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Seismic investigation of flint clay deposits in East Central Missouri

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SEISMIC INVESTIGATION OF FLINT CLAY DEPOSITS IN EAST CENTRAL MISSOURI

BY

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THESIS

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ABSTRACT

Seismic refraction surveys were conducted in several localities within the east central Missouri clay districts in order to determine the applicability and economy of this method as a clay exploration tool. Results of these surveys revealed that the sink-type clay deposits possess lithologic and structural characteristics that lend themselves favorably to this method of exploration.

Seismic records obtained from profiles shot across known deposits indicate that several factors other than velocity contrast serve to produce apparent seismic anomalies.

Some unforeseen time loss and expense was encountered because of malfunctions of the seismic equipment employed, which necessitated the purchase and installation of repair parts.

A comparison of the seismic refraction method of clay exploration with the wildcat auger drilling method presently employed indicates that the seismic method is the more economical. On the basis of present evidence, this method of exploration for clay deposits occurring in sink structures appears to be practical.

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This report testifies to the splendid and wholehearted cooperation of the entire group of employees and officials of both Missouri School of Mines and A. P. Green Firebrick Company who were in any way connected with the execution of the research.

The author also wishes to acknowledge the help of Dr. Maxwell in the compilation and writing of this thesis. His suggestions and constructive criticisms are greatly appreciated.

I. INTRODUCTION

A. Purpose of Investigation

This investigation was undertaken in order to attain, if possible, two principal objectives:

1. To determine whether the sink-type clay deposits of east central Missouri possess any seismic, structural, or lithologic properties or characteristics by which their presence and location might be detected, using seismic refraction exploration methods.
2. To develop seismic refraction procedural methods that would improve the economy and efficiency of exploration in the fire clay industry, if the presence of these deposits proved to be detectable by refraction methods.

B. Location

The localities and clay deposits at which refraction surveys were conducted lie principally in Gasconade and Osage Counties. These counties comprise a large part of the area known as the southern clay district of east central Missouri. A limited amount of work was also conducted on clay deposits occurring in Audrain County, Missouri, which lies within the clay producing area known as the northern clay district of east central Missouri. The localities and deposits from which seismic data were obtained are considered to be typical of these districts.

Localities at which seismic investigations were conducted that lie within the southern clay district (south of the Missouri River) are shown on Missouri Geological Survey Topographic maps of the Bland, Gerald, Morrison, and Mokane quadrangles.

C. Method of Investigation

Seismic refraction records were obtained from profiles shot over known clay deposits and from profiles shot in the general vicinity of known clay deposits. Data obtained from the records were interpreted as an indication of the lithology, attitude, and structure of the sediments underlying a residual overburden. Noticeable differences in the characteristics of records obtained from adjacent profiles were interpreted as an indication of anomalous conditions in the subsurface strata.

II. REGIONAL GEOLOGY

In describing the geology of the clay producing region of east central Missouri, it is appropriate to consider the two major areas of occurrence separately as it appears that geologic controls which governed the physical and mineralogical nature of the deposits were not uniform throughout the region during the time of their origin. Evidence also indicates that certain geologic agents have been influential in bringing about diagenetic changes in some deposits, and that the degree of change may have been influenced by the physical and structural setting of the deposits so affected.

> According to KELLER, WESTCOTT, and BLEDSOE (1953, p. 13) "Despite similarity in the depositional basins of the fire-clay districts north and south of the Missouri River, at least two differences distinguish them. South of the Missouri River, the base of solution work was so low that deep (200 feet plus) sinkholes formed; whereas to the north, the base level of erosion was a third to a fourth of that depth. We infer from this, and from other evidence to be stated later, that the southern region was a more positive, higher, and more stable land area than the northern district, and, therefore, that deeper solution basins (sinkholes) formed in the south than toward the north. A second difference is that the clay minerals in the southern (presumably higher land) portion have been leached of silica and fluxing cations to a greater extent than those in the north."

Investigative work was restricted almost entirely to localities and deposits lying within the southern clay district. A limited number of records were obtained from one deposit in the vicinity of Mexico, Missouri. Because the allotted time schedule did not permit a more thorough investigation in this area, however, no final conclusions regarding the applicability of the seismic refraction method in the northern clay district are possible at present.

The following geographic and geologic descriptions pertain to the southern clay district.

A. Geography of the Southern Clay District

This clay producing district lies in the north central section of the Ozark Plateau. It is bounded on the north by the Missouri River, and on the south by the Meramec River. The southwestern margin of the district is delimited by Spring Creek and the Gasconade River, and the northwestern margin by the Osage River. The area encompasses all of Gasconade County and portions of Osage, Maries, Phelps, Crawford, and Franklin Counties.

In this district the clays occur in conical or bowl-shaped sink structures. The clay types include flint fire clay, burley, and diaspore clay. The deposits are associated with the Ordovician-Pennsylvanian regional unconformity on which the basal Graydon conglomerate and sandstone was deposited.

B. Topography

The area is drained by a system of deeply entrenched meandering streams that apparently have been rejuvenated on a rather well developed peneplain. This has resulted in the somewhat rugged topography along the principal streams, with gently rolling uplands forming the most prominent topographic features of the area. A maximum relief of approximately 700 feet has been developed (although this considers the two extremes of elevation) between points which are separated by some 50 miles.

C. Stratigraphy

The southern clay district is underlain by a series of carbonate and clastic sedimentary rocks ranging in age from Cambrian to early Pennsylvanian, and comprising a total thickness of 1,500 to 2,000 feet. The generalized stratigraphic column shown in figure 1 is representative of the southern margins of the district; figure 2 (McQUEEN, 1943) is a cross section through Osage, Gasconade, and Franklin Counties.

Several of the underlying carbonate formations have been subjected to highly localized and prolonged solution, apparently by percolating ground water, during one or more periods of the geologic past. The relatively high degree of solubility of the dolomites is evidenced by the large number of caves, large springs, and solution chambers exposed in the lower Paleozoic formations of this area.

The sedimentary rocks possess a slight regional dip to the north. Locally their attitude has been influenced by the presence of a series of northwest-southeast trending folds.

One of the major unconformities of the stratigraphic column of this area involves extensive weathering and erosion of Mississippian and older formations; also,

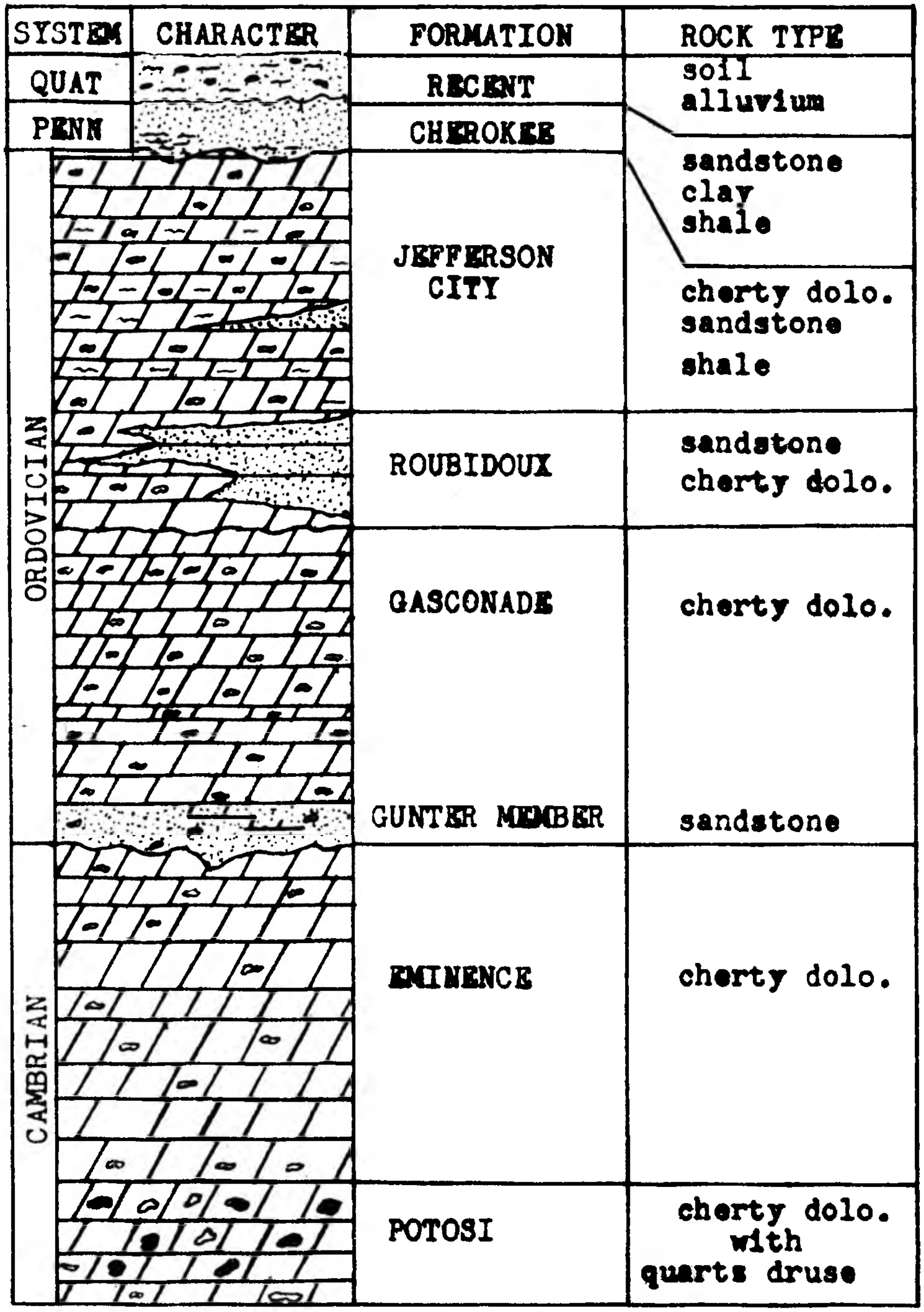


Figure 1. - Generalized stratigraphic column of southern clay district. (GRAWE, 1945)

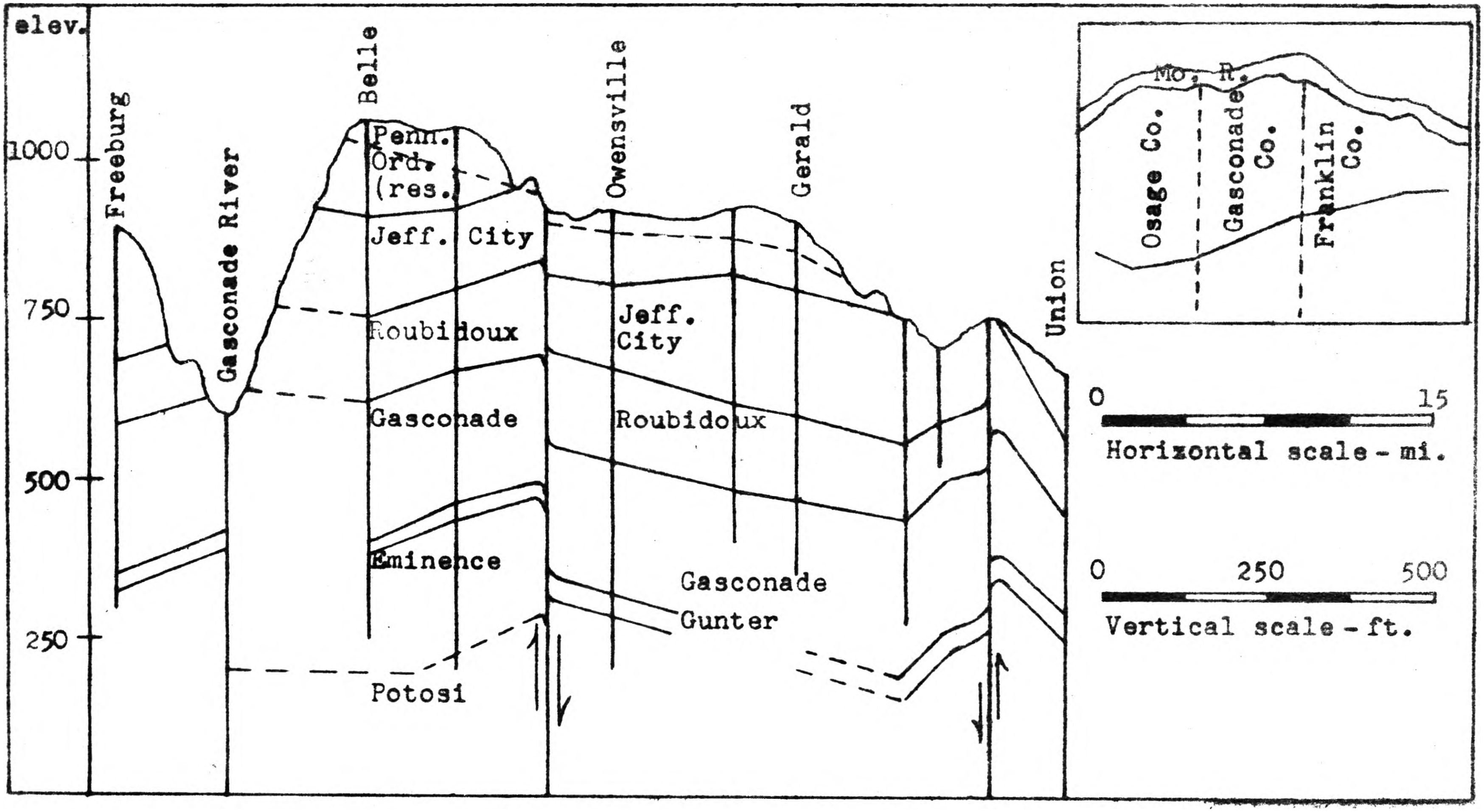


Figure 2. - General geologic cross section, Freeburg, Missouri to Union, Missouri. (McQUEEN, 1943)

deposition, during early Pennsylvanian time, of the basal Graydon conglomerate and overlying sandstone on the bevelled and truncated older Paleozoic formations dipping off the Ozark Dome. The Graydon conglomerate in this area evidently represents a transgressive depositional environment upon an erosion surface that contained large quantities of residual chert.

The sink-type clay deposits of the southern clay district all cut vertically across the horizon of this unconformity, and are located at the contact of the Graydon conglomerate and the underlying Jefferson City dolomite formation. Exposures of the Graydon formation reveal a somewhat variable thickness. It is apparently entirely absent in some of the localities studied and reaches considerable thickness in others. McQUEEN (1943, p. 34) describes the thickness of the Graydon formation as being highly variable and ranging from zero to at least 50 feet. Mr. J. F. Westcott, Chief Geologist, A. P. Green Firebrick Co., stated that the thickest sections of the Graydon observed by him have been somewhat less than 50 feet. (1961, personal communication)

III. GEOLOGIC SETTING OF THE CLAY DEPOSITS OF THE SOUTHERN DISTRICT

A. Geophysical Requirements

In the consideration of any exploration method, a knowledge of the geologic setting, or habit, of the ore deposits on which the method is to be applied is of primary importance to the person conducting the work. If the presence of a buried ore body is to be indicated through the interpretation of data gathered by an indirect method of exploration, the deposit or its immediate surroundings must possess one or more physical characteristics that will provide a basis for reasonable interpretation of the data. This requisite quality may be provided by such properties as density, conductivity, magnetic susceptibility, etc. In the case of seismic refraction exploration methods, it is necessary that conditions within, or adjacent to the ore body, cause a recognizable seismic discontinuity upon the recorded data, or seismic record. This may result from a direct seismic velocity contrast between the ore body and its surrounding country rock, and also from favorable structural, stratigraphic and lithologic conditions associated with the deposit.

In order to make clear the relationships commonly existing between the sink-type clay deposits of the southern district and their surroundings, the subject of their occurrence will be discussed in some detail.

B. Description of Deposits

South of the Missouri River the clay deposits occur almost without exception as isolated individual, roughly circular or elliptical bodies ranging from a few feet to several hundred feet in width. Depth of the deposits varies only slightly less than the horizontal dimension, the deepest known being some 200 feet. The shape of the containing structures has been variously described as inverted cones, funnels, bowls, basins, and in fact, may exhibit any of these forms. Clearly, the most unique characteristic of the deposits is that they are contained within these oddly shaped structures occurring within certain stratigraphic horizons in Paleozoic carbonates of this region.

C. Clay Types

In general terms, the clays are referred to as flint, burley, or diaspore. These terms bear certain economic and mineralogic connotations because they indicate the approximate alumina content of the particular clay type. Higher alumina clays are the more valuable. The approximate alumina content that governs the name applied to a particular clay type is given by McQUEEN (1943, p. 188).

	Percent Alumina
No. 1 Diaspore....................	+70
No. 2 Diaspore or No. 1 Burley....	+60
No. 2 Burley......................	+50
Burley Flint......................	+45
Flint Fire Clay...................	45 and less.

D. Origin

A considerable number of investigations have been made regarding the origin of the structures within which the clay deposits occur. Geologists are in general agreement that the structures are the result of solution of the relatively soluble carbonates in which they exist.

KELLER, WESTCOTT, and BLEDSOE (1953, p. 12) offer the following explanation for the origin of the structures:

> "The inference that solution work played a dominant role in the weathering of the limestone-covered land surface across the entire clay-bearing area during post-Mississippian and early Pennsylvanian time is well justified. A karst type of topography is indicated, wherein sinkholes of practically all types were developed: those formed by collapse of the roofs of caverns, by joints being enlarged, and by basins being deepened and widened by solution of the floor and walls concurrent with a variable rate of filling. Mining of clay has exposed certain ill-defined trends of apparently sinuous patterns which suggest that some surface streams connected the Pennsylvanian-age sinkholes."

GRAWE (1945, p. 180), in describing the pyrite-bearing sink structures of Missouri, makes the following statement:

> "Regardless of what his personal opinion may have been regarding the origin of the pyrites and iron ore, every geologist who has studied the deposits of these minerals in the northcentral Ozark Plateau has agreed that they are associated with structures which are the result of the solution of dolomite by groundwater. Crane[19], called these deposits "filled sinks," but he was well aware that they were not the result of the simple filling of surface sink-holes. His term is concise, but, because it does convey the idea of a filled surface sink, it is deceptive, and therefore the writer prefers to use the term, "sink structure." This appears to be especially appropriate because the sink structure is far more extensive than the ore body within it."

E. Structural Relations

Observations reveal that the structures in which the clay deposits occur commonly extend in all directions horizontally for considerable distances beyond the boundaries of the clay deposits themselves. The presence of the sink structure is often indicated by the changing attitude of the normally horizontal carbonates and clastics forming the stratigraphic horizon in which the structures occur. Not uncommonly, these beds begin to exhibit a gentle dip toward the center of the structure at distances of several hundred feet from its center. The dip normally increases gradually as the observer approaches the sink structure until, at the wall of the solution chamber, it changes very rapidly. The Pennsylvanian clastics often assume a near vertical attitude to form the so called "rimrock," a term applied by local prospectors.

A companion (and a causal) feature accompanying the centroclinal dip is often visible thinning of the carbonate beds around the perimeter of the solution chamber. This feature suggests that the country rock surrounding the sinks was subjected to solution and leaching by percolating waters flowing toward the center of the sink structure. As a result, the percentage of insoluble residual material left in the carbonates around the perimeter of the clay deposits is often noticeably higher than normal.

The thinning of carbonate beds is often accompanied by a thickening of the Pennsylvanian Graydon conglomerate and sandstone toward the solution chamber, filling the space formerly occupied by the normally horizontal carbonates. The result of this is a relatively level horizon upon which the post-Graydon overburden material is distributed.

F. Weathering

An additional feature exhibited in many flint clay deposits is a zone of weathering, oxidation, and increased fracturing in their upper margins. These processes appear to have been active during both Paleozoic and recent times, and are no doubt continuing. An example of Paleozoic weathering of flint clay is cited by KELLER, WESTCOTT, and BLEDSOE (1953, p. 35).

> "Lenticular layers of diaspore and burley clay occur in the lower two-thirds of the deposit and dip gently toward the center. Flint clay extends across the top of the pit, becoming as much as 20 feet thick in some places. This flint clay is first-quality, clean, light-colored, hard, and fresh, except in an oxidized zone, two to six feet thick, which occurs at the very top of the flint clay. In this oxidized zone the flint clay is soft, shelly, discolored (yellowish brown), and weathered. It can hardly be distinguished lithologically from weathered flint clay which is exposed to present-day surface-weathering conditions."

G. Overburden

Except within a small area in Gasconade County, all of the sedimentary rocks that may have overlain the southern district clay deposits have been removed by erosion. Overburden material consists of an accumulation of unconsolidated clastic sediments, residual, alluvial, and wind-blown soils.

Near the base of the overburden there occurs a layer of chert gravel. This material can be described as rather uniformly-sized pebbles (one to two-inch diameter), rounded, and poorly bedded. The gravel occurs rather widespread south of the Missouri River and exhibits a highly variable thickness. It may be entirely absent in one area, and in another attain a thickness of 30 feet. Unusually thick occurrences are normally limited to restricted areas, which the author believes to be buried stream channels.

The presence of this material above the clay horizon considerably increases the difficulty and expense of exploration drilling. Because of its damaging effect on drill bits, and the time required to drill through it, drilling costs are increased sharply in areas where it occurs in significant thickness. The layer is referred to by local miners and prospectors as "hardpan." Geologically, it has been tentatively identified as the "Lafayette" formation. According to KOENIG (1961, p. 129), it is of Pliocene age.

Although overburden thickness is known to vary considerably over the southern clay district, its thickness is, in general, rather uniform in a given locality. An average thickness of 12 feet would possibly be a reasonable figure when considering the entire district.

The "Lafayette" gravel is overlain by soils and subsoils of varying sand and clay content. In general, the clay content is quite high.

As a result of many years of prospecting, those deposits visible at the surface largely have been discovered and exploited. Discoveries being made at present are almost entirely the result of methodical subsurface exploration.

It is reasonable to expect that the geologic conditions described above will be present either singly or in combination in the locality of a given clay deposit. These conditions effectively influence the behavior of seismic waves. When present in the subsurface along the line of a seismic profile, they serve to produce anomalous seismic data. The manner in which seismic impulses are affected will be discussed in a later chapter.

Plate I

a. Exposed Graydon "rimrock" outlining clay deposit. Cave shown here extends downward several yards under steeply dipping massive sandstone.

b. Steeply dipping Graydon sandstone "rimrock," Holt pit #4, near Owensville, Missouri. Pencil in left center of photo is standing in vertical position.

Plate II

a. Open cut haul road entering Holt pit #4. Walls in foreground are composed of Graydon conglomerate overlying leached, argillaceous Jefferson City residual material.

b. North wall, Holt pit #4, showing overburden-"rimrock" contact with lense of Lafayette (?) gravel (arrow) at base of overburden.

Plate III

Vertical Graydon sandstone "rimrock" forming wall of clay deposit. Massive sandstone extends in semicircle around major portion of deposit (now mined out). Sandstone face shown is natural clay-rimrock contact, not result of mining activity.

IV. DESCRIPTION OF THE EQUIPMENT

The seismic equipment employed for the field work was a thirty-two trace reflection seismic unit mounted within an enclosed cab upon a one ton truck. The unit was constructed and originally used by Magnolia Petroleum Company. The inherent complexity of this unit, together with its high frequency amplification system, detracted from its desirability for refraction work. However, because no other unit was available, it was decided to conduct the investigation with the equipment on hand.

The basic components of the unit consist of seismometers (geophones), which receive the seismic impulse from the earth generated usually by an explosive charge. (This signal is transmitted to the recording unit through a multiconductor cable.) Second, a testing unit in which geophones and cable may be tested for continuity and leakage to ground; third, the amplifying mechanism in which the signal from the geophone is amplified; fourth, an oscillograph which receives the amplified signal from the amplifier and records it on photographic paper by means of light reflected from a galvanometer mirror. The relative time of arrival of the signal is also recorded by means of timing lines superimposed upon the paper.

A hydraulically operated truck-mounted auger type power drill was employed for necessary drilling.

A. Geophones

The purpose of the geophone is to convert the vertical component of the earth's seismic oscillation into an electrical signal. Of several types, the most common and widely used is the electromagnetic type which was used during the investigation of this problem.

The electrical signal is created by suspending an inertial coil with respect to the moving frame or housing of the geophone. The frame comprises a magnet. Any relative movement between the spring suspended coil and rigidly fixed magnet produces a voltage across the terminals of the coil. This electrical impulse is then transmitted through a cable to the amplifying unit.

Geophones are constructed to provide maximum voltage output when subjected to an oscillatory movement of a desired frequency. This is the "natural frequency" of the geophone and is determined by the relation

$$T = 2\pi\sqrt{\frac{m}{k}}$$

where T = period
m = mass of coil
k = stiffness coefficient of the spring

Damping of the system is necessary in order that the frequency response be smoothed out over a slightly enlarged frequency range. Otherwise, the natural frequency will be exaggerated in the output.

B. Testing System

The testing circuit provides a means of testing the cable and geophones after all connections have been made prior to detonating the impulse-generating explosive. This insures that all connections are making proper contact, and that exposed leads are not touching ground. The testing unit includes an A.C. Balance circuit which enables the operator to balance with respect to ground any extraneous, steady state signal picked up by the geophones or cable. This type noise is generated by high-tension power transmission lines and other power sources.

C. Amplifiers

The amplifiers used with this seismic unit were designed for reflection seismograph work, the frequency pass band lying between 15 and 150 cycles per second. A range of filter combinations is provided within the above band so that it is possible to choose a filter position which will provide attenuation for all frequencies above and below the desired band. High and low pass filter sections within the amplifier make it possible to control the high and low frequency response or attenuation independently. The amplifier provides three stages of amplification of the seismic signal described as follows:

The signal from the geophone is stepped up in the input transformer and introduced in the grid circuit of the first stage tube where it is amplified and appears on the plate of the tube for transmission to the second stage tube. The input attenuator controls the amount of signal fed to the first stage. This transmission path to the second stage is through the coupling condenser of the first stage and the grid resistor of the second stage. The signal is amplified more in the second stage and is then transmitted through the high and low pass filter sections before being applied to the grid of the third stage tube for further amplification. After being amplified in the third stage the signal is applied to the fourth stage or power tube which utilizes the amplified signal to develop energy in the output transformer.

D. Oscillograph

The oscillograph receives the amplified signal from the amplifier, and transfers it to photographic paper by means of reflected light rays to provide a permanent record from which the observer makes his interpretation concerning substrata structures. The principal components are a paper drive motor, timing mechanism, and galvanometers.

Paper drive is accomplished by a 12-volt D.C. motor utilizing a chain and sprocket power train. Two sets of interchangeable chains and sprockets provide paper drive speeds of 12 and 15 inches per second. The paper magazine accommodates a roll of photographic paper 8 inches wide by 200 feet long. Special adapters are available for smaller paper widths. Paper coming off the roll is inserted between two wringer-type, cylindrical rubber rollers, one of which is activated by the sprocket in the driving motor power train.

The placing of accurately spaced timing lines on the photographic paper is controlled by a 100-cycle per second tuning fork and synchronous timing motor. With the tuning fork activated, the synchronous motor is set in motion by a small fly-wheel. The motor will only revolve at a speed synchronized with the tuning fork. A 12-volt light source beamed through a narrow slotted window is enclosed within the revolving cylindrical shell of the timing motor. Milled slots in the shell are so arranged that they pass the window at 0.01 second intervals. Each fifth slot permits the passage of slightly more light than do the 0.01 second slots, and each tenth slot is still further accentuated. The light passing through the slots is reflected onto and recorded upon the photographic paper, resulting in uniformly spaced timing lines indicating 0.01 second intervals, with each 0.05 second interval indicated by a slightly heavier line, and each 0.10 second interval by a still heavier line. These lines are perpendicular to the length of the paper.

The actual recording of geophone signals upon the photographic paper is accomplished through the use of pencil-type magnetic coil galvanometers, upon the bodies of which are fastened small mirrors. Light from a steady source within the oscillograph unit is reflected from the mirrors onto the photographic paper. The geophone signal, after being amplified, is conducted to the galvanometer. This impulse induces a rotation of the galvanometer mirror; the magnitude of the rotation is proportional to the strength of the impulse. The result of this motion is a disruption of the otherwise relatively straight line or "trace" upon the record. Each trace represents a geophone, and therefore a location with respect to the seismic source.

E. Geophone Cable

The geophone cable consists of 12 twisted and individually insulated pairs of 28-gauge copper wires. The entire assemblage is encased in a neoprene or live rubber insulating jacket. Pairs of geophone connecting leads, or takeouts, are spaced at regular intervals along the length of the cable. This permits geophone spacings upon the ground at any desired distance equal to, or less than the takeout interval of the cable. Individual takeouts of each pair are identified by color and size of the connecting space to insure that all geophones are connected in the same manner. Should connections be reversed, the first arrivals will be of opposite phase, making the record more difficult to interpret.

Takeout interval of the geophone cable used during this problem was 80 feet.

F. Drilling Equipment

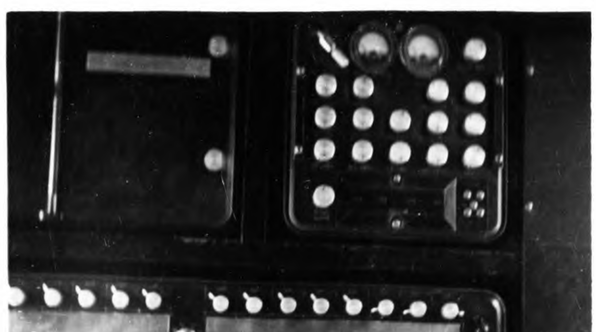
A truck-mounted power auger drill was used for the purpose of drilling shot holes. The vehicle on which the drill was mounted was a 4-wheel drive, one and one-half ton International Truck. Rotary power was imparted to the drill through a power take-off unit and gear train originating at the transmission of the truck. A two-way hydraulic pumping system permitted lowering and hoisting of drill stems. The hydraulic system was also activated from the power take-off shaft. Both systems relied upon the truck engine as a power source.

Approximately 45 feet of auger drill stems or "flights" were carried in specially constructed racks on the truck. These flights were each 3 feet, 4 inches in length, and 6 inches in diameter. Flights could be connected together to form a drill string of any desired length within depth capacity of the drill. Maximum drilling depth was considered to be approximately 35 feet. Greater depths were possible at the risk of drill string loss, either through twisting off, or failure of the drill collar couplings. The drill bit contained eight sockets, or chucks, into which replaceable tungsten-carbide tipped steel teeth could be locked.

Because of its capability of penetrating the "hardpan" described earlier, this type drill was considered to be very satisfactory as a shot hole and exploration drill.

Plate IV

a. Truck and cab enclosed seismic unit employed during seismic experiment.



b. Partial view of seismic unit showing power control (upper right) and amplifier sensitivity controls.

Plate V

a. Breast reel, geophone cable and geophones. A single geophone is shown attached to cable.

b. Truck mounted auger drill employed for drilling shot holes during experiment.

V. DIFFICULTIES ENCOUNTERED

During the course of the field work, several problems of various types were encountered. Of these, some were of a permanent nature and required continuing attention. Others were only transitory considerations. It must be admitted that perhaps some originated and remained unsolved as a result of the author's limited experience. Some were corrected more or less by accident. It is hoped that a discussion of those problems considered to be most significant will be of some value to the reader.

A. Electronic Malfunctions

During the early phases of the field work, it was noted that a random and unpredictable electrical coupling or cross-feeding effect was becoming apparent in the seismic records. This condition is evidenced by premature "breaks" of the galvanometer traces upon the record. It may involve several traces either adjacent or scattered across the record. These breaks appear much the same as an authentic seismic break, and obviously render the record useless. Superficial interpretation would indicate an infinite seismic velocity, since several traces may break simultaneously.

The condition was unexplainable on the basis of procedural errors. Precautions were taken to insure that the unit was not subjected to any mechanical motion during the taking of a record.

It was recognized that an airborne shock originating at the shot point could be responsible for some mechanical movement of the galvanometers. Ground roll also could be a possible source. The effect of either of these forces was not considered to be probable, however. The explosive charge was being detonated at an average depth of 8 or 10 feet under the surface and several hundred feet from the seismic unit. This procedure was considered adequate to minimize the effect of shock wave, and also place the arrival of any low frequency ground roll considerably later than the first arrivals.

Obviously, the source of this type of disturbance can be very difficult to determine, since it may originate at one or several localities between the geophone and galvanometer.

Inspection of the geophone cable revealed splices into which water had apparently penetrated. Discoloration of the silk insulating material surrounding the individual conductors indicated that some current leakage might be occurring at these localities. It was also noted that some loss of conductor insulation had occurred at the Cannon connecting plugs at the ends of the cable. Subsequent cable repairs reduced, but did not eliminate the original difficulty.

A thorough inspection of the seismic unit was made in the field by Mr. Denver Hudson, Electrical Superintendent of A. P. Green Firebrick Company. Mr. Hudson suggested that the unit be taken to the electrical shop at their plant in Mexico, Missouri. Locating the source of malfunction of the equipment was facilitated by the use of their modern testing instruments available in the shop.

Testing of signal circuit wiring located inside the seismic truck revealed some electrical leakage of insulation. This condition is believed to have been brought about by condensation of moisture inside the truck when it was left out-doors at night. Several gallons of water were present inside the truck at all times during the day, in the form of fixing and developing solutions for the development of seismic records. Although these solutions were discarded at the end of each day's operation, sufficient moisture was present to cause considerable condensation within the tightly sealed truck during the cool nights. This condensation on the old and deteriorated insulation of the signal circuitry could explain its failure. The faulty wiring was replaced with new wire of similar size and resistance.

Following the repairs, a detailed inspection and test was performed on the component parts of each amplifier in use. The type of amplifier being used incorporates a 10-microfarad condenser at each stage of amplification. These are provided to absorb the fluctuations in voltage caused by changes in plate current of the various tubes as they are amplifying the geophone signal. If this voltage variation is not absorbed, it affects the other amplifiers and results in a regenerated type of cross feed.

Tests on these condensers revealed that many had lost some degree of polarity, resulting in a collapse voltage at or below the minimum requirement. The faulty components were replaced as they were discovered.

As a result of the repairs described, record quality was greatly improved. It remained necessary during succeeding field work, however, to detonate the explosive charge at least 50 feet from the nearest geophone. Otherwise, cross feeding would recur, but never to the extent that had been previously present. No satisfactory explanation for this condition can be given. It is suggested that a greater electrical charge was generated by the geophone when in close proximity to the explosive charge, and that this resulted in capacitance breakdown at some point in the signal circuitry. In this regard, however, the geophone cable had been previously tested by connecting each conducting pair to a step-down transformer having an output of 6.3 volts, A.C., and metering all other pairs for leakage. No evidence of leakage had been found. This test was not conducted on other elements of the circuitry.

In summary, it is concluded that the cross feeding was largely the outgrowth of an accumulation of malfunctions at several locations within the signal circuitry. No other serious electrical problems were encountered during the field work.

B. Transitory Disturbances

In order to improve the economy and resolving ability of seismic exploration equipment, two characteristics are inherent in its component parts. These are the acute sensitivity of the geophone, and the ability of the amplification system to increase greatly the magnitude of the signal which the geophone transmits. While these properties are of prime importance in the useful application of seismic exploration methods, they are also occasionally the indirect cause of certain unwanted disturbances. Such events are collectively referred to as "noise."

Earth movements on the order of 10^{-8} inches yield distinguishable deflections on a seismic record. Such movements may be initiated by relatively slight forces that are of an accidental nature. Any unwanted signal detracts from the quality of the record.

The operational problem is concerned chiefly with amplitude control of seismic impulses and noise preceding their arrival. The desired end result is that the above events may have optimum amplitude relationship to one another.

It may be approximated that the seismic energy at a given geophone location, resulting from an explosive charge of given size, is inversely proportional to the square of the distance between shot point and geophone. (This assumes that propagation and travel of the seismic impulse takes place within a given medium.)

The above relations impose certain procedural restrictions upon the observer. Specifically, he must select a signal amplification level that will provide recognizable seismic deflections under certain distance and charge size limits. He must also strive to keep out any extraneous noise that will impair the quality of his seismic data. Several of the noise disturbances most frequently encountered during the field work are described below.

1. Farm Machinery and Vehicles: The field work was conducted entirely on privately owned property. Although seismic activity was restricted to uncultivated portions of the various properties, these areas were frequently adjacent to land parcels being used for crop raising. Farm activities such as cultivation, weed killing, and crop harvesting were in progress during most of the period while field work was being conducted. Such mechanized activities create seismic disturbances that travel considerable distances and appear usually as uniform oscillations on the oscillograph screen. In this situation it is necessary and usually possible to arrange the shot time (normally a matter of several seconds) to coincide with a period when the activity has either lulled, or is occurring at some distance from the geophone spread. A distance of two to three hundred yards between geophones and the source of such a disturbance is usually adequate to provide sufficient attenuation of the noise.

2. Airplanes: A propellor-driven airplane in flight, even beyond hearing distance, noticeably affects the stability of the galvanometer traces. Apparently, high-frequency shock waves originating at the plane's engine are received

both in the ground and upon the surface of the seismic instrument. This condition is distinctly recognizable on the screen, since the disturbance on all traces assumes a rythmic frequency synchronized with the throbbing of the engine. When such noise occurs, it is necessary to delay the shot until the disturbance is no longer visible on the screen.

3. Livestock: A major part of the field work was conducted on pasture lands, some of which was in use for stock grazing. The presence of large moving animals in the immediate vicinity of a geophone spread causes noticeable activity upon the oscillograph screen. This type noise, if recorded, appears as very irregular oscillations of varying frequency and amplitude. No correlation is discernible between traces, nor does an individual trace exhibit a rythmic pattern. Obviously, it is necessary that livestock be directed away from the geophone spread before a record can be obtained. It should be mentioned, also, that every precaution should be taken to prevent livestock from crossing the geophone spread, because serious cable damage could result. It was observed that disturbances of this nature were limited to early morning and late afternoon periods, as animals usually seek shade and lie quietly during the day.

4. Rodents: The activity of ground-dwelling rodents may create noticeable disturbances. Normally, however, this will be apparent only on one or two individual traces within

the spread. It was observed that these disturbances were particularly prevalent in wooded areas. Burrowing by mice and moles when carried on in close proximity to a geophone will cause violent and irregularly intermittent oscillations on the affected trace. Prodding the ground thoroughly in the neighborhood of the disturbance will usually serve to quiet it temporarily. The record may be taken during this period.

5. Insects: Large insects, such as grasshoppers, are occasionally attracted to the metal geophone housings. This seemed to be common during periods of hot, dry weather in the late summer. The reason for this attraction is not apparent, but may be the result of salt deposits on the surface of the geophone housing from repeated handling of the geophones with perspiring hands. The habitual, rapid leg movement of these insects on the body of a geophone causes strong and erratic disturbances on the affected trace. The amplitude and irregular frequency of this noise is sufficient to render the trace useless. Occasional spraying of the geophones and leads with commercial insecticide will remedy this nuisance.

C. Explosive Charge Size and Depth

All phases of field work were conducted with a view toward keeping operational costs at a minimum. Aside from the apparent and immediate advantages of efficiency, this consideration was of major importance in comparing the practicability of seismic exploration methods with others.

A considerable part of the expense of seismic operations is associated with expenditure of explosives and drilling shot holes. In view of this, some variations were made in charge size and shot hole depth in an effort to determine a minimum cost for these items.

This problem was approached by holding one of the above variables constant and changing the other. It was found that when shot hole depths were limited to less than 6 feet, effective absorption of the explosive energy occurred in the plastic-clay subsoil, resulting in weak signals from the more distant geophones. Increasing the depth of shot holes noticeably increased the quality of seismic signals. Obviously, however, this caused an increase in drilling costs, particularly in overburden comprised, in part, of hardpan. Following these discoveries, it was decided to explore the practicability of shooting a greater amount of explosive in a shallow shot hole. Charges were detonated in holes of approximately 3½ feet depth. (Holes of this depth could be drilled without the necessity of assembling and disassembling the drill string.) This proved unsatisfactory, as an explosive charge of the size required to provide sufficient seismic energy at the most distant geophones caused serious open cratering of the ground. This condition was objectionable on privately-owned property and was most prevalent during extended periods of dry weather, which tended to harden the clay soils.

The results of these investigations indicated that a minimum shot hole depth of 6 feet was required. Minimum size of explosive charge was controlled by other variables, including depth of overburden, strength of explosive, and geophone spacing. These will be discussed in a following chapter.

VI. THEORY AND INTERPRETATION OF REFRACTION METHOD

The scope of this paper does not permit a thorough treatment of the subject of seismic refraction methods. It is assumed that the reader has some knowledge of their application and the basic laws of physics by which they are governed. Several textbooks dealing with this subject are available. These include those by Dix, Dobrin, Heiland, Jakosky, and Nettleton. There are also numerous technical papers available. The following paragraphs are intended to present the basic theories and assumptions that govern the interpretation of refracted seismic waves.

A. Mathematical Derivations

Repeated observations indicate that seismic waves propagated beneath the earth's surface are generally governed by two basic laws of physics. These are Snell's Law and Huygen's Principle.

According to these relationships, seismic waves are subjected to reflection and refraction at favorable interfaces encountered in their trajectory. In the case of refracted waves, the angle of refraction is governed by the seismic velocities of the media on opposite sides of the refracting interface. It is also generally true that seismic velocities encountered in bedrock greatly exceed those of unconsolidated overburden material.

According to DOBRIN, (1960, p. 26):

". . . $\frac{\sin i}{\sin R} = \frac{V_o}{V_1}$ (Snell's Law) . . . "

Where i = angle of incidence.
R = angle of refraction.
V_o = velocity of wave in upper medium.
V_1 = velocity of wave in lower medium.

Applying the above relationships, it may be seen that at a certain value of i, R will reach a value of 90^o. The value of i which results in this value of R is known as the critical angle of incidence, or critical angle, i_c. ($i_c = \sin^{-1} V_o/V_1$).

According to Huygen's Principle, every point in a wavefront is the source of a new wave that travels out from it in spheres. Consider the wavefront travelling parallel to the bedrock-overburden interface as a result of having impinged upon the interface at the critical angle of incidence. This wave will be continually refracted back to the earth's surface at the same angle and at velocity V_o. The arrival of the wave at the earth's surface may be detected by geophones placed at measured distances from a shot point. It will be noted that the seismic impulse that arrives first at a given geophone will be that impulse that has travelled by the fastest time trajectory. Although greatly simplified, this concept of the refraction of seismic waves is of prime importance in refraction work.

The relative time of arrival of the refracted wave at a given geophone is available from the seismic record. The distance of the geophone from the point of origin of the wave is measured. Based on these known data, a time-distance graph is constructed, using arrival times as ordinate and measured distances as abscissa. A given segment of the time-distance slope is inversely equal to the seismic velocity of the medium represented by that segment. That is, $\Delta T/\Delta X = 1/V$. Calculation of apparent velocities and evidence of their variations in a given area forms a basis for interpretations concerning the nature of subsurface material.

The simple case of overburden and bedrock in horizontal contact will serve to demonstrate the time distance relations existing between two such media. Figure 3 represents this condition.

At geophone locations sufficiently near the shot point, the wave path will be restricted to the upper medium. Waves travelling this path are known as direct waves. They travel at velocity V_o.

B. Horizontal Discontinuities

> According to DOBRIN (1960, p. 72), "The direct wave travels from shot to detector near the earth's surface at a speed of V_o, so that $T = x/V_o$. This is represented on the plot of T vs. x as a straight line which passes through the origin and has a slope of $1/V_o$. The wave refracted along the interface at depth z, reaching it and leaving it at the critical angle i_c, takes a path consisting of three legs, AB, BC, and CD. (See figure 3.) We make use of the following relations:

$$\sin i_c = \frac{V_o}{V_1}$$

$$\cos i_c = \left(1 - \frac{V_o^2}{V_1^2}\right)^{\frac{1}{2}}$$

and

$$\tan i_c = \frac{\sin i_c}{\cos i_c} = \frac{V_o}{\sqrt{V_1^2 - V_o^2}}$$

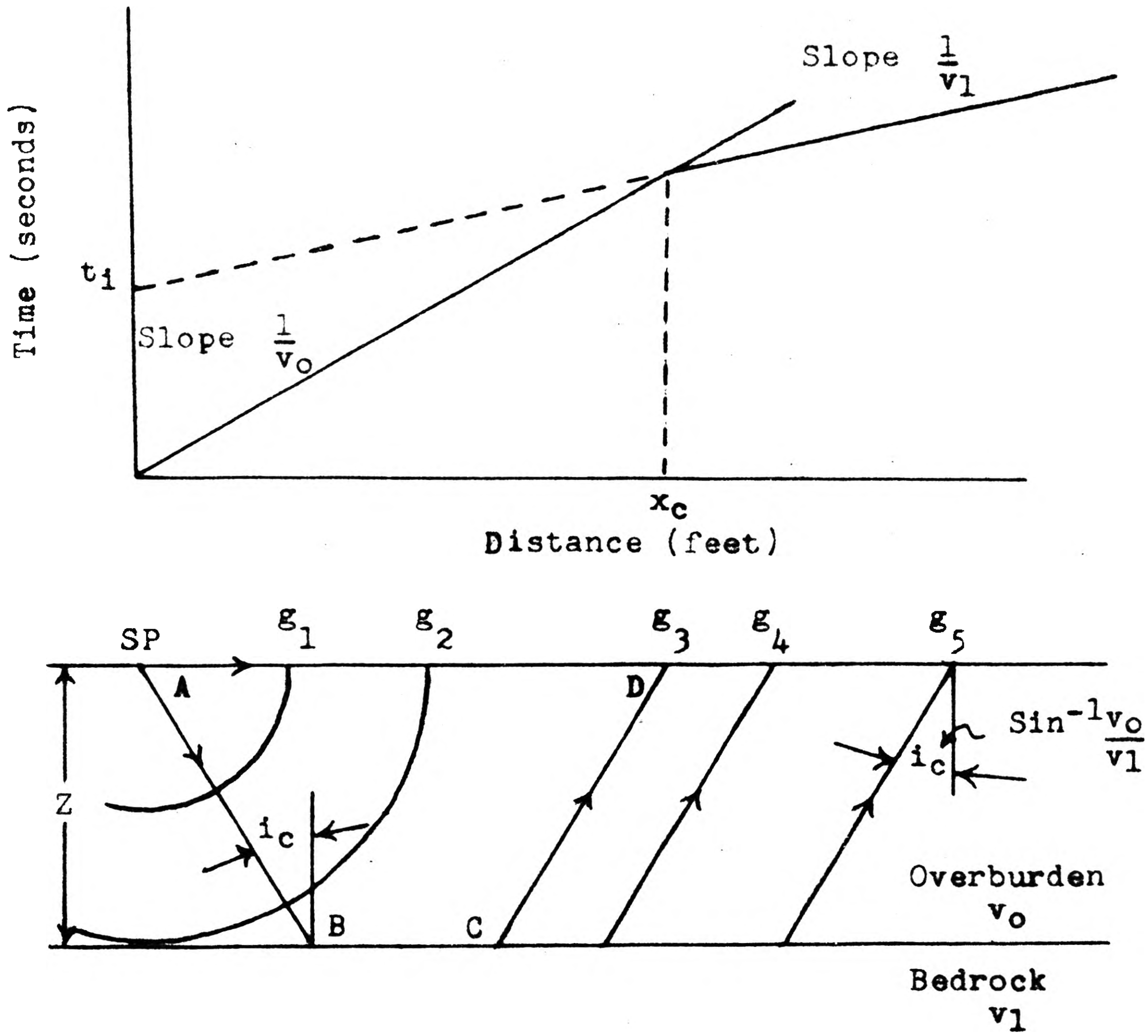


Figure 3. - Ray path and time-distance curve for refracted ray travelling path ABCD. (DOBRIN, 1960)

The total time along the refraction path ABCD is

$$T = T_{AB} + T_{BC} + T_{CD} \tag{5-1}$$

One can write Eq. (5-1) in the form

$$T = \frac{z}{V_o \cos i_c} + \frac{x - 2z \tan i_c}{V_1} + \frac{z}{V_o \cos i_c} \tag{5-2}$$

$$= \frac{2z}{V_o \cos i_c} - \frac{2z \sin i_c}{V_1 \cos i_c} + \frac{x}{V_1} \tag{5-3}$$

This can be readily transformed into

$$T = \frac{2z}{V_o \cos i_c}(1 - \sin^2 i_c) + \frac{x}{V_1} \tag{5-4}$$

$$= \frac{x}{V_1} + \frac{2z \cos i_c}{V_o}$$

$$= \frac{x}{V_1} + \frac{2z \sqrt{1 - (V_o/V_1)^2}}{V_o} \tag{5-5}$$

so that finally

$$T = \frac{x}{V_1} + \frac{2z \sqrt{V_1^2 - V_o^2}}{V_1 V_o} \tag{5-6}$$

On a plot of T vs. x, this is the equation of a straight line which has a slope of $1/V_1$ and which intercepts the T axis ($x = 0$) at a time

$$T_i = 2z \frac{\sqrt{V_1^2 - V_o^2}}{V_1 V_o} \tag{5-7}$$

T_i is known as the intercept time.

C. Critical Distance

At a distance x_c, (see figure 3) the two linear segments cross. At distances less than this, the direct wave traveling along the top of the V_o layer reaches the detectors first. At greater distances, the wave refracted by the interface arrives before the direct wave. For this reason, x_c is called the critical distance.

D. Depth Calculation

The depth z to the interface can be calculated from the intercept time by use of Eq. (5-7) or from the critical distance. In terms of T_i and the velocities V_o and V_1, Eq. (5-7) can be solved for z to obtain

$$z = \frac{T_i}{2} \frac{V_1 V_o}{\sqrt{V_1^2 - V_o^2}} \qquad (5\text{-}8)$$

T_i can be determined graphically (as shown in figure 3) or numerically from the relation $T_i = T - x/V_1$.

The depth can be solved for in terms of x_c, the critical distance, making use of the fact that

the times $T_o = \frac{x}{V_o}$ and $T_1 = \frac{x}{V_1} + \frac{2z\sqrt{V_1^2 - V_o^2}}{V_1 V_o}$

are equal to x_c. Then

$$\frac{x_c}{V_o} = \frac{x_c}{V_1} + \frac{2z\sqrt{V_1^2 - V_o^2}}{V_1 V_o} \qquad (5\text{-}9)$$

and

$$z = \frac{1}{2} \frac{V_o V_1 x_c}{\sqrt{V_1^2 - V_o^2}} \left(\frac{1}{V_o} - \frac{1}{V_1} \right) \qquad (5\text{-}10)$$

this simplifies to

$$z = \frac{1}{2} \sqrt{\frac{V_1 - V_o}{V_1 + V_o}}\, x_c \qquad (5\text{-}11)$$

. . . "

E. Vertical Discontinuities

Several seismic records obtained from profiles shot across sink-type clay deposits exhibited patterns similar to those found when shooting across a fault. This condition is described by DOBRIN (1960, p. 80).

> "If a high-speed bed (velocity V_1), situated under a low-speed overburden (velocity V_o), is faulted vertically as shown in figure 4, a refraction profile perpendicular to the strike of the fault often makes it possible to detect the faulting and measure the throw. Barton has calculated the time-distance curve for the case where the shot is on the upthrown side and the detector on the downthrown. The curve (figure 4) consists of two parallel but displaced linear segments having an inverse slope equal to the speed in the faulted formation. The segments correspond to arrivals refracted respectively from the upthrown and downthrown sides of the fault. The throw Z_t can be determined from the difference between the intercept times of the two linear segments.
>
> The curve for the case where the shot is below the fault is derived in a similar way."

F. Dipping Beds

Referring to figure 3, it is apparent that a wave being refracted along this horizontal interface and upward into an overburden layer of uniform thickness will indicate the true velocity in the bedrock layer. However, if the bedrock is dipping, and the upper surface of the overburden maintains a horizontal attitude, the true velocity of the bedrock layer will not be represented. The wave being refracted upward to the surface is required to travel an increasing or decreasing distance through the lower velocity overburden layer at each geophone station. The result is an apparent

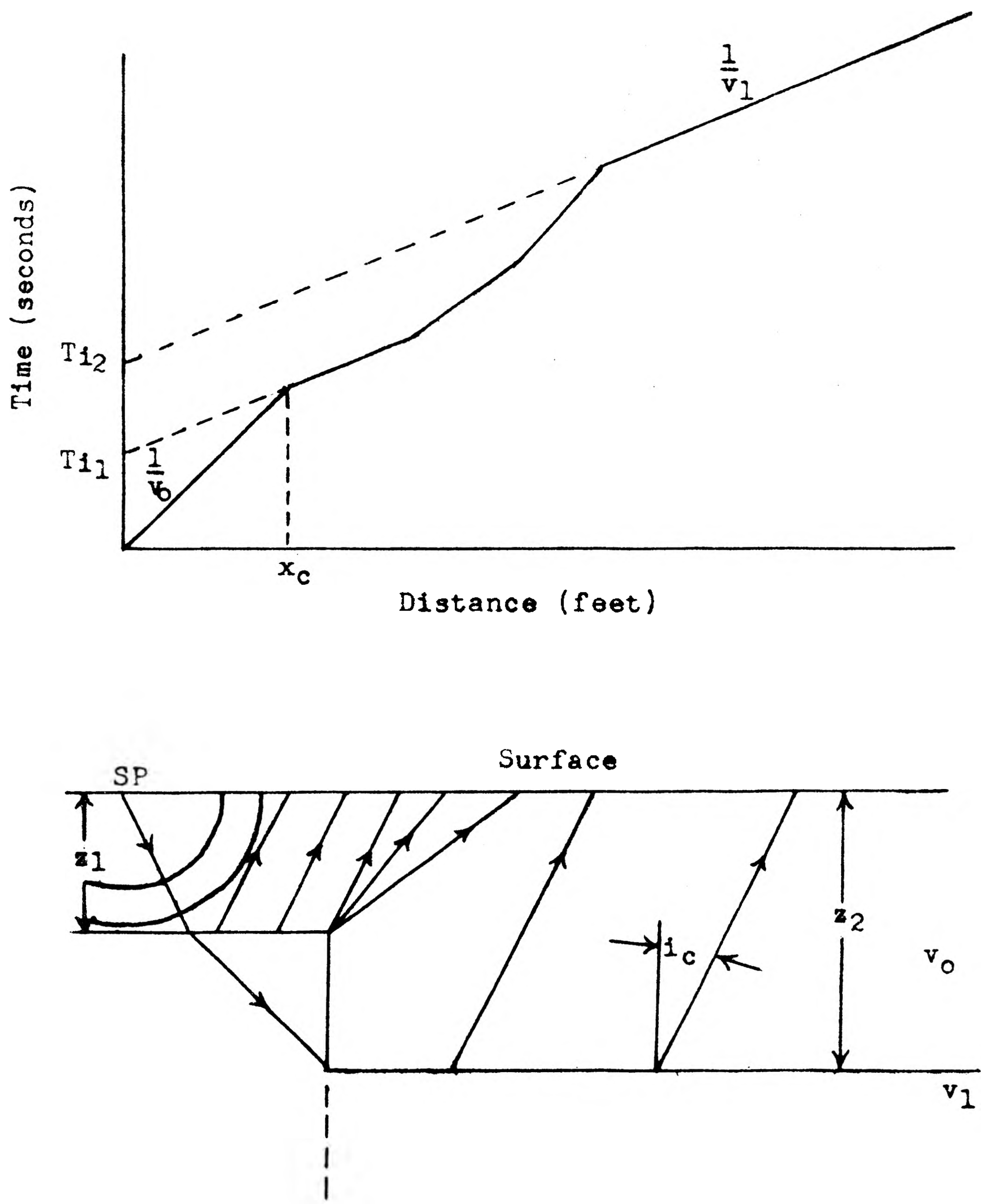


Figure 4. - Ray path and time-distance curve for rays refracted and diffracted across fault. (DOBRIN, 1960)

increase or decrease of velocity V_1, depending upon whether the profile is shot up-dip or down-dip, respectively. Figure 5 represents this condition.

As described earlier, the occurrence of dipping beds surrounding sink-type clay deposits is quite common. Records obtained from several deposits indicated that this condition influenced apparent seismic velocities in these localities.

G. Factors Influencing Seismic Velocity

In describing the general geologic setting of the sink-type clay deposits, it was mentioned that the carbonate country rock forming the perimeter of the deposits commonly shows evidence of leaching. "Westcott, J. C., (1961), personal communication."

It is to be expected that this process has brought about certain changes in the physical properties (density, compressibility, and elastic constants) of the affected strata, because the end result is a relative concentration of clayey and siliceous residual material. The theory of seismology holds that seismic velocities of earth materials are governed by these properties. According to JAKOSKY (1950, p. 658),

> "The velocities of longitudinal and transverse waves in an isotropic homogeneous solid are related to the elastic constants and the density by the equations:

$$V = \sqrt{\frac{E(1-\sigma)}{d(1+\sigma)(1-2\sigma)}} \quad * * = \sqrt{\frac{k + 4/3n}{d}}$$

$$v = \sqrt{\frac{E}{d}\left[\frac{1}{2(1+\sigma)}\right]} = \sqrt{\frac{\mu}{d}} = \sqrt{\frac{n}{d}}$$

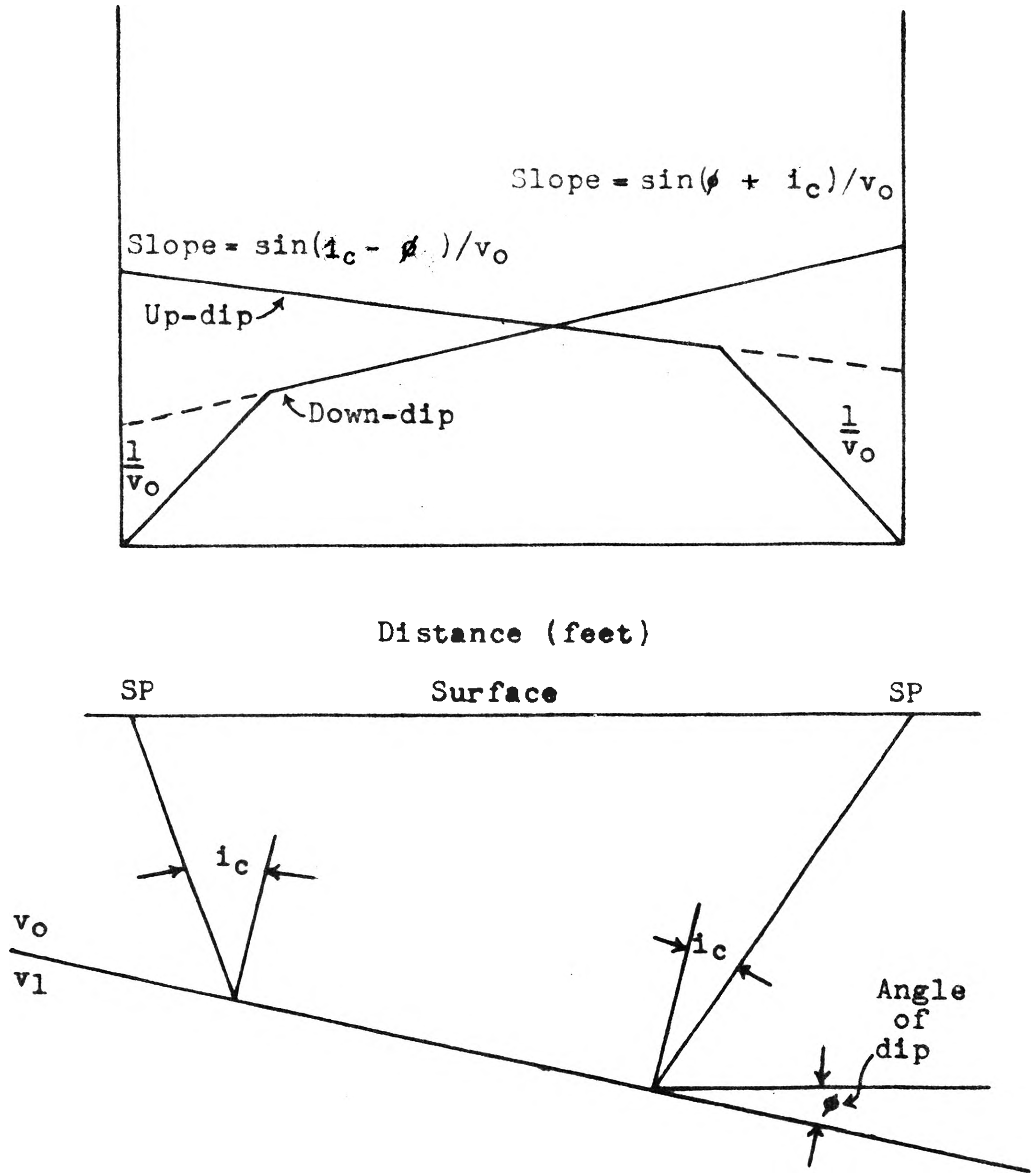


Figure 5. - Ray paths and time-distance curves for refraction along beds dipping at angle ϕ . Curves are shown for both updip and downdip shots. (DOBRIN, 1960)

where

V = velocity of the longitudinal wave.
v = velocity of the transverse wave.
d = density of the solid.
E = Young's modulus $= \frac{\text{stress}}{\text{strain}} = \frac{s}{\epsilon}$

σ = Poisson's ratio $= \frac{\text{transverse strain}}{\text{longitudinal strain}} = \frac{\Delta w}{w} / \frac{\Delta L}{L}$

$$n = \mu = \frac{E}{2(1+\sigma)}$$

k = bulk modulus $= \frac{s}{\Delta \text{volume} / \text{volume}}$

The elastic constant E varies over a wide range while σ is very nearly 1/4 for materials having good elastic properties. Hence, the velocities of the elastic waves depend almost entirely upon the ratio of the Young's modulus to the density of the material."

The precise nature and extent of velocity changes resulting from a leaching process are no doubt dependent upon its extent or duration and the original composition of the leached material. General considerations indicate, however, that the net result of leaching of carbonates would effect a velocity reduction due to the properties of the resulting silty, argillaceous material remaining as residuum.

H. Physical Constants and Seismic Velocities

Values of physical constants for rock types similar to those occurring in the clay districts of east central Missouri are given in table 1 from BIRCH (1942, pp. 76,77).

Results of numerous seismic investigations have revealed that a given type of earth material may exhibit a

TABLE 1 - Representative values of physical constants in sedimentary rocks

	$E \times 10^{-11}$	$G \times 10^{-11}$	σ	δ	E/δ
Limestone (13)	6.39 (13)	2.49 (4)	.211 (11)	2.66 (4)	2.40
Dolomite (4)	8.37 (4)	3.61 (3)	-	2.83 (1)	2.95
Sandstone (9)	4.56 (9)	2.40 (5)	.172 (3)	2.59 (3)	1.76
Shale (3)	dry 3.80 (3) wet 1.90 (3)	-	-	2.61 (2)	1.45

δ = Density, (gm./cm.^{3})
E = Young's modulus (dynes/cm.^{2})
G = Modulus of rigidity (dynes/cm.)^2
σ = Poisson's ratio, (dimensionless)

Note: Values are averages of number of samples shown in parentheses.

BIRCH (1942, pp. 76, 77)

considerable range of seismic velocities. Many factors, including bedding, jointing, alteration, moisture content, depth of burial, and perhaps unrecognizable conditions, apparently influence the rate of travel of seismic waves within the medium. The reader must recognize that any velocity determination made in the field can only represent an average based upon varying conditions. Listed in table 2 are values for seismic velocities in sedimentary materials similar to those occurring in the area being considered. Figures are from velocity values given by LEET and BIRCH (1942, pp. 95, 96).

Reference to tables 1 and 2 indicates that in general, seismic velocities tend to be lower in clastic materials than in carbonates. This tendency is obviously more pronounced in clastic materials which are unconsolidated. Evidence of carbonate leaching surrounding clay deposits indicates that unconsolidation occurs as a result of the leaching process. The removal of soluble carbonates that are acting as a cementing agent naturally leads to the concentration of insoluble residual material that is less consolidated.

KISSLINGER (1952) investigated seismic velocity as a function of carbonate composition. He concluded that the presence of insoluble impurities in limestones and dolomites resulted in a decrease in velocity.

The author believes that a discussion of leaching is

TABLE 2 - Representative values of seismic velocities in sedimentary rocks

Material	Velocity, Km./sec.	
	P	S
Dolomite	5.0 - 6.16	-
Dolomitic limestone..	5.97	3.26
Limestone "soft".....	1.7 - 4.2	
Limestone "hard".....	2.8 - 6.4	
Slate and shale	2.3 - 4.7	
Sandstone............	1.4 - 4.3	
Soils		
Alluvium.........	0.5 - 2.0	
Clay.............	1.0 - 2.8	
Loam.............	0.8 - 1.8	
Sand.............	0.2 - 2.0	

P Compressional wave
S Transverse wave
Km./sec. 3,280.8 ft./sec.

LEET and BIRCH (1942, pp. 95,96)

pertinent because of its possible influence on the behavior of seismic waves. It is suggested that its occurrence in association with sink structures is a factor in causing certain anomalies useful in seismic exploration for clay.

Specifically, a prominent (apparent) velocity decrease is frequently detectable in areas adjacent to clay deposits. While it is acknowledged that this feature can be explained as resulting from a down-dip profile, it is also believed that changing lithology associated with the dipping strata may cause an actual decrease of velocity.

The reader will recognize certain interrelations existing between dipping strata and low velocity material resulting from leaching. It is apparent that these relationships prohibit the physical determination of the extent of influence of either on velocity. In order to calculate the angle of dip of a refracting horizon by popular methods, (DIX (1952, pp. 254 - 265), DOBRIN (1960, pp. 81 - 83), JAKOSKY (1950, pp. 758 - 764)), it is necessary to assume a constant velocity for the media involved. In like manner, the assumption of a constant attitude is required in velocity determinations. It should be kept in mind, however, that numerical dimensions of these factors are not necessary for the interpretation of data in this instance. The interpreter is primarily interested in the physical presence of the gross anomaly. For exploration purposes, its specific nature requires investigation only to the extent that will best facilitate further development of the prospective area by drilling. This will be discussed in greater detail in Chapter VII.

VII. FIELD WORK AND RESULTS

A. Personnel

The regular seismic party consisted of the author and one assistant. The assistant was a regular employee of, and was provided by, A. P. Green Firebrick Company. A third party member, also an employee of that organization, was employed during a one-week period. The A. P. Green employees followed existing Company policy on working hours, travel, and lodging.

B. Period of Investigation

Geophysical research was conducted between June 5 and September 15, 1961. Field work was conducted on a 40 hours per week basis. In order to reduce field expenses (food and lodging costs while away from home), it was agreed that the work week would consist of four ten-hour days. This plan offered the further advantages of permitting a longer period of uninterrupted work, following necessary preparations each morning, and reserved one normal work day of each week for the purpose of making any necessary contact with the offices of Missouri School of Mines and A. P. Green Firebrick Company.

Actual field activity was limited to slightly less than full ten-hour days. This was because of an existing labor policy within the organization of A. P. Green Firebrick Company which permitted employees to travel between the job-site and their place of lodging (usually the nearest town) on Company time. This travel time amounted to approximately one-half hour per day, except on the beginning and closing days of the work week when the assistant was authorized to travel to or from Mexico, Missouri, during working hours.

C. Equipment

All research was conducted with the seismic unit and auger drill described in Chapter IV.

D. Plan of Field Work

Prior to the beginning of field work, a number of conferences were conducted to provide a plan for the various phases of the investigation to be conducted. Participants included the author and his class adviser, Dr. James C. Maxwell; Dr. Paul D. Proctor, Chairman of the Geology Department; Mr. James C. Westcott, Chief Geologist, and his Assistant, Mr. Dennis Duewel, A. P. Green Firebrick Company.

It was suggested during one of these meetings that the method of refraction fan shooting and/or the profile method might prove applicable in locating sink-type clay deposits.

1. Determination of Flint Clay Velocities: Initial investigations were directed toward obtaining representative values of seismic velocities in clay. This operation began on the Volkart property (sec. 31, T45N, R7W) near Chamois, Missouri, shown on figure 6. A flint clay deposit located on the property and previously outlined by drilling was used as the initial test site. A series of refraction profiles was shot on this deposit, using geophone spacings of 5 and 10 feet. Twelve geophones were used on each profile.

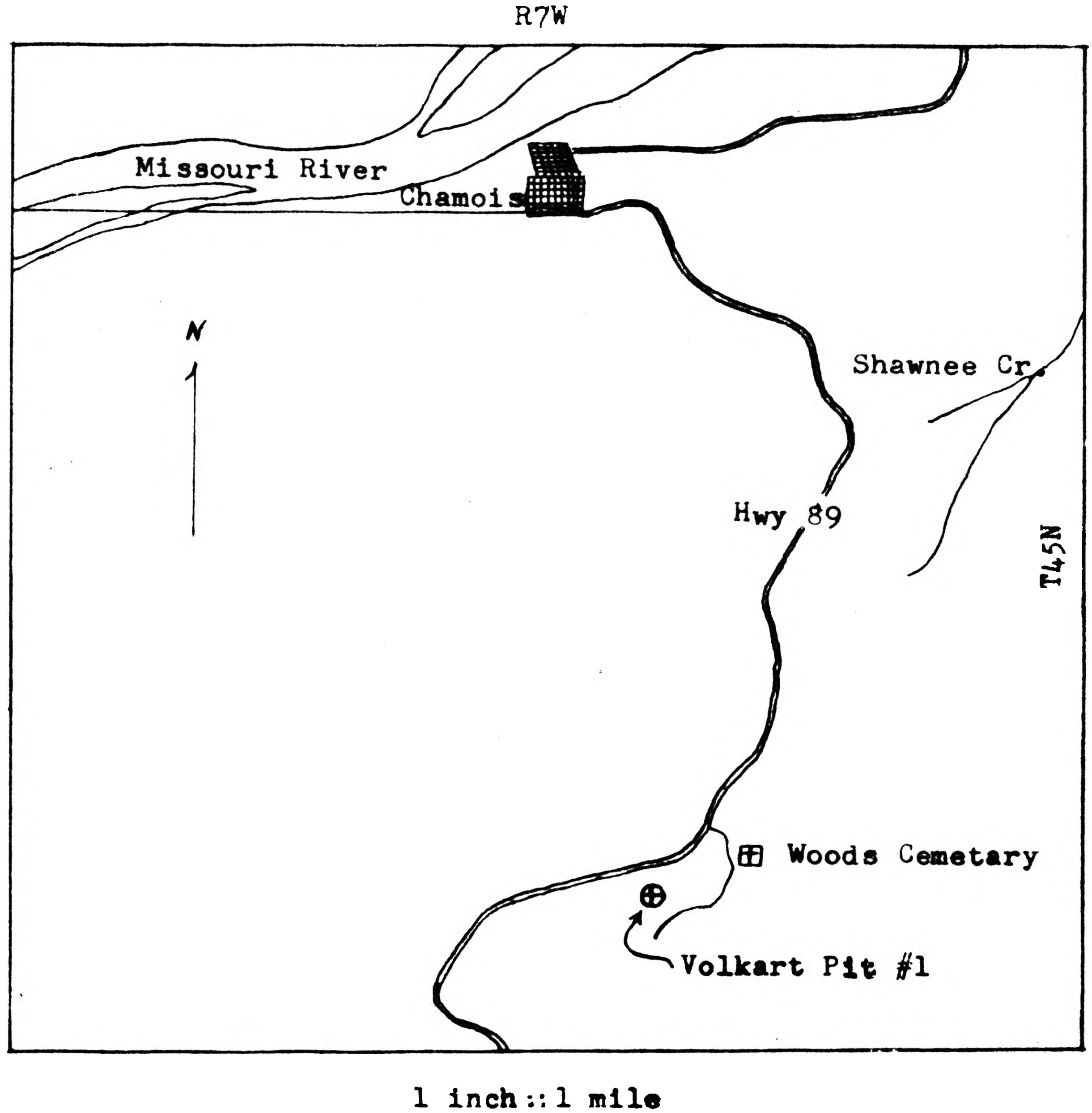
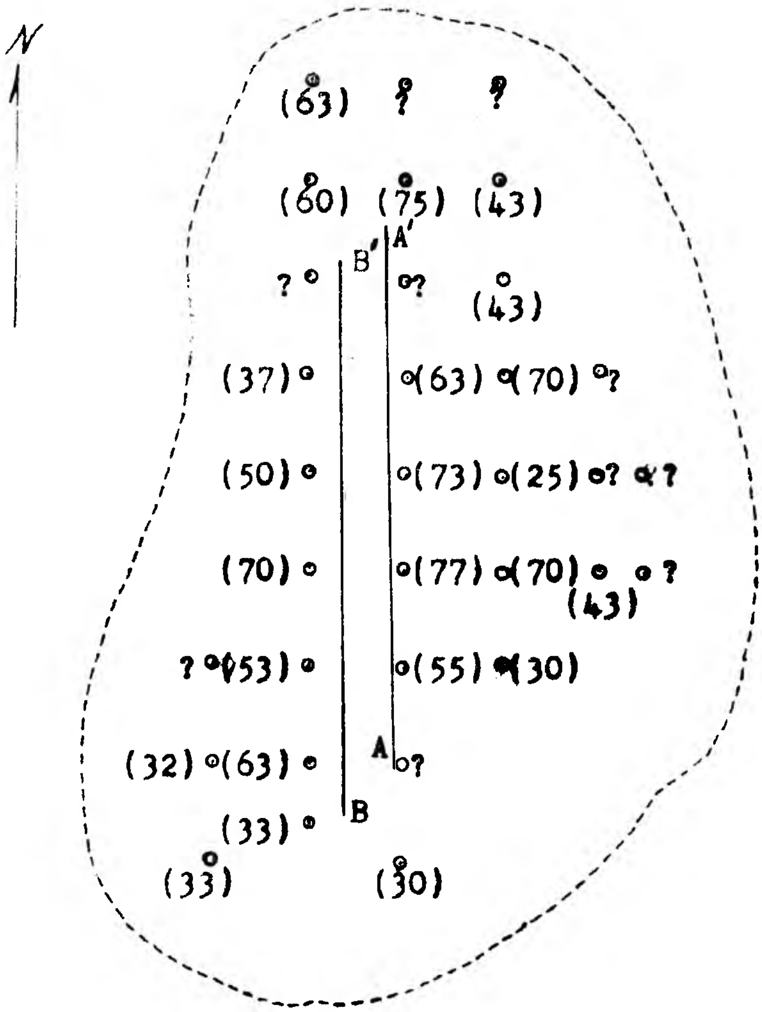


Figure 6. - Sketch map showing general location of Volkart pit #1, Osage County, Missouri.

Distance from shot point to the nearest geophone was measured in multiples of 5 feet and ranged from 10 to 25 feet for these profiles. One 1 1/8" x 8" stick of 60% strength gelatin dynamite was used for each of the initial shots. Charge size was then reduced to 1/2 stick, and later to 1/4 stick. Results remained very satisfactory for the profile lengths of 60 and 120 feet which were used during this phase of the investigation. Figure 7 shows the location of these profiles relative to the approximate outline of the deposit. Figures 8 and 9 show the seismic records and time-distance curves for profiles A and B, shot along lines AA' and BB', respectively.

Good quality records were obtained from this deposit, indicating a rather consistent flint clay velocity near 6,000 feet per second and overburden velocity near 1,500 feet per second. Velocity segments on these records were clearly distinguishable by a well defined velocity break. This indicated a good refracting interface which was at first believed to be the clay overburden contact. However, calculation of overburden depth based on seismic data consistently indicated a depth several feet greater than that based on detailed drill records which were available. This calculation was repeated several times using data obtained from a number of records in order to insure that the discrepancy was not caused by faulty velocity determination. The results continued to indicate a well defined discontinuity occurring at a uniform depth.



1 inch:: 50 feet

Figure 7. - Plan view of Volkart pit number one showing locations of seismic profiles A and B.

○ - Auger drill-hole location.
( ) Depth in feet to bottom of clay.

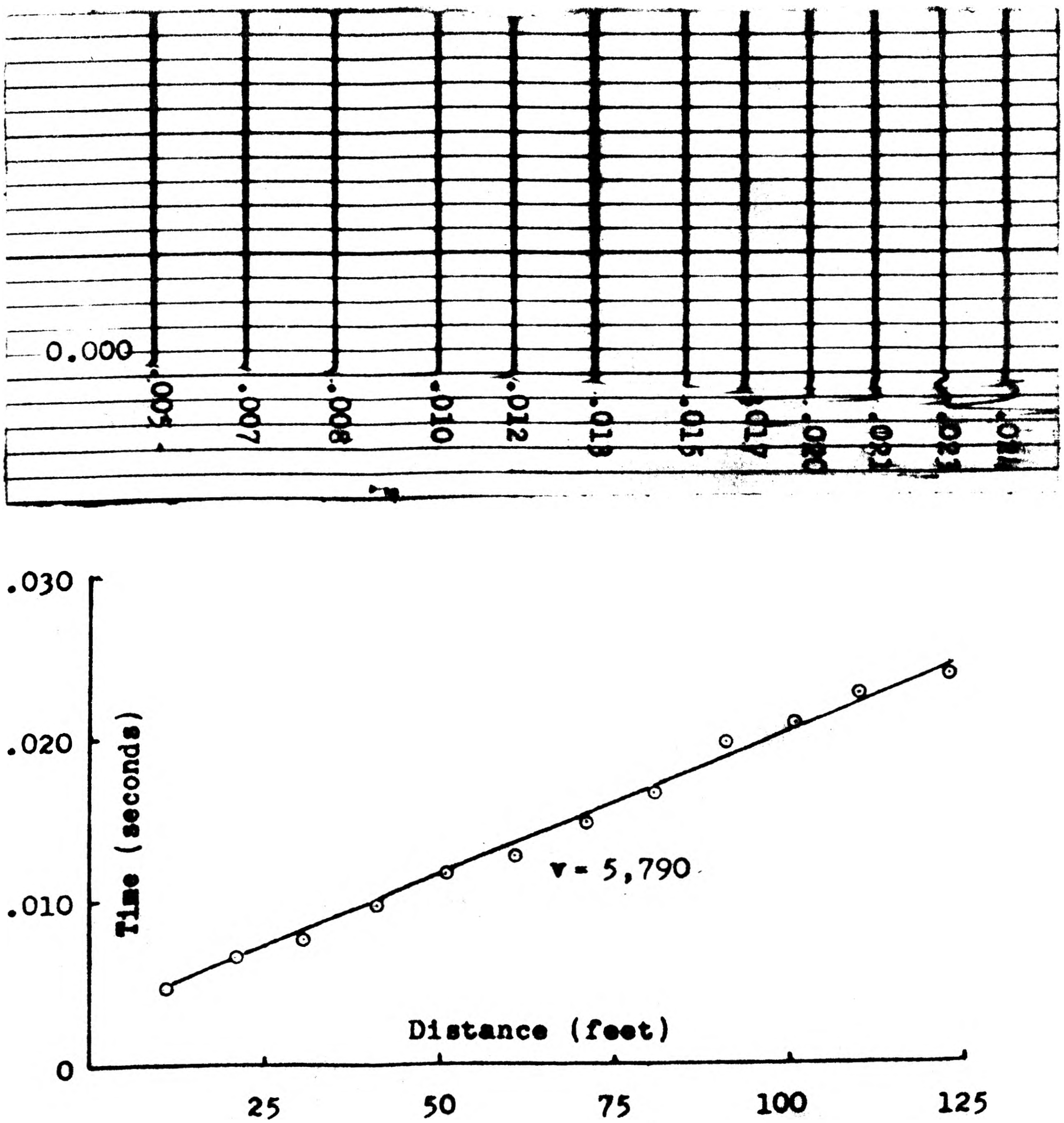


Figure 8. - Seismic record and time-distance curve for profile A along line AA', Volkart pit #1. Geophone spacing, 10 feet. Overburden velocity and depth not shown. Clay velocity, 5,790 feet per second.

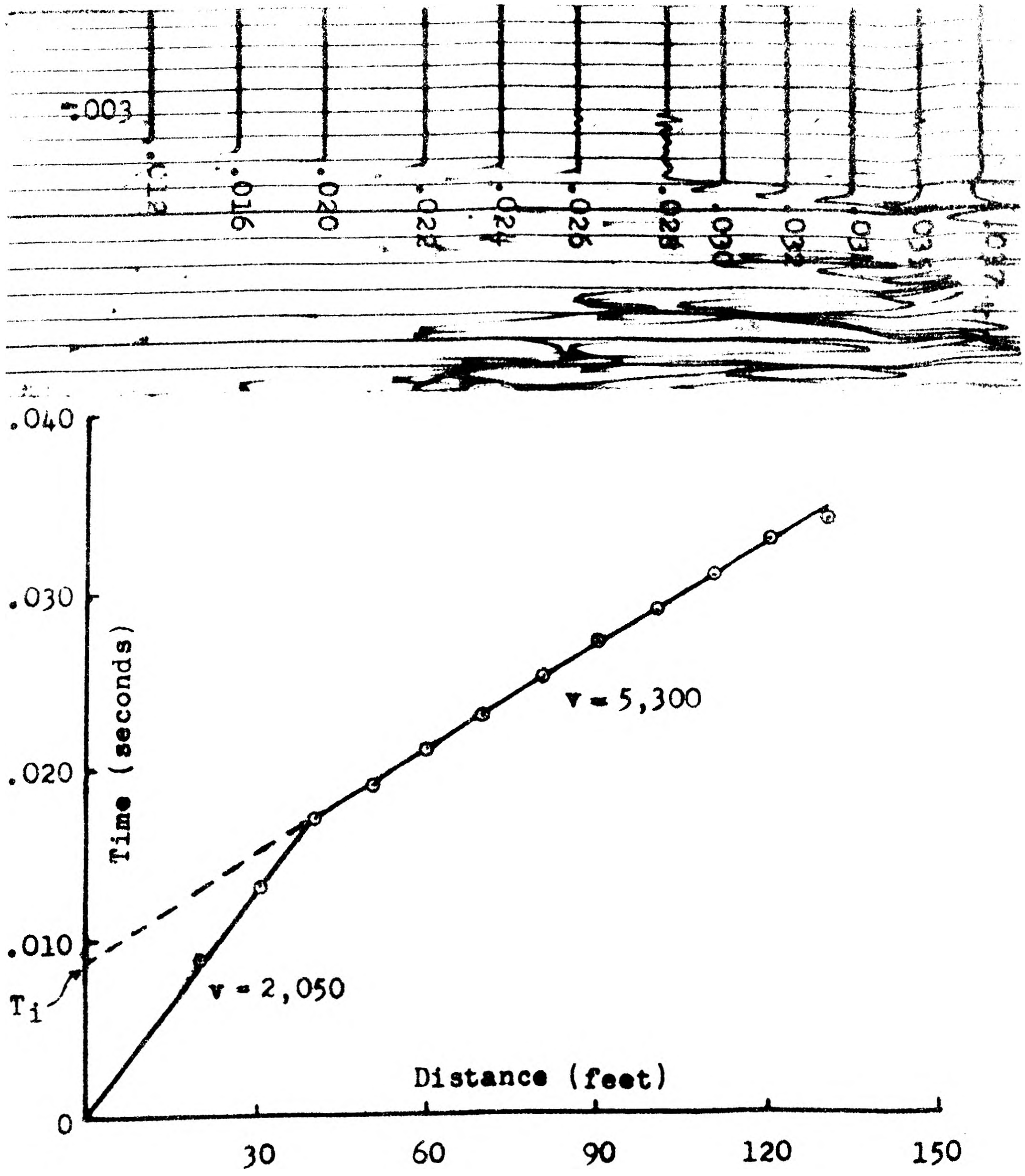


Figure 9. - Seismic record and time-distance curve for profile B along line BB', Volkart pit #1. Geophone spacing, 10 feet. Overburden depth (seismic), 27.9 feet; actual depth, 15-17 feet. Overburden velocity, 2,050 feet per second; clay velocity, 5,300 feet per second.

The deposit was being core drilled during the period in which seismic work was being conducted on it. This provided an opportunity for examination of several cores, and also for discussions with the drill operator, Mr. Carl Nordwald. Inspection of several feet of core taken from the upper limits of the deposit showed evidence of fracturing and some degree of plasticity present in the clay. These portions of the cores were referred to by the driller as "semi-hard" flint. The author believes that the conditions cited are effective in reducing the velocity in the upper margins of flint clay deposits to approximately the same as overburden velocity. A similar pattern was indicated in other deposits of this type and will be discussed later.

Following completion of the described investigative work, operations were transferred to the Poncot property (sec. 36, T44N, R8W) in the vicinity of Lynn, Missouri. Several known flint clay deposits occur on this property. The deposits vary widely in size, with diameters ranging from approximately 50 to 200 feet. Maximum depth to the bottom of the clay, based on drill records, was known to be approximately 80 feet. In general, vertical dimensions of sink-type clay deposits vary greatly in a given deposit. Cross sections based on drill records commonly show wide and abrupt variations in depth. Sections through two representative deposits are shown in figure 10.

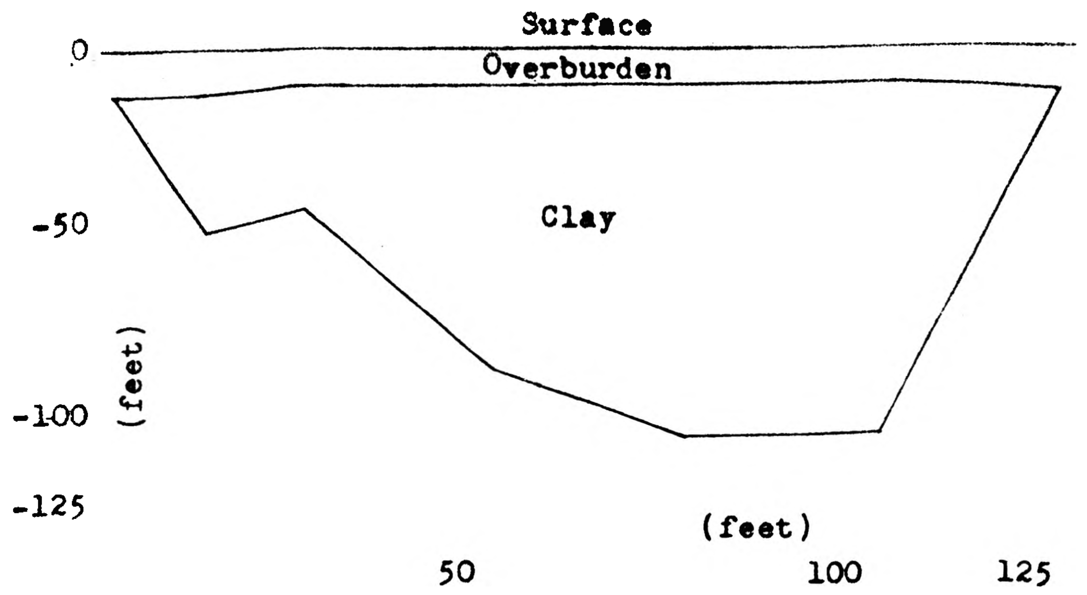


Figure 10a. - Cross section through Poncot pit #7, (sec. 36, T44N, R8W).

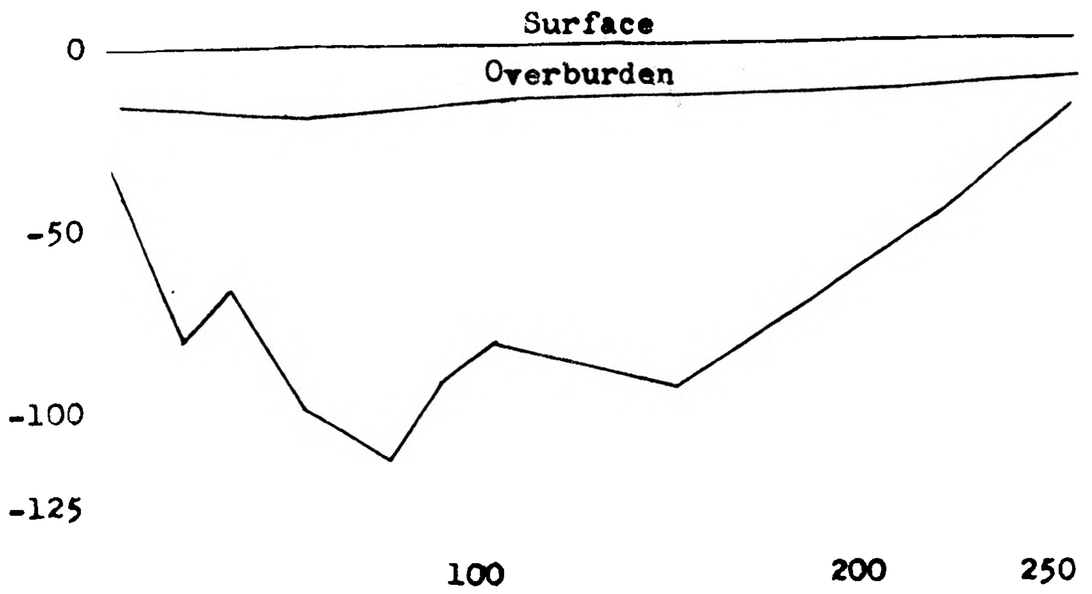


Figure 10b. - Cross section through Wacker pit #3, (sec. 9, T42N, R5W).

In order to obtain further information on flint clay velocities, several profiles were shot on one of the larger deposits occurring on this property. Geophone spacings of 5 and 10 feet were used for velocity determinations. Time-distance plots of these records indicated flint clay velocities grouping quite uniformly around 6,000 feet per second, and overburden velocity varying between 2,000 and 2,500 feet per second. Overburden thickness on this deposit was known to be 8 to 10 feet, based on drill records. Depth calculations based on velocity determinations indicated an overburden depth of 12 to 14 feet.

It was considered desirable to obtain information regarding change of clay velocity with depth. To accomplish this, four holes were drilled in a portion of the deposit where clay depth was known to be about 70 feet and fairly uniform. Holes were located so as to insure direct wave travel through clay, and were spaced at 25-foot intervals and in line. It was intended that the holes be 40 feet deep and that velocity measurements be made with explosive charge and geophones all at the same elevation. The result would be a series of subsurface profiles at regular depth intervals within the clay deposit. The plan was to obtain records at 10-foot intervals between bottom-hole elevation and the surface. The holes were drilled to the desired depth, but it was discovered after completion of the last hole that earlier drilled holes were beginning to fill with water. Some 5 feet of water was found to be present in the first hole drilled, with lesser amounts in later drilled holes. Upon this discovery, all holes were filled to a depth of 35 feet. Extensions were connected to geophone leads and the geophones were lowered to the bottom of the holes. Flat-bottom geophones were used during this experiment. Loose material in the holes was tamped prior to seating the geophones. The explosive charge was then lowered to its proper level and 10 feet of tamped earth placed over it. The charge consisted of 1/4 stick of 1 1/8" x 8", 40% strength gelatin dynamite for all shots of the series.

Records were taken at 35, 25, and 15-foot depths by repeating this procedure.

Velocity determinations based on these records are given in table 3. Consideration of variation of flint clay velocity with depth, based on the data in table 3, indicates that a linear increase with depth may be assumed. In this case it may be expressed by the general formula given by DOBRIN (1960, p. 77) ". . . . $V = V_o + kZ$."

where $V =$ velocity at depth Z
$V_o =$ velocity at depth 0
$k =$ a constant

If zero depth of flint clay is assumed to be 15 feet below the surface (the approximate horizon of the seismic discontinuity), then the velocity determined at 35 feet below the surface would represent a horizon 20 feet below the surface of the clay body. Using the data obtained at 35 and 15 foot depths, respectively,

$$7300 = 5950 + k(20)$$
$$(V) = (V_o) + kZ$$

hence $k = 67.5$

TABLE 3 - Flint clay velocity as a function of depth

Depth from Surface (ft.)	Velocity (ft./sec.)
35	7,300
25	6,600
15	5,950
0	2,300 (ave.)

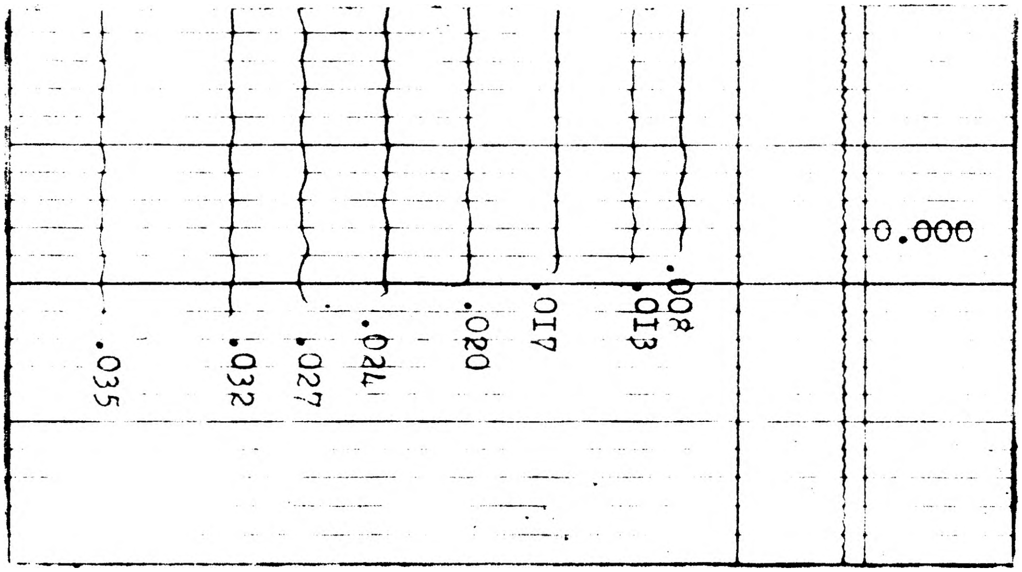
2. Velocity Determinations in Sedimentary Rocks Surrounding Clay Deposits: In order to apply either fan or profile geophone arrangements effectively, it was necessary to establish velocity values for the sedimentary formations comprising the stratigraphic horizon in which the clay deposits occur. This was undertaken by location of areas that exhibited a relatively uniform overburden thickness underlain directly by Jefferson City dolomite. It was discovered through drilling at a number of locations on the Poncot property that overburden depth in this area varied some 20 feet. Later comparisons indicated this to be a greater than average variation.

A few locations were chosen where overburden thickness had been found by auger drilling to have little variation. Several profiles employing 25-foot geophone spacings were shot on these locations.

Velocity determinations indicated velocities in this (upper) horizon of the Jefferson City formation of 12,000 to 19,000 feet per second.

Data obtained over a longer period indicated an average velocity value of approximately 14,000 feet per second. Figures 11 and 12 show seismic records and time-distance curves for profiles shot on Jefferson City dolomite bedrock on two properties.

The Pennsylvanian Graydon conglomerate and sandstone is only intermittently present in many localities of the southern clay district. Its irregular nature of occurrence



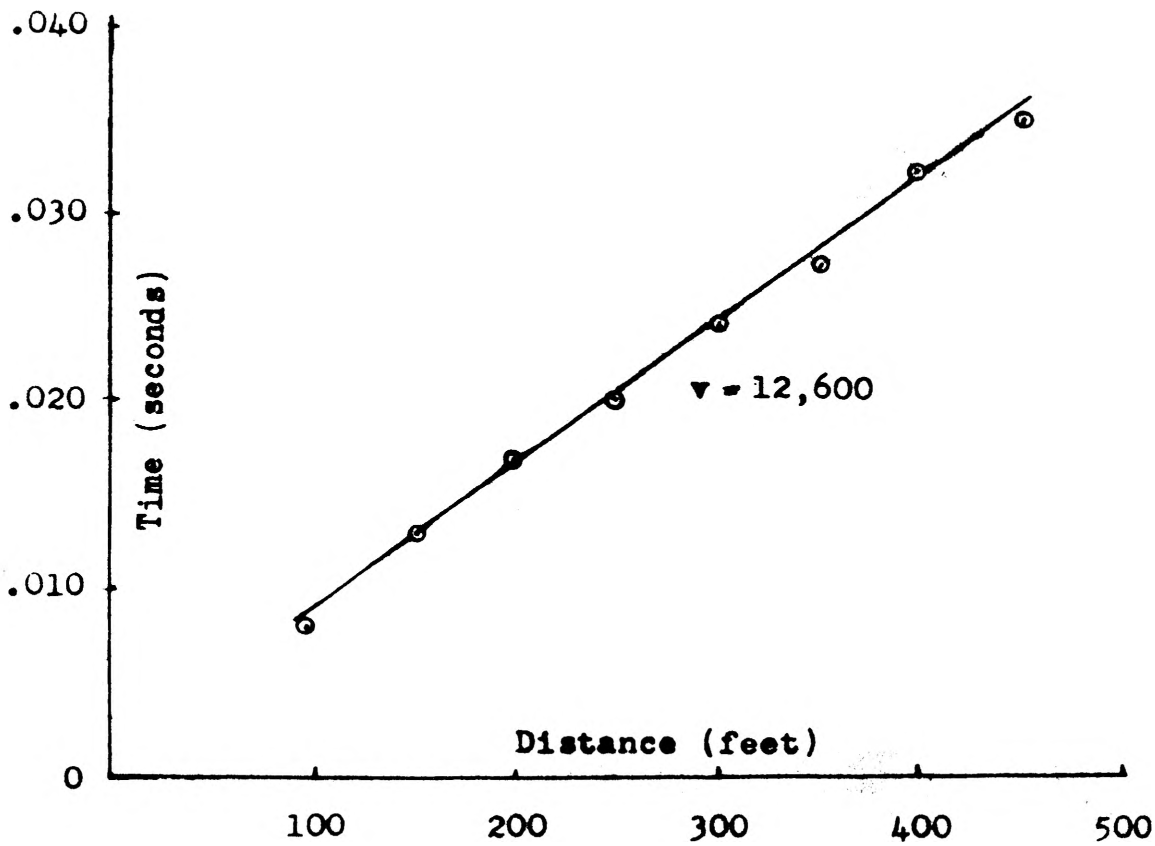


Figure 11. - Seismic record and time-distance curve for profile shot on Jefferson City dolomite, Poncot property. Velocity, 12,600 feet per second.

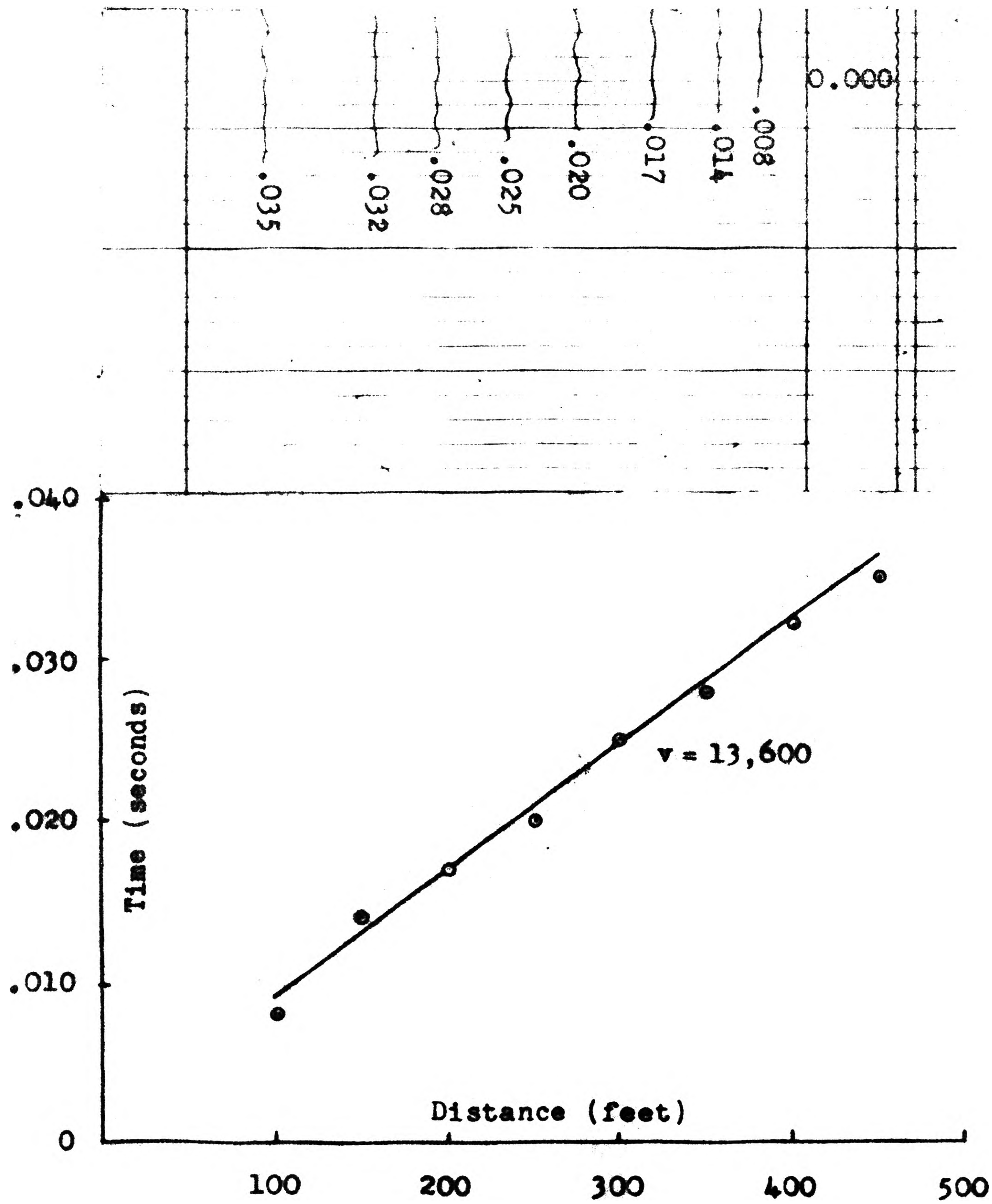


Figure 12. - Seismic record and time-distance curve for profile shot on Jefferson City dolomite, Floyd Nicks property. Velocity, 13,600 feet per second.

complicates the problem of determining a representative velocity in the formation. It exhibits a wide variety of lithologic conditions, being characteristically thicker, more massive, and harder where it forms a clay deposit "rimrock." Because these locations also provide its most common areas of occurrence, they were chosen as test sites for velocity investigations. Reliable information regarding presence and depth to the Graydon formation immediately adjacent to clay deposits was available from drill records. When the formation is encountered in outlining a deposit, the information is recorded, because the sandstone indicates the deposit boundary. By referring to these drill records, it was possible to select areas of limited extent upon which profiles of short geophone spacing could be shot. Several records were obtained from these areas. Geophone spacings of 5 feet were normally used for these profiles. The explosive charge for each record was detonated at the surface of the refracting member, the depth of shot hole averaging 8 to 10 feet in this area. Velocity determinations indicated a sizeable velocity range within the Graydon formation, the extremes having values of approximately 5,000 and 9,000 feet per second. Figure 13 shows the seismic record and time-distance curve for one profile. Considering again the irregular and complex nature of the formation, the variation in velocity is understandable.

Seismic velocities determined for the formations and materials discussed above are shown in table 4.

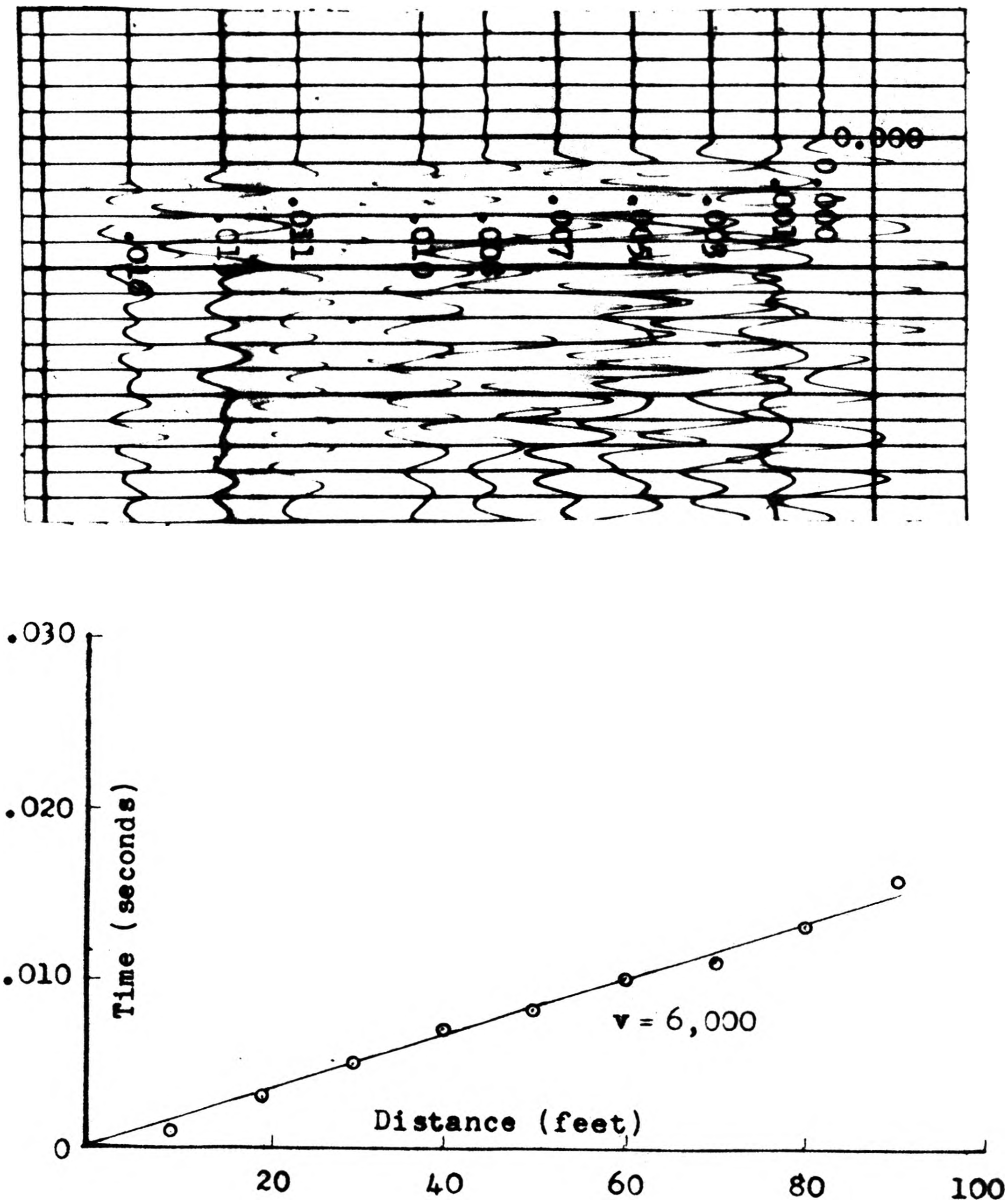


Figure 13. - Seismic record and time-distance curve for profile shot on Graydon sandstone "rimrock." Velocity, 6,000 feet per second.

TABLE 4 - Seismic velocities in rocks and materials of southern clay district

Material	Velocity (ft./sec.)
Overburden (incl. Lafayette? gravel)	2,000 - 2,500
Flint clay	5,950 - 7,300
Graydon conglomerate and sandstone	5,000 - 9,000
Jefferson City dolomite (upper)	12,000 - 19,000

3. Fan Shooting: The fan method is described by JAKOSKY (1950, pp. 775 - 778). It has been successful in outlining salt domes with which a number of petroleum fields have been associated.

The configuration employed for fan shooting consists of a geophone arrangement along a semicircular arc of any desired radius, the center of radius being the shot point. Recorded seismic waves travelling paths between shot point and geophones subtend an arc or "fan" through a portion of the earth's crust. Interpretation of the record depends upon a time lead, or lag, of first arrivals at one or more geophones. A detectable time difference between first arrivals is assumed to indicate the presence of material, along the affected paths, having a velocity different from that of the country rock. It is also true that velocity contrasts are a basis for interpretation of records obtained by the profile method. In this case, however, the effect of certain other features such as bedrock attitude and depth of overburden is more apparent.

Two small flint clay deposits were chosen to be used in refraction fan shooting. This choice was made as a result of the practical aspects of the problem. It was felt that to be useful in clay exploration, the fan method must be capable of detecting deposits of minimum economical size. The first of the two deposits to be shot across was approximately 60 feet in diameter and 50 feet in depth. In cross section, this deposit closely resembles an inverted cone.

A fan configuration was laid out with geophones spaced at 25 foot intervals, forming a semicircular arc having a radius of 300 feet. The shot point formed the apex of the fan. The configuration was located with shot point and geophones on opposite sides of the clay deposit, thus insuring that wave-travel paths would be required to penetrate the deposit or be influenced by its presence.

Three records were obtained from this configuration. All records were of good quality. None revealed any recognizable anomaly, however. Time-distance graphs plotted from observed data indicated a velocity of approximately 12,000 feet per second along each ray path. Fan shots were also conducted on a second deposit of approximately the same diameter as the first. This deposit measured about 75 feet in depth, however. The two deposits were located 200 yards apart and were considered similar in all respects except for the second having greater depth. The geophone arrangement employed on this deposit consisted of a straight line of equally spaced geophones instead of a semicircular arc, with the shot point perpendicular to the center geophone of the spread, and located 300 feet distant from it. The deposit occupied the area between shot point and geophones. Distance from the shot point to the center geophone was measured. Distance to all other geophones was computed. Three records were obtained at this deposit and time-distance graphs plotted from the determined arrival times. None of the graphs revealed velocity characteristics that were recognizably anomalous.

In view of the economic consideration attending the research, no further attempts were made to apply the fan-shooting method to sink-type clay deposit exploration.

The reason for the apparent failure of refraction fan methods to detect the presence of small sink-type clay deposits can be only suggested. It is considered possible that the negative results obtained by this method may be due to geologic and seismic characteristics known or indicated to be associated with sink-type clay deposits and their surroundings. These characteristics and their expected influence on seismic wave behavior are:

a. The commonly known occurrence of centroclinally dipping carbonate beds surrounding the deposits. It seems reasonable to expect that seismic waves being refracted along a favorable refracting horizon in such media would be directed toward the deeper, and generally smaller portion of the deposit as they approach it.

b. The indicated increase of flint clay velocity with depth. This condition, if present, would result in the transmission of seismic waves through the clay body at velocity which might approach that of the carbonate country rock.

c. The relatively greater shot-to-detector distance employed in fan shooting permits greater penetration of the refracted wave.

The above circumstances, acting in combination, might serve to minimize the effect on seismic waves of the presence of shallow clay deposits.

4. Profile Method: Application of refraction profile methods to clay deposit exploration requires several major considerations:

a. The method must be capable of detecting the presence of favorable subsurface structures.

b. To be practical in this application, it must also permit greater ground coverage per unit of time or at lower cost than conventional drilling exploration methods.

c. Geophone spacings (and consequently length of profile) must be proportional to the size of the smallest structure of economic interest. In general, a clay deposit 50 feet in diameter is considered minimum size to warrant exploitation.

The above requirements therefore dictated, to some extent, the manner in which the profile method of field work would be conducted.

The initial stage of this investigation consisted of obtaining data from a number of profiles shot over known clay deposits. These records were interpreted solely to determine the possible presence of seismic anomalies associated with the deposits. The profiles employed geophone spacings of 15, 20, and 25 feet.

Explosive charges were detonated from conventional in-line positions at either end of the profile. Normally, the charge was detonated at the end of the profile farthest from the seismic unit. This procedure reduced the possibility of ground roll shock upon the recording instruments. Size of the explosive charge was varied between 1/4 and 1/2 stick of dynamite, depending upon geophone spacing and shot hole depth.

Data obtained from profiles shot on and in the immediate vicinity of clay deposits showed positive results. Sink structures were, in general, found to be associated with anomalous seismic conditions that were detectable by the profile method. Time-distance graphs plotted from these records normally revealed extreme (apparent) velocity changes on opposite sides of the deposit. Velocities appeared to be abnormally low on the side of the deposit nearest the shot point and abnormally high on the opposite side.

As described earlier, these velocity anomalies were interpreted as being the gross result of one, or a combination of the following factors:

a. The presence of centroclinally dipping beds surrounding the deposits. This condition could itself account for noticeable apparent velocity changes on opposite sides of the deposit; the low velocity segment represents the down-dip portion of the profile; the opposite prevails on the up-dip segment.

b. An actual velocity decrease caused by a gradational increase in the amount of leached residual material adjacent to the deposits.

c. The presence of a low velocity layer in the upper margins of the clay deposits, causing a delay in arrival times of waves refracted upward through this material.

Each of the above conditions, if associated with a given clay deposit, may be present to an undetermined degree. Considered singly, none is sufficient evidence for the existence of a deposit or sink structure; conversely, the existence of a sink structure cannot be relied upon to cause all of the above conditions. The interpreter must judge, after sufficient investigation, whether the occurrence of these conditions with sink structures is common to the extent that will permit the application of refraction profiling as a reliable exploration tool.

In order to determine the frequency with which anomalous seismic conditions occur in association with sink-type clay deposits, a series of 20 profiles was conducted on and near six known deposits. Geophone spacings of 25, 40, and 50 feet were employed on all profiles during this phase of investigation. Some representative profiles are discussed in the following paragraphs.

Figure 14 shows the seismic record and time-distance curve for a profile shot across Hensley pit #6, (NE 1/4, sec. 6, T41N, R6W). The explosive charge was detonated at a depth of 10 feet below the surface on Jefferson City dolomite. A geophone spacing of 40 feet was employed with shot-to-#1 geophone distance of 75 feet. Number 3 and number 5

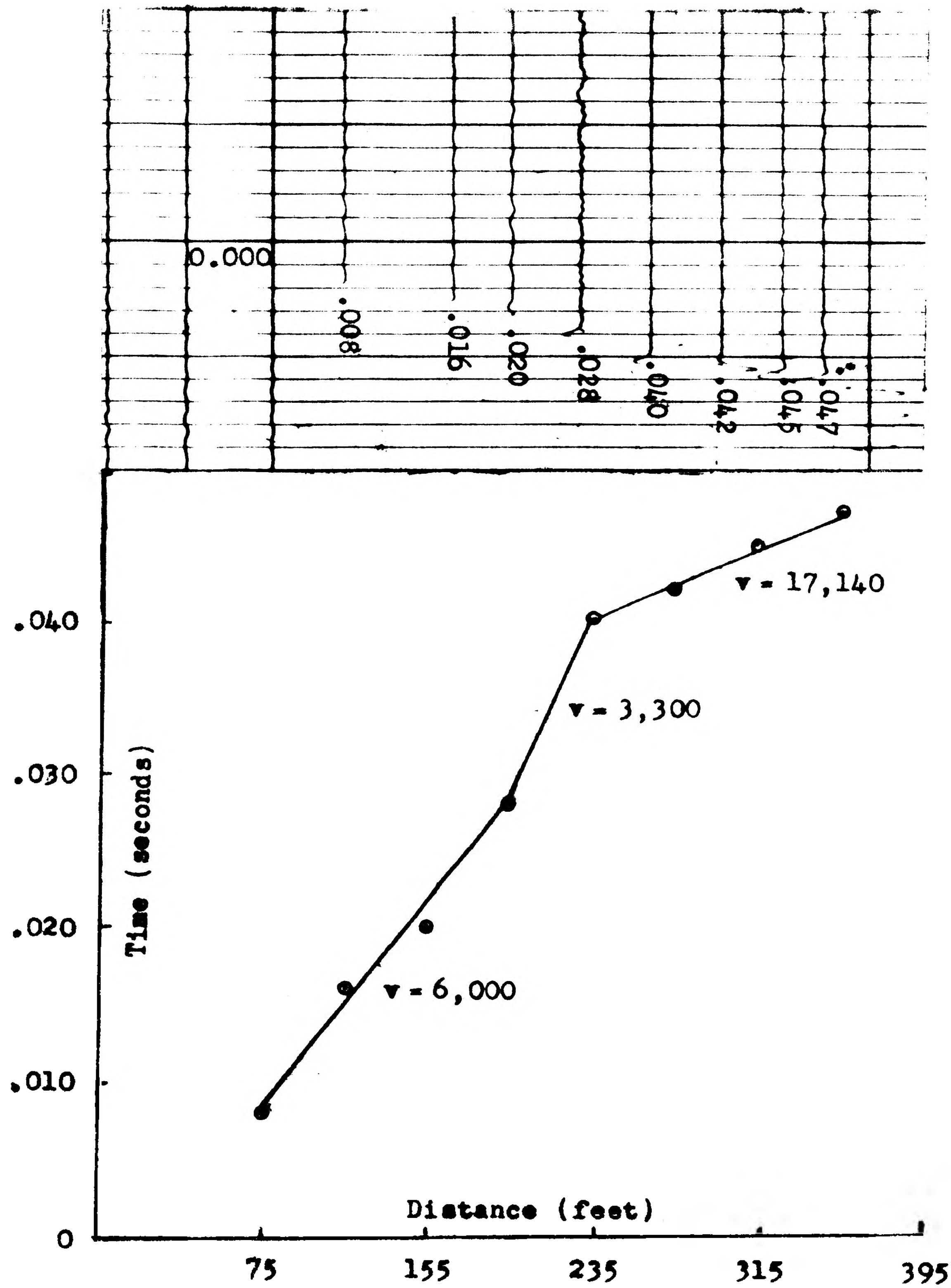


Figure 14. - Seismic record and time-distance curve for profile shot across Hensley pit #6 (sec. 2, T41N, R6W).

geophones were located approximately at opposite boundaries of the deposit. The first segment of the time-distance curve shows a velocity (6,000 ft./sec.) which could be interpreted as representing sandstone or clay, but which is well below that determined for the dolomite country rock. The second segment represents a definite time delay resulting in an apparent velocity (3,300 ft./sec.) much lower than that determined for any known country rock in the area and approaching overburden velocity. The third segment (17,140 ft./sec.) is within the velocity range of that determined for Jefferson City dolomite. Considered together, the three velocity segments may represent a combination of conditions described for dipping beds and faults. (See figures 4 and 5.)

Figure 15 shows the seismic record and time-distance curve for a profile shot across Wacker pit #3, (NE 1/4, sec. 9, T42N, R5W). A 50-foot geophone spacing was employed on this profile. The explosive charge was detonated at a depth of 10 feet below the surface in unconsolidated sand. Shot-to-#1 geophone distance was 100 feet. The deposit occupied approximately the 250 feet represented between the #2 and #7 geophones. The first segment of the curve shows a velocity which agrees with that determined for sandstone. It would be necessary, however, for the sandstone to be present in abnormally great thickness in order to prevent the influence of the higher velocity underlying Jefferson City dolomite from showing on the seismic record at a distance less than

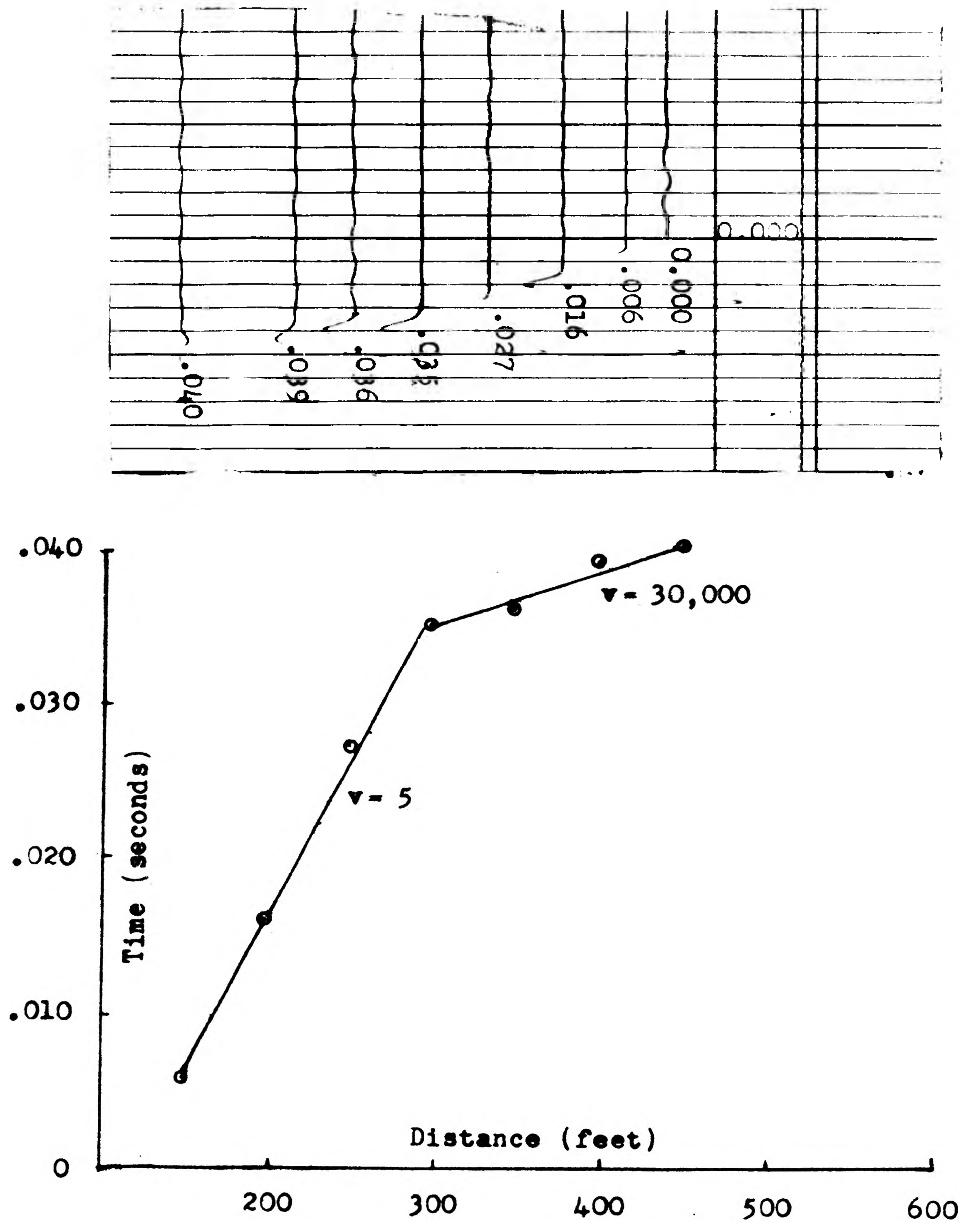


Figure 15. - Seismic record and time-distance curve for profile shot across Wacker pit #3 (sec. 9, T42N, R5W).

300 feet from the shot point. The second segment of the time-distance curve shows a velocity approximately twice that established for Jefferson City dolomite. Together the two velocity segments resemble a reversal of dip of the refracting horizon along the profile.

Figure 16 shows the seismic record and time-distance curve for a profile located on a line adjacent to Wacker pit #3. The number 3 and 4 geophones of this profile were approximately 50 feet outside the "rimrock" boundary of the deposit. The first and second segments of the curve indicate possible dip reversal conditions along this portion of the profile. It is also suggested that leaching in these areas may be responsible for an actual velocity decrease. The third velocity segment shows normal Jefferson City dolomite velocity.

Figure 17 shows the seismic record and time-distance curve for a profile shot across Floyd Nicks' pit #10 (sec. 22, T42N, R5W). This clay deposit is shown on figure 18 as the westernmost of five deposits occurring on the portion of the Nicks' property which was prospected by the refraction method. The location of the deposit was determined on the basis of interpretation of the seismic record.

The shot point for this profile was approximately 200 feet northeast of the deposit boundary. The explosive charge was detonated at a depth of 10 feet in "Lafayette" gravel. Distance from shot point to number one geophone was 100 feet. A geophone spacing of 50 feet was employed. The first

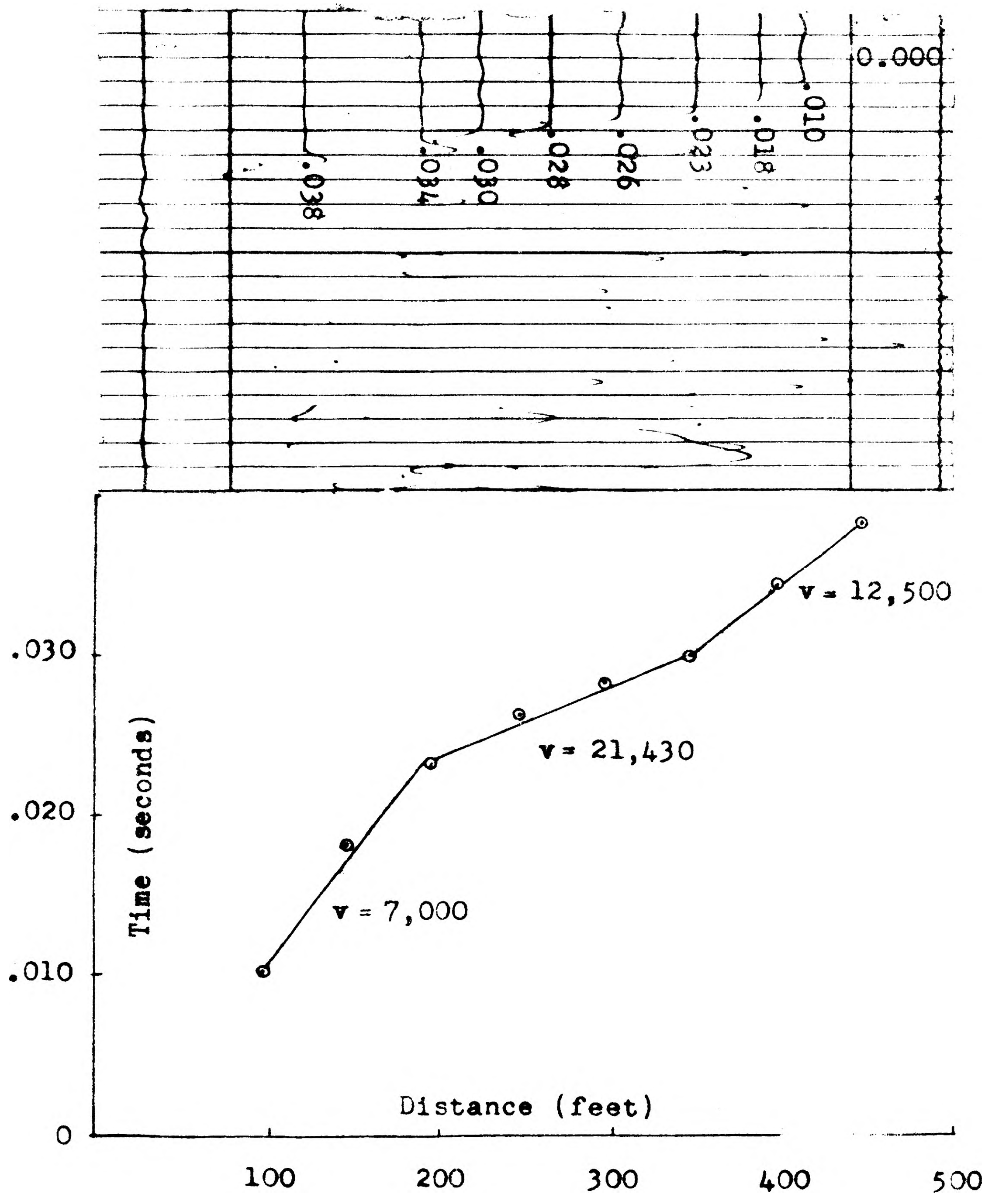


Figure 16. - Seismic record and time-distance curve for profile shot near Wacker pit #3 (sec. 9, T42N, R5W).

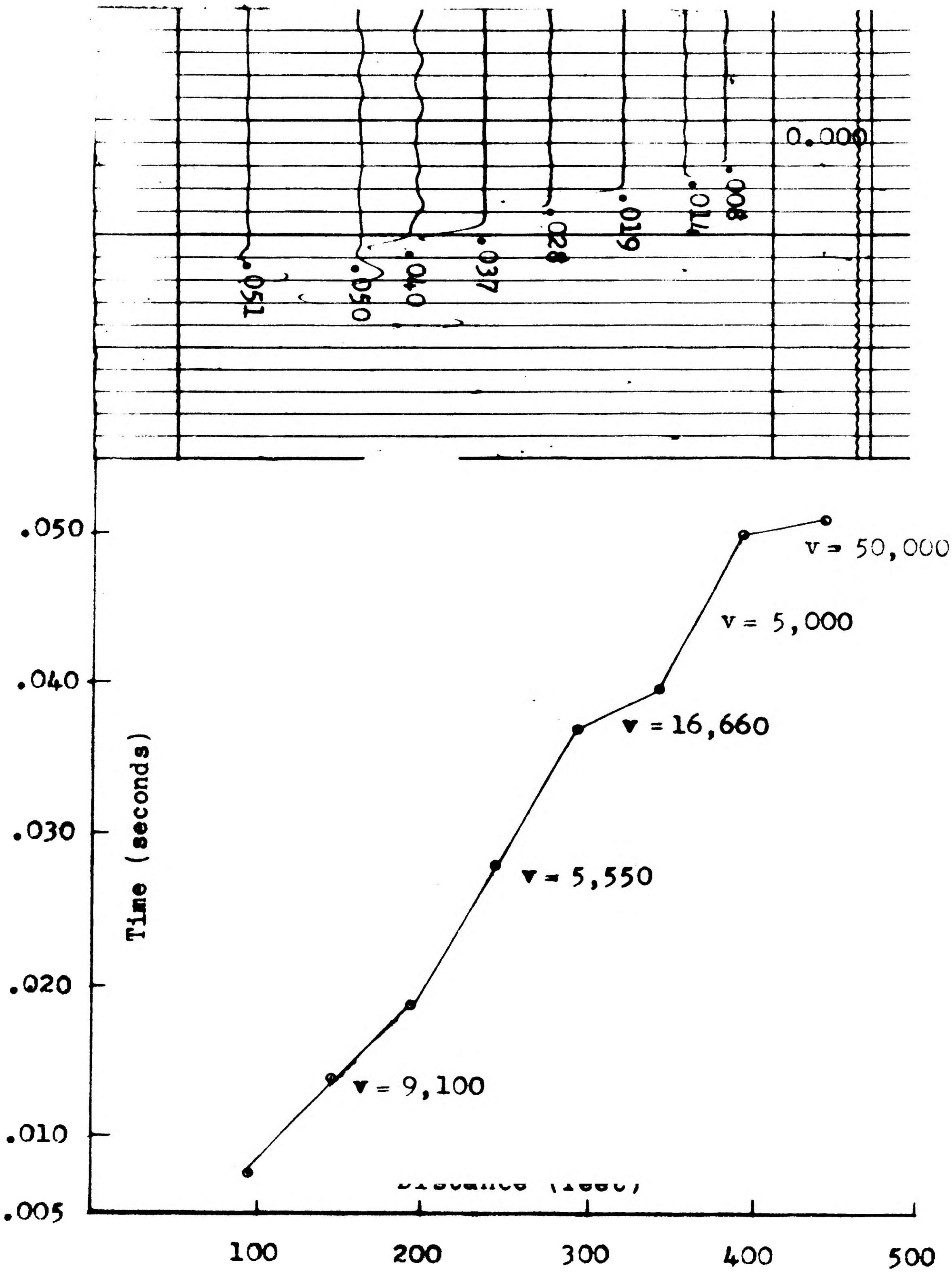


Figure 17. - Seismic record and time-distance curve for profile shot across Floyd Nicks pit #10 (sec. 22, T42N, R5W).

segment of the curve represents velocity characteristics which could be interpreted as abnormally thick Graydon sandstone or downward dipping Jefferson City dolomite. A distinct velocity decrease occurs in the second segment of the curve. This is interpreted as being the result of one or a combination of lithologic and structural changes in the subsurface material. The erratic and extreme velocity discontinuities throughout the remainder of the time-distance curve are interpreted as being caused by an extremely irregular refracting surface underlying the clay, and also by the change in lithology and structure of country rock on the side of the deposit opposite the shot point.

Seismic discontinuities of varying degree were found to be associated with all deposits tested during this phase of investigation.

5. Economic Consideration of Clay Deposit Exploration: The second stage of development of the profile method was directed toward determining the average daily unit areal coverage possible with this method of exploration. In approaching this problem, it was necessary to consider several factors which together largely control the geophone spacing along the profile. This spacing, in turn, limits the linear distance that can be explored per profile. In general, the time involved in laying out a refraction profile with

extended geophone spacings is only slightly more than that required to lay out a closely spaced profile.

Seismic patterns recorded from known sink-type clay deposits indicated that, in general, anomalous conditions were recognizable over an area somewhat larger than the actual deposit. Because of the varying nature of these conditions and their varying areas of influence, it was decided that geophone spacings should be limited to the approximate diameter of the smallest deposit of economic interest.

The economic value of a clay deposit of given quality is determined by the cost of development (in this case, stripping), and by the amount of clay recoverable from the deposit. Development costs are largely a function of overburden depth. Overburden thicknesses in the southern clay district are, with local exceptions, relatively shallow; consequently, deposits which would not be of economic interest in areas of deep overburden may be profitably exploited in this area. In general, deposits 50 feet in diameter or greater warrant investigation.

In view of the above considerations, a geophone spacing of 50 feet was chosen for use in determining areal coverage capabilities of the profile method.

6. Possible Areal Coverage Per Day: A portion of the August Wacker property (NE 1/4 sec. 9, T42N, R5W), near Owensville, Missouri, was selected as the initial site for this phase of the investigation. Four flint clay deposits were known to exist on this property. The locations of the

deposits were also known. The property was gently rolling, open pasture land of approximately 20 feet maximum relief. All portions were easily accessible with the equipment in use.

Prior to the beginning of actual seismic work, approximately 15 minutes was spent making a reconnaissance to develop a plan that would permit all profiles to be arranged in directions that would minimize elevation changes along a particular profile. Normally, the elevation change could be limited to approximately 5 feet, which was considered to be negligible in this application.

Profiles used during this phase of field work were 400 feet in length, with geophone spacings of 50 feet. Parallelism between profiles was maintained wherever topographic conditions permitted. Distance between profiles was 100 feet. All profile and geophone spacings were measured.

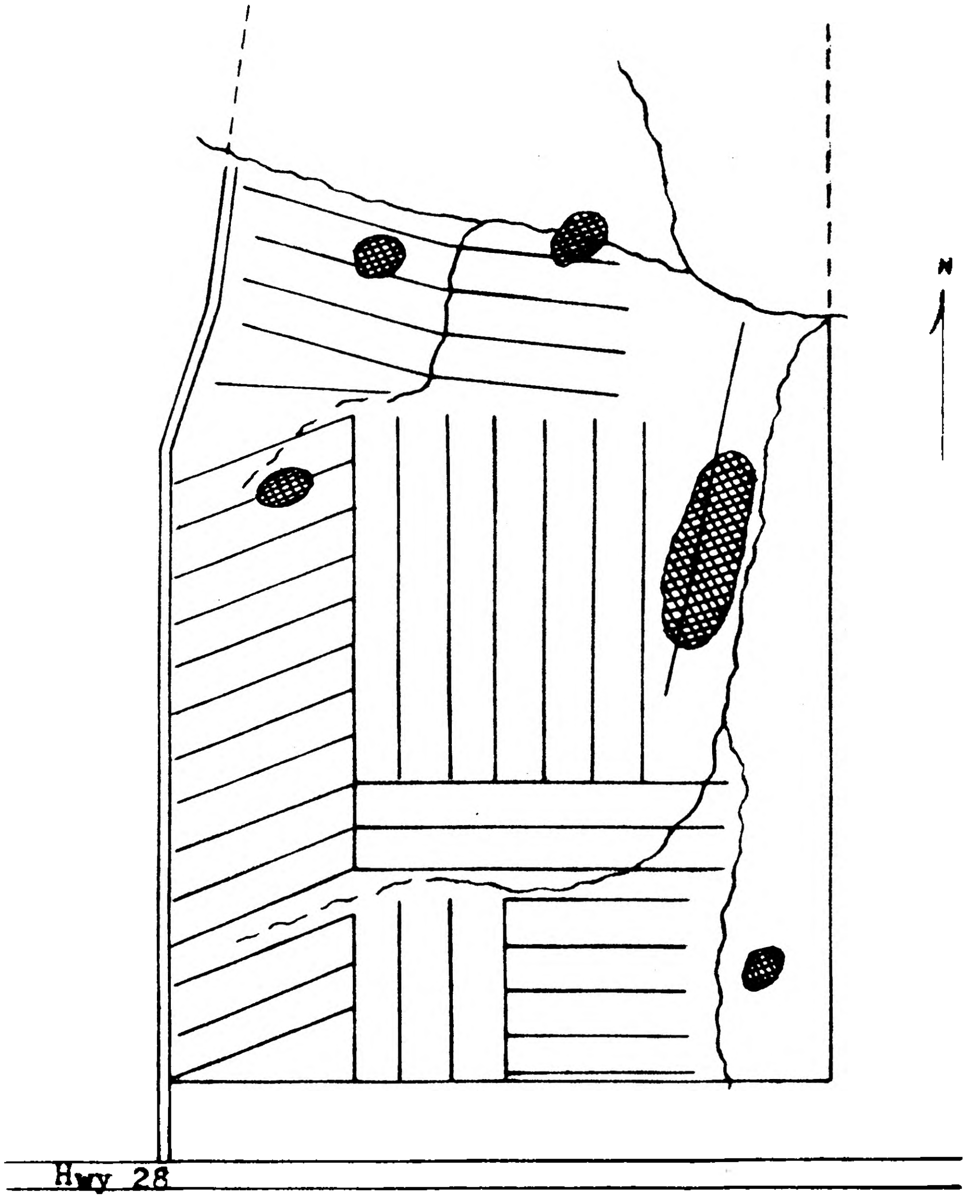
Shot holes were drilled to a depth of 10 feet for all shots unless drilling conditions were extremely difficult. A distance of 100 feet was maintained between the shot point and nearest geophone. Explosive charges consisted of 1/2 stick of 1 1/8", 40% strength gelatin dynamite.

The results of several days' field work using the above arrangement indicated that an average daily output for a two-man seismic crew was approximately 3,600 linear feet of profile. During a one-week period when a third crew member was added to the seismic party, the average daily output was increased to approximately 5,600 linear feet of profile. A total of six full working days was spent in prospecting approximately 70 acres of land on the Wacker property.

Limited periods of work in heavily wooded areas and areas of irregular topography indicated that for such terrain the above figures should be reduced 20 to 40 percent.

7. Exploration Testing of the Profile Method: The final phase of field work consisted of locating unknown clay deposits by the refraction method. This was conducted on the Floyd Nicks property (E 1/2 sec. 22, T42N, R5W) near Owensville. A portion of the property consisting of approximately 80 acres of pasture land was chosen for the investigation. Five flint clay deposits exist within this area. The location of these deposits was not known to the author or his assistant. The depth of overburden, and the diameter and depth of the deposits were also unknown to the author and his assistant. From a general knowledge of the regional geology, the author assumed that the country rock was Jefferson City dolomite. Figure 18 is a sketch map of the portion of the property prospected. The map shows the location of clay deposits and profiles.

The refraction profile method used for this test utilized 50-foot geophone spacings. The method was successful in locating four of the five existing deposits on this property. Field work was terminated by lack of time before the entire area shown on the sketch map was explored. The fifth deposit was located in the part of the property which



1 inch :: 400 ft.

Figure 18. - Sketch map of part of Floyd Nicks property (sec. 22, T42N, R5W). Hachured areas represent clay deposits. Parallel lines represent seismic profiles.

was not explored. A total of 54 profiles was shot on this property in a period of six working days. This amounts to 21,600 feet of profile.

Location of the deposits was verified by Mr. Willis Branch, Drilling Superintendent, A. P. Green Firebrick Company.

VIII. CONCLUSIONS

Results of these seismic refraction investigations conducted on sink-type clay deposits in the southern clay district indicate the following:

A. The sink structures and clay deposits appear to possess structural, lithologic, and diagenetic properties that serve to create anomalous seismic conditions.

B. The refraction profile method is successful in detecting the presence and location of sink structures and associated sink-type clay deposits.

C. Based on a limited amount of evidence, the refraction fan method as used here does not appear to be successful when applied to sink-type clay deposit exploration.

D. The refraction profile method of sink-type clay deposit exploration permits more rapid areal coverage than does conventional drilling exploration methods.

E. When applied in sink-type clay deposit exploration, the refraction profile method is most practically employed as a reconnaisance tool. Detailed seismic investigation of favorable localities is not necessary. Discovery of sink structures must in all cases be followed by closely spaced core drilling in order to determine the quality of any clay present. The location of favorable areas discovered by the profile method can be marked by flags or stakes and mapped for further investigation by drilling.

F. It is believed that the refraction profile method can be employed as a reconnaisance exploration tool to improve the economy and efficiency of exploration in the fire clay industry. The method permits rapid and economical coverage of prospective areas. Its use as an initial exploration method should greatly reduce the amount of necessary drilling on a given lease.

IX. BIBLIOGRAPHY

BIRCH, F. and LEET, L.D. (1942) Handbook of Physical Constants. Geol. Soc. America Spec. Paper No. 36, p. 76-96.

DIX, H.C. (1952) Seismic Prospecting for Oil. Harpers, New York, p. 264-265.

DOBRIN, M.B. (1960) Introduction to Geophysical Prospecting, 2nd ed., McGraw-Hill, New York, p. 69-103.

GRAWE, O.R. (1945) Pyrites Deposits of Missouri. Missouri Geol. Survey and Water Resources, ser. 2, vol. 30, p. 180.

JAKOSKY, J.J. (1950) Exploration Geophysics, 2nd ed., Trija, Los Angeles, p. 750-781.

KELLER, W.D., WESTCOTT, JAMES F., and BLEDSOE, A.O. (1953) The Origin of Missouri Fire Clays. In: Clays and Clay Minerals (proceedings). Second National Conference on Clays and Clay Minerals. Nat. Acad. Sci., Nat'l Res. Council, Wash. D.C., 1954. p. 7-43.

KISSLINGER, CARL (1952) The Effect of Variations in Chemical Composition on the Velocity of Seismic Waves in Carbonate Rocks. Doctoral diss., St. Louis University, St. Louis, Missouri. 87 p.

KOENIG, J.W. (1961) The Tertiary System. In: The Strategraphic Succession in Missouri. Missouri Geol. Survey and Water Resources. 2nd ser., vol. 40, p. 129.

McQUEEN, H.W. (1943) Fire Clay Districts of East Central Missouri. Missouri Geol. Survey and Water Resources. 2nd ser., vol. 28, 250 p.

WESTCOTT, JAMES F. (1961) personal communication.

X. VITA

Roland D. Dayley was born April 28, 1917, at Parker, Idaho. He is a son of Clarence E. Dayley (deceased) and Alzina M. Dayley. He received his elementary and high school education at St. Anthony, Idaho.

He enlisted in the Idaho National Guard as a private in 1937, and entered active military service in October 1940. He was commissioned 2nd Lieutenant, Field Artillery, AUS, September 1942. He served in the Asiatic-Pacific combat theater during the period March 1943 - December 1945, was artillery instructor in the United States during 1946, and served in China and Japan during the period January 1947 October 1948. He returned to inactive status in the rank of Major November 1948.

Between the years 1949 - 1953, he was employed on various construction and exploration jobs in Alaska.

On April 25, 1952, he was united in marriage to Elinor M. Hendrix of Independence, Kansas, at Juneau, Alaska.

He entered Montana State College, Bozeman, Montana, in September 1954. In February 1958, he was admitted to the University of Missouri School of Mines and Metallurgy and received his Bachelor of Science degree in Geology at that institution in January 1961. From February 1961 to January 1962, he was employed as a graduate assistant in the Geology Department.

He is a member of Sigma Gamma Epsilon, Tau Beta Pi, Phi Kappa Phi, and a student member of the Society of Exploration Geophysicists.