" IN THE NAME OF ALLAH, THE MOST MERCIFUL, THE MOST BENEFICIENT "

RESEARCH REPORT

ON

SHALLOW SEISMIC SURVEY IN THE AREA PETARO-HYDERABAD

BY

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FINAL APPROVAL

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GEOPHYSICS

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DEDICATION

TO

" MY BELOVED PARENTS WHO HAVE BEEN A CONSTANT SOURCE OF SOLACE AND ENCOURAGEMENT THROUGH THE UPHEAVELS OF MY ACADEMIC LIFE AND GAVE ME EVERY THING BUT ASKED FOR NOTHING"

ACKNOWLEDGEMENT

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ABSTRACT

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A project of shallow seismic refraction was carried out in PETARO-HYDERABAD(SIND), for the completion of dissertation requirements. The purpose of the survey was to establish velocity-lithology relationship, to determine the thickness of different subsurface layers and to trace the nature of refractor boundaries.

To achieve this, true velocities, depths and dip angles were obtained from TX-graph. These graphs and calculations were prepared manually as well as on the computer by using FORTRAN-77 data processing programme besides using HP-seismic refraction software. The nature of refractor boundary was mapped by HAWKIN'S METHOD. The interpretation of seismic data shows two layers having velocities Vo and V1 respectively.

Velocity of first layer ranges from 380 m/sec to 540 m/sec whereas, thickness of this layer ranges from 8.2 m to 12.3 m. The velocity range of this layer indicates a lithology of Alluvium. The velocity of second layer ranges from 1620 m/sec to 1780 m/sec. The velocity range of this layer is indicative of subweathered soil or weathered sandstone.

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CHAPTER # 1

INTRODUCTION

1.1) *INTRODUCTION*

This Dissertation is based on the seismic refraction survey carried out in "Petaro-Hyderabad" for the partial fulfillment of M.Sc.(Geophysics) of Department of Earth Sciences ,Quaid-i-Azam University, Islamabad.

Seismic prospecting is one of the most important methods of geophysical prospecting .It is widely employed in various branches of mining and particularly in exploration and prospecting of oil and gas fields .It is also used to resolve various problems of engineering geology i.e to delineate the low velocity layer,in mapping the bed rock,to detect surface fault covered by soil ,and to search water table etc.

The seismic methods of geophysical exploration utilize the fact that elastic waves travel with different velocities in different rocks.The principle is to initiate such wave at a point and to determine at a no. of other points the time of the arrival of the energy i.e refracted or reflected by the formations.This then enables the position of the discontinuities to be reduced (Parasins,1982).

The objective of the present dissertation was to map the sectional profile of the weathered and subweathered layers and also to find out the nature of the refractor boundary,weather undulating or otherwise by calculating its depth below each geophone.

To achieve these objctives ten seismic refraction spreads were laid in a profile i.e there were ten forward side shot points and ten reverse side shot points. In general ,the field data comprised of two layer refraction problem for each spread ,having a length of 280 meters between its forward and reverse shot point location. The energy detectors of each spread comprised of 24 geophones with variable inter-geophone spacing. Energy source used to obtained this data was an explosive.

The field data was processed manually as well as on the computer using a Fortran-77 programme written for two layer dipping cases. Additional computerized processing was undertaken on "Hewlett Packard" personal computer (pc) ,using HPS-13 seismic refraction processing software. Both processing operations yielded seismic cross-section for each seismic refraction spread with computed informations about :

i) Their corresponding travel time (T-X) graphs yielding a number of layers found.

ii) Layer velocities ,both apparent and true.

iii) Refractor depths below each shot point. The seismic velocity cross-sections so obtained were then interpreted for their corresponding lithological sections by using a pastulated table of velocity-cum-lithological correlation.

iv) The nature of the refrator boundary was mapped by calculating its depth below each geophone ,using Hawkin's method.

The results ,based on the above objectives ,are presented as maps ,illustrations and graphs which are given in the " APPENDICES ".

1.2) ***LOCATION AND EXTENT***

The project area forms part of the Eastren Valley of lower Indus Basin ,which lies South of Distt. Hyderabad and East of Indus river. It is bounded by latitudes $25^{\circ} 20'$ North to $25^{\circ} 0'$ North and by logitudes $68^{\circ} 15'$ East to $68^{\circ} 30'$ East.The total area is covered by the toposheet no. 40 C/8 ,Scale 1:50,000 published by the " Survey of Pakistan ".

CHAPTER # 2

GENERAL GEOLOGY

2.1) *INTRODUCTION*

The project area is located in the eastern part of the Sind province of Pakistan (bounded by latitudes 25 20 to 25 0 north and longitudes 68 15 to 68 30 east). This province is a part of lower Indus Basin which itself is part of a broad fore-land Basin in front of growing Himalayas. This fore-land basin extends westward from Bengal through the flood plains of the Ganges and to the plains of Indus towards west.

2.2) *GEOLOGY OF THE PROJECT AREA*

No geological map,of the area is available except the tectonic map of Pakistan(Kazim and Rana,1982). This map indicates that surface is generally covered by unconsolidated material i.e alluvium. However,Well data ,1987 by Muzaffar and V.Ranke ,"Pak-German Technical Co-operation" report of Hydrocarbon Development Institute of Pakistan,located in the project area suggests that following formations are present in the subsurface of the area.

i) Laki formation

ii) Bara formation

iii) Lakhara formation

iv) Khadro formation

Description of these formations according to the stratigraphy of Pakistan(Shah,1977) is briefly given as :

i) *LAKI FORMATION*

The term " Laki series " was proposed by Noetling for the lower part of Blandford's "Kirthar series". Later Hunting Survey Corporation(1961) re-defined the units as " Laki group ".

The formation consists mainly of cream coloured to grey limestone. However, marl,calcareous shale ,sandstone and lateritic clay are also present locally. The shale is grey ,greenish yellow ,weathering dark rustay brown and gypsiferous. The limestone is thin bedded and arenaceous where as sandstone is commonaly ferruginous.

The formation contains fossils including gastropods,bivalves,foraminifers and algae. The fossils indicate an early Eocene age. The formation is correlated with the Kharan formation and parts of the Chharat group of the Kohat-Potwar Province. According to the log data of Well#21 near the project area, formation is found at the depth ranging from 0 - 984.4 m.

ii) *BARA FORMATION*

The formation is named after Bara Nai ,Laki range. It consists of dominant sandstone with lesser shale and minor volcanic debris. The sandstone is varicoloured,fine to coarse grained,soft and crumbly. Massive looking sandstone beds ranging in thickness from few centimeters to three meters are common. The interbedded shale is soft and has dark shades of similar colour to that of sandstone. Some carbonaceous material is also preset both in shale and sandstone ,however,shale is some times highly carbonaceous.

No fossils have been found in the formation except some oysters and reptile remains. The formation is correlated with the Hangu formation of the Kohat-Potwar Province and with the lower part of Rakhshani formation of Baluchistan Basin. Since the formation overlies the Khadro formation of Danian age and underlies Upper paleocene Lakhra formation ,it is regarded as Middle paleocene.

iii) ***LAKHARA FORMATION***

The Lakhara formation represents the upper "Ranikot formation" and upper parts of Bedkachu, Rathore and Thar formations. The formatrion dominantly composed of limestone on weathered surface limestone shows brown,buff and at other places orange brown and pinkish brown colours. The limestone is some times sandy. Sandstone is mainly present in the lower part of the formation while few interbeds of sandstone and shale are also

TABLE # 2.1

WELL LOG DATA OF SUNBAK WELL

Name	Sunbak
Area	Lower Indus
Company	Hunt
North(DDMM.SS)	2524.400
East(DDMM.SS)	6754.450
Groundelev(m)	108.2
KB/DF(m)	112.8
TD(m)	1932
Formation at TD	Khadro
Status	P & A
Remarks	Oil shows in Ghazij
Spud-Abd	9.9.57-14.10.57
Laki/Ghazij	- 984.4 m
Bara/Lakra	984-1737.2 m
Khadro TD	1737.2-1932 m

present in the upper part. The sandstone is calcareous and in places grades into arenaceous limestone. It is grey ,fine to coarse grained ,thin to thick bedded and cross-stratified.The shale present is grey on fresh surfaces and yellowish brown on weathered surface. On the basis of its fauna late paleocene age is assigned to the formation the formation is correlated with the upper parts of the Dungan and the Rakhshani formations. According to well log data of Sunbak near the project area both " Bara and Lakhara formations " are found at the depth ranging from 984.4 - 1737.2 m.

iv) ***KHADRO FORMATION***

The Khadro formation includes the basal parts of the " Karch,Gidar dhor and Jakker " group of the Hunting Survey Corporation(1961).

The formation consists of sandstone and shale with some limestone. The sandstone is soft and medium grained and show different colours like brown, grey and green. The shale is olive, pale bluish grey and contain limestone and sandstone interbeds. At the type locality , the basal part of the unit consists of dark limestone bed with reptile bones. Top of the unit is usually marked by a volcanic flow. At karkh and Jakker the formation consists dominantly of interbedded soft and brown shale , and soft, grey to green well bedded sandstone. The age of the formation is recorded as Early paleocene which in places,extends down into Late Cretaceous. According to the well log data, this formation was encountered at depth ranging from 1337.2 -1932.0 m.

CHAPTER # 3

SEISMIC REFRACTION METHOD

3.1) INTRODUCTION-

Seismic method is one of the most important method in the investigation of geological structures of the Earth.Seismic prospecting is one of the most important branch of geophysical exploration.This is due to its capability of high accuracy by virtue of its high resolution and capability of deep penetration.Its field methodology depends upon the refraction and reflection of elastic waves produced by artificial source,called the shot-point.These elastic waves propagate radially in all directions from the source and undergo reflection as well as refraction at different elastic discontinuities encountered by these propagation waves.These reflected or refracted waves bouncing back to the surface can be detected by specially designed receivers called geophones,which in-fact are electromechanical devices capable of converting the up and down mechanical motion of the ground into electrical signals.Basically the signal so received is very weak and requires amplification.Thus the system amplifies and also displays these signals in the form of a photographic trace of a moving spot and can also be taped on the systems magnetic tape or be registered by a digital recorder. This final output of the seismic instrument is called the refraction or reflection seismogram as the case may be. The processing of these refraction seismograms leads to in determining the velocities of propagation of the refracted seismic waves along a geological layer in which the velocity of propagation of elastic wave is greater than in the overlying strata ,from which data the depth/s of the refracting interface/s can be computed. Such depth/s computed below each shot-point distributed in the project area , eventually leads towards the mapping of geological boundaries so that the subsurface tectonic setup of different rocks could be studied (Gurvich ,1972).

Seismic methods ,both refraction and reflection are now very commonly used in the world in exploration of oil ,gas ,water ,minerals etc. The method has special advantages in the location of structural traps ,in petroleum prospecting . Seismic methods are also useful for many engineering projects. Modern digital recording equipment ,mechanical energy source and tendency to replace manual treatment of seismic data by computer processing increase the accuracy and reliability of the seismic results (Sjogren ,1984).

For the seismic refraction method to be applicable the following two conditions must exist in the subsurface horizon :

(A) The velocity must increase with depth. If it does not ,the seismic wave will not be refracted at the critical angle of the interface between two transmitting media.

(B) The various layers through which the refracted waves propagate horizontally must have a minimum thickness which permits transmission of the refracted wave .If a layer is thinner than a particular thickness ,the refracted wave will not be transmitted horizontally through that layer and therefore refraction signature will not be recorded. Thus we will have a blind zone problem.

Structural information is derived principally from ray paths which fall into two main categories :-

3.1.1) *REFRACTED PATH*

In which the major portion of the path is along the interface between two rock layers and hence is approximately horizontal (fig.3.1).

3.1.2) *REFLECTED PATH*

In which wave travel downwards initially and at some point is reflected back to the surface ,the overall path being essentially vertical (fig.3.2).

3.2) *SEISMIC THEORY*

In order to understand the theoretical background

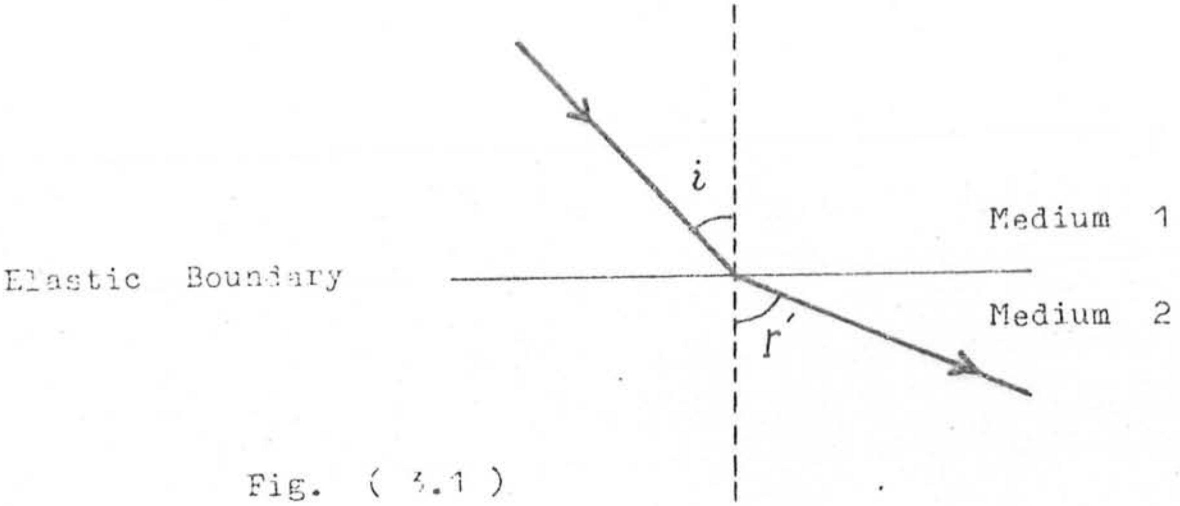


Fig. (3.1)

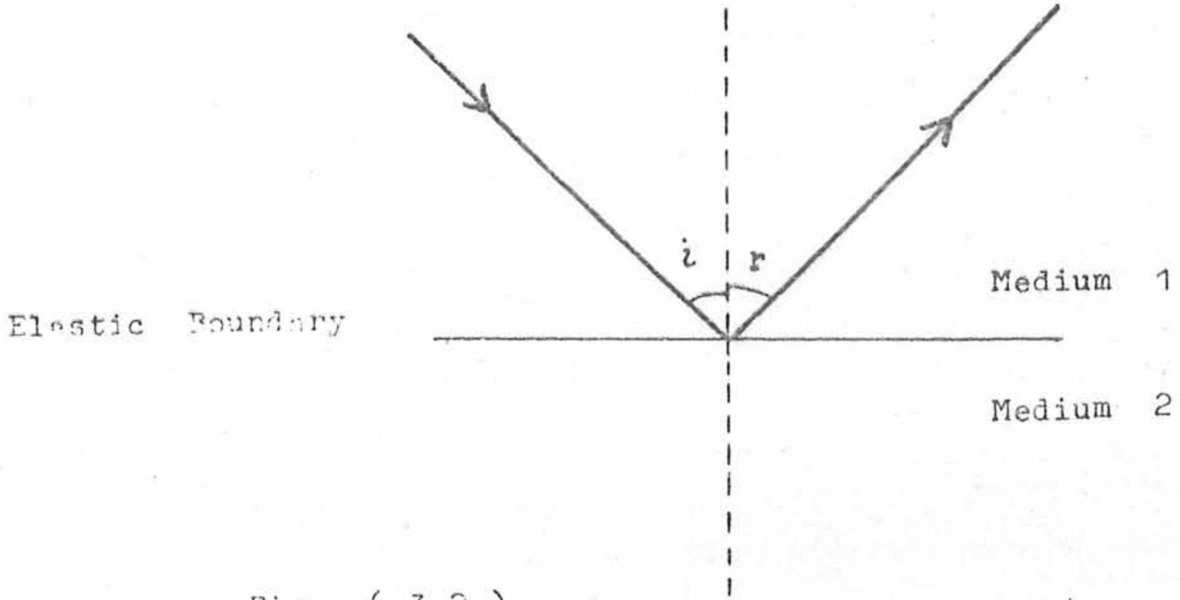


Fig. (3.2)

Fig. (3.1) Refraction of ray path

Fig. (3.2) Reflection of ray path

of seismic method ,it is important to mention properties of the rocks and their nature and propagation of seismic waves in the rocks. For this purpose ,theory of elasticity and optics are given below :

3.2.1) *ELASTICITY*

The property or quality of being elastic i.e the size and shape of a solid body can be changed by applying forces to the external surface of the body. These external forces are opposed by the internal forces ,which resist the change in size and shape. As a result body tends to return to its original position when external forces are removed. This property of the resisting change in size or shape and of returning to unformed condition when external forces are removed is called elasticity.

3.2.2) *STRESS AND STRAIN*

Stress is defined as ," The force per unit area " . Thus when a force is applied to the body then stress is the ratio of the force to the area on which force is applied. If the applied forec is perpendicular to the area the stress is said to be a " Normal stress " . When the forces are tangential to the element of the area ,the stresses are called the "Shearing stresses " .

Stress is a vector quantity .Let " F " be the force acting at a point " P " in small area " A " ,the stress at point " P " will be vector quantity given by limits :

$$\lim_{A \to 0} F/A$$

This orientation of the area is given by the unit normal vector " n " .

Strain is defined as ," Deformation resulting from applied fofce within elastic limits " .

When the elastic body is subjected to stress changes in shape and dimensions occure .These changes are called strain .Strain is also a vector quantity .If deformations takes place along normal stress vector , the strain is called "Normal Strain " and if deformation is along the shearing stress vector , then it is called "Shearing Strain " .The changes in the dimensions by the normal strains result in volume changes when a body is strained .The change in volume per unit volume is called the " Dilatation " . The permanent strain developed in a material stressed beyond its elastic limits is called "Plastic Strain " .

3.2.3) *HOOKE'S LAW*

According to hooke's law ,"Strain is proportional to strain,up to a limit value of stress, depending upon the nature of the body " .

i.e $\quad$ Stress $\propto$ Strain

Stress / Strain = Elastic Constant

3.3) *SEISMIC WAVES AND THEIR SUBSURFACE PROPAGATION*

Seismic waves propagate out from the source following the principles of optics. In seimic prospecting ,we have two type of waves in accordance with the physical properties and dimensions of the medimum.

3.3.1) *BODY WAVES*

" Those waves which are transmitted in the interior of an elastic solid or fluid material are called the body waves "

Body waves are further divided into two types :

3.3.1a) *LONGITUDINAL WAVES*

This type of wave is also known as compressional or primary (or just P) wave. An elastic wave in which the direction of particle motion in the medimum is parallel to the direction of propagation of waves like sound waves.

The travelling disturbance in this case is the cubical dilatation or " Volume deformation " . Thus the wave path traversed by a P-wave consists of a sequence of alternating zones of compressions and rarefactions. Fig.(3.3a) shows wave fronts of a plane P-wave which are drawn at half-wavelength intervals. The particles of the medium oscillate about their zero - positions in a direction coincident with the raypath at those positions. P - wave is the fastest wave for a given medium and , therefore ,it is the earliest phase normally detected on earthquke seismograms.

This is the type of wave which is commonly employed in seismic reflection and refraction prospecting (Hamid N. Al Sadi ,1980).

3.3.1b) *TRANSVERSE WAVES (S)*

"An elastic wave in which the direction of particle motion within the transmitting media is at right angle to the direction of propagation of the wave " .

These waves are also called secondary waves, shear waves , in general S- wave .The travelling disturbance in this case is the shearing strain or "shape deformation " .The medium which is traversed by an S-wave experiences no volume changes .

As S-wave moving in a horizontal direction ,which is so polarized that the particle motion is confined to the horizontal plane ,is known as SH-Wave (fig. 3.3b).

When the polarization plane is vertical ,it is called SV-Wave (fig.3.3c).

In a solid medium ,the P-wave is about 1.7 times as fast as the S-wave.In liquid, where $\mu = 0$, S-waves do not propagate (Hamid N.Al-Sadi,1980) .

3.3.2) *SURFACE WAVES*

At the contact surface between two media ,there are also other waves .Those waves which are moving along the free boundary or surface of the medium so they are called as surface waves .Surface waves may be classified into:

3.3.2a) *RAYLEIGH WAVES*

This type of wave develops at the free surface of a semi-infinite medium .The wave amplitude decays rapidly with the increasing depth .

The travelling deformation is a sort of combination of both dilatation and shear strains .The particle motion takes place in a vertical plane parallel to the direction of propagation and has an elliptical retrograde orbit (fig.3.3d).The minor axis of the ellips (which is parallel to the propagation direction) is about two-thirds of the major vertical axis.Rayleigh waves travel with a velocity , Vr given by :

$$Vr = 0.92\ Vs$$

Where Vs is the S-wave velocity in the same medium . The velocity in the same medium .The velocity of Rayleigh wave is less than

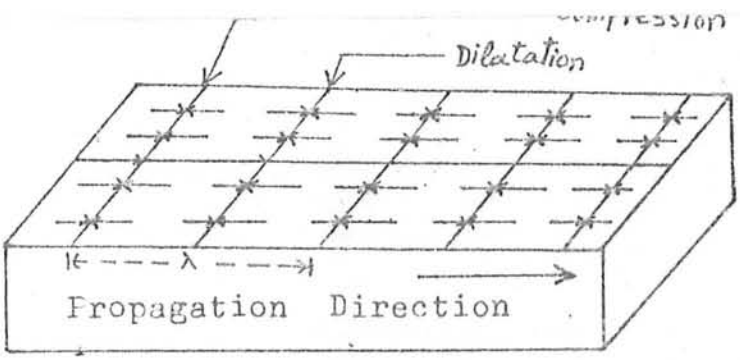


Fig.(3·3a): Particle displacement for a plane P-wave

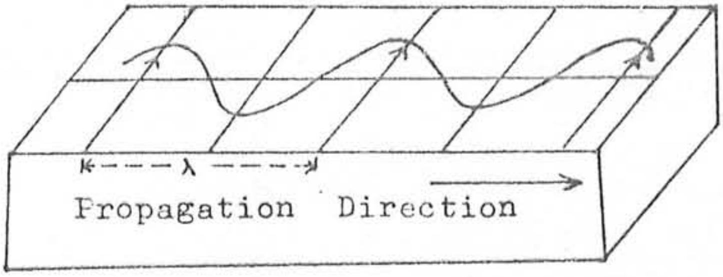


Fig.(3·3b): SH=Wave

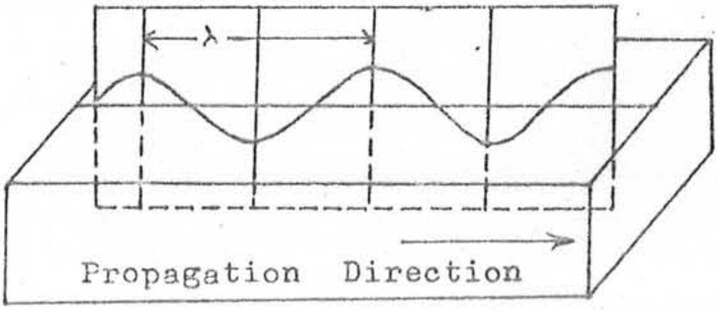


Fig.(3·3C): SV-Wave (Particle displacements fpr S-Waves)

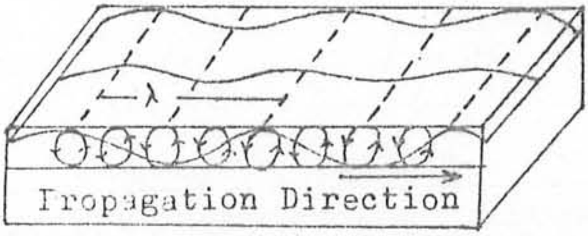


Fig.(3·3d): Particle retrograde motion in a medium traversed by aRayleigh Wave.

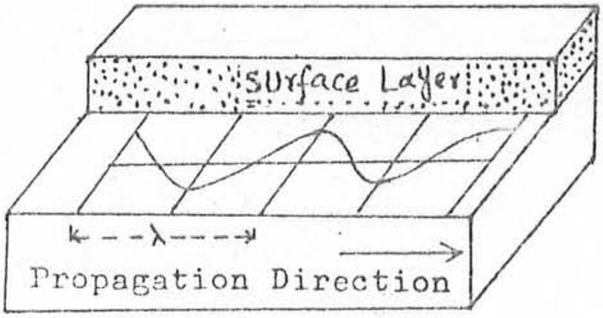


Fig.(3·3e): Particle motion during the passage of a L-Wave the velocity of the shear waves .

3.3.2b) *LOVE WAVES*

These are the surface seismic waves in which the particles of an elastic medium vibrate transverse to the direction of the waves travel,with no vertical component .These waves develops in a low-velocity surface layer which overlies a semi-infinite medium (fig.3.3e).The vibration amplitude decays rapidly with increasing depth in lower medium and the velocity of these waves depends upon the wavelength.

The particle motion is transverse and in the horizontal plane .This type of wave travels by multiple reflections between the top and bottom boundaries of the surface layer .

Since it possesses no vertical component ,Love waves are not detected by the geophone or by another vertical-component instrument (Hamid N.Al-Sadi,1980).

3.4) *VELOCITIES OF PROPAGATION OF SEISMIC WAVES IN VARIOUS ROCKS AND MEDIA*

Velocities of seismic waves in different rocks depends upon various elastic properties of the earth materials and rocks through which they travel .Seismologically there are five major categories in which earth materials can be characterized :

(i). Alluvium , soil , drift ,unconsolidate sufficial deposits that are generally recent in age .

(ii).Sandstone and shale.

(iii). Limestone,dolomite and other deposits.

(iv). Crystalline rocks(both igneous &metamorphic).

(v). Evaporites.

In general igneous rocks have seismic velocities which show a narrower range of variation then sedimentary or metamorphic rocks and average velocity for them is higher than that for other types .The following table indicates the range of values for velocities for different types of rocks :

SEISMIC VELOCITIES :

MATERIAL :	VELOCITY(m/sec)
Anhydrite(S)	3500-5500
Basalt(SH)	5500-6300
CementedConglomerate(SJ)	1200-3500
Clay (D)	1100-2500
Coarse sand (SJ)	1000-2000
Dolomite (S)	3500-6900
Dunite (SH)	7500-8100

Gabbro (S)	6450-6700
Gneiss (S)	6400-7500
Granite (SJ)	4200-6000
Gypsum (S)	2000-3500
Gravel ,Dry Sand (SJ)	1000-2000
Ice (G)	3100-4200
Limestone (P)	3500-6500
Rock Salt (P)	4000-5500
Sandstone (D)	1400-4300
Shale (G)	2000-4300
Water (G)	1400-1590
Weathered soil (G)	1000-2000

Refrences used in compiling this table are the following :

(P) Parasnis (1982),(G) GURVICH (1972),(SH) Sharma (1976),(SJ) Sjogren (1984),(D) Dobrin (1984),(S) Sadi (1980).

3.5) *FACTOR INFLUENCING SEISMIC VELOCITIES*

Seismologically rocks show marked differences in elasticity depending on petrologic composition .Elastic sediments such as sand , sandstone and shale are less elastic than sediments composed of crystalline matter , such as limestone and dolomite .In addition to the rock type there are several other factors which play an important role in determining seismic wave velocities .

FAUST (1951), showed remarkably that velocity of propagation of seismic waves through sedimentary rocks is a complex function of depth of burial , geological time since deposition and many other variables like porosity ,density & the degree of saturation etc.Following is the brief account of these factors :

(1).In sedimentary rocks, the velocity of seismic waves tend to increase with depth of burial and geologic age .Many empirical attempts have been made to represent this increase .For shale and sandstone concluded :

$$V = 46.5 \; (T \; Z)^{1/6} \; m \;/sec.$$

where " Z " is the depth in meters and "T " the age in years.Thus with depth of burial material becomes more compact and hence velocity will increase .

(2).The velocity is inversely proportional to the square of density .It is common observation that velocity appears to increase with density i.e elasticity increases with more dense material and the velocity too .

(3).The effect of porosity and decomposition decrease the modulus of elasticity ,that is why the velocity of porous material is considerably small .The effect of porosity on wave velocity is much pronounced in the near surface layer i.e weather layer (Telford etal 1985).

(4).The effect of moisture of water content on the velocity in sedimentary rocks is involved .In consolidated bed the moisture appears to decrease the velocity and in unconsolidated beds moisture increase the velocity appreciably .

-(5).In an isotropic medium the recorded velocities are generally higher when measured along the strike of structure, than when measured perpendicularly to the structure .The difference may be of the order of 5 --> 15 % (Sjogren,1984).

3.6) *ELASTIC CONSTANT*

The base of all the seismic waves is on the elastic constants .In case of homogeneous ,isotropic medium a few constants ,called as elastic moduli or elastic constant,describe the stress-strain linear relation representing the elastic response of the medium.For historical reason more elastic constants are in use when are actually needed (Robinson,1983).So the various constants are not independent of each other.The most common elastic moduli are the following :

1- YOUNG'S MODULUS (E)

2- BULK MODULUS (K)

3- RIGIDITY MODULUS (μ)

4- POISSON'S RATIO (σ)

5- LAME'S CONSTANT (λ)

Any one of these five constants may be expressed in terms of any two of the remaining ones.Therefore ,any two of the constants can be used to define the elastic properties of a homogeneous and isotropic body (Robinson ,1983).

3.6.1) *YOUNG'S MODULUS (E)*

According to hook's law ,"Stress is proportional to strain ".This definition is for small strains only.If a body offers maximum resistance to the applied stress, then there is no change in the body and strain is almost zero.In this case the Young's modulus has maximum value e.g in solids.So we can say that Young's modulus measures the resistance offered by a body to the applied stress .The relation between longitudinal stress and strain is :

$$\Delta L / L = (F / A) / E$$

$$\text{OR} \quad E = (F / A) / (\Delta L / L)$$

which is the stress per unit area divided by the relative elongation or shorting .The constant "E" is called the Young's modulus .

3.6.2) *BULK MODULUS (K)*

"Under increasing force per unit area , a body will decrease in size but increase in density ".OR. The stress divided by relative change in volume is called as the Bulk modulus .

Mathematically ,

$$K = (F / A)/(\Delta V / V)$$

3.6.3) *RIGIDITY (SHEAR) MODULUS (μ)*

The measure of the material's resistance to shear-strain is called Rigidity (Shear) modulus .

Mathematically,

$$\mu = (F / A)/\phi$$

where (ϕ) = Shearing strain .The value of "μ" is zero for the liquid media .

3.6.4) *POISSON'S RATIO (σ)*

Poisson's ratio is the relation between the elongation and the contraction of a body and the reduction in thickness of the body.

Mathematically,

$$\sigma = (\Delta W / W)/(\Delta L / L)$$

The value of Poisson's ratio for different materials is given below :

Solids = 0.25

Liquids = 0.50

Hard rigid rocks = 0.05

Soft materials = 0.45

3.6.5) *LAME'S CONSTANT (λ)*

The Lame's constant is valid for iosotropic medium and is expressed in terms of "E" and " σ " as :

$$\lambda = (\sigma E)/(1 + \sigma)*(1 - 2 \sigma)$$

3.7) *LAWS OF OPTICS FOR SEISMIC WAVES*

The geometry of the refracted or reflected ray path along which elastic waves are propagated in a medium is governed by certain simple rules which are as follows :

3.7.1) *HUYGEN'S PRINCIPLE*

According to this principle , waves in a medium spread out from a point source as expanding spheres so that every point on the advancing wave front is the source of a secondary wavelet , that also travels out from its ,in spherical shell as shown in Fig.(3.4), (Al sadi,1984).This law helps us in understanding the geometrical shapes of the propagation of waves and its associated ray path help to interpret the time distance relations.

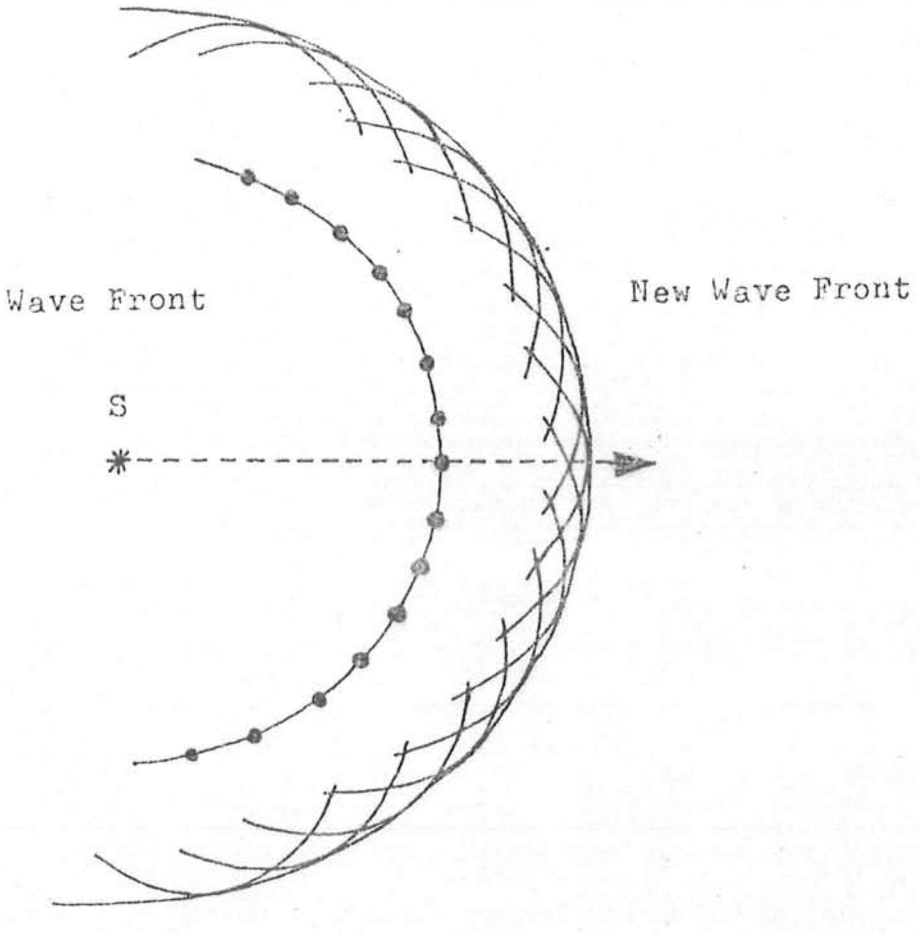


FIG.(3.4) HUYGEN'S PRINCIPLE

3.7.2) *FERMAT'S PRINCIPLE*

The French mathematician "Pierre de Fermat" has pointed out that the time required for light to travel from one point to another along a given ray is less than the time taken to do this journey by another route .

After applying this principle to seismic rays ,we can say that a wave propagates along the ray path for which the travel time is minimum (Hamid N. Al-Sadi,1980).

3.7.3) *SNELL'S LAW*

Snell's Law describe the relationship between the incident and refracted ray path at an elastic boundary .This law states,"A wave incident on the boundary between two media having velocities V1 and V2 is partly reflected or refracted such that for reflaction the angle of incident is equal to the angle of refraction".i.e

$$\text{Sin } i = \text{Sin } r$$

and for refraction

$$\text{Sin } i \,/\, \text{Sin } r' = V1 \,/\, V2$$

OR

$$\text{Sin } i \,/\, V1 = \text{Sin } r \,/\, V2$$

where i = Angle of incidence

r = Angle of reflection

r' =Angle of refraction

The Snell'a Law for a particular ray path is expressed as :

$$\sin i \,/\, \text{Velocity of ray path} = \text{Constant}$$

In seismic refraction method , we consider the case when :

(i). $i = ic$ = Critical angle

(ii). When $V2 > V1$

When angle of incidence becomes the critical angle ,then

$$\text{Sin } ic \,/\, \text{Sin } (r' = 90^{o}) = V1 \,/\, V2$$

Since $\text{Sin } 90^{o} = 1$

Therefore, $\text{Sin } ic = V1 / V2$, ($i=ic$,when $r' = 90^{o}$)

$$ic = \text{Arc Sin } (V1 \,/\, V2)$$

For a critical angle of incidence the refracted ray travels along the interface, i,e the angle of incidence for which $r = 90^{o}$ is called critical angle ic .

For any angle of incidence greater than ic ,no ray will be refracted in the second medium and all the energy incident at such an angle is reflected .

Let us consider a wave that strikes the interface at critical angle of incidence .This wave then propagates as the refracted wave according to the Huygen's principle ,and returns to the surface , as shown in the Fig.(3.7) where its arrival time

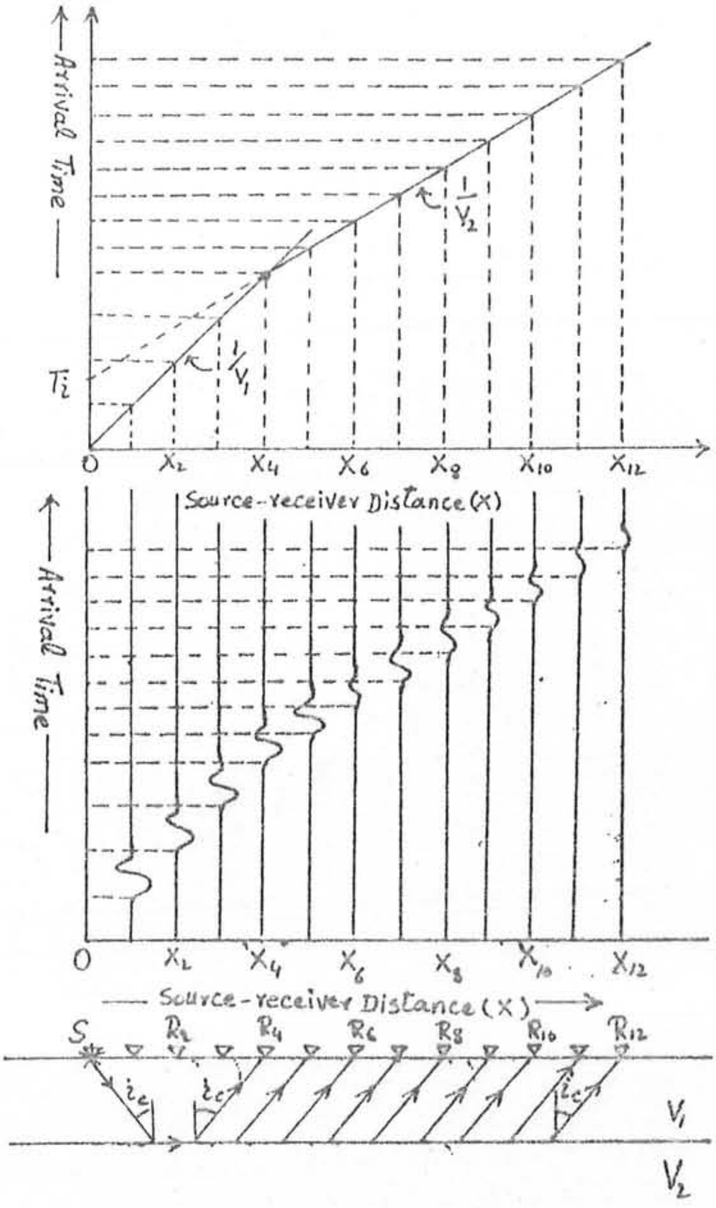


Fig. (3·7): Wave Path and Travel-Time Curves can be picked up and recorded in the form of seismogram .These arrival times are used to draw time-distance graph .

The graph will be in the form of straight line segments representing different layers of subsurface .Each straight line segment of time-distance curve generates a slope value from which velocity of that segment can be calculated as :

Velocity = 1 / Slope of segment.

3.8) *MATHEMATICAL EXPRESSIONS FOR THE SEISMIC REFRACTION PARAMETERS*

L .MOTA (1954) developed mathematical expressions for seismic refraction for a number of homogeneous velocity layers having plane dipping interfaces .The following assumptions are involved in the mathematical expressions :

(i).The true velocities of the lithological wave propagation within the layers is constant .

(ii).The refractor along which the energy is supposed to travel and return to the surface via a critical angle ,is considered plane and continuous from one end of the profile to the other .

(iii).Angles from the horizontal upward and to the left are taken as positive and those of upward and to the right are negative .

The formulae which are used to calculate the velocities in the two layer and three layer cases are as :

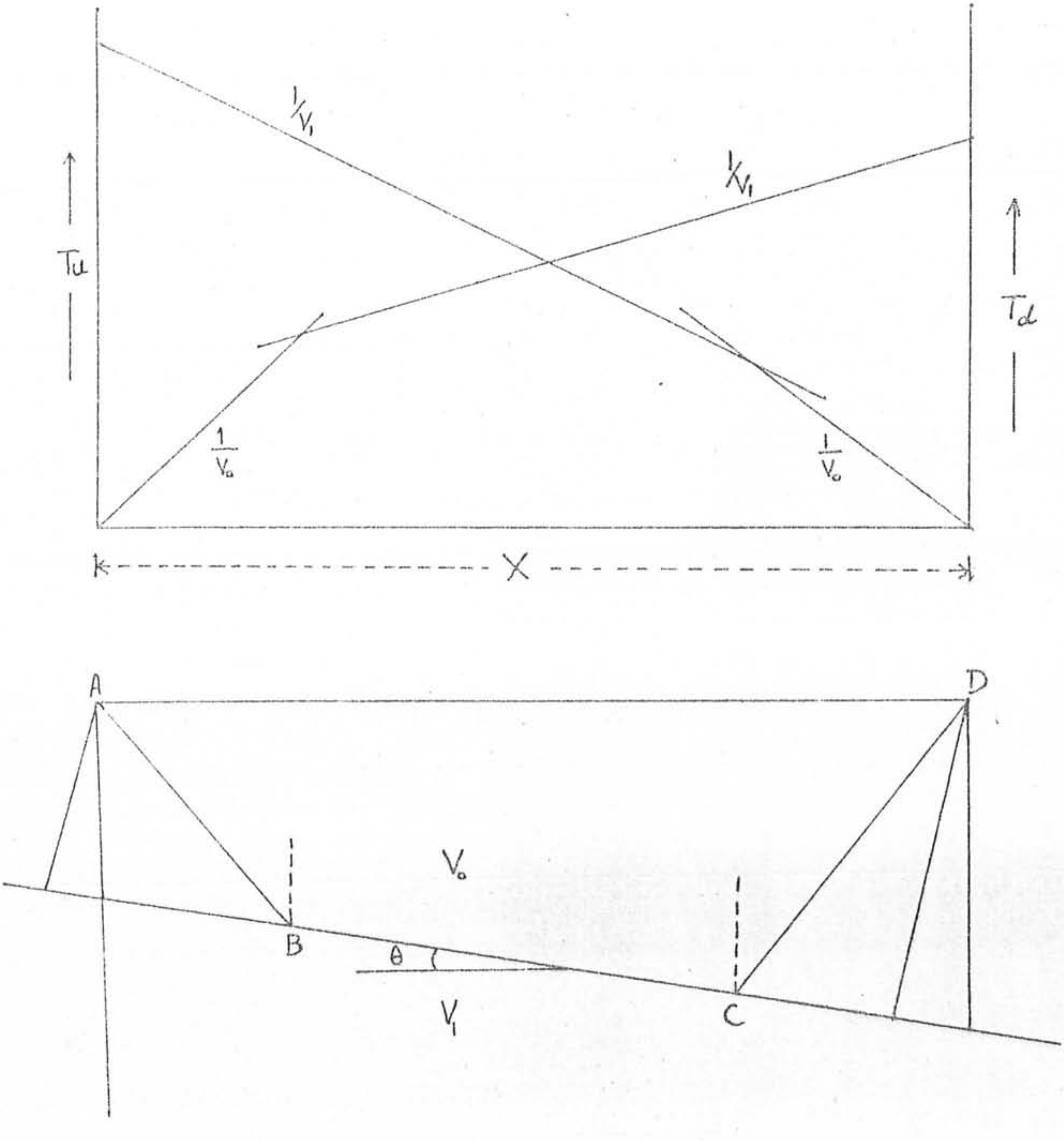


Fig.(3.8) Two Layer Dipping Case

3.8.1) *TWO LAYER DIPPING CASE*

The formulae for true velocities , up dip and down dip,the depth to the first refractor are given below :

True velocity ,Vo = 2 (Vou)*(Vod)/(Vou + Vod)

True velocity ,V1 = 2 (V1u)*(V1d)/(V1u + V1d)

Depth,Z1u = Vo T1u /2 Cos ic1

Similarly, Depth,Z1d = Vo T1d /2Cos ic1

where Vou, Vod, V1u and V1d are the velocities of the first and second layers for up and down dip cases respectively.Also Z1u and Z1d are depths of first layer for up and down dip cases respectively .T1u and T1d are the intercept times for up dip and down dip cases respectively .The critical angle ic1 and the angle of dip O1 of the refractor are given by formulae :

ic1 = 1/2 (Arc Sin Vo/V1d + Arc Sin Vo/V1u)

And $\theta 1$ =1/2 (Arc Sin Vo/V1d - Arc Sin Vo/V1u)

3.8.2) *THREE LAYER DIPPING CASE*

Up dip and down dip depths of second refractor are given by the following formulae :

Z2u = V1 [T2u-Z1u{COS(α_1 + β_1)+1}/VoCosα_1]/2Cos ic1

and Z2d = V1 [T2d-Z1d{Cos(α_1 + β_1)+1}/VoCosβ_1]/2Cos ic1

where Vo and V1 for the true velocities ,Z1u and Z1d are up and

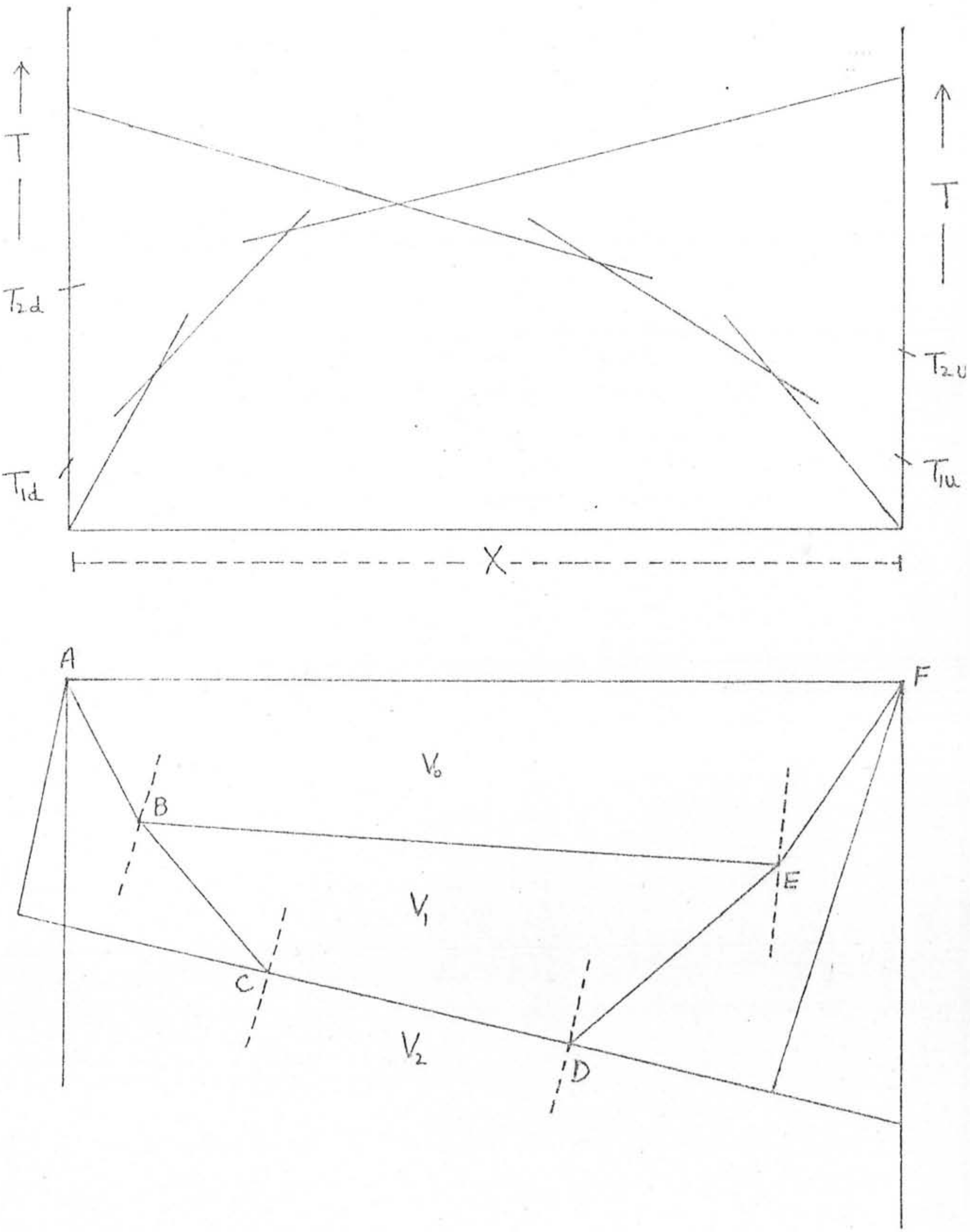


Fig.(3·9): Three Layec Dipping Case

down dip depths to first refractor , T2u and T2d are up and down dip intercept times respectively.Also (α_1) is the angle of incidence for first refractor, and (β_1) is the angle of emergence for first refractor , while ic is the critical angle for second refractor as shown in Fig.(3.9).

Where,

$$ic1 = (\gamma_1 + \delta_1) /2$$

Also

$$\alpha_1 = \text{Arc Sin} (Vo/V2d) - \theta o$$

$$\beta_1 = \text{Arc Sin} (Vo/V2d) + \theta o$$

$$\theta 1 = (\gamma_1 - \delta_1)/2 + \theta o$$

Dip angle of second refractor is θ2 is given as

$$\theta 2 = (\gamma_1 - \delta_1)/2 + \theta 1$$

where

θo = Dip of first refractor

$\theta 1$ = Dip of second refractor

$$\gamma_1 = \text{Arc Sin} (V1/Vo * \text{Sin}\,\alpha_1)$$

$$\delta_1 = \text{Arc Sin} (V1/Vo * \text{Sin}\,\beta_1)$$

3.9) ***ANOTHER METHOD FOR THREE LAYER DIPPING CASE***

Travel times for three layer dipping case are derived in the same manner as for the two layer dipping case and the double horizontal layer.Thickness of the layers below the shot-points are designated as Z1u and Z2d for up dip shooting and Z1d and Z2d for down dip shooting as shown in Fig.(3.10).For the sake of simplicity,it is assumed that :

(a).The dip of the two boundaries is in the same general direction, however the dip angles may change.

(b).The layer velocities increase with depth such that

$$V2 > V1 > Vo$$

Computations proceed in the following steps :

(i).Compute (ic1 - θo) and (ic1 + θo) from the formulae :

$$Vo/V1u = \sin(ic1 - \theta o)$$

$$Vo/V1d = \sin(ic1 + \theta o)$$

where Vo = True velocity of first layer

θo = Dip angle of first layer

ic1= Critical angle of first layer

V1u and V1d are the velocities of first layer in up and down dip cases respectively.

(ii).Compute θo and ic1 from the formulae

$$\theta o = 1/2\ [(ic1 + \theta o)-(ic1 - \theta o)]$$

$$ic1 = 1/2\ [(ic1 + \theta o)+(ic1 - \theta o)]$$

(iii).Determine , $V1 = Vo/\sin ic$

(iv). Calculate,Zou and Zod from the formulae :

$$Zou = X12u\ [1 - \sin(ic1 - \theta o)]/2\cos ic1 * \cos\theta o$$

and $Zod = X12d\,[1 - \sin(ic1 + \theta o)]/2Cos ic1 * Cos\theta o$

Where Zou = Depth of first refractor in up dip case

Zod = Depth of first refractor in down dip case

$X12u$ = Crossover distance in up dip profile

$X12d$ = Crossover distance in down dip profile

(v).Find $(\beta - \theta o)$ and $(\alpha + \theta o)$ from the relations :

$$Vo/V2u = \sin(\beta - \theta o)$$

$$Vo/V2d = \sin(\alpha + \theta o)$$

Then calculate angles (α) and (β).

(vi).Calculate $ic2 + (\theta 1 - \theta o)$ and $ic2 - (\theta 1 - \theta o)$ from the relations:

$$\sin\alpha / \sin ic1 = \sin[ic2 + (\theta 1 - \theta o)]$$

and

$$\sin\beta / \sin ic1 = \sin[ic2 - (\theta 1 - \theta o)]$$

(vii). Determine ic2 as :

$$ic2 = 1/2\,[\{ic2 + (\theta 1 - \theta o)\} + \{ic2 - (\theta 1 - \theta o)\}]$$

(viii).Calculate $(\theta 1 - \theta o)$ as :

$$\theta 1 - \theta o = 1/2\,[\{ic2 + (\theta 1 - \theta o)\} - \{ic2 - (\theta 1 - \theta o)\}]$$

From this relation calculate the value of $\theta 1$,which is the dip angle of second layer and ic2 is critical angle of second layer .

(ix). Determine , $V2 = V1/ \sin ic1$

(x). Calculate Z1u and Z1d from the formulae:

$$Z1u = [X13u\{1 - \sin(\beta - \theta o)\} - Zou\{\cos(\alpha + \theta o) + \cos(\beta - \theta o)\}]/2\sin ic1 * \cos ic2$$

$$* \cos\theta_1$$

$$Z1d = [X13d\{1-\sin(\alpha+\theta_o)\} - Zod\{\cos(\alpha+\theta_o)+\cos(\beta-\theta_o)\}]/2\sin ic1 * \cos ic2$$
$$* \cos\theta_1$$

where Z1u = Depth of second refractor in up dip case .

Z1d = Depth of second refractor in downdip case

X13u= Crossover distance in up dip case.

X13d= Crossover distance in down dip case.

For the computation of Z1u and Z1d the use of the crossover distances is made ,that is the first and third parts of the travel time curve may be extended to the intermediate crossover distances .

3.10) *SEISMIC NOISE*

In seismic prospecting the concept of signal to noise is of paramount importance.Whereas the reflected and refracted energy is classed as signal,their recorded version on the seismic record is not a pure or unbiased record of the required signal ,but it is to a lesser or greater extent modulated by the unwanted components of energy which are called noise component.This means that the geophones not only pick signals but the noise components also .Thus it distorts our observed data ,from which these disturbing effects have to be determined and removed so that pertinent undertaken,therefore classification,determination and attenuation of noise is very important for improved S/N ratio of our reduced data .The problem of S/N improvement is very critical in seismic reflection but not so in seismic refraction work.

There are two types of seismic noises:

3.10.1) *COHERENT NOISE*

Coherent noise is due to the unwanted sources such as surface waves ,multiples ,diffraction from sharp edges like fault etc,and also due to vehicular traffic .The characteristic of such noise is that its effect in most cases is repeatable.Noise due to vehicular traffic is not repeatable.In seismic refraction work the vehicular disturbance is great source of noise .

3.10.2) *INCOHERENT NOISE*

Incoherent noise is random noise and is also repeatable and is generally due to near sufface irregularities such as boulders ,cracks ,small scale faulting etc.

Incoherent noise is characterized by its dissimilarity on all seismic traces.Non repeatable random noise may be induced by the :

(i). Artificial traffic such as rail roads , aircraft.

(ii).Wind swaying trees ,bushes and grass .

(iii).A person walking near a geophone.

(iv). Stone ejected by the shot and falling back near to the geophone.

(v). Fluctuating pressure in the air caused by wind variation due to topography.

3.10.3) *ATTENUATION OF NOISE*

Various methods can be applied for reducing noise so that ultimately S/N ratio of the record is improved.

i).Spatial Filtering.

ii).Electrical Filtering.

3.10.4) *SPATIAL FILTERING*

The most effect technique for handling random noise are to attenuate certain wavelengths of horizontally propagated noise is to spread out arrays of geophones or shot-points constitute spatial or wavelength filters.The simplest array consist of a line of geophones or shot holes or librators.Since

Velocity = Distance travelled/Time taken .

Therefore,depth of refracting interface = Velocity * Time

So that slope of the line = 1/Velocity of refractor.

3.11) *APPLICATIONS OF SEISMIC REFRACTION SURVEY*

The refraction method can be used in any types of structural problems ,most successfully when applied to shallow depth problems.This method gives reliable results for the following problems:

(i). Shallow structural features can be mapped such as fault which may disappear under overburden,shear zones and contact zones may be delineated.

(ii).Strikes and dips of geological formations and location of bed rocks .

(iii).Non metallic mineral deposits such as gypsum,limestone,and ore bodies.

(iv).Igneous intrusions,salt domes and other similar intrusions can be delineated.

(v).Bed rocks lithology can be determined on the basis of seismic velocity .

(vi).The location of ancient burried river,channels .

(vii).Measure of thickness of over burden for proposed road,pipe line etc.

(viii). To determine the composition and hardness of the rocks.

(xi). Bridges ,dames and resevoir location.

(x).To determine the weathering layer thickness and sub-weathering velocity.

(xi).The water table and areal extent for some aquifers .

3.12) *LIMITATIONS OF SEISMIC REFRACTION SURVEY*

There are certain conditions which must fulfil to ensure the recording of refracted events :

(a).The velocity of seismic wave must increase with depth i.e

$$V_o < V_1 < V_2 \ldots\ldots\ldots\ldots < V_{n-1} < V_n .$$

(b).Thickness of each subsurface layer should be greater than the half wavelength of the wave.

(c).Geophone spread must be three times the depth of interest.

(d).Waves critically refracted from each of the boundaries produce the first arrivals along some interval of distance from the source.

CHAPTER # 4

FIELD PROCEDURE

4.1) *FIELD PLANNING*

Field planning demands the consideration of the problem in hand and selection of appropriate geophysical parameters .The main objective of the survey was to map the sectional profile of the weathered and subweathered layers and also find out the nature of refractor ,whether undulating or otherwise by calculating its depth below each geophone ,using Hawkin's Method.

To achieve these objectives ,ten seismic refraction spreads were laid out in a straight line along the profile,in the area of investigation .Reverse shooting technique was applied to obtain the precise refraction field data .

Before starting the survey ,physiographic and geological set up of the project area and its surrounding were studied in order to have some knowledge of its lithological and geological set up .Then some experimental refraction profiles with end-to-end shooting were shot to obtained optimised refraction geometry parameters.

4.2) *PARAMETERS OF THE REFRACTION SURVEY*

The seismic refraction data was obtained in the field by using the following parameters .

(i). Project area : Petaro (Distt. Hyderabad)

(ii).Topo sheet No. : 40 C/8

(iii) Location of the area : Latitudes 25 20 to 25 0 Norh & Longitudes 68 15 to 68 30 East.

(iv) Scale of map : 1:50,000

(v). Geophysical Method : Seismic Refraction Method .

(vi) Shooting Scheme : Reverse shooting.

(vii) Spread Length : 280 meters each .

(viii) No.of geophones : 24 / each .

(ix). Off-set Distance : 10 meters on each (forward & reverse) side of each spread .

(x). Intergeophone Spacing : Variable .

(xi).Energy Source Used : Explosive.

4.3) *REFRACTION FIELD PROCEDURE*

Refraction field procedure depends mainly upon :

(a).Refraction spread lay out scheme .

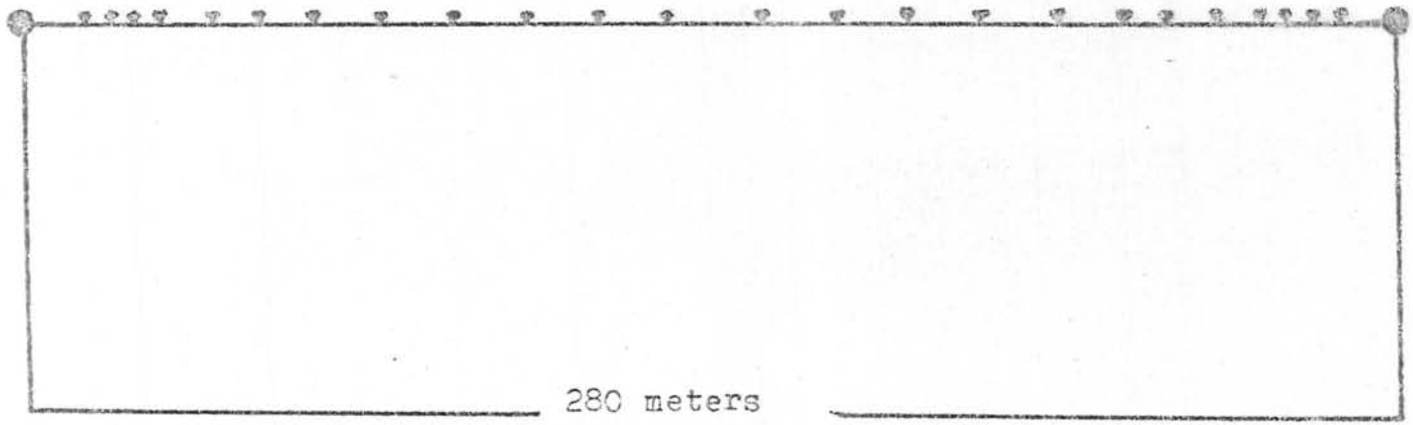
(b).Seismic refraction data recording procedure

The refraction spread lay out scheme for the collection of data in the project area is explained below :

4.3.1) *REFRACTION SPREAD LAY OUT SCHEME*

The geophone geometry for reverse shooting was

Geophone and Shot point Geometry



Shot point

Geophone

Off-set distance = 10 meters

Inter-geophone distance = Variable

Fig.(4.1)

carried out in the manner as shown in Fig. (4.1).

The two shot-point S1 and S2 were laid 280 meters apart from each other so that 24 geophones could be planted in between S1 and S2 according to the following pattern :

S1 to G1 = Off-set distance = 10 meters

G1G2 = G2G3 = G3G4 = 5 meters

G4G5 = G5G6 = G6G7 = 10 meters

G7G8 = G8G9 = G9G10 = G10G11 = G11G12 = 15 meters

G12G13 = 20 meters

G13G14 = G14G15 = G15G16 = G16G17 =G17G18 = 15 meters

G18G19 = G19G20 = G20G21 = 10 meters

G21G22 = G22G23 = G23G24 = 5 meters

G24 to S2 = Off-set distance = 10 meters .

Each geophone was planted essentially vertical and buried into the thin but firm soil cover to avoid wind disturbance and to ensure better elastic coupling between the ground and geophones .The geophones were connected to the refraction cable having takes out at fixed points by means of clips so that 24 geophones could be connected to it .

CHAPTER # 5

DATA PROCESSING

5.1) *INTRODUCTION*

Once the seismic refraction data has been acquired in the field ,which is in the form of wiggly traces ,the next step is its processing .This processing ,normally called as data processing ,is the transformation of these field observation into a form which helps in subsurface geological interpretation .

The field data obtained from the seismic refraction survey consists of measurements of the time taken by seismic waves to travel in the subsurface from a shot-point .These waves are refracted from elastic discontinuities and then arrive back to the surface to be detected by geophones placed according to predetermined geometry .The data obtained in the field is processed and converted into a subsurface geological model.

Refraction field data processing was done manually as well as on the "HEWLETT PACKARD" model 216 personal computer using a compatible software.Results obtained from both these processing operations are compared and discussed .Both these manual and computerized data processing operations are based on obtaining true velocities of subsurface layers and their vertical depth below each shot-point .As for as the depth below each geophone is concerned ,the above method fails to determine the depth below each geophone .However ,for this purpose i.e the depth below each geophone ,the refraction data was also processed by "HAWKIN'S METHOD".

The major steps involved in the processing of seismic refraction data are briefly described below:

(i). Picking of first arrival from "Seismogram".

(ii). Plotting of the refraction travel-times along Y-axix versus the distance from the shot-point to the respective geophone along X-axis by using least square fitting .

(iii).Manual and computer processing of the data and getting the results in the form of true velocity values from up dip and down dip layer velocities and to compute refractor depth beneath each shot-point besides the dip angle of the refractor .

(iv). Additional field data processing using "HAWKIN'S METHOD".

5.2) *PICKING OF FIRST ARRIVAL FROM THE SEISMOGRAM*

The first recorded signal attributable to seismic wave which travel from a known source (shot-point) is termed as first arrival(Sheriff,1981).Refraction arrival times were picked from each seismic refraction record (seismogram) ,comprising of 24 wiggle traces aligned horizontally on a seismogram .The refraction first breakes were read at the traces corresponding to geophones respectively .The first arrival of the nearest geophone from the shot-point is recorded much earlier than the first arrival corresponding to last geophone .Thus ,the last geophone trace will record maximum travel-time .

5.3) ***LEAST SQUARE FITTING OF TRAVEL-TIME CURVES***

One way of fitting is termed as visual fitting ,in which the travel-time curves for refraction data were plotted on the graph paper .A travel-time curve is a graph between the arrival times of refracted waves and distance of geophones along the refraction spread .The ordinate shows the time in milliseconds and abcissa represent the distance in meters . The main object of this was to identify the number of layers under each shot-point .

But in order to avoid the human personal error which is inherent in any visual fitting of the straight line in a refraction segment of any travel-time plot ,the statistical method of least square straight line fitting was undertaken as :

The equation of straight line used for least square fitting is :

$$Y1 = A1 + B1X$$

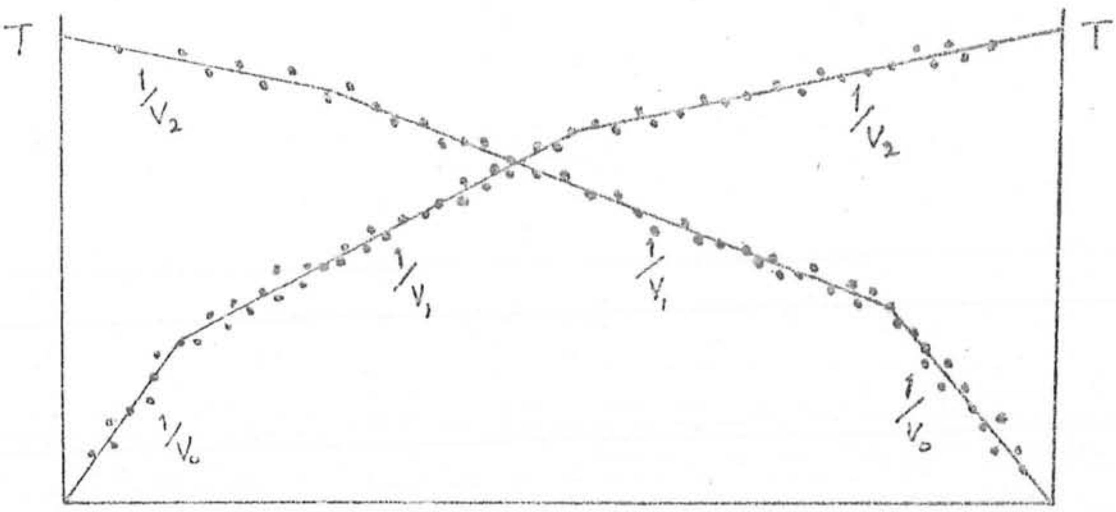


Fig. (5·1) Visual Fitted Travel-Time Curve

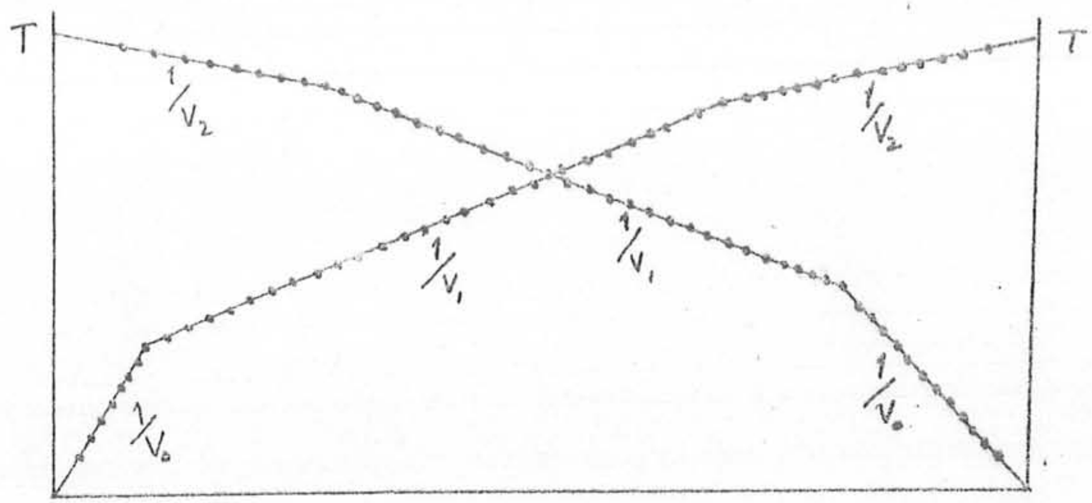


Fig. (5·2) Least-Square Fitted Travel-Time Curve

Where

$$A1 = \frac{Xi^{2} \Sigma Yi^{2} - \Sigma Xi Yi}{n \Sigma Xi^{2} - (\Sigma Xi)^{2}}$$

= Intercept on Y- axis .

= Intercept time .

Also

$$B1 = \frac{n \Sigma Xi Yi - \Sigma Xi Yi}{n \Sigma Xi^{2} - (\Sigma Xi)^{2}}$$

= Slope of line.

= Reciprocal of refractor's apparental velocity.

In the above formulae :

n = Total No. of points occupied by the respective layer.

Xi= Distance of recording geophone i from the shot-point

Yi= Observed travel-time.

Y1= Least square fitted values of Yi .

5.4) *PLOTTING OF REFRACTION TRAVEL-TIME CURVES*

A travel-time curve is a graph between the travel-times of refracted waves and distance of geophones along the seismic spread (Sheriff,1981).

After picking the first arrival times of each

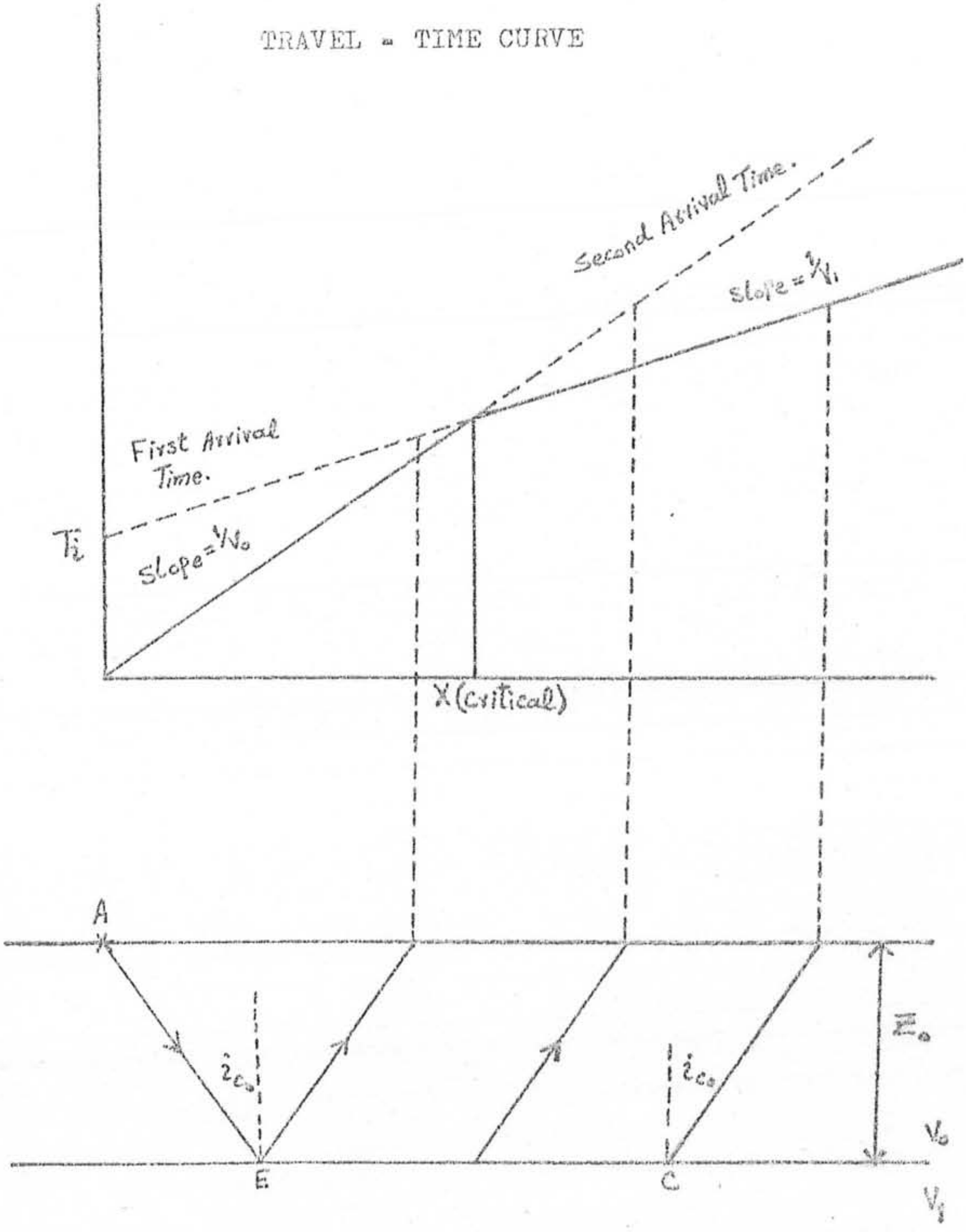


Fig.(5.3) Raypaths of least time and time-distance curve for a layer separted from its sub-stratum by horizontal interface profile ,a plot of these (travel-times) versus distances from shot-point to each geophone was made .The TX-graphs were prepared by plotting the arrival time in millisecond along Y-axis and distance of each geophone in meters from shot-point along X-axis

The TX-graphs were prepared manually as well as on the computer .The time scale was plotted in milliseconds ,where as the distance scale in meters.These curves are plotted as a least square straight fit to the (X,t) points.Thus straight lines having different slopes were obtained and each such line represent a layer .

5.6) *COMPUTER PROCESSING AND ANALYSIS PROCEDURE*

The computerized refraction data was carried out on the " HEWLETT PACKARD " computer model 216 using MC-SEIS software pack "HPS-13 Simple Refraction".This computer programme is designed to process and interpret seismic refraction data on the assumption that layers have no rregularities .Using key board of the computer ,the results were plotted on a plotter .

After booting the system ,the programme software disk was inserted into the disk drive and the peogramme was loaded on the main memory of the computer .On programme activation a series of messages appeared on the bottom of the monitor screen (CRT) one after the other .The informations asked by the computer were :

(i). Curve type (one way or resiprocal).

(ii). Maximum no. of geophones used in the spread .

(iii). Off-set distance in meters .

(iv). Is geophone spacing equal (Y/N).

(V). Travel-time for each geophone in milliseconds.

After receiving all these informations the data is automatically plotted on the monitor screen (CRT) in the shape of small crosses .The computer was instructed to draw a least square straight line fit by using these crosses . A similar procedure was adopted for the data of the reverse shooting .Then all the segmental curve was rechecked ,"OK" key was pressed , computer did the processing and the TX-graph with subsurface seismic section was appeared on the screen .Moreover the following parameters were also listed on the TX-graph for each layer :

(i).True velocity V (Km/sec.)

(ii).Apparent velocity on forward side V1 (Km/sec.)

(iii).Thickness of layer below first shot-point Z1 (meters)

(iv). Thickness of layer

below second shot-point Zr (meters)

(v). Apparent velocity on

reverse side Vr (Km/sec.)

(vi).Slope of layer Dip (Degree).

If the graph and these parameters for each layer are found satisfactory ,the computer is asked to plot the TX-graph along with seismic section and the above parameters.The out put graph with these parameters are shown in "APPENDIX".

CHAPTER # 6

INTERPRETATION AND DISCUSSION

6.1) *INTRODUCTION*

The interpretation of geophysical data involves the conversion of the process geophysical data into true geological character within the area by using some standared informations. The interpretation may be regarded as the back bone of dissertation work.

After data processing, the next step was to interpret the data in order to achieve the objective of the survey. The interpretation has been carried out in order to map the shot point to shot point and geophone to geophone refractor profile between different subsurface velocity layers, along the 9.7 K.m. seismic line. Travel time curves indicate the presence of two subsurface layers having velocities Vo and V1 and thickness Ho respectively. Some idea about the lateral distribution of velocity and thickness at a given depth may be infered from the maps. HAWKIN'S METHOD, which uses delay time, was also employed for processing and its results are in agreement with other methods. Tables, also represent the result of different techniques used in the processing of this data.

6.2) *STUDY OF SURFICIAL GEOLOGY*

TABLE # 6.1

SP NO.	Vo(Km/sec)		V1(km/sec)		Dip(Θo)	
	comp.	man.	comp.	man.	comp.	man.
1	0.43	0.43	1.78	1.76	$0^{\circ}23'$	$0^{\circ}39'$
2	0.38	0.39	1.77	1.60	$0^{\circ}6'$	$0^{\circ}7'$
3	0.43	0.42	1.65	1.59	$0^{\circ}48'$	$0^{\circ}30'$
4	0.40	0.41	1.72	1.62	$0^{\circ}36'$	$0^{\circ}13'$
5	0.47	0.48	1.66	1.68	$0^{\circ}36'$	$0^{\circ}58'$
6	0.50	0.49	1.76	1.70	$-0^{\circ}18'$	$-0^{\circ}7'$
7	0.39	0.38	1.71	1.69	$-0^{\circ}6'$	$-0^{\circ}7'$
8	0.43	0.43	1.72	1.70	$0^{\circ}12'$	$0^{\circ}2'$
9	0.54	0.53	1.62	1.64	$0^{\circ}48'$	$0^{\circ}33'$
10	0.46	0.46	1.74	1.70	-1°	$-1^{\circ}10'$

Where;

Vo = True velocity of first layer

V1 = True velocity of 2nd layer

Θ = Dip angle in degree

TABLE # 6.2

SP NO.	Zf(m)			Zr(m)		
	Comp.	Man.	Hawkin	Comp.	Man.	Hawkin
1	12.3	12.6	13.5	10.4	9.5	10.9
2	9.7	9	9.5	8.7	8.2	9
3	9.1	8.5	10.5	6.6	6	8.2
4	9.3	9	10.5	8	8	8.9
5	9.9	11.7	12.4	7.9	7	8.6
6	9	11	12.7	13.5	9.5	11.2
7	8.3	8.5	9.4	9.1	8	9.8
8	8.2	8.5	9.7	8.6	8.2	9.5
9	10.6	11.2	9.5	8.3	10.9	9.5
10	10.9	9.3	10	9.8	10.7	11

Where

Zf = Forward side depth in meters

Zr = Reverse side depth in meters

The project area, PETARO- HYDERABAD lies in the SIND province of Pakistan. No rocks are exposed in the project area and surface is generally covered by unconsolidated material i.e Alluvium.

The interpretation of the processed seismic refraction data pertains the integrated study of geology of project area and the following maps and illustrations.

i). Velocity distribution maps (Vo and V1) showing the velocity variations in different subsurface layers in the project area.

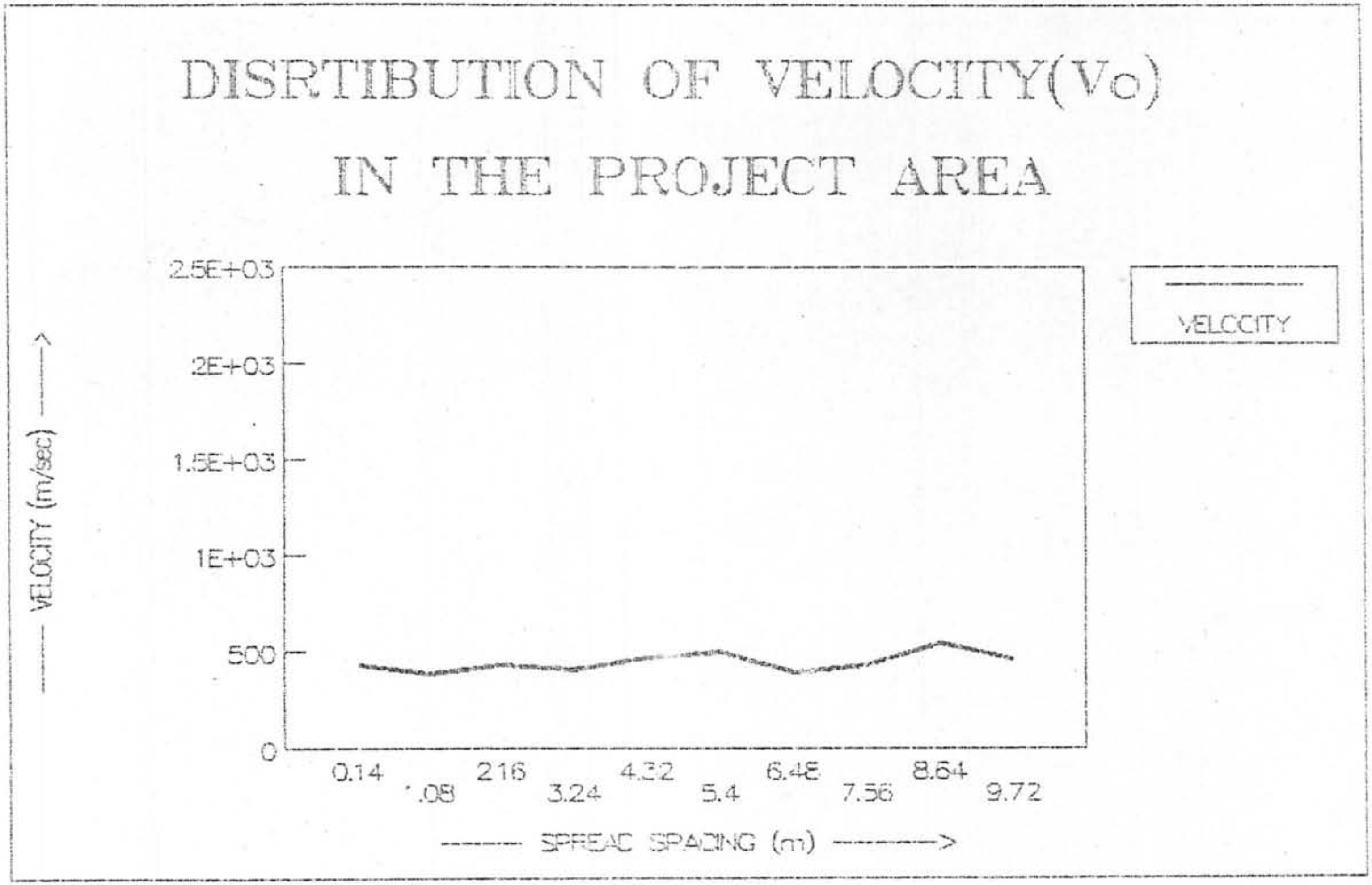
ii). Vertical depth (below shot points only) distribution map (Ho) showing the thickness variation of the weathered layer.

iii). Interpreted section below each refraction profile by HAWKIN'S METHOD showing the mapped undulation of the refractor.

6.3) *INTERPRETATION OF VELOCITY DISTRIBUTION MAP (Vo)*

The first layer is characterised by its velocity (Vo) and it is presented in the form of map shown in Fig(6.1).The over all variation in the mapped velocity pattern is in the range of 380 m/sec to 540 m/sec. The depth of this layer ranges from 8.2 meters to 12.3 meters. Study of the map of velocity distribution (Vo) shows that, the sequence of variation of velocity may be discussed as follows:

On the left of the curve, velocity has a value of

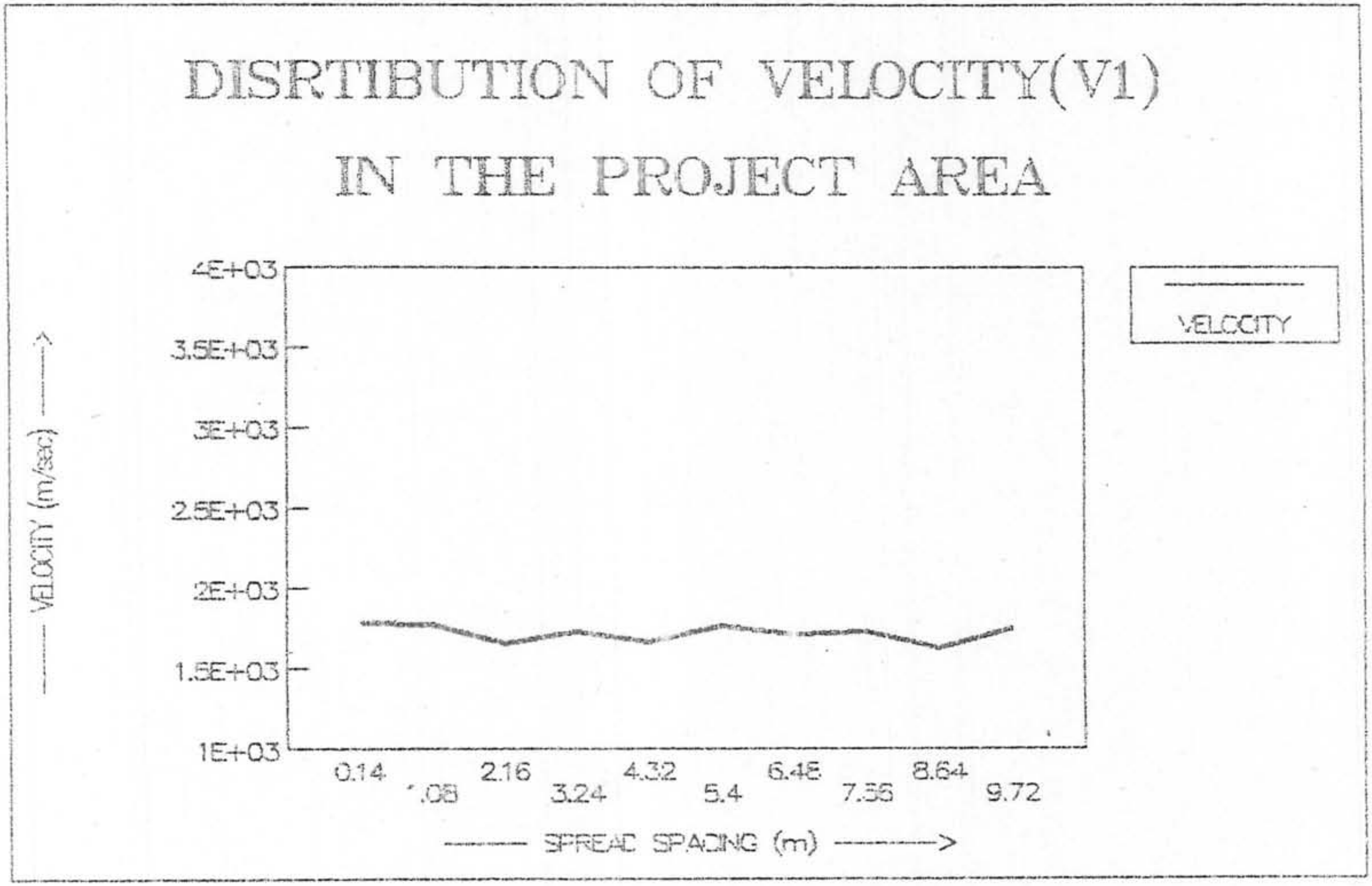

DISRTIBUTION OF VELOCITY(Vo)
IN THE PROJECT AREA
VELOCITY (m/sec) ——>
2.5E+03
2E+03
1.5E+03
1E+03
500
0
0.14
1.08
2.16
3.24
4.32
5.4
6.48
7.56
8.64
9.72
SPREAD SPACING (m) ——>
VELOCITY

430 m/sec. The velocity decreases with the distance and attains a value of 380 m/sec, which is also the minimum value for this velocity range. It can be said safely that this value of velocity showing the presence of loose material. Afterwards velocity starts increasing and continues to increase untill a value of 540 m/sec is reached at the right of a map. THis value of velocity is also maximum showing that the most compact material may be present, here, in the first layer. Then after this, velocity again starts decreasing untill the end of the curve, showing the loose material due to decreasing velocity value.

From the range of velocity, geology of the project area and the well log data of SUNBAK we can say that the lithology of this layer may be thought as unconsolidated material i.e Alluvium.

6.4) *INTERPRETATION OF VELOCITY DISTRIBUTION MAP (V1)*

The second layer is designated by the velocity (V1) and it is presented in the form of velocity map Fig (6.2). It can be said that the material of this layer is relatively more compact as compared with the material of first layer. The velocity of second layer ranges from 1620 m/sec to 1780 m/sec. The sequence of this variation may be described as follows :



DISRTIBUTION OF VELOCITY(V1)
IN THE PROJECT AREA
4E+03
3.5E+03
3E+03
2.5E+03
2E+03
1.5E+03
1E+03
VELOCITY (m/sec) ------->
0.14
1.08
2.16
3.24
4.32
5.4
6.48
7.56
8.64
9.72
------- SPREAD SPACING (m) ------->
VELOCITY

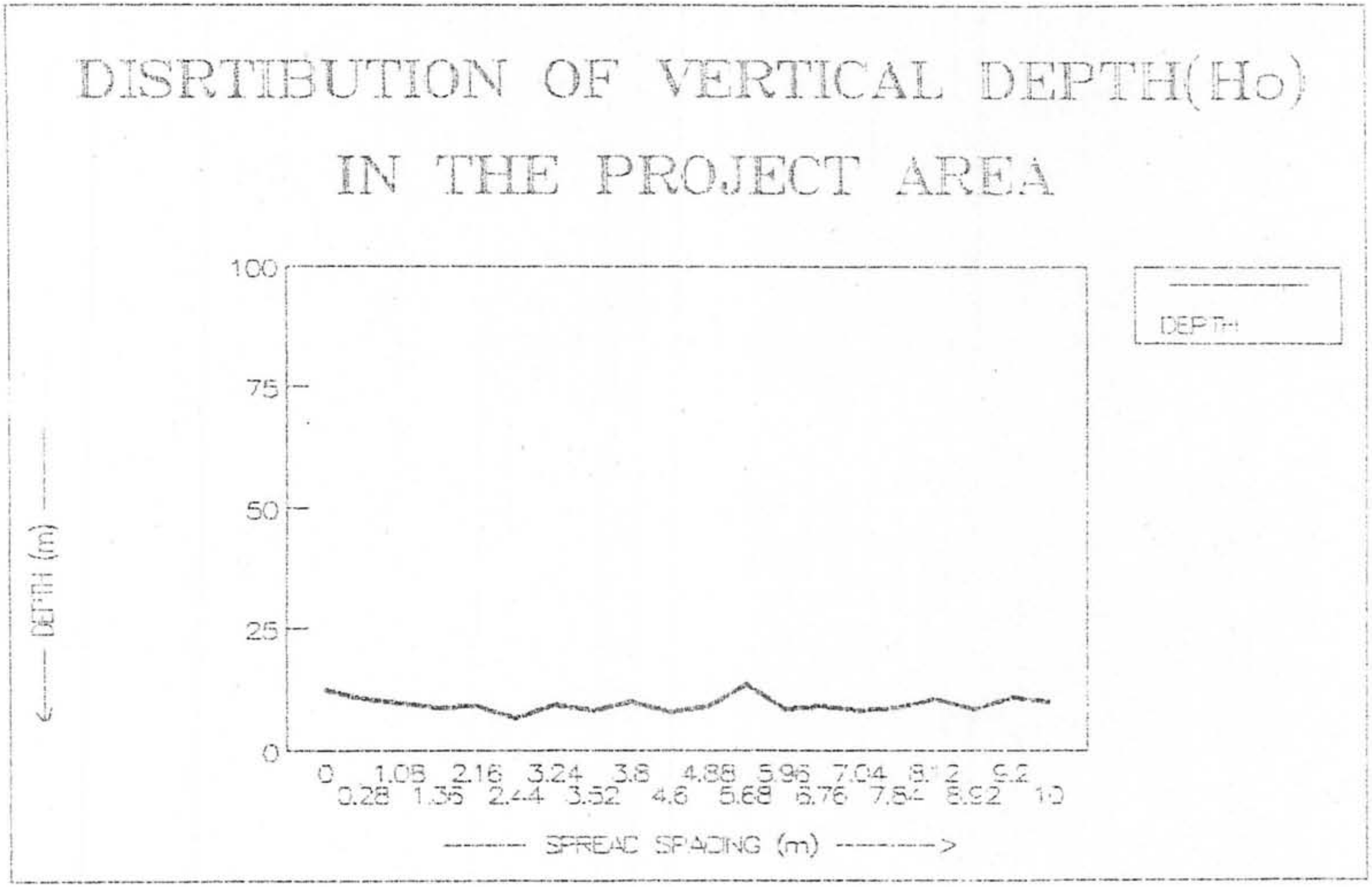
At the start of the curve velocity has a value of 1780 m/sec which is also the maximum velocity in the second layer. It can be said said that this maximum value of velocity is showing the presence of most compact material in the second layer. Afterwards just after the beginning of curve, there is a linear undulation up to extreme right to the profile. This undulation ranges from velocity 1770 m/sec to 1740 m/sec .This undulated trend of curve shows that in this range of velocity, the material present may be loose or compact because at some points velocity values is low and at other points it is high.

From the range of velocity , geology of the project area and the well log data of SUBARK , we can say that this layer may be composed of subweathered soil and weathered sand stone.

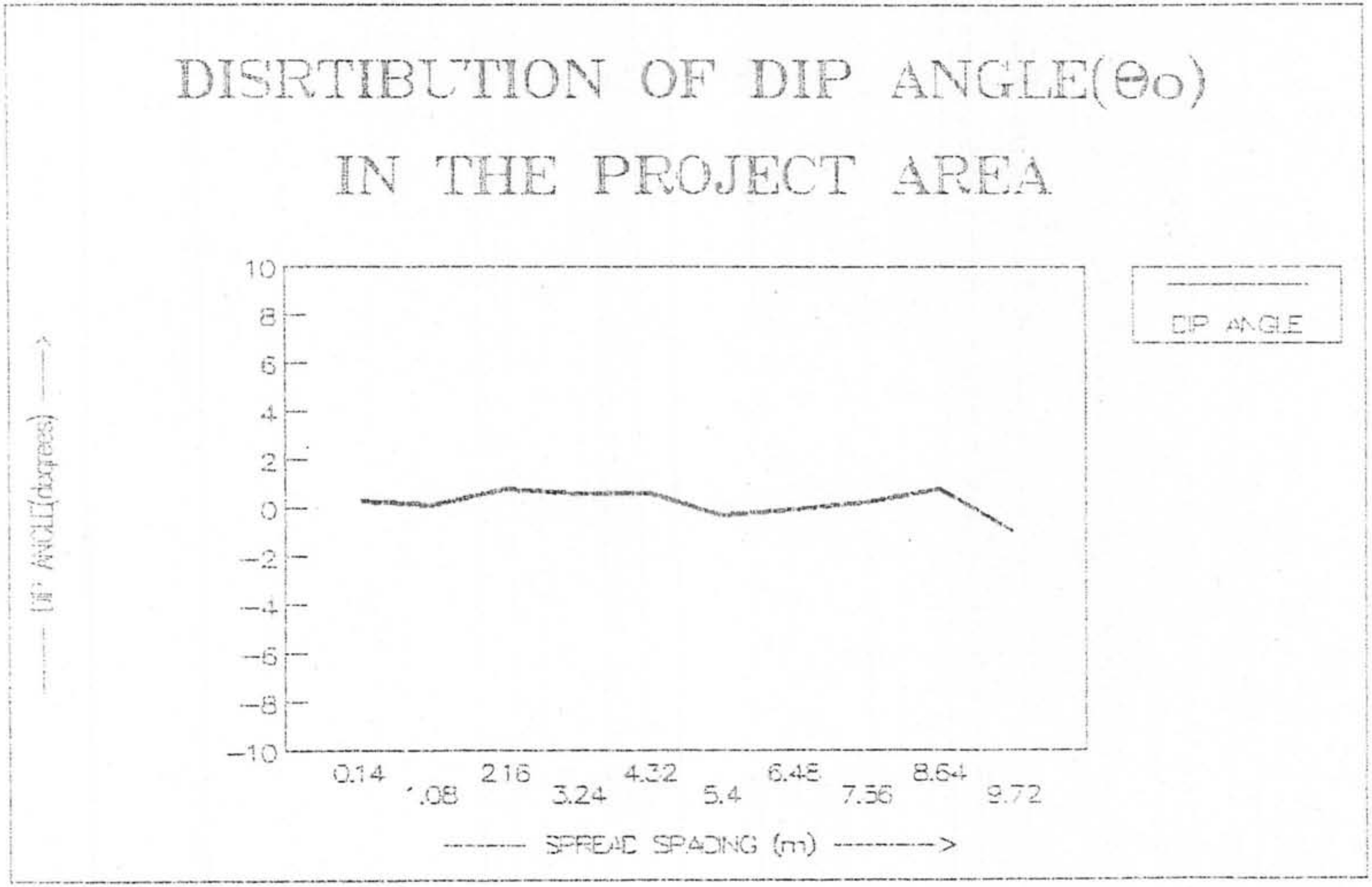
6.5) *INTERPRETATION OF VERTICAL DEPTH MAP (Ho)*

This map of distribution of vertical depth in the project area is designated by Ho and it is presented in the form of depth map Fig(6.3). This map indicates the thickness pattern of the first layer below each shot point only and shows the increase in depth from 8.2 to 12.3 meters .

The distribution of dip angle map in the project area is also attached herewith, for seeing the trend of dipping subsurface layer



DISRTIBUTION OF VERTICAL DEPTH(Ho)
IN THE PROJECT AREA
100
75
50
25
0
DEPTH (m)
0 1.08 2.16 3.24 3.8 4.88 5.96 7.04 8.12 9.2
0.28 1.36 2.44 3.52 4.6 5.68 6.76 7.84 8.92 10
SPREAD SPACING (m)
DEPTH


DISRTIBUTION OF DIP ANGLE(θo)
IN THE PROJECT AREA
10
8
6
4
2
0
−2
−4
−6
−8
−10
0.14
1.08
2.16
3.24
4.32
5.4
6.48
7.56
8.64
9.72
DIP ANGLE
SPREAD SPACING (m)

6.6) *CONCLUSIONS AND RESULTS*

On the basis of interpreted seismic refraction data the following conclusions and results have been obtained.

i). The field data represents two layers through out the project area.

ii). Velocity within the first layer varies from 380 m/sec to 540 m/sec and its thickness varies from 8.2 to 12.3 meters.

iii) The first layer consists of Alluvium.

iv) Velocity of second layer varies from 1620 m/sec to 1780 m/sec .

v). This layer showing the presence of subweathered soil or weathered sandstone.

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REFERENCES

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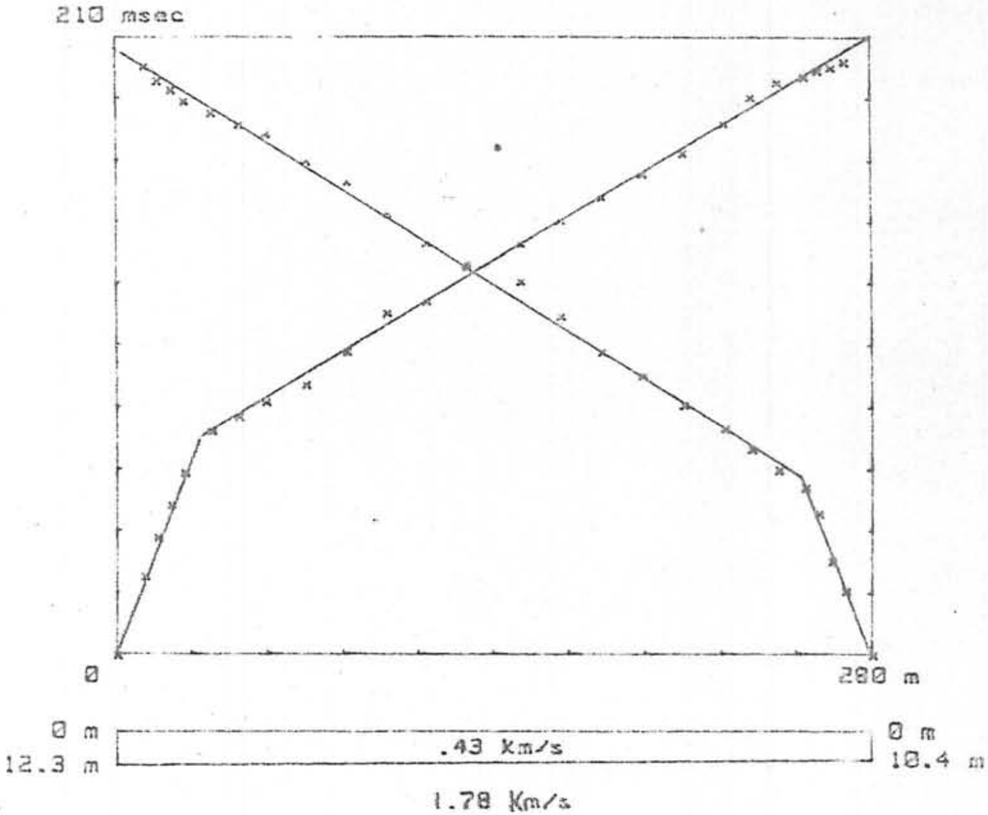
APPENDIX

"A"



SP No: 1

1st Layer

V= .43 Km/s

Zl= 12.3 m Zr= 10.4 m

Dip12= .3

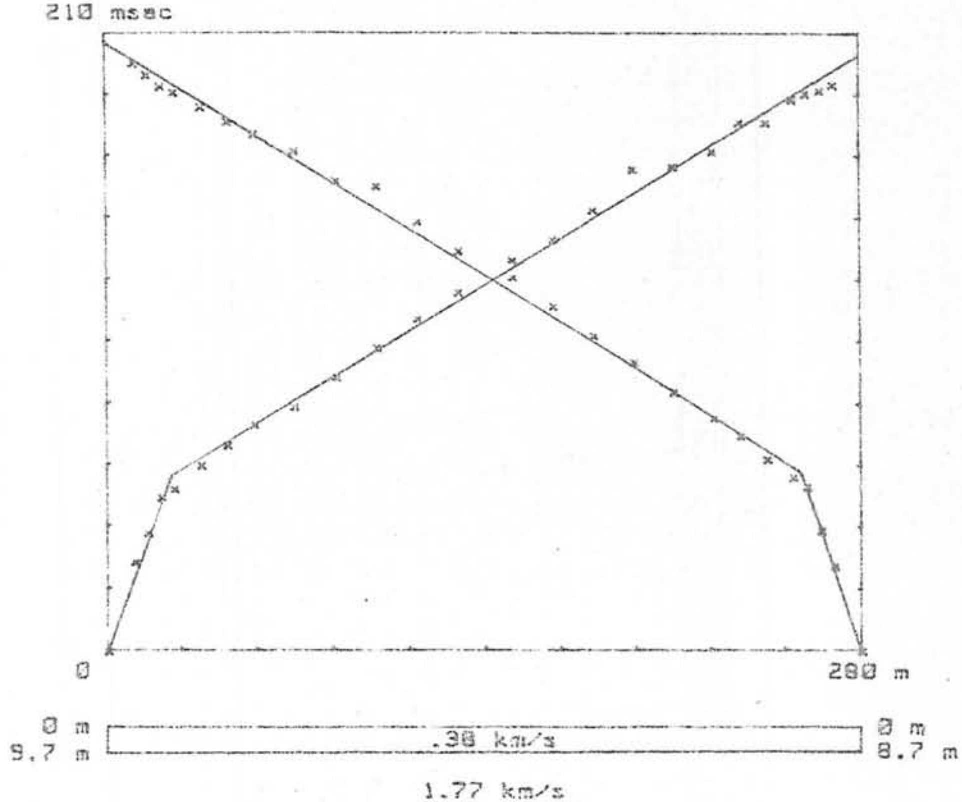
2nd Layer

V= 1.78 Km/s

Vl= 1.82 Km/s

Vr= 1.75 Km/s

SP No: 2



1st Layer

V= .38 Km/s

Z1= 9.7 m Zr= 8.7 m

Dip12= .1

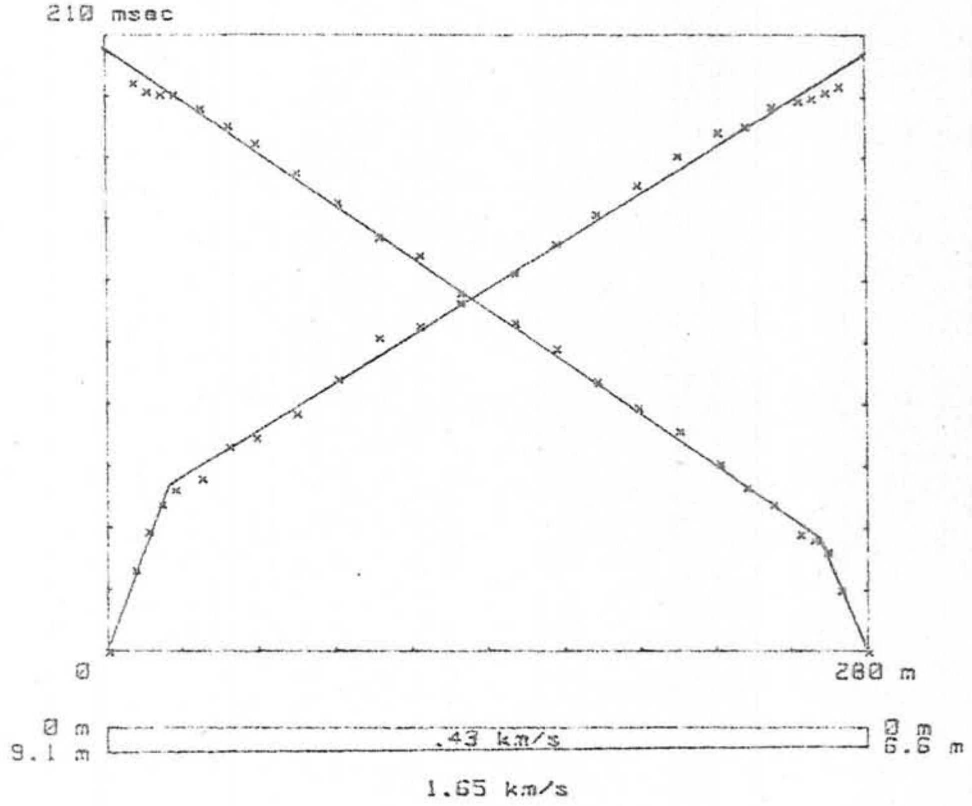
2nd Layer

V= 1.77 Km/s

Vl= 1.78 Km/s

Vr= 1.76 Km/s

SP No: 3



1st Layer

V= .43 Km/s

Zl= 9.1 m Zr= 6.6 m

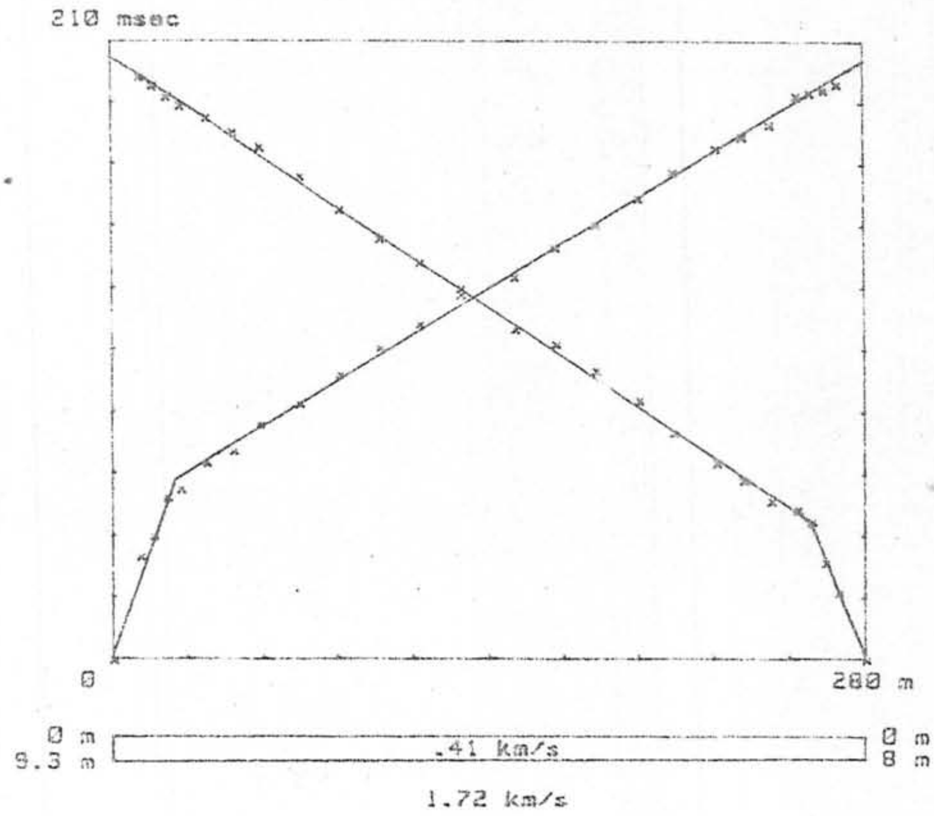
Dip12= .8

2nd Layer

V= 1.65 km/s

Vl= 1.74 km/s

Vr= 1.58 km/s



SP No: 4

1st Layer

V= .41 Km/s

Zl= 9.3 m Zr= 8 m

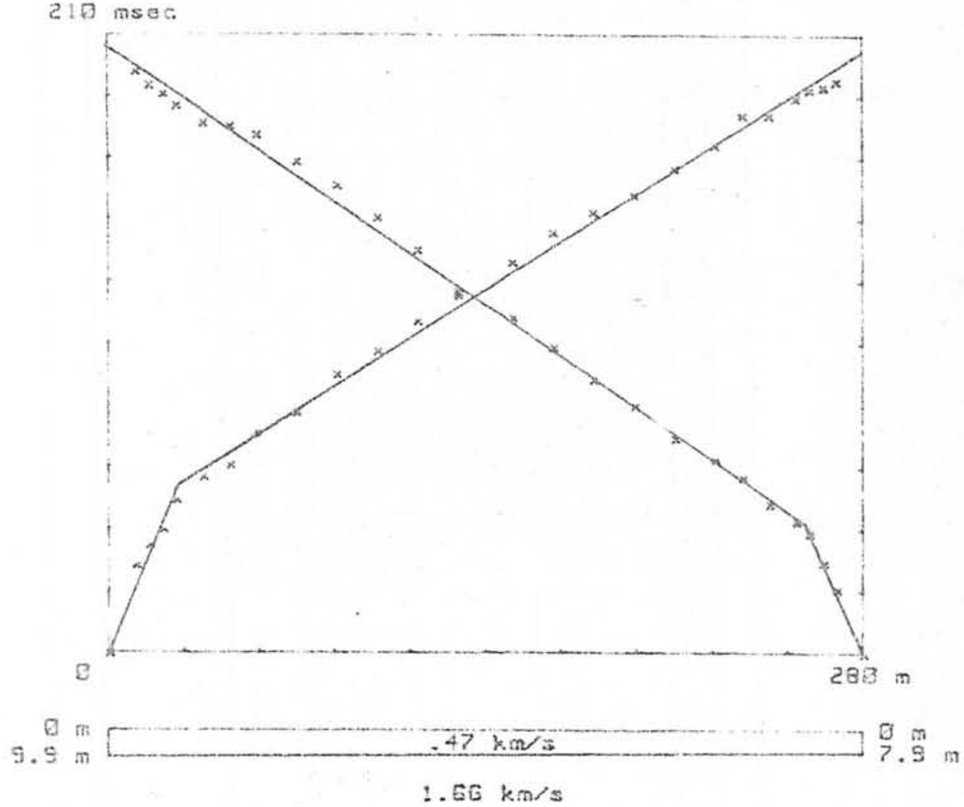
Dip12= .6

2nd Layer

V= 1.72 Km/s

Vl= 1.8 Km/s

Vr= 1.65 Km/s



SP No: 5

1st Layor

V= .47 Km/s

Z1= 9.9 m Zr= 7.9 m

Dip12= .6

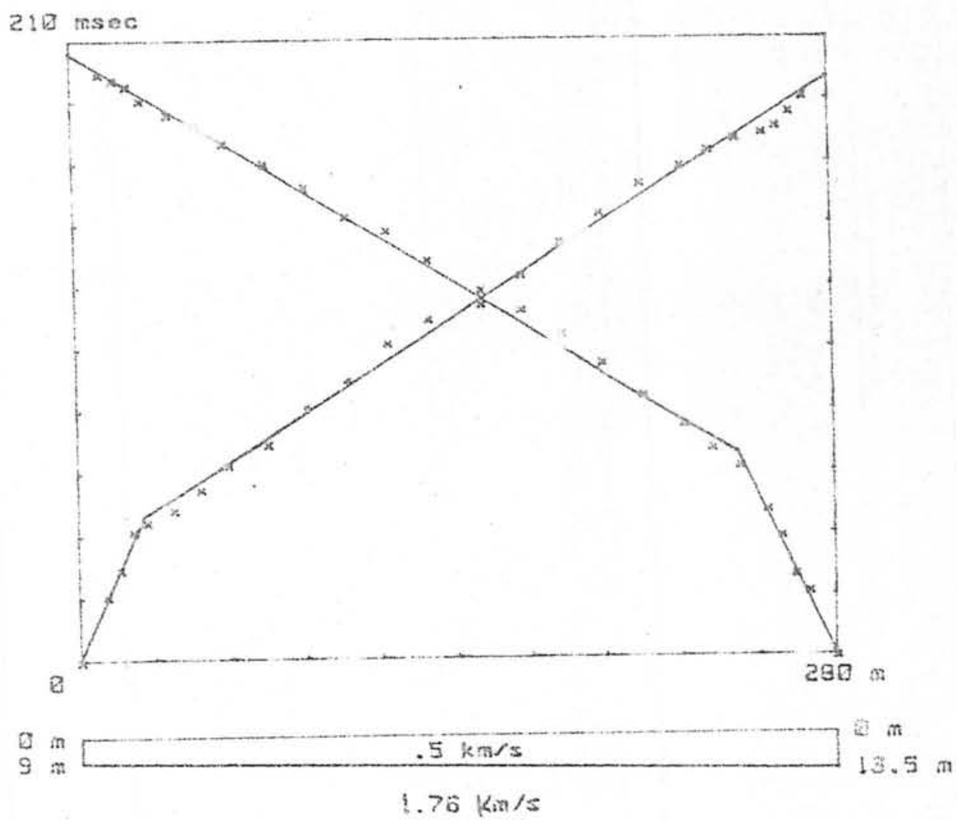
2nd Layor

V= 1.66 Km/s

V1= 1.72 Km/s

Vr= 1.6 Km/s

SP No: 6



1st Layer

V= .5 Km/s

Z1= 9 m Zr= 13.5 m

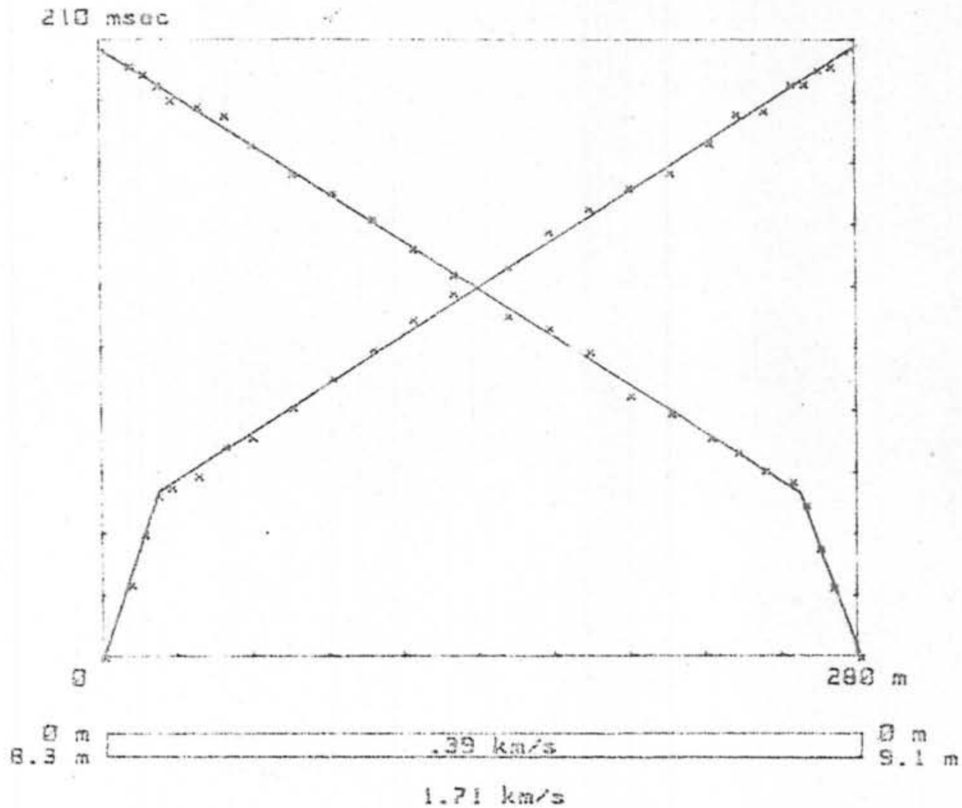
Dip12=-.3

2nd Layer

V= 1.76 Km/s

Vl= 1.73 Km/s

Vr= 1.79 Km/s



SP No: 7

1st Layer

V= .39 Km/s

Zl= 8.3 m Zr= 9.1 m

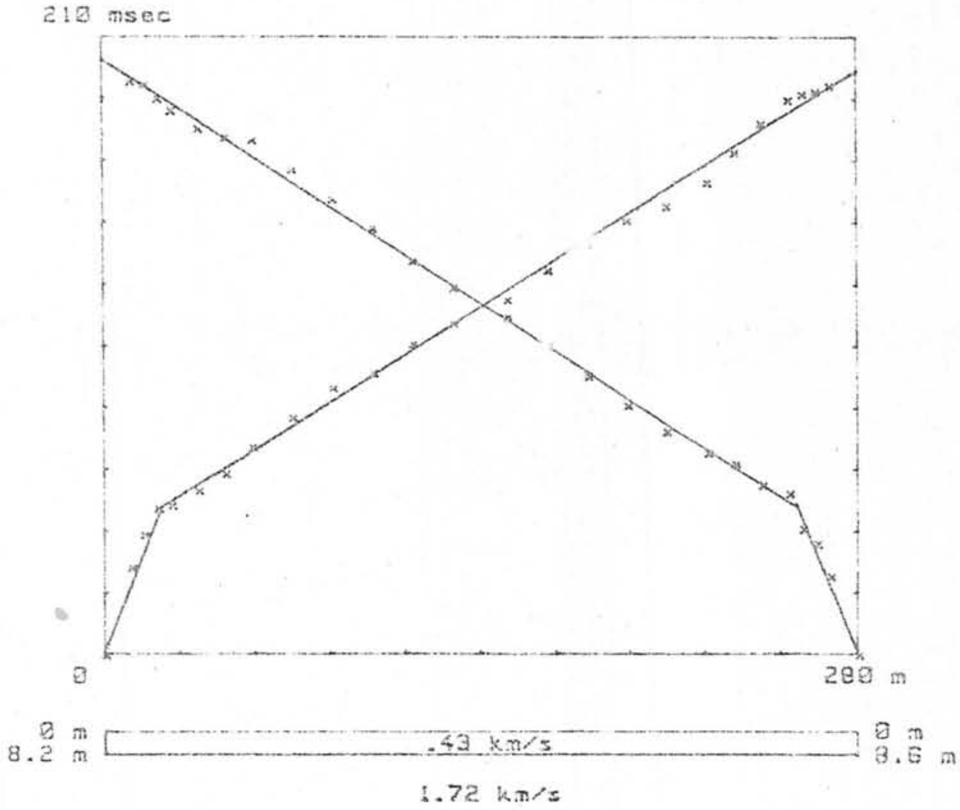
Dip12=-.1

2nd Layer

V= 1.71 Km/s

Vl= 1.7 Km/s

Vr= 1.72 Km/s



SP No: 8

1st Layer

V= .43 Km/s

Zl= 8.2 m Zr= 8.6 m

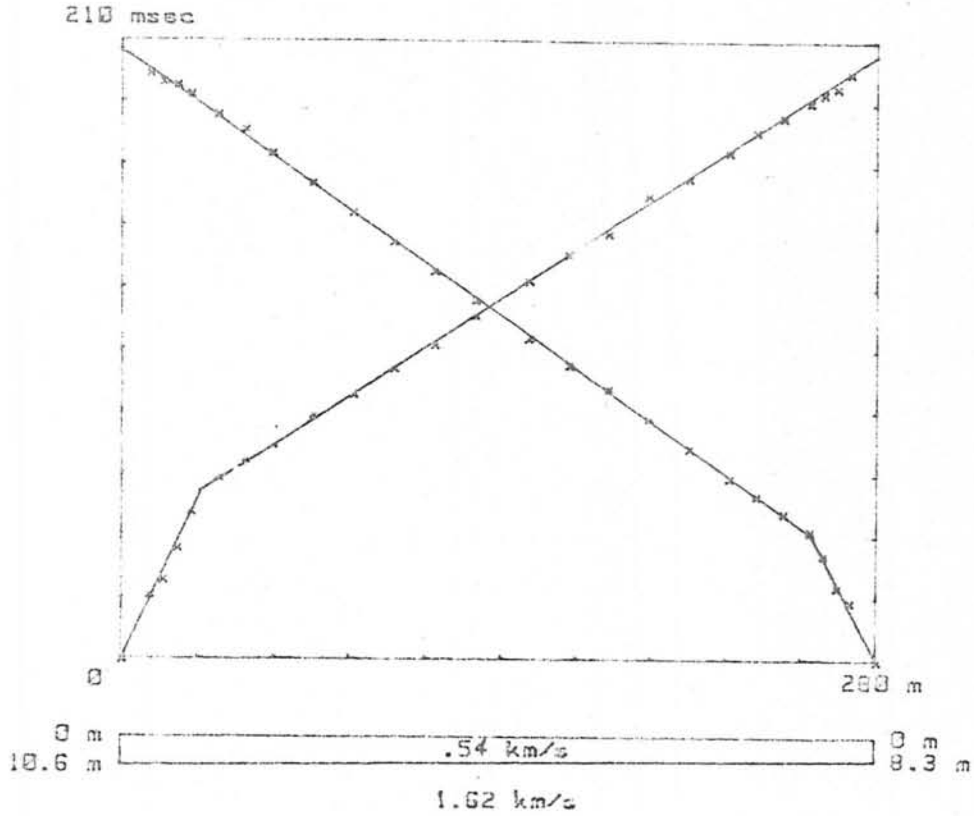
Dip12= .2

2nd Layer

V= 1.72 Km/s

Vl= 1.74 Km/s

Vr= 1.7 Km/s



SP No: 9

1st Layer

V= .54 Km/s

Zl= 10.6 m Zr= 8.3 m

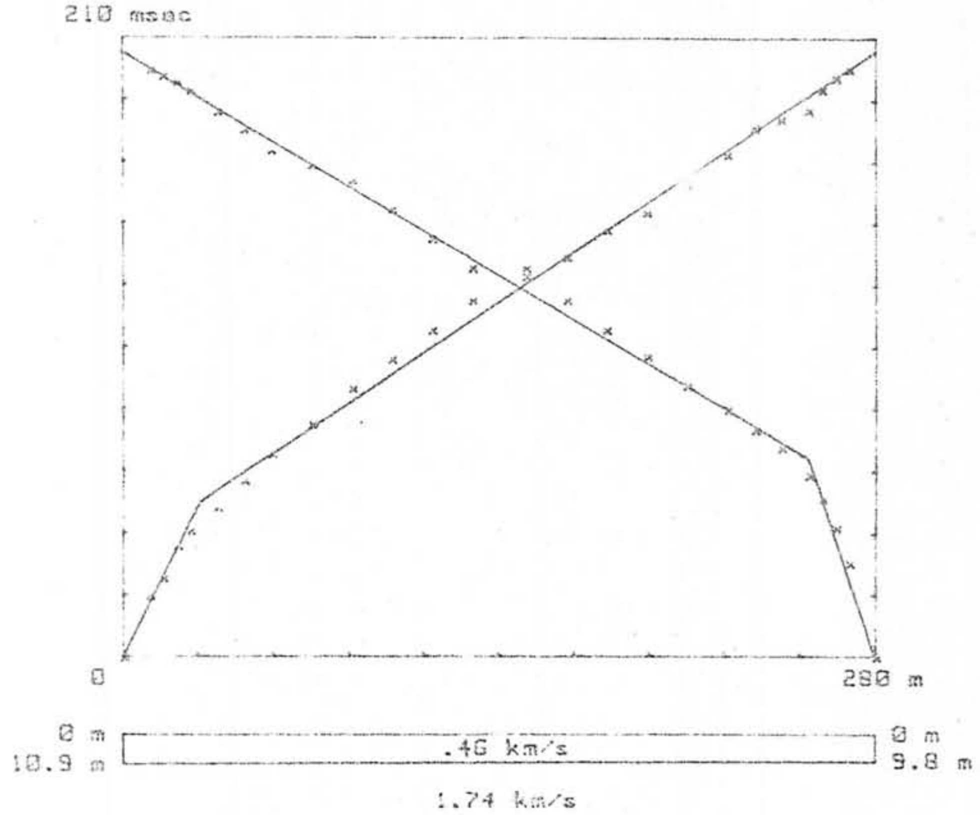
Dip12= .8

2nd Layer

V= 1.62 Km/s

Vl= 1.69 Km/s

Vr= 1.56 Km/s



SP No: 10

1st Layer

V= .46 Km/s

Zl= 10.9 m Zr= 9.8 m

Dip12=-1

2nd Layer

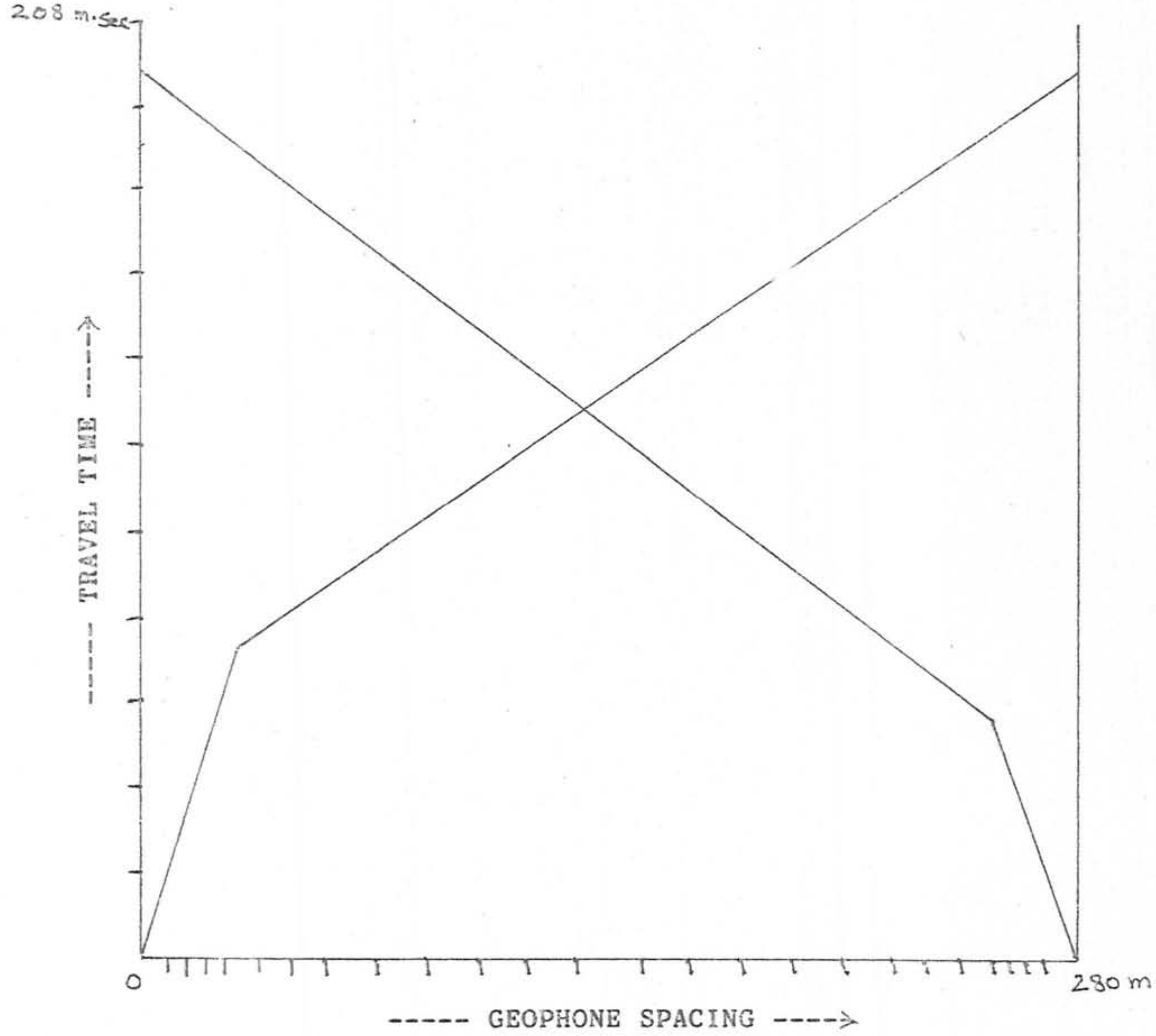
V= 1.74 Km/s

Vl= 1.64 Km/s

Vr= 1.85 Km/s

APPENDIX

"B"



SP No: 1

V_{ou} = 423.8 m/sec.

V_{od} = 454.5 m/sec.

V_o = 439 m/sec.

Z_{ou} = 12.6 m

Z_{od} = 9.5 m

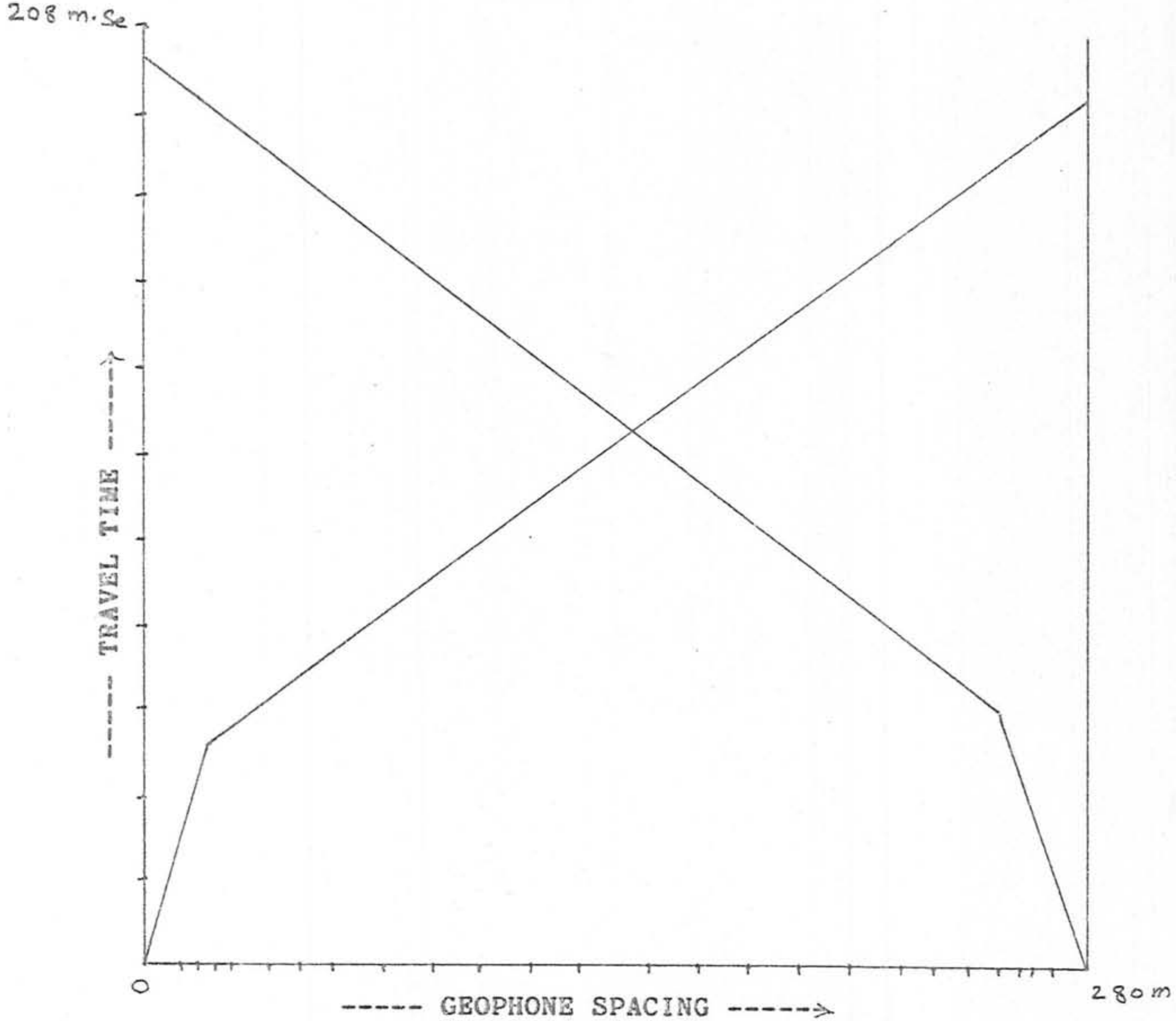
Dip 12 = 039

ic_o = 1425

V_{1u} = 1842.8 m/sec.

V_{1d} = 1687 m/sec.

V_1 = 1762 m/sec.



<u>SP No: 2</u>

V_{ou} = 428.6 m/sec.

V_{od} = 375 m/sec.

V_o = 399 m/sec.

Z_{ou} = 9 m

Z_{od} = 8.2 m

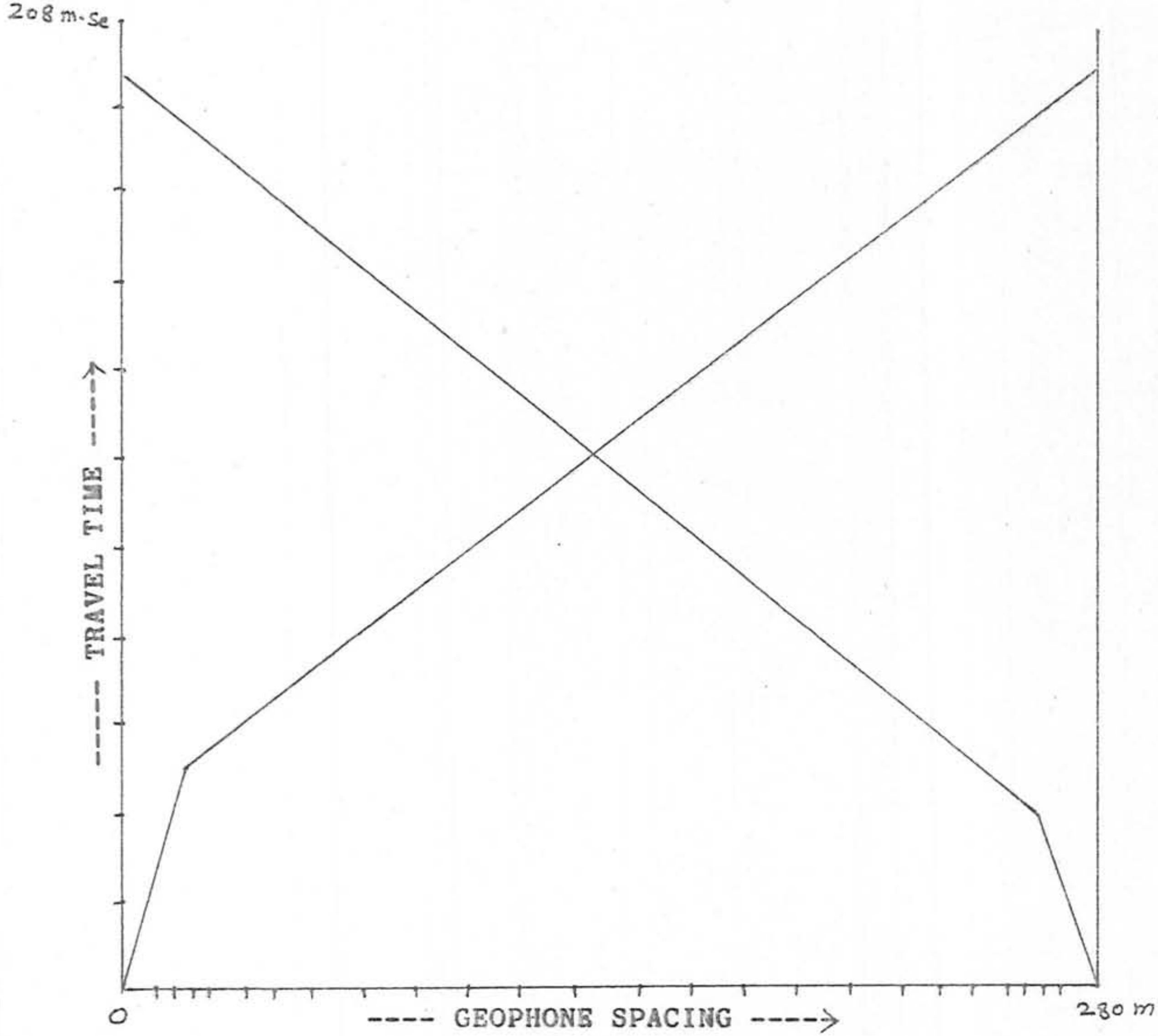
Dip 12 = 073

ic_o = 1353

V_{1u} = 1676.6 m/sec.

V_{1d} = 1647 m/sec.

V_1 = 1663.3 m/sec.



SP No: 3

V_{ou} = 425.5 m/sec.

V_{od} = 428.5 m/sec.

V_o = 427 m/sec.

Z_{ou} = 8.5 m

Z_{od} = 6 m.

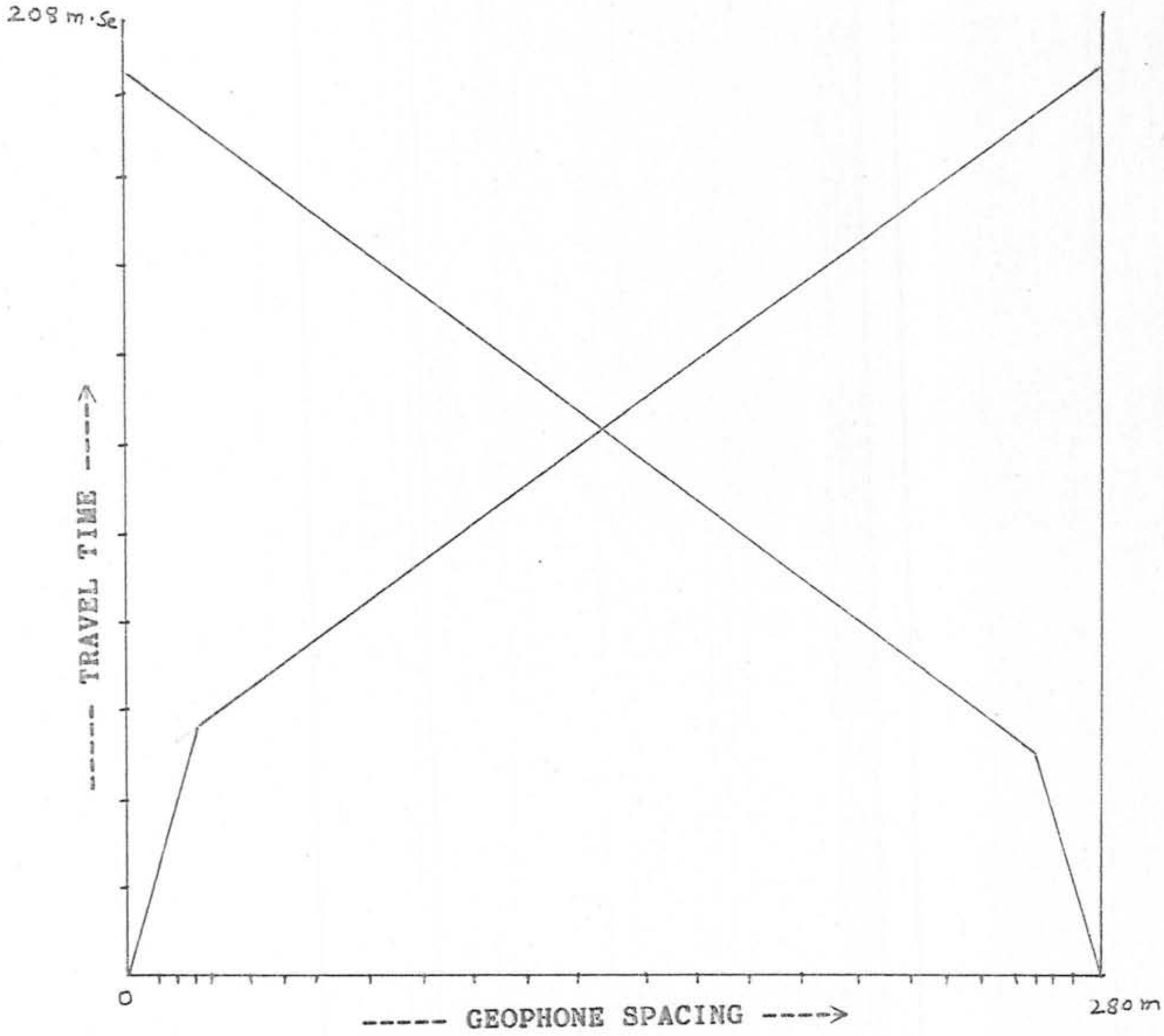
Dip 12 = 030

ic_o = 1531

V_{1u} = 1647 m/sec.

V_{1d} = 1547 m/sec.

V_1 = 1596 m/sec.



SP No: 4

V_{ou} = 387 m/sec.

V_{od} = 434 m/sec.

V_o = 410 m/sec.

Z_{ou} = 9 m

Z_{od} = 8 m

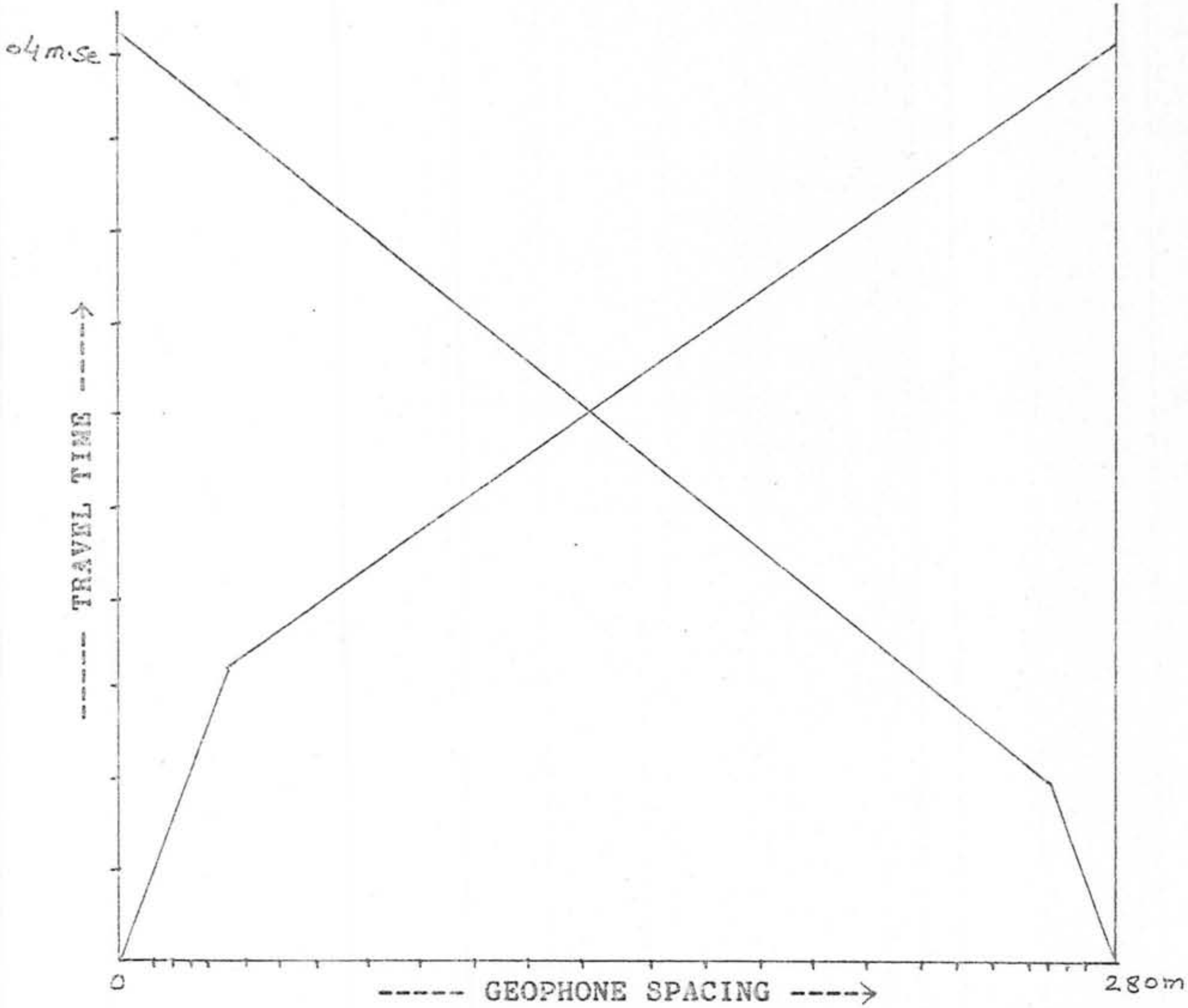
Dip 12 = 013

ic_o = 140

V_{1u} = 1717.8 m/sec.

V_{1d} = 1666 m/sec.

V_1 = 1692.4 m/sec.



SP No: 5

V_{ou} = 487 m/sec.

V_{od} = 475 m/sec.

V_{o} = 480.9 m/sec.

Z_{ou} = 11.7 m

Z_{od} = 7 m

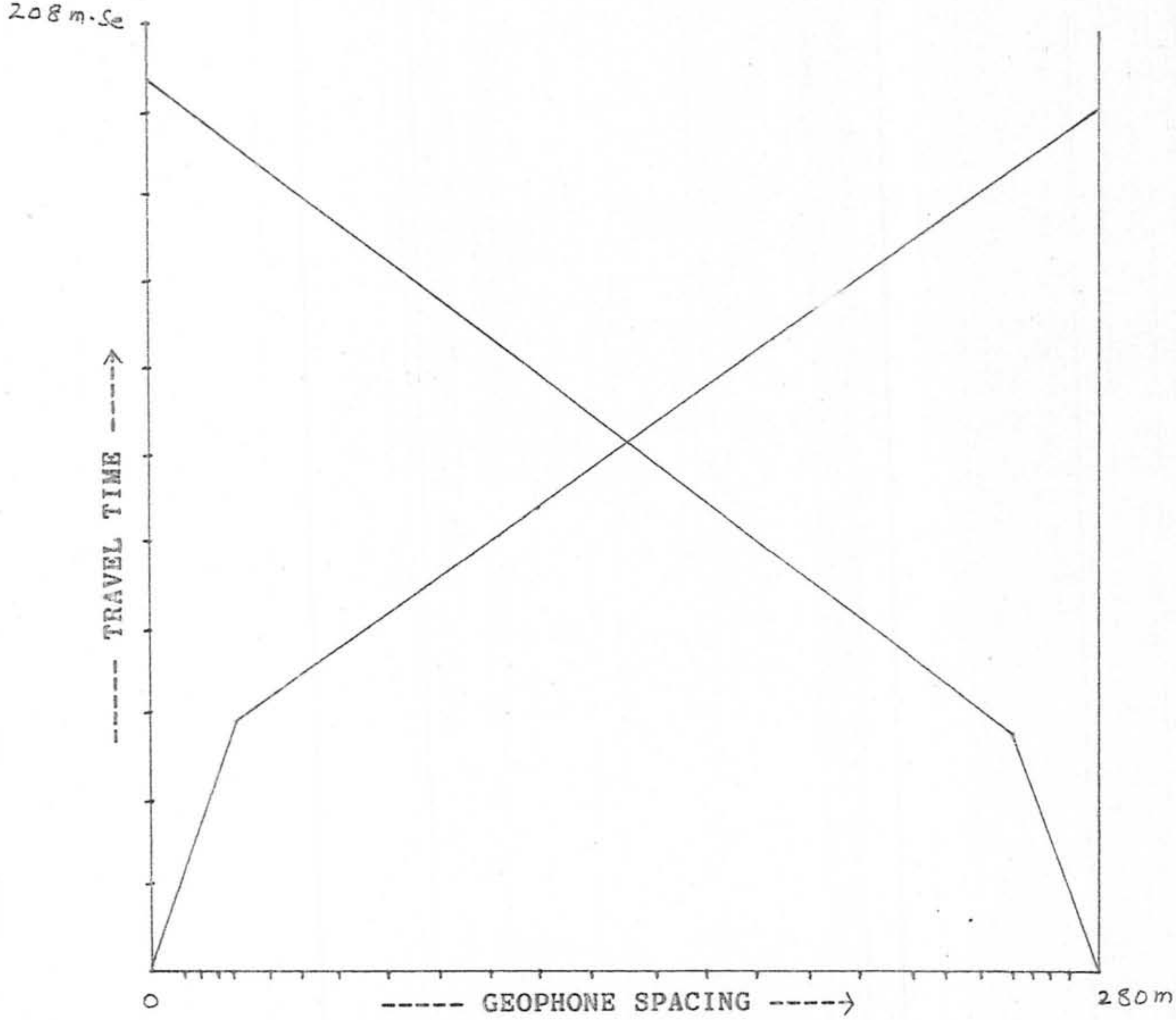
Dip 12 = 058

ic_{o} = 1637

V_{1u} = 1783.5 m/sec.

V_{1d} = 1590 m/sec.

V_{1} = 1681.3 m/sec.



<u>SP No: 6</u>

V_{ou} = 488 m/sec.

V_{od} = 500 m/sec.

V_o = 494 m/sec.

Z_{1u} = 11 m

Z_{od} = 9.3 m

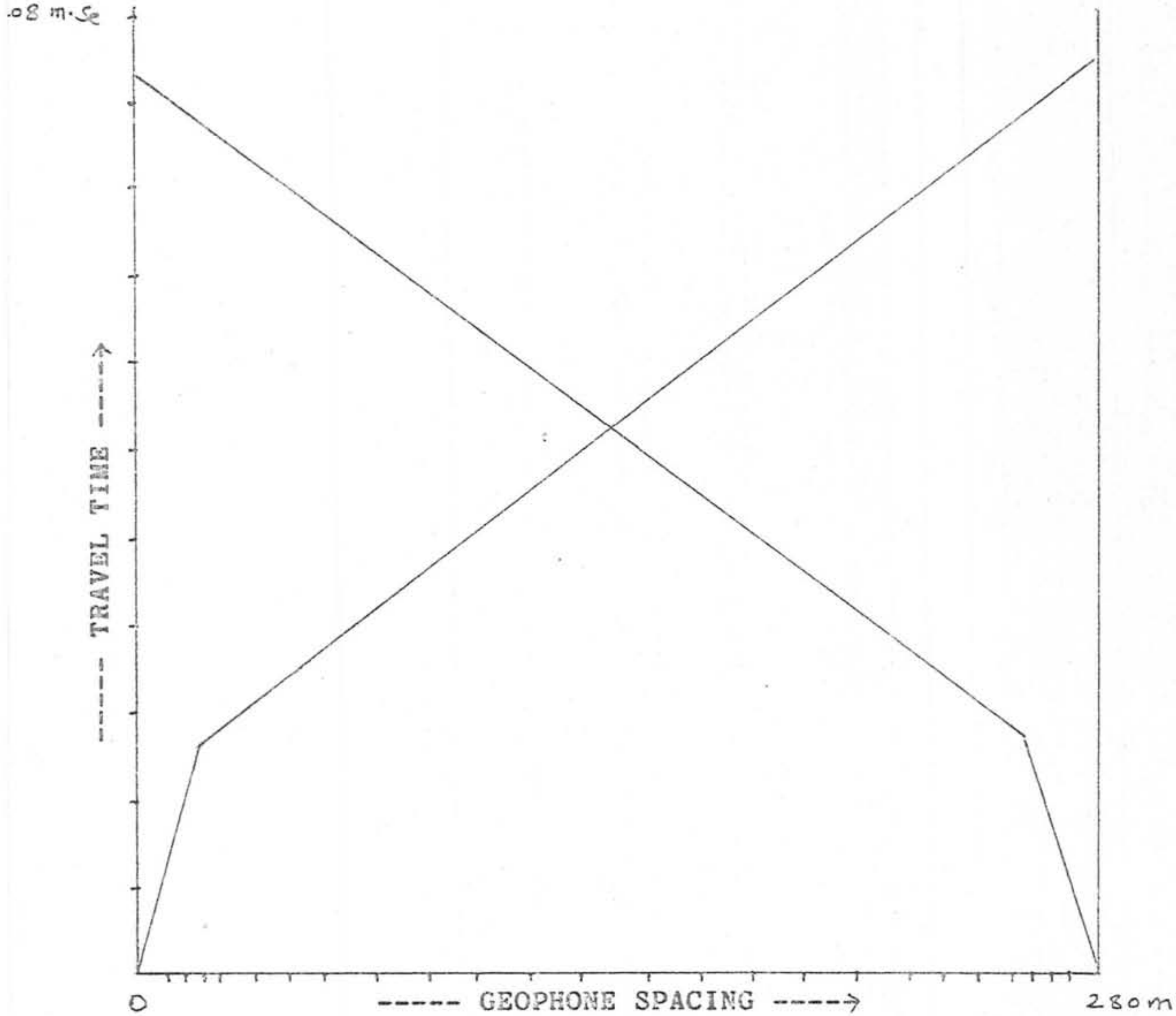
Dip 12 = -712

ic_o = 1648

V_{1u} = 1720 m/sec.

V_{1d} = 1616 m/sec.

V_1 = 1708 m/sec.



<u>SP No: 7</u>

V_{ou} = 400 m/sec.

V_{od} = 375 m/sec.

V_o = 387 m/sec.

Z_{ou} = 8.5 m

Z_{od} = 7.9 m

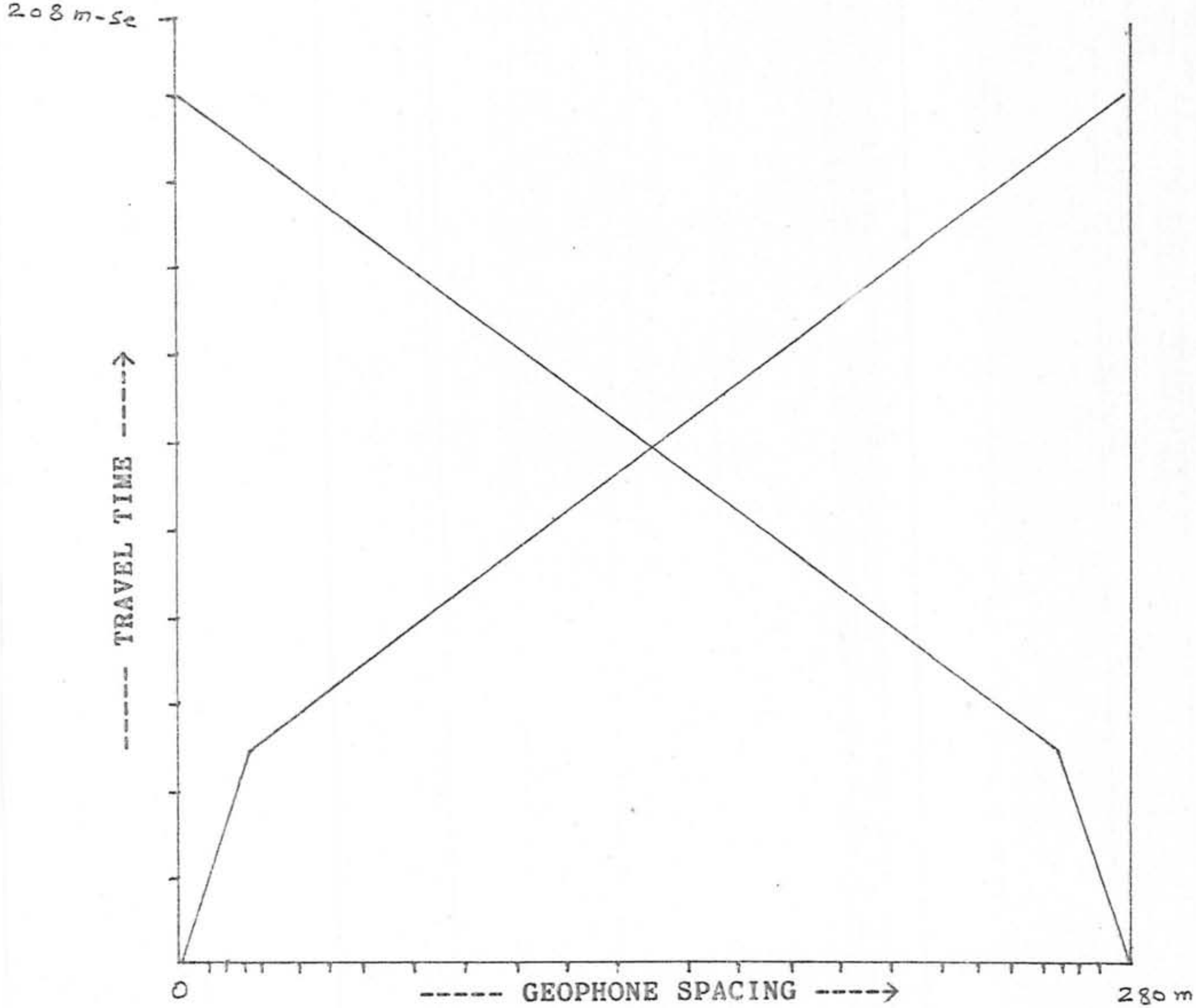
Dip 12 = -712

ic_o = 1313

V_{1u} = 1707.3 m/sec.

V_{1d} = 1676.7 m/sec.

V_1 = 1692.3 m/sec.



SP No: 8

V_{ou} = 425.5 m/sec.

V_{od} = 441 m/sec.

V_o = 433.11 m/sec.

Z_{ou} = 8.5 m

Z_{od} = 8.2 m

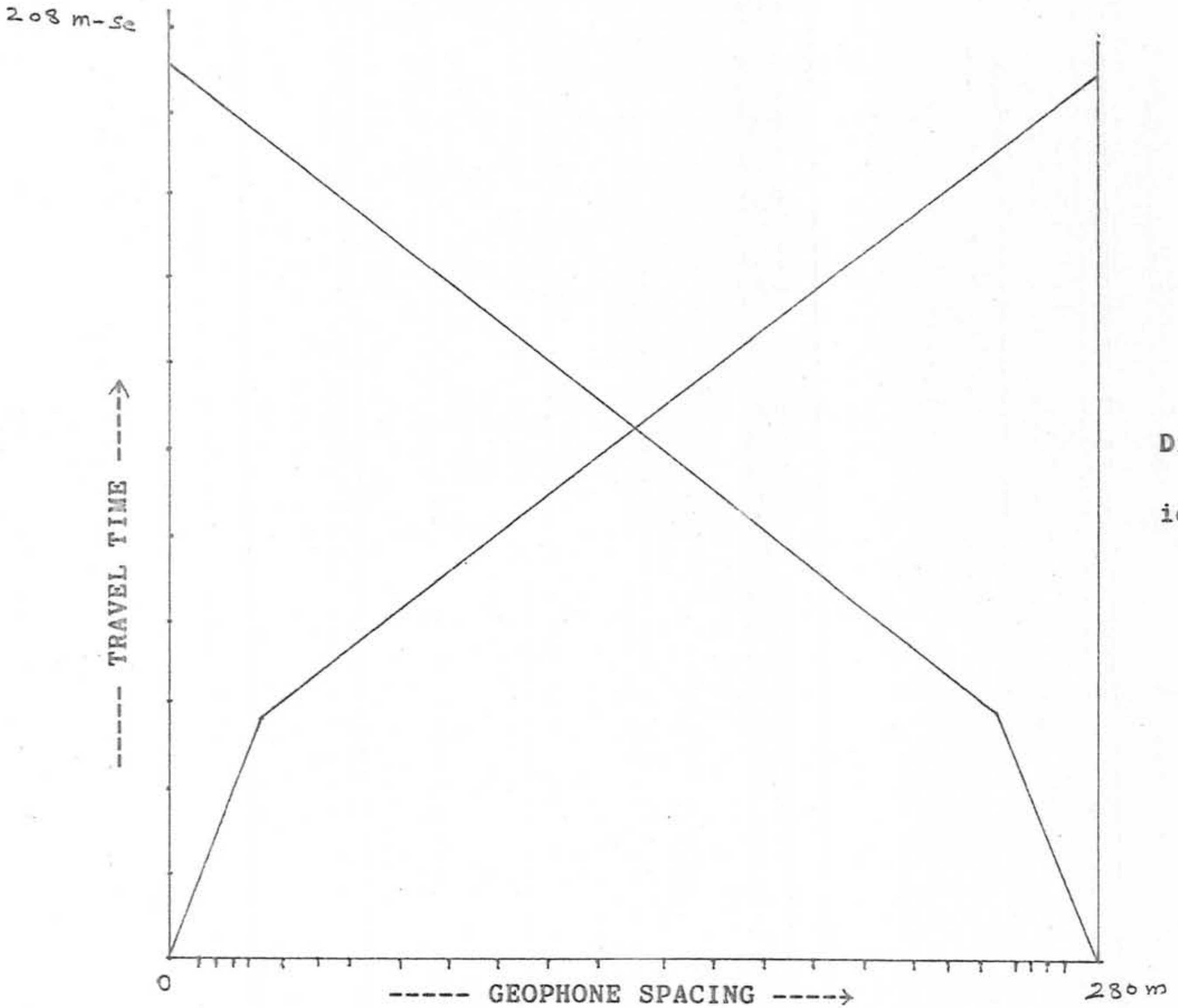
Dip 12 = 024

ic_o = 1444

V_{1u} = 1707.3 m/sec.

V_{1d} = 1697 m/sec.

V_1 = 1703 m/sec.



SP No: 9

V_{ou} = 535.7 m/sec.

V_{od} = 524 m/sec.

V_o = 530 m/sec.

Z_{ou} = 11.2 m

Z_{od} = 10.9 m

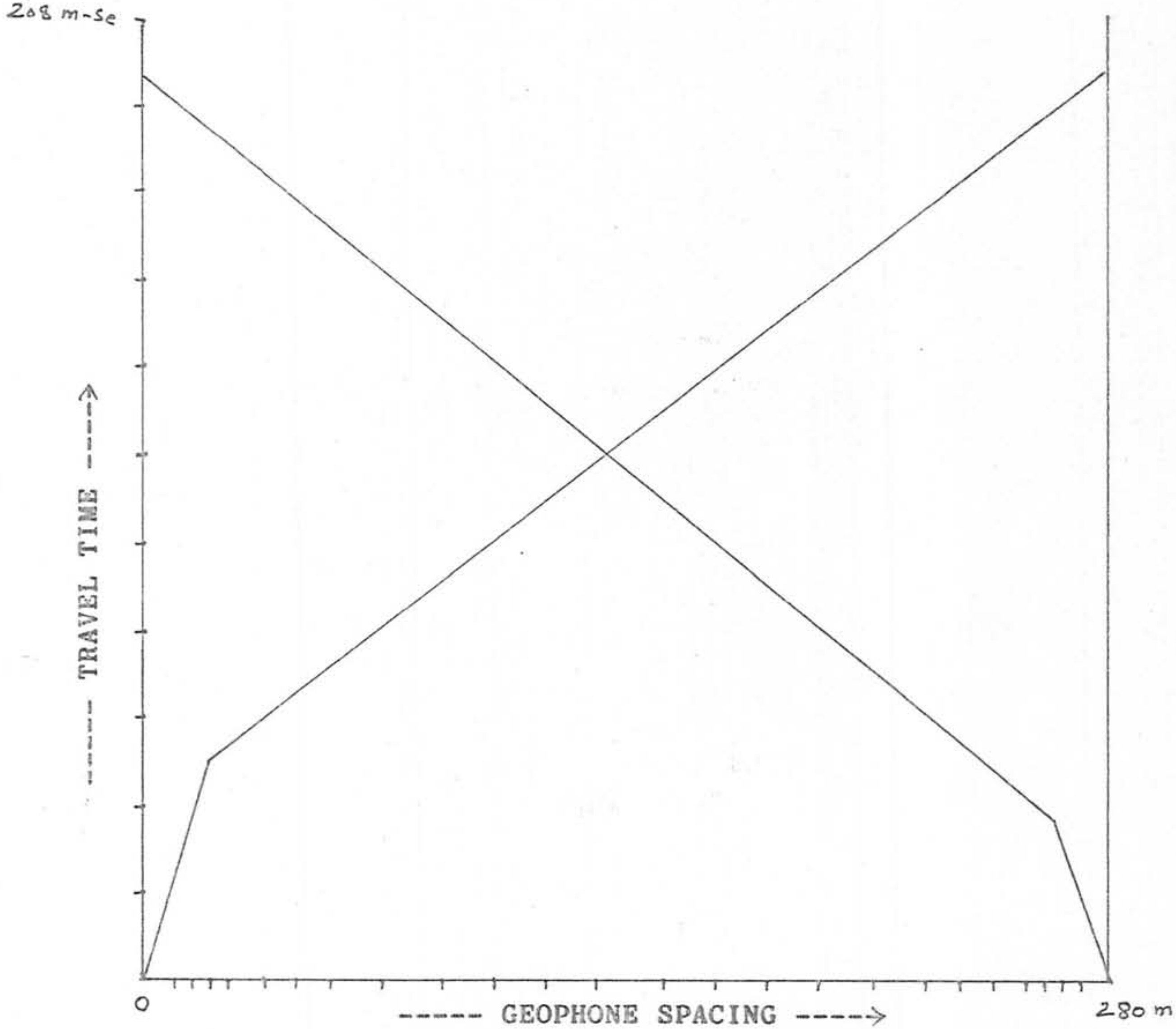
Dip 12 = 033

ic_o = 1833

V_{1u} = 1647 m/sec.

V_{1d} = 1637 m/sec.

V_1 = 1642 m/sec.



SP No: 10

V_{ou} = 455 m/sec.

V_{od} = 463.4 m/sec.

V_o = 460 m/sec.

Z_{ou} = 93 m

Z_{od} = 10.7 m

Dip 12 = -110

ic_o = 1544

V_{1u} = 1637.4 m/sec.

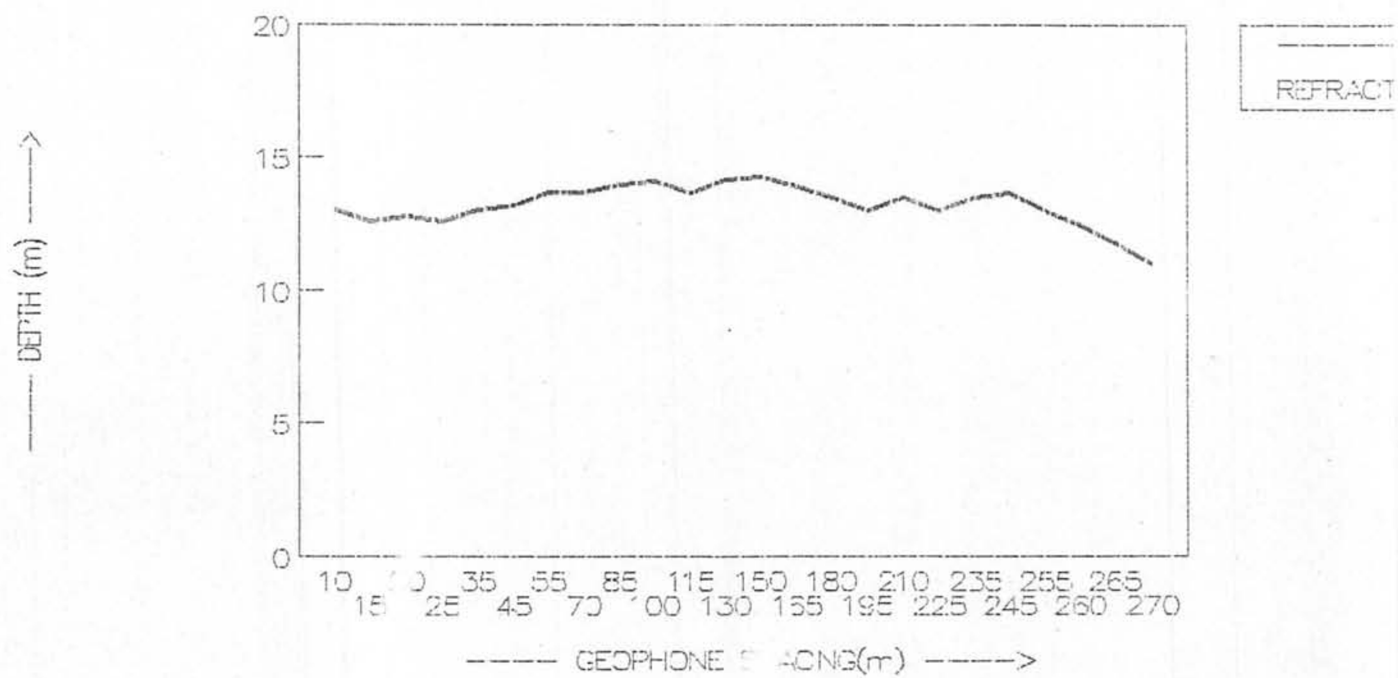
V_{1d} = 1761 m/sec.

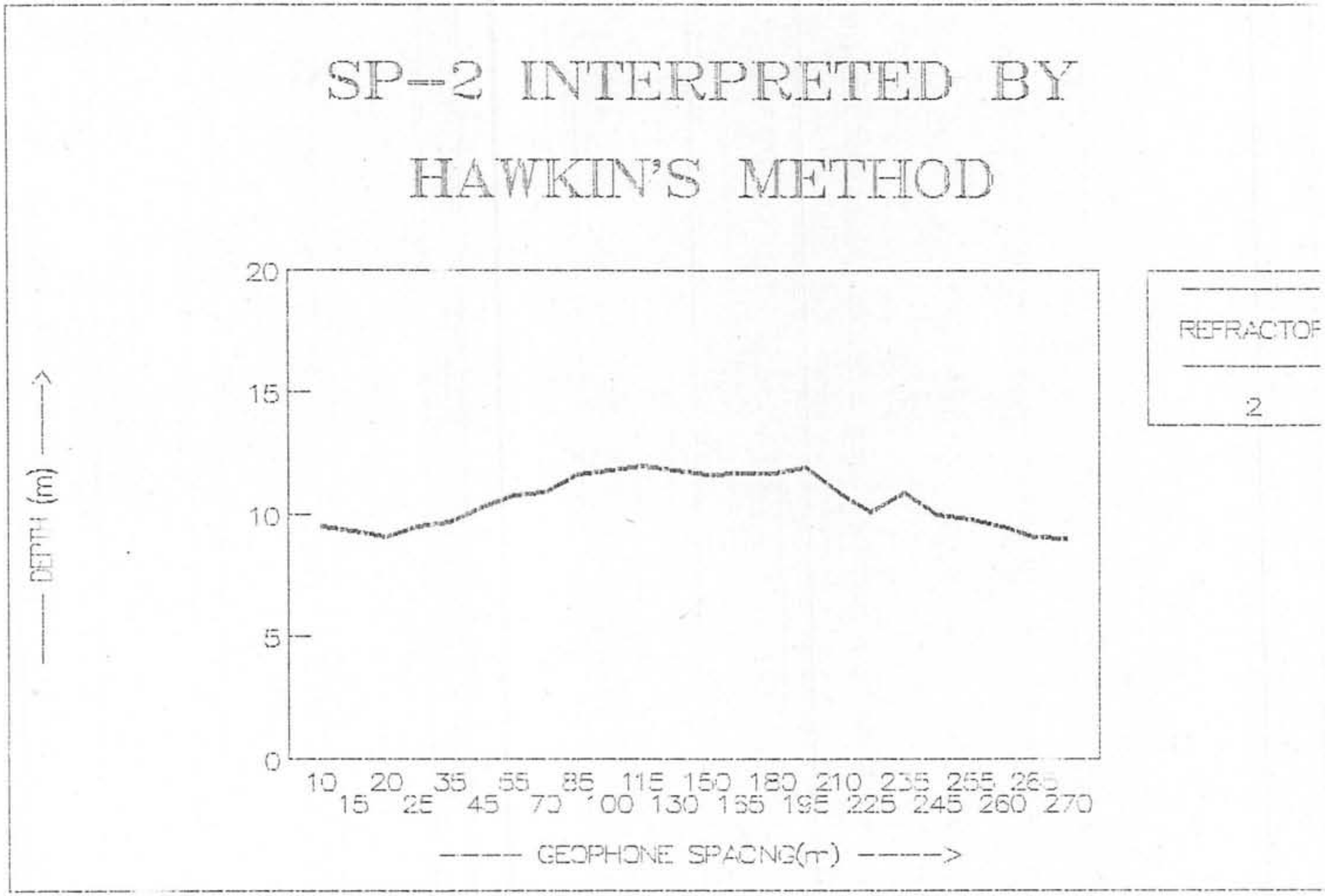
V_1 = 1696.8 m/sec.

APPENDIX

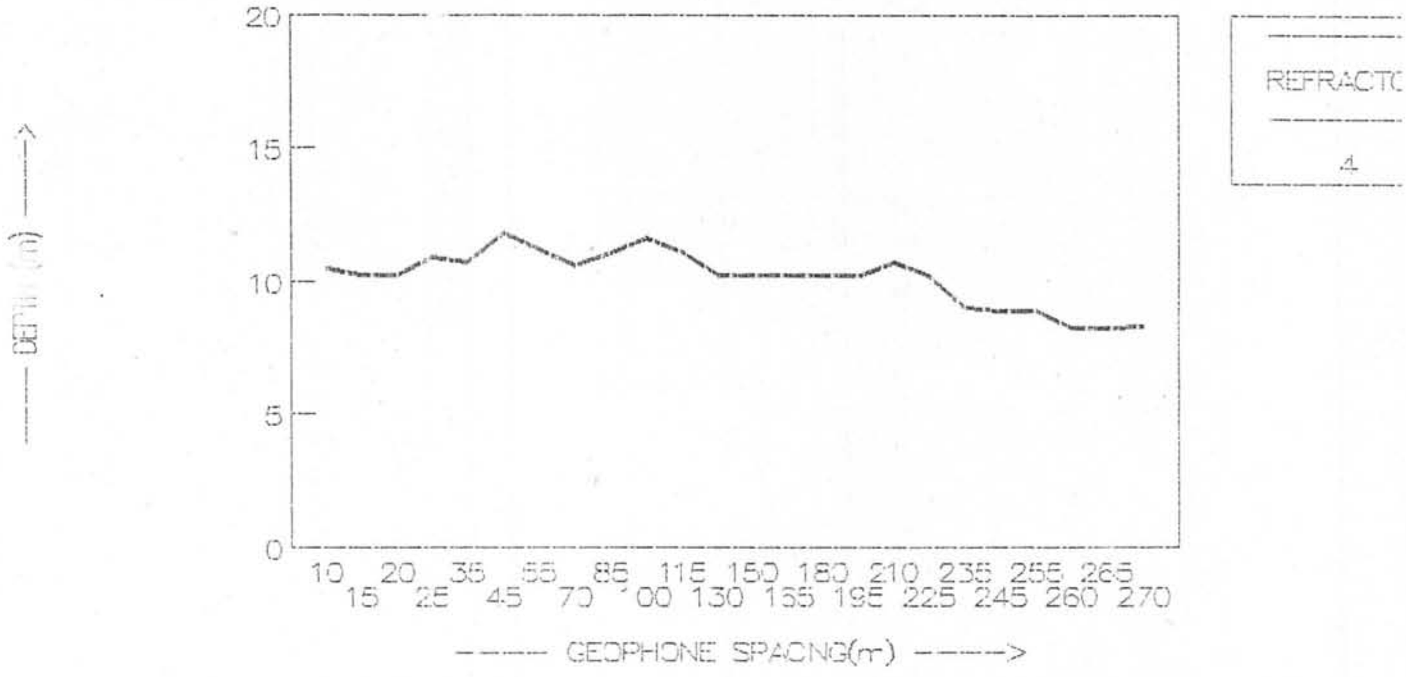
"C"

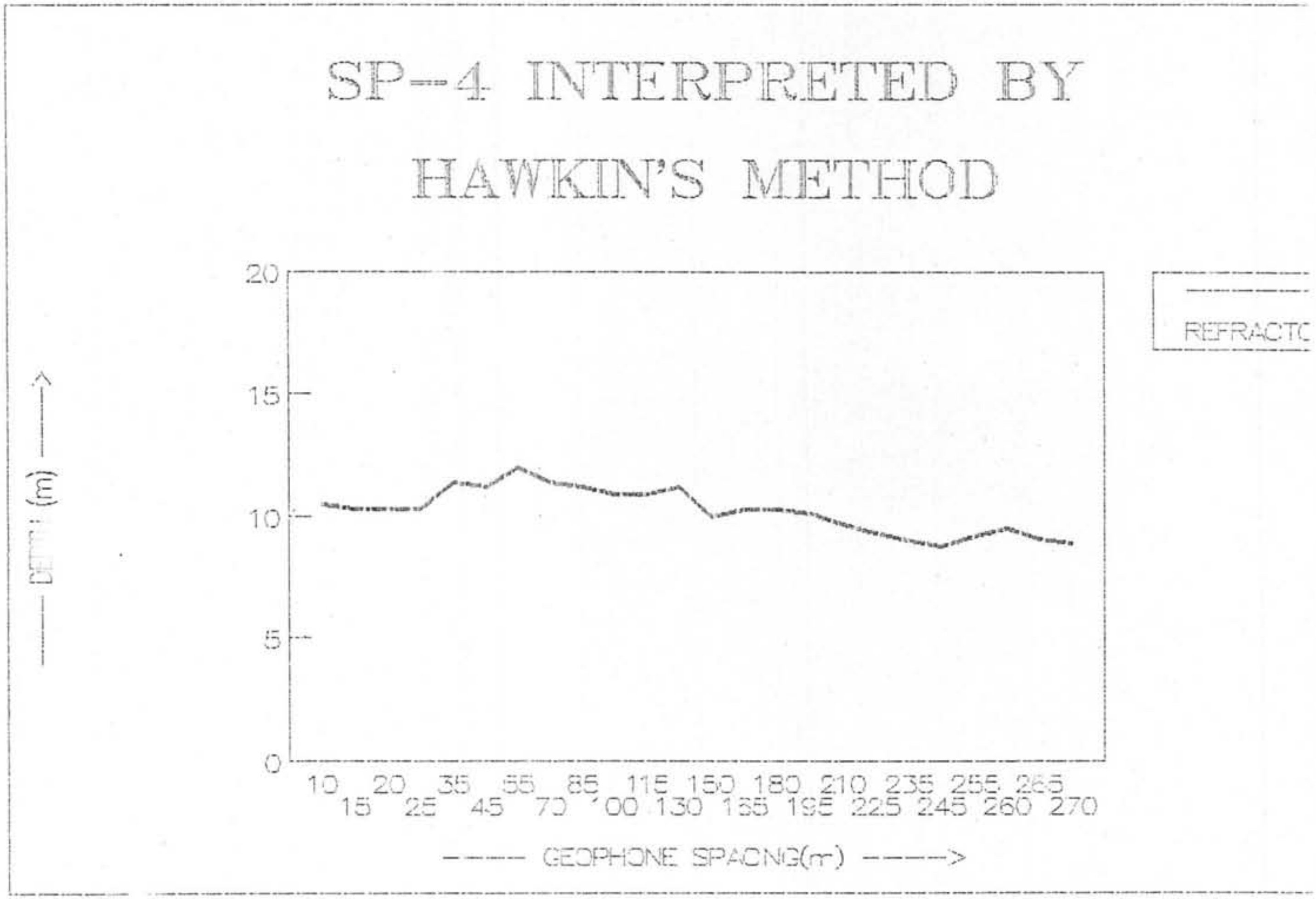
SP-1 INTERPRETED BY HAWKIN'S METHOD




SP-2 INTERPRETED BY
HAWKIN'S METHOD
DEPTH (m)
20
15
10
5
0
10 15 20 25 35 45 55 70 85 100 115 130 150 165 180 195 210 225 235 245 255 260 265 270
GEOPHONE SPACING(m)
REFRACTOR
2

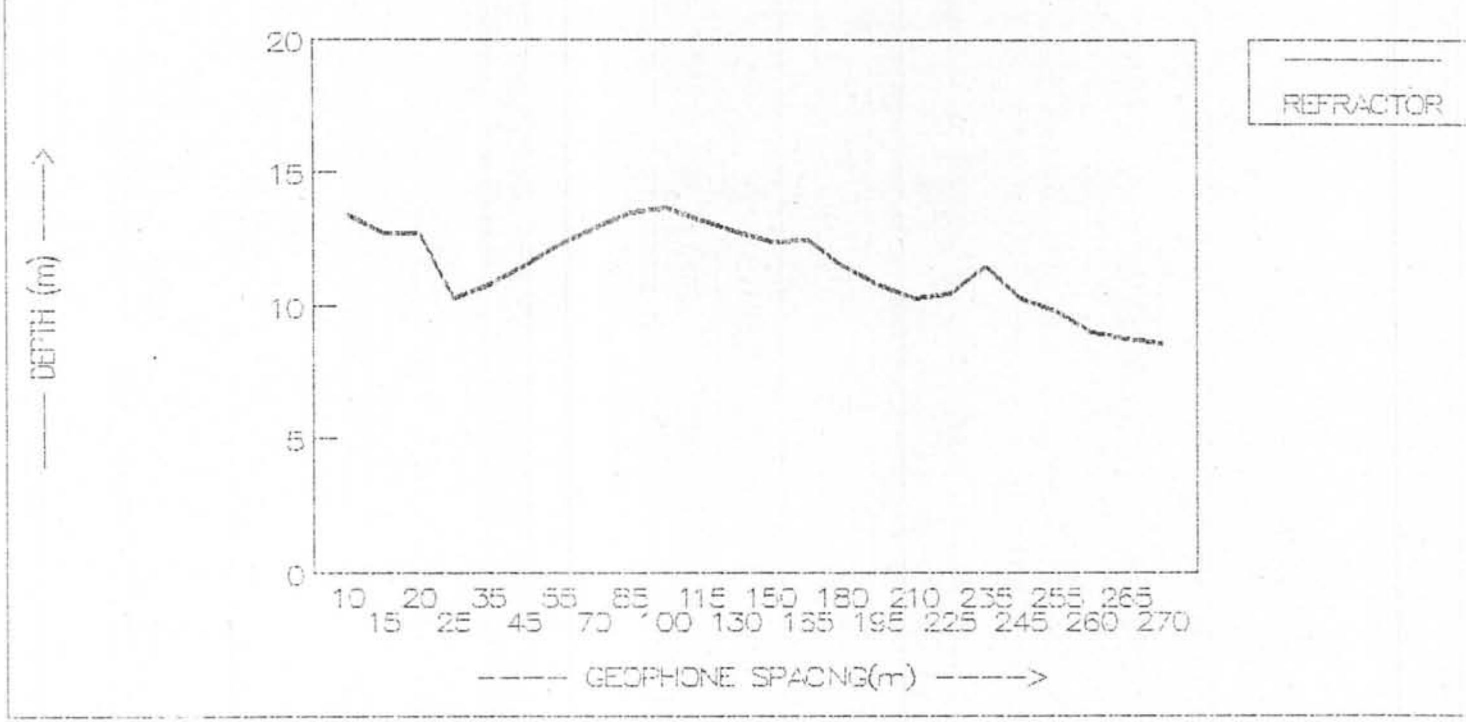
SP—3 INTERPRETED BY HAWKIN'S METHOD



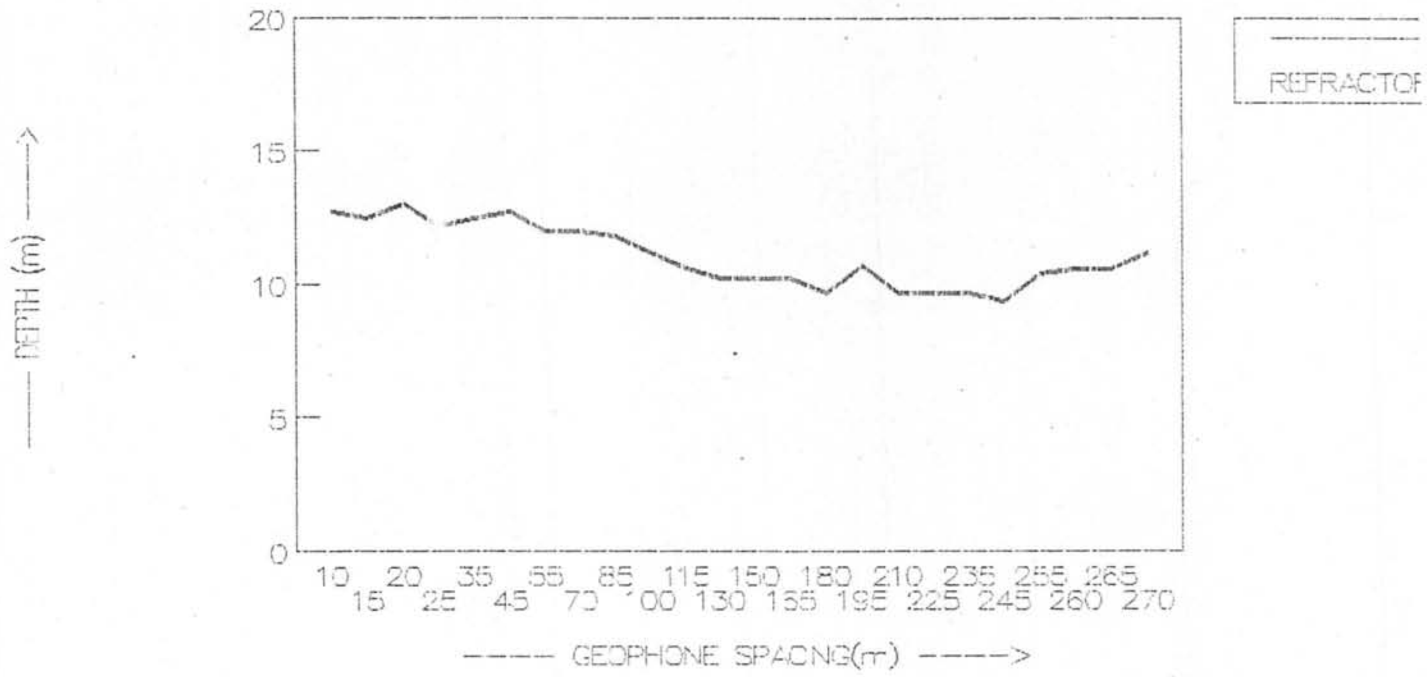


SP-4 INTERPRETED BY
HAWKIN'S METHOD
20
15
10
5
0
10 20 35 55 85 115 150 180 210 235 255 265
15 25 45 70 100 130 165 195 225 245 260 270
GEOPHONE SPACING(m)
REFRACTO

SP-5 INTERPRETED BY HAWKIN'S METHOD



SP–6 INTERPRETED BY HAWKIN'S METHOD



SP-7 INTERPRETED BY HAWKIN'S METHOD