyor.

Previous Geophysical Investigations in the Tri-State Area

All previous geophysical investigations in the Tri-State area have been either of very short duration or regional rather than detailed in character.

The Missouri Bureau of Mines and Geology (cf. Grohskopf and Reinoehl, 1933, pp. 10-13), in connection with magnetic surveys throughout the state, made a magnetic survey of that portion of the Tri-State area included in the state of Missouri. In that work readings were taken at section corners and the data plotted on a contour interval of 100 gammas. In the area surveyed, there was a range of magnetic intensity of 1,311 gammas. They state that, in a general way, "the areas occupied by the faults" were magnetically low and that ore bodies are generally associated either in or on the flanks of magnetic lows. They believe that the magnetic highs are related to high points on the pre-Cambrian surface. However, since the configuration of the pre-Cambrian surface is not known, such a relationship cannot be established. Study of the published map does not reveal any marked correlation between magnetic anomalies and either structure or mineralization.

The North American Exploration Company of Houston made a brief torsion balance survey in 1926 (George, 1928). The areas surveyed included the Duenweg lease, the Federal Brewster, and the Federal Jarrett leases. In the Duenweg area, 61 stations were read over an area of 17 acres. A marked gravity maximum and a marked minimum were found, but the ore zone (at a depth of 130 feet) corresponded to neither the maximum nor to the minimum. The gravity maximum coincided with an area in which the limestone was closest to and the chert farthest from the surface. The gravity minimum corresponded to a zone where the chert was nearer to the surface. The gravity of the limestone in this case was, therefore, apparently greater than the gravity of the fractured chert plus the ore minerals. On the Federal Brewster lease there was an ore zone 15 to 20 feet thick at a depth of about 215 feet. The gravity minimum appears to correspond to areas of brecciated chert. It appears that the openings in the chert have more than counteracted the added gravity of the ore minerals with the result that the solid limestone has a higher gravity than the limestone which has been silicified, brecciated, and mineralized. The survey thus made possible a distinction, in this area, only between unaltered limestone and the silicified, brecciated limestone. On an area west of Picher, 106 stations were read on a 120-acre tract. Gravity minima correlated only with zones of brecciated chert. On the Federal Jarrett lease, 118 stations were read on a 130-acre tract over an ore zone at a depth of 300 feet. Ore was found in zones of gravity minima corresponding to zones of brecciated chert. The survey appears to indicate that gravity minima appear in those areas in which there is a large amount of chert at relatively shallow depth. The torsion balance work thus appears to be of value only in distinguishing silicified, fractured limestone from unaltered limestone. George concludes that gravity work would be of value only where: (1) there are no dumps or caves, (2) there are no mine workings, (3) there are no sandstones of great enough thickness to give gravity minima.

Several gravity-meter traverses were run for the Eagle-Picher Mining and Smelting Company in October, 1939, with stations at 100-foot intervals. The traverses were as follows: (A) a line 100 feet north and parallel to the south line of the SW¼ sec. 14, T. 34 S., R. 23 E., Cherokee county, Kansas; (B) a line 100 feet east and parallel to the west line of the SE¼ SW¼ sec. 34, T. 34 S., R. 23 E., Cherokee county, Kansas, and (C) a line 450 feet south and parallel to the north line of the NW¼ NW¼ SW¼ sec. 7, T. 35 S., R. 24 E., Cherokee county, Kansas. Line A shows a gravity range of from —2.0 to +0.2 milligals, but there is no apparent correlation between gravity and mineralization. Line B shows a gradual decrease in gravity intensity going from north to south, but there is no mineralization in the area. Line C shows several marked anomalies, but there are no geologic data available for correlation. A line over the Pelican ore body shows a range of from —1.1 to +0.8 milligals, with a low over the center of the ore-body.

In 1928, a one-week inductive radio-frequency electromagnetic survey was made by the Radiore Company, Los Angeles, to determine the location and direction of trend of conductive horizons.

Several such conductors were mapped in each area. The following areas were studied: (A) SE¼ SW ¼ and NW¼ SE¼ sec. 36, T. 29 N., R. 22 E., Ottawa county, Oklahoma; (B) SE¼ NW¼ sec. 22, T. 33 S., R. 25 E., Cherokee county, Kansas; and (C) SE¼ NW¼ and NE¼ NW¼ sec. 22, T. 44 N., R. 17 W., Moniteau county, Missouri. Drilling on the Missouri area has indicated that the conductors represented chiefly shallow underground water courses, the water being highly mineralized. There was no correlation, apparently, between the trend of the shallow conductors and the ore zones.

In 1940, F. C. Farnham, of the Missouri School of Mines, made a one-week resistivity survey across the Miami Trough at several places in Ottawa county, Oklahoma, as follows: (A) Along the south line of the NE¼ sec. 12, T. 28 N., R. 22 E.; (B) along the south line of the SE¼ sec. 12, T. 28 N., R. 22 E.; (C) along part of the south line of the N½ sec. 13, T. 28 N., R. 22 E.; and (D) along part of the south line of the N½ sec. 23, T. 28 N., R. 22 E. Readings were made at hundred-foot intervals. Farnham states the following (unpublished manuscript, courtesy Eagle-Picher Mining and Smelting Co.):

> The low resistivity areas have been selected as the most favorable areas in which to drill because of the fact that they are probably due to a thickening of the shale over the limestone; and, since there probably is some correlation between slumpage of the limestone and the fractured zone in which the mineralization occurs, it appears that a thickening of the shale over the limestone may be used as a guide to follow in drilling. The resistivity measurements did not give data which is actually interpretable in terms of actual depth to the shale limestone contact, but did give consistent results which may be interpretable in terms of the direction of thickening of the shale.

In 1929-1930 the Schlumberger Well Surveying Corporation made resistivity surveys for the American Zinc, Lead and Smelting Company in the area around Aurora, Missouri. The only results of this work seen by us were structure contour maps drawn at the shale limestone contact or on the surface of unweathered limestone where no shale cover is present. The shale varies from 0 to 150 feet in thickness; and, in the places where the contact is shallow, later drilling has shown that the shale-limestone contact depth determinations, in most cases, were accurate to within 10 feet. As far as is known, no correlations were made between resistivity and mineralization.

GEOGRAPHY

Location of the Area

The Tri-State zinc and lead mining district is located in southeastern Kansas (southeastern Cherokee county), northeastern Oklahoma (northeastern Ottawa county), and southwestern Missouri (southwestern Jasper county and northwestern Newton county). The district is covered by a network of good highways and county roads and is served by the following major railroads: Kansas City Southern; St. Louis and San Francisco; Missouri Pacific; Missouri, Kansas and Texas. The greater part of the area which has not been diverted to mining is being intensively pastured and farmed —the major crops being wheat, corn, oats, and flax.

Following is a list of the areas studied during this series of geophysical investigations. (The areas are named after the owner of the particular property on which, in each case, the major amount of the geophysical work was done.)

(A) Neutral area (Cherokee county, Kansas), fig. 1: W½ sec. 10, T. 34 S., R. 24 E.

(B) Mullen area (Cherokee county, Kansas), fig. 2: SW¼ sec. 6, T. 35 S., R. 24 E.; SE¼ sec. 1, T. 35 S., R. 23 E.

(C) Federal Jarrett area (Cherokee county, Kansas), fig. 3: S½ sec. 10, T. 35 S., R. 23 E.

(D) Walton area (Cherokee county, Kansas and Ottawa county, Oklahoma) fig. 4: NE¼ sec. 15, T. 35 S., R. 22 E. (Cherokee county, Kansas); N½ sec. 13, T. 29 N., R. 21 E. (Ottawa county, Oklahoma).

(E) Karcher area (Cherokee county, Kansas) fig. 5: S½ and NW¼ sec. 34, T. 34 S., R. 23 E.; N½ sec. 3, T. 35 S., R. 23 E.

(F) Swalley area (Cherokee county, Kansas) fig. 6: NE¼ sec. 4 and NW¼ sec. 3., T. 35 S., R. 24 E.; SE¼ sec. 33, T. 34 S., R. 24 E.

(G) Federal Greenback area (Ottawa county, Oklahoma) fig. 7: SW¼ sec. 26, T. 29 N., R. 23 E.

(H) McBee-Martin area (Jasper county, Missouri) fig. 8: SE¼ sec. 2 and NE¼ sec. 11, T. 28 N., R. 34 W.

Topography

The topographic relief in the areas covered by these investigations is very slight. The greater part of the region, however, has a slope sufficient to effect good drainage. The good drainage and flat topography combine to make most of the area readily accessible for geophysical exploration.

The maximum range of elevation found on any one of the areas used for geophysical prospecting is 33 feet (Neutral area). The minimum range of elevation found on any of the areas is 5 feet (McBee-Martin area). The maximum elevation on any of the prospected areas is 876 feet (Mullen area). The minimum elevation on any of the areas is 818 feet (Walton area). The maximum difference in elevation between the various prospect areas is thus 58 feet, over an area of approximately 100 square miles.

Zinc and Lead Production in the Tri-State District

The Tri-State district is the largest producing zinc district and the third largest producing lead district in the United States. In 1940, the mine production of zinc in the Tri-State district was 232,437 short tons or 35.0 percent of the total U. S. mine production (Pehrson and Ransome, 1941, pp. 147-148), or 14.2 percent of the total world smelter production for 1939 (Pehrson and Ransome, 1941, p. 155). Of this amount, 24.5 percent was produced in Kansas. In 1940, the mine production of lead in the Tri-State district was 35,311 short tons or 7.7 percent of the total U. S. mine production (Pehrson and Ransome, 1941, p. 124), or 2.6 percent of the total world smelter production for 1939 (Pehrson and Ransome, 1941, p. 132). Of this amount, 33.9 percent was produced in Kansas.

Recent accelerated operations in the Tri-State district have resulted in a marked depletion of the high-grade ore reserves. It has thus been considered advisable to attempt to develop a geophysical technique which would expedite exploration for the higher grade deposits.

GEOLOGY

GENERAL GEOLOGIC SETTING

The occurrence and genesis of the zinc-lead ores of the Mississippi Valley region (including the Tri-State district) have been discussed in detail in *Special Paper* 24 of the Geological Society of America (Bastin et al., 1939). This publication also gives a detailed bibliography of the previous literature relating to the geologic occurrence of lead-zinc ores in the Tri-State district. It will be necessary here, therefore, only to summarize such features of the geology as are of significance in making geophysical measurements and interpretations. The geology to be discussed will be essentially that of the northwestern portion of the district (northern Ottawa county, Oklahoma, and Cherokee county, Kansas) in which the geophysical work was done.

In the portion of the mining district studied, the thickness of Paleozoic rocks (Cambrian to Pennsylvanian) is stated to be about 1,700 to 1,800 feet (Weidman, 1932, p. 7). Below the Paleozoic is pre-Cambrian granite, stated to occur at a depth of 1,700-1,850 feet at Miami, Oklahoma; 1,772 feet at Carthage, Missouri; and 1,770 feet at Columbus, Kansas (Weidman, 1932, p. 6). Weidman (p. 6) reports that granite was found in a well at the Bird Dog mine at a depth of 1,245 feet. No other intrusive masses have been recorded in the Tri-State district, although many small intrusive bodies are found throughout the Mississippi Valley region (Tolman and Landes, Bastin et al., 1939, pp. 71-103).

Above the pre-Cambrian, but below the ore horizons, is 1,300 to 1,500 feet of pre-Mississippian sediments (Weidman, 1932, p. 6). This series of pre-Mississippian sediments is overlain unconformably by the thin Mississippian Chattanooga shale above which is an average of 300 to 400 feet of Mississippian chert and limestone belonging to the Meramec and Osage (Boone formation) series (Moore, Fowler, and Lyden, Bastin et al., 1939, pp. 2-4). Some ore is found in the Warsaw limestone (Meramec), but the majority of the ore zones are confined to the Keokuk and Reed Springs limestones and cherts (Osage) averaging from 100 to 200 feet below the overlying Cherokee shale. The Warsaw and Keokuk in the Tri-State district have been carefully subdivided on the basis of minor lithologic variations (Moore, Fowler, and Lyden, Bastin et al., 1939, pp. 2-4). Most of the structural mapping is based on the structure as determined on one or more of the lithologic horizons within the Keokuk.

Unconformably overlying the Meramec series are as much as 80 feet of strata belonging to the Mayes, or Cartersville, formation of Chester age (Moore, Fowler, and Lyden, Bastin et al., 1939, p. 11). According to Weidman (1932, pp. 18-20), the Mayes is variable in thickness and lithology, but is everywhere present beneath the Cherokee in the Oklahoma-Kansas mining field. The thickness is said to vary from 10 to 60 feet. Although the lithology of the Mayes varies considerably, Weidman states (1932, p. 20) that the upper part of the formation is generally composed of sandstone or shale, whereas the lower 15 to 30 feet is limestone.

It has been customary in the Tri-State district to begin saving churn drill samples only after the first limestone is reached. The overlying shale is generally all listed as Cherokee. However, it must be remembered that the lower portion of the shale section may be merely the upper shaly portion of the Mayes formation. Moreover, since the lithology of the Mayes varies considerably, structure contours drawn on top of the limestone represent neither the top of the Mississippian nor the top of any definite stratigraphic horizon within the Mississippian. Contours drawn on the limestone surface, therefore, do not necessarily represent either a structural or erosional surface, but merely a lithologic boundary. Fortunately, for geophysical interpretation, the position of this lithologic boundary is of greater importance than the position of stratigraphic boundaries.

The Pennsylvanian Cherokee shale (Des Moines) lies unconformably upon the Mississippian in the western part of the district. The Cherokee consists of dense clay and shale with several definite sandstone horizons. In common with the other sediments of the district, the Cherokee dips gently northwestward. The eastern boundary of the Cherokee overlap is, in the Tri-State district, somewhat west of the Missouri border (Weidman, 1932, pl. 1, and Pierce and Courtier, 1937, pl. 1). In the area studied, the Cherokee reaches a maximum thickness of about 200 feet.

Locally, deposits of "Tertiary" clay and coarse chert gravel overlie the Cherokee. Weidman states (1932, p. 27) that such deposits have a thickness of as much as 30 feet. This figure accords with field exposures and drill records examined by us. The driller's logs generally group these clays with the surficial soil mantle. It is therefore often impossible to determine from a driller's log whether the term "soil" or "clay" indicates "Tertiary" deposits or simply material derived from the weathering, in situ, of the underlying Paleozoic rocks. Where gravel is recorded, the material above and including the gravel is generally Tertiary. Often, however, the gravel and "clay" or "soil" are grouped together. Therefore, as a general rule, the actual thickness of the Tertiary cannot be ascertained nor can the presence of Tertiary sediments be established with certainty unless gravel is present.

The Mississippian and Pennsylvanian sediments in the Tri-State district have an average dip of 15 to 20 feet per mile to the northwest (Weidman, Bastin et al., 1939, p. 49). The most prominent structural feature, in the portion of the district geophysically studied, is the Miami trough—a series of disconnected structural lows, averaging about half a mile in width, trending northeastward from Commerce, Oklahoma to Lawton, Kansas, and having a maximum structural relief of something over 200 feet. It is believed that the trough has resulted from repeated shearing, solution, and slumping.

Ore bodies generally occur only in those parts of the district which have been subjected to pre-mineralization flexing, shearing, and brecciation (Fowler, Bastin, et al., 1939, pp. 53-60). Concerning structural control of ore deposition, Fowler says (Bastin et al., 1939, pp. 55-58):

> All beds of the Boone formation are barren of mineralization except where deformation created structures favorable for ore reservoirs. . . . In the search for ore in the Tri-State district, the structural features of importance have been determined largely by contouring convenient strata and by mapping the shear zones in the underground workings. As minor flexing was of great importance in creating ore reservoirs, the contours were drawn at vertical intervals of five feet. They show that nearly all of the ore bodies in the district trend with the strike of the structure contours. . . . The main part of the Oklahoma-Kansas field is a roughly circular area in which the rocks were compressed and shortened in a general north-south direction and elongated in an east-west direction. This deformation relieved the stresses by flexing the strata and by forming northwesterly and northeasterly trending shear zones. Widespread shattering of marked intensity occurred contemporaneously. . . . Zones of intense deformation where the deformed and shattered strata moved from a few inches to several feet, instead of many feet, were particularly favorable ore reservoirs. Structural displacement of many feet generally lacked the intense shattering and opening of beds so essential in localizing these ore bodies. Fissures or shear zones are very numerous throughout the district and range from a few inches to several hundred feet in width and from a few feet to several miles in length. . . . The structural conditions most favorable for major ore reservoirs are wide, strong, and intensely shattered shear zones contiguous to deformed strata that have been opened along the bedding planes and stylolite partings.

Sink holes and caverns are found in the Mississippian limestone throughout the district, but there is believed to be no general correlation between the occurrence of caverns and of ore.

For the purposes of this paper, two types of ore bodies will be recognized—"runs" and "sheet ground." Sheet ground deposits are tabular deposits generally paralleling definite stratigraphic horizons and having horizontal dimensions large in comparison to the vertical dimensions. Run deposits are those having a large vertical and one large horizontal dimension and are generally believed to be related to shear zones. It is recognized that there may be all gradations between the two types of deposits. The ore bodies are, in general, highly irregular in outline and in sulphide content. Any ore horizon may, within a few feet horizontally or vertically, grade into barren ground.

The principal ore minerals are sphalerite (zinc sulphide, sp. grav., 3.9 to 4.1) and galena (lead sulphide, sp. grav., 7.4 to 7.6). Occasionally pyrite or marcasite (iron disulphide, sp. grav., 4.9 to 5.1) occurs in the ore. Iron disulphide is also commonly found in the Cherokee shale—especially near its base. The occurrence of pyrite in the shale is generally not recorded in the driller's logs. The sulphide mineralization is generally accompanied by intense brecciation and chertification of the surrounding limestone and, occasionally, by dolomitization. The many other minerals reported from the district generally occur in only minor amounts in the northwestern portion of the mining field.

Concerning the relative occurrence of galena and sphalerite, Weidman (1932, pp. 76, 77) makes the following observations:

> If the ratio of zinc to lead ore for the entire district be taken as 5.5:1, the ratio for individual mines in the syncline (Miami Trough) is generally between 4.5:1 and 1:1 and that outside the syncline is generally between 4.5:1 and 24:1. . . . .
>
> Two significant facts appear to be brought out by a study of the relative distribution of the zinc and lead ores:
>
> 1. There is a pronounced lack of uniformity in the composition of ore bodies as indicated by the marked variation in the ratio of zinc ore to lead ore in individual mines of the district.
>
> 2. In addition to the recognized tendency for the galena to form above sphalerite, as observed in cavities and in large mined-out ore bodies, indicating a vertical zonal distribution, there is also a distinct lateral zonal distribution of the galena and the sphalerite.

METHOD OF SELECTING AREAS FOR GEOPHYSICAL INVESTIGATIONS

Most of the geophysical work was done over areas in which data derived from drilling afforded considerable geologic information. In selecting the areas for geophysical investigations, the first prerequisite was that the area have a rather large zone of mineralization which had been thoroughly delineated by drilling, or that the area contain some important structural feature. Secondly, areas were selected to represent the various types of ore occurrence. The Walton and Karcher deposits are essentially deep run-type areas of mineralization. The Swalley area is one of deep sheet-ground mineralization. The Mullen area was selected because it represents a zone of large structural relief on the Miami trough. The Greenback and McBee-Martin areas are shallow run-type zones of mineralization. The gravity work on the Jarrett area was done for the purpose of determining the influence of shallow structures on gravity readings, and for comparison with torsion balance work run some fifteen years earlier over the same area. The Neutral area was selected as one in which it would be possible to determine the type of anomalies in an area distant from the mining field and apparently devoid of mineralization.

After an area had been considered on the basis of size, shape, grade, and form of the zone of mineralization, as well as on the extent of drilling, several other factors entered into the selection of suitable investigational areas. It was desirable that the area selected have a barren area immediately adjacent to the zone of mineralization so that the geophysical traverses would pass over well-defined mineralization boundaries. Although several of the areas have zones of mineralization with relatively marked boundaries, it was not possible in all cases to have boundaries as sharp as might be desired. Because variations in the flow and content of ground water markedly affect resistivity and natural earth potential and, possibly, geothermal investigations, it was deemed desirable to work in portions of the district where ground water conditions had not been disturbed by mine pumping. All of the areas in which electrical measurements were made are believed to be sufficiently distant from active pumping operations so that the ground had not been appreciably de-watered.

For the geochemical investigations it was deemed desirable to select areas in which there is no cover of Tertiary clay and gravel. Since, from the drillers' logs, it generally is not possible to distinguish Tertiary clay from soil derived from weathering of Paleozoic sediments, there is considerable uncertainty in several areas as to the presence or absence of Tertiary overburden.

In geophysical work, it is desirable that there be a minimum of topographic relief. This factor constituted no problem under the conditions of gentle relief found in the Tri-State district. Because much heavy equipment is used in geophysical investigations, it is likewise highly desirable that the areas to be studied be readily accessible by automobile. The good network of roads throughout the district greatly facilitated the investigations.

Pipe lines, power lines, cased drill holes, "tramp" iron, etc., sometimes cause measureable resistivity, magnetic, and natural earth potential anomalies. Locations containing any of these objects were avoided, in so far as possible.

GEOLOGIC DESCRIPTION OF THE AREAS STUDIED IN GEOPHYSICAL INVESTIGATIONS

Figure 1 shows the general area covered by the geophysical investigations, and the location of the various areas studied in detail.

On the profiles to be presented subsequently with the geophysical results in each area, topography and configuration of the limestone surface have been plotted on a natural scale. The profiles likewise

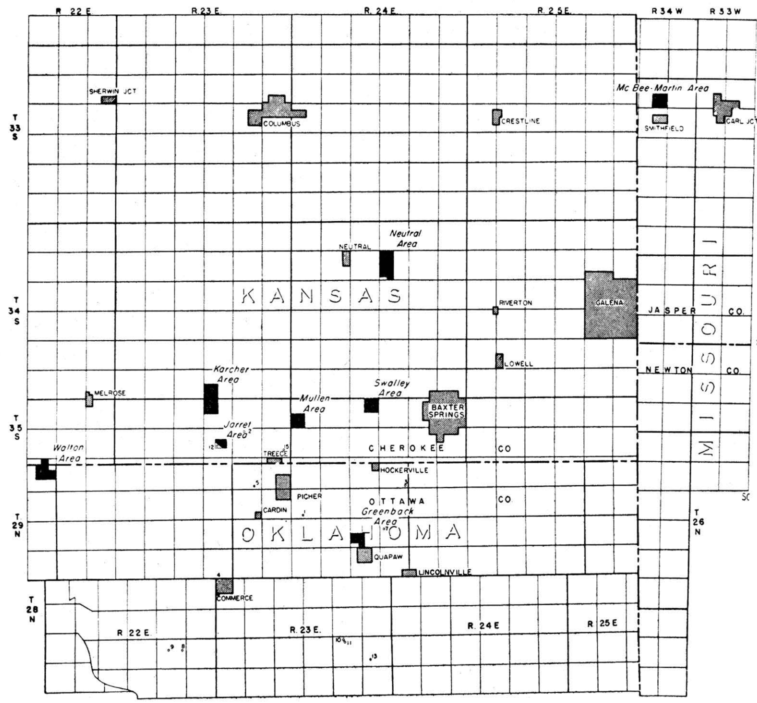

FIG. 1. Regional map of northwestern part of Tri-State mining district showing location of areas geophysically studied and location of wells from which samples for geochemical analyses were taken.

show the position of the boundaries of the general zone of mineralization as projected downward from the surface map. On these profiles, drill hole assays have been projected a maximum of fifty feet to the line of traverse. Mineralization is indicated on the profiles as of "high-grade" or "low-grade." Arbitrary boundaries have been selected for the terms "high-grade" and "low-grade," and the same arbitrary boundaries have been used on all of the profiles. *However, it is to be strongly emphasized that the terms "high-grade" and* *"low-grade" are arbitrary terms and carry no absolute evaluation concerning the economic value of the ground included within the zone of mineralization.*

A discussion of the geology of each area follows.

Neutral Area

The Neutral area (sec. 10, T. 34 S., R. 24 E.) is about a quarter of a mile west of a marked depression in the Miami trough. Geophysical measurements were made along a line trending north-northeastwardly near the western boundary of the section in a portion of the area in which the limestone surface has been mapped as nearly flat (cf. Pierce and Courtier, 1937, pl. 5). The topographic relief along this line is about 40 feet.

The thickness of the shale cover varies from about 100 to 150 feet (Pierce and Courtier, 1937, pl. 5). Drilling in and within a radius of two miles of the traverse area has revealed no mineralization. Geophysical work was done in the Neutral area to determine the type of anomalies to be obtained in an area apparently devoid of

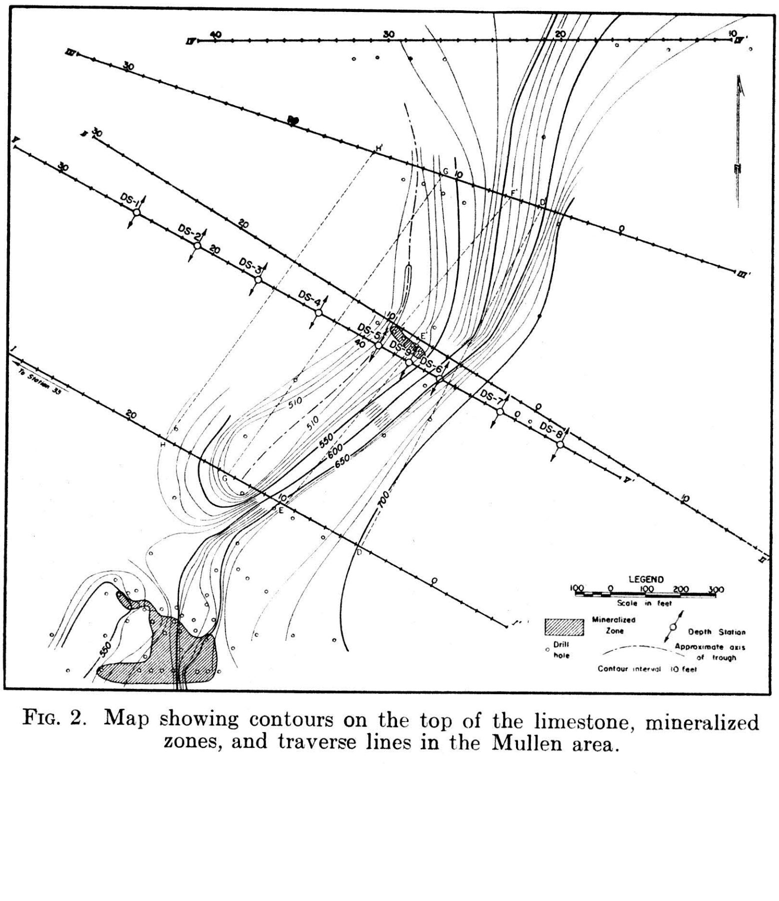

Fig. 2. Map showing contours on the top of the limestone, mineralized zones, and traverse lines in the Mullen area.

mineralization and distant from the mining field. The following geophysical methods were used in the Neutral area: magnetic, gravity, natural potential, resistivity, geothermal, and geochemical.

Mullen Area

The Mullen area (fig. 2) contains the deepest portion of the Miami trough in Kansas. Geophysical work was done in the Mullen area to determine whether marked buried relief on the subsurface limestone surface can be determined geophysically.

The topographic relief in the portion of the area studied is about 30 feet. The shale has an average thickness of about 175 feet outside of the trough and about 350 feet within the trough. The structural relief of this sharp, northeastwardly trending trough is about 200 feet within an average horizontal distance of about 400 feet in the portion of the area traversed. Data made available to us indicates a small zone of mineralization (largely mined) in the southwestern corner of the property. Because of the previous mining operations and the numerous habitations, no work was done on the southwestern corner of the property. Except for this zone of mineralization, the only other mineralization recorded by the rather extensive drilling is that shown by the four drill holes outlined between traverses I-II′ and V-V′. In these holes, galena and sphalerite are found at a depth of about 400 feet or about 50 to 100 feet below the top of the limestone. There is no evidence of Tertiary overburden; in fact, sandstone crops out over a considerable portion of the area traversed.

Figure 2 shows contours on the limestone surface, zones of mineralization, and the various traverse lines used during the geophysical investigations by the following geophysical techniques: magnetic, gravity, natural potential, resistivity, geothermal, and geochemical.

Jarrett Area

Two east-west gravity-meter traverses were run across the northwestern part of the Federal Jarrett property. These gravity meter results were compared with torsion balance investigations published in 1928 by P. W. George.

The shale cover in the part of the area studied averages about 150 feet in thickness. A northward trending trough cuts the western end of both traverse lines. The structural relief of the trough increases northward.

Figure 3 gives contours showing the elevation of the top of the limestone and shows, also, the two gravity-meter traverse lines.

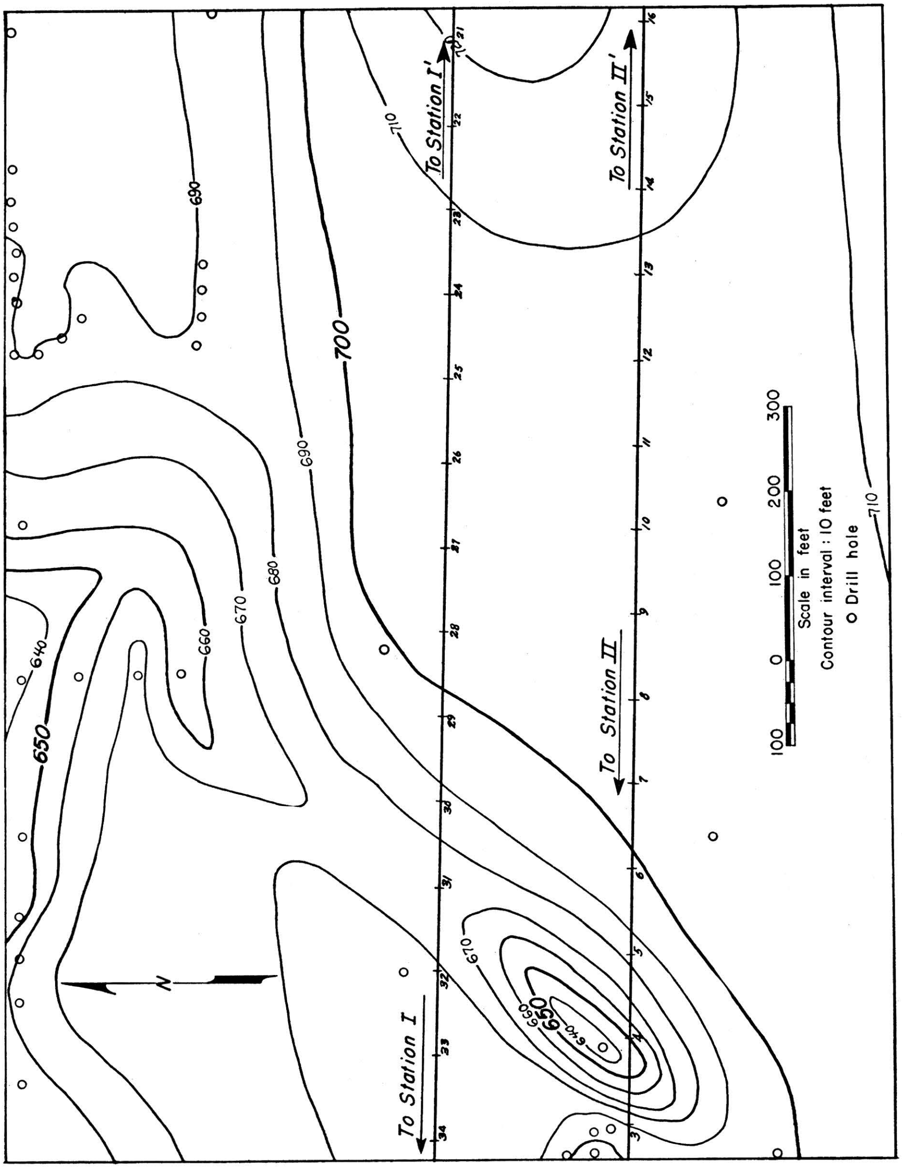

FIG. 3. Map showing contours on the top of the limestone and traverse lines in the Jarrett area.

Walton Area

Figure 4 shows topographic contours, contours on the limestone surface, zones of mineralization, and traverse lines on the Walton area. The Walton area has a maximum topographic relief of about 10 feet. There is a pond adjacent to the southern part of the zone of mineralization at the southern end of the area studied. The pond

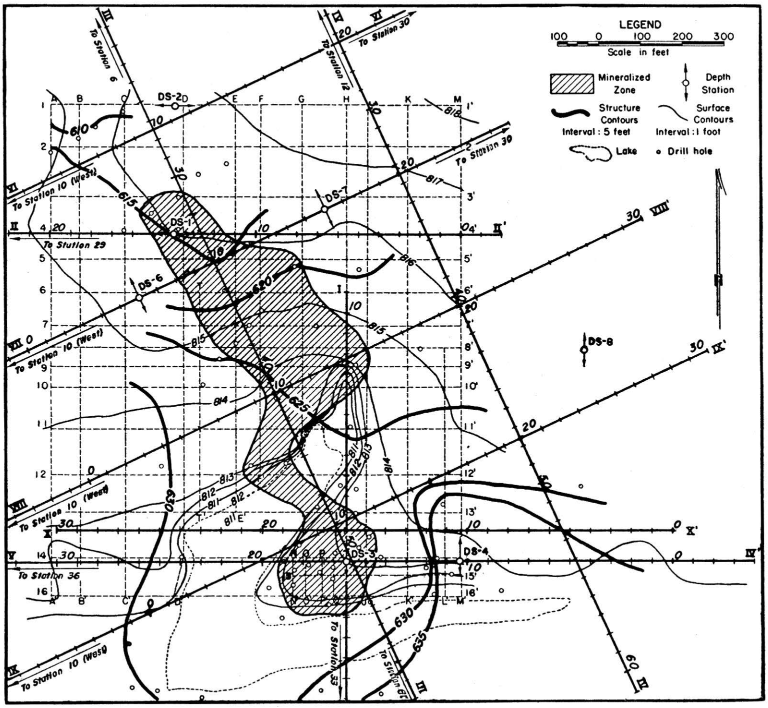

Fig. 4. Map showing contours on the top of the limestone, topography, mineralized zone, and traverse lines in the Walton area.

was somewhat of an impediment to the field conduct of the electrical investigations.

Over the portion of the area studied, the shale-limestone contact has a maximum relief of about 25 feet. The shale has an average thickness of from 175 to 200 feet. Drilling done during the period of this investigation revealed "Tertiary" clays and gravels to a depth of about 30 feet.

The zone of mineralization is of the run type with the mineralization at an average depth of 300 to 350 feet. Many of the drill holes

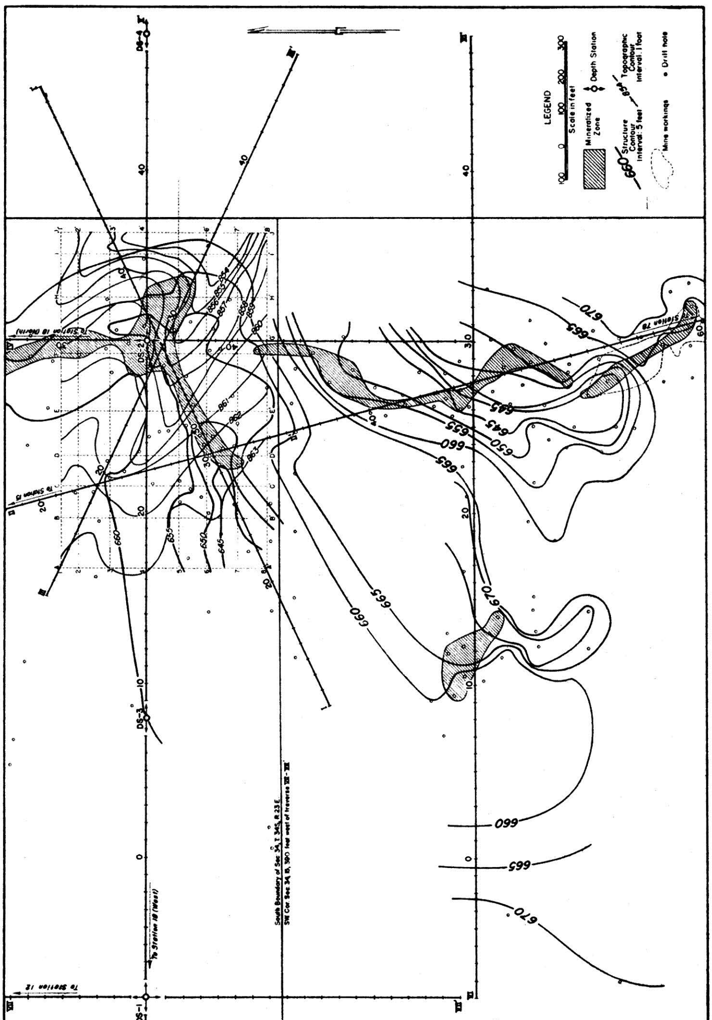

FIG. 5. Map showing contours on the top of the limestone, topography, mineralized zone, and traverse lines in the Karcher area.

in the zone of mineralization show a relatively high lead:zinc ratio. The boundary between the zone of mineralization and barren ground appears to be somewhat more abrupt than is usual for this district.

The Walton area was studied as an example of a deep, run-type zone of mineralization by the following methods: magnetic, gravity, natural potential, resistivity, geothermal, and geochemical.

Karcher Area

Figure 5 shows topographic contours, contours on the limestone surface, zones of mineralization, and traverse lines on the Karcher area. The Karcher area has a maximum topographic relief of about 10 feet.

Over the portion of the area studied, the limestone surface has a maximum relief of about 35 feet. The shale has an average thickness of about 200 to 220 feet. It is impossible to ascertain from the available drill logs whether there is any "Tertiary" overburden.

The zone of mineralization is of the run-type with the mineralized zones at an average depth of 350 to 400 feet. Galena occurs in this area in only very minor amounts.

The Karcher area was studied as an example of a deep, run-type zone of mineralization with little lead. The area was studied by the following geophysical methods: magnetic, gravity, natural potential, resistivity, geothermal, and geochemical.

Swalley Area

Figure 6 shows contours on the limestone surface, zones of mineralization, and traverse lines on the Swalley area. The portion of the Swalley area traversed has a maximum topographic relief of about 10 feet.

The limestone surface has a relief of about 30 feet. The shale has an average thickness of 40 to 80 feet. It is impossible to ascertain from the available drill logs whether there is any "Tertiary" overburden.

The zone of mineralization is of the sheet-ground type with the mineralized zones at an average depth of 300 to 350 feet. Very little galena occurs in this area.

The Swalley area was studied as an example of a deep, sheet-ground type of mineralization with little lead. The area was studied by the following geophysical methods: gravity, resistivity, and geochemical.

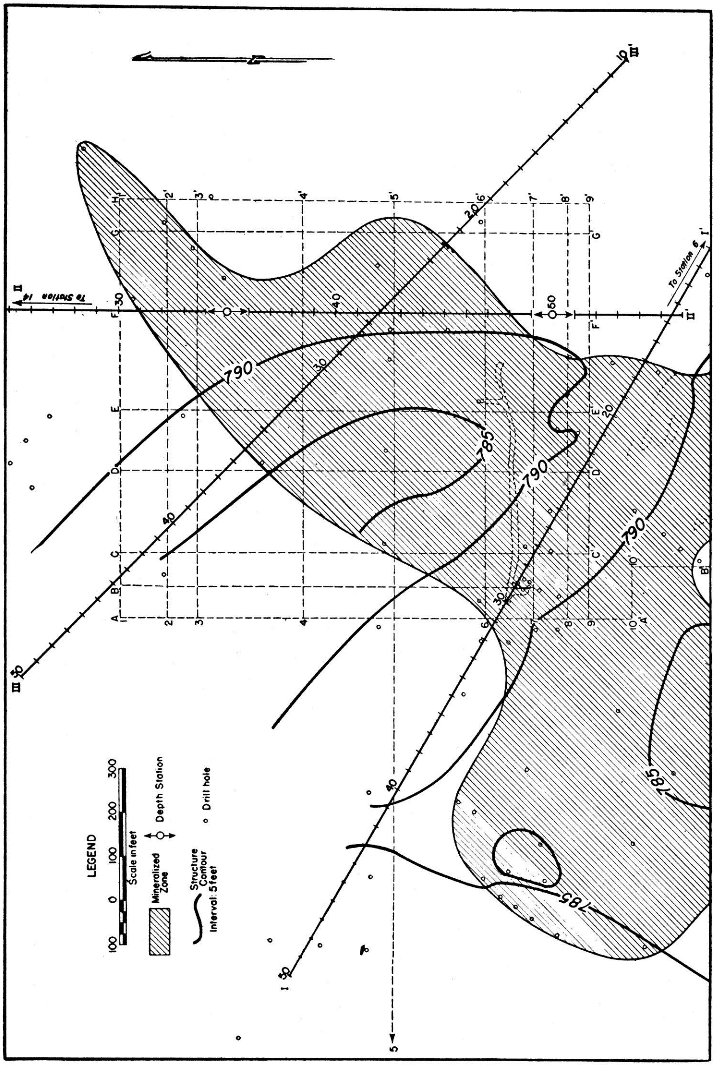

FIG. 6. Map showing contours on the top of the limestone, mineralized zone, and traverse lines in the Swalley area.

Greenback Area

Figure 7 shows contours on the limestone surface, zones of mineralization, and traverse lines on the Greenback area. The portion of the Greenback area traversed has a maximum topographic relief of 10 feet.

The limestone surface has a relief of about 50 feet. The shale has an average thickness of 15 to 70 feet. In the few cases in which shale is not recorded below the soil and clay at the surface, it is impossible to tell whether the surface soil and clay represent weathered

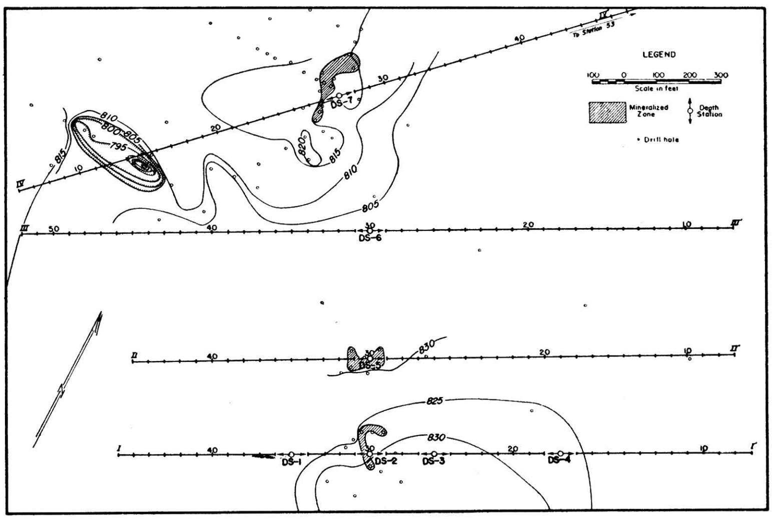

Fig. 7. Map showing contours on the top of the limestone, mineralized zone, and traverse lines in the Greenback area.

shale or simply weathered limestone. It is likewise not possible to ascertain from the available drill logs whether there is any "Tertiary" overburden.

The zone of mineralization is of the run-type with the mineralized zones at an average depth of 150 to 200 feet. Very little galena occurs in this area.

The Greenback area was studied as an example of a shallow run type of mineralization with little lead. The area was studied by the following geophysical methods: gravity, resistivity, geothermal, and geochemical.

McBee-Martin Area

Figure 8 shows zones of mineralization and traverse lines on the McBee-Martin area. The portion of the McBee-Martin area traversed has a maximum topographic relief of 5 feet.

The limestone surface has a relief of about 20 feet. The overburden has an average thickness of 20 to 40 feet. It is impossible

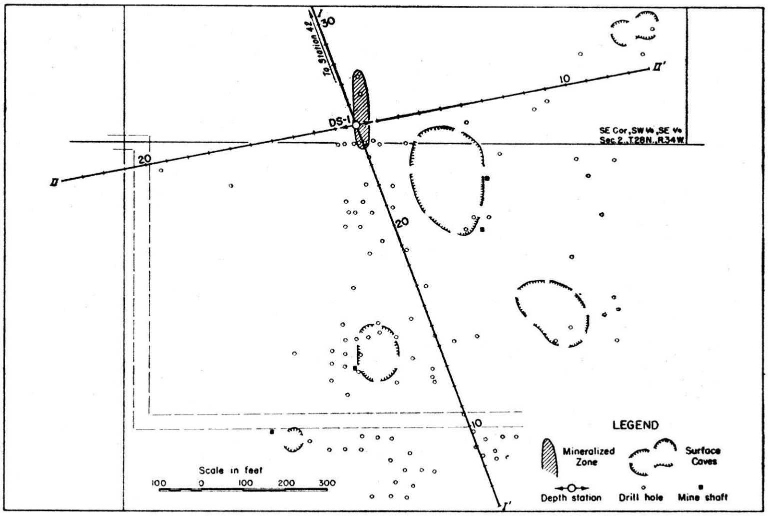

Fig. 8. Map showing mineralized zone and traverse lines in the McBee-Martin area.

to tell from the data available whether the overburden is "Tertiary," weathered shale, or weathered limestone.

The mineralized zone is at an average depth of 100 to 160 feet. Very little galena occurs in this area.

The McBee-Martin area was studied as an example of a shallow run-type of mineralization with little lead. The area was studied by the following geophysical methods: gravity, resistivity, and geothermal.

GEOPHYSICAL SURVEY

INSTRUMENTS, FIELD PROCEDURE, AND PRESENTATION OF DATA

Introduction

A uniform procedure was employed for the different methods, both in making the field measurements and in compiling and presenting the data.

Station grids and traverses were laid out beforehand in accordance with the general requirements of the geological problems, (see pp. 23-32). These layouts were used for all of the geophysical methods, with changes and additions required as the work progressed.

To aid interpretation, a uniform scale was adopted for plotting the topography, geology, and geophysical anomalies. Insofar as possible, the same scale was used for plotting each series of geophysical data for all of the areas, in order to facilitate comparison of data within areas as well as from area to area. The geophysical data are plotted on maps and profiles in such a way that: (1) the results of the different geophysical methods may be compared and (2) anomalies in each method may be compared to topographic and geologic data.

The corrected geophysical measurements are expressed in the following units:

Magnetic	gammas
Gravity	milligals
Natural potential	millivolts
Resistivity	ohm-centimeters
Geothermal	degrees centigrade
Geochemical	relative spectral intensity (arbitrary units)

On the contour maps the following intervals are employed:

Topography	1 foot
Geology	5 feet (except 10 feet
Regional magnetic	in Mullen area)
Local magnetic	50 gammas
Regional gravity	10 gammas
Local gravity	0.2 milligals
Natural potential	0.05 milligals
Geothermal	5 millivolts
	0.2°C in the Walton area
	1.0°C in the Karcher area

Magnetic Survey

INSTRUMENTS

A magnetic vertical field balance of the Askania-Schmidt type was employed for the magnetic studies (pl. 1). This instrument (known also as a vertical magnetometer) measures local variations (anomalies) in vertical magnetic intensity, (Joyce, J. W., 1937).

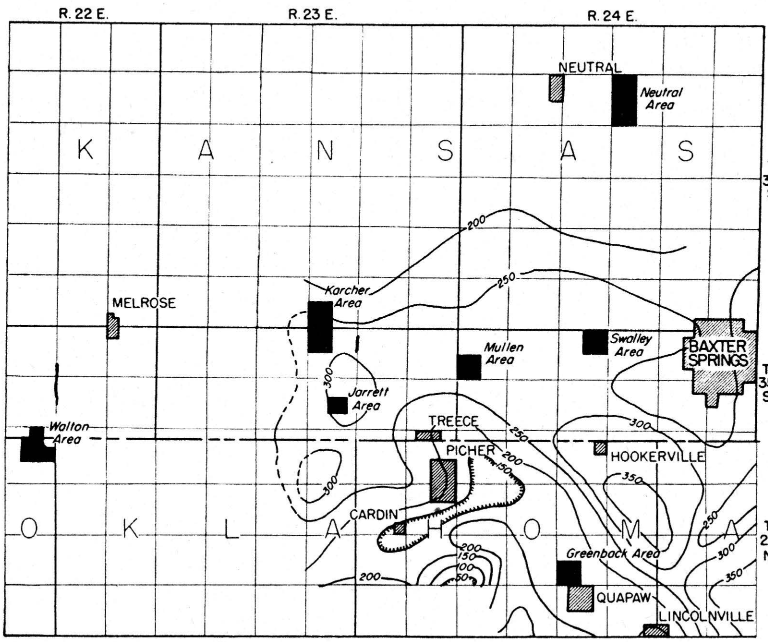

FIG. 9. Isodynamic contour map showing anomalies in vertical intensity of the earth's magnetic field, near Baxter Springs, Kansas.

FIELD PROCEDURE

The magnetic work comprised: (1) a regional survey in which readings were taken at intervals of approximately one mile over an area of approximately 75 square miles (fig. 10) and (2) local surveys in which readings were taken at intervals of 50 to 400 feet at grid stations and along traverses in the Neutral, Mullen, Walton, and Karcher areas. Regional and local survey readings were converted to the same datum. The work was conducted by an operator and an assistant.

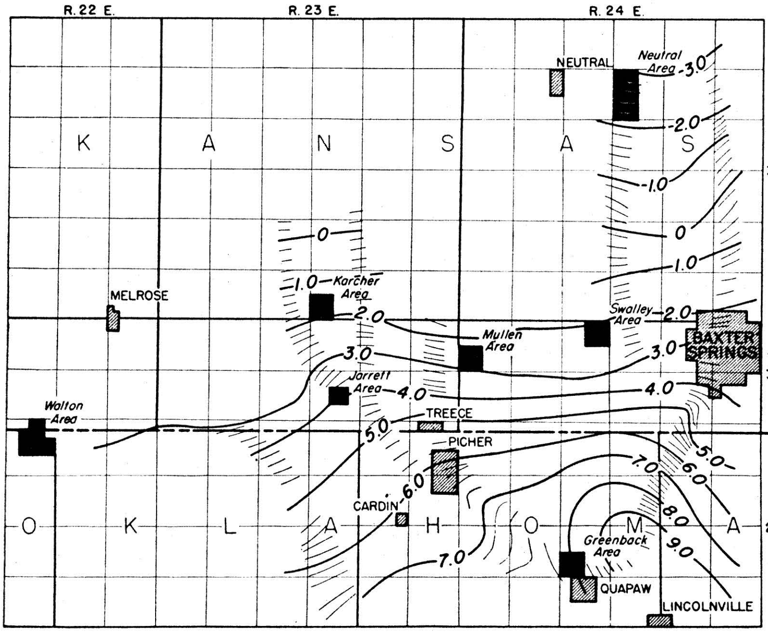

FIG. 10. Map showing isanomalic gravity contours in an area near Baxter Springs, Kansas.

CORRECTION OF FIELD MEASUREMENTS

In order to convert the field observations into anomalies of vertical magnetic intensity the corrections listed below were all applied to the magnetic measurements made in the Tri-State area:

(1) Temperature correction.
(2) Diurnal correction.
(3) Latitude correction.
(4) Longitude correction.
(5) Base station correction.
(6) Correction to arbitrary datum.

Temperature Corrections

Changes in temperature affect the magnetic system of the magnetometer in a number of ways that influence its response to variations in strength of the earth's magnetic field. For the instrument used in this survey, the temperature coefficient was 4 gammas per degree centigrade. The scale constant was 1 scale division = 21.0 gammas.

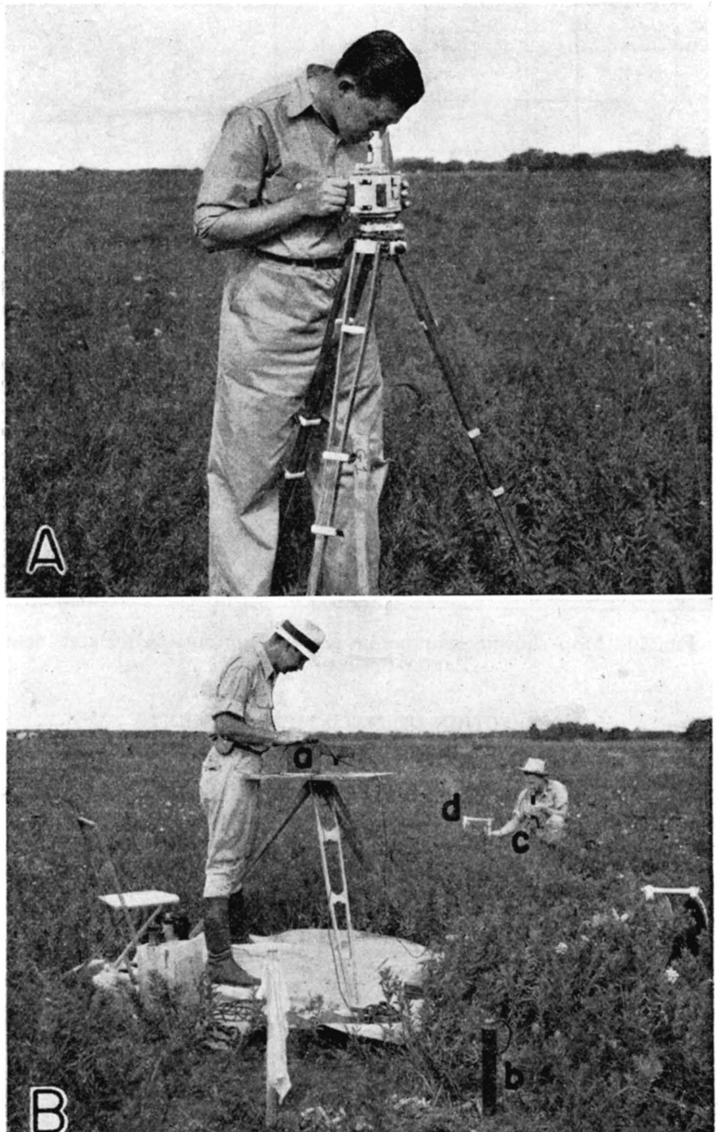

PLATE 1. A. Magnetometer and operator in the field. B. Field set-up for measuring natural earth potentials: a. potentiometer, b. nonpolarizing electrode at base station, c. nonpolarizing electrode being set at field station, d. reel carrying connecting wire. (After Jakosky, 1940, p. 259.)

Diurnal Corrections

The approximate diurnal variations were determined by making readings several times during each working day at base stations in the area. Diurnal curves were plotted from the base station readings. Corrections based upon these curves were added to or subtracted from (depending upon their algebraic sign) the readings made at the various stations during the day, so as to eliminate the effect of the diurnal change.

The base station correction was not determined separately from the diurnal correction in this survey. This correction is applied to correct for any change in instrument calibration, especially sudden changes that might be caused by jarring the instrument. No effects of this type were noted during the course of this work.

Latitude and Longitude Corrections

The value of the earth's normal magnetic field varies from place to place over the earth's surface. In surveys extending over distances greater than a mile, it is usually necessary to apply corrections to remove the effect of differences in location (*i e.*, latitude and longitude). Corrections for both latitude and longitude were applied to the Tri-State magnetic readings. For this purpose base lines (lines of zero correction) were assumed as follows: latitude, Kansas-Oklahoma state line; longitude, township line between ranges 24 east and 25 east.

Datum Correction

Absolute values of the magnetic vertical intensity were not computed for this survey. Neither was any particular value of the earth's field chosen as a datum. Instead, an arbitrary datum was employed wherein the lowest reading in the area of the survey (NW cor. sec. 33, T. 29 N., R. 23 E.), was assumed to have zero anomaly. The field readings were then computed in terms of anomalies in gammas above this assumed arbitrary base.

ACCURACY OF DATA

During the course of the magnetic work numerous check readings were made to determine the accuracy of the computed values. Errors in this type of survey are chiefly: (1) errors in field manipulation and observation and (2) errors in applied corrections. As determined experimentally, the sum of these errors probably does not exceed one-half of one scale division (approximately 10 gammas). Variations of more than 10 gammas in any of the areas, therefore, probably represent valid anomalies.

PRESENTATION OF DATA

The magnetic variations are illustrated in one or both of two ways for the several areas: (1) profiles of anomalies in vertical magnetic intensity (vertical magnetic intensity in gammas plotted against distance in feet) and (2) magnetic isodynamic contours.

Gravity Surveys

INSTRUMENTS

A Mott-Smith gravity meter was employed in this work. Determination of the relative force of gravity over an area with this instrument consists of "weighing" the same object with very great precision at several stations. The weight of an object at any location on the earth's surface is proportional to the acceleration of gravity, which, in turn, is proportional to the unit mass beneath any given point on the earth's crust. Local variations in the weight of an object are therefore indicative of variations in subsurface mass and, hence, of variations in geologic structure (Jakosky, 1940, pp. 168, 180-182).

FIELD PROCEDURE

The gravity work comprised: (1) a regional survey in which readings were taken at intervals of approximately one mile, over an area of approximately 60 square miles (fig. 10) and (2) surveys in the various local areas in which readings were taken generally at 100 foot intervals along traverses and on grid layouts.

In the regional work, the instrument was transported in a closed automobile and the observations were made by setting the instrument on a tripod extending through the floor of the car. For the local areas, the instrument and auxiliary equipment were transported from station to station by hand. This work required two to three men for the gravity observations and a two-man surveying crew for accurately determining the elevations of the gravity stations.

COMPUTATION AND CORRECTION OF FIELD MEASUREMENTS

The gravity meter readings are proportional to the changes in acceleration due to gravity. In order to convert these into milligals of acceleration change, it is necessary to apply a number of corrections. It is possible to convert the readings into absolute gravity by tying them in to base stations established by the United States Coast and Geodetic Survey. This was not done for this work since no base has been established nearby. For convenience, an arbitrary base station was set 25 feet east of the northeast corner of the Kansas City Southern Railroad station in Baxter Springs, Kansas. This base was assigned an assumed value of 870 milligals. All readings were tied in to this base, and the computed values shown in this report represent variations from this base value.

Calibration of the Instrument

The instrument used in this survey was calibrated by reading it at a series of base stations near Houston, Texas, for which the acceleration of gravity is accurately known, from pendulum observations.

Elevation Correction

In this area the acceleration of gravity decreases at the rate of approximately 0.063 milligals per foot of increase in elevation as determined empirically by measurements made at different levels in mine shafts. Using this factor and the station elevations, the gravity meter readings were reduced to equivalent values at the levels of the base station.

The elevations of the gravity stations were determined to within 0.1 foot by differential leveling. Elevations for several bench marks in the area were obtained from the U. S. Geological Survey in Washington, D. C., and these were used for base stations. A number of closed survey loops were run. The maximum error of closure on any of these was 0.35 feet.

Latitude Correction

The value of the earth's normal gravitational field varies with a change in geographical latitude. The gravity-meter readings, therefore, must be corrected so as to remove the effects of difference in station location. In the Tri-State survey the correction factor was based upon values computed from the International Gravity Formula of 1930. The gravity variation in the area was determined to be 1.2569 milligals per mile.

Regional Gradient

A regional gradient of approximately 1.0 milligal per mile in this area is indicated by the plotted gravity values (fig. 10). It is sometimes desirable to correct for regional gradient in order to more clearly portray local changes. In the present survey, this was necessary only for the Neutral area gravity profile (fig. 16).

ACCURACY OF DATA

Errors in gravity measurements are due chiefly to: (1) reading error due to instrumental variations, (2) errors in calibration, and (3) errors in the elevation and latitude corrections.

The probable reading error as determined from plotting "drift" curves of successive readings at the same station appears to be of the order of 0.03 to 0.05 milligal. It is believed that the calibration for the instrument used in this work is accurate to 0.2 percent. The latitude and elevation were determined with sufficient accuracy to reduce errors from these corrections to less than the reading error. It is believed, therefore, that the sum of these errors probably does not exceed 0.05 milligals. The close agreement between the gravity meter values and the prior torsion balance work in the Jarrett area is interesting and indicates approximately this order of accuracy.

PRESENTATION OF DATA

The corrected gravity values are plotted as isanomalic contours and as profiles, representing the variation in value above or below the base assumed for the area. The contour interval for all of the local areas is 0.05 milligal, while an interval of 0.2 milligal was used for the regional gravity map.

Natural Potential Survey

INSTRUMENTS

A Leeds-Northrup potentiometer was used to measure differences in potential associated with natural current flowing in the earth between selected points at the surface. Contact with the ground was made by means of nonpolarizing electrodes consisting of copper rods immersed in saturated solutions of copper sulphate contained in porous cups. Connections between the instrument and the electrodes were made through flexible, rubber-insulated, connecting wire cables wound on hand-operated reels. A photograph of the set-up of instrument and auxiliary equipment is shown in plate 1.

FIELD PROCEDURE

The purpose of the natural potential measurements was to determine the relative potential and polarity between selected stations in the various areas, so that potential profiles and contours could be plotted therefrom. These stations were located along either traverses (Neutral and Mullen areas) or on a grid work of stations (Walton and Karcher areas).

The instrument was set up at a central station, with one nonpolarizing electrode set in the ground at this station. Other electrodes were then set successively at various stations in the area, and the potential and polarity between the two electrodes observed for each setting. The potentials at the various stations relative to one or more bases in an area thus were determined.

In order to detect potential variations related to changes in intensity and direction of flow of the natural ground currents during any series of measurements, "base" readings were made in several azimuths between points spanning the width of area, or along traverses, as the case required. For each station, the time of reading, potential value, and polarity were recorded.

COMPUTATION AND CORRECTION OF FIELD MEASUREMENTS

Computation of the potential readings into values suitable for plotting consisted in: (1) correction for variations indicated by the base station readings (diurnal variations) and (2) reduction of all readings to a common base for each area. In this latter operation the station showing the highest negative polarity in each area was considered to be at zero potential, except in the Walton area where the readings were not reduced to zero base. All computed values, therefore, represent positive potential, relative to a common base, except in the Walton area where both positive and negative potentials are plotted. There is no relationship between the potentials or base values of the separate areas.

Earth potential measurements are subject to a number of errors, the importance of which depend largely upon the smallness of the potentials being measured. In the Tri-State area the potential measured between any two points was seldom more than 20 millivolts, which is a relatively small quantity. Consideration of the possible errors is important.

Three types of influence are mainly responsible for errors in natural potential surveys: (1) variations in electrode contact potential due to variation in soil and moisture conditions around the electrode, and to differences in electrolyte concentration in the electrodes, (2) relatively rapid cyclic variations in earth currents (period usually less than one minute), and (3) earth current flucuation of slower frequency (variations noted during one day or from day to day).

The first-named error was minimized by employing a uniform procedure for setting electrodes, as well as by careful attention to the non-polarizing electrodes and to the uniformity of the electrolyte. The electrodes were tested occasionally by immersing them in a glass container and measuring the differences in potential. This difference in potential was found to be sometimes as high as 2 millivolts. Although it is not possible to determine the differences in contact potentials due to minor variations at the different electrode set-ups, it is believed that the combined effects enumerated under (1) do not exceed 2 millivolts.

Comparatively rapid earth current flucuations were noted only occasionally in the area; and, when necessary, the effect of these was minimized by averaging readings over the range of the fluctuation. This error probably does not exceed 2 millivolts.

Variations of a type listed under (3) proved to be serious in this work, especially in the case of the Walton area where the intensity variations were not only especially pronounced during the course of the survey, but were influenced by a somewhat random directional variation for which it was impossible to devise an accurate correction, even from the base station readings made in different azimuths. The reason for these variations is not known.

ACCURACY OF DATA

The accuracy of the natural potential readings is different for the separate areas. A statement of the probable accuracy of the potential values is contained in the discussions under each area. In general, in order of decreasing accuracy, the areas may be listed as follows: Mullen, Neutral, Karcher, Walton.

PRESENTATION OF DATA

The natural potential values are plotted as equipotential contours and as profiles representing the variation in potential above an arbitrary base assumed for each area. In discussing the results of natural potential work it is customary to use the term "negative center." An area of low potentials represented by a "depression" contour on the contour map is an area of relative negative potentials, and therefore an area toward which natural current flows, locally, from all directions. Such an area is a negative center. An oxidizing ore body can sometimes be located by detecting the presence of a negative center over the top of the ore body (Jakosky, 1940, pp. 256-266).

Resistivity Survey

INSTRUMENTS AND MEASUREMENT TECHNIQUE

By means of electrical resistivity methods it is possible to secure quantitative electrical data over a controlled range of effective depths. Calculations may be made which will give the average resistivity of the portion of the subsurface included in the measurements.

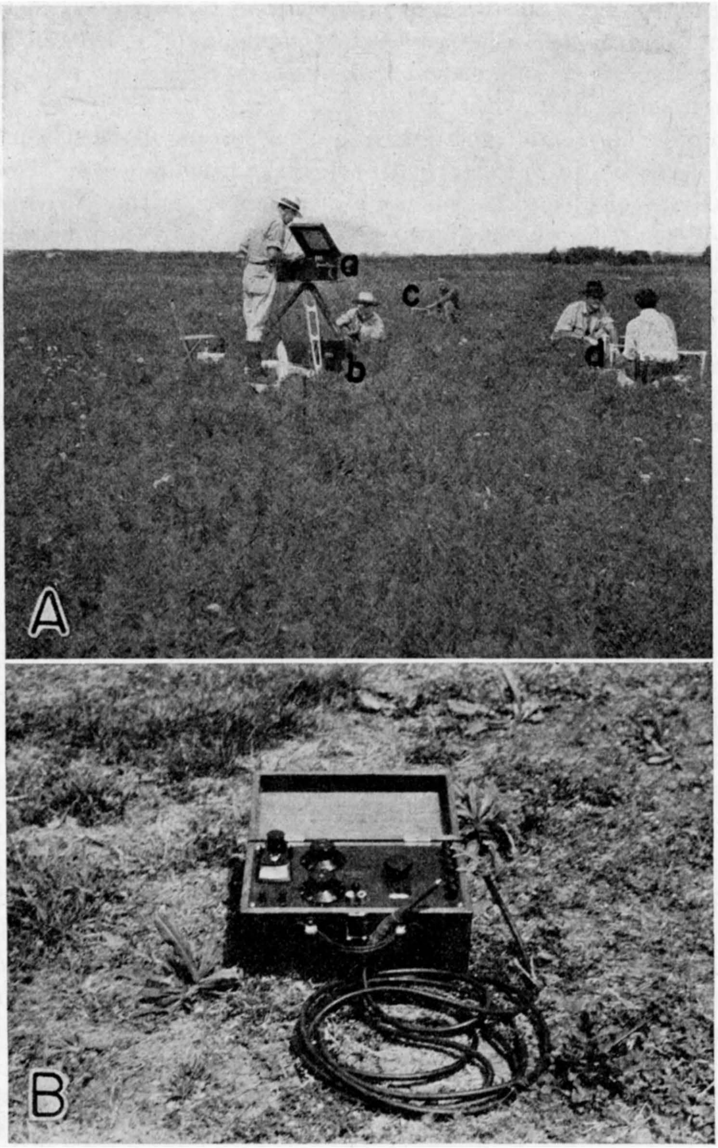

PLATE 2. A. Field set up for measuring earth resistivity: a. electrical ratio instrument, b. battery box, c. reels and electrodes set along line of measurement. B. Thermometer bridge and resistance thermometer.

In this work, the electrical ratio instrument was employed. This instrument allows the direct determination of the E:I ratio, thereby simplifying the field measurement technique (Jakosky, 1940, p. 351). Plate 2 shows the instrument and auxiliary equipment set up for measurements in the field.

In order to measure the resistivity of a portion of the subsurface it is necessary to cause current to flow through the earth. This is usually accomplished by passing a measured energizing current between electrodes placed at two selected points and then measuring the potential drop between two or more potential electrodes which are usually placed along a straight line passing through the energizing electrodes. The effective depth of measurement depends upon the configuration and spacing of the various electrodes, and the resistivities of the subsurface strata. From a knowledge of the current, E:I ratio, and the configuration of the electrodes, it is possible to compute the average resistivity of the material included within the zone of measurement. Many types of electrode configurations may be employed.

Two types of resistivity measurements were conducted: (1) lateral investigations and (2) vertical or depth investigations. In the former, ground resistivities are measured over an essentially constant depth range, along a traverse line, for the purpose of detecting horizontal changes across an area. In the latter, resistivities are measured at increments of gradually increasing depth (increasing spread of electrodes) for the purpose of detecting vertical changes (changes in resistivity with depth).

FIELD PROCEDURE

In this survey four electrodes were spaced equidistant along a straight line, with two potential electrodes inside two energizing electrodes. The spacing between the potential electrodes is therefore equal to one-third of the spacing between the energizing electrodes. This symmetrical arrangement of electrodes facilitates the computations and interpretations and is easily handled in the field. (Wenner, 1916; Gish and Rooney, 1925.)

Power for energization was supplied by a bank of heavy duty "B" type batteries, so assembled that voltages from 22½ volts to 500 volts could be obtained by easy manipulation of a control switch. Spring-steel rods, 2 to 4 feet long, were used as energizing electrodes. The potential electrodes were of the nonpolarizing type like those previously described under natural potential procedure. Connections between the various electrodes, power supply, and instrument were made with flexible rubber insulated wire cables wound on hand reels.

Lateral resistivity investigations were conducted along traverses in all areas except the Jarrett area. These lateral studies were of two types: (1) longitudinal traverses and (2) transverse traverses. In the *longitudinal* traverse, measurements are made as the electrode configuration (spread and spacing remaining constant) is moved along the traverse. The direction of the electrode movement and the direction of measurement, therefore, coincide with the direction of the traverse. In the *transverse* traverse, measurements are made in a direction at right angles to the direction of the traverse. The electrode configuration (spread and spacing remaining constant) is moved across the area, with the center point of the configuration falling on and moving along the traverse. The electrode spacings used on the various traverses were determined by the depth of investigation required in the different areas. In some of the areas, measurements over two different depth ranges were made along some of the traverses. The locations and directions of the various traverses and the depths and types of measurement conducted along them were governed by geological factors. In general, the traverses cross the significant geological features (mineralized zones or structural trends) at approximately right angles.

Vertical investigations (hereinafter called resistivity depth measurements) were conducted at selected places (stations) in several of the areas, for the purpose of ascertaining their usefulness in the problems of mapping the top of the limestone and securing information to aid interpretation of the lateral measurements. The resistivity work required a personnel of five to seven men.

COMPUTATION OF FIELD MEASUREMENTS

The instrument reading, after making instrumental scale corrections, is the E:I ratio, or resistance of the ground circuit for any particular spacing of the electrodes. This is converted into terms of apparent resistivity from formulae which relate the E:I ratio to factors dependent upon the electrode spacings. In this survey all readings were converted to resistivity in ohm-centimeters.

The resistivity values as computed above are essentially the final values, the only correction subsequently required being a reduction to a common base of values read under variable conditions of temperature, current density, etc. The influence of natural earth currents is eliminated by the use of balancing potentials in the instrument. The chief sources of error in these measurements are: (1)

reading errors, (2) error in recorded value due to variation in reading conditions (temperature changes, etc.), and (3) errors in surveying or in setting of electrodes along the lines of measurements. These errors can be minimized by proper technique and care in taking the measurements. The estimated maximum error in this work is about 1 percent of the final computed values.

FACTORS INFLUENCING INTERPRETATION

The resistivity data in this report are expressed in absolute units. The absolute values are of interest in showing the general range of rock resistivities in the area, but are not useful in interpretation, except in a very general way. For example, it is found that the higher values are found in areas in which the limestone is nearer the surface. Interpretation, with respect to the possible effects of mineralized zones, relief on the limestone surface, brecciated, or cavernous zones, etc., is based primarily upon variations from mean trends along plotted profiles. Resistivity values in the areas range from 6,000 to 20,000 ohm-centimeters over a range of depth extending from the surface to approximately 400 feet.

The penetration factor (ratio of effective depth of measurement to the total spacing of the energizing electrodes) for this area was determined experimentally by making depth measurements at locations where the depths to the limestone were known. For the electrode configuration employed in these tests an approximate value of 0.30 to 0.35 was indicated for the penetration factor.

On some of the resistivity traverses, measurements were made at two different depths. In general, the purpose of this procedure was to determine the influence of relatively shallow subsurface conditions upon the measurements that were extended to and beyond the depth of the mineralized zones. The computed resistivity values are the weighted averages of all the resistivity changes present between the surface and the effective depth of measurement. Prominent changes relatively near the surface, therefore, will greatly influence the attempted deeper measurements. The relative influence of shallow and deeper subsurface resistivity changes may be determined from a comparison of the resistivity trends at different depths.

The values of resistivity obtained in these measurements, representing, as they do, weighted values, are more properly termed "apparent" resistivity. A further reason for using the term apparent is the fact that these values are influenced by the configuration of the electrodes and the direction of the measurements as related to changes in the subsurface. Only in the ideal case of homogeneous, isotropic ground could true values of resistivity be obtained by these measurements.

The effect of the electrode configuration upon the apparent resistivity values is often useful in interpretation. An example of this is the so-called "W" effect. This is a distortion of the normal values along a traverse as the electrode configuration moves across an electrically conductive subsurface zone, and may be explained as follows (fig. 11): Referring to the figure, the positions of the electrodes are shown with reference to a subsurface zone of relatively high conductivity. The energizing electrodes are designated as 1 and 4, and the potential electrodes are 2 and 3 (Jakosky, 1940, p. 307).

At some distance to the left of the diagram the subsurface is considered to be homogeneous. At this position the current flowing in the ground between electrodes 1 and 4 follows a normal path, and the computed resistivity values are normal. As the electrode configuration approaches the conductive zone, there is a tendency for the current to be concentrated in the better conductor. This causes a diminution in the current density between 2 and 3, resulting in a decreased potential difference. Since the apparent resistivity is proportional to the potential drop between the potential electrodes, this results in a decrease in apparent resistivity, as at A in the lower part of the figure. Now, as the electrode configuration reaches the position shown by B, the potential drop between 1 and 2 becomes less than normal, due to the short circuiting effect of the conductive zone. This causes most of the potential drop to occur between 2 and 3 and, therefore, results in a maximum value of apparent resistivity. When the electrode configuration reaches the position shown by C, the potential difference between 2 and 3 becomes very small since it is measured directly across the conductive zone. For this position the apparent resistivity is a minimum. As the electrode configuration proceeds through positions D and E the effects are similar to the effects noted at B and A, respectively.

It should be noted that the positions of the maximum and minimum resistivity values have a definite relationship to the electrode spacing and the location of the subsurface conductive zone. Recognition of this type of anomaly in the field work is useful, therefore, in determining locations and extents of subsurface conductors.

PRESENTATION OF DATA

The resistivity traverse data are plotted as profiles of apparent resistivity. These show lateral changes along the lines of the tra-

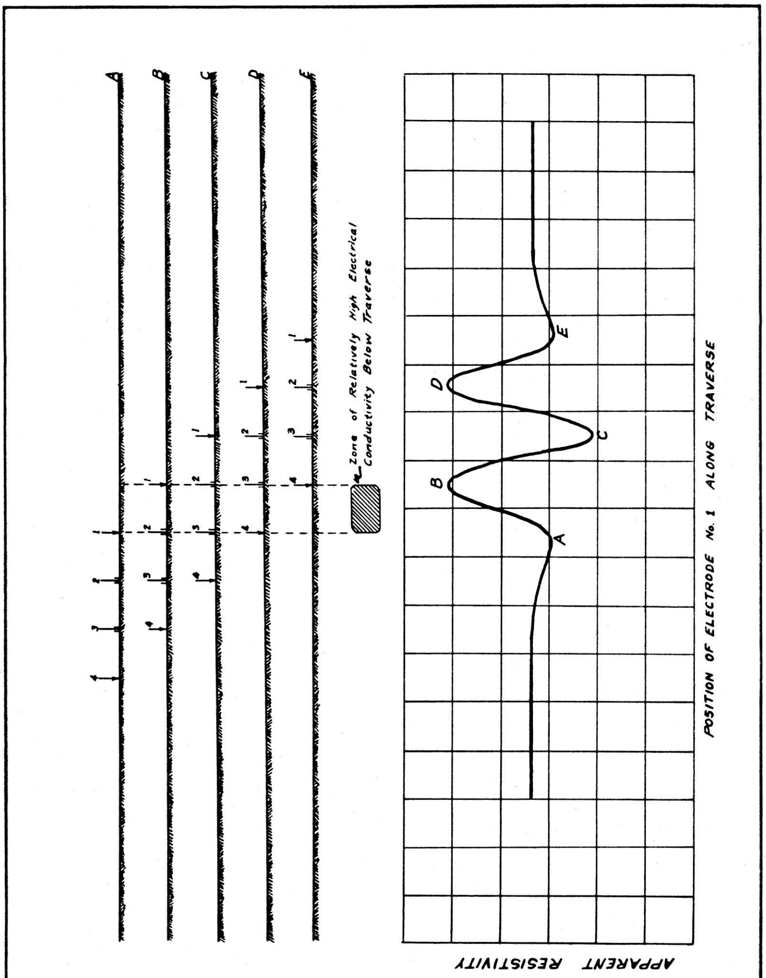

FIG. 11. Anomaly caused by electrically conductive zone crossed by resistivity traverse.

verses within a selected depth range. The resistivity depth data are plotted as resistivity depth curves which show the variations of resistivity with depth in a restricted zone below the line of measurement.

Geothermal Survey

INSTRUMENTS AND EQUIPMENT

The temperature measurements in this area were obtained by the use of Leeds and Northrup resistance thermometers and a Leeds Northrup Semi-Precision Thermometer Bridge (fig. 16). The thermometers consist of resistance elements encased in brass protection tubes, with suitable connecting leads extending from the tubes through heavy rubber conduits. The resistance of the thermometer element varies with changes in temperature. This relationship, having been determined beforehand, is expressed in the form of calibration tables giving the temperature in Fahrenheit and Centigrade degrees for different resistance readings. To determine the temperature at a thermometer station it is necessary only to measure the resistance of the thermometer. This reading is then converted to temperature by consulting the calibration charts.

The thermometer bridge used for the resistance measurements is a double slide-wire Wheatstone bridge designed to measure resistance from 0 to 200 ohms. Measurements accurate to 0.005 ohms (corresponding to $\pm$ 0.014° C.) can be made easily with this instrument.

FIELD PROCEDURE

The temperature measurements were taken at selected stations on the traverses and grid layouts. At each temperature station, a hole three feet deep was drilled with a hand-auger, a day or more before the temperature measurements were to be taken. The thermometers were placed in the holes so that the thermometer tube rested firmly against the bottom of the hole or was pressed into soft soil at the bottom of the hole. After the thermometer was placed in a hole, a cover with a sharp-edged cylindrical flange was fastened securely over the top of the hole.

A uniform reading and thermometer-setting procedure was used so as to minimize the influence of diurnal temperature variations and other extraneous effects. The temperature measurements were made at the same time each morning ordinarily before the atmospheric temperature had started to increase. After completion of the readings, the thermometers were moved to another set of holes in which they were left until the next morning when measurements were again made. Ordinarily the thermometers were left in the holes for at least 16 to 20 hours before reading, so as to insure their reaching equilibrium with the ground temperature.

Although an attempt was made to secure uniform reading conditions, there were many variables that could not be controlled practicably, such as differences in soil and vegetative conditions, variations in topography and surface drainage, and effects of rainfall entering the holes.

Experimental work indicated that three-foot holes are not sufficiently deep to be beyond the range of diurnal variations in this area. However, it was not practicable in this survey to drill deeper holes, and it was found that the practice of making readings at approximately the same time each day sufficiently minimized the effect of the cyclic variation in temperature over a 24-hour period.

Another effect was important. It was noted that, over a period of days, there were fairly uniform increases or decreases in the temperatures measured at base stations. These changes are due apparently to differences in the rate of thermal absorption and radiation by the earth over these periods of time. In order to determine a correction for these variations, a base station was read in each area. The base thermometer was left in the hole throughout the survey of the particular area. Readings of the base station were made each day at the same time, as the other thermometers were read.

COMPUTATION AND CORRECTION OF FIELD MEASUREMENTS

Owing to slight fabrication differences, the various thermometers have slightly different temperature coefficients. To determine these differences, the thermometers were calibrated in a water bath over the general range of temperatures measured in the field. One thermometer was used as an arbitrary base. These corrections were applied to the field readings to reduce them to comparable resistance values.

Then, a curve was plotted from the base station readings, showing the variation in ground temperature during the course of the survey. Correction factors derived from this curve were used to reduce all readings in the local area to a common base. The reading, observed at the start of the survey, was arbitrarily taken.

Finally, the resistance readings were converted into terms of temperature in degrees, Centigrade, by reference to the resistance-temperature calibration charts.

ACCURACY OF DATA

The reading accuracy of the thermometer bridge (± 0.014° C.) is an indication of the field measurement accuracy that could be obtained were errors not introduced either by thermometer calibration, by diurnal correction, or by errors inherent in the field procedure. Probably the chief source of error in these measurements is the practical impossibility of setting up the same measurement conditions at different stations, or of duplicating measurement conditions at any one particular station. No attempt was made to segregate or determine the relative effects of different sources of error. Instead, the field procedure was kept as uniform as possible and the probable error for each area was determined by running a series of check readings.

Reading conditions in the Walton area were somewhat more favorable than in the other areas. The measurements in this area were made after the ground had become saturated with rain water. With but a few exceptions, the readings in this area were made under water. Check readings indicate the probable limit of error to be of the order of 0.2° C.

In the other areas, readings were undoubtedly affected by water seepage from intermittent rainfall, as well as by other local variations related to variations in topography and drainage. These variations were especially prominent in the Karcher area. In the Karcher area the limit of error is believed to be of the order of 0.3° C. to 0.4° C.

Variations in the near-surface conditions are discussed further under the results of the individual areas.

PRESENTATION OF DATA

The geothermal data are plotted as: (1) isothermal contours and (2) profiles showing the indicated variation in temperature along traverses.

GEOCHEMICAL SURVEY

INSTRUMENTS AND PROCEDURE

The samples for geochemical analysis are of two main types: (1) soil samples, taken with a post-hole auger at a depth of three feet, and (2) drill hole samples, taken at more or less regular intervals from selected exploratory drill holes in Kansas and Oklahoma. There are two types of drill hole samples: (1) samples from the Cherokee shale and (2) samples from the Mississippian limestone.

All samples were given identical preparation. First, they were crushed so that they would pass through a Jones sample splitter. Next, a 20 gram sample was ground to minus 60 mesh. The sample was then placed in a manila envelope and labeled. Subsequently, before making the analysis, the contents of the envelope were poured out on a clean sheet of wrapping paper and mixed by lifting corners of the paper and rolling the sample. A quarter of the sample was cut out and mixed to provide the sample for analysis. The weight of the sample used for analysis was about 0.1 gram.

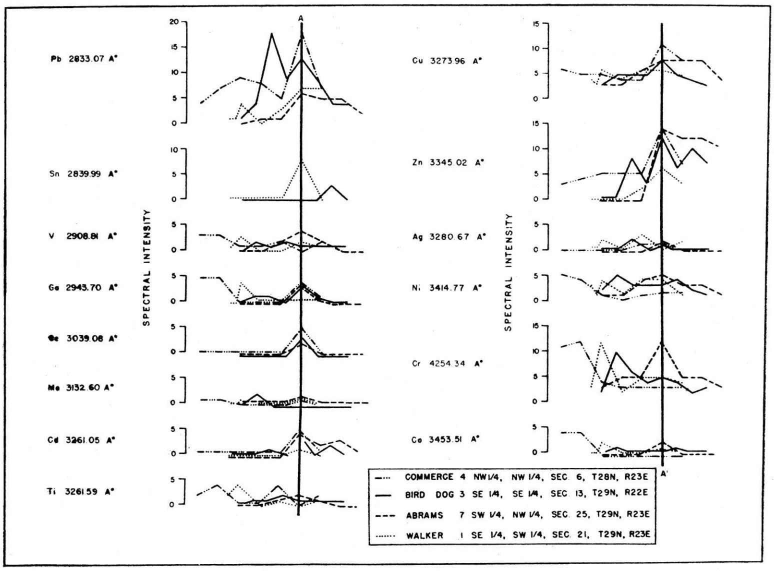

FIG. 12. Geochemical profiles for drill holes showing ore mineralization. A-A′ indicates mineralized zone.

An Applied Research Laboratory grating spectrograph was used for the analyses. The wave length range employed was about 2,400 to 4,550 angstroms (which includes the most useful portions of the visible and ultra-violet spectra).

Two graphite rods, five-sixteenths of an inch in diameter and 3 inches long, were used for electrodes. Two holes were drilled one-fourth inch deep in the top of the lower electrode as a container for the sample. The upper electrode was sharpened in a pencil sharpener and the point flattened off with a carbon steel file.

The electrodes were spaced 5.5 mm. apart and a portion of the sample placed in the holes drilled in the lower electrode. The exposure was made by starting an electric arc across the gap and letting it run for one minute. The potential across the gap was 115 volts and the current flow was about 8 amperes.

Eastman number 10 negative 35 mm. film was used for the spectrograms, eight samples being run on a single strip of film 18 inches long. The spectrograms were read by projecting them onto a screen

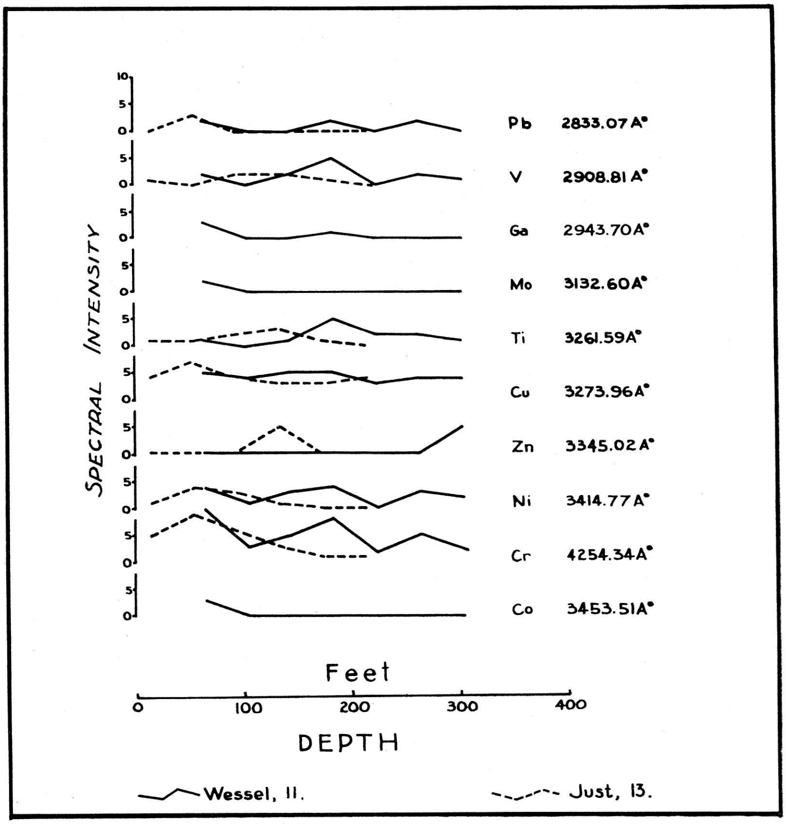

FIG. 13. Geochemical profiles for nonmineralized drill holes.

and comparing the lines on the spectrogram with a series of cards indicating the position of the significant lines. The intensities of those lines which were present were estimated by visual inspection using an arbitrary scale of spectral intensity. Increasing numbers on this arbitrary scale indicate increasing spectral intensity. The numbers presented on the accompanying geochemical maps and profiles indicate these arbitrary spectral intensities.

The set of master cards used in locating the significant lines was

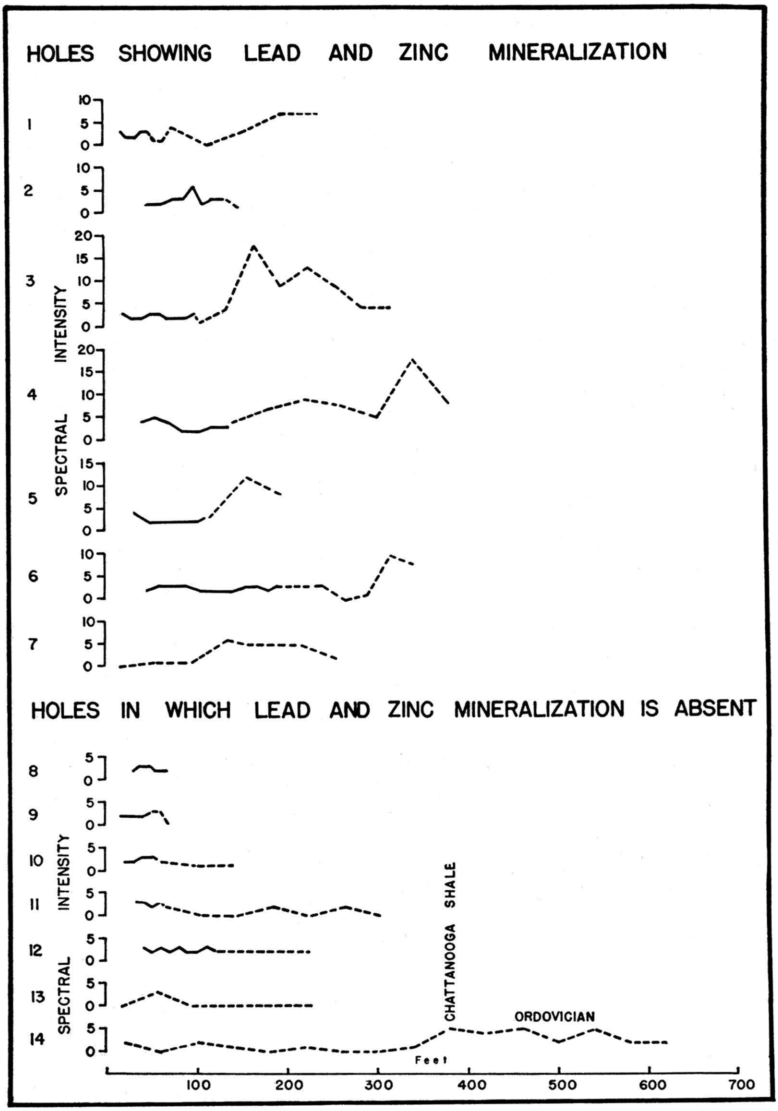

FIG. 14. Vertical distribution of lead in drill holes. For location of drill holes see table 13, p. 86

prepared by Dr. J. H. McMillen, of the Department of Physics at Kansas State College. The scale of these cards is, approximately: 0.6 centimeter equals one angstrom, a scale which makes it possible to differentiate between lines only 0.2 angstrom apart. Table No. 1 gives a list of lines used:

TABLE No. 1.—*List of elements and spectral lines used in the spectrographic analyses*

Wave length, Å	Element	Wave length, Å	Element
2,496.8	Boron*	3,261.59	Titanium
2,536.52	Mercury*	3,273.96	Copper*
2,652.48	Aluminum	3,280.67	Silver*
2,741.2	Lithium	3,282.33	Zinc or Titanium
2,801.08	Manganese	3,302.94	Sodium*
2,802.71	Magnesium	3,345.02	Zinc*
2,833.07	Lead*	3,345.51	Zinc
2,839.99	Tin*	3,345.91	Zinc
2,860.46	Arsenic*	3,391.96	Zirconium
2,877.92	Antimony*	3,414.77	Nickel*
2,897.98	Bismuth*	3,446.37	Potassium
2,905.9	Gold	3,451.4	Boron
2,908.81	Vanadium	3,453.51	Cobalt*
2,943.70	Gallium*	4,008.76	Tungsten*
3,039.08	Germanium*	4,034.45	Manganese*
3,096.9	Magnesium	4,047.2	Potassium
3,122.79	Gold	4,077.71	Strontium*
3,132.6	Molybdenum	4,254.34	Chromium*
3,175.04	Tin	4,294.62	Tungsten
3,256.08	Indium or Manganese	4,358.34	Mercury
3,261.05	Cadmium*	4,554.04	Barium*

* Most sensitive line in this range.

Several of these lines were not found on any of the spectrograms and others are of doubtful value because of the presence of interfering lines. A list of the interfering lines and a discussion of each element is given on pages 55-60. A 35 mm. projector was used for projecting the spectrograms. An assistant ran the projector and recorded the readings.

Spectrograms which are similar can be read very rapidly by this procedure. The soil sample spectrograms proved easiest to read, with the shale sample spectrograms second. Spectrograms for the limestone and chert samples were much more difficult, requiring about a 3-fold longer reading time per sample. This is due chiefly to the absence of many of the iron and titanium lines which were used as guides in locating the significant lines.

Discussion of Elements

The numbers following the name of the elements are the wave lengths of the lines of that element for which readings of intensity were taken.

Boron, 2,496.8 and 3,451.4 Å

The first of these lines is very difficult to read because of the bands in the background. Almost no variation in intensity was detected in the soil samples but there is some variation in the drill hole samples. The line at 3,451.4 Å was not detected in any of the sample analyses. There are no coincident lines, but the 2,496.54 Å iron line is very near the first-named Boron line.

Mercury, 2,536.52 and 4,358.34 Å

The first of these lines is about ten times as strong as the second, but it was not usable because of interference by band spectra. An indistinct line was present at a wave length of 4,358.34 Å, but it is doubtful if this indicates the presence of mercury.

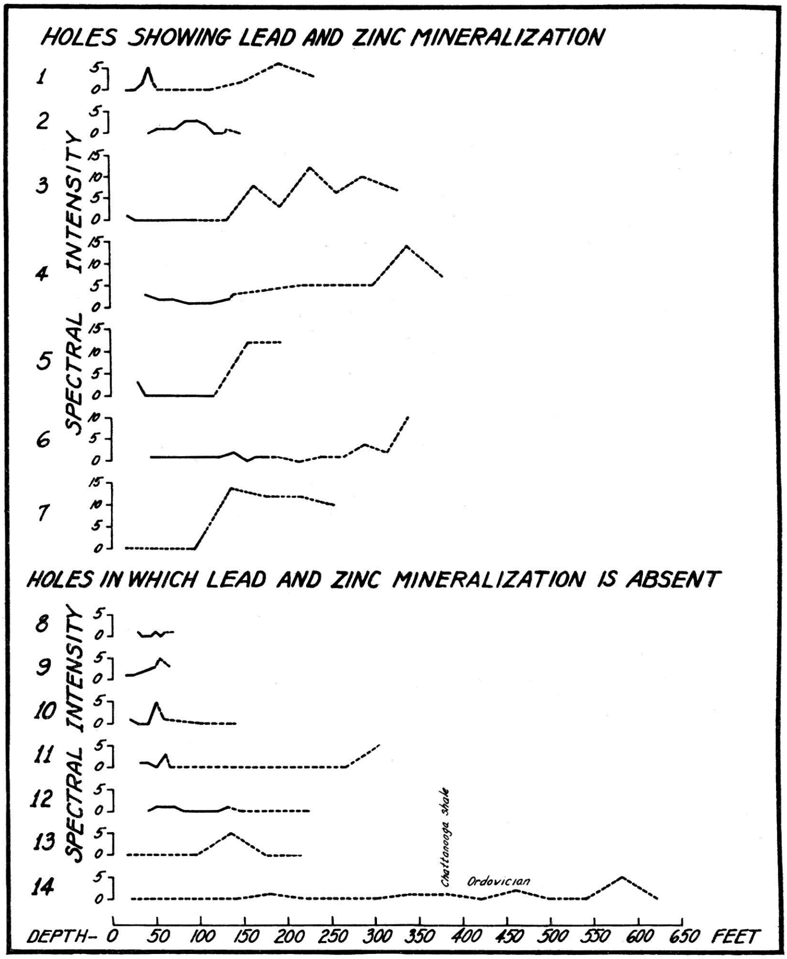

FIG. 15. Vertical distribution of zinc in drill holes. For location of drill holes see table 13, p. 86.

Aluminum, 2,652.48 Å

This line was chosen because the more sensitive lines were too strong. Small differences in intensity cannot be determined on strong lines. There are no coincident lines which could cause reading trouble, but there are bands which make difficult the reading of the very low intensities.

Large differences in intensity were found when using this line, but these differences may not indicate variations in the aluminum content. Variations on repeating the same sample are often as great as the variations between samples.

Lithium, 2,741.20 Å

This line is easily identified but does not vary greatly in intensity. It is present on most of the spectrograms.

Manganese, 2,801.08 and 4,034.45 Å

Both of these lines are distinct and there are no interfering or coincident lines. Manganese is not present in the carbon electrodes. Both lines show considerable variations in intensity readings for different samples and give consistent readings in the same sample. The 4,034.45 Å line is more sensitive than the 2,801.08 Å line.

Magnesium, 2,802.71 and 3,096.9 Å

The 2,802.71 Å line is a heavy line and does not show valid differences in intensity on any of the soil or shale sample spectrograms. For this reason the 3,096.9 Å line was used for the drill hole samples. The 3,096.9 Å line is fuzzy and indistinct but shows considerable variation.

The 2,802.71 Å line shows up in analyses of the electrodes, but the 3,096.9 Å line does not.

Lead, 2,833.07 Å

Lead was detected in all of the shale samples and in most of the soil samples. The intensity of this line does not vary much, except in the mineralized zones in the limestone. There are no coincident lines.

Tin, 2,839.99 and 3,175.04 Å

There are interfering lines of chromium at 2,840.02 Å, aluminum at 2,840.11 Å, and tellurium at 3,175.13 Å. There is also a thick, fuzzy line or band at about 2,840 Å. The tellurium line at 3,175.13 Å was used originally to identify tellurium, but this can not be differentiated from 3,175.04 Å. Identification of tin is not certain unless both lines are present.

Arsenic, 2,860.46 Å

This is the most sensitive line available and there are no coincident lines. This line was not present on any of the spectrograms. The absence of the line does not mean that arsenic was absent in the sample; it merely indicates that arsenic was not present in sufficient quantities to be detected under the conditions of the procedure employed.

Antimony, 2,877.92 Å

This line is very near a heavy "ghost" line which sometimes causes difficulty in identification. Antimony was detected in only one sample.

Bismuth, 2,897.98 Å

This line occurs in a very clear portion of the spectrum and there is no danger of coincidence except from platinum at 2,897.88 Å. A trace of bismuth was detected in only a very few samples.

Gold, 3,122.79 and 2,905.90 Å

There are lines near by which might possibly be confused with gold: titanium at 3,123.07 Å, vanadium at 2,906.13 Å, chromium at 2,905.5 Å, and platinum at 2,905.90 Å. Gold was not detected in any of the samples.

Vanadium, 2,908.81 Å

The only possibility of coincidence is with chromium, at 2,909.06 Å. Vanadium is present as an impurity in the electrodes and is present in most of the samples. The intensity of this line is seldom over 5.

Gallium, 2,943.70 Å

Gallium does not occur in the electrodes and there are no coincident lines. This line is much more prominent in the soil and shale samples than in the limestone and chert samples.

Germanium, 3,039.08 Å

Germanium does not occur in the electrodes and there are no coincident lines. Germanium was detected only in a few of the ore samples.

Molybdenum, 3,132.06 Å

Molybdenum does not occur in the electrodes and there are no coincident lines. Molybdenum was indicated in some of the samples.

Indium, 3,256.08 Å

An interfering line of manganese at 3,256.14 Å renders this identification doubtful. All samples in which this line was identified were high in manganese.

Cadmium, 3,261.05 Å

This is a sensitive line with no seriously interfering lines. Cadmium is not present in any of the soil or shale samples but was found frequently in the limestone samples obtained near the ore horizons.

Titanium, 3,261.59 Å

This is not the most sensitive line for titanium, but it was utilized because the more sensitive lines are too heavy. Titanium occurs in the electrodes and in most of the samples.

Zinc, 3,282.33 Å, 3,345.02 Å, 3,345.51 Å, 3,345.91 Å

There is a titanium line at 3,282.33 Å which makes the zinc line at 3,282.33 Å useless for samples of low zinc content. The 3,282.33 Å zinc and titanium line occurs in most of the soil samples, but cannot be used for identification of zinc. There are three zinc lines between the wave lengths 3,345 Å and 3,346 Å. The 3,345.02 Å line is the most sensitive and the 3,345.91 Å is the least sensitive. The first of these lines occurs in a very few of the soil samples. All three are prominent in the ore samples. The possible interfering lines are zirconium 3,344.7 Å, cerium 3,344.76 Å, and molybdenum 3,344.75 Å.

Copper, 3,273.96 Å

This is the most sensitive copper line. There are no interfering lines. Very little variation in intensity was noted in some of the limestone samples. Copper occurs in the electrodes and in all of the samples.

Silver, 3,280.67 Å

This is the most sensitive silver line and there are no coincident lines. Silver is present in many of the samples but does not give consistent quantitative results.

Sodium, 3,302.94 Å

Sodium occurs in almost all the soil and shale samples and in most of the limestone samples. There is a zinc line at this wave length which makes this line useless for determinations on the ore samples. There is another zinc line at 3,302.59 Å which is slightly more sensitive; and, if it is absent, then the 3,302.94 Å zinc line will not cause trouble.

Zirconium, 3,391.96 Å

Zirconium occurs in most of the soil samples, but it varies as much when a sample is repeated several times as it does between different samples. For this reason zirconium could not be used in this study.

Nickel, 3,414.77 Å

This is the most sensitive nickel line and there are no coincident lines. Nickel is present in most of the samples.

Cobalt, 3,453.51 Å

This is a very useful line because it is in a clear portion of the spectrum, shows considerable variation on different samples, and gives consistent readings on the same sample. There is a chromium line at 3,453.33 Å, but this is far enough away to prevent mistaking it for the cobalt line. Cobalt occurs in most of the samples and ranges in intensity from 0 to 7.

Tungsten, 4,008.76 and 4,294.62 Å

The line at 4,008.76 Å is very difficult to read because of the bands. There is a titanium line at 4,008.93 Å. The 4,294.62 Å line is less sensitive but is in a clear portion of the spectrum. Tungsten was not identified in any of the samples.

Potassium, 4,047.2 Å

An attempt was made to use the potassium line at 3,446.37 Å, but the 3,446.4 Å cobalt line interfered. Therefore, the 4,047.2 Å potassium line was used, although it is subject to interference by band spectra.

Strontium, 4,077.71 Å

This is a heavy, wedge-shaped line which shows up through the bands. Because of its irregular shape it is impossible to read this line accurately. Strontium is present in all of the samples and also in the electrodes.

Chromium, 4,254.34 Å

This is the most sensitive chromium line and there are no coincident lines. Chromium shows very little variation in the soil and shale samples. Larger intensity variations were found in the limestone samples. The presence of chromium (in very low intensities) is indicated on a few of the electrode spetrograms.

Barium, 4,554.04 Å

Barium has a wedge-shaped, heavy line which is impossible to read accurately. Barium is present in all of the samples and is prominent in the electrode spectrograms.

Relation Between Spectral Intensity and Sample Composition

The spectrograph is, primarily, an instrument for the qualitative detection of minute quantities of the various elements. Since variations in the amount of an element present in a given sample, however, cause variations in the intensity of the spectral lines of that element, it is possible to use the spectrograph for quantitative analyses. The rate of increase or decrease of spectral intensity, however, is not a direct function of the rate of increase or decrease in quantitative content of an element within a sample. Therefore, in order to make exact quantitative spectrographic analyses, it is necessary to plot variations in spectral intensity as a function of known variations in elemental composition. To make such exact quantitative spectrographic analyses requires much time and expense. Such relationships between spectral intensity and elemental composition, moreover, are valid only as long as the particular element occurs in material of essentially the same composition. Since, for this work, it was necessary to make a large number of quantitative determinations and since a number of rock types were analyzed, it was necessary to use, instead, a method of semi-quantitative analyses. The intensities of selected spectral lines, thus, were estimated visually by comparison with an arbitrary standard; and the estimated spectral intensities were given arbitrary values. It is these arbitrary values of spectral intensity which have been used in this report.

These arbitrary values indicate only the relative amounts of one element in several samples. There is no direct relationship between the arbitrary values assigned to various elements, nor is there any direct relationship between variations in quantitative content of an element and variations in the arbitrary spectral intensity values. A cobalt reading of 4, for example, indicates more cobalt than a cobalt reading of 2 and less cobalt than a cobalt reading of 8. It does not, however, mean that the sample having a spectral intensity of 4 has twice as much cobalt as the sample showing a spectral intensity of 2, nor half as much as a sample showing a spectral intensity of 8. Nor does a spectral intensity reading of 2 for both cobalt and vanadium indicate that the same amounts of both elements are present in the sample. It means only that all cobalt readings of 2 indicate approximately the same amount of cobalt in the sample (within limits to be noted).

Occasionally, two spectral lines were read for the same element. In such cases, it is to be noted that intensity values may be different for the two lines. Manganese, for example, is an element for which two different lines were read. The A-10 sample on the Swalley area gives an intensity reading of 10 for the 2,801.08 Å line and a reading of 15 for the 4,034.45 Å line. The E-7 sample on the same area reads 5 for both lines. These results show that the 4,034.45 Å line is more sensitive to changes in the amount of manganese present than is the 2,801.08 Å line.

ACCURACY OF DATA

Sources of Analytical Error

There are many possible sources of error in the spectrographic method used in this work. The important sources of error are listed below in approximately the order of their importance:

1. Errors due to variations in arcing conditions.
2. Errors due to variations in visual determination of spectral intensity.
3. Errors due to the presence of impurities in the electrodes.
4. Errors due to interfering lines.
5. Errors due to contamination of sample.
6. Errors due to sampling.
7. Errors due to slight variations in method of developing spectrograms.
8. Errors due to slight variations in exposure time.

Errors due to variations in arcing conditions.—The electric arc, which is the cause of volatilization producing the spectrum, shifts from one side of the electrode to the other. This erratic movement causes a difference in the amount of light received by the spectrograph and consequently a difference in spectral intensity on the spectrograms. Another factor is that the position of the electrodes cannot be kept exactly the same for all exposures. There are also minor fluctuations in current and voltage.

The magnitude of the error due to variations in arcing conditions is difficult to determine because of other possible sources of error present at the same time.

The probable magnitude of this error is indicated in the readings tabulated in table No. 2, which are from samples which were arced four times on the same film. Comparison of samples run on the same film eliminated much of the reading error; and, thus, the differences obtained are due largely either to variation in arcing conditions or to the sampling procedure.

The error due to variations in arcing conditions seldom exceeds an intensity of 1, except for aluminum, silver, and zirconium. Because of the large intensity variations for these three elements, their relative concentrations in the various samples could not be determined accurately by the methods employed in this analysis. The variation

TABLE No. 2.—*Comparison of spectral intensity values for three samples which were arced four times*

	Al	Mn	Pb	V	Ga	Ti	Cu	Ag	Na	Zr	Ni	Co	Mn
WD 4	5	5	1	2	1	5	5	2	4	2	1	1	4
WD 4	2	4	1	1	1	4	6	0	3	0	1	1	5
WD 4	4	4	1	2	1	5	6	0	3	0	1	0	3
WD 4	7	5	1	1	1	5	5	0	4	2	2	0	4
WA 16	3	5	1	2	2	5	7	1	5	1	2	0	4
WA 16	4	5	1	2	2	5	6	1	4	1	2	0	4
WA 16	5	4	0	0	0	3	6	0	2	0	1	0	3
WA 16	4	5	1	1	1	5	6	0	5	0	2	1	4
KF 4	9	8	2	4	3	5	6	0	4	3	4	4	10
KF 4	4	8	2	4	2	5	6	1	4	1	4	4	10
KF 4	6	8	2	4	2	5	6	0	4	0	4	4	10
KF 4	4	8	2	4	3	5	6	0	5	1	4	4	9

shown by the third spectrogram of WA 16 is the extreme example of errors due to variations in arcing conditions.

Errors due to variations in visual determination of spectral intensity.—The ability of a person to uniformly estimate the intensities of lines on a spectrogram is a result of his personal temperament and various other factors involved in the reading conditions. The limitation may introduce errors of considerable importance. A range of intensities from 1 to 20 was used, except in a very few cases where higher intensities were indicated. A line which was barely detectable was assigned an intensity of 1, a distinct black line, 5, and a slightly thickened, heavy black line, 10. Above 10, distinctions were made on the basis of the thickness of the line.

For most of the elements the error in estimating the spectral intensities is as great as the arcing error. This error is especially significant when readings taken a week or more apart are compared. The accuracy of the intensity readings depends upon spectrogram background, the distinctness of the line, and the uniformity of the line. Consistent readings are not possible for lines such as the barium and strontium lines, which are thick, but wedge out.

The magnitude of the reading error can be determined by reading the same spectrogram on different dates. Table No. 3 is a compilation of the results of check readings of 24 samples from the Swalley area, read 10 days apart.

The data in table No. 3 shows that the error in reading intensities is seldom greater than an intensity of one. The actual reading error

TABLE No. 3.—*Spectral intensity variations in samples read ten days apart*

	(a) Duplicate reading	(b) Variation of one	(c) Variation of two
	Percent	*Percent*	*Percent*
Mn	54	29	19
Pb	83	17	.....
V	50	50	.....
Ga	92	8	.....
Mo	75	25	.....
Ti	67	33	.....
Cu	63	33	4
Ag	79	21	.....
Na	42	58	.....
Zr	75	25	.....
Ni	75	25	.....
K	67	33	.....
Co	50	50	.....
Mn	25	58	17
Ba	54	38	8

on a given area is probably less than is indicated by the above table, because, with the exception of the Walton area, all samples from each area were read in a single day.

The reading error could be eliminated by reading the lines on a photo-electric densitometer. This method is very accurate, but it would not be practical for so many elements because of the greatly increased time required for the readings. If one or two lines of special significance were to be found, it might be practical to read them by this method.

Errors due to impurities in the electrodes.—Ordinary spectrographic carbons of the type used for this study contain appreciable amounts of iron, silicon, magnesium, titanium, copper, calcium, aluminum, vanadium, boron, strontium, barium, and chromium. The presence of any of these elements in the spectrogram is not conclusive proof that it is present in the sample unless the intensity in the sample is substantially greater than the corresponding line from an electrode test.

The effect of the impurities in the electrodes is largely masked when a sample is run. For example, several samples show an absence of titanium and vanadium although both of these elements were present in electrode tests taken at the same time. Strontium and barium show up stronger in the electrode tests than they do in most of the samples.

Electrodes can be obtained which are practically free of impurities, but only at considerable greater cost. There are methods of removing the impurities by leaching with acids or heating to high temperatures. No attempt was made in this study, however, to eliminate the error due to impurities in the electrodes.

Errors due to interfering lines.—One of the main advantages of the grating spectrograph (here used) over the prism type is that the former has a linear scale. After the wave lengths of a few prominent lines are determined, it is relatively simple to locate the position that a line of a given wave length would occupy.

Thirty-one elements and 42 lines were considered in the analyses here presented. Many of these lines were never present and some were not usable because of interfering or coincident lines. Gold, arsenic, and tungsten were not identified in any of the samples; and the identification of bismuth, antimony, tellurium, indium, and mercury is questionable.

Enlarging the spectrogram by projection made it possible to differentiate between lines 0.2 of an angstrom apart, provided that neither line was very heavy. Any line which is less than 0.2 of an angstrom from a line which is being used for identification might make identification difficult. Heavy lines may cause trouble even when 0.5 Å apart.

In this study several lines which were chosen originally had to be discarded because of interfering lines. The zinc line with a wave length of 3,282.33 Å could not be used in the soil sample analyses because of a titanium line at the same wave length. A tellurium line with a wave length of 3,175.13 Å was not usable because of the presence of a tin line with a wave length of 3,175.04 Å. This line was used to confirm the presence of tin, because the tin line at 2,839.99 Å has interfering lines of aluminum and chromium. The indium line at 3,256.08 Å could not be used because of a manganese line at 3,256.14 Å. A check was made of the samples in which indium had been identified; and, in all cases, those samples were high in manganese. A discussion of the possible interfering lines is given in the previous discussion of each element (pp. 55-60).

Errors due to contamination of samples.—Contamination of the samples is an ever-present danger when dealing with metals which are present in such small quantities. Although many precautions were taken against such contamination, there is no doubt that small errors were introduced.

Drill hole samples are always subject to contamination from overlying formations and metals present in the drill bit or sample containers. The drillers poured the drill hole samples into small pits where they remained until they were collected several days later.

Most of the sources of contamination apply only to the drill hole samples. The soil samples are more nearly free from contamination.

Errors due to sampling.—No checks were run on the sampling procedure (see p. 51). It would be difficult to differentiate such errors from the error due to variations in arcing conditions.

Errors due to variations in method of developing spectrograms.—Any changes in temperature, concentration of developer, or time of development would cause variations in the intensity of the lines on the spectrograms. All of these factors were held nearly constant in this study, and it is not likely that any appreciable errors were introduced by the developing procedure.

Errors due to variations in exposure time.—The exposure was made by allowing the electric arc to run for 60 seconds. It was not exceptional for the arc to go out one or more times, which made accurate timing difficult. This variation in timing seldom exceeded 5 seconds. Two test readings to 90 seconds show only slight differences from those of 60 seconds. Slight differences in exposure time do not seem to make any significant differences in the results.

Validity of Readings

In view of the many possible sources of error one might wonder if any results could be considered valid. By taking several readings of the same sample, however, the maximum variation can be determined. This maximum variation is the sum total of all the errors except those due to contamination and mis-identification. Any differences between two samples which exceed the variations in repeated readings of the same samples can be considered valid differences in chemical composition.

Validity of soil analyses.—A compilation of the results of 73 readings taken on 14 samples from the various areas is given in table No. 4.

In this list of eight selected elements nearly 75 percent of the readings were duplicated when repeated. Only 2.5 percent of the readings varied more than 1 unit from the standard reading. The above table shows that a difference in line intensity of 2 units for any of the selected elements almost always represents a valid difference in the amount of that element present in the sample. The few exceptions to this rule can practically be eliminated by questioning the validity of single station anomalies.

TABLE No. 4.—*Results of check readings on soil samples*

	Duplicate readings		Vary by one unit		Vary by two units	
Manganese	53	72.6%	19	26.0%	1	1.4%
Lead	55	75.2	17	23.4	1	1.4
Vanadium	53	72.2	17	23.4	3	4.0
Gallium	52	71.2	17	23.4	3	4.0
Molybdenum	59	80.8	13	17.8	1	1.4
Titanium	58	79.4	14	19.2	1	1.4
Nickel	56	76.7	16	23.0	1	1.4
Cobalt	52	71.2	20	27.4	1	1.4

In a few cases a difference of 2 was not considered valid for vanadium and gallium. This is true on the Swalley, Walton, and Karcher areas.

Out of 31 elements for which readings were taken, all but nine were eliminated from consideration in the soil samples.

Elements which do not occur or occur only rarely in the soil samples could not be used. These elements are: gold, tin, antimony, bismuth, germanium, cadmium, and tungsten.

There are a number of elements which were eliminated because the arcing error exceeded the differences between samples. These elements are: aluminum, zirconium, sodium, and silver.

Elements which are prominent in the electrodes were eliminated. These include magnesium, copper, strontium, and barium.

Boron, lithium, copper, and chromium seldon vary in intensity by more than one, so they were eliminated from consideration.

Elements for which there are coincident lines are: zinc, potassium, tellurium, and indium. The identification of mercury is uncertain.

Only manganese, lead, vanadium, gallium, titanium, molybdenum, nickel, and cobalt, therefore, remain to be considered in the discussion of results.

The following tables are a compilation of the total variation for each area compared with the analytical variation within a given sample. For example the readings for manganese on the Swalley area range from 4 to 10 and the analytical error in determination of individual samples is only one. This indicates that a number of valid differences in manganese content can be plotted for this area.

TABLE NO. 5.—*Table comparing total variation of spectral intensities with analytical errors for each element.—Mullen area*

Element	Number of samples having line intensity of—											Sample number
	0	1	2	3	4	5	6	7	8	9	10	
Mn	....	....	....	....	....	14	11	8	3	3	....	Entire area
	....	....	....	....	....	....	....	2	1	....	....	II 6
	....	....	....	....	1	2	....	....	....	....	....	II 14
Pb	....	3	34	2	....	....	....	....	....	....	....	Entire area
	....	....	3	....	....	....	....	....	....	....	....	II 6
	....	....	3	....	....	....	....	....	....	....	....	II 14
V	....	....	....	3	25	11	....	....	....	....	....	Entire area
	....	....	....	....	2	1	....	....	....	....	....	II 6
	....	....	....	2	1	....	....	....	....	....	....	II 14
Ga	....	1	9	20	8	1	....	....	....	....	....	Entire area
	....	....	....	3	....	....	....	....	....	....	....	II 6
	....	....	....	2	1	....	....	....	....	....	....	II 14
Mo	3	33	3	....	....	....	....	....	....	....	....	Entire area
	....	3	....	....	....	....	....	....	....	....	....	II 6
	....	3	....	....	....	....	....	....	....	....	....	II 14
Ti	....	....	....	....	....	26	13	....	....	....	....	Entire area
	....	....	....	....	....	3	....	....	....	....	....	II 6
	....	....	....	....	....	3	....	....	....	....	....	II 14
Ni	....	....	....	7	25	7	....	....	....	....	....	Entire area
	....	....	....	....	3	....	....	....	....	....	....	II 6
	....	....	....	....	3	....	....	....	....	....	....	II 14
Co	....	13	14	6	5	1	....	....	....	....	....	Entire area
	....	....	....	....	1	2	....	....	....	....	....	II 6
	....	3	....	....	....	....	....	....	....	....	....	II 14

TABLE NO. 6.—*Table comparing total variation of spectral intensities with analytical errors for each element.—Walton area*

Element	Number of samples having line intensity of—											Sample number
	0	1	2	3	4	5	6	7	8	9	10	
Mn	....	....	....	2	42	102	3	....	....	....	....	Entire area
	....	....	....	....	2	3	....	....	....	....	....	WD 4
	....	....	....	1	3	1	....	....	....	....	....	WM 4
	....	....	....	....	2	3	....	....	....	....	....	WH 13
	....	....	....	....	1	4	....	....	....	....	....	WA 16
Pb	3	132	15	....	....	....	....	....	....	....	....	Entire area
	....	5	....	....	....	....	....	....	....	....	....	WD 4
	..	2	3	....	....	....	....	....	....	....	....	WM 4
	....	4	1	....	....	....	....	....	....	....	....	WH 13
	1	4	....	....	....	....	....	....	....	....	....	WA 16
V	....	4	74	69	4	....	....	....	....	....	....	Entire area
	....	3	2	....	....	....	....	....	....	....	....	WD 4
	....	2	2	1	....	....	....	....	....	....	....	WM 4
	....	....	2	3	....	....	....	....	....	....	....	WH 13
	....	1	4	....	....	....	....	....	....	....	....	WA 16
Ga	....	25	101	7	....	....	....	....	....	....	....	Entire area
	....	5	....	....	....	....	....	....	....	....	....	WD 4
	....	1	4	....	....	....	....	....	....	....	....	WM 4
	....	1	4	....	....	....	....	....	....	....	....	WH 13
	1	1	3	....	....	....	....	....	....	....	....	WA 16
Mo	147	4	....	....	....	....	....	....	....	....	....	Entire area
	5	....	....	....	....	....	....	....	....	....	....	WD 4
	5	....	....	....	....	....	....	....	....	....	....	WM 4
	5	....	....	....	....	....	....	....	....	....	....	WH 13
	5	....	....	....	....	....	....	....	....	....	....	WA 16
Ti	....	....	....	1	26	121	3	....	....	....	....	Entire area
	....	....	....	....	2	3	....	....	....	....	....	WD 4
	....	....	....	1	2	2	....	....	....	....	....	WM 4
	....	....	....	....	1	4	....	....	....	....	....	WH 13
	....	....	....	1	....	4	....	....	....	....	....	WA 16
Ni	....	9	122	20	....	....	....	....	....	....	....	Entire area
	....	4	1	....	....	....	....	....	....	....	....	WD 4
	....	1	3	1	....	....	....	....	....	....	....	WM 4
	....	....	3	2	....	....	....	....	....	....	....	WH 13
	....	1	4	....	....	....	....	....	....	....	....	WA 16
Co	56	88	7	....	....	....	....	....	....	....	....	Entire area
	3	2	....	....	....	....	....	....	....	....	....	WD 4
	4	1	....	....	....	....	....	....	....	....	....	WM 4
	4	1	....	....	....	....	....	....	....	....	....	WH 13
	3	2	....	....	....	....	....	....	....	....	....	WA 16

TABLE No. 7.—*Table comparing total variation of spectral intensities with analytical errors for each element.—Karcher area*

Element	Number of samples having line intensity of—											Sample number
	0	1	2	3	4	5	6	7	8	9	10	
Mn	....	....	....	....	1	26	24	20	18	2	....	Entire area
	....	....	....	....	....	4	1	....	....	....	....	KG 6
	....	....	....	....	....	....	....	1	4	....	....	KF 4
	....	....	....	....	....	....	....	1	1	....	....	KG 4
	....	....	....	....	....	....	....	....	2	....	....	KG 1
	....	....	....	....	....	....	2	....	....	....	....	KB 3
Pb	....	9	79	3	....	....	....	....	....	....	....	Entire area
	....	....	4	1	....	....	....	....	....	....	....	KG 6
	....	....	5	....	....	....	....	....	....	....	....	KF 4
	....	....	2	....	....	....	....	....	....	....	....	KG 4
	....	....	2	....	....	....	....	....	....	....	....	KG 1
	....	....	2	....	....	....	....	....	....	....	....	KB 3
V	....	....	3	24	51	12	1	....	....	....	....	Entire area
	....	....	....	....	4	....	1	....	....	....	....	KG 6
	....	....	....	1	3	1	....	....	....	....	....	KF 4
	....	....	....	....	2	....	....	....	....	....	....	KG 4
	....	....	....	1	1	....	....	....	....	....	....	KG 1
	....	....	....	1	1	....	....	....	....	....	....	KB 3
Ga	....	2	12	56	19	2	....	....	....	....	....	Entire area
	....	....	....	4	....	1	....	....	....	....	....	KG 6
	....	....	2	3	....	....	....	....	....	....	....	KF 4
	....	....	....	2	....	....	....	....	....	....	....	KG 4
	....	....	1	1	....	....	....	....	....	....	....	KG 1
	....	....	....	2	....	....	....	....	....	....	....	KB 3
Mo	12	77	2	....	....	....	....	....	....	....	....	Entire area
	....	5	....	....	....	....	....	....	....	....	....	KG 6
	....	5	....	....	....	....	....	....	....	....	....	KF 4
	....	2	....	....	....	....	....	....	....	....	....	KG 4
	1	1	....	....	....	....	....	....	....	....	....	KG 1
	....	2	....	....	....	....	....	....	....	....	....	KB 3
Ti	....	....	2	4	63	21	1	....	....	....	....	Entire area
	....	....	....	....	4	1	....	....	....	....	....	KG 6
	....	....	....	....	4	1	....	....	....	....	....	KF 4
	....	....	....	....	1	1	....	....	....	....	....	KG 4
	....	....	....	....	2	....	....	....	....	....	....	KG 1
	....	....	....	....	2	....	....	....	....	....	....	KB 3

TABLE No. 7.—*Concluded*

Element	Number of samples having line intensity of—											Sample number
	0	1	2	3	4	5	6	7	8	9	10	
Ni	....	....	....	15	65	9	2	....	....	....	....	Entire area
	....	....	....	....	....	4	1	....	....	....	....	KG 6
	....	....	....	....	5	....	....	....	....	....	....	KF 4
	....	....	....	....	2	....	....	....	....	....	....	KG 4
	....	....	....	....	1	1	....	....	....	....	....	KG 1
	....	....	....	1	1	....	....	....	....	....	....	KB 3
Co	....	....	6	54	17	10	4	....	....	....	....	Entire area
	....	....	....	....	....	3	2	....	....	....	....	KG 6
	....	....	....	....	....	4	1	....	....	....	....	KF 4
	....	....	....	....	1	1	....	....	....	....	....	KG 4
	....	....	....	....	2	....	....	....	....	....	....	KG 1
	....	....	....	2	....	....	....	....	....	....	....	KB 3

TABLE NO. 8.—*Table comparing total variation of spectral intensities with analytical errors for each element.—Swalley area*

Element	Number of samples having line intensity of—											Sample number
	0	1	2	3	4	5	6	7	8	9	10	
Mn	....	....	....	....	1	8	9	14	19	10	7	Entire area
	....	....	....	....	....	....	5	1	....	....	....	SF 4
	....	....	....	....	....	....	....	....	....	4	1	SA 10
	....	....	....	....	....	....	....	....	5	....	....	SC 4
Pb	....	12	52	3	1	....	....	....	....	....	....	Entire area
	....	3	3	....	....	....	....	....	....	....	....	SF 4
	....	....	....	2	3	....	....	....	....	....	....	SA 10
	....	....	5	....	....	....	....	....	....	....	....	SC 4
V	....	....	2	49	15	2	....	....	....	....	....	Entire area
	....	....	....	5	1	....	....	....	....	....	....	SF 4
	....	....	....	2	2	1	....	....	....	....	....	SA 10
	....	....	1	3	1	....	....	....	....	....	....	SC 4
Ga	....	1	32	34	1	....	....	....	....	....	....	Entire area
	....	....	2	4	....	....	....	....	....	....	....	SF 4
	....	....	1	3	1	....	....	....	....	....	....	SA 10
	....	....	1	4	....	....	....	....	....	....	....	SC 4
Mo	17	49	19	1	....	....	....	....	....	....	....	Entire area
	1	5	....	....	....	....	....	....	....	....	....	SF 4
	....	....	....	5	....	....	....	....	....	....	....	SA 10
	....	....	5	....	....	....	....	....	....	....	....	SC 4
Ti	....	....	....	2	5	49	11	1	....	....	....	Entire area
	....	....	....	....	....	3	3	....	....	....	....	SF 4
	....	....	....	....	4	1	....	....	....	....	....	SA 10
	....	....	....	....	2	3	....	....	....	....	....	SC 4
Ni	....	....	....	12	52	4	....	....	....	....	....	Entire area
	....	....	....	1	5	....	....	....	....	....	....	SF 4
	....	....	....	....	2	3	....	....	....	....	....	SA 10
	....	....	....	....	5	....	....	....	....	....	....	SC 4
Co	....	9	13	22	16	7	1	....	....	....	....	Entire area
	....	4	2	....	....	....	....	....	....	....	....	SF 4
	....	....	....	....	....	4	1	....	....	....	....	SA 10
	....	....	....	3	2	....	....	....	....	....	....	SC 4

TABLE No. 9.—*Table comparing total variation of spectral intensities with analytical errors for each element.—Greenback area*

Element	Number of samples having line intensity of—											Sample number
	0	1	2	3	4	5	6	7	8	9	10	
Mn	....	....	....	....	1	57	17	7	1	....	....	Entire area
	....	....	....	....	....	....	3	3	....	....	....	I 20
	....	....	....	....	....	....	....	4	1	....	....	I 14
	....	....	....	....	....	....	4	2	....	....	....	IV 30
	....	....	....	....	....	....	1	....	4	....	....	II 38
	....	....	....	....	....	3	2	....	....	....	....	I 30
Pb	1	54	28	1	....	....	....	....	....	....	....	Entire area
	....	1	5	....	....	....	....	....	....	....	....	I 20
	....	....	3	2	....	....	....	....	....	....	....	I 14
	....	....	6	....	....	....	....	....	....	....	....	IV 30
	....	....	2	3	....	....	....	....	....	....	....	II 38
	....	3	2	....	....	....	....	....	....	....	....	I 30
V	....	1	27	48	6	2	....	....	....	....	....	Entire area
	....	....	1	5	....	....	....	....	....	....	....	I 20
	....	....	....	2	3	....	....	....	....	....	....	I 14
	....	....	....	6	....	....	....	....	....	....	....	IV 30
	....	....	....	5	....	....	....	....	....	....	....	II 38
	....	....	5	....	....	....	....	....	....	....	....	I 30
Ga	....	16	56	12	....	....	....	....	....	....	....	Entire area
	....	1	5	....	....	....	....	....	....	....	....	I 20
	....	....	2	3	....	....	....	....	....	....	....	I 14
	....	....	5	1	....	....	....	....	....	....	....	IV 30
	....	....	1	5	....	....	....	....	....	....	....	II 38
	....	1	4	....	....	....	....	....	....	....	....	I 30
Mo	69	15	....	....	....	....	....	....	....	....	....	Entire area
	3	3	....	....	....	....	....	....	....	....	....	I 20
	1	3	1	....	....	....	....	....	....	....	....	I 14
	2	4	....	....	....	....	....	....	....	....	....	IV 30
	1	3	1	....	....	....	....	....	....	....	....	II 38
	5	....	....	....	....	....	....	....	....	....	....	I 30
Ti	....	....	....	1	6	73	4	....	....	....	....	Entire area
	....	....	....	....	....	6	....	....	....	....	....	I 20
	....	....	....	....	....	4	1	....	....	....	....	I 14
	....	....	....	....	....	6	....	....	....	....	....	IV 30
	....	....	....	....	....	5	....	....	....	....	....	II 38
	....	....	....	....	1	4	....	....	....	....	....	I 30

TABLE NO. 9.—*Concluded*

Element	Number of samples having line intensity of—											Sample number
	0	1	2	3	4	5	6	7	8	9	10	
Ni	....	1	23	55	5	....	....	....	....	....	....	Entire area
	....	1	2	3	....	....	....	....	....	....	....	I 20
	....	....	....	5	....	....	....	....	....	....	....	I 14
	....	....	1	5	....	....	....	....	....	....	....	IV 30
	....	....	....	4	1	....	....	....	....	....	....	II 38
	....	....	3	2	....	....	....	....	....	....	....	I 30
Co	18	35	20	5	3	2	1	....	....	....	....	Entire area
	....	5	1	....	....	....	....	....	....	....	....	I 20
	....	....	....	....	....	4	1	....	....	....	....	I 14
	....	1	5	....	....	....	....	....	....	....	....	IV 30
	....	....	....	....	....	3	2	....	....	....	....	II 38
	....	5	....	....	....	....	....	....	....	....	....	I 30

All results for a given element on a given area were plotted if there were valid differences in concentration on the area. The presence of valid results was determined by comparing the total range of the readings on the area with the range of readings obtained from a single sample repeated five or six times. Readings are said to be valid if the range of variation is greater than the determined analytical error.

The compilations of total validity readings (pp. 68-74) show that, insofar as the elements manganese, lead, vanadium, gallium, molybdenum, titanium, nickel, and cobalt are concerned, a difference of 2 units of intensity is valid 95 percent of the time, and a difference of 3 units is always valid.

Neutral Area.—No validity checks were run for the five samples on this area. As determined by the work in other areas manganese and cobalt generally show valid variations. The geochemical variations are shown on figure 16.

Mullen Area.—Manganese and cobalt were plotted on the Mullen area (figs. 18, 19, 20). There are valid readings for a few of the other elements but they are one-station anomalies.

Walton Area.—The validity table for the Walton area shows that the variations in readings on this area are very slight and hardly exceed the variations within a sample. The readings for cobalt were plotted, but there are only seven valid readings and four of these are one-station readings (fig. 35). These seven readings comprise less than 5 percent of the total samples in the area and thus the validity of these anomalies is questionable.

Karcher Area.—Cobalt, manganese, nickel, and lead, in the order named, show the greatest variation in the Karcher area. Variations for cobalt and manganese are shown herein (fig. 46). There are no valid readings for molybdenum on the grid part of the area. Vanadium and gallium have a variation of three, but there are only four valid readings for these elements.

Swalley Area.—The range of readings on the Swalley area is the largest of any of the areas. Manganese has a variation of 7 and cobalt of 6. Eight samples showed valid readings for titanium. There were only 4 valid readings for lead, 1 for gallium, 1 for molybdenum, and 4 for nickel. Figure 36 shows the areal distribution of manganese in the soil of this area.

Greenback Area.—Cobalt has a variation of 6 and manganese of 5 on the Greenback area. There are 28 valid readings for cobalt and 9 for manganese. Lead and canadium both show a few valid readings. There are no valid readings for molybdenum. There are a few valid readings, also, for titanium, nickel, and gallium, but profiles were not plotted for these elements. The variations for cobalt, manganese, lead, and vanadium are shown on the profiles (figs. 51, 52).

Validity of Cherokee shale analyses.—Only seven elements in the Cherokee shale have a variation greater than the maximum analytical error: lead, zinc, cobalt, manganese, potassium, magnesium, and titanium. The analytical error was determined by repeating one of the samples 16 times. Table No. 10 is a compilation of the results obtained by this procedure.

The data in table No. 10 show that a difference of two intensity units represents a valid difference in concentration for manganese, cobalt, lead, and zinc. A difference of 3 units is valid for potassium and a difference of 4 units is valid for magnesium.

Validity of Mississippian limestones analyses.—The spectral line intensities for elements in the Mississippian limestone samples show much greater variations than is the case for the soil and shale samples. Table No. 11 gives a list of the elements for which there are valid readings, the minimum and maximum readings for those elements, and the indicated analytical error. The analytical error was determined by arcing a limestone sample 15 times.

Variations greater than the analytical error represent valid differences in concentration of the elements. Thus, a difference of

TABLE No. 10.—*Table showing variations in spectral intensity obtained by arcing Cherokee shale samples sixteen times*

ELEMENT	Wave length	Duplicate readings	Variation of one	Variation of two	Variation of three
Manganese....	2,801.08 Å	94%	6%	....	....
Lead..........	2,833.07 Å	75	25	....	....
Magnesium....	3,096.0 Å	31	25	19%	25%
Titanium......	3,261.05 Å	94	6	....	....
Zinc..........	3,345.02 Å	88	12	....	....
Cobalt........	3,453.51 Å	100	....	....	....
Potassium.....	4,047.2 Å	50	37	13	....

TABLE No. 11.—*List of elements indicated in the limestone samples*

ELEMENT	Wave length	Minimum reading	Maximum reading	Analytical error
Boron..................	2,496.8 Å	0	5	2
Lithium..................	2,741.2 Å	0	3	2
Manganese...............	2,801.08 Å	2	10	1
Magnesium...............	2,802.71 Å	5	18	2
Lead....................	2,833.07 Å	0	20	1
Tin......................	2,839.99 Å	0	8	1
Vanadium................	2,908.81 Å	0	5	2
Gallium..................	2,943.70 Å	0	4	2
Germanium...............	3,039.08 Å	0	5	1
Magnesium...............	3,096.9 Å	5	18	3
Molybdenum.............	3,132.6 Å	0	5	1
Cadmium................	3,261.05 Å	0	4	1
Titanium.................	3,261.59 Å	0	4	1
Copper..................	3,273.96 Å	3	8	1
Silver...................	3,280.67 Å	0	3	1
Zinc.....................	3,345.02 Å	0	14	1
Nickel...................	3,414.77 Å	1	5	1
Cobalt..................	3,453.51 Å	0	4	1
Potassium...............	4,047.2 Å	0	12	2
Chromium...............	4,254.34 Å	2	12	2

three spectral intensity units represents a valid difference in the Boron concentration, and a difference of two units represents a valid difference in the lead concentration.

PRESENTATION OF DATA

A representative portion of the results of the soil sample analyses is illustrated herein in two ways: (1) on maps which show the areal distribution and relative concentrations of one or more of the elements in each area and (2) on profiles which show the relative concentrations of one or more of the elements along traverses in each area. The results of the drill hole sample analyses are plotted as profiles showing the distribution and relative concentrations of the elements, vertically, in the formations traversed by the drill hole.

The soil samples from the Walton, Karcher, and Swalley areas were collected from stations on a grid. It is thus possible to show the areal distribution of certain elements on these areas. In the interpretation separate maps were drawn for each element for which there were valid readings. Lines were drawn around all readings of each intensity. An area showing intensities of 5 was thus separated from an area showing intensities of 4, an area of 4's from an area of 3's, etc. These areal boundaries, therefore, separate areas between which the difference in spectral intensity is 1. While such lines do not define the boundaries of valid differences in elemental concentration (such differences require that the difference in spectral intensity be at least 2 as shown in tables 5 to 9), this manner of plotting aids in determining the probable distribution of the elements. For representation in this report, however, the areal boundaries were drawn so as to separate areas between which valid differences in spectral intensities exist (figs. 35, 46, 50).

For the Mullen, Greenback, and Neutral areas, the results are shown in profiles only (figs. 16, 18, 19, 20, 51, 52).

Profiles showing spectral intensity plotted against depth are used to illustrate the results of drill hole spectral analyses (figs. 12, 13, 14, 15).

GEOLOGICAL BASIS FOR GEOPHYSICAL CORRELATIONS

MAGNETIC ANOMALIES

Any factors which cause local variations in the vertical magnetic intensity of the earth's magnetic field will cause the vertical magnetometer to record local anomalies. Such local magnetic variations generally are caused either by local variations in the magnetite content of a given rock or by variations in the distance from the surface (structural effects) of a rock having uniform magnetite content. In this connection, certain generalizations may be made: As a general rule, igneous rocks have a greater magnetic intensity than sedimentary rocks, and basic igneous rocks have a greater magnetic intensity than acidic rocks. Clastic sediments generally exhibit greater magnetic intensity than chemically precipitated sediments, and sandstones are generally greater in magnetic intensity than shales.

Following are some of the factors which might possibly account for magnetic anomalies in the Tri-State district:

A. Causes for increase in vertical component of magnetic intensity.
   1. Topographic highs on the pre-Cambrian igneous surface.
   2. Basic intrusives or differentiates in the pre-Cambrian granite.
   3. Igneous intrusives cutting the lower portion of the Paleozoic section.
   4. Arching of the sediments which would bring nearer to the surface the probably more magnetic pre-Mississippian clastics.
   5. Pennsylvanian sandstones (probably more magnetic than the Pennsylvanian shales) found locally nearer to, or at, the surface as a result of:
      (a) The normal regional dip.
      (b) Local folding.
      (c) Local slumping into caverns in the underlying Mississippian limestone.

B. Causes for decrease in vertical component of magnetic intensity.
   1. Topographic lows on the pre-Cambrian surface.
   2. Downwarping of the sediments which would remove farther from the surface the probably more magnetic pre-Mississippian clastics.
   3. Pennsylvanian sandstones (probably more magnetic than the Pennsylvanian shales) found locally farther from the surface than the shales as a result of:
      (a) Normal regional dip.
      (b) Local folding.
      (c) Local slumping into caverns in the underlying Mississippian limestone.

Gravity Anomalies

Any factors which cause local variations in the total mass of a given section of the earth's crust will result in an increase or a decrease in the local value of the earth's gravitational field. Such resultant local variations in the earth's gravitational field can be measured directly by the gravity meter. In this connection, certain generalizations can be made: as a general rule, igneous rocks have a greater specific gravity than sedimentary rocks, and basic igneous rocks have greater specific gravity than acidic rocks. Whenever rocks of higher specific gravities are, by structural deformation, brought nearer than normal to the surface, the structure responsible for this condition may cause gravity maxima on the earth's surface. Any factors which create voids, moreover, tend to reduce the mass of a given section of the earth's crust. Therefore, such features as caverns, brecciation, and fracturing may cause gravity minima.

Following are some of the factors which might possibly account for gravity anomalies in the Tri-State district:

A. Causes for gravity maxima.
   1. Topographic highs on the pre-Cambrian igneous surface.
   2. Basic intrusives or differentiates in the pre-Cambrian granite.
   3. Igneous intrusives cutting the lower portion of the Paleozoic section.
   4. Dolomitization (dolomite S. G. 2.8-2.9) of limestone (calcite S. G. 2.71).
   5. Filling of voids normally present due to secondary cementation—especially chertification.
   6. Local lithologic variations in the Mississippian and Pennsylvanian sediments.

B. Causes for gravity minima.
   1. Topographic lows on the pre-Cambrian igneous surface.
   2. Silicification (chert S. G. 2.64) of limestone (calcite S. G. 2.71).
   3. Development of secondary voids as a result of fracturing, brecciation, or solution (including development of caverns).
   4. Local lithologic variations in the Mississippian and Pennsylvanian sediments.

Natural Potential Anomalies

Natural potential anomalies are the result of differences in electrical potential between two points in the earth's crust. In this connection, certain generalizations may be made: Any factors which serve to create water-soluble, metallic salts in a region of active ground-water movement will cause the natural development of potentials (galvanic action). Since most ground-waters are weak electrolytes, a marked uni-directional ground-water flowage will generally produce measureable potentials. Sulphide oxidation is one means of developing electrolytes.

Following are some of the factors which might cause the development of natural potentials in the Tri-State district:

1. Relatively rapid, constant, uni-directional flow of ground-water. Such flow may indicate that the rock strata at the horizons being studied are porous and permeable, brecciated, fractured, or cavernous.
2. Oxidation of sulphides producing electrolytes. Because the rate of oxidation of pyrite (or marcasite) is more rapid than that of galena or sphalerite, pyrite or marcasite concentrations may be related to greater natural potentials than galena or sphalerite concentrations. Therefore, a negative potential center may or may not indicate the presence of sulphide concentration. If such a sulphide concentration is present, it may be economically valuable sulphide (here galena or sphalerite) or it may be sulphide without economic value in this district (pyrite or marcasite).

Resistivity Anomalies

Resistivity anomalies are the result of differences in resistance to the passage of electric current exhibited by rocks at diverse points within the earth's crust. Since, for this work, no attempt was made to secure an effective current flow to a depth greater than 400 feet, the anomalies were due chiefly to resistivity variations within this distance from the surface. In this connection, certain generalizations may be made: The apparent resistivity of a selected portion of the subsurface is a function of the separate resistivities of its several components and of the size, shape, and structural configuration of the components. Fresh waters are relatively poor conductors. The best natural conductors generally are electrolytic solutions and conate waters. The ground resistivity, therefore, will decrease with an increase in the soluble, metallic salt content of the contained ground-water. Most sulphides, with the notable exception of sphalerite, have relatively low resistivity. Such low resistivity is characteristic of galena, pyrite, and marcasite. The resistivity of sphalerite, however, is often very little different from that of accompanying gangue minerals.

The depth to an anomolous condition was calculated by a modification of the Roman method (Jakosky, 1940, pp. 292-299).

Following are some of the factors which might cause the development of resistivity anomalies within a general range of 400 feet from the surface in the Tri-State district:

A. Causes for high resistivity anomalies.
  1. Presence of dry caverns, dry voids, or dry fractures (above the water table).
  2. Local arching bringing the often dense Mississippian limestones closer to the surface than the porous, generally water-saturated Pennsylvanian clastics.
  3. Filling of normally water-filled voids in the Mississippian limestone due to secondary cementation; viz., chertification or dolomitization.

B. Causes for low resistivity anomalies.
  1. Presence of concentrations of galena, pyrite, or marcasite. Sphalerite might or might not cause such anomalies.
  2. Presence of zones of water-saturated rock—especially where the water has a high electrolyte content.
  3. Presence of voids filled by electrolytic solutions. Voids may be pores, fractures, or caverns.
  4. Local down-warping or slumping, creating a thicker section of the porous, generally water-saturated Pennsylvanian clastics.

Geothermal Anomalies

Temperature variations within the earth's crust, independent of diurnal atmospheric variations, constitute geothermal anomalies. Any factors which upset the thermal equalibrium within the earth's crust produce geothermal anomalies. Since all geothermal measurements on this project were taken in shallow holes, any factors serving to change the thermal equilibrium must be of a type the effects of which would be apparent near the surface.

Following are some of the factors which might cause geothermal anomalies under the conditions of study in the Tri-State district:

A. Causes for high geothermal anomalies.
  1. Oxidation of sulphides—especially pyrite and marcasite.
  2. Arching of the sediments, or decreased depth to the basement rocks.

3. Local variations in surface drainage resulting from topographic irregularities or variations in lithologic permeability.

B. Causes for low geothermal anomalies.
   1. Marked and rapid flow of ground-water, usually descending.
   2. Down-warping or slumping of sediments.
   3. Local variations in surface drainage resulting from local topographic irregularities or variations in lithologic permeability.

Geochemical Anomalies

Geochemical anomalies, as the term is here used, refer to variations in spectro-graphically determinable concentrations of metals in soil or rock samples. Any factors which would serve to produce a variation in the content of one or more metals in a soil or rock sample would, therefore, produce geochemical anomalies.

Following are some of the factors which might cause geochemical anomalies in the Tri-State district:

1. Precipitation of minor amounts of metals from mineralizing solutions which rose above the main ore zone during the period of mineralization.
2. Local chemical or lithologic variations in the rock or soil.
3. Local variations in surface drainage which might produce minor differential leaching or precipitation of metals in the soil.
4. Local variations in vegetative growth which might subtract from, or add to, the normal metallic assemblage within the soil.

GEOPHYSICAL INTERPRETATIONS AND GEOLOGICAL CORRELATIONS

Geological Correlations in Different Areas

REGIONAL SURVEY

Surveys of regional character undertaken in the present investigation consist of magnetic and gravity measurements covering an area of approximately 75 square miles west and southwest of Baxter Springs, Kansas. In general, readings were taken at intervals of approximately 1 mile at, or adjacent to, section-corner road intersections. These regional data are presented as magnetic contours (fig. 9) and gravity contours (fig. 10). The gravity survey was conducted by the Mott-Smith Corporation of Houston, Texas. The magnetic work was conducted by us. A total of 69 gravity stations and 92 magnetic stations were occupied during the course of the regional surveys.

A portion of the geochemical investigations consisted of spectrographic analysis of shale and limestone samples secured from many widely separated exploratory churn drill holes. These studies, therefore, may be said to be of regional character. Results of this work are illustrated in figures 12 to 15.

Magnetic Survey

It was noted, at several places in this area, that abnormally high or low magnetic readings were sometimes a result of near-surface effects. This was determined in the field by measuring the gradient of change over short horizontal distances at locations where abnormally high readings were obtained. Some parts of the area, such as the Picher mining district, Baxter Springs, and other populated centers, are crossed by intersecting net-works of pipe lines, railroads, and power lines. Parts of these areas also have various kinds of iron and steel structures as well as "tramp" iron left from prior construction. An effort was made to get beyond the range of the local magnetic attractions that would be exerted by these objects. Nevertheless, in view of these conditions and in view of the possible influence of near surface structural and lithologic effects, single-station anomalies are considered to be uncertain. In any event, such anomalies probably do not represent the effect of deep structures.

The magnetic map (fig. 9) reveals the following: (1) a variation of approximately 400 gammas in the area covered; (2) an area of higher magnetic intensities, approximately 100 gammas relief, extending westward from Baxter Springs and lying north, northwest, and northeast of the Picher district; (3) the Picher mining district covered, in part, by a magnetic low; and (4) a well-defined magnetic high of approximately 200 gammas relief, southwest of Baxter Springs, in the area between Quapaw and Hockerville.

The magnetic survey conducted over a much larger area by the Missouri Bureau of Geology and Mines (Grohskopf and Reinoehl, 1933) shows a considerable number of anomalies of greater intensity than the anomaly mapped in this regional work. Although tentative interpretations were suggested by the above authors, no definite geological significance has yet been assigned to the magnetic anomalies; and, accordingly, no program of ore exploration by magnetic methods has been postulated or devised for this district.

Gravity Survey

The gravity map (fig. 10) shows two significant features: (1) a regional gradient with gravity values increasing southward at a rate of approximately 1.0 milligal per mile and (2) a local gravity maximum in the area between Quapaw and Hockerville, east of the main Picher district. This gravity high is about a mile to the south of the location of the previously described magnetic high.

Comparison and Correlation of Magnetic and Gravity Results

Because of the limited area covered and the lack of stratigraphic and structural information at depths below the ore horizons, it is not possible to assign definite geological significance to the magnetic and gravity anomalies. However, the approximate coincidence in location of magnetic and gravity highs in the Quapaw-Hockerville area suggests that these anomalies are the result of a structural or lithologic variation in the basement rocks. Basement structural or lithologic conditions which might account for these anomalies are: (1) a topographic high in the pre-Cambrian surface; (2) an intrusive stock cutting the Paleozoic sediments; and (3) a lithologic variation in the pre-Cambrian basement, localizing constituents of relatively high density and high magnetic susceptibility (*e. g.;* basic intrusives or differentiates in the pre-Cambrian granite).

Regional magnetic and gravimetric reconnaissance may be useful in practical exploration for ore districts in this territory if it can be demonstrated by further work that basement structural conditions, such as mentioned above, either constitute the sources of ore mineralization or are directly related to ore occurrence through indirect structural influence on the localization of the deposits. Such relationships cannot be demonstrated by the data now available. A solution of the problem, however, might be derived from a comparison of magnetic and gravity results over a larger area, combined with information secured from deep drilling in a few localities. Such a program would be relatively inexpensive as compared with the cost of "wild-cat" drilling extending outward from the present mining fields.

Geochemical Survey

Shale samples.—Samples for geochemical analysis were collected at more or less regular intervals from a number of exploratory drill holes in the Oklahoma-Kansas portion of the district. Samples from 15 of these drill holes (table No. 12) were subjected to spectrographic analysis to determine the distributions and relative concentrations of the elements, vertically, in the formations traversed by the drill hole. The purpose of this investigation was to ascertain whether variations in the metallic content of the Cherokee shale might indicate the presence or absence of ore mineralization in the underlying Mississippian limestone.

TABLE No. 12.—*Drill holes from which shale and limestone samples were obtained**

Name identification	Number identification	Name identification	Number identification
Walker	1	Miami	9
Black Eagle	2	Wessel	10
Bird Dog	3	Wessel	11
Commerce	4	Jarrett	12
Gordon	5	Just	13
Davis	6	Ingram	14
Abrams	7	Weber	15
Miami	8		

* For location of drill holes see table No. 13.

Samples for the investigation were obtained as follows: (1) from eight drill holes in which high grade zinc and lead mineralization was encountered in the limestone and (2) from seven holes in which no zinc or lead mineralization was encountered. The non-mineralized holes are all beyond the present producing areas.

For comparative purposes, analyses were made of 10 samples of Cherokee shale obtained from oil well drillings in Cherokee, Crawford, and Labette counties, Kansas.

The composition of the Cherokee shale, as determined by the spectrographic analysis, remains nearly constant except for a few elements. Manganese, lead, zinc, cobalt, titanium, potassium, and magnesium are the only elements for which the variations in readings exceed the possible analytical errors (see page 75, and table No. 11). Table No. 13 gives the location of the exploratory drill holes and the average spectral line intensities (relative concentrations) of the elements in the Cherokee shale. The values in this table are arbitary line intensities and represent only relative quantities.

TABLE NO. 13.—*Average spectral line intensities of elements in the Cherokee shale*

LOCATION	No. of samples	Well No.	Pb	Zn	Mg	Co	Ti	K	Mn
Holes in which ore mineralization is absent									
SE¼ NE¼ sec. 14, T. 28 N., R. 22 E.	9	8	2.44	.55	4.89	3.89	4.33	10.33	7.77
SE¼ NW¼ sec. 14, T. 28 N., R. 22 E.	4	9	2.25	1.75	4.75	4.00	4.00	10.25	7.50
SW¼ sec. 13, T. 28 N., R. 23 E.	No shale	13	....	....	....	....	....	....	....
SW¼ SW¼ sec. 3, T. 27 N., R. 23 E.	No shale	14	....	....	....	....	....	....	....
NE¼ NW¼ sec. 14, T. 28 N., R. 23 E.	4	10	2.50	1.50	4.75	3.75	4.25	10.50	8.00
NE¼ NW¼ sec. 14, T. 28 N., R. 23 E.	4	11	2.75	1.25	7.00	3.25	4.75	10.25	7.75
NE¼ SW¼ sec. 10, T. 35 S., R. 23 E.	10	12	2.40	.40	2.55	3.80	3.90	10.20	8.40
Total: Nonmineralized	31	....	2.45	.87	4.52	3.77	4.26	10.29	7.97
Holes in which ore mineralization is present									
SE¼ SW¼ sec. 21, T. 29 N., R. 23 E.	7	1	2.59	1.43	4.29	3.86	3.86	10.29	7.14
NE¼ NW¼ sec. 11, T. 35 S., R. 23 E.	9	2	2.89	1.22	4.22	3.20	4.00	9.44	7.33
SE¼ sec. 12, T. 35 S., R. 23E.	7	15	3.00	.29	4.28	4.57	4.14	10.71	7.86
SE¼ SE¼ sec. 13, T. 29 N., R. 23 E.	9	3	2.44	.11	5.33	4.00	4.44	10.22	8.00
SW¼ NW¼ sec. 25, T. 29 N., R. 23 E.	No shale	7	....	....	....	....	....	....	....
NW¼ NW¼ sec. 6, T. 28 N., R. 23 E.	7	4	3.28	1.71	4.28	4.00	4.14	11.29	7.71
S½ SE¼ sec. 18, T. 29 N., R. 23 E.	9	5	3.22	.33	3.33	3.89	4.33	11.44	7.55
NE¼ sec. 13, T. 29 N., R. 21 E.	10	6	2.60	1.00	2.70	3.82	3.60	11.20	8.40
Total: Mineralized	58	....	2.85	.85	4.16	3.93	4.07	10.66	7.74
Oil well samples	10	....	2.20	1.10	2.70	3.20	3.60	7.10	8.10

These data may be summarized as follows: (1) The total average lead, cobalt, and potassium readings are only slightly higher in the mineralized holes than in the non-mineralized holes. (2) The total average readings for magnesium, titanium, and manganese are slightly higher in the non-mineralized holes than in the mineralized ones. (3) The average zinc readings are practically the same in both cases. (4) The samples from the Tri-State district show a higher concentration of magnesium, cobalt, lead, potassium, and titanium than do the samples from the oil well drillings and lower concentrations of zinc and manganese. (5) The average indicated differences in concentrations are much less than the possible analytical errors.

A comparison of averages from individual drill holes shows that the relative concentrations of lead, zinc, magnesium, cobalt, titanium, potassium, or manganese in the Cherokee shale do not indicate the presence or absence of mineralization in the underlying limestone. For example, the indicated average lead content of the shale in mineralized holes is 2.85 and in the non-mineralized holes it is 2.45, but the maximum for the non-mineralized holes is 2.44. Similar results are indicated by comparing the maximum and minimum results for the other six elements.

Although the average readings do not show significant differences between the mineralized holes and the non-mineralized holes, it should be noted that the five samples which have valid concentrations of lead are from holes showing mineralization (fig. 14). This relationship is not true for any of the other elements.

Limestone samples.—Figure 12 shows geochemical profiles for four drill holes which encountered ore mineralization. These profiles show the relative concentrations of the elements, vertically, in the formation traversed by these holes. The samples used in these studies were taken from the limestone at 30 to 40 feet intervals. In plotting these values the lead and zinc mineralized zone, as determined by assays (A-A′, in fig. 12), was used as a reference datum. As shown by these profiles, the content of lead, zinc, copper, cadmium, and germanium is a maximum in the mineralized zone, indicating that these five elements were introduced by the mineralizing solutions. The presence of a relatively large amount of tin in the mineralized zone of the Walker hole (1, fig. 12) indicates that tin was present in some of the solutions. Gallium, molybdenum, nickel, and cobalt generally give maximum readings at the top of the limestone, drop off to a minimum, and then rise again slightly in the mineralized zone. The Abrams hole (7, fig. 12) does not show maximum readings at the top of the limestone. This hole, however, does not have a shale cover. The titanium content tends to be a minimum in the mineralized zone. Silver, chromium, and vanadium do not show any correlation with the mineralized zone.

Figure 13 shows geochemical profiles for a group of drill holes where no ore mineralization was encountered. Tin, germanium, silver, and cadmium were not detected in samples from these holes. Molybdenum and cobalt were detected in only one sample, and that was from just below the shale in the Wessel hole (11, fig. 13). Zinc and lead are present in small concentrations in a few samples. Copper, nickel, and chromium show close correlation with one another in the holes which do not show ore mineralization, and are present in concentrations as large as in the mineralized holes.

Lead, zinc, copper, cadmium, germanium, and tin are present in the mineralized zones in concentrations greater than in the shale or limestone and, therefore, must have been introduced by the mineralizing solutions. Some gallium, molybdenum, nickel, and cobalt may have been introduced, but the concentrations in the mineralized zones are lower than the maximum concentrations in the limestone.

A group of samples was taken from the Ingram well (14, table 13), which penetrated to the Cotter dolomite (Ordovician). The results of the analyses at this location may be stated as follows: Nearly all of the elements show increased concentrations in the Chattanooga shale. Vanadium, gallium, nickel, chromium, and cobalt generally give higher readings in shale than in limestone. The lead and molybdenum values are higher in the Chattanooga shale than in the Cherokee shale. The Ordovician dolomites show a slightly higher lead, zinc, tin, and molybdenum content than does the Mississippian limestone.

Shale and limestone samples.—Figures 14 and 20 show profiles of the vertical distribution of lead and zinc concentrations respectively, in the shale and limestone. Figure 1 shows location of drill holes from which samples were taken. Two of the wells in Oklahoma (6 and 14) do not appear in the area shown in figure 1. The profiles plotted from the Cherokee shale samples give no indication as to the grade of mineralization which might be encountered in the limestone, but in some cases the lead and zinc content of the first 50 feet of limestone is indicative of the presence or absence of ore mineralization near by.

Profiles for magnesium were plotted also. These show the degree of dolomitization of the limestone but do not indicate that any correlation exists between magnesium content and ore mineralization. The highest values for magnesium were obtained from the Ordovician dolomites in the Ingram water well located in the SW¼ SW¼ sec. 3, T. 27 N., R. 23 E.

NEUTRAL AREA

The geophysical data in the Neutral area were all obtained along a single traverse. The following geophysical measurements were made: *magnetic,* at 400 foot intervals; *gravity,* at 100 foot intervals; *natural potential,* at 500 foot intervals; *resistivity* longitudinal traverse, at 50 foot intervals; *resistivity* depth measurements, at stations 20 and 50; *geothermal* measurements, at 100 foot intervals; *geochemical* soil samples, at stations 10, 30, 50, 70, and 90. The geophysical data are plotted as profiles along the traverse (fig. 16). The resistivity depth curves are shown in figure 17.

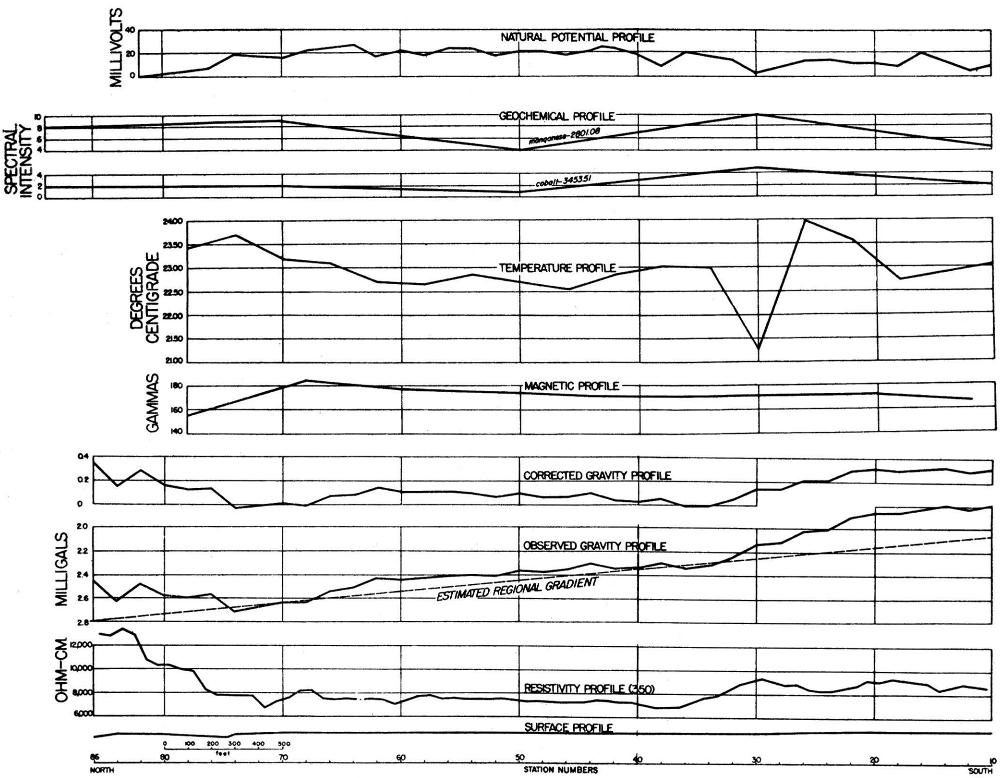

FIG. 16. Profiles along a traverse in the Neutral area, showing magnetic, gravity, natural potential, resistivity, geothermal, and geochemical anomalies.

Magnetic Survey

The magnetic gradient between stations 12 and 68 is exceptionally uniform, increasing northward at a rate of 30 gammas per mile. Between stations 68 and 78 the vertical magnetic intensity decreases 30 gammas in a distance of 500 feet, a much more rapid variation than on the southern portion of the traverse.

Gravity Survey

The gravity variation is more clearly observed after correcting for regional gradient. A zone of relatively low gravity values occurs between stations 34 and 74. South and north of these stations the gravity values increase at an average gradient, over and above regional gradient, of approximately 0.35 milligal in a distance of 600 feet. The small lateral range of these changes in gravity suggests that they primarily reflect the influence of shallow structure.

Natural Potential Survey

The total range of the natural potential readings is approximately 30 millivolts. It is estimated that the calculated values are subject to a probable error of $\pm$ 2 millivolts, due, chiefly, to: (1) fluctuation in the natural potentials and (2) uncertainty of the diurnal correction. A zone of relatively high potential, *i. e.*, + polarity relative to zones of relatively low potential, extends between stations 34 and 74. Lower potentials are present on both north and south ends of the traverse.

Resistivity Survey

Profile.—A resistivity low (7,000 to 8,000 ohm-cms.) extends between stations 36 and 76. Higher values are present on the north (13,000 ohm-cms.) and south (9,000 ohm-cms.) ends of traverse.

Depth stations.—Depth readings were made to determine the variation of resistivity with depth below the above-mentioned zones of high and low resistivity shown by the resistivity profile. It was hoped that this work might contribute information as to the subsurface structure responsible for the profile anomalies. One station (DS-2) was placed in the center (station 50) of the low resistivity trend, and the other (DS-1) was placed over the high resistivity trend (station 20) at the southern end of the traverse. Comparison of the curves plotted from the depth readings shows a marked difference in electrical characteristics at the two locations below a depth of approximately 100 feet, a well-defined decrease in resistivity occurring below this depth, at station DS-2.

No subsurface geologic information is available along the line of these electrical measurements. For this reason, an interpretation of the structural implications of the effects observed on the resistivity depth curves can only be postulated on a basis of what is known of the general geology in this area (see p. 23). On this basis, it is believed that the decrease in resistivity below a depth of 100 feet at station DS-2 indicates a more porous zone, possibly associated with slumpage or cavernous conditions in the limestone under the central part of the traverse.

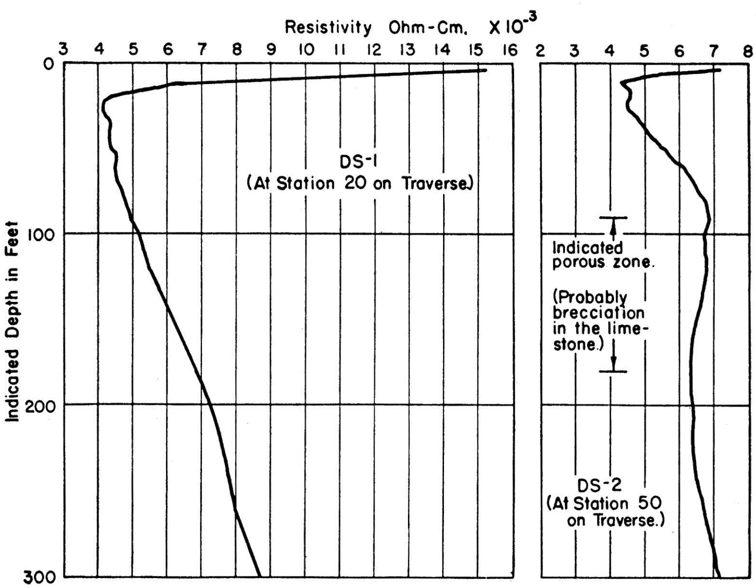

FIG. 17. Resistivity depth profiles in the Neutral area.

Geothermal Survey

The temperature profile shows a zone of relatively low temperature along the central portion of the traverse between stations 46 and 62.

Geochemical Survey

Only five soil samples were taken along the traverse. Analysis of these indicated relatively lower cobalt and manganese content in the soil station 50 in the center of the traverse.

Conclusions

The various geophysical data obtained in the area show a degree of mutual correlation that is notable, considering the difference in the methods and the physical parameters measured. The most prominent, and probably most significant, example is the close resemblance of the resistivity and gravity profiles over the entire length of the traverse, and, in particular, the coincidence of resistivity and gravity lows over the central part of the traverse. In lesser degree, however, the other data, with the exception of the magnetic, show somewhat comparable anomalies as shown in the following tabulation:

Resistivity: "low" between stations 36 to 76
Gravity: "low" between stations 34 to 74
Natural potential: "high" between stations 34 to 74
Goethermal: "low" between stations 46 to 62
Geochemical: "low" at station 50

The resistivity measurements (profile and depth curves) were made to a maximum depth of approximately 350 feet. The resistivity anomalies, therefore, are due to comparatively shallow structural conditions, the most prominent of which are probably: (1) variations in depth to the shale-limestone boundary, (2) changes in the lithology and porosity of the shale and upper portions of the limestone, and (3) variations in amount, content, and distribution of ground water.

The similarity of the various profiles indicates that all of the geophysical anomalies in the Neutral area are due to the effects of shallow geologic factors. It is probable that a structural trough or slumped zone with probable brecciation in the shale and limestone beds lies under the central part of the traverse. Such a structure would account for the various geophysical anomalies observed in this area. This postulated trough or slumped zone is probably a tributary of the Miami trough.

The geophysical results in the Neutral area are significant, chiefly because: (1) They indicate the type and magnitide of anomalies that may be found in areas that are devoid of ore mineralization. (2) They provide a measure of control in evaluating the influence of structure in the anomalies found subsequently in the mineralized areas, and (3) they indicate that anomalies in several types of geophysical measurements may be caused by relatively shallow geologic conditions in this district.

MULLEN AREA

The locations of the various geophysical traverses and stations in the Mullen area are shown in figure 2. The following geophysical measurements were made: *magnetic,* at intervals of 50 to 100 feet along traverses I-I′ and II-II′; *natural potential,* at approximately 100 foot intervals on a grid extending over the structural trough between traverses I-I′ and III-III′ and along traverse II-II′, extending from the grid; *resistivity* longitudinal traverses, at intervals of 50 feet along traverses I-I′, II-II′, III-III′, and IV-IV′; *resistivity* transverse traverse, with line of centers at 50-foot intervals along

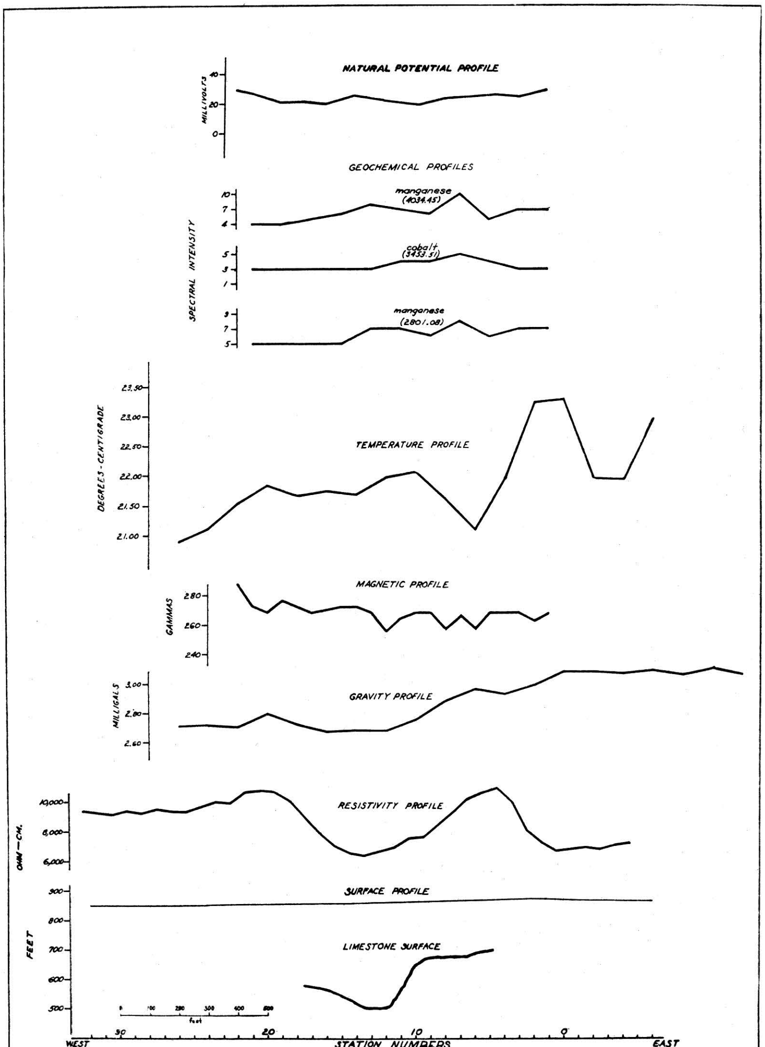

FIG. 18. Profiles along traverse I-I′ in the Mullen area, showing magnetic, gravity, natural potential, resistivity, geothermal, and geochemical anomalies, and configuration of the top of the limestone.

traverse V-V′; *resistivity* depth measurements, at stations DS-1 to DS-9, all located on traverse V-V′ (fig. 2); *geothermal,* at 100- and 150-foot intervals along traverses I-I′ and II-II′; *geochemical,* soil samples at intervals of 100 and 200 feet along traverses I-I′, II-II′, and III-III′.

Profiles and contour maps illustrating representative portions of the geophysical data and results for this area are shown in figures 18 to 22.

Magnetic Survey

The magnetic readings in this area are erratic, in the sense that variations in values from station to station impart a "saw-tooth" character to the profiles (compare with uniform magnetic values in the Neutral area, fig. 16). These variations are probably due to near surface magnetic variations in the formations underlying this area.

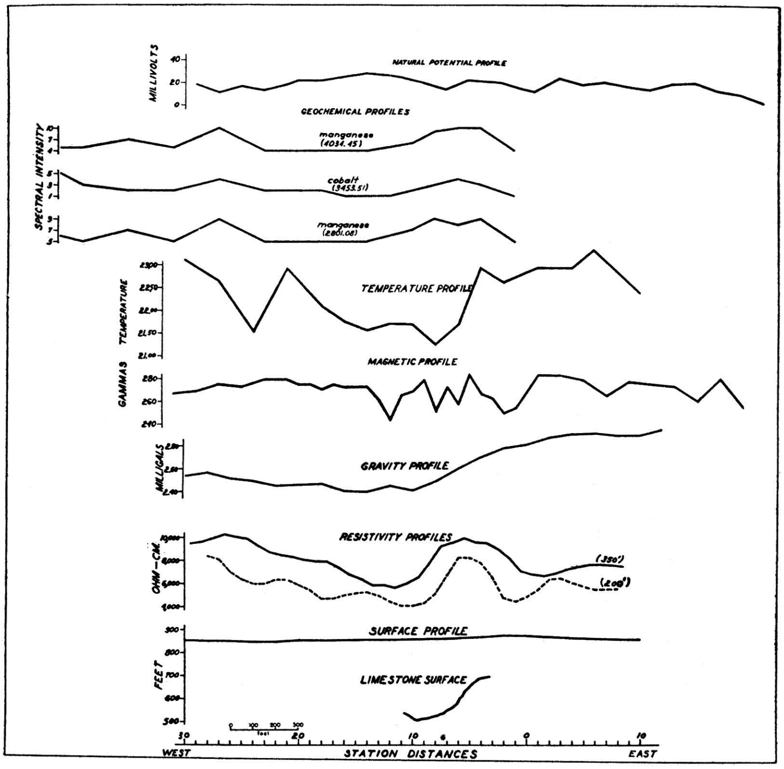

FIG. 19. Profiles along traverse II-II′ in the Mullen area, showing magnetic, gravity, natural potential, resistivity, geothermal, and geochemical anomalies, and configuration of the top of the limestone.

All three magnetic profiles across this area show slightly lower magnetic values in the general vicinity of the Miami trough. The trends, however, are so uncertain and general and the profile values so erratic that the only conclusion that is warranted is that magnetic work is of doubtful value for determination of local structure in this area.

Gravity Survey

The gravity profiles along traverses I-I′ and II-II′ show very similar variations: (1) high values to the east, (2) central gavity minima in the vicinity of the Miami trough, and (3) slightly higher gravity values west of the trough. On traverse I-I′ the gravity minimum extends from station 12 to 16 and closely coincides with the position of the bottom of the trough as indicated by drilling. On traverse II-II′ the gravity minimum extends from station 10 to 16, indicating that the bottom of the trough at this location is probably broader and farther to the west than is indicated by drill hole information. The steeper, dipping eastern flank of the trough is well shown by the higher gravity gradients over this portion of the structure.

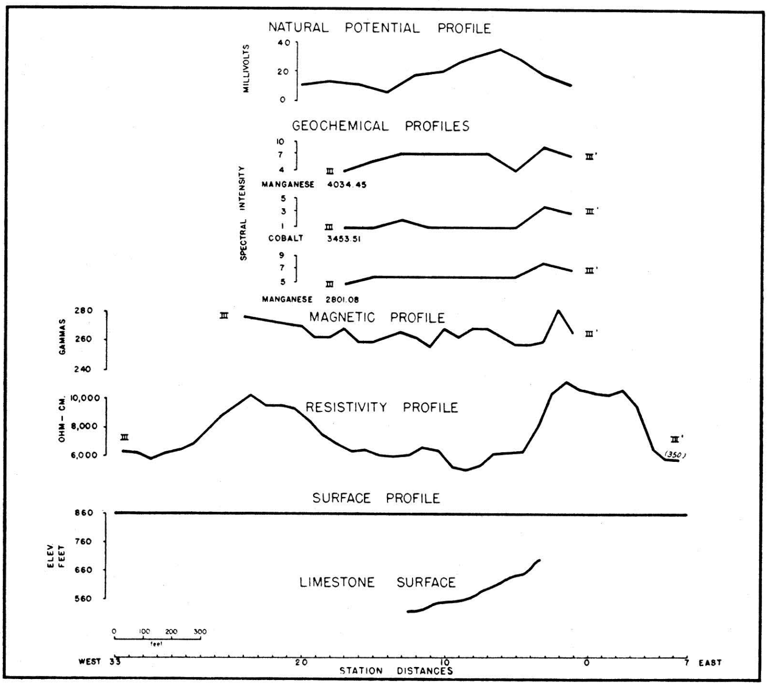

FIG. 20. Profiles along traverse III-III′ in the Mullen area, showing magnetic, natural potential, resistivity, and geochemical anomalies, and configuration of the top of the limestone.

Natural Potential Survey

The three natural potential profiles (traverses I-I′, II-II′, and III-III′) show markedly different trends, although all cross the Miami trough at similar orientations. Profile I-I′ shows a slight potential low. However, this is not confined to the subsurface limits of the trough as defined by drill holes, nor is there any apparent influence of the known asymmetry of the trough. Profile II-II′, on the other hand, shows a broad potential high over the portion of the area overlying the Miami trough. Profile III-III′ shows low potentials between stations 14 and 20, somewhat west of the indicated bottom of the trough. The reversal in trend at station 6 does not conform to the trend of the limestone surface which continues to rise eastward from this location.

The distribution of the natural potential values, as outlined above, shows no relation to the profiles of the limestone surface, nor do they show a negative center over the small zone of zinc mineralization indicated at the center of the area (between traverses II and V). Negative centers are indicated at three locations (fig. 21), but available geologic information is insufficient to account for these anomalies. They may be due to near surface concentrations of oxidizing iron dissulphides or to a non-uniform distribution of electrolytic solutions. Any effects of the major structure of the trough or of the mineralized zone are clearly over-shadowed by these more shallow electrolytic or oxidation effects.

Resistivity Survey

Profiles.—The resistivity profiles (longitudinal type) along traverses I-I′, II-II′, III-III′, and IV-IV′ (figs. 18-20) are similar, with two significant features on all of them: (1) the well-defined resistivity low, occurring where the traverses cross the Miami trough and (2) the sharp maxima over the edges of the trough. These results indicate that the water-saturated, brecciated material within the trough is a better electrical conductor than the adjacent limestone. The sharp maxima over the edges of the trough are the result of a "short circuiting" of the electrical current between power and potential electrodes as the advancing line of electrodes extends over the conductive trough. (See "Factors Influencing Interpretation.")

The lowest value on *profile I-I′* falls between stations 13 and 14. This is in good agreement with the drill hole data. On *profile II-II′* the resistivity low extends between stations 11 to 14 with a gradual increase in values to the west. This indicates that the trough is broader and the bottom somewhat farther west than indicated by drill hole data. (Compare gravity profile II-II′, fig. 19.) *Profile III-III′* (fig. 20) shows a resistivity low over the trough, but it is ambiguous, especially on the east side, where apparently a near-surface conductor (possibly pyrite) has caused the superimposition of a "W" effect on the profile (apparent resistivity peaks at Stations 2-3 west and 11-12 east). If this effect is discounted, the low, normally due to the trough structure, will fall at about station 13-14 which is in accord with drill hole data. On traverse IV-IV′ a broad resistivity low is present with the lowest value at stations 26-27, indicating that this location marks the approximate position of the bottom of the trough.

The transverse type traverse (traverse V-V′) produced results dificult to interpret. The resistivity variations found on this traverse cannot be correlated with the position of the trough under the central part of the traverse. If the trough were straight and extended in a known direction some distance beyond the electrode spread, and if it were uniform in width and depth, this type of traverse could be expected to produce a marked resistivity low over the center of the trough. In the present case the actual conditions do not sufficiently approximate the ideal to produce interpretable data. The resistivity variations along this traverse are probably the effect of lateral variations in structure or lithology spanned by different parts of the electrode configuration as it progressed across the area.

Depth stations.—The depth curves at stations DS-1, DS-2, DS-3, DS-4, DS-5, and DS-9 (fig. 22) are similar and show a characteristic trend change that can be traced through this set of curves. This change is probably the influence of the shale-limestone boundary; although this cannot be definitely confirmed, in view of the absence of drill hole information in this part of the area. The depth curves DS-6, DS-7, and DS-8 are similar also, but the resistivity trends exhibited by them are different from the characteristic trends of the curves on the west end of the traverse. This difference in the curves is due, apparently, to the influence of a highly resistant outcropping sandstone on the east end of the traverse. Curves DS-6, DS-7, and DS-8 are similar to the curves obtained in areas of relatively shallow limestone (*e. g.*, resistivity depth measurements in the Greenback area). Because of this difference in curve character, it is not possible to make a direct correlation between the two groups of curves. Figure 22 shows the resistivity depth correlations and the indicated structural profile along traverse V-V'.

From these results the conclusion seems warranted that under favorable conditions the top of the limestone can be mapped by resistivity depth measurements. In this connection, it is of interest to note that the geophysical interpretation indicates the low point in the trough to be near station DS-4, some 150 to 200 feet farther west than indicated by drill hole information. As mentioned previously,

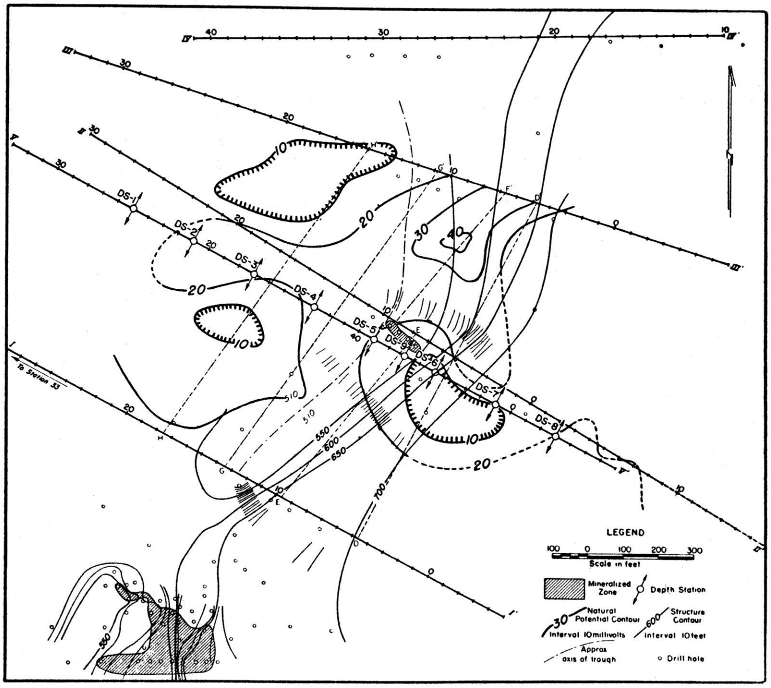

FIG. 21. Map showing natural potential contours in the Mullen area.

both the gravity and the resistivity profiles along traverse II-II' also indicate a more westward location of the bottom of the trough (fig. 19).

Geothermal Survey

The two temperature profiles along traverses I-I' and II-II' (figs. 18,19) are quite dissimilar in trends, although the structure is essentially the same under the two traverses. Profile II-II' shows a general conformity to the limestone profile and to the other geophysical data along this traverse, with low temperature values recorded over the trough. There is no indication that the presence of

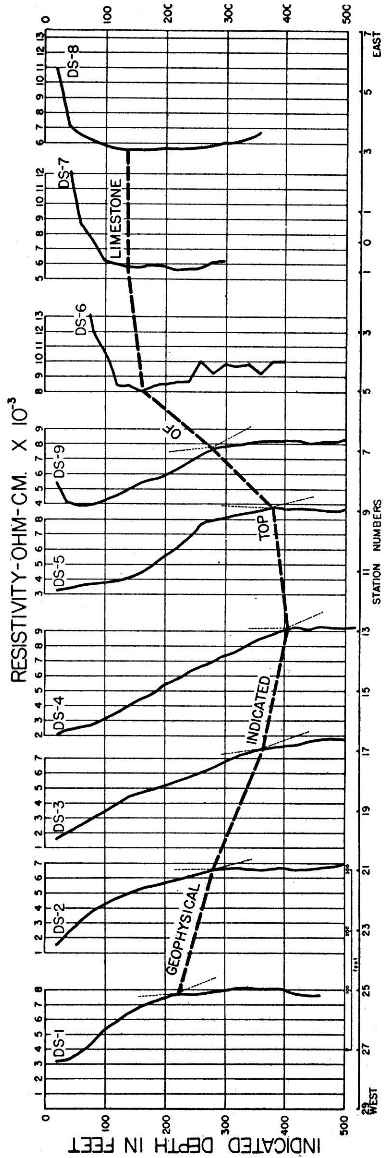

FIG. 22. Resistivity depth profiles and indicated structure in the Mullen area.

ore mineralization extending between stations 7 and 10 has influenced the temperature readings. Profile I-I′, however, shows no relation whatever to the trough structure, and the recorded values apparently are influenced primarily by effects at, or near, the surface of the ground.

Most of the high values measured on the east ends of these traverses are in an area where sandstone crops out at the surface. Some of the low readings, as at station 24 on profile II-II′ and station 26 on profile I-I′, coincide with the location of surface drainage courses. This is not true, however, of other apparently anomalous lows on these traverses.

Geochemical Survey

Spectrographic analysis of the soils in the Mullen area showed only cobalt, manganese, and gallium to be present in amounts exceeding the analytical error of the measurements.

The distribution and relative concentrations of cobalt and manganese in the soil along traverses I-I′, II-II′, and III-III′ in the Mullen area are shown in profiles on figures 18, 19, and 20.

In general, the variation in cobalt and manganese content appears to be similar for each traverse. There is an apparent correlation between the cobalt highs occurring between stations 4 and 12 on traverse I-I′, between stations 4 and 9 on traverse II-II′, between stations 0 and 4 on traverse III-III′, and, to a lesser extent, between manganese highs in approximately the same locations. These cobalt and manganese variations, however, have no apparent relationship either to subsurface structure or to mineralization. The areas of higher relative concentration on the three traverses lie over the steep eastern flank and edge of the trough, adjacent a gentle ridge formed by out-cropping sandstone beds. No explanation for these variations is offered at the present time.

JARRETT AREA

The locations of the two gravity-meter traverses in the Jarrett area are shown on figure 3, which also shows the configuration of the top of the limestone. Gravity profiles along the two traverses are shown on figure 22.

The profiles are practically identical in character of gravity variations along the two traverses. The gravity values, however, are uniformly higher along profile II-II′ by an average of about 0.10 milligals. Considering the close spacing of the traverses (230 feet) this represents a north-south gradient about twice that estimated for the district as a whole (1.0 milligal per mile—see "Regional Survey").

This increased gradient is probably due to local structure. A reasonable explanation is afforded by the presence of a relatively sharp structural low north of traverse I-I′.

Comparison of the gravity profiles with the profile of the top of the limestone indicates that the gravity values are directly related to shallow structure. The most pronounced features on the gravity profiles are the gravity minima near the west ends of the traverses. These agree closely in location with an indicated structural low. This depression in the limestone plus probably related zones of brec-

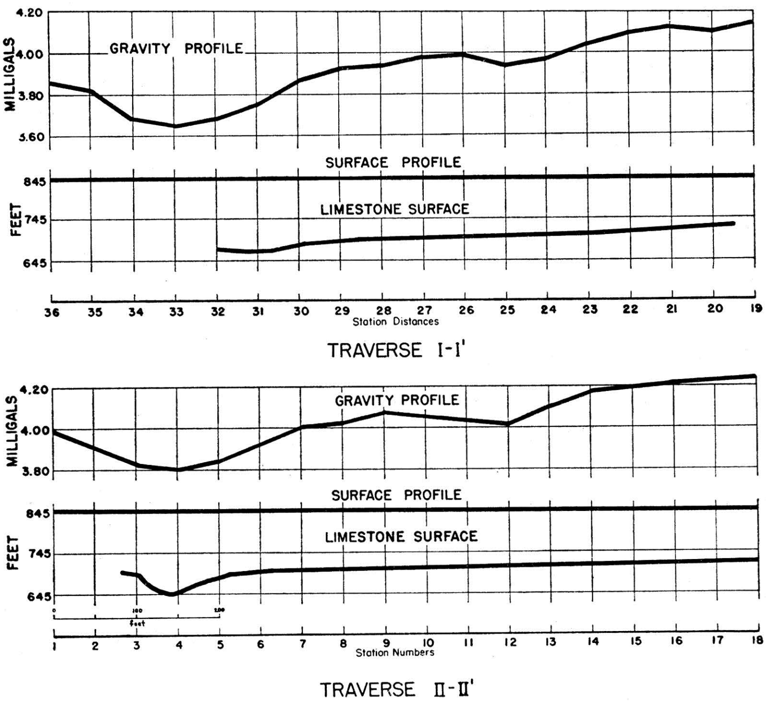

FIG. 23. Profiles along traverse I-I′ and II-II′ in the Jarrett area, showing gravity anomalies and configuration of the top of the limestone.

ciation are believed to be responsible for the gravity minima. It is to be observed, also, that the eastward increasing gravity values appear to be directly related to the trend of the limestone surface along the two traverses.

A comparison of the gravity-meter results with the prior torsion balance work conducted by P. W. George (1928) over this area shows close agreement. Inverse gradients (contour distances) computed from the torsion balance gradients were compared directly to the plotted gravity-meter values.

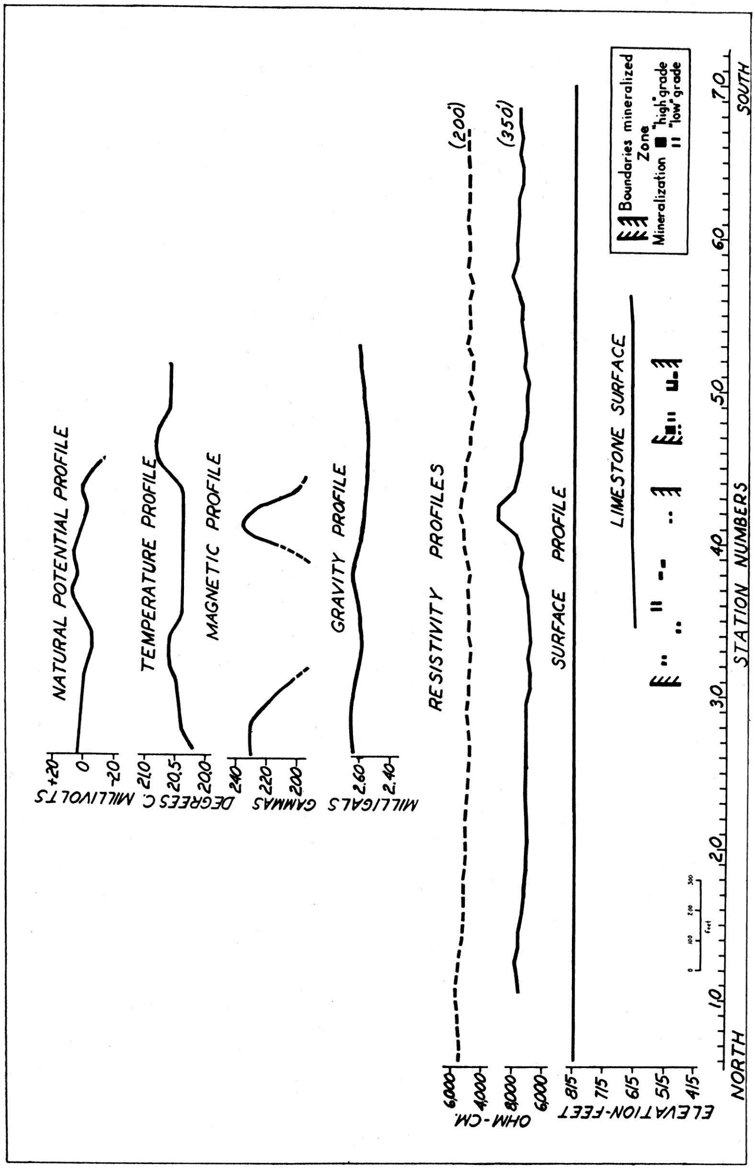

FIG. 24. Profiles along traverse III-III' in the Walton area, showing magnetic, gravity, natural potential, resistivity (longitudinal), and geothermal anomalies, zone of mineralization, and configuration of the top of the limestone.

WALTON AREA

The locations of the various geophysical traverses and stations in the Walton area are shown in figure 4. The geophysical measurements are described as follows: *magnetic,* 135 stations on the grid layout and 5 stations on the eastward extension of the grid line 16; *gravity,* 128 stations on grid layout and extensions of traverses I-I′, II-II′, and V-V′; *natural potential,* 105 stations, covering a portion of the grid layout; *resistivity* longitudinal traverses at intervals of 50 feet along traverses I-I′, II-II′, III-III′, IV-IV′, V-V′, VII-VII′, and VIII-VIII′; *resistivity* transverse traverses, with lines of centers at 50 foot intervals, along traverses V-V′, VI-VI′, VII-VII′, VIII-VIII′, IX-IX′, and X-X′; *resistivity* depth measurements at stations DS-1 to DS-8 (fig. 14); *geothermal,* 127 stations on grid layout and extensions of traverses I-I′, II-II′, and V-V′; *geochemical* soil samples, 149 stations on the grid layout and traverse extensions.

Profile and contour maps illustrating representative portions of the geophysical data and results for this area are shown in figures 24 to 36.

Magnetic Survey

The magnetic map of the Walton area (fig. 31) shows lower magnetic values in the central part of the area, except for the small magnetic high immediately north of the pond. A value of 220 to 230 gammas appears to be normal for the area.

The most prominent features are the magnetic lows, one at the intersection of traverses III-III′ and VII-VII′, and another at grid station K-7. The first-named low and the trend of magnetic contours agree quite closely with the outline of the mineralized zone in this part of the area. The other low appears to be east of the mineralized zone. A trace of sulphide mineralization was noted in the drill hole located about 30 feet east of grid station K-8. The field

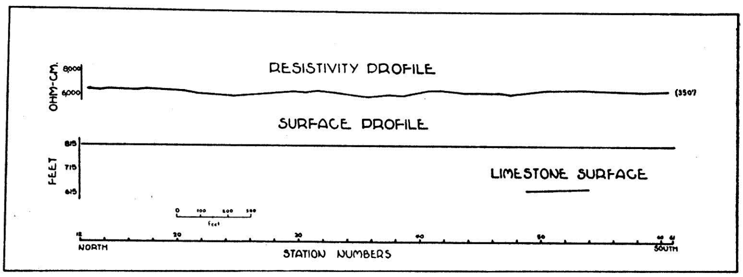

FIG. 25. Profiles along traverse IV-IV′ in the Walton area, showing resistivity (longitudinal) anomalies and top of limestone.

work indicated that these anomalies might be due to the presence of casing in some of the drill holes. Casing was observed at the drill hole near grid station D-4 and, although unobserved, might be present in some of the other holes. A more thorough analysis indicates that these anomalies could not be caused entirely by casing, and, therefore, that natural anomalies of a magnitude of at least 50 gammas probably are present in the area. There is a possibility that a

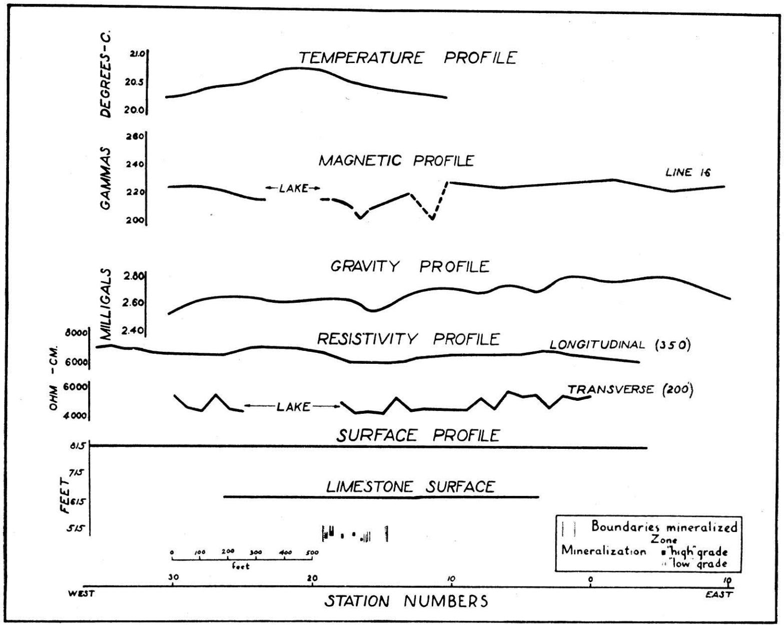

FIG. 26. Profiles along traverse V-V′ in the Walton area, showing magnetic, gravity, resistivity (longitudinal and transverse), and geothermal anomalies, zone of mineralization, and configuration of the top of the limestone.

magnetic low might normally be present in the area over the mineralized zone at the south end of the property, except for the effect of drill hole casing.

Although there appears to be some correspondence in the position of low magnetic values and the trend of mineralization in this area, a theoretical basis for actual relationship cannot be seen at this time. The anomalies are of small lateral extent and may, therefore, be due to shallow structural or lithologic variations within the shale and the upper portion of the underlying limestone (including the zone of mineralization). The magnetic lows cannot be attributed to the ore mineralization itself, since any small difference existing between the magnetic susceptibilities of the ore minerals and the surrounding rocks would not be such as would tend to produce magnetic lows over the mineralized zones. Brecciation and cavernous conditions in the limestone may be associated with mineralization in this area. If extensive enough, such conditions might cause magnetic minima

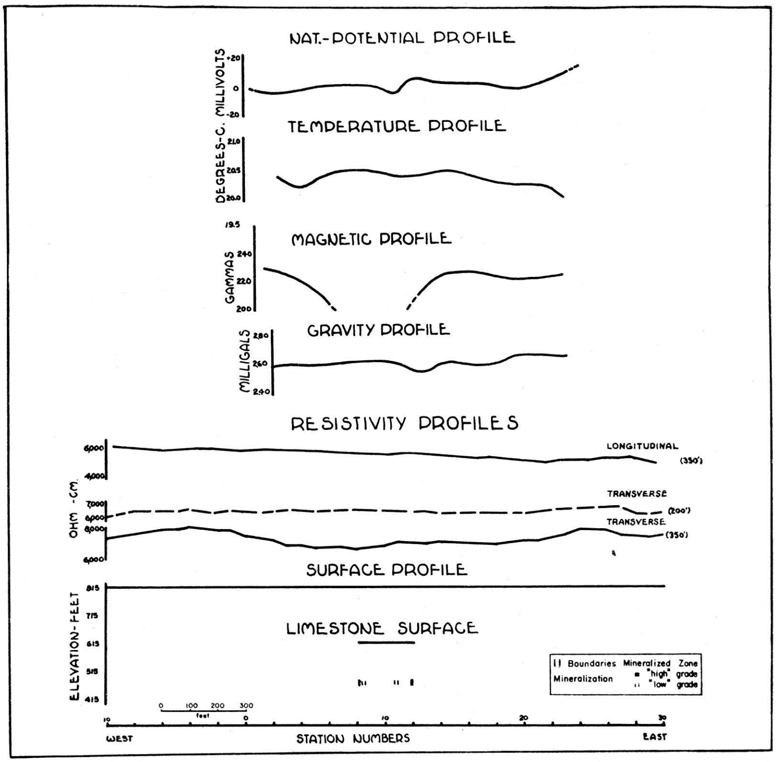

FIG. 27. Profiles along traverse VII-VII′ in the Walton area, showing magnetic gravity, natural potential, resistivity (longitudinal and transverse), and geothermal anomalies, zone of mineralization, and top of the limestone.

due to the reduction in normal magnetic susceptibility of the limestone. It would be logical to expect that such conditions might also cause gravity minima. (See *Gravity Survey.*) Another possible explanation is that the magnetic lows are the result of a lateral variation in the thickness and magnetite content of sandstone horizons in the Cherokee shale. Such variations would have no relation to the occurrence or location of lead-zinc mineralization.

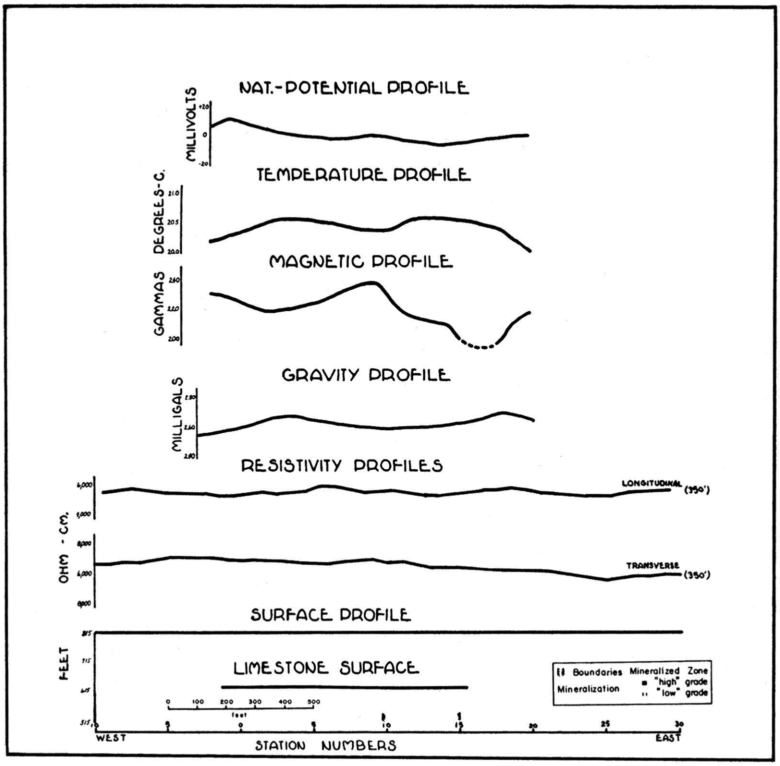

FIG. 28. Profiles along traverse VIII-VIII′ in the Walton area, showing magnetic, gravity, natural potential, resistivity (longitudinal and transverse), and geothermal anomalies, zone of mineralization, and configuration of the top of the limestone.

Gravity Survey

The gravity map of the Walton area (fig. 32) shows several high and low anomalies. The maximum gravity relief in the area is approximately 0.4 milligals, and the average relief between the individual anomalies is approximately 0.1 to 0.15 milligals. A gravity low in the central part of the area coincides in part with the position and trend of the zone of mineralization, suggesting a possible relationship. However, it is to be noted that except for the values along profiles IX-IX′ and X-X′ (figs. 29, 30), this central gravity low departs considerably from the indicated position of the mineralized area. It is true, also, that the gravity values at places along the east and west borders of the area are as low as, and sometimes lower than, values over the mineralized zone.

The gravity anomalies, therefore, do not show any unique diagnostic relationship to the trend of the mineralized zone. It is probable that the variation in gravity values are related to irregular zones of brecciation and cavernous conditions in the limestone which may or may not be related to the mineralized zone.

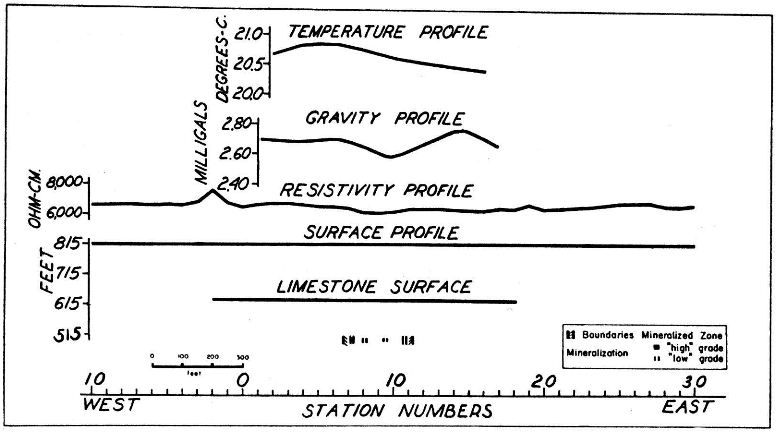

FIG. 29. Profiles along traverse IX-IX′ in the Walton area, showing gravity, resistivity (transverse), and geothermal anomalies, zone of mineralization, and configuration of the top of the limestone.

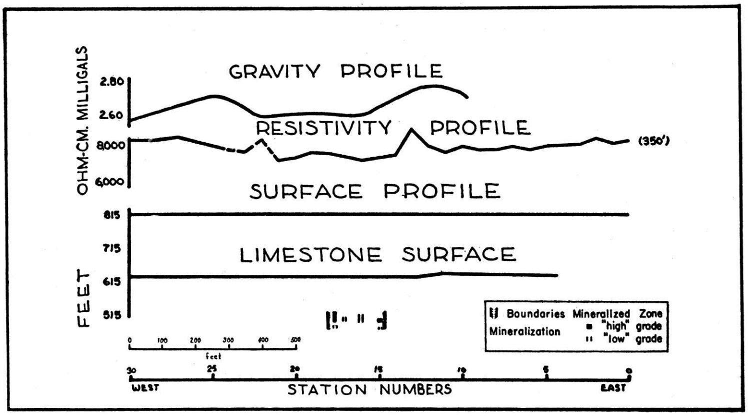

FIG. 30. Profiles along traverse X-X′ in the Walton area, showing gravity and resistivity (transverse) anomalies, zone of mineralization, and configuration of the top of the limestone.

Natural Potential Survey

The natural potential readings in the Walton area were less satisfactory from the standpoint of reading accuracy than in any of the other areas. The total observed variation in the area was approxi-

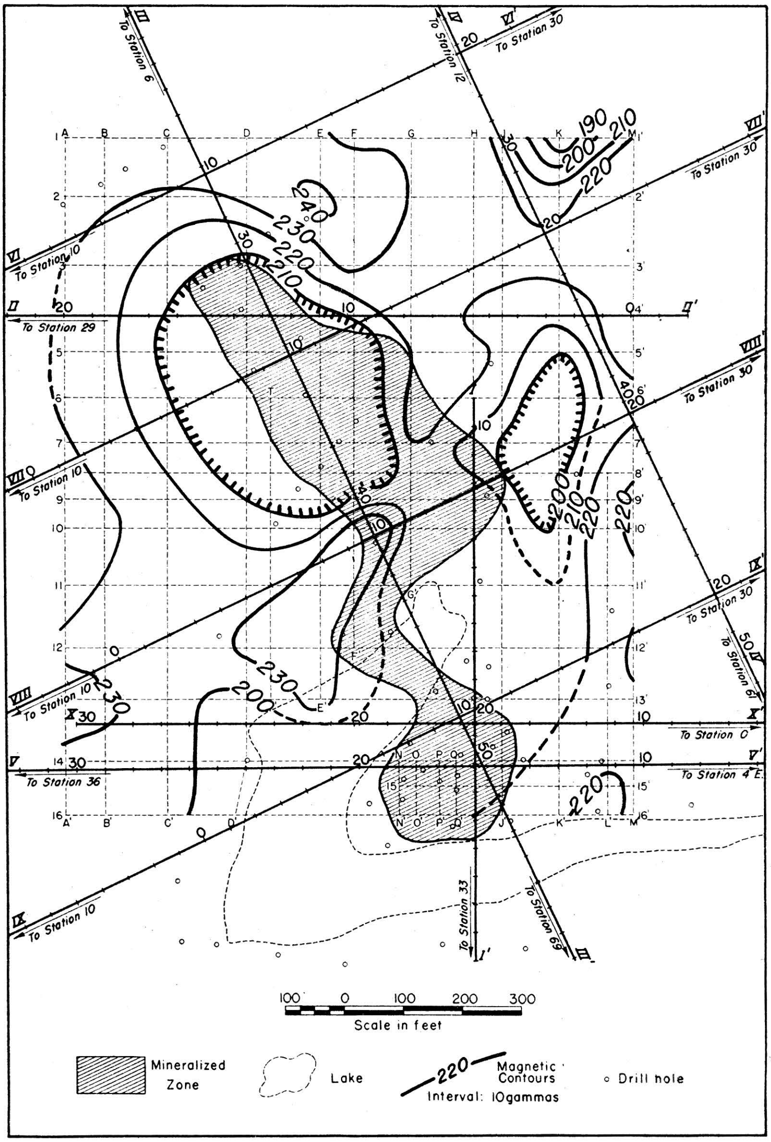

FIG. 31. Map showing magnetic contours in the Walton area.

mately 30 millivolts. In this area particularly, it was difficult to secure accurate readings because of an apparently random directional and intensity variation in the natural potentials. It is thought that this may be due to changing distribution and flow of ground water, associated with possibly cavernous conditions in the limestone. The contour map (fig. 33) shows natural equi-potential contours with an interval of 5 millivolts, which is believed to correspond approximately to the error of the observations.

No relationship to structure or mineralized zones is apparent in this contour map. The erratic distribution of potentials suggests that they are either related to ground water conditions or, perhaps, to even more shallow near-surface effects.

Resistivity Survey

Profiles.—The resistivity results in the Walton Area are shown in profiles which exhibit the variations in apparent resistivity along the various traverses (figs. 24 to 30). The results obtained along the various traverses are described below:

Traverse I-I′ (longitudinal): There is evidence of a slight resistivity low over the southernmost mineralized zone. The north part of the profile is ambiguous, probably as the result of an extraneous near-surface resistivity variation.

Traverse II-II′ (longitudinal): The profile shows a slight resistivity low with associated "W" effect, partially obscured by a westward increasing resistivity gradient.

Traverse III-III′ (longitudinal): A resistivity low extending from station 31 to 37 extends over a portion of the northermost indicated mineralized zone. The normal values on the curve are disturbed by the sharp resistivity high at station 42 which appears to be part of the same condition which causes a resistivity high at station 12 on traverse I-I′. Another resistivity low extending from station 47 to station 53 coincides quite closely with the location of the southermost indicated zone of mineralization.

These resistivity lows are reflected only very slightly in the readings taken at a depth of 200 feet. This indicates that the conditions responsible for lows lie within the limestone, below the bottom of the shale.

Traverse IV-IV′ (longitudinal): Insofar as is known, this traverse crosses barren area throughout its extent. Measurements along this line were made for the purpose of determining the magnitude of resistivity variations in barren ground and for the purpose of direct comparison to the resistivity profile along traverse III-III', crossing the mineralized zone 500 feet to the west.

Resistivity lows are present in the vicinity of station 25 and station 36. In variation from mean average values along the traverse these lows are of approximately the same magnitude as the lows observed over the mineralized zones along traverse III-III'.

Traverse V-V' (longitudinal): A well-defined resistivity low extends between stations 14 and 18. This agrees closely with the location of the underlying mineralized zone. (Transverse): The transverse profile at this location was measured at 200 feet depth, primarily for the purpose of comparison to the transverse profile at 350 feet depth along traverse X-X'. An offset location was necessary in order to span the pond in the vicinity. The profile values are erratic but show slightly lower resistivity values in the area over the mineralized zones.

Traverse VI-VI' (transverse): The values on this profile show only slight departures from the average trend, a slight low extending between stations 10 and 16. This traverse is believed to cross barren area.

Traverse VII-VII' (longitudinal): The values on this profile show only very slight departures from the mean average values. The gradient of westward increasing values is possibly due to decreasing depth of shale cover in this direction (fig. 4). (Transverse): This profile shows lower resistivity values in the central part of the traverse with a well-defined low extending between stations 3 and 9.

This low extends chiefly to the west of the projected outline of the mineralized zone and apparently represents a structural change which may or may not be related to the mineralized zone. The increasing values to the westward may be due to decreasing thickness of shale or to greater induration of the limestone west of the mineralized zone.

Traverse VIII-VIII' (longitudinal): This profile shows a slight resistivity low with associated "W" effect at station 13, over the projected outline of the mineralized zone. (Transverse): The transverse profile shows a westward increasing gradient but no indication of an anomaly related to the mineralized zone or immediately adjacent structure.

Traverse IX-IX' (transverse): This profile shows a definite, but very slight, resistivity low occurring over the mineralized zone at stations 8 and 10.

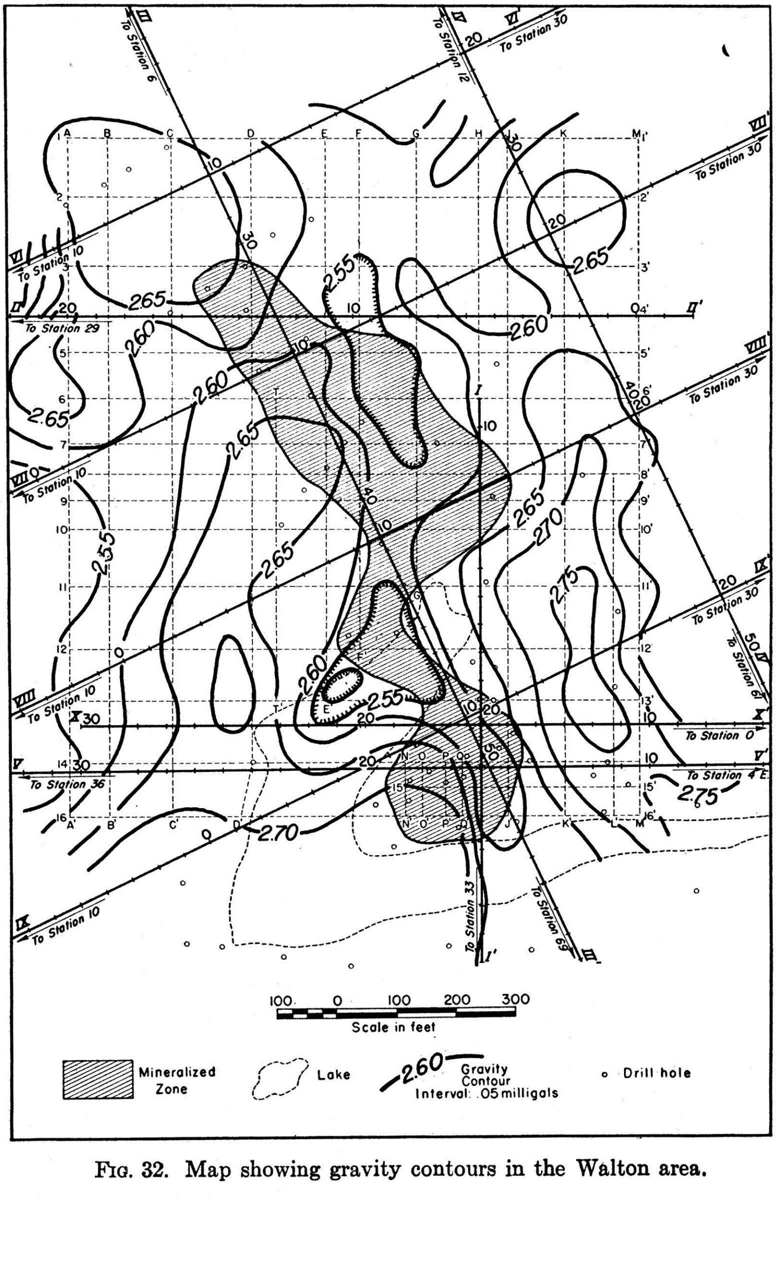

FIG. 32. Map showing gravity contours in the Walton area.

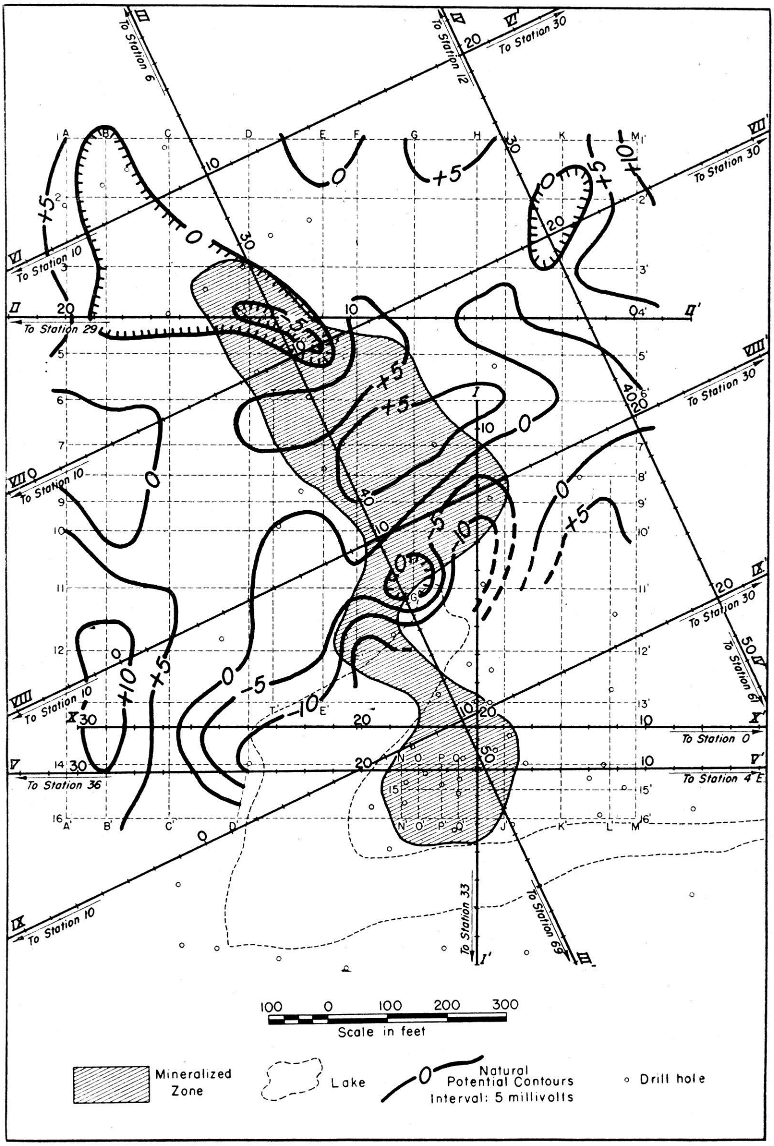

FIG. 33. Map showing natural potential contours in the Walton area.

Traverse X-X' (transverse): A well-defined resistivity low extends between stations 14 and 21. This covers the projected outline of the mineralized zone and extends, as well, out over the pond to the west. Since no control is available in this vicinity, however, it is possible that the mineralized zone extends somewhat farther west than indicated on the maps.

Depth stations.—The resistivity depth profiles in this area (fig. 55) are somewhat similar to those previously described for the Mullen area. As in the latter area, a definite change in curve trend appears to be associated with the shale-limestone boundary.[1] However, this does not appear on all of the curves. All resistivity curves were interpreted by the theoretical method previously described and the depth to the shale-limestone boundary calculated.

Table No. 14 illustrates the geophysical calculations and a comparison to drill-hole indicated elevations.

TABLE No. 14.—*Resistivity-depth correlation.—Walton area*

STATION	Surface elevation	Geophysical depth to limestone	Geophysical elevation of limestone	D. H. elevation of limestone
1	816	210	606	614
2	817	275(?)	542(?)	605
3	813	200	613	625–630
4	814	175	639	630–640
5	815	225	590	no data
6	816	175	641	620–625
7	816	no trend change	....	....
8	816	200	616	610

Geothermal Survey

The temperature contour map of the Walton area (fig. 34) shows a central area of slightly higher temperatures. The total range of temperature in the area is approximately 1.0 degree Centigrade. The contour interval is 0.2 degree, which is the estimated probable error in the final corrected values.

1. It is recognized that conventional theory will not account for these trend changes. Nevertheless, they are sometimes found in field resistivity curves. Electrolytic or polarization effects at the formation boundaries may be influential in causing these variations.

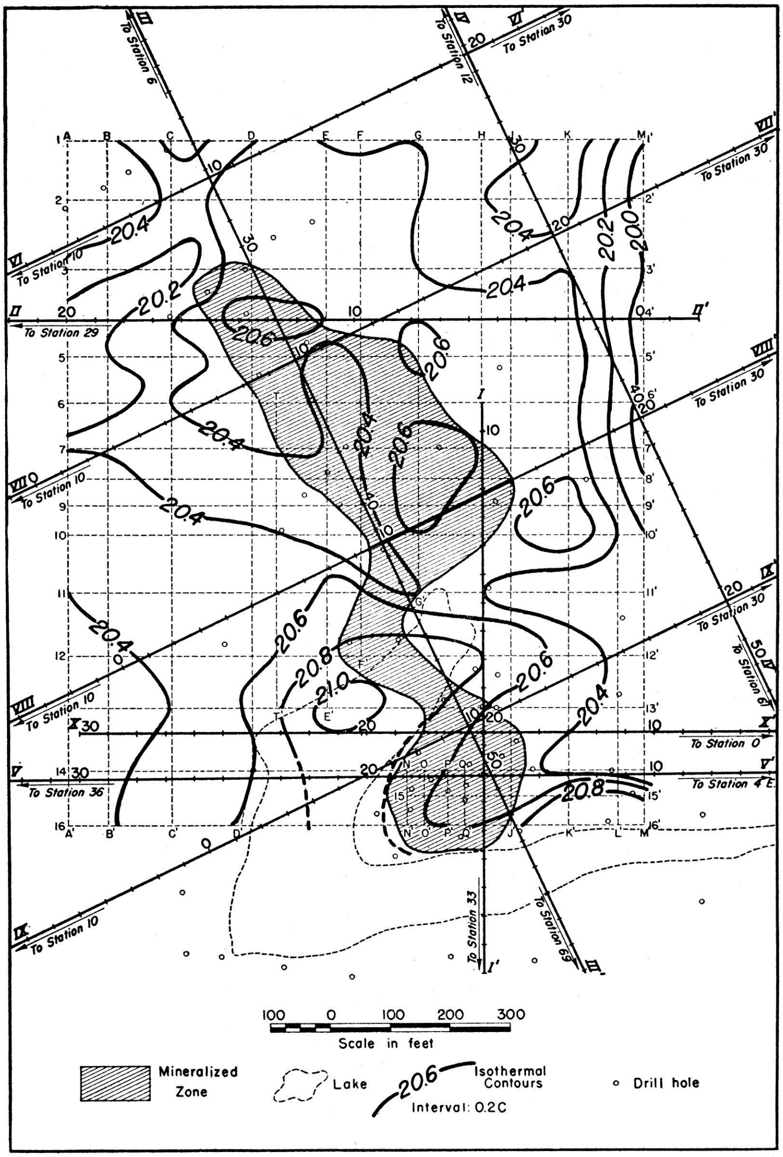

FIG. 34. Map showing temperature contours in the Walton area.

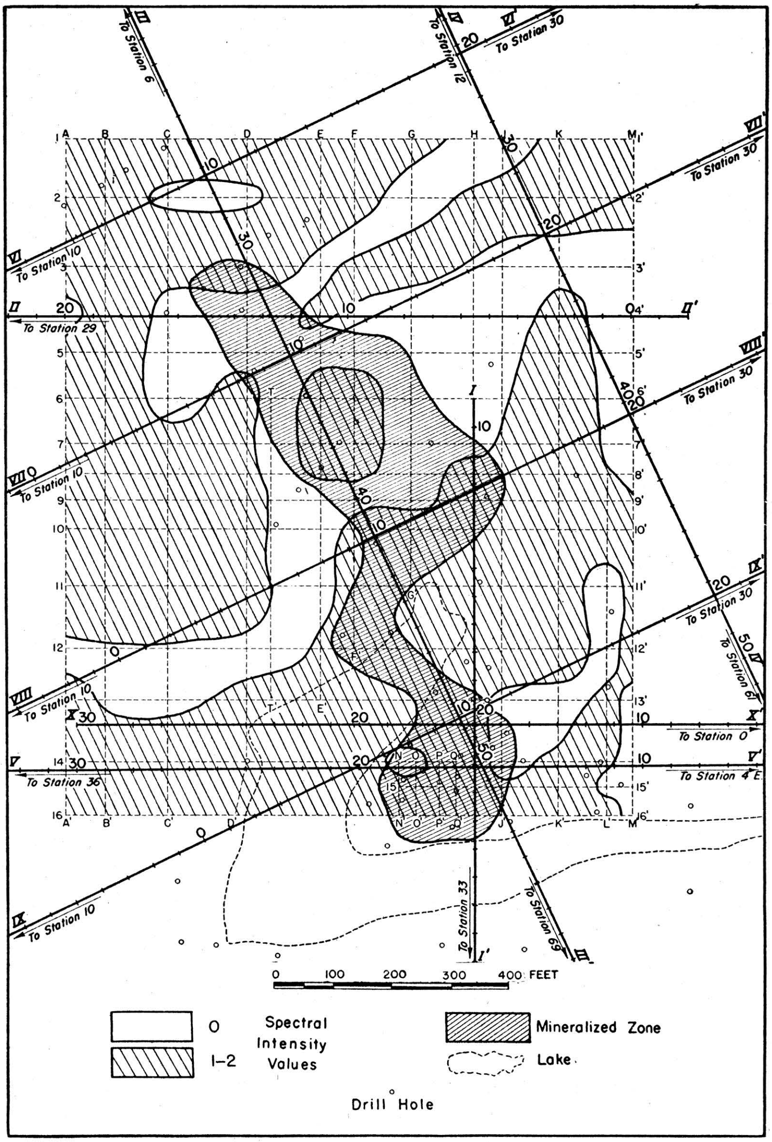

FIG. 35. Map showing areal distribution of cobalt in the soil of the Walton area.

The areal extent of this survey was not sufficient to allow definite conclusions with regard to a possible relationship between this broad temperature high and the central mineralized zone. It is to be noted, however, that the highest temperature values fall in an area west of the south end of the mineralized zone (south ends of grid lines D, E, and F). Traverses II-II′ and III-III′ both show local temperature highs of small intensity occurring over portions of the mineralized zones. Traverses VII-VII′ and VIII-VIII′, however, show local highs outside of the indicated mineralized zone.

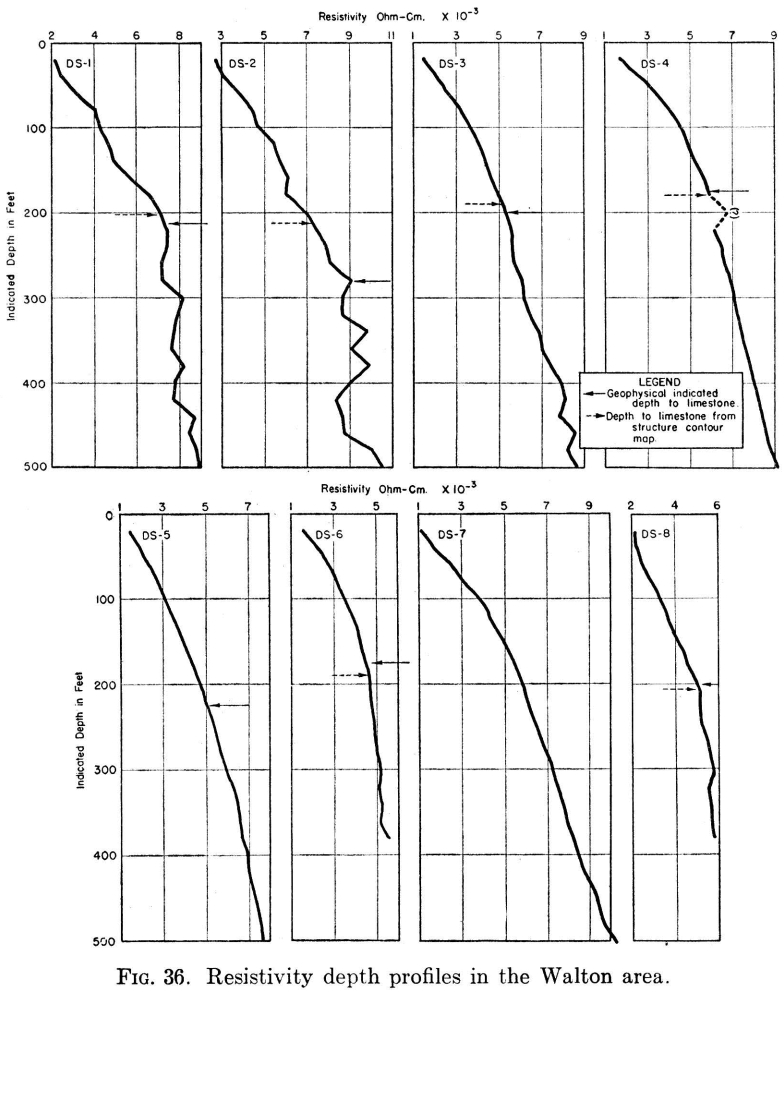

FIG. 36. Resistivity depth profiles in the Walton area.

Geochemical Survey

In the spectrographic analyses of the Walton soil samples, cobalt was the only element found to vary to a degree definitely beyond the possible analytical error of the measurements. The map (fig. 35) shows the approximate distribution of cobalt in the soils of the Walton area.

The distribution of cobalt as shown by this map apparently has no relationship to ore mineralization or structure on the Walton area. Neither is there any significant resemblance of this data to the other geophysical data in the area. The presence of a relatively thick Tertiary cover in this area probably explains, in part, the lack of correlation between geochemical data and geology.

Summary

One of the most significant features in the study of the geophysical data for this area is the small magnitude of the anomalies. In order to adequately illustrate the anomalies by means of contours it has been necessary to use a contour interval which is approximately equal to the error in the observations. The data in table No. 15 were compiled to compare, for each type of geophysical method, the intensities of the various geophysical anomalies relative to the maximum error in the observations.

From this compilation it is apparent that, regardless of any geological significance, resistivity, magnetic, and gravity anomalies, in the order given, are the least likely to be due to, or influenced by,

TABLE NO. 15.—*Magnitude of geophysical anomalies.—Walton area*

GEOPHYSICAL METHOD	Ratio of anomaly to maximum error*	Ratio of total range of observations to maximum error
Magnetic	5	10
Gravity	3	8
Natural potential	2	6
Resistivity	10	40
Geothermal	2	5
Geochemical	2	2

* Ratio of variation from approximate mean average values to the indicated maximum error in the measurements (see pp. 37, 39, 40, 42, 45, 46, 51, and 62-77).

observational error; whereas, observational error is likely to be influential in the natural potential, geothermal, and geochemical anomalies.

The relief on the limestone surface in this area is so gentle as to eliminate this feature from consideration as a primary cause for anomalies in the area, although some of the resistivity curves apparently indicate the effect of greater or less depth of shale in parts of the area where the change is most pronounced. Of most importance, therefore, are possible relationships of the various anomalies either to the mineralized zone or to conditions of porosity or brecciation which are related to the mineralization.

None of the geophysical methods gave consistently correlatable results for this area. Six of the resistivity traverses exhibit anomalies that appear to be due either to the mineralized zone or to directly related structural conditions (traverses II-II′, III-III′, V-V′, VIII-VIII′, IX-IX′, and X-X′). However, a traverse in supposedly barren territory (traverse IV-IV′) exhibits anomalies of approximately the same strength as those over the mineralized zones.

The resistivity depth studies are summarized as follows: From a total of eight stations, it was possible on five (DS-1, DS-3, DS-4, DS-6, and DS-8) to determine the probable depth to the limestone. On the average, these computed depths are within 5 percent of the depths indicated by drilling information. One station (DS-2) gave an erroneous correlation; one (DS-7) showed no correlatable trend change; and one (DS-5) exhibited a trend change, but it was outside the area of drill hole check information.

The magnetic work reveals an apparent coincidence in location of magnetic lows with parts of the mineralized zone. No theoretical basis for actual relationship between the magnetic values and the mineralized zone is evident from available data.

The gravity work affords evidence of an occasional relationship between gravity minima and the mineralized zones. The areal relationship is not well-defined, however, nor are gravity minima unique criteria, since adjacent barren areas also show low gravity values. The results indicate that gravity minima correspond to zones of fracturing or cavernous conditions which may or may not be related to mineralization.

The broad geothermal high extending over the central part of the Walton area is of unknown significance due to the restricted areal extent of the measurements.

The natural potential and geochemical anomalies appear to be unrelated to structure, lithology, or mineralization, in this area.

KARCHER AREA

The locations of the geophysical traverses and stations in the Karcher area are shown on figure 5. The geophysical measurements were conducted as follows: *magnetic,* 66 stations on the grid layout and 4 stations on the eastward extension of grid line 5; *gravity,* 79 stations on the grid layout and extensions of traverses IV-IV′ and V-V′; *natural potential,* 76 stations on the grid layout and extensions of traverse V-V′; *resistivity* longitudinal traverses, at intervals of 50 feet along traverses I-I′, II-II′, III-III′, IV-IV′, V-V′, VI-VI′, and VII-VII′; *resistivity* depth measurements, at stations DS-1, DS-2, DS-3, and DS-4, all located on traverse V-V′ (fig. 5); *geothermal,* 84 stations on the grid layout and extensions of traverses IV-IV′ and V-V′, and grid line 5; *geochemical* soil samples, 91 stations on the grid layout and extensions of traverse V-V′.

Profile and contour maps illustrating representative portions of the geophysical data and results for this area are shown herein (figs. 37-46).

Magnetic Survey

The range of variation of the vertical magnetic intensity in the Karcher area is approximately 150 gammas. Most of this is represented by the two magnetic lows in the southeastern part of the grid layout. Over most of the grid, the values range between 250 and 300 gammas. A magnetic high with a closure of approximately 40 gammas covers most of the northern half of the grid layout (fig. 41).

The magnetic anomalies apparently have no relation to the mineralized zones or to the contour of the shale limestone boundary. The smaller anomalies probably are caused by extraneous near-surface lithological variations; while the somewhat more extensive magnetic high may represent a change at greater depth. This change, however, does not appear to be related to the mineralized zone.

Gravity Survey

The gravity map of the Karcher area (fig. 42) shows quite a number of minor variations (small undulations in the contours) but no well-defined gravity maxima or minima. The total range of gravity change in the area is approximately 0.6 milligal, about half of which represents regional gradient (profile IV-IV′, fig. 38). The total range of variation, in an east-west direction, crossing the mineralized zone at its indicated widest extent (profile V-V′), and excluding the apparently anomalous reading at station 42, is approximately 0.2 milligal.

A series of small gravity variations occur throughout the area. This can be best observed by following the 2.00 milligal contour on the map (fig. 42). As in the Walton area, gravity minima in the Karcher area occur both in the vicinity of and at locations away from the mineralized zones. It is believed that the lower gravity values are probably due to zones of brecciation or cavernous conditions. The results indicate that gravity minima in this area are not uniquely diagnostic criteria indicating the presence of mineralized zones, either directly or indirectly.

Natural Potential Survey

A range of variation of approximately 50 millivolts in natural potential was observed in the Karcher area. Over the grid layout, the range was only about 30 millivolts. The readings in this area are considered to be somewhat more accurate than was the case for the Walton area, since less diurnal variation was noted during the time devoted to the Karcher survey.

In addition to the readings on the grid stations, measurements were made along traverse V-V′ in order to allow comparison to the subsurface structure and to the other geophysical data along an extended line of measurement (fig. 39). On this traverse the natural potential values are somewhat lower in that part of the area covered by the grid, but no correlation to structure or mineralized zones is apparent. The low readings at stations 23, 34, and 42 correspond in position to slight topographic lows representing drainage courses. The low values at station 42 are in the vicinity of a near-surface resistivity low as indicated by the shallow resistivity measurements along this traverse.

The contour map (fig. 43) shows the areal distribution of natural potential values. There is no evidence that negative centers are associated with the mineralized zones. The slight potential high extending along grid line 7 and turning northward along line H follows the general trend of a slight depression in the shale limestone contact (fig. 5), suggesting that these two features may possibly be related. No relationship to the mineralized zone is necessarily indicated thereby.

Resistivity Survey

Profiles.—The resistivity traverses in the Karcher area were all of the longitudinal type, and all extended to an effective depth of approximately 400 feet.

Traverses I-I′, III-III′, IV-IV′, and V-V′ all cross the Karcher mineralized zone near the position of its greatest width as indicated by drill hole logs. Of this group of traverses, traverse V-V′ was extended a considerable distance east and west to get beyond the mineralized area. Along a part of traverse V-V′, measurements to a depth of 200 feet were also made in order to indicate the presence of near-surface effects and to ascertain whether the effects of near-surface conditions on the deeper measurements could thus be determined and suitably evaluated.

The measurements along traverses II-II′ and VI-VI′ were for the purpose of ascertaining the possible effect of narrow mineralized zones on the apparent resistivity values.

Traverse VII-VII′ is in known barren area, and the observed resistivity variations are, therefore, characteristic of barren ground in this area, as are also the eastern and western ends of the profile along traverse V-V′.

Traverse I-I′: The resistivity profile shows a well-defined anomaly (resistivity low and "W" effect) centering at station 35, approximately over the center of the widest part of the Karcher mineralized zone. The narrow mineralized zone extending southwestward apparently has little effect upon the measurements.

Traverse II-II′: The resistivity values on this profile decrease rather uniformly toward the south with only slight departures from the mean average trend. The relatively narrow mineralized zones crossed by this traverse apparently have no effect upon the resistivity values. Likewise, the effect of the contour of the limestone surface is very minor, if effective at all, (cf. structure and resistivity profiles at the south end of the traverse).

Traverse III-III′: This profile exhibits a well-defined anomaly centering at station 29, over the center of the main mineralized zone. At this location the indicated zone of mineralization is 275 feet wide, the widest crossed by any of the traverses.

Traverse IV-IV′: The anomaly shown on this profile over the mineralized zone is similar to the preceding anomalies (resistivity low with symetrical "W" effect); but, with reference to variations along the rest of the profile, the low over the mineralized zone is not as prominent as the increases in apparent resistivity over the edges of the mineralized zone. A resistivity low occurs at stations 10 to 12 (south). A gravity low was also observed at this location. The only drill holes in this immediate vicinity are 200 to 400 west of the traverse, and none of these indicate more than a trace of zinc mineralization. The coincidence of resistivity and gravity lows probably indicates either increased thickness of shale

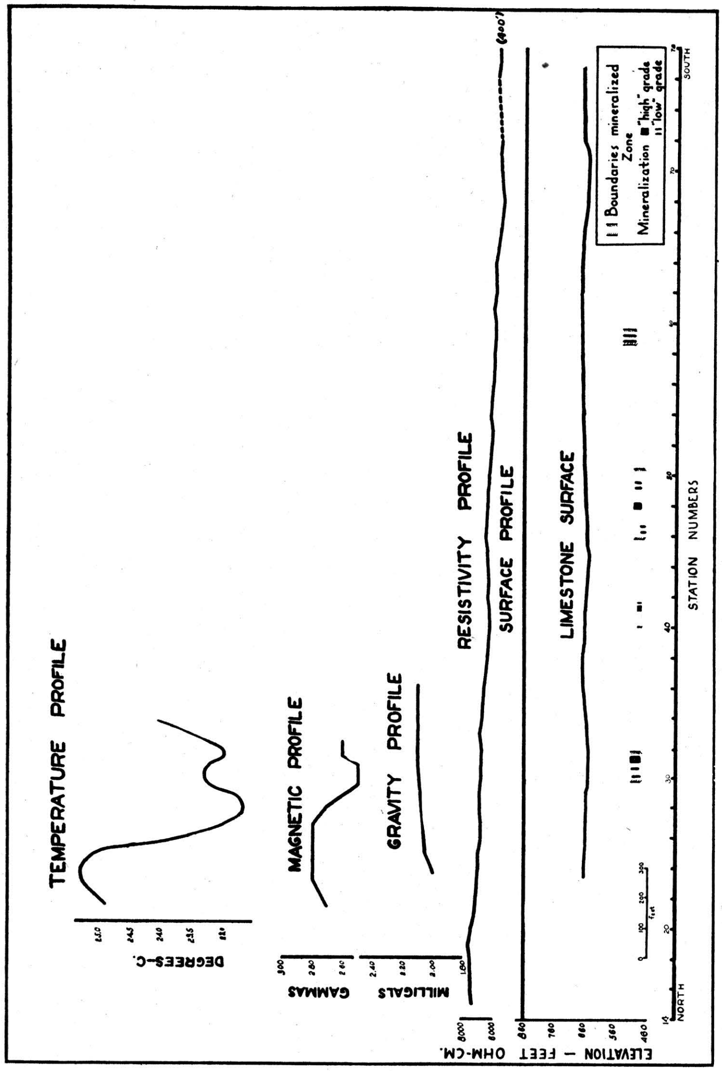

FIG. 37. Profiles along traverse II-II' in the Karcher area, showing magnetic, gravity, resistivity, and geothermal anomalies, zone of mineralization, and configuration of the top of the limestone.

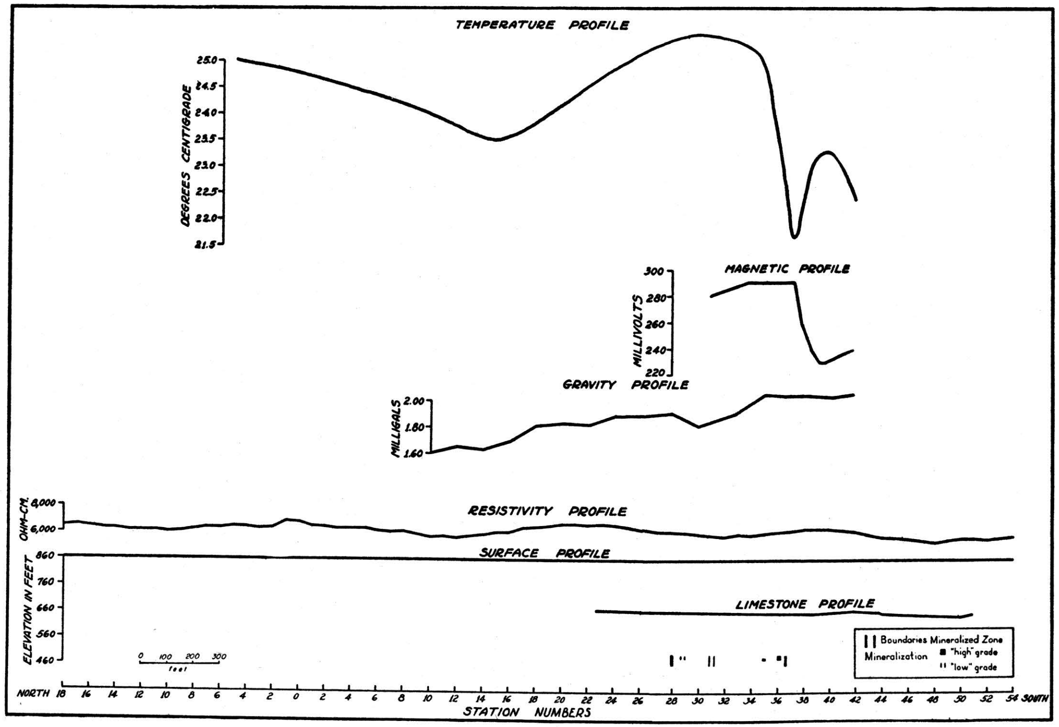

FIG. 38. Profiles along traverse IV-IV′ in the Karcher area, showing magnetic, gravity, resistivity, and geothermal anomalies, zone of mineralization, and configuration of the top of the limestone.

at this location, or brecciation and cavernous conditions in the limestone, or both.

Traverse V-V': The anomaly shown by this profile, centering at station 30 over the mineralized zone, is very well-defined and is the only notable resistivity variation in a traverse distance of 4,800 feet. The normal trend of resistivity values is shown on the east and west portions of the traverse. That this anomaly is the

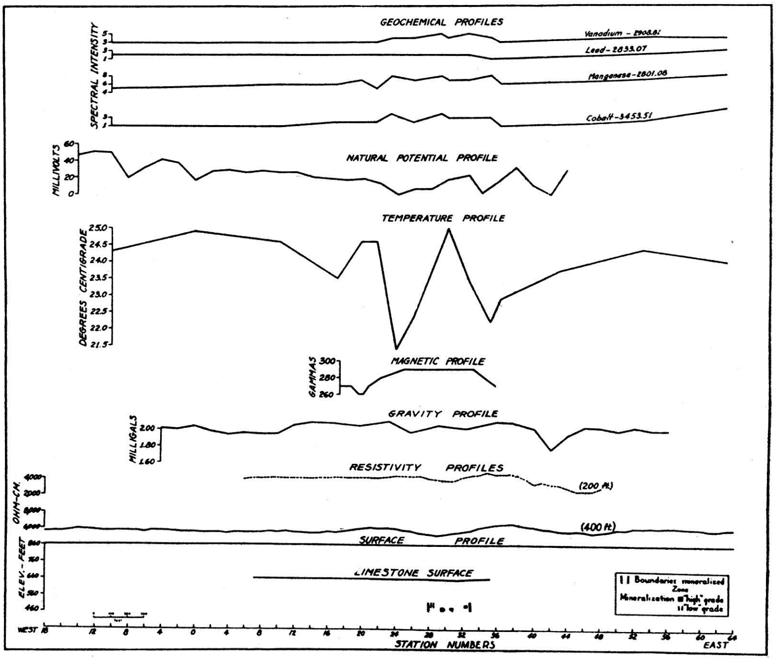

FIG. 39. Profiles along traverse V-V' in the Karcher area, showing magnetic, gravity, natural potential, resistivity, geothermal, and geochemical anomalies, zone of mineralization, and configuration of the top of the limestone.

effect of conditions in the limestone is shown by the relatively minor effect on the near-surface measurements at this location. It is interesting to note the relatively pronounced resistivity low at stations 45 to 47 on the shallow curve. This effect is present also on the deeper curve, but the relative magnitudes of the variations indicate that a shallow structural condition is responsible for the low at stations 45 to 47.

Traverse VI-VI': The profile along this traverse shows a number of minor variations, none of which show any correlation to the indicated mineralized zones or trend of the shale-limestone contact. *Traverse VII-VII′:* This profile represents the resistivity variation in barren ground. It is notable for its extremely uniform trend with values decreasing slightly toward the south.

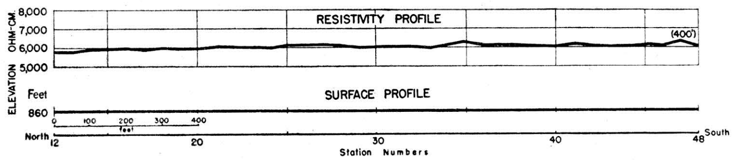

FIG. 40. Resistivity profile along traverse VII-VII′ in the Karcher area.

Depth stations.—The resistivity-depth curves in this area (fig. 45) are similar to those of the Mullen and Walton areas. They appear, however, to be less useful for determining the depth of the shale-limestone contact. The first measurements were made in an east-west direction. In view of the poor diagnostic quality of these curves, some north-south measurements were made for comparison at DS-1 and DS-2. Both of the north-south measurements gave better results than the east-west measurements at the same locations, and a trend change is present on the curve at the approximate depth to the shale-limestone contact.

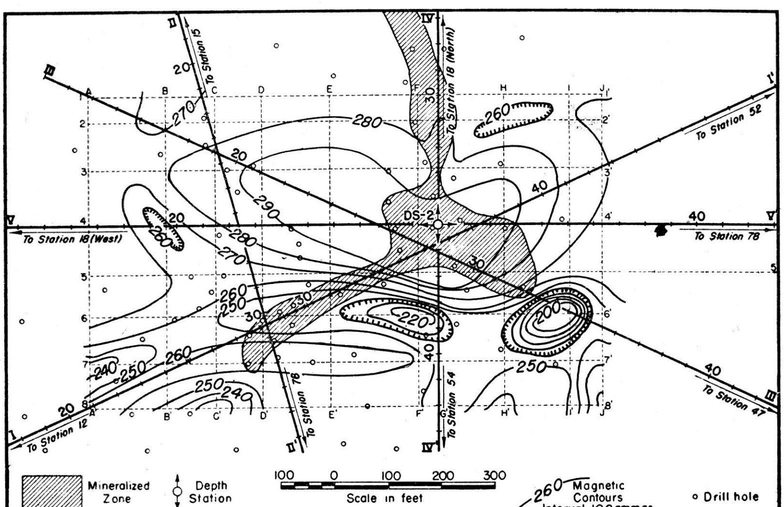

FIG. 41. Map showing magnetic contours in the Karcher area.

Table No. 16 summarizes the results of the resistivity-depth measurements.

TABLE No. 16.—*Resistivity-depth correlations—Karcher area.*

STATION	Surface elevation	Geophysical depth to limestone	Geophysical elevation of limestone	Drill hole elevation of limestone
DS-1 (N-S)..........	865	190	675	none
DS-1 (E-W)..........	865	225(?)	640	none
DS-2 (N-S)..........	860	190	670	655
DS-2 (E-W)..........	860	120(?)	....	....

DS-3 (E-W)—There are several minor trend changes but none that appear to be related to the shale-limestone contact.

DS-4 (E-W)—A trend change at 140 feet (elevation of 715 feet) appears to be too high to be the shale-limestone contact.

Geothermal Survey

The Walton area geothermal survey was conducted after the onset of a period of prolonged rainfall. During the course of the measurements the ground was quite uniformly saturated with water, and the temperature measurements were made under water, with comparable conditions at each station.

On the Karcher area, the temperature measurements were made under quite different conditions. The Karcher readings were made earlier in the year, before the full onset of the rains, but during a period of intermittent rainfall. As a result, near-surface moisture conditions were often different at the various measurement stations. These conditions seem to be reflected in: (1) higher temperature readings, (2) greater range of earth temperature (5° C. as compared to 1° C. on the Walton area), and (3) a definite relationship of temperature anomalies to the surface topography (lows often in close proximity to drainage courses).

In view of those conditions it is extremely doubtful that any temperature effect associated with the mineralized zone would be sufficiently strong to influence the surface measurements made in this area. On the northwest part of the grid layout and over the northern part of the mineralized zone, topographic effects are at a minimum; but even in this part of the area there are no diagnostic changes in temperature gradient over the mineralized zone.

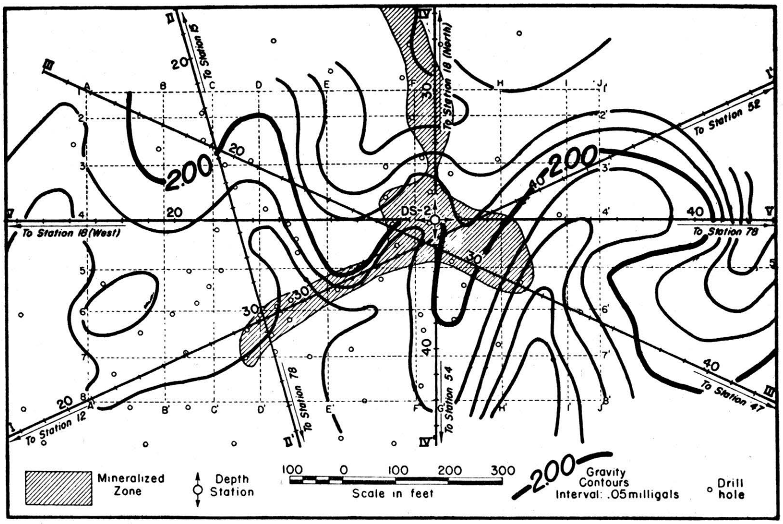

FIG. 42. Map showing gravity contours in the Karcher area.

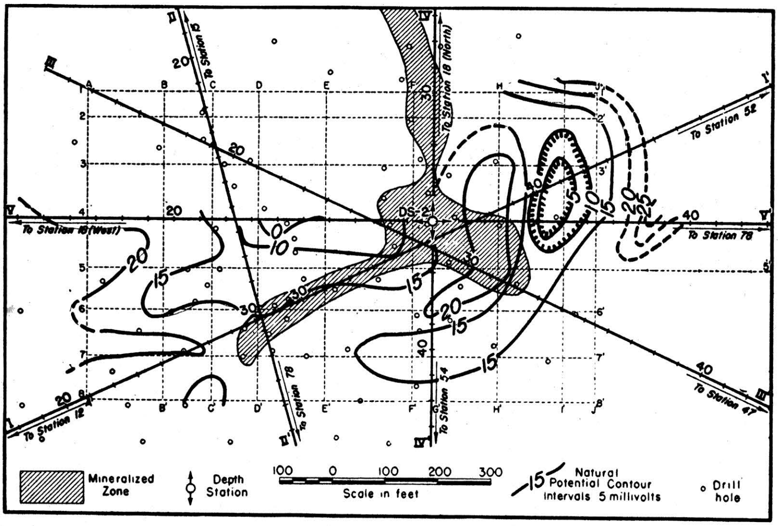

FIG. 43. Map showing natural potential contours in the Karcher area.

Geochemical Survey

Spectrographic analyses of the Karcher soil samples indicate that the following elements show a quantitative variation in the soil to an extent exceeding any possible analytical error; cobalt, manganese, nickel, lead, and vanadium. Of this group, cobalt and manganese show the greatest range of variation, and lead shows the least.

The cobalt and manganese maps (figs. 46A, 46B) indicate a relative concentration of these metals in the soil over a rather broad area, which includes, but is not confined to, the major portion of the mineralized zone. No such concentration pattern is shown by the

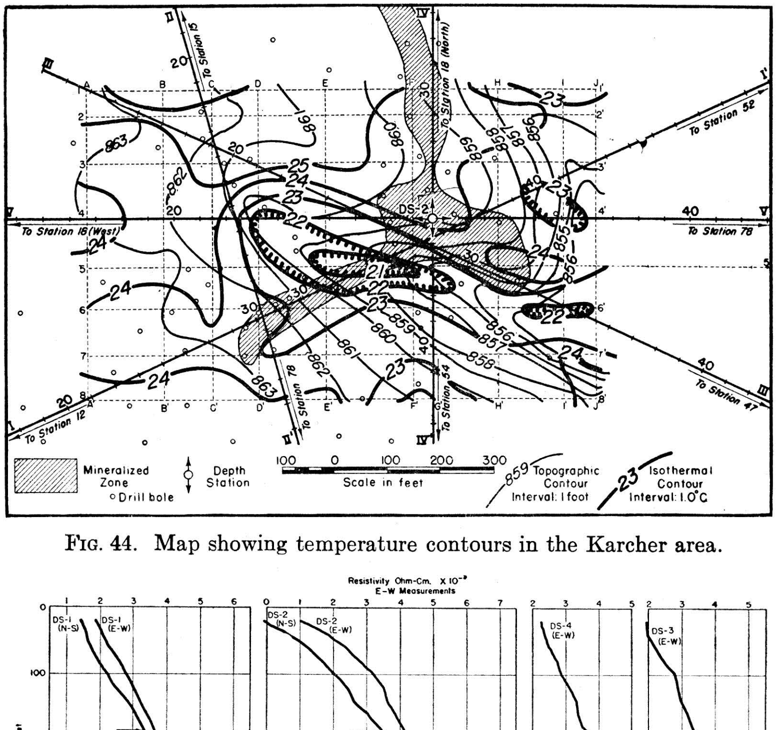

FIG. 44. Map showing temperature contours in the Karcher area.

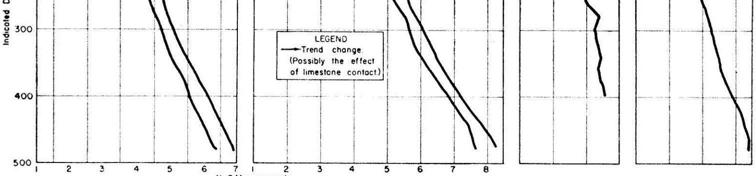

FIG. 45. Resistivity depth profiles in the Karcher area.

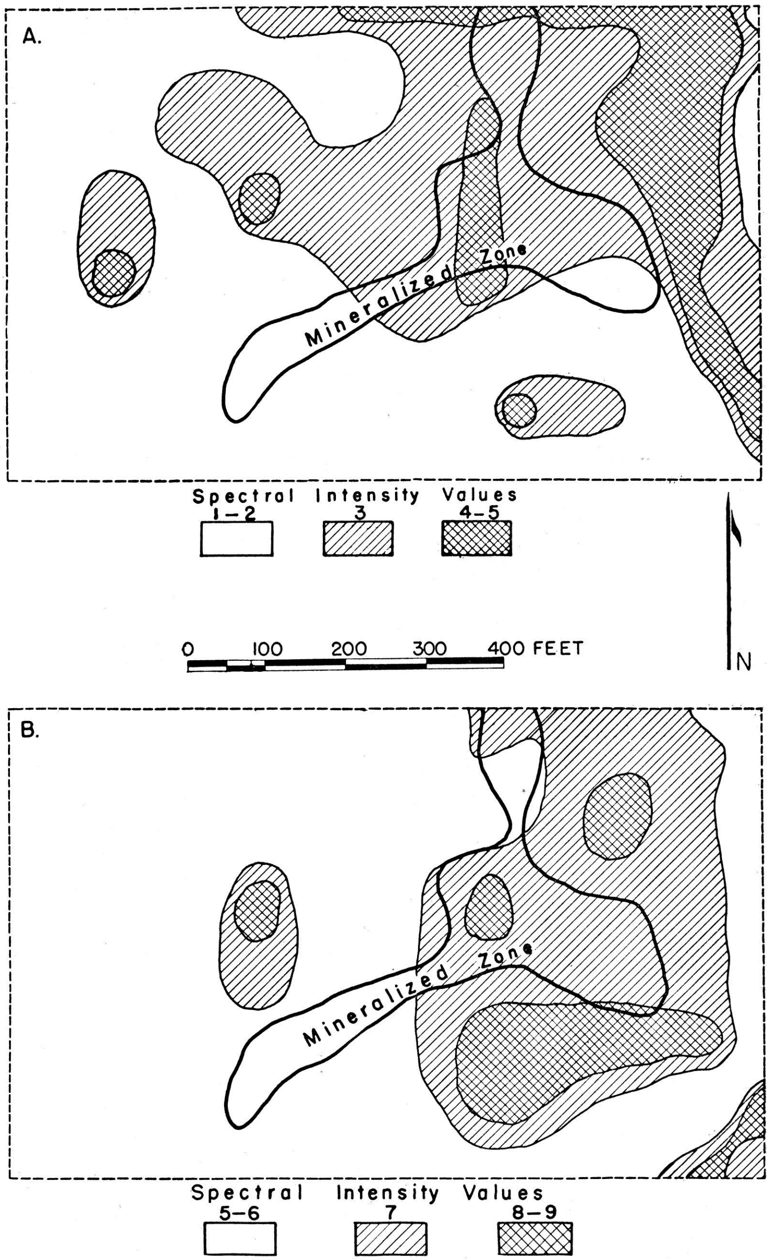

FIG. 46. A. Map showing the areal distribution of cobalt in the soil of the Karcher area; B. Map showing the areal distribution of manganese in the soil of the Karcher area.

lead and nickel maps. The indicated relative concentrations of lead and vanadium are plotted in profile (fig. 39). Concentrations of nickel and cobalt occur along the eastern end of grid line 6. This location is in a slight topographic depression (drainage course) which might have influenced the metallic content of the soil samples taken in this vicinity.

Although some of the indicated increases in metallic content may have been influenced by erosional processes along the drainage courses (*e. g.*, as the above mentioned along the east part of grid line 6 and, possibly, in the northeast corner of the grid layout), no such influence could have accounted for the entire central zone of relatively higher concentrations.

Summary

Table No. 17 gives the ratios of the individual anomalies and of the total range of values to the estimated maximum error in the geophysical values for the Karcher area. Comparison of these figures with those for the Walton area indicates that, in the Karcher area, the range of the geophysical readings is somewhat larger for each method; and, except for gravity and natural potential, the individual anomalies are also larger. As in the case of the Walton area, the resistivity anomalies are the least likely to have been significantly influenced by observational error.

The relief on the limestone surface in the Karcher area is so gentle as to eliminate this feature from consideration as primary cause for

TABLE No. 17.—*Magnitude of geophysical anomalies.—Karcher area*

GEOPHYSICAL METHOD	Ratio of anomaly to maximum error*	Ratio of total range of observations to maximum error
Magnetic	10	15
Gravity	2	12
Natural potential	2	10
Resistivity	12	48
Geothermal	7	15
eochemical (cobalt and manganese)	3	5

* See footnote, p. 117.

anomalies in this area. Possible slight influence has been noted at a few places as mentioned previously.

In the resistivity work, well-defined anomalies were observed over the indicated mineralized zone on those traverses which crossed this zone at or near its widest extent (traverses I-I′, III-III′, IV-IV′, and V-V′). On the two traverses which cross narrower zones of mineralization no indicative anomalies were found (traverses II-II′, VI-VI′). Traverses in barren area (traverses VII-VII′ and extensions of traverse V-V′) show very uniform resistivity trends. On these barren area profiles the maximum departure from mean average trend is of the order of 2 percent; whereas, the aforementioned anomalies over the mineralized zone represent departures of from 8 to 10 percent.

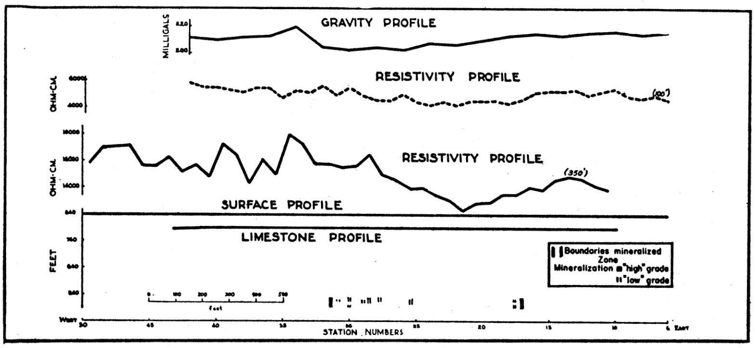

FIG. 47. Profiles along traverse I-I′ in the Swalley area, showing gravity and resistivity anomalies, zone of mineralization, and configuration of the top of the limestone.

From the above, it is indicated that the resistivity anomalies on traverses I-I′, III-III′, IV-IV′, and V-V′ are due either to the mineralized zone or to some directly related structural condition which influences the electrolytic properties of the ground in the vicinity of the mineralization. Fracturing and brecciation of a type which might have controlled and influenced the distribution of mineralization might effectively localize conductive electrolytes, which would cause anomalies in ground resistivity.

The failure to find resistivity anomalies over the narrower mineralized zones possibly may be attributed to the absence of electrically conductive sulphide mineralization in sufficient quantity and concentration to cause detectable variations in ground resistivity, less brecciation in the rock surrounding these smaller zones, or low resolving power of the resistivity methods.

The gravity survey indicated a slight gravity minimum in the vicinity of the mineralized zone. It is believed that the decrease in gravity may be due to brecciation in and around the mineralized zone. However, anomalies of this kind are not always diagnostic of mineralization since other minima of equal or greater intensity occur in barren territory beyond the mineralized zone.

The geochemical survey revealed slight concentrations of cobalt, manganese, and vanadium in the soil in the general vicinity of the mineralized zone. This suggests a possible relationship between metallic constituents in the soil and underlying mineralization. The survey in the Karcher area was too limited to draw definite conclusions from this work alone.

The magnetic, natural potential, and geothermal anomalies observed in the Karcher area appear to be unrelated to structure or mineralized zones.

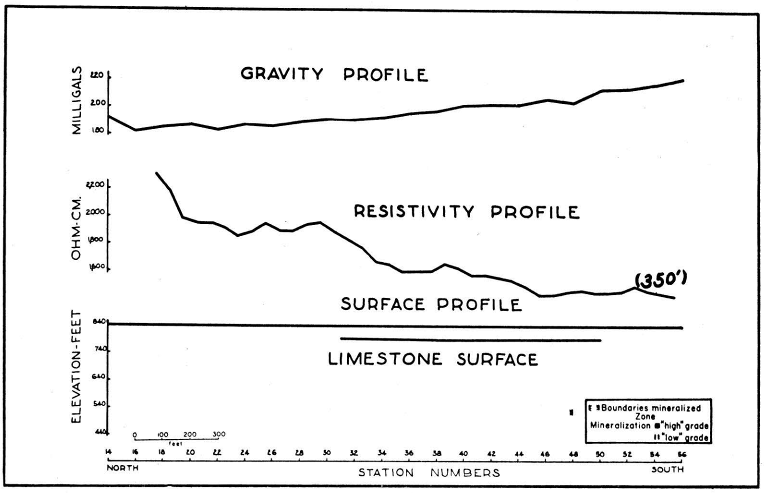

FIG. 48. Profiles along traverse II-II′ in the Swalley area, showing gravity and resistivity anomalies, zone of mineralization, and configuration of the top of the limestone.

SWALLEY AREA

Figure 6 shows the locations of the geophysical traverses and stations in the Swalley area. The following geophysical measurements were made: *gravity,* 41 stations at intervals of 100 feet, along traverses I-I′ and II-II′; *resistivity* longitudinal traverses, at intervals of 50 feet, along traverses I-I′, II-II′, and III-III′; *resistivity* depth measurements, at stations 35 and 50, on traverse II-II′; *geochemical* soil samples, at 68 stations on grid layout.

Geophysical data and results in this area are illustrated in figures 47 to 50.

Gravity Survey

Gravity measurements in the Swalley area were taken only along two traverses; hence, the data are insufficient for contour representation. The gravity values on traverse II-II′ increase quite uniformly to the southward, showing only slight departure from the estimated regional gradient. On traverse I-I′ there is a small gravity minimum between stations 22 to 32 over the west edge of the mineralized zone. The assay values are somewhat higher here than to the east. Since an unknown quantity of material has been removed from the subsurface here by mining operations, it is not possible to draw conclusions as to the significance of this gravity anomaly.

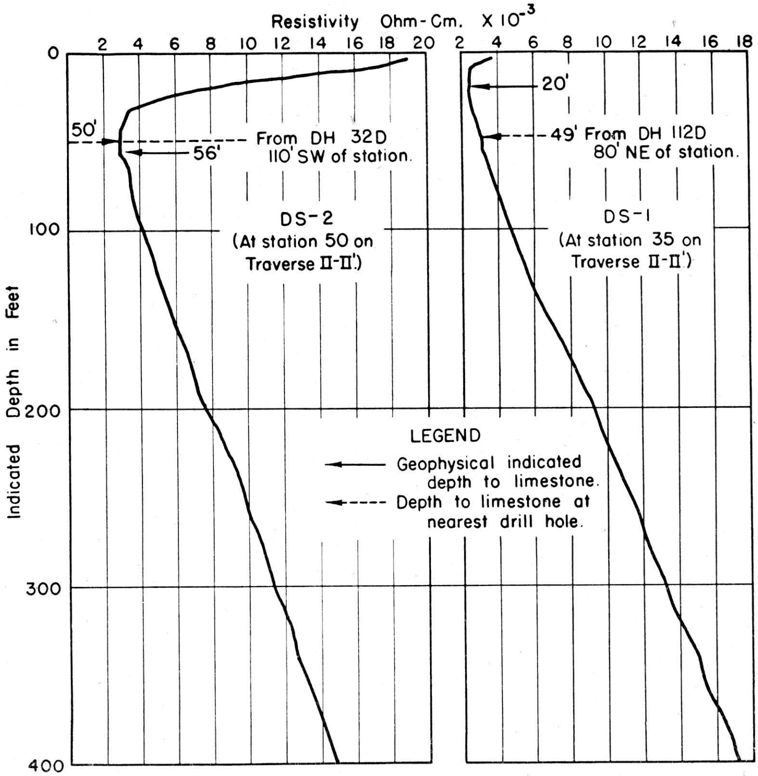

FIG. 49. Resistivity depth profiles in the Swalley area.

Resistivity Survey

All three resistivity profiles (traverses I-I′, II-II′, and III-III′) show a similar pattern of variations, with the apparent resistivity increasing irregularly toward the north and northwest. None of those variations have any apparent relation to the mineralized zone or to the profile of the limestone surface. They are probably due to lateral lithologic or textural variations either in the comparatively shallow soil, shale cover, or in the underlying limestone. It is to be noted that there is no correspondence between the gravity and resistivity gradients in this area, such as has been noted in some of the other areas (cf., Neutral and Mullen areas, figs. 16, 18, 19).

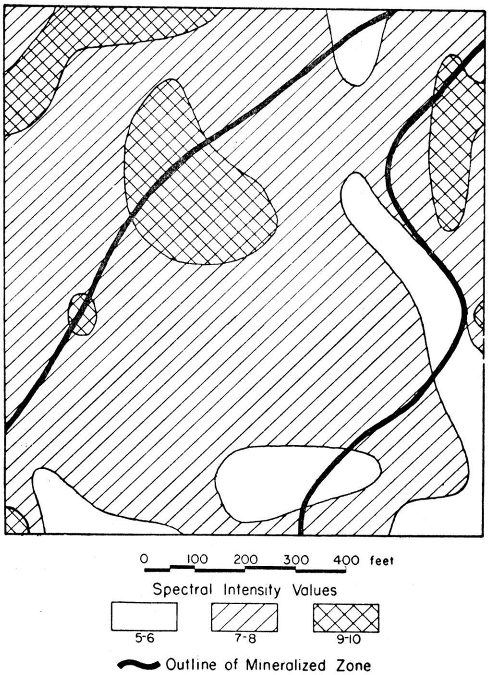

FIG. 50. Map showing the areal distribution of manganese in the soil of the Swalley area.

Resistivity-depth measurements were made at two locations (DS-1, DS-2, fig. 6) to determine whether depth to limestone could be mapped under shallow cover (the shale cover averages 40 to 80 feet in thickness in this area as compared to 175 to 200 feet in the Walton and Karcher areas). Both depth curves show shallow changes in trend indicative of a boundary between a relatively thin conductive layer and an underlying, more resistant formation. In the case of station DS-2 the indicated depth of this change agrees well with the projected depth to the top of the limestone. At station DS-1 the calculated depth is considerably shallower than shown by the projected limestone elevation.

Geochemical Survey

Analyses of the soil samples from the Swalley area indicate that the following elements vary from station to station to an extent exceeding any possible analytical error; cobalt, manganese, titanium, nickel, lead, gallium, and molybdenum. Except for cobalt, manganese, and titanium, however, the variations are small and consist chiefly of single station anomalies. As in the Karcher area, the cobalt and manganese distributions in the Swalley area are very similar. Titanium shows a smaller range of variation than cobalt or manganese. Figure 50, showing the areal distribution of manganese in the soil, is representative of the geochemical results for this area.

Also, as in the Karcher area, weathering and erosion along drainage courses evidently affects the concentration values. A drainage course runs along the west boundary of the grid layout and crosses the northwest corner. Increased concentrations of cobalt and manganese at the southwest and northwest corners of the grid layout appear to be associated with this surface drainage course. Indicated content of titanium, however, is less along the drainage course than in adjacent area.

The pattern of distribution of these elements in the soil of the Swalley area apparently is unrelated to ore mineralization or to configuration of the limestone surface. High and low concentration trends cut across the strike of the mineralized zone. Variations in grade within the general mineralized zone show no relationship to the local variations in metallic content of the soils.

GREENBACK AREA

Figure 7 shows the locations of the geophysical traverses and stations in the Greenback area. The following geophysical studies were conducted: *gravity*, 44 stations at intervals of 100 feet along traverses I-I′, and IV-IV′; *resistivity* longitudinal traverses, at intervals of 50 feet along traverses I-I′, II-II′, III-III′, and IV-IV′; *resistivity* depth measurements, at station DS-1 to DS-4 on travese I-I′, DS-5 on traverse II-II′, DS-6 on traverse III-III′, and DS-7 on traverse IV-IV′; *geothermal*, 42 stations on traverses I-I′ and IV-IV′; *geochemical*, 84 stations on traverses I-I′, II-II′, III-III′, and IV-IV′.

Gravity Survey

Neither of the two gravity traverses show anomalies in the vicinity of the indicated zones of mineralization. On traverse I-I′ slight gravity minima are present at stations 36 to 38 and stations 16 to 20

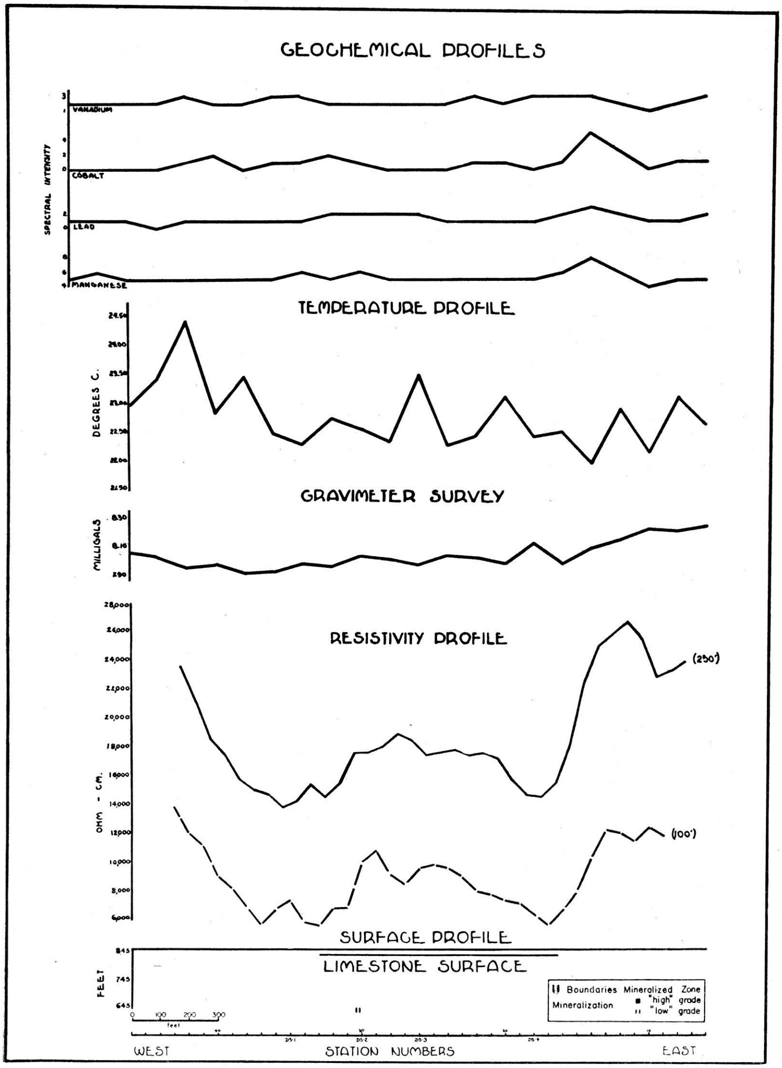

FIG. 51. Profiles along traverse I-I′ in the Greenback area, showing gravity, resistivity, geothermal, and geochemical anomalies, zone of mineralization, and configuration of the top of the limestone.

On traverse IV-IV′ a gravity minima occurs at stations 10 to 12. The gravity gradient is flat over the locations of the mineralized zone, but increasing values are noted at the east end of the traverse.

Resistivity Survey

Large resistivity variations were found along all of the traverses in this area. Particularly strong anomalies are present along traverses I-I′ and III-III′. Comparison of the shallow and deep re-

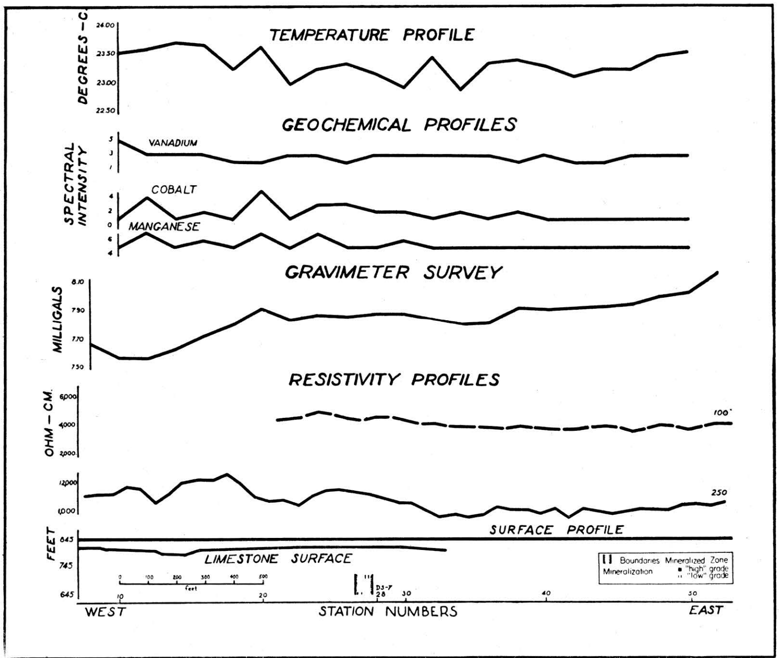

FIG. 52. Profiles along traverse IV-IV′ in the Greenback area, showing gravity, resistivity, geothermal, and geochemical anomalies, zone of mineralization, and configuration of the top of the limestone.

sistivity profiles for traverses I-I′ and IV-IV′ indicates that shallow geologic conditions are responsible for these anomalies.

Available drill hole data are insufficient to allow detailed correlation of all of the observed anomalies. Depth measurements along traverse I-I′ were made, therefore, for two purposes: (1) to secure information to help explain the traverse resistivity anomalies, and (2) to determine whether the top of the limestone could be mapped in this manner. This work indicated slightly greater depths to the top of the limestone at the locations where the resistivity profile shows resistivity lows (DS-1, DS-4, corresponding to stations 35 and 18, respectively, in traverse I-I′). It has been noted that gravity minima are found at these same locations on this traverse. It would appear from the depth measurements that the resistivity variations are due to variations in depth to the limestone. The size of the variations and the presence of gravity minima, however, would seem to require a more pronounced physical change in the subsurface than slight changes in elevation of the limestone contact. It is probable, therefore, that brecciation and fracturing with, perhaps, cavernous conditions and attendant slumpage in the limestone are contributary causes for the observed resistivity and gravity anomalies. A possible "sink hole" is indicated near the west end of traverse IV-IV′ near the location of a gravity minima (stations 10-12, traverse IV-IV′, as previously described).

None of the anomalies appear to be due to the effect of the mineralized zone or its structural environment.

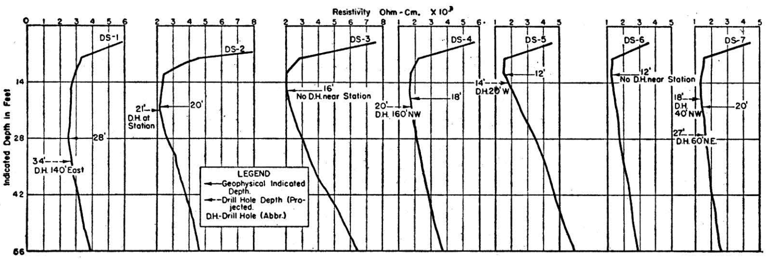

FIG. 53. Resistivity depth profiles in the Greenback area.

Geothermal Survey

The geothermal profiles (traverses I-I′, IV-IV′) exhibit general trends that are similar to the resistivity profiles, indicating the influence of the same structural conditions (compare with the Neutral area, fig. 16). The temperature values are too erratic, however, to be of any diagnostic value in this area.

Geochemical Survey

Analyses of the Greenback soil samples indicate that the following elements vary to an extent exceeding any possible analytical error: cobalt, manganese, vanadium, and lead. The distribution of these metals along traverses I-I′ and IV-IV′ is shown in the accompanying profiles (figs. 51, 52).

The distribution seems to be quite random and no relationship to mineralized zones or structure is apparent. On some of the traverses the positions of the mineralized zones coincide with the location of relatively high concentrations of the above elements. At other locations lower concentrations occur over the indicated mineralized zones. The variations in the barren parts of the area are as pronounced as those above the mineralized zones.

MCBEE-MARTIN AREA

Figure 8 gives the locations of the geophysical traverses and stations in the McBee-Martin area. Geophysical measurements were made as follows: *gravity,* 34 stations at intervals of 100 feet along traverses I-I′ and II-II′; *resistivity* longitudinal traverses, at intervals of 50 feet along traverses I-I′ and II-II′; *resistivity* depth measurements, at station DS-1 (at station 25, on traverse I-I′); *geothermal,* 17 stations, at intervals of 100 feet along traverse I-I′.

The results of these measurements are given in figures 54 and 55.

Results of Gravity, Resistivity, and Temperature Measurements

Analysis of the geophysical data for this area has disclosed no relationships between the geophysical anomalies and the mineralized zone. The variations in geophysical values appear to be the result of near-surface structural and lithologic changes that are unrelated to the ore mineralization.

Logs for drill holes in the area indicate not only variable depths (20 to 40 feet) to the limestone, but variations in the character of the material overlying the limestone. The presence of Tertiary gravel is indicated by some of the logs. According to the logs, shale is present at some places. At other places soil and clay lie directly upon the limestone. Lateral lithologic variations of this kind plus cavernous or brecciated conditions in the limestone are believed to be responsible for the anomalies observed in this area, but it is not possible to correlate the anomalies in detail due to inadequate geologic information.

On traverse I-I′ a resistivity high occurs over the mineralized zone on both shallow and deep curves, indicating the probable influence of lithologic variation rather than the effect of mineralization.

A temperature high also occurs at this location; but it is probably due to the same structural condition causing the resistivity anomaly rather than to any effect of the mineralized zone, since an even stronger temperature anomaly occurs at station 12 in barren territory.

The gravity profile shows a number of irregular variations which might have been influenced in part by the surface caves in this vicinity. No correlation with the mineralized zone is apparent.

The gravity and resistivity profiles on traverse II-II′ are very similar in appearance. No correlation with the mineralized zone is indicated. The lows on the east end of the traverse appear to be related to the increased depth to the limestone at this location as shown by the structure profile. A similar structural condition is probably present on the west end of the traverse, as indicated by the resistivity and gravity values.

Resistivity depth measurements gave results similar to those obtained in the Greenback area, and indicate that, at shallow depths, the top of the limestone can be mapped by these measurements.

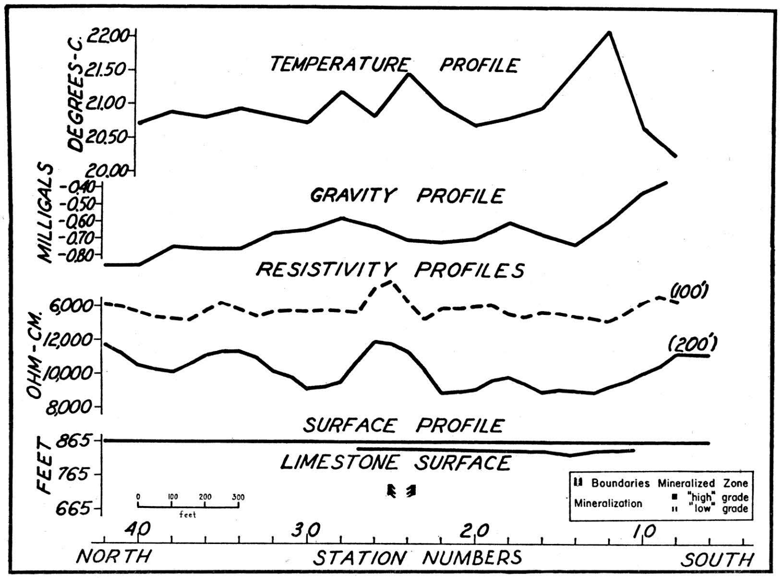

FIG. 54. Profiles along traverse I-I′ in the McBee-Martin area, showing gravity, resistivity, and temperature anomalies, zone of mineralization, and configuration of the top of the limestone.

Summary and Coördination of Geophysical Results

Factors Influencing Interpretations

In the Tri-State geophysical investigations, the problem of interpretation was two-fold: (1) to indicate anomalies due to structural conditions, whether related or unrelated to the mineralized zones, and (2) to indicate anomalies due either directly to ore mineralization or to structural conditions that are related to the occurrence of ore mineralization. The regional survey and the studies in the Neutral, Mullen, and Jarrett areas were concerned, primarily, with the structural problem; whereas, the work in the Walton, Karcher, Swalley, Greenback, and McBee-Martin areas was concerned, for the most part, with the problem of mineralization.

In making interpretations, it was necessary to consider a great many geological factors that might influence the geophysical values. Chief among these are the following: depth and configuration of the pre-Cambrian basement, depth to limestone, relief of the limestone surface, porosity of the limestone (*i. e.*, whether massive or brecciated), type of formation overlying limestone (*i. e.*, whether soil, Tertiary gravel and clay, or shale), topography and surface drainage courses, ground water conditions, form of mineralized zones (*i. e.*, whether "run" or "sheet ground"), type of mineralization (*i. e.*, ratio of galena to sphalerite), size of mineralized zone, and grade or ore mineralization (see pp. 17-22, 23-32, 77-82).

The amount and detail of available geological information varies among the different areas. In the Neutral area, drill hole information is not available in the immediate vicinity of the geophysical studies. In other areas, the available information is sufficient to permit the plotting of contours on the limestone surface and the drawing of generalized outlines of the mineralized zones.

The geophysical interpretations represent deductions which consider: (1) information from local drilling and (2) knowledge of general geological conditions in the district.

REGIONAL MAGNETIC AND GRAVITY INVESTIGATIONS

Regional magnetic work (including the work of the Missouri Bureau of Mines) has shown that prominent magnetic anomalies occur over a wide territory, including some of the ore producing districts. These anomalies evidently are influenced by magnetic variations both in the basement rocks and in the overlying sediments, the relative effects of which it is impossible to determine from magnetic work alone.

In this survey only a relatively small area was covered by both magnetic and gravity work. A comparison of the results (approximate coincidence in location of magnetic and gravity highs in the Quapaw-Hockerville area, figs. 9, 10) indicates that, at this particular location, the gravity and magnetic anomalies are the result of structural or lithologic variations in the pre-Cambrian basement.

INVESTIGATIONS IN LOCAL AREAS

Magnetic Survey

In the Walton area a magnetic low occurs over the mineralized zone in the north part of the area. In all of the other areas, the magnetic data show no correlation to structure or to mineralized zones. The cause of the anomaly in the Walton area is not known, but that it is actually related to the mineralized zone seems doubtful, from theoretical considerations. The apparent agreement in location between the magnetic anomaly and the mineralized zone may be a coincidence.

The preponderance of evidence indicates that neither the mineralized zones nor significant local structure in the sediments (*e. g.*, configuration of the surface of the limestone) influences the earth's magnetic field under conditions exemplified by the territory studied in this work. Magnetic anomalies which apparently are due to relatively near surface lateral lithologic variations were noted in both the regional and local surveys.

Gravity Survey

Gravity minima are indicated over depressions in the limestone surface at the following locations: over the Miami trough in the Mullen area, in the Jarrett area, in the McBee-Martin area, in the Greenback area, and probably in the Neutral area. At all of these locations (except the Jarrett area in which no resistivity measurements were made) there is close coincidence and similarity between the gravity and resistivity anomalies. This is especially well shown by the comparison between the resistivity and corrected gravity profiles in the Neutral area (fig. 16). This similarity between the gravity and resistivity anomalies indicates that the local gravity anomalies are due, primarily, to relatively shallow subsurface condition in the sedimentary section. With the possible exception of the Miami trough, however, the amount of relief on the limestone surface appears to be insufficient to cause anomalies of the observed magnitude, since the specific gravity of shale ordinarily is but slightly less than that of limestone. It is indicated, therefore, that brecciation and cavernous conditions associated with slumped zones or depressions in the limestone surface are influential in causing the gravity lows. Either a thickening of the shale cover or increased porosity in the underlying limestone could reduce the average density of local portions of the subsurface sufficiently to cause the observed gravity minima. It seems probable, however, that, in most cases, these conditions are so intimately related in the subsurface that determination of the relative influence of each would be most difficult.

The results of the gravity measurements in the mineralized areas may be summarized, briefly, as follows: In all cases the gravity anomalies in the general vicinity of the mineralized zones are smaller than the anomalies found over known structural variations (*e. g.*, the Miami trough). In a few cases (*e. g.*, traverse X-X′, Walton area, fig. 30), gravity minima coincide with the location of the mineralized zones. In the Walton, Karcher, and Swalley areas, in which the mineralized zones are the most extensive, gravity minima are not confined to the trends of mineralization. Minima of equivalent intensity are found outside of the areas of mineralization. In the Greenback and McBee-Martin areas, gravity anomalies show no relationship to mineralized zones.

Natural Potential Survey

In the Neutral area higher potential values were found at locations showing resistivity and gravity minima. In the other areas, no apparent correlation was found between the natural potential values and either structure or mineralized zones. The following conditions

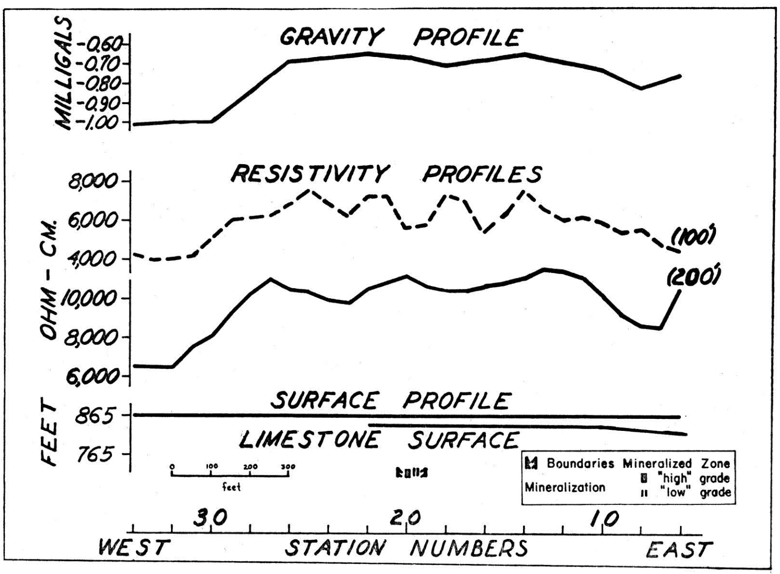

Fig. 55. Profiles along traverse II-II′ in the McBee-Martin area, showing gravity and resistivity anomalies, zone of mineralization, and configuration of the top of the limestone.

probably are mainly responsible for the natural potential anomalies: (1) oxidizing iron disulphides unrelated to ore mineralization, (2) non-uniform distribution of electrolytes in the subsurface, and (3) irregular distribution of moisture at the surface (perhaps influenced by topography).

Resistivity Survey

The resistivity measurements were influenced chiefly by portions of the subsurface extending from the surface to a depth of approximately 400 feet. The measurements, therefore, are influenced primarily by relatively shallow geological conditions; whereas, the gravity and magnetic measurements are without depth control and are influenced by both shallow and the larger, deeper structures. It was helpful, in the interpretations, to utilize the resistivity anomalies as a guide or comparison, in order to indicate the relative importance of shallow and deeper structural influences in causing other geophysical anomalies.

It is well recognized that any of the resistivity methods and the so-called potential-ratio methods, employing a pair of energizing electrodes and a pair of potential electrodes, are unsuitable for detection of small subsurface bodies. This unsuitability is due chiefly to their poor resolving power caused by the large spreads of the surface electrodes.

Variations in subsurface resistivity were found in all of the areas investigated. In the Mullen area, well-defined resistivity lows are associated with the Miami trough (figs. 18 to 20). The resistivity low in the Neutral area is also attributed to a probable depression in the limestone surface (fig. 16). In the McBee-Martin area, a resistivity low on the east end of traverse II-II′ coincides with a depression in the limestone surface (fig. 55). The occurrence of resistivity lows over depressions in the limestone surface is well established by these examples and by other examples that have been mentioned in the discussions of the separate areas.

Some very pronounced resistivity variations occur in the Greenback area (*e. g.*, traverse I-I′, fig. 51). Geologic control is inadequate for detailed correlations in this area; but, in general, the lower resistivity values appear to be associated with depressions in the limestone surface. In this area, however, the amount of relief on the surface of the limestone appears to be insufficient, alone, to account for the magnitude of the anomalies. Evidence from the gravity survey indicates that brecciation and cavernous conditions are probably present in the limestone. With or without thickening of the overlying shale, the increased porosity due to brecciation or cavernous conditions would result in the lowering of the average resistivity values.

The resistivity depth results indicate that, under favorable conditions, the depth to limestone can be determined by these measurements (figs. 22, 36, 45, 49, 53).

The results of resistivity measurements that were conducted along traverses in the mineralized areas are summarized briefly as follows:

In the *Walton area* (deep run-type mineralization, 300 to 350 feet deep, medium to high grade, relatively high lead:zinc ratio, shale cover 175 to 200 feet deep), six of the eight resistivity traverses that cross the mineralized zone show resistivity lows that agree closely in location with the indicated outlines of the mineralized zone. A resistivity traverse in probably barren area (traverse IV-IV′) shows resistivity lows of approximately the same intensity as those over the mineralized zones (p. 118).

In the *Karcher area* (deep run-type mineralization, 350 to 400 feet deep, medium to high grade, relatively little galena, shale cover 200 to 220 feet deep), all traverses that cross the central, widest (200 to 275 feet) zone of mineralization show well-defined resistivity lows over the mineralized zone. Traverses in barren ground (traverse VII-VII′ and portions of traverses V-V′) show no variation. However, a resistivity low at stations 10 to 12 (south) on traverse IV-IV′ appears to be outside of the mineralized zone. On the traverses that cross the narrower portions of the mineralized zone, no resistivity variations were observed over the mineralized zones (p. 131).

In the *Greenback area* (shallow run-type mineralization, 150 to 200 feet deep, low grade, very little galena, soil-shale cover 15 to 70 feet deep), the resistivity anomalies show no correlation with the ore mineralization. Available drilling information indicates that the mineralized zone is relatively narrow.

In the *McBee-Martin area* (shallow run-type mineralization, 100 to 160 feet deep, medium to high grade, relatively little galena, overburden 20 to 40 feet deep), the resistivity anomalies show no correlation with the ore mineralization. Available drilling information indicates that the mineralized zone is relatively narrow.

Geothermal Survey

In a few cases, temperature minima appear to be related to depressions in the limestone surface (*e. g.*, profile II-II′ in the Mullen area, fig. 19; profile I-I′ in the Greenback area, fig. 51; and the Neutral area profile, fig. 16, all of which show some similarity to the resistivity profiles). Consistent structural correlation has not been found, since, in other cases, the temperature variations do not reflect subsurface structure (*e. g.*, traverse I-I′ in the Mullen area, fig. 18).

No definite correlation between temperature anomalies and mineralized zones was found in any of the areas. Additional work would be necessary in the Walton area to determine whether the slightly higher temperature values in the central part of the area have any relationship to mineralization.

The geothermal data are strongly affected by surface topography and drainage.

Geochemical Survey

Only in the Karcher area is there any evidence of a possible relationship between the mineralized zone and the relative distribution and concentration of metallic elements in the soil (fig. 39). This apparent correlation is very general.

In several of the areas, distribution of the indicated metallic elements appears to be influenced by weathering and erosion along surface drainage courses.

Conclusions

In the geophysical methods which were employed in these investigations, the most prominent anomalies are the result of: (1) relatively shallow structural conditions (*e. g.*, configuration of the limestone surface and brecciation, fracturing, or cavernous conditions in the limestone), (2) near surface lithologic variations (*e. g.*, variations in the shale or other formations overlying the limestone), or (3) topography and surface drainage.

It has been demonstrated in particular, by the Neutral area anomalies, that relatively shallow structural conditions which probably are unrelated to ore mineralization may cause anomalies in any of the various types of geophysical measurements employed in this work.

In this Tri-State region the effects of near-surface variations are especially important in the natural potential, geothermal, and geochemical methods and are present to smaller extents in the magnetic and resistivity data. The natural potential, geothermal, and geochemical methods, therefore, are of doubtful value for either the determination of structure or for direct location of mineralized zones.

In the resistivity measurements the effect of surface drainage is negligible. Near-surface lithologic variations are responsible for resistivity anomalies in many cases (*e. g.*, the Swalley area profiles; the east end of traverse V-V′, in the Karcher area). The effects of these variations ordinarily can be evaluated by employing double-depth traverses (pp. 46, 47).

The magnetic and gravity values, when influenced by near-surface variations, are of small lateral extent and readily apparent on a plot of the traverse readings.

Coincident resistivity and gravity minima related to the configuration of the limestone surface and to the physical character of the upper portion of the limestone (whether of massive fractured, brecciated, or cavernous character) are found in the Neutral, Mullen, Greenback, and McBee-Martin areas. In the Walton and Karcher areas, similar coincident resistivity and gravity minima are found. In the latter areas, since the relief of the limestone surface is very gentle, the minima are probably due to increased porosity in the limestone. These results indicate that both resistivity and gravity work are useful in locating depressions in the limestone surface as well as zones of increased porosity. The problem of determining the relative influence of these two effects at a particular location will be difficult without geologic control of a nature to indicate the probable depth to the limestone. Under favorable conditions resistivity-depth measurements can supply information that will aid in this differentiation. Such measurements are of especial importance in areas of shallow cover, where the influence of equivalent relief on the limestone surface is relatively larger than in areas of deeper cover (cf., resistivity and gravity anomalies in the Walton and Karcher areas with those in the Greenback and McBee-Martin areas).

In a few cases both gravity and resistivity lows occur over the mineralized zones. The resistivity lows are much more frequent and more consistent than the gravity lows. Resistivity anomalies are present only over mineralized zones of considerable width (100 to 300 feet, *e. g.*, Walton and Karcher areas). No effects are discernible over narrower mineralized zones (*e. g.*, Karcher and Greenback areas) even though they are of relatively high grade (*e. g.*, McBee-Martin area). This is due, as previously mentioned, to the low resolving power of all methods employing surface potential measurements.

The following lines of evidence support the belief that these resistivity lows are due to increased porosity of the limestone rather than to the direct conductive effect of sulphides, although the increased porosity may be due to brecciation indirectly related to mineralization: (1) Coincident resistivity and gravity lows occur over areas in which shale thickening and brecciation are known to exist; (2) Coincident resistivity and gravity lows occur over areas which are indicated by drilling to be devoid of ore mineralization; and (3) The resistivity anomaly over the Karcher sphalerite zone is just as pronounced as the anomalies over the Walton mineralized zone which has a relatively high content of galena, although sphalerite is generally a poor conductor and galena a good conductor.

From the gravity work in the mineralized areas, it may be concluded:

(1) The gravity anomalies mapped in this work are not directly related to ore mineralization.

(2) In a few instances, gravity minima appear to be due to the effects of brecciation or cavernous conditions which are directly related to the mineralized zones.

(3) Presence or absence of gravity minima are not conclusive evidence of the presence or absence of mineralized zones.

From the resistivity work in the mineralized areas it may be concluded that:

(1) Resistivity anomalies probably are not directly related to the ore mineralization.

(2) When the mineralized zones are of sufficient size (comparable to those in the Walton and Karcher areas) resistivity lows frequently may be related indirectly to the mineralized zone, as a result of the conductive effect of water-saturated zones of brecciation or fracturing in the limestone. Comparison of the gravity and resistivity data indicates that brecciation, fracturing, or cavernous conditions of insufficient extent to cause gravity anomalies, may, however, be extensive enough to cause detectable changes in resistivity.

(3) Presence or absence of resistivity minima are not conclusive evidence of the presence or absence of mineralized zones. However, brecciation, fracturing, and cavernous conditions related to mineralization are more likely to cause resistivity lows than gravity lows.

REGIONAL GEOLOGICAL IMPLICATIONS OF GEOPHYSICAL DATA

The geophysical data show several features that appear to be of interest from the point of view of regional geology. For example, the resistivity measurements show a sharp resistivity low over the Miami trough. The gravity low is of practically the same areal extent as the resistivity low; and there is no discernible magnetic anomaly.

These relationships indicate that the Miami trough is a relatively shallow structure and is not reflected in the basement.

The regional gravity survey, considered with the regional magnetic survey and with the earlier magnetic work of the Missouri Bureau of Mines, indicates that the configuration of the pre-Cambrian basement is very irregular. Further gravity work, however, will be necessary before it is possible to state whether there are any regional correlations between gravity anomalies and areas of zinc or lead mineralization.

The lack of correlation between geothermal or natural potential anomalies and intensity of lead and zinc mineralization gives added evidence to the small amount of sulphide oxidation in the ore bodies.

The geochemical data appear to indicate either that there was no consistent permeation of the mineralizing solutions into the Cherokee shale above the zones of lead and zinc deposition, or, if such permeation occurred, that there was no consistent sequence of metallic deposition such as would be represented by differential metallic concentrations in the soil above zones of mineralization. The chemical complexity of the ordinary soil attests to the fact that the major differences between metallic concentrations are quantitative rather than qualitative.

EVALUATION OF GEOPHYSICAL PROSPECTING AS AN AID TO ORE EXPLORATION IN THE TRI-STATE DISTRICT

Results obtained in this investigation make it appear undesirable to do further geochemical, geothermal, or natural potential work. Further magnetic work should be only regional in character and then should be used only as guide in the interpretation of regional gravity anomalies, *i. e.*, to determine whether such gravity anomalies are shallow or deep-seated in character.

The indications given by the regional gravity survey that regional gravity maxima are present and are deep-seated (as indicated by coincidence with regional magnetic maxima) make it appear advisable to recommend further regional gravity investigations. The present regional gravity survey covered too small an area, regionally, to permit speculation as to the significance of such regional gravity highs. It might be possible, however, in the Mississippi Valley area, to separate potential zinc-lead producing areas from potentially nonproductive areas, by the presence or absence of deep-seated gravity maxima. Especially could this be done if it should prove possible to demonstrate that such gravity maxima indicate the presence of post-Paleozoic igneous intrusions. Such regional gravity work should be carried on in conjunction with regional magnetic work, so that it might be possible to separate shallow from deep-seated gravity anomalies. It would be advisable to drill several deep holes over that portion of the Quapaw-Hockerville area in which there is an indicated coincidence of gravity and magnetic maxima. Such drilling might reveal the causes of the observed anomalies.

Resistivity and gravity measurements can be used successfully to map structures reflected by variations in the elevation of the limestone surface. It is not possible geophysically to map structures within the limestone.

It has not been found possible, by resistivity measurements, to determine the presence of lead and zinc sulphides. It is possible, however, to use resistivity measurements in mapping certain structural and lithologic features associated at many places with ore mineralization, especially increased porosity of the limestone resulting from fracturing and brecciation. Such measurements, therefore, would permit the selection of ground which might have productive possibilities, although an area could not definitely be classified as necessarily productive because of the presence of resistivity minima. The judicious use of resistivity methods, however, should serve greatly to minimize the amount of exploratory drilling required, by directing drilling to the most favorable prospecting areas. On the average, a saving of but one drill hole would pay for the cost of conducting detailed resistivity work over an area of 10 to 20 acres.

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