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GEOPHYSICAL INVESTIGATIONS
IN THE IONE AREA, AMADOR,
SACRAMENTO, AND CALAVERAS
COUNTIES, CALIFORNIA

1975

CALIFORNIA DIVISION OF MINES AND GEOLOGY

SPECIAL REPORT 117



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IN THE IONE AREA, AMADOR,
SACRAMENTO, AND CALAVERAS
COUNTIES, CALIFORNIA

By

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1975

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ABSTRACT

The lone area in western Amador County and adjoining parts of Sacramento and Calaveras Counties, California, contains important resources of clay, silica sand, and lignite. The California Division of Mines and Geology began a geophysical investigation in the lone area in 1962 to provide basic data for use in studies of the geology and in exploration for mineral commodities in the lone district and other potentially productive areas in the foothill belt of the Sierra Nevada. The investigation consisted primarily of a reconnaissance gravity survey but included tests of the electrical resistivity, magnetic, and seismic refraction methods. Additional data were provided by three core holes drilled to basement rock by the Division of Mines and Geology and the U.S. Bureau of Mines during the course of the study.

The basement rocks in the lone area consist chiefly of steeply dipping greenstone of the Logtown Ridge Formation and slate of the Mariposa Formation, both of Jurassic age. Nearly flat-lying Tertiary sedimentary rocks, including the lone, Valley Springs, and Mehrten Formations, were deposited on a fairly rugged erosion surface developed on the basement rocks. The commercially important clay, sand, and lignite deposits are found in the lone Formation of Eocene age.

The residual gravity map shows a long, narrow, negative anomaly which extends about 20 miles from near Michigan Bar on the north to the Buena Vista Peaks area on the south. This negative anomaly is interpreted as a pre-lone valley system in the basement rocks which was subsequently filled with relatively low-density sediments.

A contour map of the basement surface was constructed using basement elevations from drill hole information and seismic data supplemented by gravity data. The known lignite deposits are shown to be associated with the margins of the buried basin. The results from three core holes drilled on the basis of the geophysical work in relatively unexplored parts of the lone basin have confirmed the presence of thick sequences of Tertiary sedimentary rocks including unexploited deposits of clay, sand, and lignite.

Magnetometer data were found to be effective for locating serpentine in the basement rocks and volcanic units of the Mehrten Formation. Resistivity soundings, however, were only marginally successful in identifying lignite beds.

The new information obtained as a result of this study, particularly the basement contour map and data from the three drill hole logs, should prove to be of value in future exploration for some of the mineral deposits in the lone area.

GEOPHYSICAL INVESTIGATIONS IN THE IONE AREA, AMADOR, SACRAMENTO, AND CALAVERAS COUNTIES, CALIFORNIA

by Rodger H. Chapman and Charles C. Bishop

INTRODUCTION

Important resources of clay, silica sand, and lignite are found in a 200-square-mile area in the vicinity of the town of Ione in western Amador County and adjoining parts of Sacramento and Calaveras Counties, California (figure 1). These non-metallic mineral commodities are produced from the Ione Formation of Eocene age, which crops out in a discontinuous belt about 24 miles long and 8 miles wide in the foothills along the western margin of the Sierra Nevada. Placer gold, laterite, copper, zinc, and building stone have also been produced in the district.

The California Division of Mines and Geology undertook an investigation in the Ione area in 1962 to provide basic geophysical data for use in studies of the geology and to enhance exploration for mineral deposits in the district. The investigation consisted primarily of a reconnaissance gravity survey but included resistivity soundings, ground magnetometer lines, and seismic refraction depth determinations. Magnetic susceptibility and density measurements were made on rock samples in the laboratory. Field work was done during intervals between February 1962 and October 1967. During the course of this investigation, three core holes were

drilled by the U. S. Bureau of Mines in the Ione basin area in a cooperative program with the Division of Mines and Geology.

The authors gratefully acknowledge the help of the following individuals: Frank de Angelis and Joseph de Angelis of the former American Lignite Products Company (now a division of Interpace Corporation), who provided logs from several drill holes and data on lignite deposits in the Ione area; Russell J. Hayden of the FMC Corporation who furnished information on the results of lignite exploration in the district; and William Craven and W.D. Anderson of Interpace Corporation who provided much valuable information about the geology of the area.

Leigh Readdy and Arthur Smith of the California Division of Mines and Geology staff assisted the authors during various phases of the field work. Gordon Chase and Bert Jeffries, also of the Division staff, were responsible for most of the seismic field work and interpretation. C.T. Weiler, at the time with the U.S. Bureau of Mines, supervised the drilling project. Some regional gravity data in the area was provided by Howard Oliver of the U.S. Geological Survey (written communication, 1966).

GEOLOGY

Geologic investigations of the Ione area date back to the late 19th century. A stratigraphic section of rocks at Buena Vista Peak and a general account of the geology of Amador County was given by Mason (1881, p. 125-126). The Buena Vista-Ione area was shown on maps in the Jackson folio (Turner, 1894). Lindgren (1911, p. 21-28, 196-197) delineated the courses of the Tertiary rivers of the western Sierra Nevada and showed that they carried the sediments that now compose the sedimentary rocks of the Ione Formation. Allen (1929, p. 347-348) studied the Ione Formation and restricted it by excluding the upper rhyolite member that had been included by Turner. Stearnes and others (1930) published a regional geologic map, but the part showing the Ione area was largely taken from Turner. Piper and others (1939) named and described the Valley Springs and Mehrten Formations and published a geologic map of the area. The pre-Tertiary rocks were more completely described and defined in a report on manganese by Taliaferro (1943, p. 280-286, 306-307). Bates (1945, p. 1-38) studied the commercial clays of the Ione area. The Buena Vista area was mapped in detail and the Ione

Formation was described in a report by Pask and Turner (1952) on the geology and clay resources of the Ione Formation. The ages of the Tertiary sedimentary rocks have been discussed in studies by Dickerson (1913, p. 257-298, and 1916, p. 387-417), Clark (1921, p. 161-165), Clark and Vokes (1936, p. 851-878), and Dalrymple (1963).

The geologic map accompanying this report (plate 1) is chiefly a compilation of earlier work. It includes a part of an unpublished map of the Sutter Creek 15-minute quadrangle by Taliaferro (1949), which was slightly modified during this investigation. The geologic units were grouped for the purpose of this report as follows: 1) Basement complex, composed of the Calaveras Formation, Amador Group, Mariposa Formation and granitic intrusive rocks (serpentine, in reality a part of the basement complex, is shown on the map as a separate unit); 2) Tertiary sedimentary rocks, composed of auriferous gravels, pre-Ione sedimentary rocks, the Ione Formation, the Valley Springs Formation, and the Mehrten Formation; and 3) Quaternary deposits.

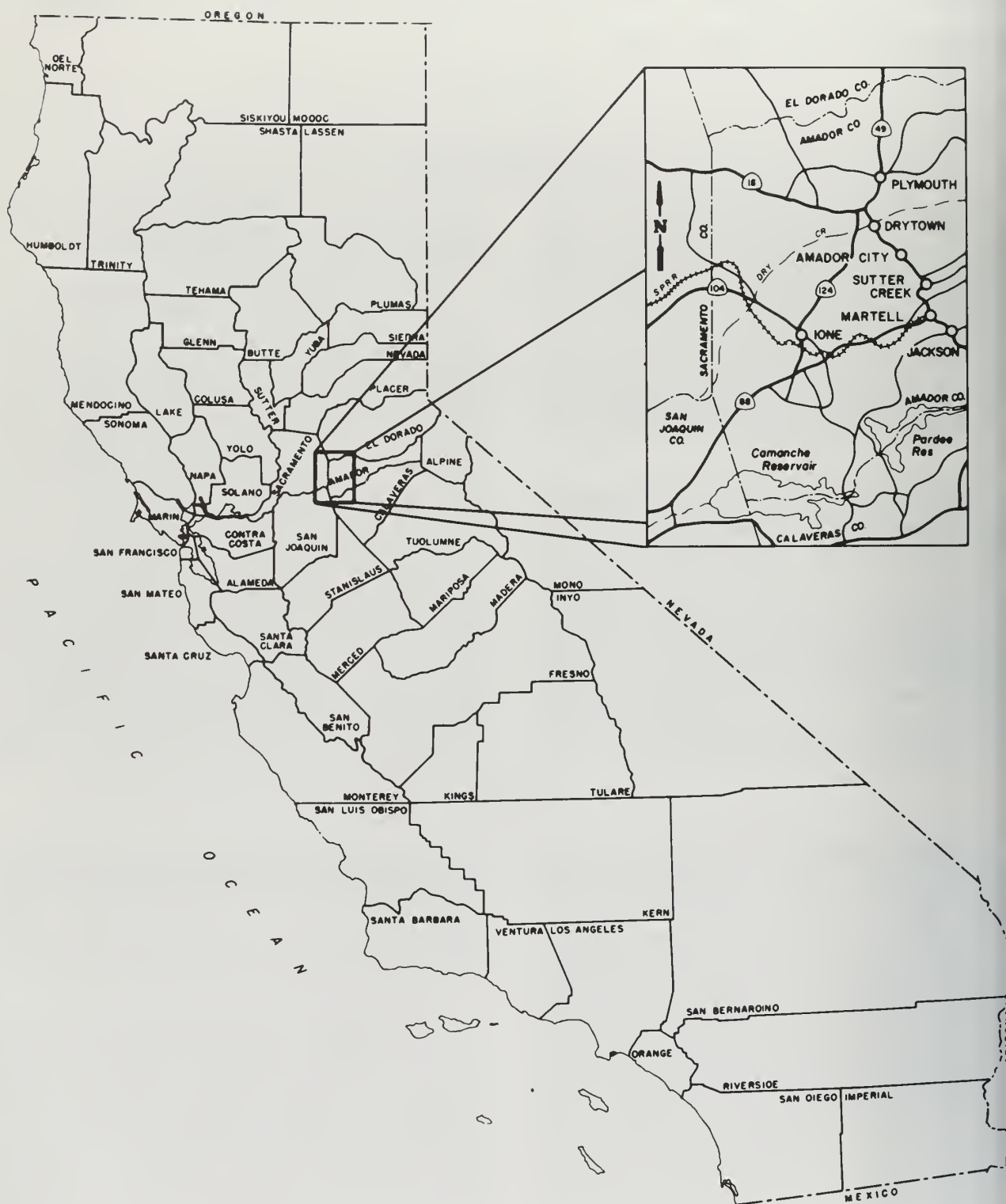


Figure 1. Map showing location of the lone area.

The basic rock units in the Ione area may be further grouped into two major divisions: the basement complex (unit 1) and the overlying sedimentary rocks (units 2 and 3). The basement complex is composed of highly folded, metamorphosed volcanic and sedimentary rocks and related intrusive rocks of pre-Cenozoic age. The later sedimentary rocks overlie the basement complex with marked angular unconformity. These rocks are nearly flat-lying but show a slight southwestward dip, probably the result of tilting of the Sierra Nevada during Tertiary time.

BASEMENT COMPLEX

The basement complex consists of metamorphic rocks of the Calaveras Formation, Amador Group, Mariposa Formation, intrusions of plutonic rocks, and serpentinite. The Calaveras Formation is the oldest rock unit in the area and includes all known pre-Mesozoic rocks. It consists chiefly of recrystallized limestone, metachert, and quartzite. The Calaveras Formation crops out on the eastern and northeastern edges of the area covered by this report, where these rocks lie unconformably below rocks of the Amador Group.

Taliaferro (1943, p. 282-284) divided the Amador Group into two formations, the Cosumnes and the Logtown Ridge. In most of the area covered by this report, the Amador Group consists almost entirely of greenstone (metamorphosed andesitic and basaltic lavas) and amphibole schist of the Logtown Ridge Formation. A metamorphosed greenish sandstone, which may be part of the Cosumnes Formation, was encountered in the bottom of drill hole 1967-1 in the NE 1/4 Section 30, T. 1 N., R. 9 E. (see plate 1 and figure 7). Rocks of the Amador Group generally have a moderate-to-steep dip and crop out in long northwest-trending belts separated by bands of slate of the Mariposa Formation. The prominent ridge north of Jackson Valley and west of Ione is composed of greenstone of the Logtown Ridge Formation. The Amador Group is believed to be late Middle and early Late Jurassic (Taliaferro, 1943, p. 284). In this area, it is in sharp conformable contact with the overlying Mariposa Formation.

The Mariposa Formation, assigned by Taliaferro (1942, p. 77-81) to a Late Jurassic age, is composed of black slate with a few lenses of metamorphosed sandstone and conglomerate. It is generally less resistant to erosion than the Logtown Ridge Formation and commonly underlies gentle alleys between ridges of the more resistant greenstone. In a fairly extensive area north of Ione and directly south of Irish Hill, the slate of the Mariposa Formation has been altered, possibly hydrothermally, to a sericitic clay. In this general area, clay is mined from both the Ione and Mariposa Formations for ceramic uses.

Plutonic igneous rocks that range in composition from gabbro to granodiorite intruded the

other rocks of the basement complex. The igneous rocks appear to be associated with the Sierra Nevada batholith and were probably intruded in Late Jurassic or Early Cretaceous time. Serpentinite is a common intrusive rock of the foothill belt; in this area, it occurs in a nearly continuous narrow northwest-trending belt extending southward from the vicinity of Willow Springs School to the Pardee Reservoir.

TERTIARY SEDIMENTARY ROCK SEQUENCE

Unconformably overlying the basement rocks is a series of gently dipping sedimentary rocks which has been divided into unnamed pre-Ione beds and the Ione, Valley Springs, and Mehrten Formations.

The pre-Ione beds are described by Pask and Turner (1952, p. 15-16). They consist of beds of sandy clay, sandy silt, and clay, commonly green. Their mineral composition indicates that the source rocks sustained less severe weathering or more rapid erosion than occurred during Ione time. These beds do not crop out but have been encountered in many drill holes in the Buena Vista area, where the maximum thickness penetrated was 131 feet. Pask and Turner (1952, p. 16) considered the pre-Ione beds tentatively to be Eocene. Drill holes 1967-1 and 1967-3 (see figure 7) encountered strata of gray sandstone and greenish clay below the Ione Formation that may correspond to pre-Ione beds. Pre-Ione beds were not recognized in drill hole 1967-2, southwest of Buena Vista Peaks.

The Ione Formation was originally named by Lindgren (1894, p. 3). Turner (1894) described the type section near the towns of Ione and Buena Vista. The formation was deposited on an irregular, deeply weathered erosion surface developed on the older rocks. It consists of alternating lenticular beds of sandstone and claystone with lenses of brown carbonaceous claystone and lignite. The beds are commonly white but locally may be colored red, yellow, or purple by mineral staining.

Pask and Turner (1952, p. 16) divided the Ione Formation into upper and lower members in the Buena Vista region: the lower member contains most of the commercial clay in the area and is characterized by the rarity of chlorite, biotite, and certain clay minerals; the upper member is predominantly sandy. The writers were unable to recognize this subdivision in drill hole 1967-2, southwest of Buena Vista Peaks, where practically the entire section is sandy. Dickerson (1916, p. 397) reported marine Eocene fossils from a quarry in Ione sandstone 3 miles southeast of Buena Vista. The presence of these fossils suggests occasional invasions of the sea into this predominantly continental environment of deposition. The sandstone beds are commonly cross-bedded and usually occur in relatively narrow channels, which indicates that deposition occurred in stream beds or river channels (Allen, 1929, p. 357-358). The silts and clays were deposited in quiet water, probably in lakes or



Photo 1a. Greenstone, of the Logtown Ridge Formation, exposed in quarry about 3 miles southwest of Lone.



Photo 1b. Agglomeratic greenstone of the Logtown Ridge Formation which was quarried for use as riprap on Camanche Dam.



Photo 2. Close-up view of slate of the Mariposa Formation in a roadcut showing slaty cleavage dipping to the northeast at about 70 degrees. The roadcut is on U. S. Highway 88, about 2 miles southwest of Lone.

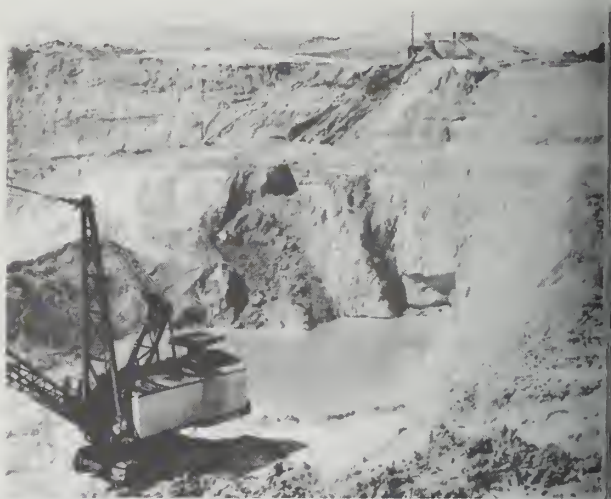


Photo 3a. Interpace Corporation sandpit in the Lone Formation about 1 mile southwest of Lone (view west).



Photo 3b. Interpace Corporation sandpit in the Lone Formation about 1 mile southwest of Lone (view southwest). Note the large-scale cross bedding in the fluvial deposits exposed on the pit walls.



Photo 4. Tuffaceous sandstone of the Valley Springs Formation exposed in a roadcut about 6 miles northwest of Ione.



Photo 6. Andesite cobble conglomerate of the Mehrten Formation exposed in a roadcut about 2 miles southwest of Buena Vista.



Photo 5. Buena Vista Buttes, a prominent landmark in the Ione area, as seen from the southwest. The Buttes consist of relatively resistant sandstones and tuffs of the Valley Springs Formation.



Photo 7. Interpace Corporation Indian Hill clay plant, located about 3 1/2 miles northwest of Ione.



Photo 8. View of an Interpace Corporation sand plant, about 1 mile southwest of Ione, showing the tailings disposal pond in the foreground. Photo by William B. Clark.

lagoons. The lignite was derived from altered vegetation that grew near the margins or within these bodies of water.

The thickness of the Lone Formation varies considerably throughout the area. Piper and others (1939, p. 80) suggest a maximum thickness of about 450 feet. In drill hole 1967-2, southwest of Buena Vista Peaks, however, the total thickness was found to be 630 feet (figure 7).

The Valley Springs Formation is composed of conglomerate, sandstone, tuff, and claystone derived principally from rhyolitic volcanic material (Piper and others, 1939, p. 71-80). The best exposures of this formation are found on Buena Vista Peaks, where it is 440 feet thick. The thickness varies considerably throughout the area; for example, in drill hole 1967-2, only 50 feet were encountered (figure 7b). Rocks from this formation have been dated by Dalrymple (1964, p. 6) as middle Miocene on the basis of potassium-argon dates of 19.9 to 22.8 million years.

The Mehrten Formation unconformably overlies the Valley Springs. It is composed principally of sandstone, siltstone, and andesite cobble conglomerate. These beds were described in detail by Piper and others (1939, p. 61-71). The thickness of the Mehrten Formation ranges from a thin band to about 200 feet in the area of this investigation. At the type section north of the Mokelumne River, the formation is 183 1/2 feet thick (Piper and others, 1939, p. 62). Dalrymple (1963, p. 388, 1964, p. 10) concluded that the Mehrten Formation is most likely middle and late Miocene to late Pliocene, based on potassium-argon age dates obtained from latite flows found in a section from the Sierra Nevada.

QUATERNARY DEPOSITS

In the Buena Vista area, terrace deposits of coarse-grained conglomerate were reported by Pask and Turner (1952, p. 21-22) to be as much as 150 feet above the present level of Jackson Creek. These beds contain pebbles and cobbles of white quartz and andesite and metamorphic rocks of the type found in the Calaveras Formation in a matrix of greenish-brown to red-brown sandy clay.

Alluvium is found along the present stream channels and their tributaries principally in Jackson Valley, Lone Valley, and the area north and west of Carbondale. The alluvium is generally buff to brown, silty, clayey sand, and sandy conglomerate. Drill holes in Jackson Valley have encountered 25 to 50 feet of this material (Pask and Turner, 1952, p. 22).

STRUCTURE AND GEOLOGIC HISTORY

The metasedimentary and metavolcanic rocks of the basement complex are exposed in long northwest to locally northward-trending isoclinal folds

that dip steeply northeastward. Two ages of metamorphism are indicated, one affecting the Paleozoic rocks and another involving both Paleozoic and Mesozoic rocks. The latter was associated with folding which began in the Late Jurassic and continued into the Cretaceous (Taliaferro, 1943, p. 285-286).

The area was reduced by erosion during Late Cretaceous and early Tertiary time to a surface of moderate relief. Differential erosion of the beds of the basement complex prior to the deposition of the Tertiary rocks appears to have resulted in the formation of a trellis-type drainage pattern. Present differences in elevation of the erosion surface at the top of the basement complex are in excess of 400 feet in the Buena Vista area.

The lower Tertiary sediments were deposited on the eroded surface of the basement complex. These Tertiary beds are still essentially flat lying, showing only a slight dip to the south and west. No folding of these rocks can be seen; the discordance between the Lone, Valley Springs, Mehrten, and younger deposits is the result of renewed uplifts of the Sierra Nevada. Downbowing of parts of the Lone Formation in the deep parts of the basin of deposition was probably caused by compaction of the sediments, particularly of the clay and the plant material that formed lignite.

ECONOMIC GEOLOGY

The principal mineral deposits of the Lone area are shown on plate 1. Of all the mineral commodities produced, clay, silica sand, and lignite have the greatest economic significance.

The Lone area has yielded about a third of the fire clay produced in California since the mining of this commodity began about 1860 (Cleveland, 1952, p. 136). More than 60 clay pits are distributed in the area between Carbondale and Buena Vista. Most of the fire clay is used in heavy clay products, but a significant amount is used in refractory products.

The U.S. Bureau of Mines conducted an investigation in the Lone-Carbondale area during World War II to determine the suitability of the Lone clays for the production of alumina (Johnson and Ricker, 1948, p. 1). Seventy holes aggregating 8,800 feet were drilled in areas about 2 miles northwest of Lone and near Carbondale. Analysis of a composite sample of the clay showed the recoverable alumina (Al_2O_3) to be 23.6 percent and the iron oxide (Fe_2O_3) content to be 2.8 percent.

Because the clays were deposited in local topographic depressions, the clay deposits are discontinuous. They commonly consist of clay-sand mixtures with a sand content that ranges from a few percent to 60 percent. The deposits range in thickness from a few feet to 30 feet. The clays of the Lone Formation are kaolinitic whereas the residual clay of the Mariposa Formation south of Irish Hill



Photo 9. A lignite bed overlain by clay in the lone Formation. This exposure is in a pit about 1 1/2 miles southeast of Buena Vista.

Photo 10. The Interpace Corporation lignite plant located about 1 mile south of Buena Vista. This view is looking toward Buena Vista Buttes (compare with Photo 5). Since the photo was taken in 1952, the waste pile in the foreground has increased in size and now tends to obscure the view of the buttes. Photo by William B. Clark, 1952.



Photo 11. The Interpace Corporation laterite pit located about 4 miles northwest of Ione. The laterite is overlain by light-colored clay and sand of the lone Formation exposed in the cut on the hill in the background.



Photo 12. Close-up of the laterite exposed in the shown in photo 11. The pencil in left middleground dicates scale.



Photo 13. The Newton copper mine (inactive), located about 3 miles southeast of Lone and south of U. S. Highway 88.

sericitic. Open pit methods are now used to mine the clays although in the past selective underground mining was used for some of the highly refractory clays.

Silica sand, a basic raw material for the glass industry, is also mined from the Ione Formation in the Ione area. The deposits being mined are generally mixtures of clay, quartz, and feldspar and a small proportion of heavy minerals. Sand grains are commonly coated with iron oxide. Some deposits are mined for both the clay and the sand content. The heavy minerals are usually removed in processing the sand.

The chief use of the silica sand produced in the Ione area is in the making of glass containers. However, because a mill product can meet the specifications for flint glass, the silica sand could also be used for the manufacture of plate glass (Gay, 1957, p. 554).

Lignite occurs in the Ione Formation in nearly out-lying lens-shaped bodies as much as 24 feet thick interbedded with the claystone and sandstone. The lignite may be relatively pure, or it may be intermixed with clay. At the Interpace mines near Ione, the lignite is mined by open pit methods, but most of the older lignite mines were underground operations. The locations of the known important mines are shown on plate 1.

Lignite has been mined in the Ione area since early in the 1860s (Goodyear, 1877, p. 79). According to Carlson and Clark (1954, p. 160), the total recorded production in the district before 1903 was about 247,000 tons, valued at \$358,000. Most of this lignite was used locally for fuel. Between 1903 and 1947, there was only sporadic production of lignite because of the competition from petroleum products.

After it was found that the lignite contains a high proportion of wax suitable for industrial uses,

lignite mining was resumed on a continuous basis in 1948 by the American Lignite Products Company at Ione. The Ione lignites are the only ones in the United States being utilized for the commercial production of montan wax. Details on the method of extraction of this wax are given by Jennings (1957, p. 158-159).

Gold, laterite, copper, zinc, and building stone are other mineral products from the Ione area. Placer gold was discovered in the early 1850s (Mason, 1881, p. 265). Mining of the alluvial gold deposits in the area was most active between 1855 and 1885.

Laterite, red or buff in color and high in aluminum and iron oxides, is exposed in the Jones Butte area northwest of Ione and on the greenstone ridge north and south of Jackson Creek. Small quantities of laterite mined near Ione have been utilized in making cement.

Several copper-zinc deposits have been found in the basement rocks in the Ione area. In particular, the Newton mine in Section 28, T. 6 N., R. 10 E., M.D.B.M. about 3 miles southeast of Ione, and the Penn mine in Sections 3 and 4, T. 4 N., R. 10 E., and Section 33, T. 5 N., R. 10 E., were important producers of copper and zinc ores. None of the mines is active at the present time. The "ore bodies" are replacement deposits consisting of pyrite, chalcopyrite, sphalerite, and other sulfides and usually contain recoverable amounts of gold and silver.

Sandstone from the upper part of the Ione Formation and red-and-white rhyolite from the Valley Springs Formation in the Buena Vista Peak area have been quarried for local use as building stone. Greenstone from the hill northwest of Buena Vista was quarried for use as riprap in the construction of Camanche Dam on the Mokelumne River.

GEOPHYSICAL SURVEY

FIELD METHODS AND REDUCTION OF DATA

Approximately 270 irregularly distributed gravity stations were occupied in the Ione area at bench marks, surveyed elevation points, and photogrammetric points from the U.S. Geological Survey 7 1/2-minute preliminary topographic maps. Some elevations were obtained by means of a level and a barometer. With the exception of the altimeter points and those obtained photogrammetrically, most of the station elevations are probably determined to an accuracy of about 1 foot. Some of the altimeter and photogrammetric points may be as much as 5 feet in error, but checks indicate that this large an error is unusual. The average station density is about 1 1/2 stations per square mile, with the greatest con-

centration of stations being in the Ione and Jackson Valley areas where the greatest number of elevation points is available.

Worden gravity meter No. 558 with a sensitivity of about 0.01 milligal per vernier unit was used for the survey. Gravity readings at all stations were tied to bases at U.S. Coast and Geodetic Survey (now National Ocean Survey) bench mark L-795 at Ione and U.S. Geological Survey bench mark 3 M at Buena Vista. Bench mark L-795 is one of the gravity bases in the California Division of Mines and Geology statewide network (Chapman, 1966, p. 30).

The values of observed gravity were corrected for drift, latitude, and elevation. To minimize the ef-

fects of topographic features on the gravity anomaly values, the Bouguer and elevation corrections were made to a local datum level of 400 feet. This is approximately the highest elevation reached by the basement rocks in the immediate lone basin area. All stations below the datum were raised to this level using a density of 1.9 g/cm^3 , the value adopted for the Tertiary sedimentary rocks. All stations above 400 feet were reduced to this level using a density of 1.9 g/cm^3 for those stations on Tertiary rocks and 2.9 g/cm^3 (density adopted for greenstone) for those stations on basement rocks. Finally, all stations were reduced to sea level using a density of 2.9 g/cm^3 .

Terrain corrections for most stations were found to be less than 0.10 milligal through Hammer Zone J (Hammer, 1939, p. 184). Corrections which exceeded 0.10 milligal were made for a total of 17 stations located mostly in the vicinity of the higher elevations around Buena Vista Peaks.

Resistivity soundings were made using direct-current equipment and porous pots for potential electrodes. A Wenner electrode configuration (Dobrin, 1960, p. 349) was used, and the depth of current penetration was controlled by varying the electrode spacing. The direct current was reversed and the readings averaged to eliminate the effects of natural currents.

Magnetic readings were taken with a Jalander flux-gate magnetometer. Temperature and diurnal effects were removed by repeated readings at a base station.

Seismic refraction data were obtained with Mid-western portable seismic refraction equipment which recorded the output of 12 geophones on photographic paper. The geophone spacing ranged from 50 to 100 feet, and energy was supplied by small dynamite charges buried at depths of 3 to 6 feet.

PHYSICAL PROPERTIES

Density and magnetic susceptibility measurements were made on a few samples of the most common rock types in the lone area and are listed in table 1.

Samples 1 through 6 are greenstone from the Amador Group and have a range of density values between 2.80 and 2.97 g/cm^3 . Sample 7, with a density of 2.67 g/cm^3 , is from the granitic intrusive rocks of the basement complex. The eight remaining samples of the basement complex are from the Mariposa Formation and fall between 1.97 g/cm^3 for a sample altered to clay and 2.66 g/cm^3 for fairly fresh micaceous schist. The samples of dry lone sandstone and clay range between 1.83 and 2.15 g/cm^3 , except for one iron oxide-cemented sample which was 2.42 g/cm^3 . Dry samples of the Valley Springs and Mehrten Formations are in the density range of 1.82 - 1.88 g/cm^3 ; corresponding water-saturated samples, 2.05 - 2.09 g/cm^3 . The one sample of lignite tested had a density of 1.20 g/cm^3 .

Table 1. Rock property measurements — lone area

Sample no.	Description	Density (g/cm^3)	Magnetic susceptibility (emu/cm^3)
<i>Basement complex</i>			
1	Amphibole schist	2.80	5.2×10^{-5}
2	Pale green agglomerate	2.82	5.2×10^{-5}
3	Green dense agglomerate or flow	2.91	
4A	Pale green dense agglomerate	2.95	
4B	Pale green dense agglomerate	2.97	
5	Pale green somewhat altered agglomerate	2.80	
6	Green dense andesite	2.88	
7	Quartz porphyry	2.67	6.0×10^{-5}
8	Gray slate	2.54	
9	Gray slate	2.57	
10	Pale gray micaceous schist with quartz lenses	2.66	
11	Sheared graywacke	2.54	
12	Altered whitish-gray slate	2.45	
13	Altered whitish-gray slate	2.50	
14	Gray clay (altered slate)	1.97 (wet)	
15	Gray clay (altered slate)	1.99 (wet)	
<i>lone Formation</i>			
16	White sandy clay	1.98 (dry)	
17	White sandy clay	1.83 (dry)	9.0×10^{-5}
18	Yellow sandstone with limonite cement	2.42 (dry)	5.0×10^{-5}
19	Yellow sandstone	2.15 (dry)	
20	Lignite	1.20 (dry)	very sm
<i>Valley Springs Formation</i>			
21	Buff rhyolite tuff		5.2×10^{-5}
22A	Buff rhyolite tuff	1.86 (dry)	
22B	Buff rhyolite tuff	2.06 (wet)	
23A	Buff rhyolite tuff	1.88 (dry)	
23B	Buff rhyolite tuff	2.09 (wet)	
<i>Mehrten Formation</i>			
24A	Grayish-brown tuffaceous sandstone	1.82 (dry)	270×10^{-5}
24B	Grayish-brown tuffaceous sandstone	2.05 (wet)	
25A	Grayish-brown tuffaceous sandstone	1.84 (dry)	
25B	Grayish-brown tuffaceous sandstone	2.08 (wet)	

Because the number of specimens tested is too small to provide an adequate sampling of the whole area under consideration, two density profiles were utilized to obtain independent values of the density of the lone and Valley Springs Formations following the method outlined by Nettleton (1940, p. 57). In this procedure, the gravity values for stations across a topographic feature are reduced, including terrain effects, for a number of different density values. The value that shows the least correlation with topography should be the proper density for use in the reductions. One of the profiles was over a hill of sedimentary rock of the lone Formation; the other was over a hill composed of rocks of both the lone and Valley Springs Formations. In both profiles, the least correlation with topography was found for a density of about 1.8 g/cm^3 . However, because the average of the measured density values is close to 1.9 g/cm^3 , a value of 1.9 g/cm^3 was adopted for the gravity reductions.

The magnetic susceptibility measurements were made on a Geophysical Specialties Company bridge, which was made available through the courtesy of Mr. S.G. Sargis, Columbia Geneva Division, United States Steel Corporation. The measurements of the samples of the basement complex and the Ione and Valley Springs Formations all fall in the range of 5×10^{-5} to 10×10^{-5} emu/cm³, indicating low values of magnetic susceptibility with no great differences among the rock types. The one sample of tuffaceous sandstone from the Mehrten Formation gave a value of 270×10^{-5} emu/cm³, which indicates a strongly magnetic rock, much more so than any of the other rocks tested. Serpentine, commonly a very magnetic rock, is present in the exposed basement rocks east of Ione. Hand specimens of this rock type were found to be very magnetic, but no susceptibility measurements were made. However, DuBois (1963, p. 271) found an average value of 420×10^{-5} emu/cm³ for a suite of serpentine specimens collected near Mariposa, in the foothill belt, about 8 miles south of Ione.

ANALYSIS OF DATA

Gravity Maps

Figure 2 is a Bouguer gravity map of the Ione area contoured at a 2 milligal interval. The most conspicuous features of the gravity field are the trend of the contours of about N. 30° W. and a regional gradient of about 5 milligals per mile, downward toward the northeast. This strong regional gradient is caused in part by the presence of a positive gravity anomaly just west of the map area in the Sacramento Valley. It is also caused in part by a thickening of the earth's crust under the Sierra Nevada (Oliver, Pakiser, and Kane, 1961, p. 469). The steepness of the gravity gradient tends to obscure local anomalies in the Ione area, but one noteworthy feature is the prominent negative anomaly which forms a northeast-trending saddle in the southern part of the map area, just north of the Mokelumne River. This feature shows up well because it is nearly normal to the regional trend.

To study the local features of the gravity map, it was necessary to remove the steep regional gradient. This was accomplished by utilizing seven gravity profiles which cross the area (see plate 1); the regional gravity trend was determined on each profile by using stations located on or near basement rocks, then a "smoothed" regional map was prepared from these results. Residual gravity values were obtained by taking the difference between the observed and interpolated regional values at each station. Plate 1 shows the resulting residual gravity contours superimposed on the geologic map of the Ione area.

The principal anomaly shown by the residual map is a prominent gravity low with a trend of about N. 30° W. for most of its length, centered approximately over the known basin structure west of the towns of Ione and Buena Vista and east of Cardale. This gravity low extends for about 20 miles

northwest from near Buena Vista Peaks to a point near Bridge House. At each end, extensions of the anomaly turn sharply toward the southwest. In the area southwest of Buena Vista Peaks, the anomaly is prominent and corresponds to the "saddle" mentioned in the discussion on the Bouguer gravity map. From a point northwest of Ione near Indian Hill, the anomaly amplitude increases both northwest and southeast.

The gravity low is flanked on both sides by positive anomalies. On the west, the positive anomaly is over discontinuous outcrops of greenstone of the Logtown Ridge Formation. Between Jones Butte and Jackson Creek, this greenstone forms prominent hills; but, northwest of Jones Butte, no outcrops of greenstone are known for a distance of about 9 miles until it reappears near Bridge House, just south of the Cosumnes River. The presence of the buried greenstone ridge is suggested, however, by the nearly continuous positive gravity anomaly in this area. There are three distinct interruptions in this positive anomaly trend: one southeast of Bridge House, another in Jackson Valley, and the third southwest of Buena Vista Peaks. The positive gravity anomaly on the eastern side of the Ione basin passes very close to the towns of Ione and Buena Vista. It corresponds to exposed greenstone in most of the area north of Ione. A low-amplitude negative gravity anomaly, which also has a trend of approximately N. 30° W., is found east of Ione over exposures of Mariposa Formation.

On a smaller scale, there are several distinct negative gravity anomalies along the eastern edge of the Ione basin. The largest of these is about 2 miles southeast of Ione on the east side of the basin near a gravel delta mentioned by Pask and Turner (1952, p. 18). There are others in the areas where Jackson Creek, Sutter Creek, and Dry Creek leave basement rocks and enter the valley.

Because measurements indicate a distinct density contrast between basement rocks and the Tertiary sedimentary rocks, it is reasonable to assume that the main negative gravity anomaly is caused in large part by low-density sedimentary rocks in the Ione basin. This basin is now known from drill holes to be present most, if not all, of the distance between points southeast of Bridge House and southwest of Buena Vista Peaks. However, in this area the basement complex includes different rock types such as: greenstone (measured density range 2.80-2.97 g/cm³); slate (measured density range 2.45-2.66 g/cm³); intrusive igneous rocks (measured density of one sample of quartz porphyry 2.67 g/cm³); and possibly rocks of the Cosumnes Formation. The relative abundance of these units varies from place to place; furthermore, near Irish Hill the basement rocks (slate) are known to be extensively altered to sericite. Thus, density contrasts within the basement rocks and possibly within the overlying Tertiary sedimentary rocks also undoubtedly have a significant effect on the gravity anomalies. All of these factors must be considered in any interpretation of the gravity data.

With these limitations in mind, the gravity data were used with the information from the drill holes and seismic data to investigate the configuration of the buried basement surface in the Ione area along the seven profiles A-A' through G-G' (plate 1).

The maximum gravity anomaly caused by a basin structure where the width of the basin is much greater than the depth can be calculated by the Bouguer gravity formula for an infinite plate (Dobrin, 1960, p. 230) in which the gravity anomaly Δg is given by:

$$\Delta g = 2 \pi b (\Delta \sigma t)$$

Where b is the universal gravitational constant, $\Delta \sigma$ is the density contrast, and t is the average maximum thickness of anomalous density. Conversely, if the anomaly and density contrast are known, the thickness may be calculated. The use of this simple approximation is limited to structures which have much larger horizontal dimensions than vertical; the more the structure deviates from a simple slab, the larger the error.

The gravity anomaly caused by a basin structure can also be calculated with greater accuracy from the actual cross section by means of a gravity graticule of the type described by Dobrin (1960, p. 258), as done in this study, or by the computer method described by Talwani and others (1959, p. 49). In the use of the latter two methods, the assumption is usually made that the structure is two-dimensional; that is, the length of the structure can be disregarded in the calculations since it is much longer than the other dimensions. This should be a valid approximation for much of the Ione basin.

Profile B-B' (plate 1) is drawn across Jackson Valley near Buena Vista where there are a number of drill holes that reach basement rocks and thereby provide a means of checking the interpretation of the gravity data. In this area, the amount of slate underlying the basin may be relatively small, because the authors know of only one drill hole (see Pask and Turner, 1952, p. 31) which is reported to have encountered rock of this type. Profile B-B' shows a generalized geologic cross section obtained principally from the drill hole data provided by Pask and Turner (1952, p. 27-39) and a comparison of the residual gravity anomaly with the anomaly calculated by the use of a graticule from the geologic cross section, using a density contrast of 1.0 g/cm³. Agreement between the observed and the calculated anomalies is reasonably good; this tends to confirm the assumed density contrast and the over-all shape of the basin structure as drawn from seismic and drill hole data. Profile C-C' (plate 1) is located near seismic profile d-d', southwest of Ione. There are no drill holes that reach basement rock in the deeper parts of the basin in this area, so the geologic cross section is based on seismic data alone. In this example, the correlation between observed and calculated gravity anomalies is only fair. The good-to-fair success of the method for these profiles suggests that it

should be possible to use the gravity data in other parts of the Ione area to extend the structural information.

Gravity profiles A-A', D-D', E-E', F-F', and G-G' are also shown on plate 1. Geologic cross sections were constructed for all of the profiles--using known basement depths from outcrops, drill holes, and seismic data where available and depths derived from gravity data between known points. The geologic sections and other available data were then used to construct a contour map of the basement rock surface (plate 1), with a contour interval of 100 feet.

The profiles and basement contour map undoubtedly reflect some of the possible errors discussed earlier. For example, gravity data alone would have led to a misinterpretation of the geology in the vicinity of profile D-D' (plate 1), which is located near the apparent divide in the ancient basin at Indian Hill. The gravity anomaly here suggests a larger and deeper basin than actually is the case, probably because, as mentioned earlier, the basement rocks in this area have been extensively altered, resulting in a lower density. Perhaps these altered rocks represent a remnant of the pre-Ione weathered basement surface which was not eroded because of its protected location.

Seismic Data

Seismic refraction was used at three locations near Carbondale and one location southwest of Ione to determine the depth to basement rocks. A reversed refraction profile (a-a' plate 1 and figure 3), located at a point along Dry Creek in the valley between exposures of greenstone, shows two layers with average velocities of about 2000 and 16,500 feet per second, respectively, which are interpreted to represent a thickness of about 40 feet of sand and alluvium over greenstone.

The second seismic determination (b-b' on plate 1) was located in the southern part of sec. 28, T. 7 N., R. 9 E., on the eastern side of the Ione basin. At this location, the depth to the high velocity basement layer was found to be approximately 100 feet. Farther west, near the center of sec. 30, T. 7 N., R. 9 E., (c-c' on plate 1)—no high velocity layer was detected using a geophone spread¹ approximately 800 feet long. For this reason, the basement contour map (plate 1) indicates that the depth to greenstone should be more than 200 feet in this area.

Seismic profile d-d' (plate 1 and figure 4), located about 1 1/2 miles southwest of Ione, is a northeast-trending line 5500 feet long, consisting of five 1100-foot-long geophone spreads, each with a detector spacing of 100 feet. Depths to bedrock were computed at each geophone by a method

¹ The geophone spread is the total distance between the shot point and the most distant geophone in the profile. A geophone spread of at least four times the depth to be investigated is usually required in refraction work.

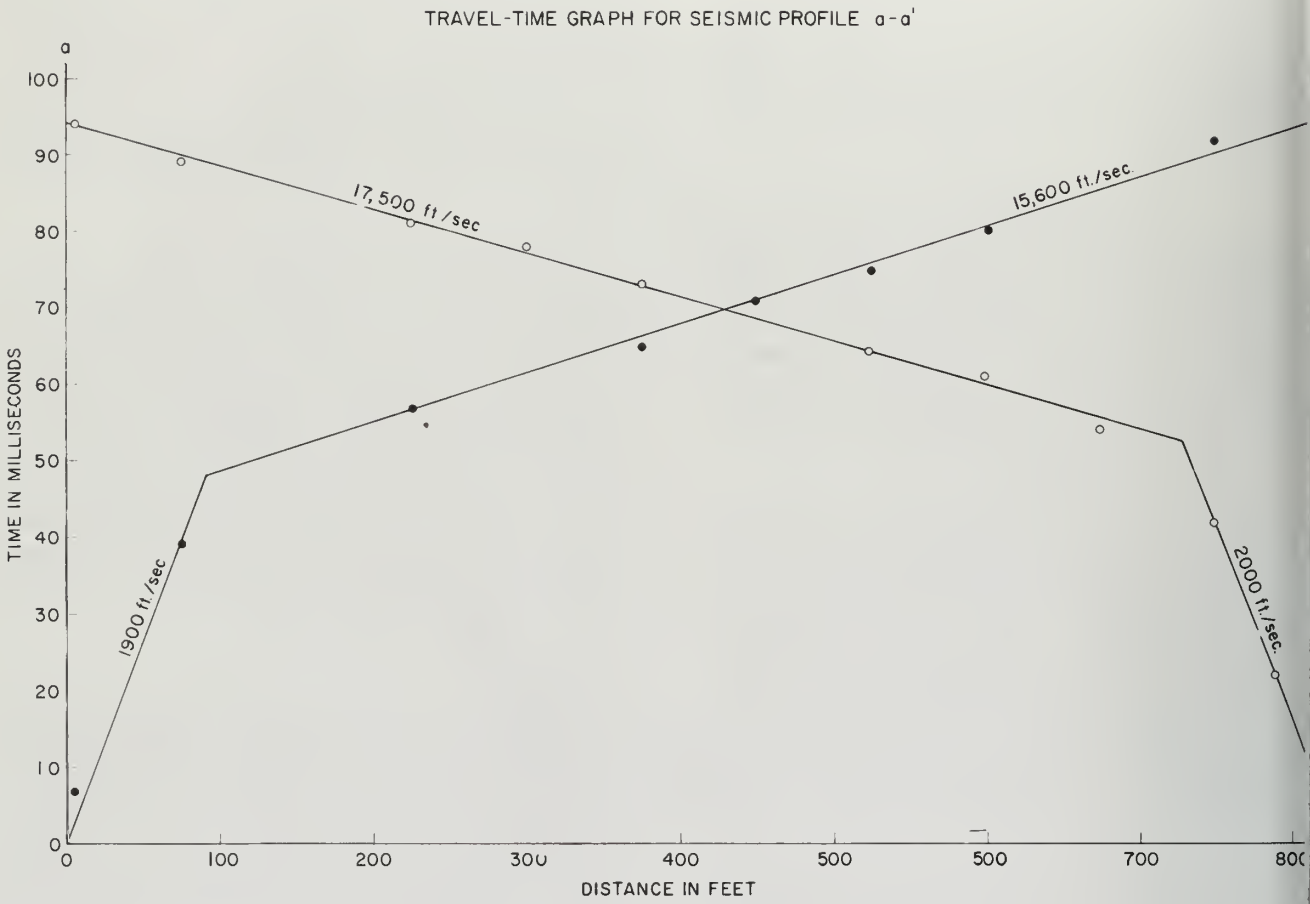


Figure 3. Travel-time graph for seismic profile a-a'.

osely similar to the time-depth method described by Hawkins (1961); the time-distance plots and seismic velocity section are shown in figure 4. The velocity of the principal layer (presumably Ione Formation) overlying basement rock ranges between 4000 and 6000 feet per second, except for a thin near-surface weathered layer. The velocity of the basement rocks on this profile ranges between 10,000 and 20,000 feet per second. The elevation of basement rock decreases to approximately - 190 feet at the deepest part of the basin on this profile according to the seismic depth calculations.

An anomalously thick (as much as 50 feet) low velocity zone consisting of two layers with velocities of about 1000 and 2000 feet per second, respectively, is found between stations 4200 and 4400 on the northeastern end of the profile. These layers may represent relatively unconsolidated material which fills the site of an abandoned lignite strip-mining operation. Also, a zone of material near the surface at station 3300 shows a seismic velocity of about 3000 feet per second. This layer may represent a relatively consolidated part of the Ione Formation or possibly a small erosional remnant of either the Valley Springs or Mehrten Formations.

The logs of four shallow drill holes located near seismic profile d-d' were furnished by William Caven of Interpace Corporation. The locations and intervals drilled are shown in figure 4, projected to the plane of profile d-d'. Below the soil layer, the drill hole logs show sedimentary rocks more or less typical of the Ione Formation. None of these drill holes is believed to have penetrated basement rock.

Magnetic Profiles

Three east-west magnetometer traverses were made across the Ione basin to determine whether the magnetic field would indicate differences in rock types. A Jalander flux-gate magnetometer with a sensitivity of about 10 gammas per scale division was used for the survey. Profile X-X' (figure 5 and plate 1) extends for about 10 miles along State Highway 88. Profile Y-Y' (figure 5) extends from the junction of State Highway 88 and the Jackson Valley and generally eastward about 9 miles to a point northeast of the Pardee Reservoir. Profile Z-Z' (figure 5) was made along State Highway 16 from west of Ridge House eastward about 13 miles. Most of the rock types found in the area are crossed by these profiles.

The only rock types from the Ione area found to have relatively high values of magnetic susceptibility are specimens of andesite tuff of the Mehrten Formation and serpentine (table 1). Confirming these observations, the eastern part of profile X-X' shows little distinction among the rock types traversed, except for some very minor anomalies. On the west side of this profile, the values rise, somewhat

irregularly, and reach a level about 1200 gammas higher than that to the east. This anomaly probably is caused, at least in part, by volcanic rocks in the Mehrten Formation. However, a published aeromagnetic map (Meuschke and others, 1966) shows a major anomaly in this part of the Sacramento Valley. This large anomaly is undoubtedly caused by magnetic rocks in the basement underlying the valley (Griscom, 1966, p. 410-411).

Profiles Y-Y' and Z-Z' (figure 5) which cross basement rocks and sedimentary rocks of the Ione Formation are both nearly featureless except for sharp magnetic highs over areas of serpentine.

Although the magnetic data appear to be of little value for distinguishing among basement rock types other than serpentine, the traverses do suggest that there are no major serpentine masses in the basement rocks of the Ione area, except for those which are shown on the geologic map (plate 1).

Resistivity Soundings

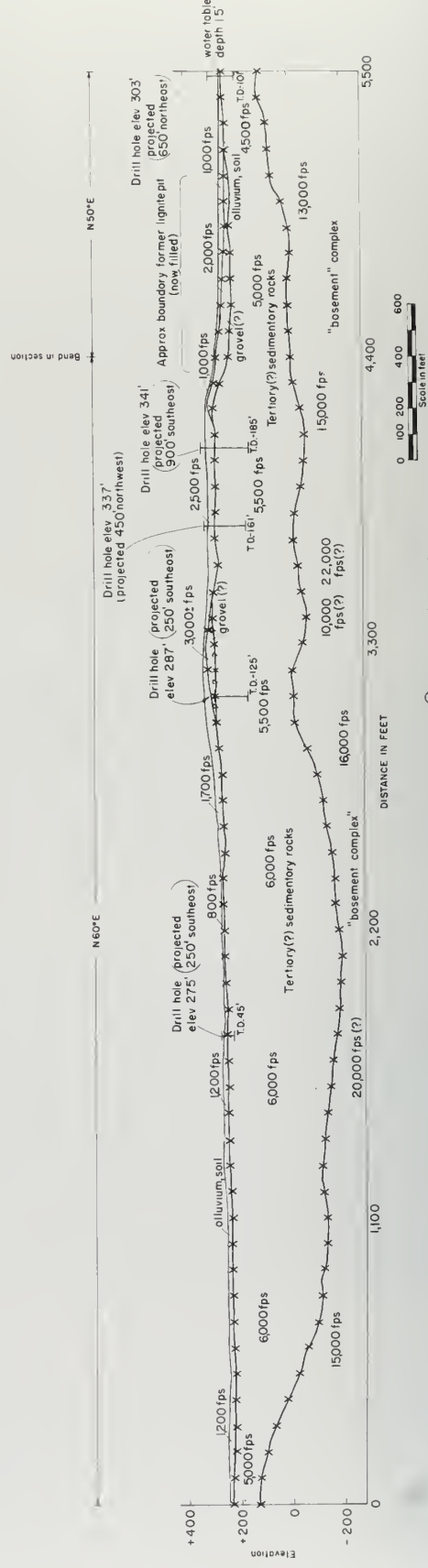
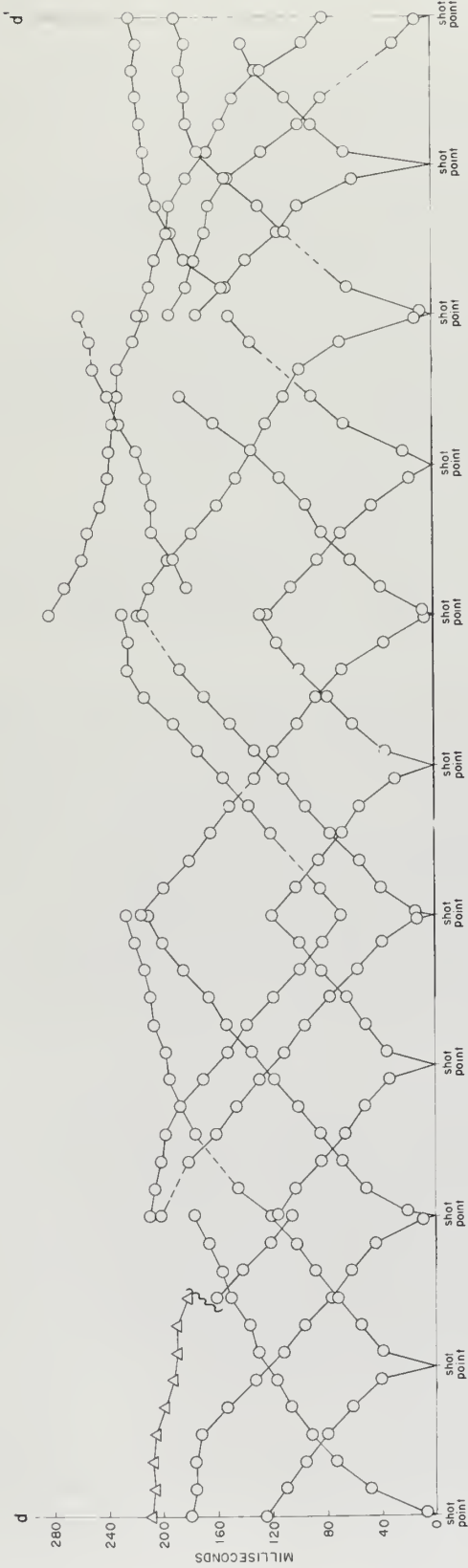
Electrical resistivity soundings were made at three locations in the area primarily to determine whether or not the known lignite beds at these locations might be detected from surface electrical measurements.

A number of attempts have been made to apply resistivity methods to prospecting for lignite in other areas. The method depends on a contrast in electrical conductivity between the lignite and the surrounding beds. Heiland (1946, p. 739-740) discussed a number of examples and concluded, "If the lignite beds are soaked with mineralized waters and the overburden formations are poor conductors, fairly definite results may be obtained." These conditions may be fulfilled when glacial drift or sand, for example, overlies the better-conducting lignite. In the Ione area, however, the overburden commonly consists of clayey sand or clay, which could be expected to have a high conductivity; and the outlook for success is much less promising.

Electrical soundings were attempted at several locations (plate 1); but except possibly for one case where the lignite was at a relatively shallow depth, no evidence of the lignite was found on the sounding curves. Possibly this is because the ratio of overburden depth to thickness of lignite was relatively high in most locations. Figure 6 shows the drill hole log and a plot of apparent resistivity vs. electrode separation on double logarithmic paper for an electrical sounding at drill hole 11, in Jackson Valley, just southwest of Buena Vista.¹

The log of the drill hole shows, from the surface down, 6 feet of brown soil, 13 feet of gravel, 2 feet of clay, and 10 feet of lignite underlain by clay. The

¹Drill hole log presented through the courtesy of Joseph De Angelis of the American Lignite Products Company (now American Lignite Products Division of Interpace).



5,500 fps = Seismic velocity in feet per second
x = Points on seismic velocity discontinuity (calculated)
o = First arrival of geophones
Δ = Second arrival of geophones
Drill hole data after William Crover (personal communication)

sistivity sounding at this location was interpreted using the album of theoretical curves from Mooney and Wetzell (1956). Interpretation yields two layers, the uppermost with a resistivity of about 160 ohm-meter, underlain at a depth of about 23 feet by a layer with a resistivity of about 130 ohm-feet. The second

layer agrees quite well with the known depth of the lignite, but it does not have a very distinct resistivity contrast. Thus, it is clear that detection of lignite beds in this area by surface electrical resistivity methods would probably be very difficult except under ideal conditions.

RESULTS OF DRILLING

During the course of the investigation of the Ione area, three core holes were drilled under a cooperative program by the California Division of Mines and Geology and the U.S. Bureau of Mines. One of the purposes of this drilling program was to test the structural interpretations based on the geophysical data. The holes were drilled both to the north and south of the presently producing clay, sand, and lignite properties in relatively unexplored parts of the basin (see plate 1). These are areas in which the gravity and seismic data indicate that substantial thicknesses of Tertiary sedimentary rocks could be expected. All of the holes were cored continuously from near the surface into relatively fresh basement rock. A graphic representation and brief geologic description of the rock types encountered in these holes are given in figure 7.

Hole 1967-1 (figure 7), drilled 2 miles northwest of Carbondale in the NE 1/4 of sec. 30, T. 7 N., R. 9 E., penetrated rocks typical of the Ione Formation from the surface to a depth of 193 feet. Relatively pure clays of possible commercial value were encountered in the upper 50 feet of the hole. Beds of lignite were cored between 50 and 75 feet and between 113 and 161 feet. Green claystone and light gray sandstone, probably equivalent to the pre-Ione beds, were encountered from 193 feet to the top of the basement at 251 feet. The upper 10 feet of the basement is weathered and is composed of a residual green claystone. This grades downward into medium dark green, feldspathic and tuffaceous metasandstone which may represent part of the Combes Formation. The total depth of the hole is 251 feet.

Hole 1967-2 (figure 7) was drilled south of Buena Vista Peaks in the SW 1/4 of the NE 1/4 of sec. 30, T. 5 N., R. 10 E. The well spudded in sandstone and conglomerate composed of pebbles of quartz, chert, metamorphic, and volcanic rocks. Many of the volcanic rock clasts in the conglomerate and some of the sand grains are magnetic, a characteristic of the Mehrten Formation. The Valley Springs Formation was encountered at 68.6 feet. It consisted of gray, pale green, and buff to brown sandstone and sandy claystone. Beds of the Ione Formation were penetrated from 118.6 feet to the top of the weathered basement at 752.4 feet, a total of 633.8 feet. The Ione Formation is characterized by a high proportion of sandstone and clayey sandstone. Carbonaceous material is common, but only a few very thin lignitic seams were encountered. The top of the hard unweathered basement, composed of

metasedimentary and metavolcanic rocks, is at 764.7 feet. No rocks corresponding to the pre-Ione beds were recognized in this hole.

Hole 1967-3 (figure 7) was drilled in the northern part of the Ione basin, halfway between Bridge House and Carbondale in the NE 1/4 sec. 13, T. 7 N., R. 8 E. The upper 90 feet of rocks penetrated in this hole consist of light gray to yellowish sandstone and green bentonitic claystone of the Valley Springs Formation. The Ione Formation was encountered between 90 and 359 feet. It consists of light gray claystone and sandy claystone commonly stained buff-brown or red by iron oxide. Carbonaceous claystone beds were logged between 112 feet and 154 feet and between 221 feet and 228 1/2 feet, but no significant thicknesses of lignite were found. Green silty, sandy claystone, probably representing the pre-Ione beds, was cored from 359 feet to 425 feet. Twelve and a half feet of blue-gray sandstone including about 1 (one) foot of basal quartz pebble conglomerate overlies the weathered basement which was encountered at 437.3 feet. The hole penetrated weathered greenstone to a total depth of 455 feet.

All three core holes encountered thick sequences of Tertiary sedimentary rocks before reaching the pre-Cenozoic basement complex. The northernmost hole, 1967-3, penetrated 437 feet of these sedimentary rocks; and the southernmost hole, 1967-2, 752 feet. The corresponding elevations of the basement rocks for these two holes are -192 feet and -250 feet, respectively. These basement depths tend to confirm the presence of a subsurface northwest-southeast trending basin system, as outlined by the geophysical data. Hole 1967-1 is believed to be on the eastern flank of a buried greenstone ridge northwest of Carbondale. In this hole, the basement rocks were encountered at a depth of 251 feet (elevation -33 feet), considerably higher than in the others which, judging from the geophysical data, are located nearer to the axis of the basin.

Holes 1967-1 and 1967-3 encountered sequences of sedimentary rocks directly above the basement that differ in physical appearance from the rocks of the Ione Formation. These older rocks, which underlie the Ione Formation, do not appear to have been subjected to the high degree of weathering associated with the Ione. For this reason, they may be equivalent to the pre-Ione beds described by Pask and Turner (1952, p. 15 and 16) in the Buena Vista area. The absence of these beds from hole 1967-2

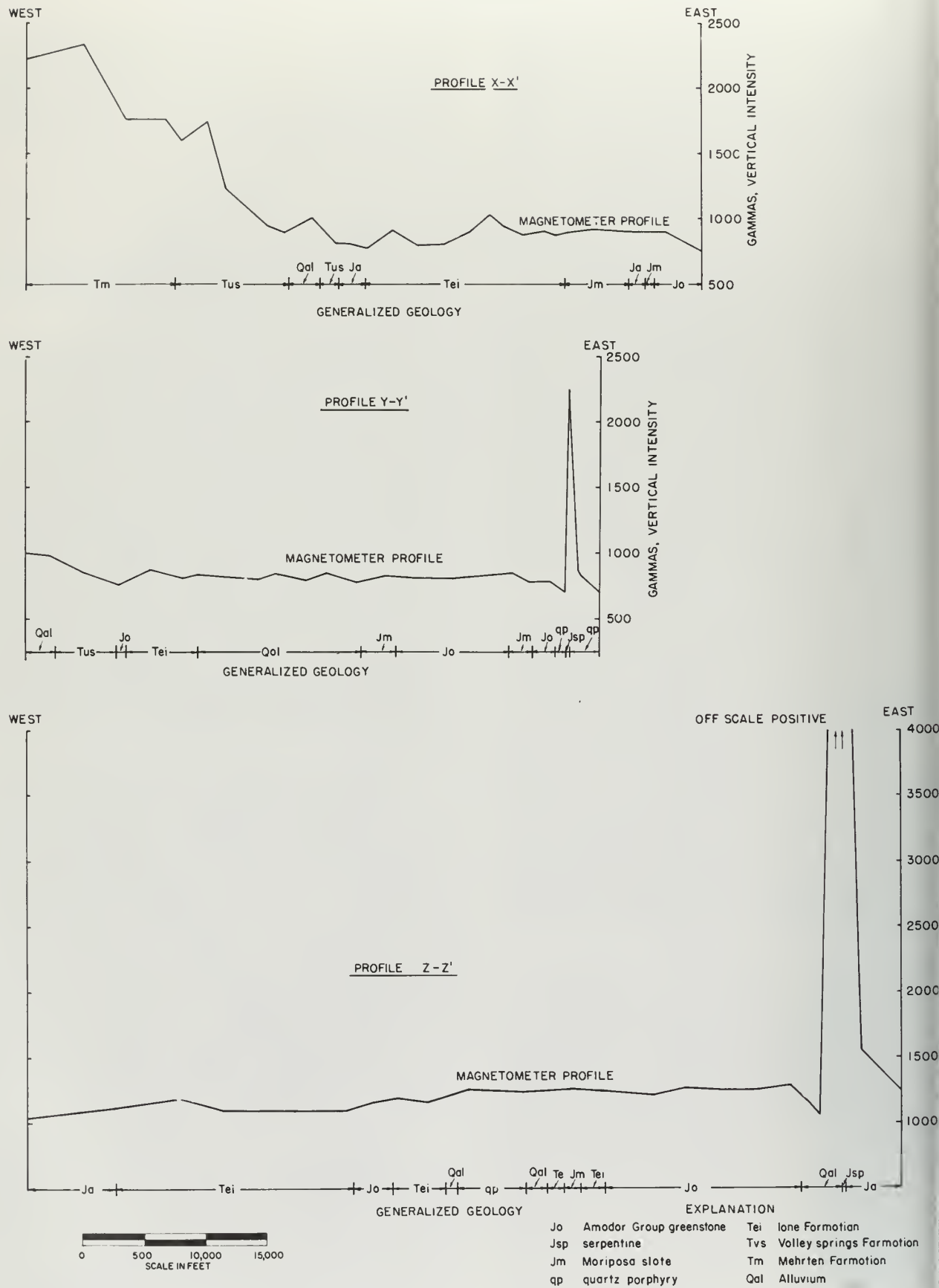


Figure 5. Magnetic profiles X-X', Y-Y', and Z-Z' showing generalized geology.

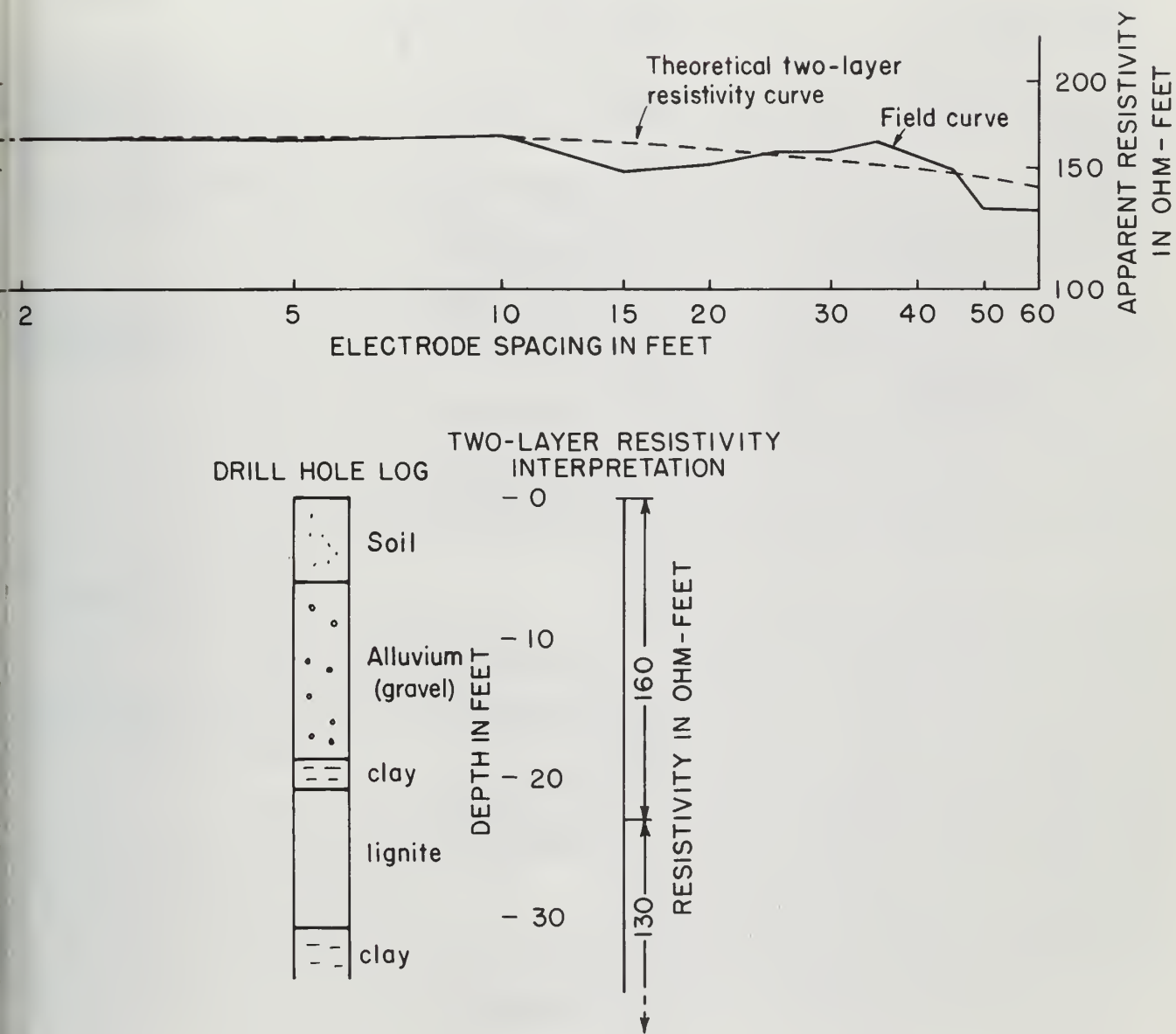
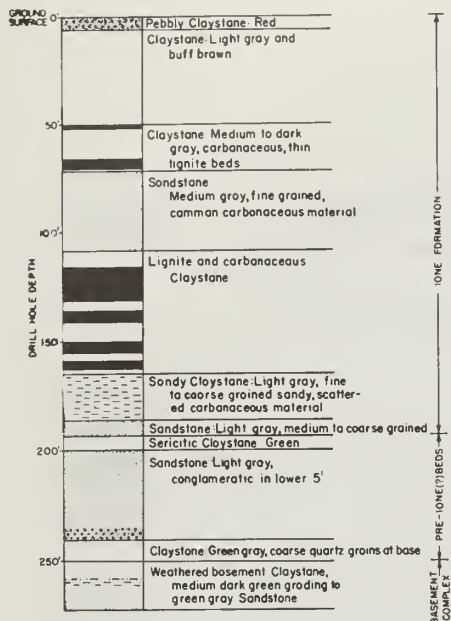


Figure 6. Resistivity sounding, interpretation, and log of drill hole 11.

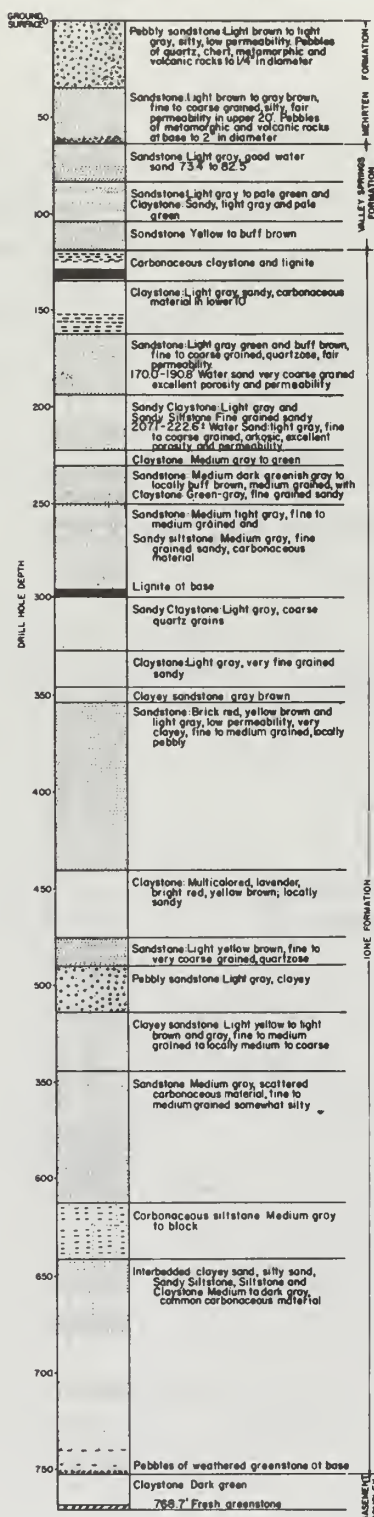
Drill hole 1967-1

U.S. Bureau of Mines-California Division of Mines and Geology
Approximate location 1200'S and 750'W of the
N.E. corner of Section 30 T 7 N, R 9 E, M D B M
Elevation 218'
Spud: 6-23-67, Completed: 7-6-67, Total Depth: 273'



Drill hole 1967-2

U.S. Bureau of Mines-California Division of Mines and Geology
Approximate location 2450'S and 1990'W of the N.E. corner
of Section 30 T 6 N, R 10 E, M D B M
Elev 502'
Spud: 7-11-67, Completed: 8-23-67, Total Depth: 771'



Drill hole 1967-3

U.S. Bureau of Mines-California Division of Mines and Geology
Approximate location 1400'S and 1600'W of the
N.E. corner of Section 30 T 7 N, R 8 E, M D B M
Elevation 245'
Spud: 8-24-67, Completed: 9-8-67, Total Depth: 455'

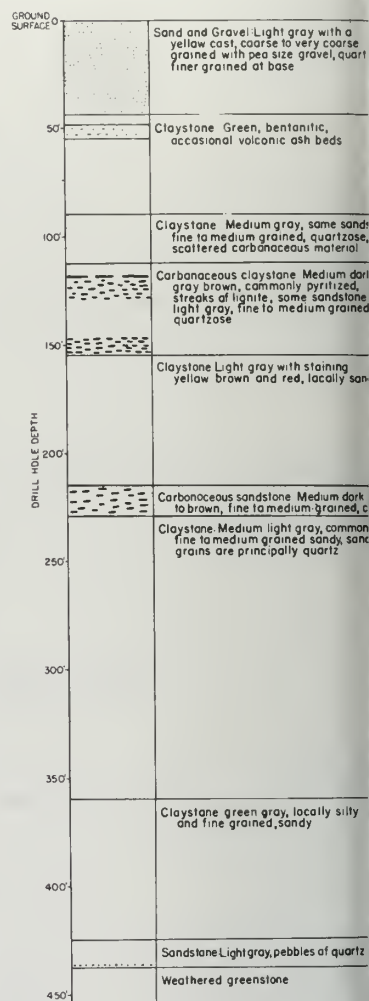


Figure 7. Graphic logs of CDMG-USBM core holes (3).

suggests that a period of erosion followed the deposition of the pre-Ione sedimentary rocks.

None of the holes encountered laterite, which is known to have formed in the basin area as a result of the intense chemical weathering of the basement

(Pask and Turner, 1952, p. 14). It is likely that basement rocks in holes 1967-1 and 1967-3 were protected from this weathering by a covering of the pre-Ione beds. Erosion may have removed the laterite, if any was formed, in the vicinity of hole 1967-2.

GEOLOGIC INTERPRETATION

Analysis of the gravity maps and profiles given in the preceding sections indicates that the sedimentary rocks of the Ione Formation were deposited in a basin or valley extending from south of Michigan Bar on the north to the Buena Vista Peaks area on the south. This basin is bounded on the west by a resistant greenstone ridge which is represented by the outcrops of greenstone west of Ione and northwest of Buena Vista. Interruptions in the ridge, possibly outlets for the Eocene streams, are suggested in three places by the gravity data southeast of Bridge House, Jackson Valley, and southwest of Buena Vista Peaks (see plate 1). The third of these, a particularly distinct anomaly just north of the Mokelumne River, indicates a structural erosional feature that extends into the Great Valley for some distance; this suggests the location of a major buried drainage system. The gravity data also suggest that there was a divide in the buried basin northwest of Ione, near Indian Hill, which separates the basin into two parts.

The Ione basin appears to have an asymmetrical shape, generally with a gentle eastern slope and a more abrupt western flank, particularly in the southern half of the area. The high relief associated with the greenstone ridge and Ione basin could have resulted in part from faulting but is probably primarily an erosional feature.

Lindgren (1911, p. 195-213) discussed the Tertiary history of the Jackson and Big Trees quadrangles, including the Ione area, and showed the distribution of the auriferous deposits of the Tertiary streams. According to Lindgren's map (1911, plate 1), the Tertiary Mokelumne River flowed westward through the present site of the town of Plymouth and entered the Ione area somewhere north of Carbondale and south of State Highway 16. The divide in the Ione basin near Indian Hill may have separated the northern ancestral Mokelumne River drainage from another westward-flowing drainage system in the south. In Eocene time, the Ione basin valley was filled with sediments of the Ione Formation. Tropical conditions at this time may have been a reason for the accumulation of large quantities of vegetation represented by the lignite beds. These conditions were also responsible for the high degree of weathering of the basement rocks, the development of lateritic soils, and the formation of the high-purity clays and high-silica sands found in the Ione Formation (Allen, 1929, p. 354).

Eventually the sediments filled the basin and covered all but possibly the highest points on the confining ridges. When the basin became filled, the newly established drainage found numerous outlets thus changing conditions of sedimentation. It appears that the important lignite and clay beds are mostly found at elevations below the top of the greenstone ridge. Piper and others (1939, p. 82) remarked: "The thickest coal beds are found in basins that are bounded on the east by pre-Cretaceous crystalline rocks in the Sierra Nevada foothills and on the west by outlying parallel ridges of the same rocks."

Deposits of sedimentary rocks of the Ione Formation may have covered limited areas east of the known limits of the Ione basin; but, if they did, most of them have since been removed by erosion. Evidence for this are the deposits along the Mother Lode belt in the vicinity of the towns of Jackson and Sutter Creek (Taliaferro, 1949).

Turner (1894, p. 4) reported a bore hole made many years ago at the location of Coal Mine No. 3, north of Clarkson siding on the Southern Pacific Railroad, which was said to have penetrated 800 feet of sandy clay below the coal horizon. This information has been reported in most of the subsequent literature on the area. Gale (Piper and others, 1932, p. 82) questioned the validity of this record, however, on geologic evidence. The gravity study also suggests that this is an unreasonable figure because such a thickness of sedimentary rock of Tertiary age should produce a much larger gravity anomaly than that actually observed. Plate 1 shows the estimated basement surface in this area at about present-day sea level in the center of the basin. This interpretation indicates approximately 200 feet of sedimentary rock below the coal bed.

LIGNITE

Plate 1 shows the important known lignite mines and prospects and their relationship to the basement structure in the Ione area. All of the mines, except the Interpace mines at Ione and near Indian Hill, are inactive at this time. Although some lignite is nearly always found in the Ione Formation, the locations shown indicate areas where the lignite reaches possible commercial thicknesses.

The locations of the known lignite deposits, as shown on Plate 1, indicate that the deposits in the

area south of Lone are all on the eastern side or slope of the basin; those near Carbondale in the northern part of the area are mostly on the western side. Few of the deposits appear to be at or near the axis of the basin in the deeper parts although exploration may not have tested these areas thoroughly. This relationship may indicate that the thick accumulations of the vegetation, which was the source material for the lignite, occurred principally along the margins of the basin and that the most favorable locations varied from one side of the valley to the other.

The observed relationship between the basement structure and the locations of the lignite deposits suggests other parts of the Lone basin where lignite might be found. Areas between known lignite deposits such as between Buena Vista and Lone and south of Buena Vista, on the east side of the basin, and both north and south of the Carbondale area, on the west side, might be of interest because of the continuation of the basin structure in these directions.

CLAY, SAND, LATERITE, AND GRAVEL

The basement contour map, by revealing the extent and configuration of the basin, may also be of

use as a general guide in the exploration for clay, sand, laterite, and possible auriferous gravels. Deposits in, and possibly beneath, the Lone Formation. It is reasonable to assume that deposits of these commodities occur in the less explored parts of the Lone basin such as north of Carbondale and south of Buena Vista. Some of the sand and gravel units in the basin might also have another value as a source of water.

Evidence from drill holes in the Lone basin (Pask and Turner, 1952, p. 15) suggests that a change to a tropical climate which resulted in the formation of laterite occurred subsequent to the deposition of the pre-Lone beds. This laterite would be expected to form on the basement rocks at the margin of the basin at an elevation higher than the top of the pre-Lone beds. The western flank of the basin would appear most favorable for the formation and retention of laterite deposits as it has been better protected from erosion than the eastern flank.

CONCLUSIONS

A combination of gravity and seismic refraction methods was found to be effective for determining the depth to the basement complex in the Lone area. Using data generated by these methods, it was possible to construct a map showing the approximate configuration of the basement rock surface. This general configuration was confirmed by three holes drilled on the basis of the geophysical data.

A knowledge of the configuration of the basement rock surface is important because this is one of the factors that controlled the deposition of the Tertiary sedimentary rocks, including some of the important mineral commodities which are found within the Lone Formation. For example, the prin-

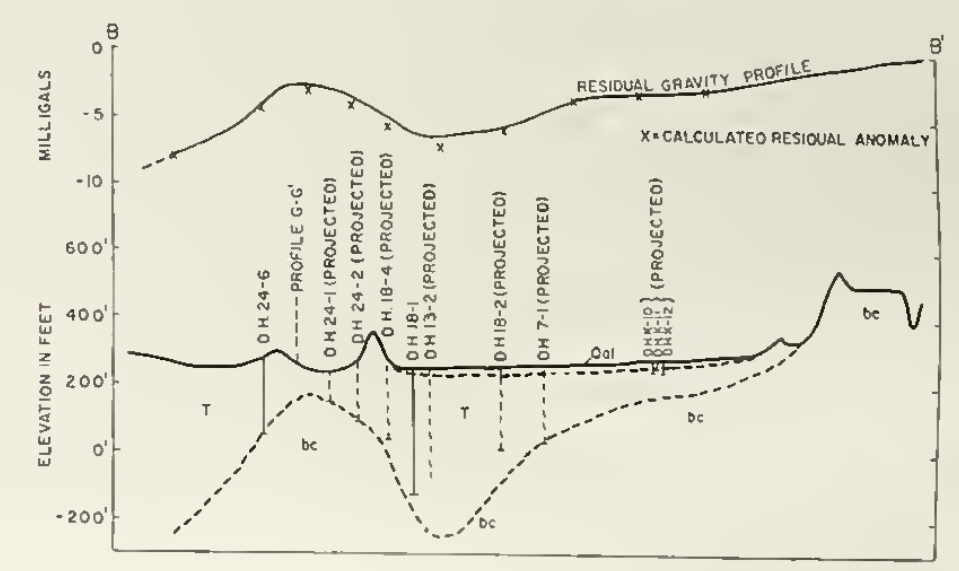
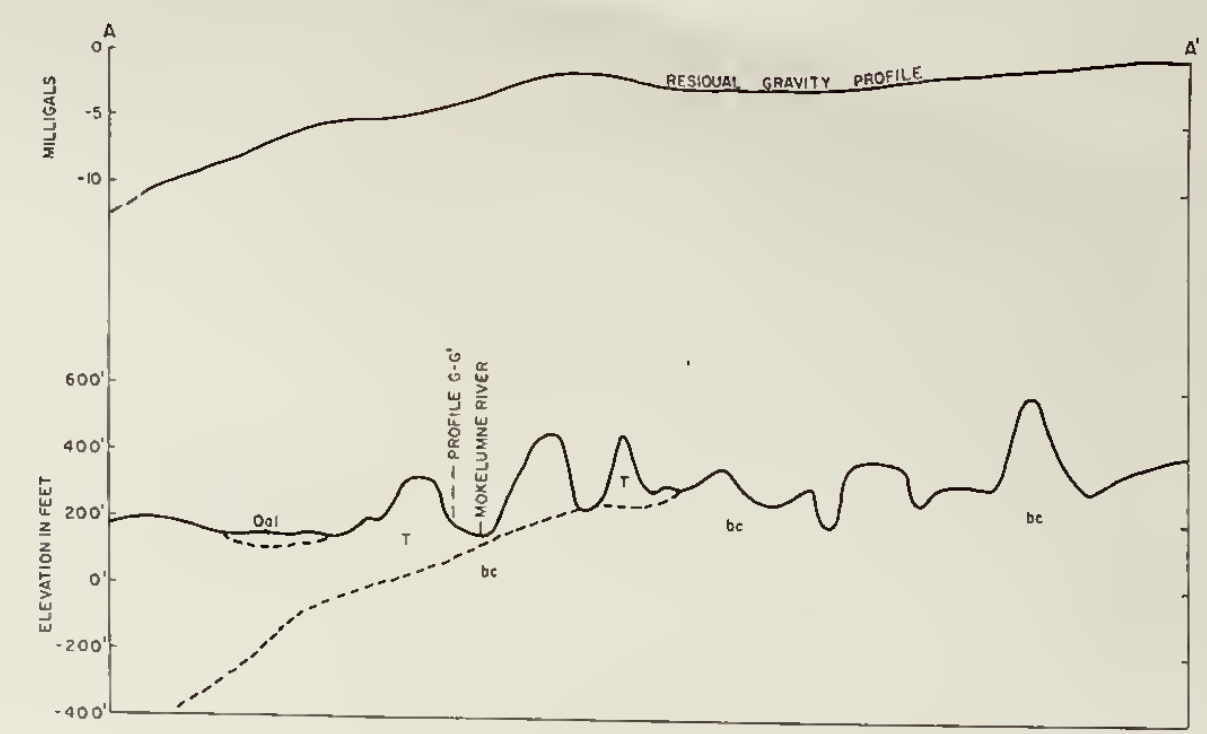
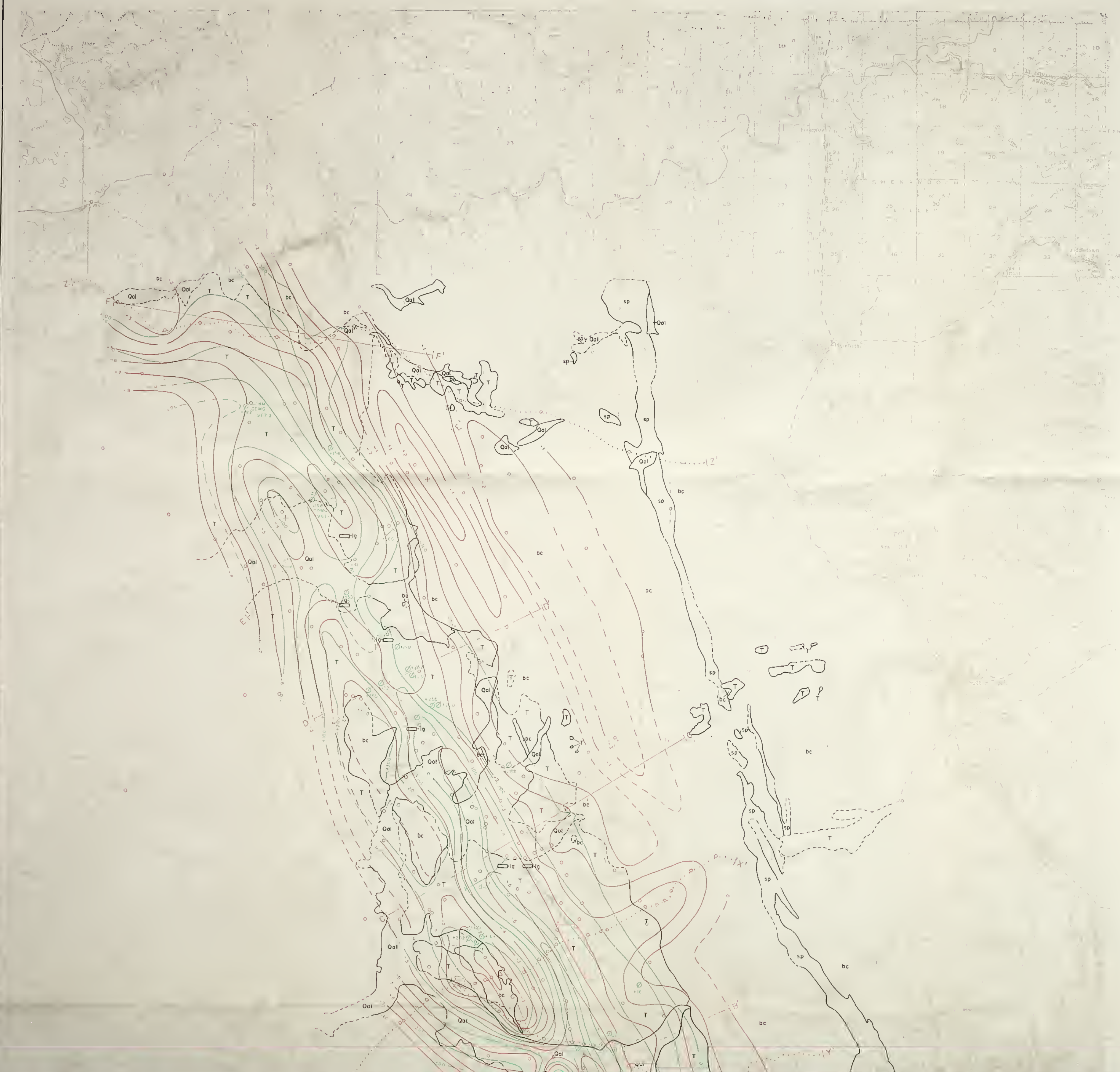
cipal known lignite deposits appear to be located near the margins of the basin, laterite deposits may be found on or near buried basement ridges, and sand and gravel units found in the deeper parts of the basin may be possible sources of water or placer gold.

Magnetic data were not used to outline structures in the basement rocks in this area but were found to be useful in locating certain rocks with anomalous magnetic properties, such as serpentinite or volcanic rocks of the Mehrten Formation. Resistivity methods were found to be of doubtful value in detecting lignite beds but might be useful in other problems such as locating shallow deposits of clay or sand.

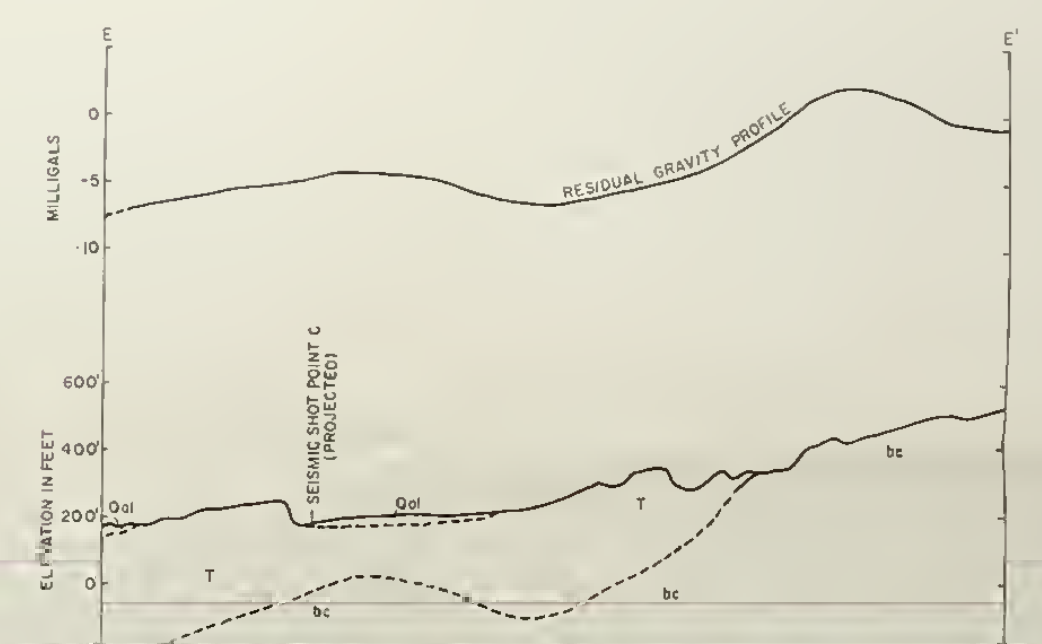
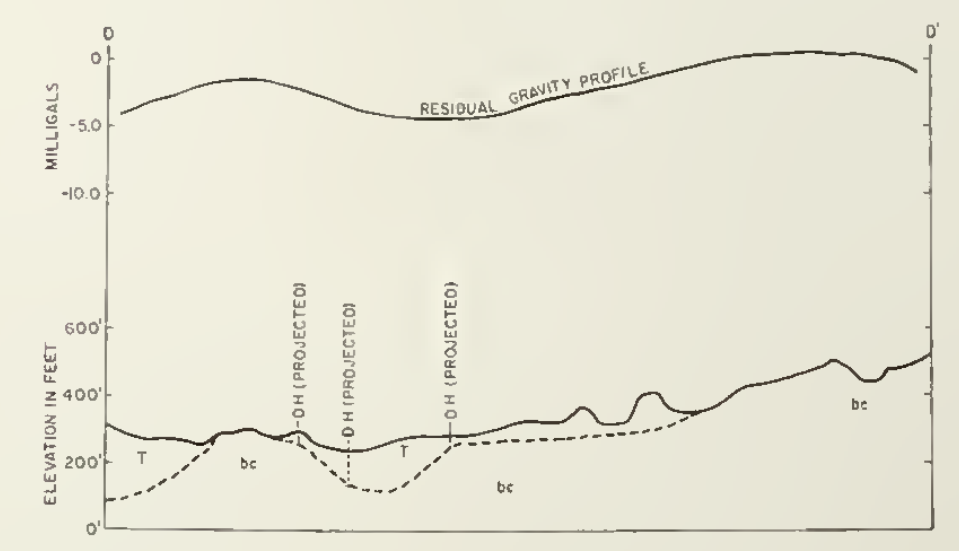
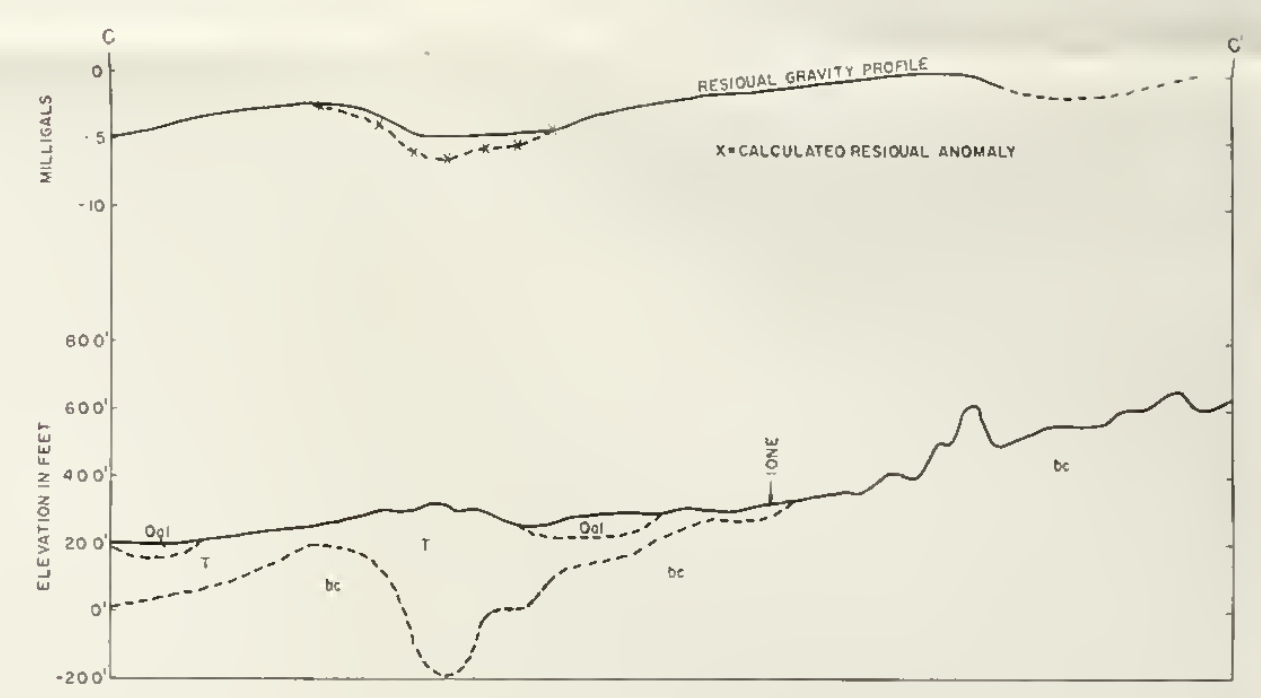
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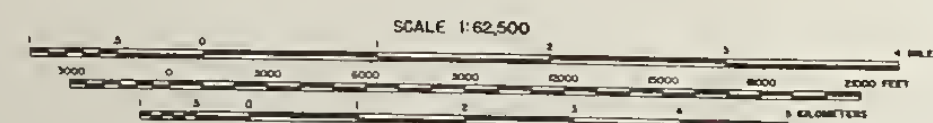


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MAP OF IONE AREA SHOWING - GEOLOGY, RESIDUAL GRAVITY, INTERPERETED CROSS SECTIONS AND CONTOURS ON BASEMENT SURFACE

By RODGER H. CHAPMAN and CHARLES C. BISHOP
1975

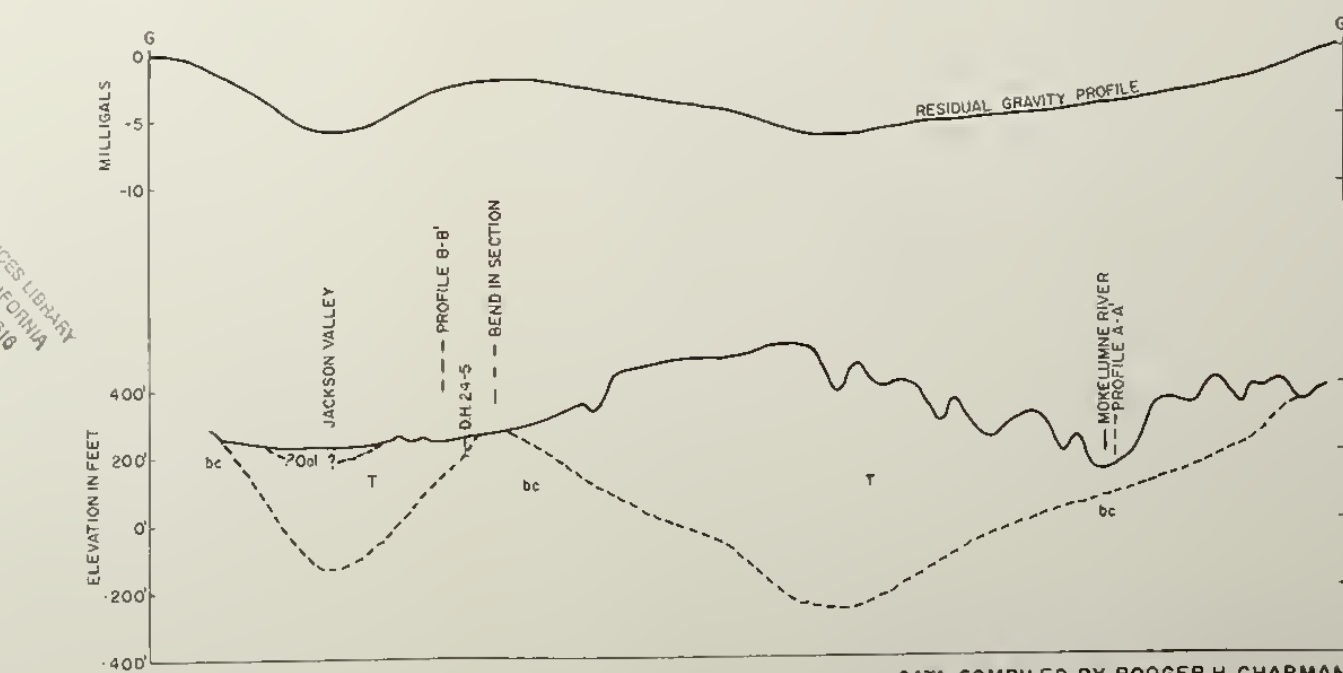
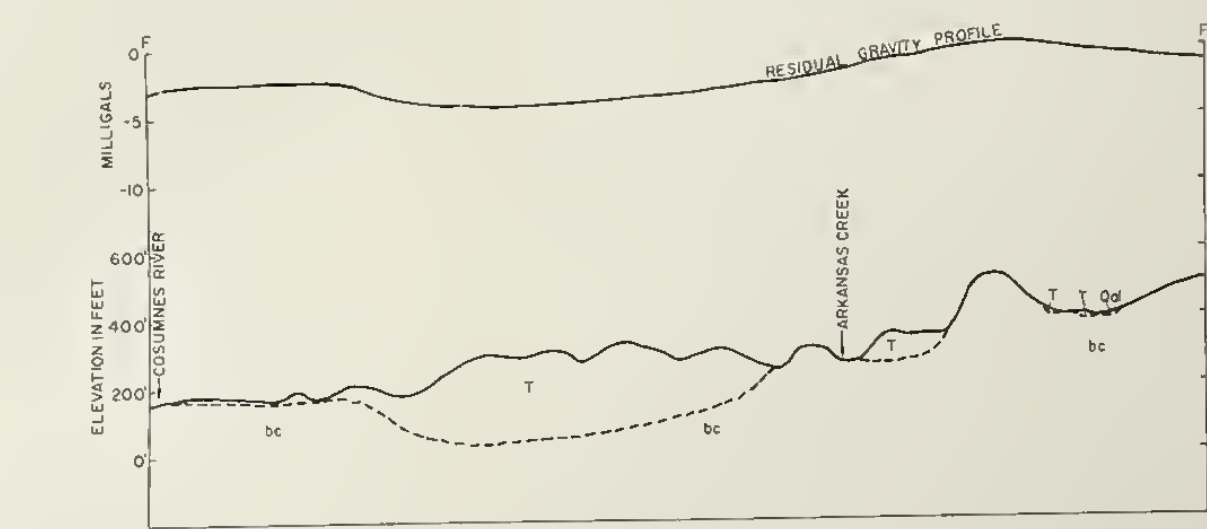
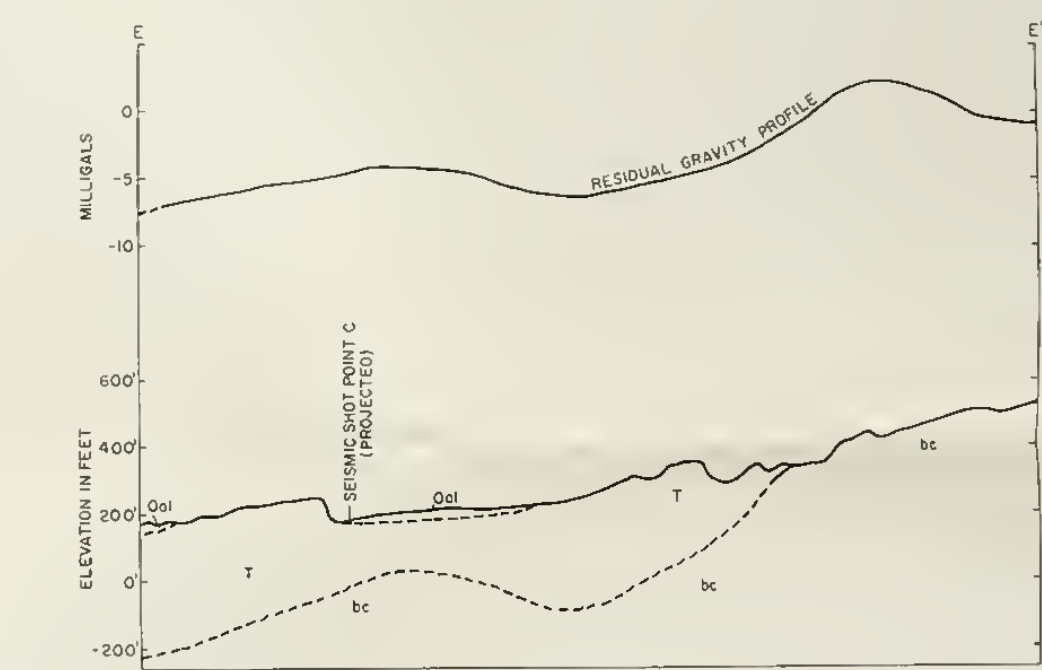
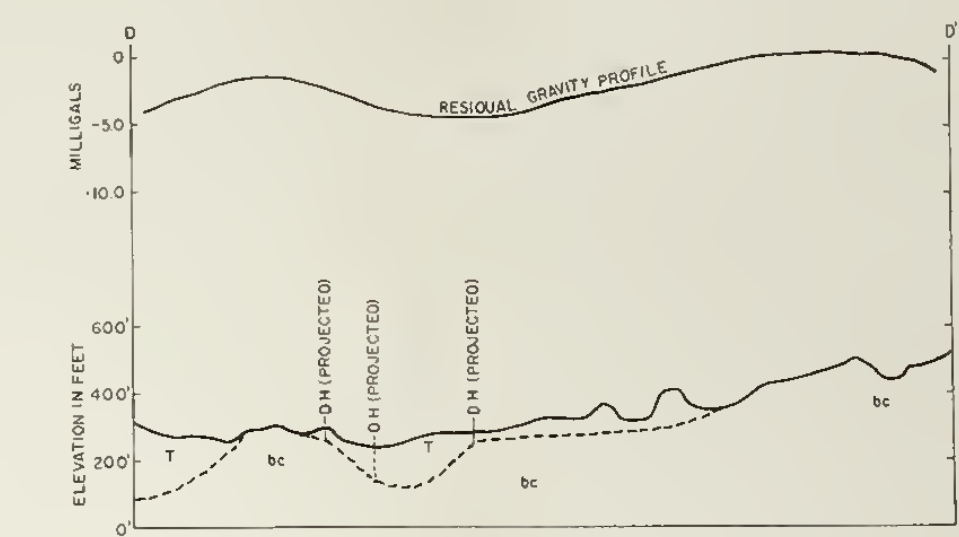
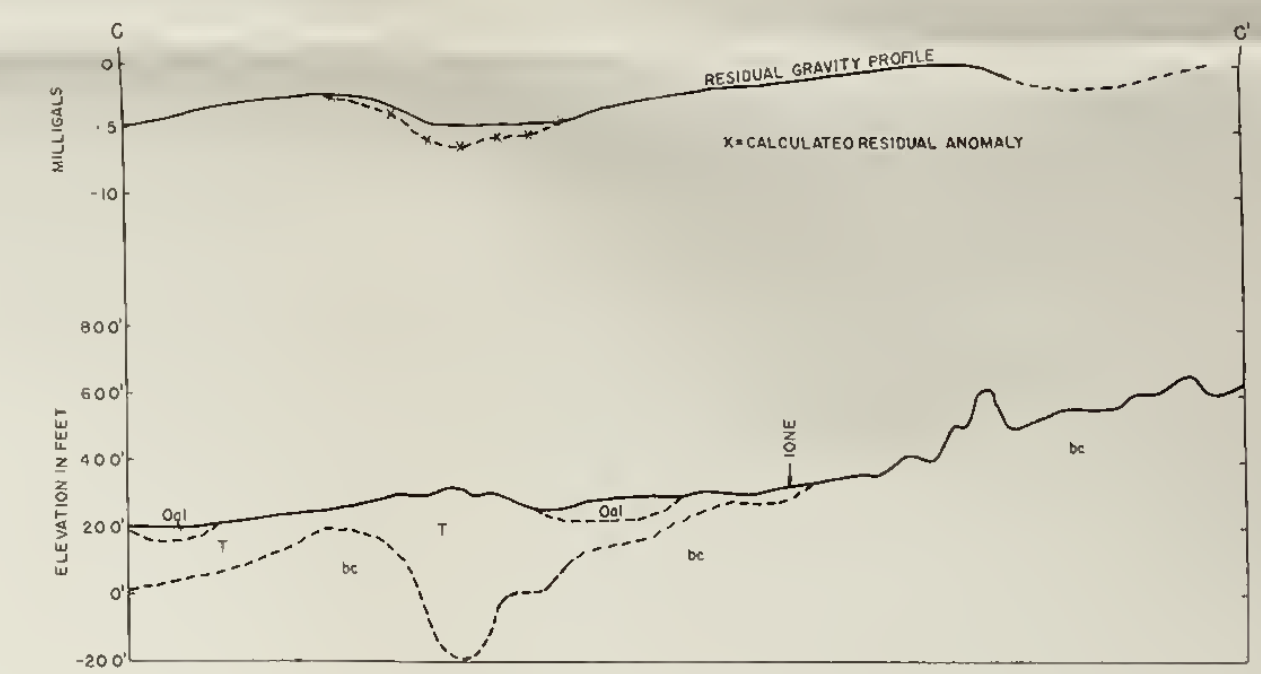


EXPLANATION

- | | |
|---|--|
| Qal Quaternary alluvium | ○ Gravity station |
| T Tertiary sedimentary rock | — Seismic refraction line |
| bc Basement complex | Δ Gravity profile |
| sp Serpentine | X-Magnetometer profile |
| lg Lignite deposit | # Resistivity sounding |
| — Gravity contour (interval: 1 mgal) | ○ Drill hole showing elevation of basement |
| — Basement surface contour (interval: 100') | |

GEOLOGY MODIFIED FROM PIPER AND OTHERS (1939, PLATE 1) AND TALIAFERRO (1949)

TOPOGRAPHIC BASE BY U.S. GEOLOGICAL SURVEY
This map is a reduction of 1:24,000-scale published maps



DATA COMPILED BY RODGER H. CHAPMAN
AND CHARLES C. BISHOP (1967-1971)

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