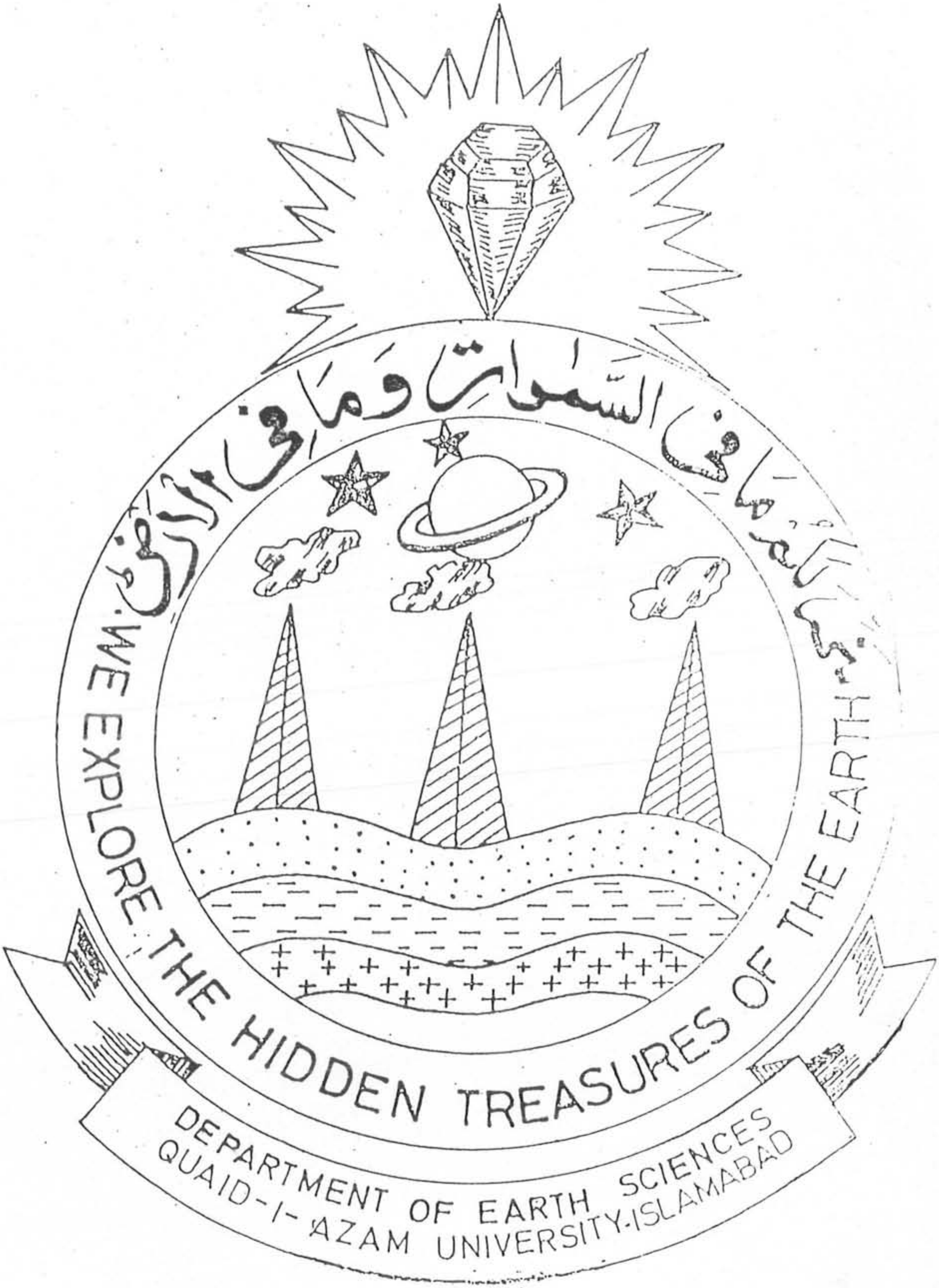
IN THE NAME OF ALLAH
THE MOST BENEFICIAL,
THE MOST MERCIFUL.


يعلم ما في السموات وما في الارض
WE EXPLORE THE HIDDEN TREASURES OF THE EARTH
DEPARTMENT OF EARTH SCIENCES
QUAID-I-AZAM UNIVERSITY-ISLAMABAD

A Shallow Seismic Refraction Survey to map the velocity-lithology relationship of the weathered & sub-weathered layers

BY

ABDUL GHAFOOR

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FINAL APPROVAL OF THESIS

This thesis submitted by Mr. Abdul Ghafoor is accepted in its present form by the Department of Earth Sciences as satisfying the requirements for the degree of Master of Sciences in Geophysics.

COMMITTEE:

Mr. Arif Raza Jafree,
Supervisor(Geophysics).

Dr. Abdul Rauf,
Supervisor(Geology).

External

Dr. Khawaja Azam Ali.
Chairman.

DEDICATION

Dedicated to my parents, brothers, sisters and all those who earn their living by honest means.

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All thanks to Almighty Allah who gave me strength and capability to complete this dissertation. I am utmost thankful to Panjtan Pak (A.S.) who are source of blessing for the whole universe. [illegible]

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I am grateful for all those who prayed for me and having good wishes for me.

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ABSTRACT

A seismic refraction survey was carried out in Tarlai Khurd a village of Islamabad to map the weathered and subweathered layers and to establish their velocity-lithology relationship. Six refraction profiles covering 500 sq.m of area were laid in the area and covered by reverse shooting. The parameters such as true velocities, depth and dip angle of the refractor were obtained on Hewlett Packard Model-216 personal computer. The results have been presented in the form of Iso-velocities (Vo,V1), Iso-dip and Iso-Pach (Ho) maps.

The velocity in the mapped weathered layer ranges from 320-540 m/s and in subweathered layer from 1600-2270 m/s. The depth of weathered and subweathered layers varies from 5.1-10 meteres and 11.5-21.4 meteres respectively. The weathered layer may comprise of clay, silt and shale while sub-weathered layer may comprise of friable sandstone with clayey and shaley intercalations and at places may be moisture impregnated.

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CHAPTER 1
INTRODUCTION

CHAPTER NO.1

1.1 INTRODUCTION.

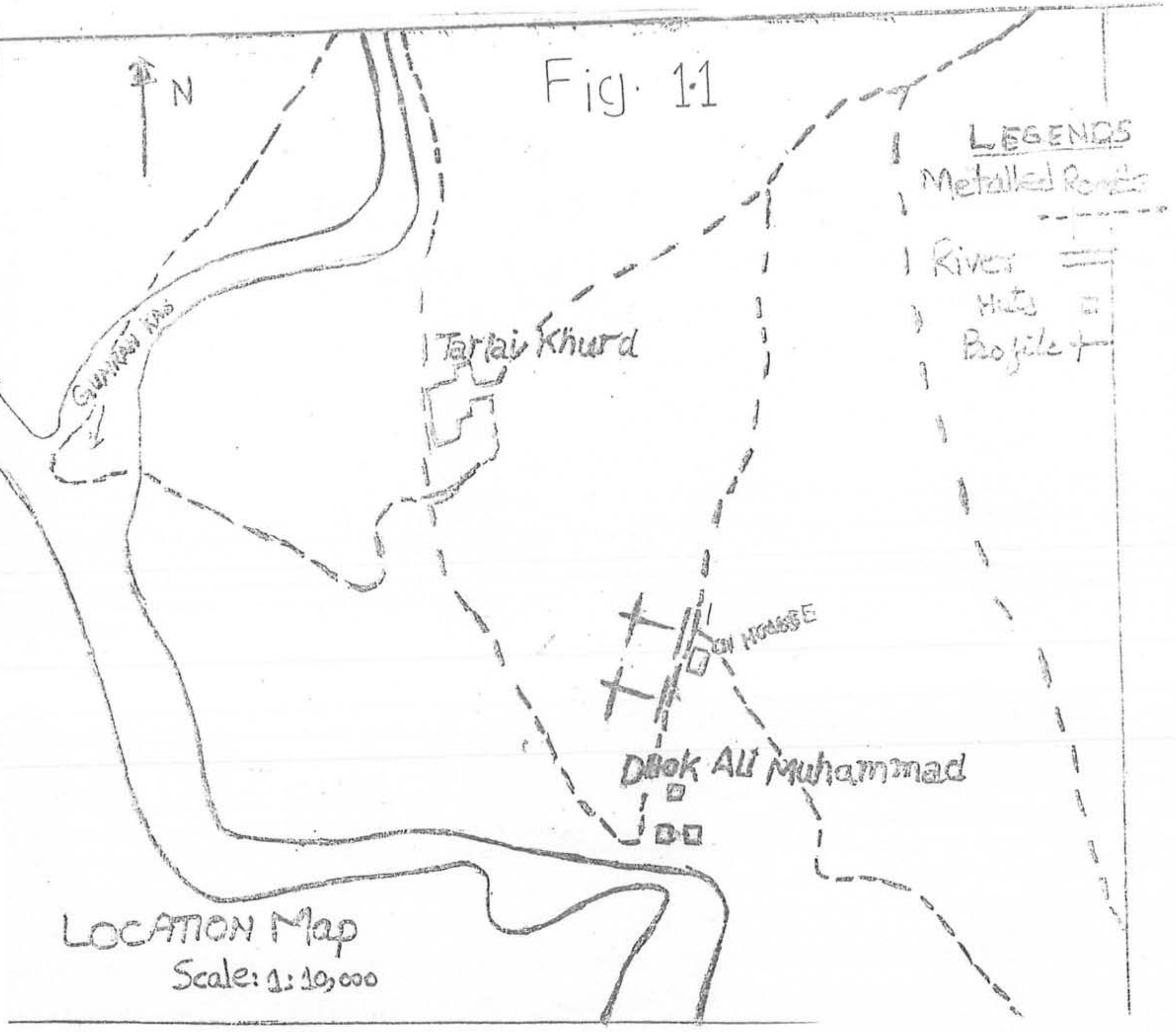
A shallow seismic survey was carried out in village "Tarlai Khurd" near the capital city of Islamabad as shown fig (1.1) in the month of May, 1991. The object was to map the weathered and sub-weathered layers in the context of their interpreted velocity-lithology relationship by shallow seismic refraction in this area. For this purpose six seismic refraction profiles were laid as shown in fig (1.2).

The description of the profiles is as under:-

Profile No.	Orientation	Total spread length (m)
SP-1	N-S	110
SP-2	N-S	105
SP-3	E-W	105
SP-4	N-S	105
SP-5	N-S	110
SP-6	E-W	105

Field work on these profiles was conducted using reverse seismic refraction shooting technique, to record both the updip & downdip velocities in order to calculate the dip angle(s) of the refracting horizons &then to eliminate their effect on velocity of the layer(s) because Vupdip ≠ Vdowndip ≠ Vtrue.

Fig. 1.1


N
LEGENDS
Metalled Roads
River
Huts
Profile
GUMRAN KAS
Tarlai Khurd
GH HOUSE
Dhok Ali Muhammad
LOCATION Map
Scale: 1: 10,000

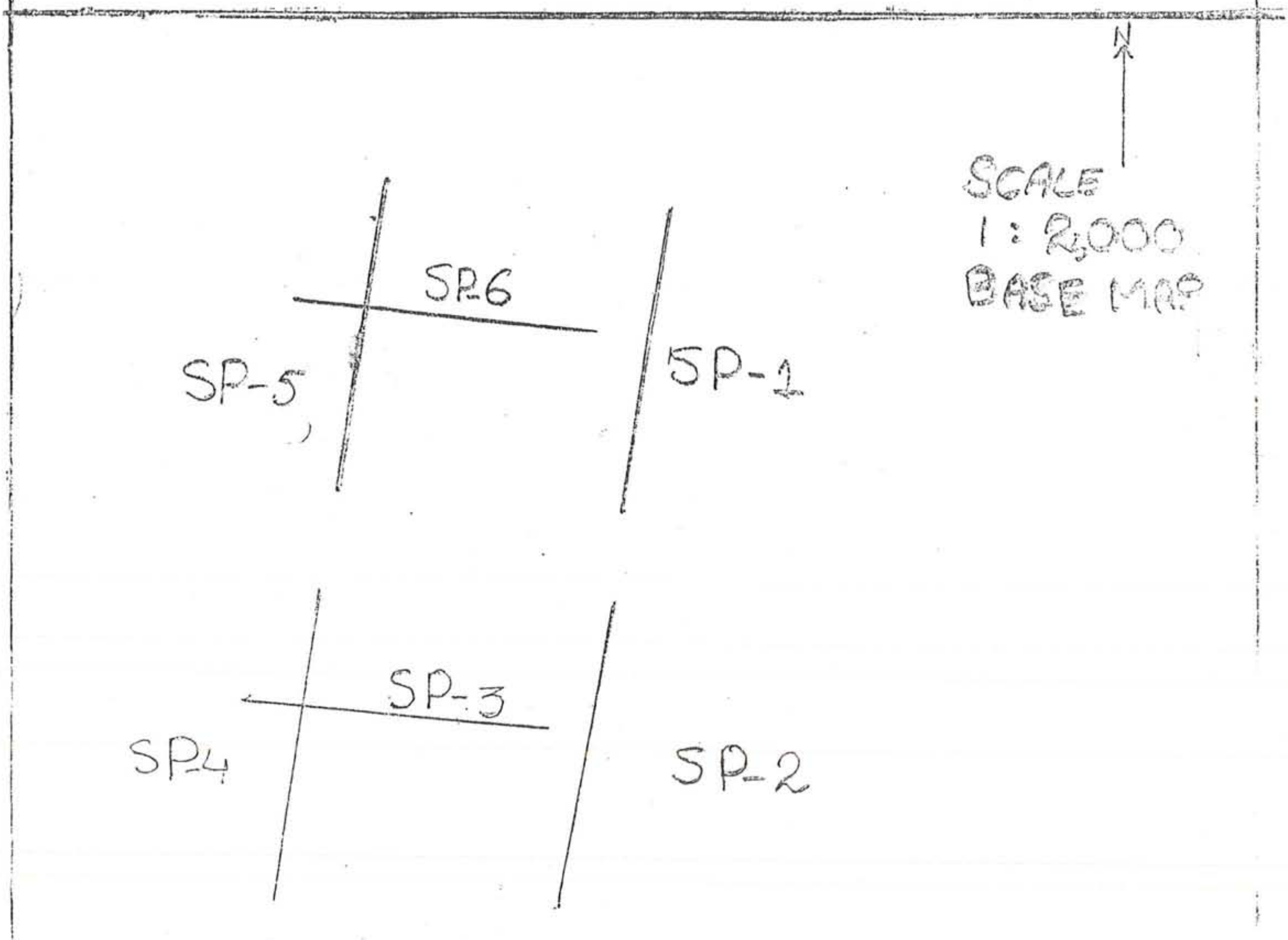


Fig. 1.2

Hammer, weighing 10 Kg, was used as seismic source at each shot point, Inter-geophone distance and shot point off set distance in all the six profiles were kept at 5 meters. With this profile geometry the maximum computed depth investigated in the area is about 21 m. Velocity ranges in 1st layers (Vo), 2nd layers (V1) and third layers (V2) ranged from 320 - 540 m/s, 1600-2270 m/sec and 2650-3740 m/sec. respectivel yielding depth ranges of 1st layers (Ho) and 3nd layers varying from 5.4-10.4 m and 11.5-21.4 m respectively. However in two cases three layers could be mapped while in all the remaining cases only two layers could be penatrated. When co-related with the existing geological environments of the area it appears from the velocity distribution that whereas the 1st layer in the area consists of weathered products as unconsolida sediments comprising of clay, sand and shale admixtures, the 2nd layer is likely to consist of clayey and shaley friable sandstones underlain by well compacted high velocity yielding sandstones. The ranges of velocity (320-540 m/sec) within the 1st layer of unconsolidated sediments may reflect their assorted admixture of clay, shale & Silt. In the 2nd layer the, velocity range (1600-2270 m/sec) may characterise the varied percentage of clay & shale in the sandstone which at places may be moisture or water saturated resulting in its fiable nature. In high velocity third layer, with thickness inteterminate, the velocity ranges from 2650-3740 m/sec.

be due to the well but variable compaction within rather clean sandstone.

1.2 LOCATION AND EXTENT.

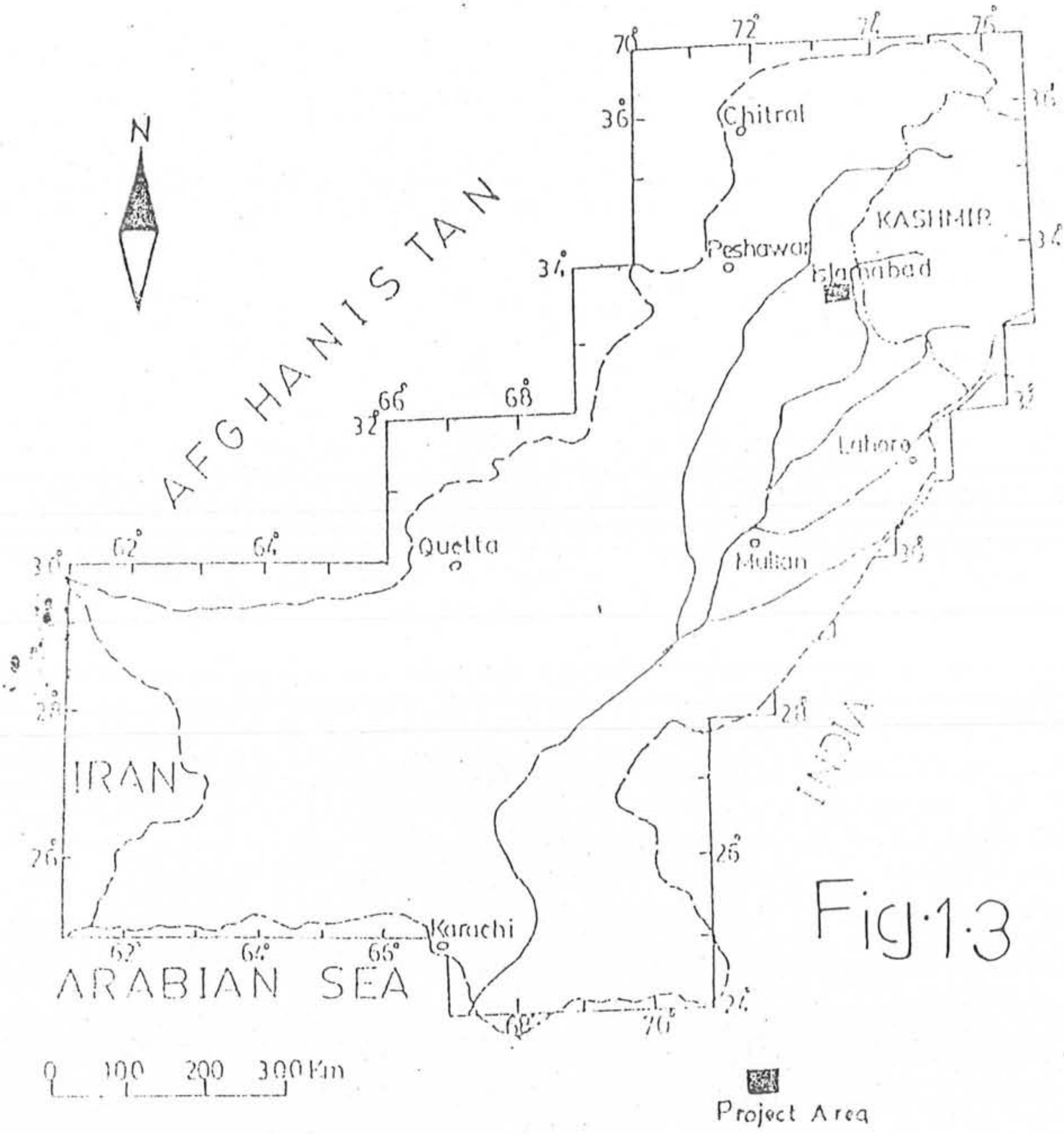
The project area is bounded by Longitude $73^{O}9'10''$E ' to $73^{O}9'20''$E and $33^{O}36'30''$N to $33^{O}36'45''$ N Latitude with reference to the Survey of Pakistan Toposheet No. 43 G/2, Scale: 1: 50,000.

The main boundaries of the project area are Kurng River and Gumrah Kas River on the Western side and Eastern Side respectively.

1.3 ACCESSIBILITY.

The project area is easily accessible from Islamabad by a metalled road called the National Park Road to reach "Tarlai Kalan" village

Index Map Of Pakistan Showing The Project Area



Fig·1·3

CHAPTER 2
GENERAL GEOLOGY

CHAPTER NO.2.

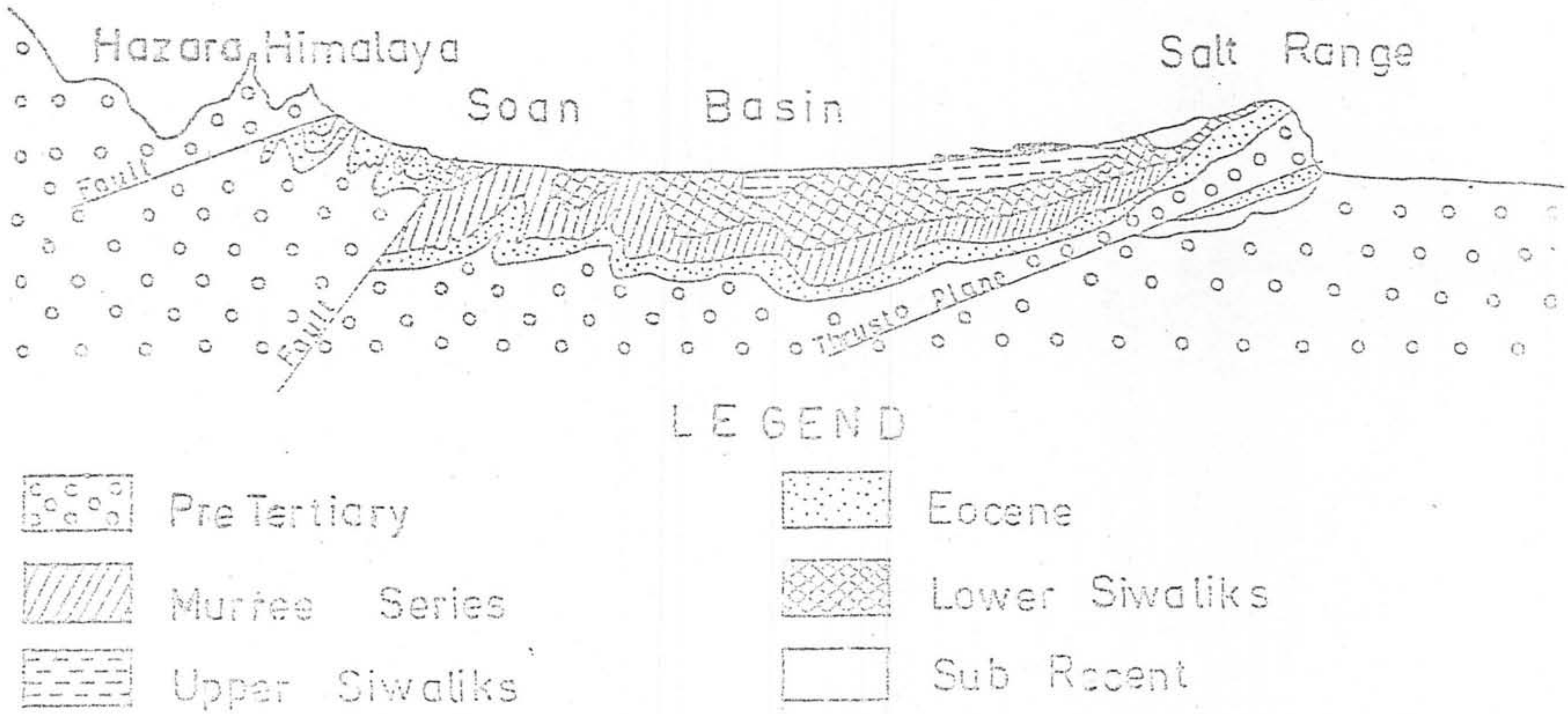
GENERAL GEOLOGY OF THE AREA:-

The geological set up of an areas, its lithological characteristics of various rock formations and weathering products forming sufficial deposits have important bearing on the respective layers seismic velocity values. In sedimentry rock environments as it exists in this project area, the specific rock composition, it compaction, fluid saturation or absence of saturation in its pore spaces as effect their seismic velocity values. Thus variations in these characteristics & environments produce corresponding variation in their seismic velocities.

The project are being part of the village Tarlai Kalan near Islamabad lies on the North Eastern boundary of the central potwar Plateau (Elahi & Martin) which forms the part of the geosynclinal trough known as Indo-Gangtic Synclinorium filled with tertiary and pre-tertiary sediments as shown in fig. (2.1). This part of synclinorium lies between the Salt - Range and the foothills of the Himalyas and includes the whole of Soan River Basin.

SECTION ACROSS THE POTWAR GEOSYNCLINE

FIG. 2.1



2.2 PHYSIOGRAPHY AND STRATIGRAPHY OF THE AREA.

Physiographically the project area is characterized by uneven topography. Two perennial streams flow in this area from NE to SW direction. Influent or afluent character of these streams has not been studied. However the distribution of different lithologies suggest that the possibility of surface recharge of ground water exists.

Because of the Himalayan uplift during the deposition of Siwalik the area is folded, faulted and overthrusted. The rocks in the Potwar area are mainly over lain by unconsolidated pleistocene and recent alluvium and loose deposits consisting of clay, silt, sand, shale and gravel. The thickness of these alluvial deposits varies from a thin mantle to more than 20 meters

The rocks exposed in the Potwar Plateau mainly belongs to Rawalpindi Group of Miocene to Lower Pleistocene age. The rocks of these groups mainly consists of sandstone, shales, conglomerates and clay which were formed as a result of disintegrati of pre-existing rock transported by water wind and deposited over the land (Shah 1977).

The rocks exposed in this project area are Quaternary shale comprising of silt and caly with lenses of sand and gravel. On the Eastern side of the project area Potwar clay of Quaternary age is exposed which contains clay, siltstone and mudstone interbede with sandstone. Stratigraphic succession of Rawalpindi and Siwalik

Physiographic units of the Potowar

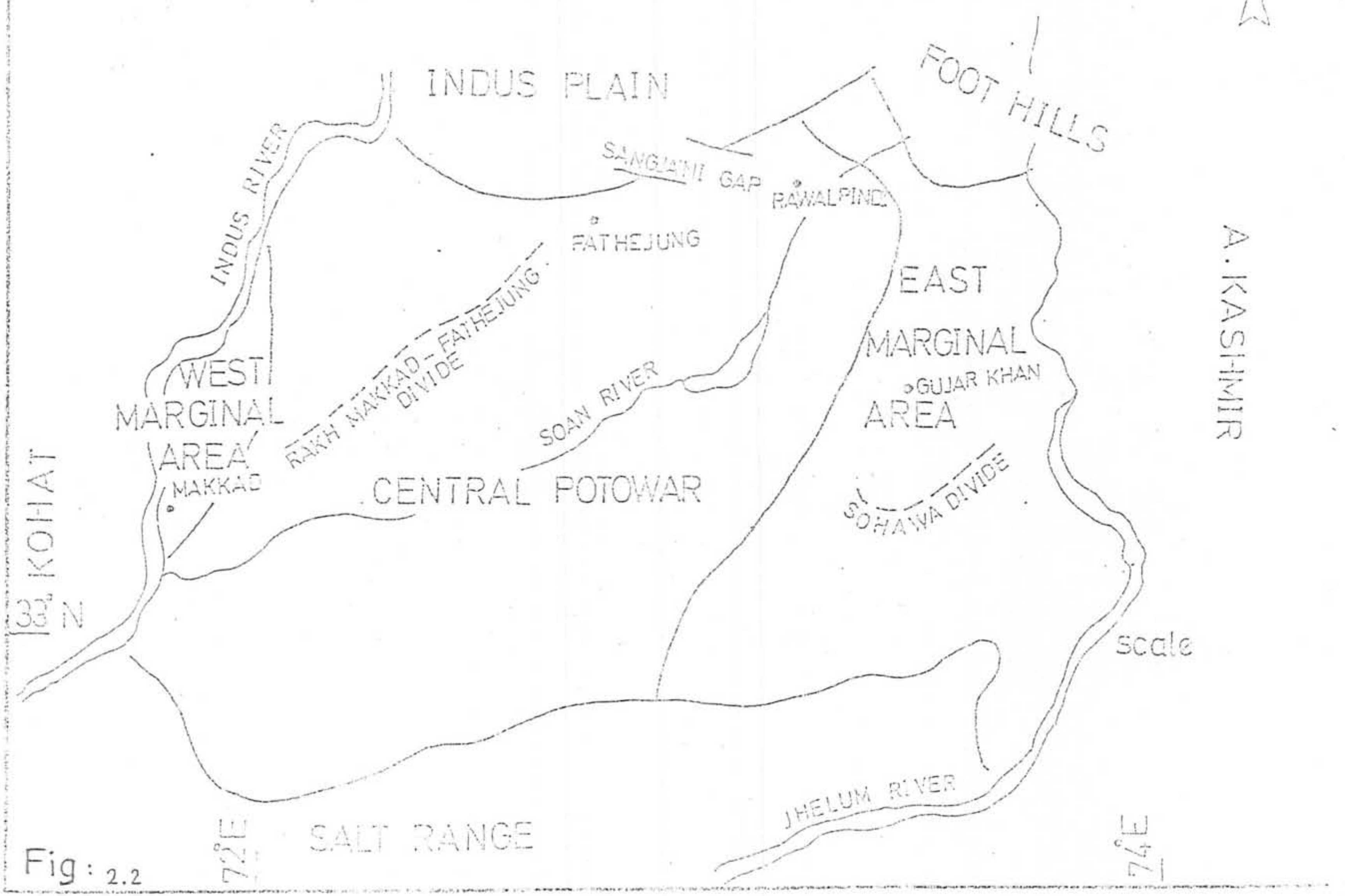


Fig : 2.2

Group is given in the table.

TABLE NO.2a

GROUP	FORMATION	LITHOLOGY	AGE
SIWALIK GROUP	Soan Formation	Conglomerates with vari-coloured sand-stone, silt-stone, clay-stone	Late Pliocene to early Pliostocene
	Dhok Pathan Formation	Alternation of Sandstone and clay. Sand-stone is either grey, light grey, white, reddish brown. Clay is orange brown, dull red or reddish brown	Early to Middle Pliocene
	Nagri Formation	Predominantly sandstone subordinate clay-stone and conglomerate.	Early Pliocene to late Miocene
	Chingi Formation	Red clay and, subordinate brown grey sand-stone	Middle to Late Miocene
RAWALPINDI GROUP	Kamlial Formation	Purple and brick-red Sand-stone, some purple shale and conglomerate	Middle to late Miocene
	Murree Formation	Dark red and purple clay stone, grey and green grey sand-stone	Early Miocene

CHAPTER

SEISMIC REFRACTION METHOD

CHAPTER NO. 3.

SEISMIC METHOD

3.1 INTRODUCTION.

Seismic prospecting is one of the most important branch of geophysical exploration. This is due to it capability of high accuracy by virtue of its high resolution and capability of deep penetratio Its feild methodology depends upon the refraction & reflection of elastic waves produced by on artificial source called the shot point. These elastic waves propagate radially in all directions from a source located within the shallow or deep crust and undergo reflection as well as refraction at different elastic discontinuities encountered by these propagating waves. These reflected or refracted waves bouncing back to the surface can be detected by specially designed receivers called geophones, which infact are electro-mechanical devices capable of converting the up & down mechanical motion of the ground into electrical signals. Basically the signal so received is very weak and requir amplification. Thus the system amplifies and also displa these signals in the form of a photographic trace of a moving spot and can also be taped on the systems magneti tape or be registered by a digital recorder. This final out put of the seismic instrument is called the refracti or reflection seismogram as the case may be. The process of these refraction seismograms, as is the case in this project, leads to in determining the velocities of propagation of the refracted seismic waves 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 lead towards the mapping of geological boundaries of the refracting horegous in the project area.

3.2 PRINCIPLES GOVERNING REFLECTION AND REFRACTION OF SEISMIC WAVES.

The elastic waves propagation in the earths crust is governed by laws of geometrical optics of waves propagation within an isofropic medium & then at an interface of another medium. The following laws of optics are applicable in seismic exploration:-

1) Huygen's Principle.
2) Fermat's Principle.
3) Snell's Law

3.2.1 HUYGEN'S PRICIPLE.

It describes the propagation of a wave and its forms in a medium and states that each point on an advancing wave front in an isotropic, homogeneous medium may be considered as a new source of secondary spherical wavelets which so that the position of this advancing wave front at any time "t" is given by the tangential envelops of these secondary wavelets.

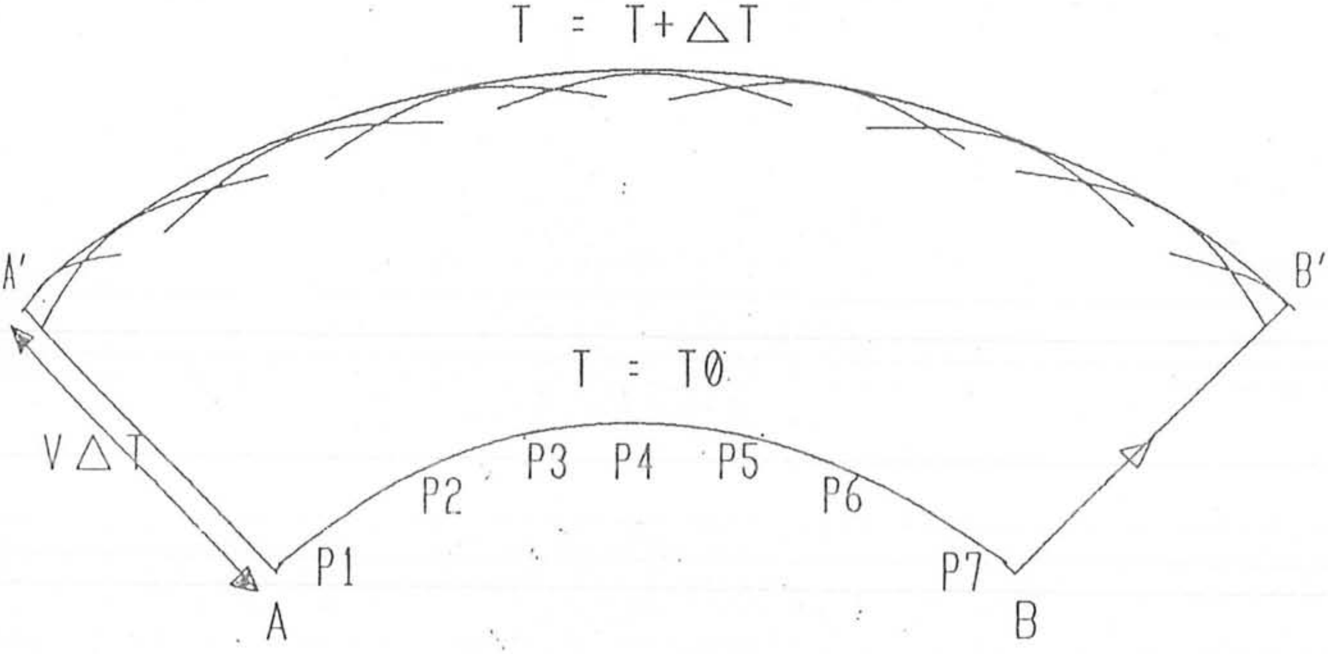


fig 3.2.1 Huygens Principle to locate new wave front.

Thus the geomatrical shapes of the propagating waves at any point of time and their associated ray paths can be plotted to help interpret eventually the time-distance relations (Fig. 3.2.1)

3.2.2 FERMAT'S PRINCIPLE.

It describes the ray path geometry for a propagating wave and states that a ray which is perpendicular to the wave front, reaching a given point from a given source reaches that point through a "minimum time" path between the source and that point.

3.2.3 SENELL'S LAW.

Snell's law describes the relationship between the incident and the refracted raypath at an elastic bourdary (also called the elastic discontinuity) at which the change from one medium to another medium takes place. When seismic wave strikes such an elastic discontinuity it encounters an abrupt change of elastic properties and in its propagating ray path resulting in the incident energy partitioning so that a part ofthe incident energy is reflected back and thus remains in the same medium as the incident energy while some part of this energy is refracted into the other medium &thus undergoing a sudden change in direction of its propagati The remaining part of the incident energy is scattered and lost as heat. The refracted part now propagates into the second medium obeying snell's law. This law states

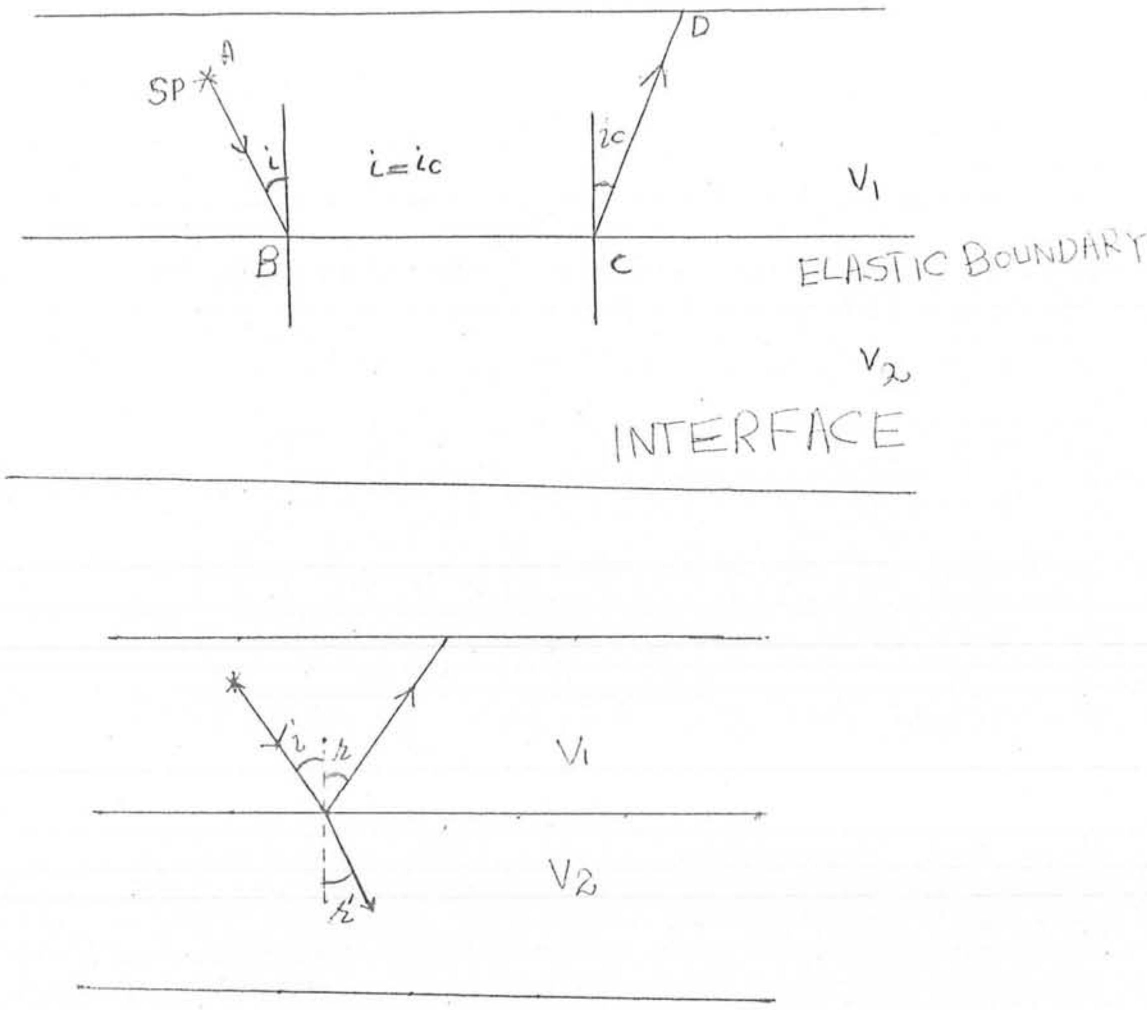


Fig. 3·2·2

that a wave incident at an elastic discontinuity characterized by the boundary between two media having different velocities V1 & V2 is partly reflected and partly refracted such that for reflection the angle of reflection is equal to the angle of incidence. i.e.

$$\angle r = \angle i$$

and for refraction the following relation

i) $$\frac{\text{Sin } i}{\text{Sin } r'} = \frac{V1}{V2}$$

Where $\angle i \neq \angle i$

See fig (3.2.3)

i = angle of incidence

r = angle of reflection

r' = angle of refraction

ii) But when $i = i$ = critical angle

and $V1 < V2$

then $r' = 90$

$\text{Sin } r' = \text{Sin } 90 = 1$

Therefore Snell's law is modified for this situation as follows:-

$$\frac{\text{Sin } i_c}{\text{Sin } 90} = \frac{V1}{V2}$$

But $\text{Sin } 90 = 1$

$\text{Sin } i_c = V1/V2$

$i_c = \text{Sin}^{-1}(V1/V2)$

Actually for critical angle of incidence i , the refracted ray bends away from the normal at 90 angle & thus travels along the interface. This is called total internal refraction. This inherent property of the incident waves is used in seismic refraction as shown in fig (3.2.2)

For any angle of incidence greater or less than i_c. there will be no refracted ray along the intergace and all the energy incident at such angles will be reflected or refracted and will not be useful to us in our seismic refraction methodology.

3.3 SEISMIC REFRACTION METHOD

Seismic refraction method is generally used as a shallow seismic prospecting method and is employed to resolve a wide range of geological and geophisical problems pertaining to the shallow depth, i.e. depths ranging upto about 500 meters. The geophysical aspect of seismic refraction is based on the fact that the elastic waves travel at characteristics velocities through different geological formations and thus there exists a "velocity cum lithological" relationship which is used as a basis in the interpretation of refraction date into a lithological even section. In seismic refracti refraction prospecting linear refraction profile is set up with a predetermined geometry of its shot point and

a number of geophones (12, 24 or 48). Such typical geometries can be optimized to cater for specific requirements of the project objectives in the area. The depth of investigation being the major factor to be considered. This optimization is achieved after a few experimental refraction profile geometries are shot and results studied. Experimental, to short with, based on the rule of thumb that the length of a refraction profile should be 3 times the maximum depth to be investigated. This in no way is a definite rule but only a basis for a short model for experimenta work. Here, during the experimental phase, other important element of the seismic refraction.
Viz: The source (short point) strength (amount of charg or impact) and the depth of the short point is also determined. Thus best workable values of shot point strength & its depth, shot point off set distance, and geophone to geophone interval to be used in the project area are determined. Thus when a seismic refraction profile has been shot, the time between the initiation of seismic wave at the shot point called the shot instant. and the times of arrival of the refracted waves at the surface are detected by. The series of geophones forming the refraction profile. The waves so picked by the geophones are the refracted P-waves. Their arrival times at the geophones are recorded as first refracted arrivals on the refraction

seismogram. These first arrival times are then utilized in constructing a time - distance graph (fig 5.4.1) by plotting the co-ordinates of distance from shot point to the recording geophone and the arrival time read from the seismogram along X-axis and Y-axis respectively. These plotted points are then linearly joined to form straight line segments of varying slopes. The number of such linear segments will then represent the number of subsurface layers mapped, and the respective slopes of these lines will respectively represent. The layer velocity which can be calculated from the following formulae:-

Slope of a line joining two points (X1,Y1) and (X2, Y2)

$$\frac{Y2-Y1}{X2-X1} = \frac{t2 - t1}{S2 - S1}$$

$$= \frac{\text{Time taken}}{\text{distance travelled}}$$

$$= 1 \,/\, \text{Apparent velocity of the layer.}$$

$$V = 1/\text{slope of the segment}$$

Hence the above experimental single shot refraction profile will yield some important subsurface parameters:-

i) No of layers mapped by the above geometry of the refraction profile.

ii) The characteristic apparent velocity of each layer

At this stage distinction has to be made between an apparent layer velocity as determined from the time-distance graph and its TRUE LAYER VELOCITY that is yet to be calculated. Actually the velocity calculated from a single shot refraction profile data, because of the general possibility of dipping nature ofthe subsurface layers, is generally a function of the layers dip below that single shot point. This velocity calculated a refraction profile dipping downward from shot towards the geophone line will be different from velocity calculated for the same profile when shot from the opposite i.e. say the downdip side. The down dip shooting will result in down dip velocity value which will be different from the up-dip velocity value previously calculated.

V updip $\neq$ V downdip $\neq$ V true

Because V true is not a function of dip whereas both V up & V down are functions of dip. Thus to arrive at true velocity value of a layer its removed from the apparent velocity value obtained from a single shot. For this purpose we can proceed as follows:-

1) A refraction profile must be shot from its both ends so as to obtain APPARENT UP-DIP & DOWN-DIP VELOCITIES for each single layer. That is END-TO-END Refraction shooting must be done. This was done for this project.

2) The refraction profile must be as closely as possible and as allowed by existing field conditions be oriented along the general geological dip prevailing in the project area. This was done for this project.

3.4 Theoratical aspects of refraction in two layers and three layers dipping beds with discrete velocities Vo, V1, V2.

3.4.1 Two layer dipping case:-

The formulae for true velocities, updip and downdip depths to first refractor are as follows:-

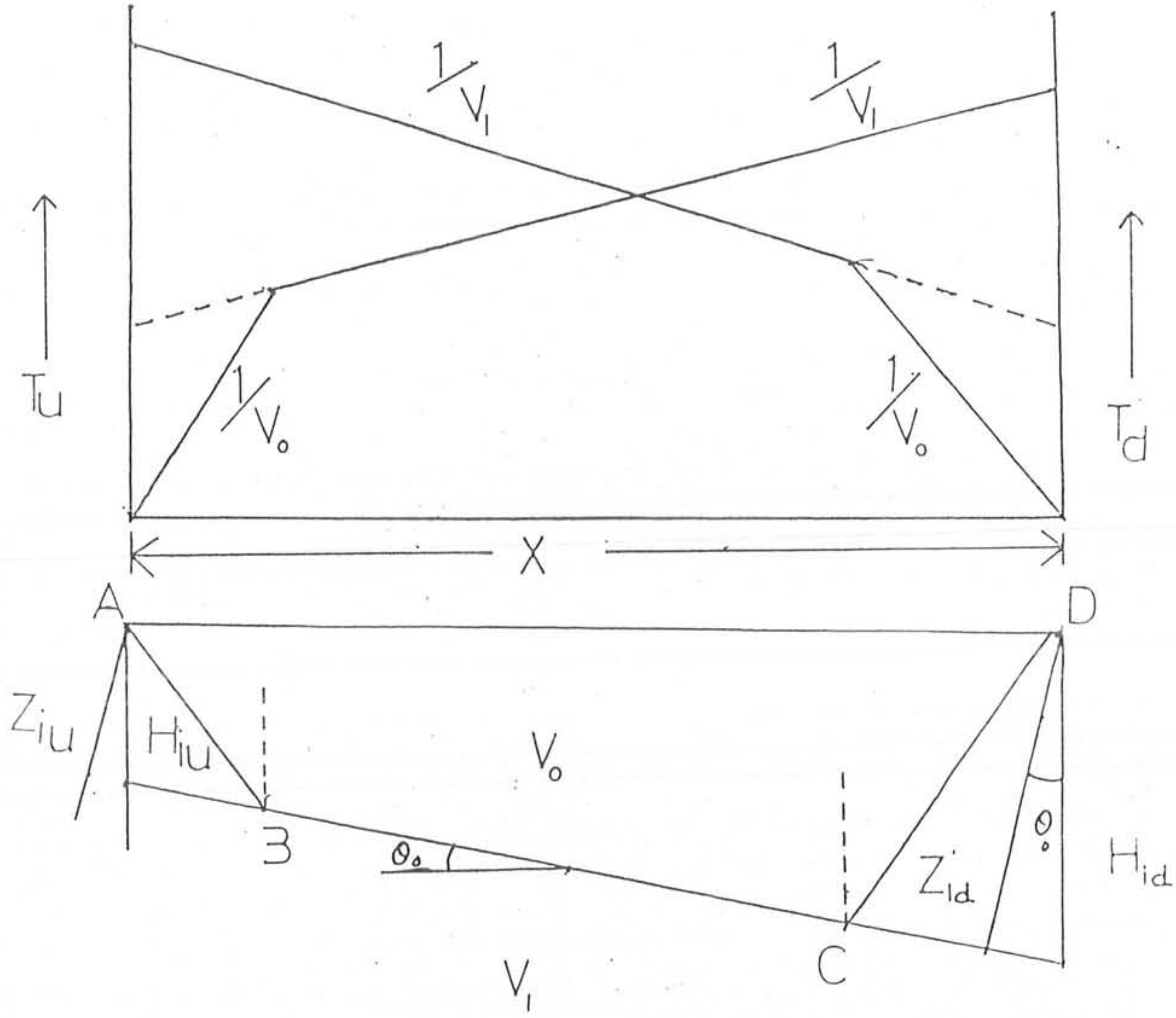
$$\text{True Velocity} = Vo = \frac{2\ Vou\ \ Vod}{Vou +\ Vod}$$

$$\text{True Velocity} = V1 = \frac{2\ V1u\ \ V1d}{V1u +\ V1d}$$

Perpendicular depth from shot point at side 'd' to the first refractor. $= Z1d = \frac{Vo\ Tid}{2\ Cos\ ic}$

Perpendicular depth from shot point at side 'u' to the first refractor. $= Ziu = \frac{Vo\ Tiu}{2\ Cos\ ic}$

Where Vou, Vod and V1u, V1d are the updip and downdip velocities of the first and second layer respectively. Z1d is downdip prependicular depth to first refractor from dwon dip shot pt. Z1u is updip prependicular



TWO LAYER DIPPING CASE

FIG. 3.4.1

depth to 1st refractor from up dip shot point, Tid and Tiu are the intercept time for downdip and updip cases respectively, ic is the critical angle and Θo is the angle of dip of the first refractor. Ic and Θo can be calculated by following formulaes:-

$$Ic = \tfrac{1}{2} \left(Sin^{-1} \frac{Vo}{V1d} + Sin^{-1} \frac{Vo}{V1u} \right)$$

$$\Theta o = \tfrac{1}{2} \left(Sin^{-1} \frac{Vo}{V1d} - Sin^{-1} \frac{Vo}{V1u} \right)$$

For verticale depth of refractor below each shot point we use the following formula:-

$$H1u = \frac{Z1u}{Cos\ \Theta o} \qquad H1d = \frac{Z1d}{Cos\ \Theta o}$$

Where H1u and H1d are vertical depths from respective shot points to the first refractor for updip and downdip cases respectively.

3.4.2 Three layer dipping case.

Up dip and downdip depths of the 2nd refractor are given the following formulae:-

$$Z2u = \frac{V1 \left[T2u - \frac{Z1u}{Vo} \; \frac{Cos\ (X+B) + 1}{Cos\ \alpha 1} \right]}{2\ Cos\ ic1}$$

$$Zed = \frac{V1 \left[Ted - \frac{Z1d}{Vo} \; \frac{Cos\ (X+B) + 1}{Cos\ B1} \right]}{2\ Cos\ ic1}$$

Where Vo and V1 are the true velocities, Z1u and Z1d are the updip and downdip depths to 1st refractor respectively, T2u and T2d updip and downdip intercept time respectively, X1 is the angle of incidence for 1st refractor, and Ic is the critical angle for 2nd refractor as shown in Fig. (3.4.2)

$$Ic1 = \alpha 1 = B2 = \frac{\gamma 1 + \delta 1}{2}$$

$$\alpha 1 = Sin^{-1}\left(\frac{Vo}{V2d}\right) - \theta o$$

$$B1 = Sin^{-1}\left(\frac{Vo}{V2d}\right) + \theta o$$

$$\theta 1 = \frac{\gamma 1 - \delta 1}{2} + \theta o$$

Where θo = dip of 1st refractor

$\theta 1$ = dip of 2nd refractor

$$\gamma = Sin^{-1}\left(\frac{V1}{Vo} Sin\,\alpha 1\right)$$

$$\delta = Sin^{-1}\left(\frac{V1}{Vo} Sin\ B1\right)$$

$$\text{True velocity} = V2 = \frac{2V2u\ V2d}{V2u + V2d}$$

From fig (3.4.2)

$$H2u = \frac{Z2u}{Cos\ \theta 1} \qquad H2d = \frac{Z2d}{Cos\ \theta 1}$$

Where H2u and H2d are vertical depths from shot point to 2nd refractor for updip and downdip respectively.

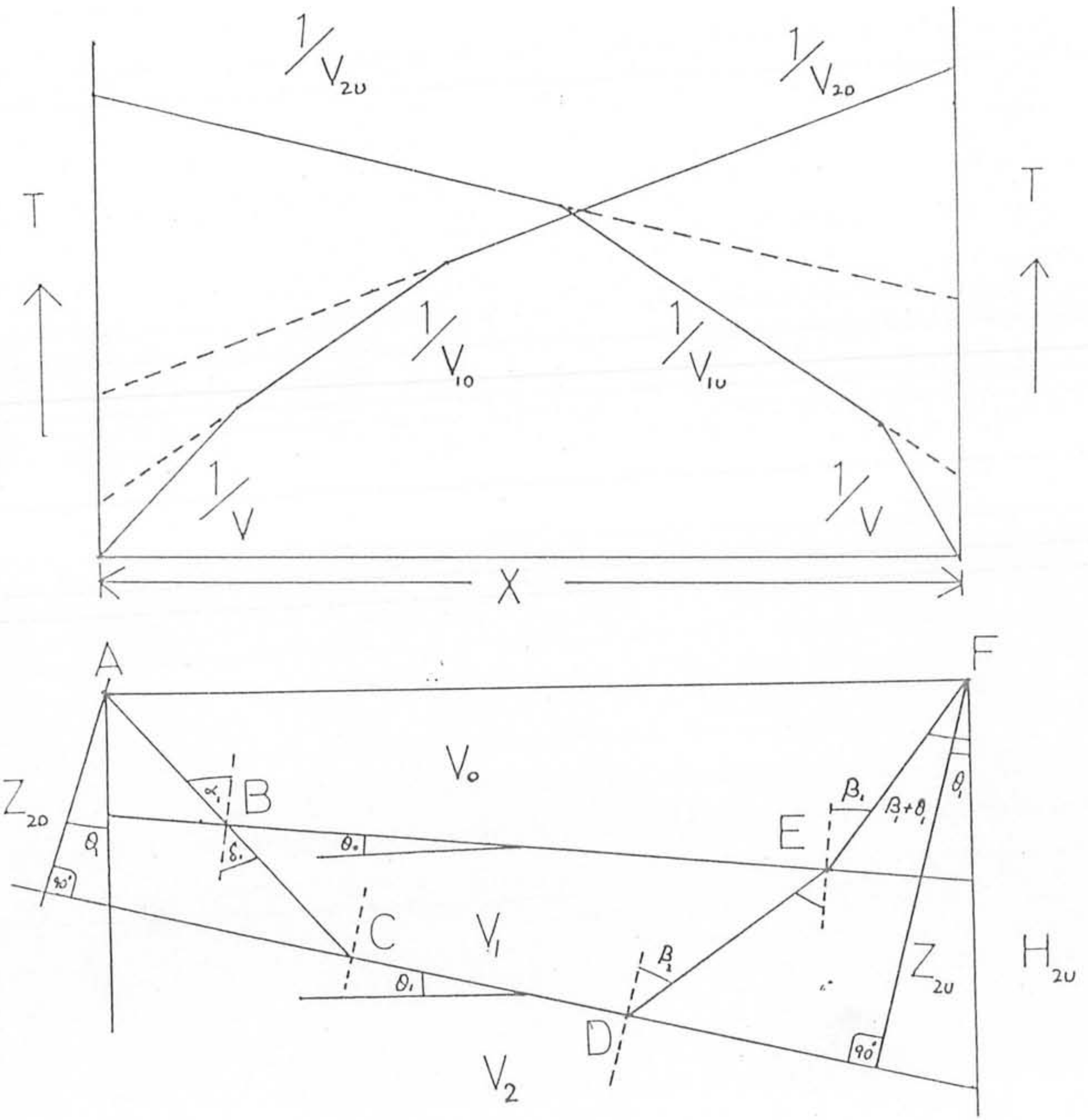


FIG: THREE LAYER DIPPING CASE

3.5 TYPICAL EXAMPLE OF VELOCITY-LITHOLOGY RELATIONSHIP.

An idea of how velocity distribution of seismic waves in various rocks in a project area can pattern itself vis-a-vis the subsurface lithology pattern is of great importance in the interpretation of seismic data. The following table indicates an example of range of the propagation velocities (Vp) of compressional waves (P-waves) for some typical media lithologies. These values and ranges may change from one area to another for the same lithologies because of various other factors besides the media composition. Hence the necessity of pre-field experimental shooting in the project area to asses its velocity-cum-lithological pattern is essential. However, the following table does give a starting model of this pattern:-

TABLE No.- SHOWING TYPICAL VELOCITY-CUM-LITHOLOGICAL PATTERN.

Various lethological Velocity	Velocity in m/sec.
Alluviam	350-650
Sand(wet)	600-1850
Clays	1100-2500
Chalk	2100-4200
Shale	2700-4800
Water(depending on temperature).	1430-1590
Limestone	3400-7000
Anhydrite	3500-5500
Rock salt	4200-500
Granite	4750-6000

3.6 APPLICATIONS OF SEISMIC REFRACTION METHOD.

Generally seismic refraction method is applied for the:-

1) Delineation of geological boundaries at greater depths.
2) Mapping of basement top and to determine thickness of different layers.
3) To have accurate depth control.
4) Mapping of surface and subsurface low velocity zone to be omitted from reflection results.
5) Foundation studies for civil engineering project.
6) Applied in structural geology to find the strike and dip of geological formations.
7) Saltdomes and similar instructions which may be of interest in oil exploration can be delineated.
8) Ore bodies, may be delineated if they transmit seismic waves at a velocity which is appreciably higher or lower than surrounding rocks.
9) Placer deposits may be located.
10) The extent of gravel deposits both on shore, and off shore, particularly in latter environment are readily determined.
11) Acombination of longitudinal and shear wave velocities determined by refraction teachinque can also be useful in classification of materials.
12) Seismic refraction method can be used in ground water exploration for the demarcation of potential aquifers boundaries.

CHAPTER 4

INSTRUMENTATION

CHAPTER NO.4

INSTRUMENTATION

4.1 SEISMIC REFRACTION RECORDING INSTRUMENTS.

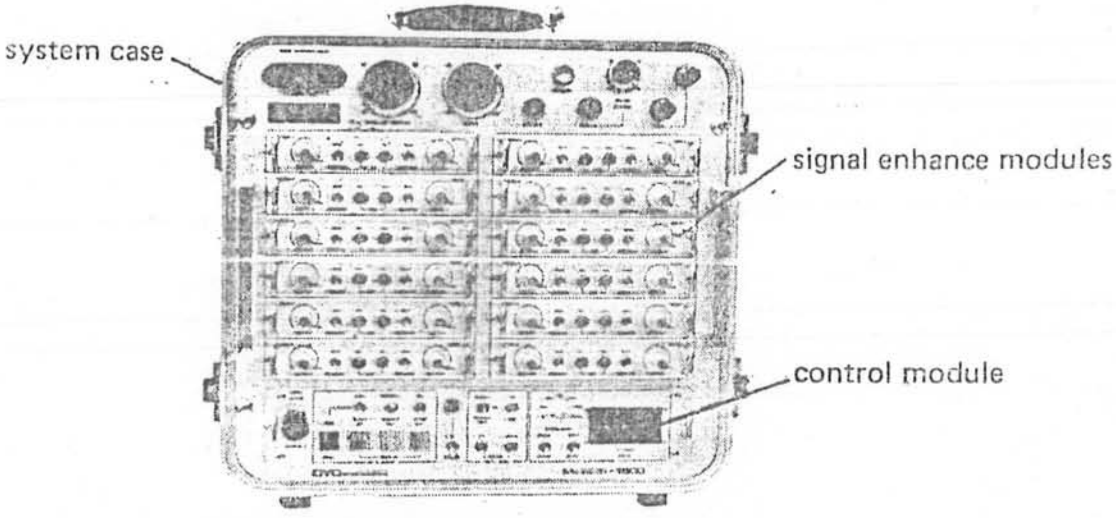
1. In this project, feild work was carried out using Japanese MC-SEIS: 1500 model computerized shallow seismic refraction instrument of the Department of Earth Sciences Quaid-i-Azam University, manufactured by OYO corporation. This instrument has the recording capacity of 24 channels with the distinction of computerized floppy disk recording as well as playback. This Mc SEIS-1500 system consists of four separately portable units :-

1) Amplifier Unit (Model-1182)
2) Signal Enhance Unit (Model-1197 -B)
3) Display Unit (Model_1216 A)
4) Processing Disk Computer Unit(Mosel-5744)

Working functions of each unit are described below :-

4.1.1 AMPLIFIER UNIT :-

This unit has 24 amplifier i.e. one amplifier for each geophone channel this amplifier unit amplifiers the input seisnil signals received from the field geophones. Its component channels are of multi-stage type and can have variable gain upto a maximum of 140 db (decibels). An amplifiers variable gain has to be kept low for its input from the geophone nearest to the shot


system case
signal enhance modules
control module

point and it is steadily kept higher for input from geophones located at increasingly higher Distances from the shot point. General rule is that amplification is kept lower for signals from near to shot point geophones and higher for signals from distant to shot point geophons this unit is inner-connected to the signal enhance unit.

4.1.2 SIGNAL ENHANCE UNIT.

Signal Enhance Unit like amplifier unit has following mai functional features:-

i) It may be connected to any seismic prospecting amplifier.

ii) It has seven "record length" ranges that can run from 50 to 5000 milliseconds.

iii) Trigger delay upto 9.99 second can be set if required.

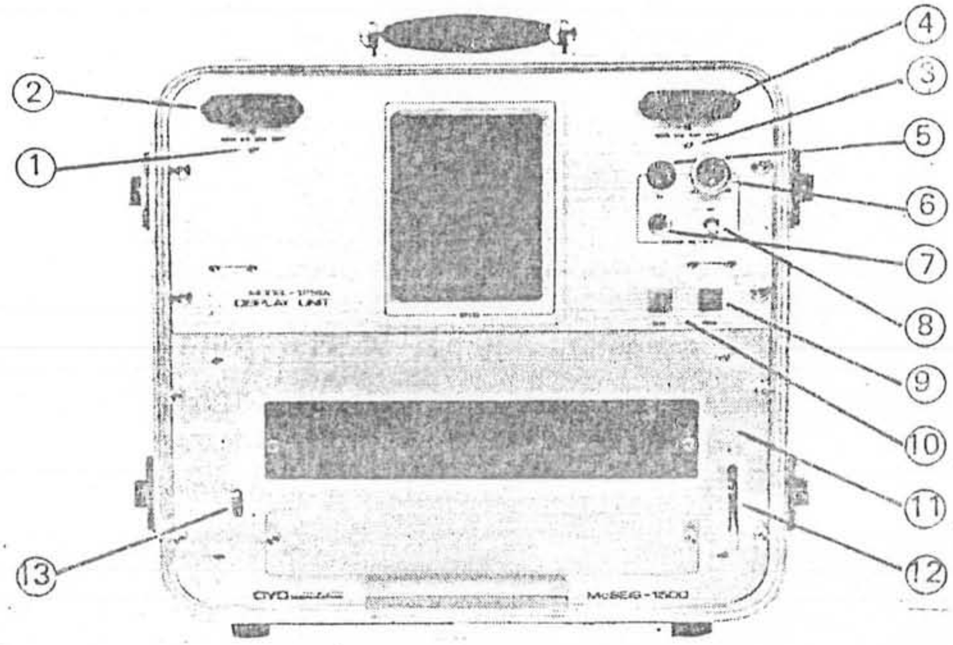
iv) Triggering may be done by hammer, switch or a shot mark from blaster or by GEOPHONE.

V) Data may be displayed in wiggle trace which helps in the identification of first refretion arrivals or in variable area traces, which is convenient for judging phase continuity.

vi) It also has a print record length selector Record length is approximately 23 cm for short print which was used for print refraction work and 42 cm for long print.

4.1.3 DISPLAY UNIT

This unit gives a visual display of data output from enhancement unit or the processing disk unit, thus



① DISK LED
② DISK DATA I/O
③ AMP LED
④ AMP DATA I/O
⑤ FUSE
⑥ POWER CONNECTOR
⑦ BATTERY MONITOR
⑧ POWER SWITCH
⑨ FEED
⑩ TEST
⑪ PRINTER PANEL
⑫ MANUAL FEED LEVER
⑬ PAPER FEED LOCK LEVER

permitting instant checking of data quality at the shooting site in the field. Additionally this unit has an in-built high resolution thermal printer that provides exceptionally good quality seismogram hardcopy.

FEATURES OF DISPLAY UNIT.

Following are important features of display Unit :-

i) It has a wide band and a highly stable CRT screen which provides good wave form display

ii) The high resolution (60dot/minute) of ultra high speed thermal printer gives sharp, clear and hard copy of the recorded seismogram.

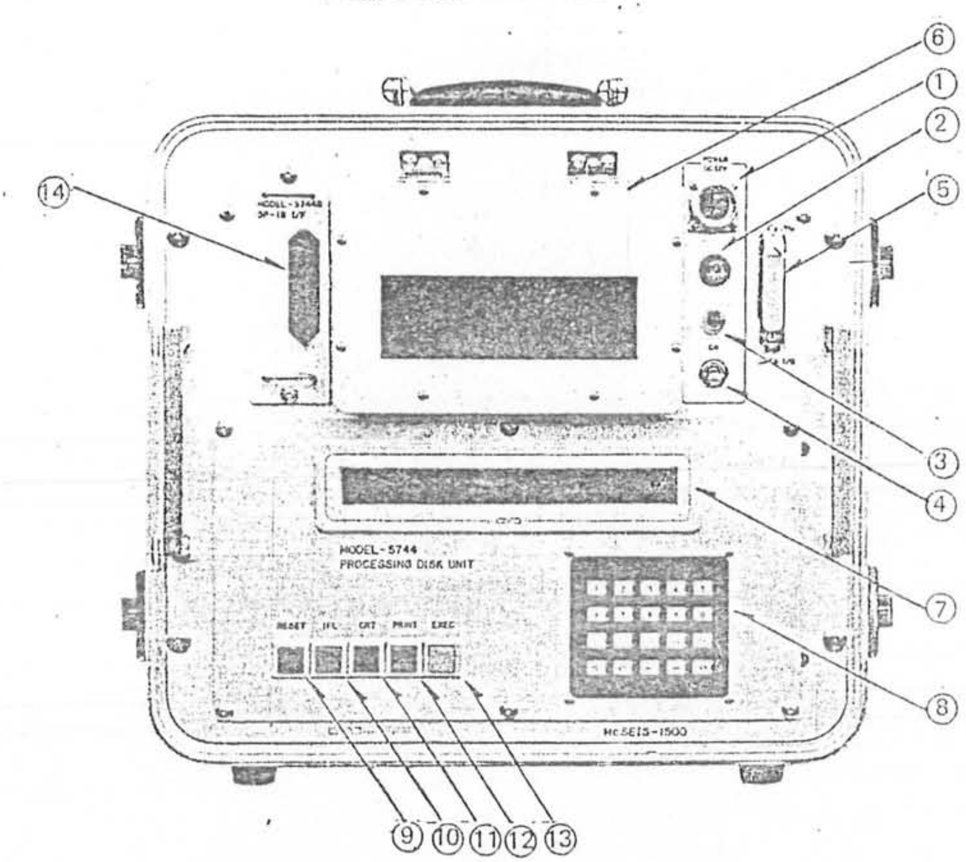
iii) For ease of data processing, parameter values such as the measuring conditions, including record lengths, delay time, timing line and number of stacking are printed at the top of head copy.

iv) This unit with all these features is still low in power consumption.

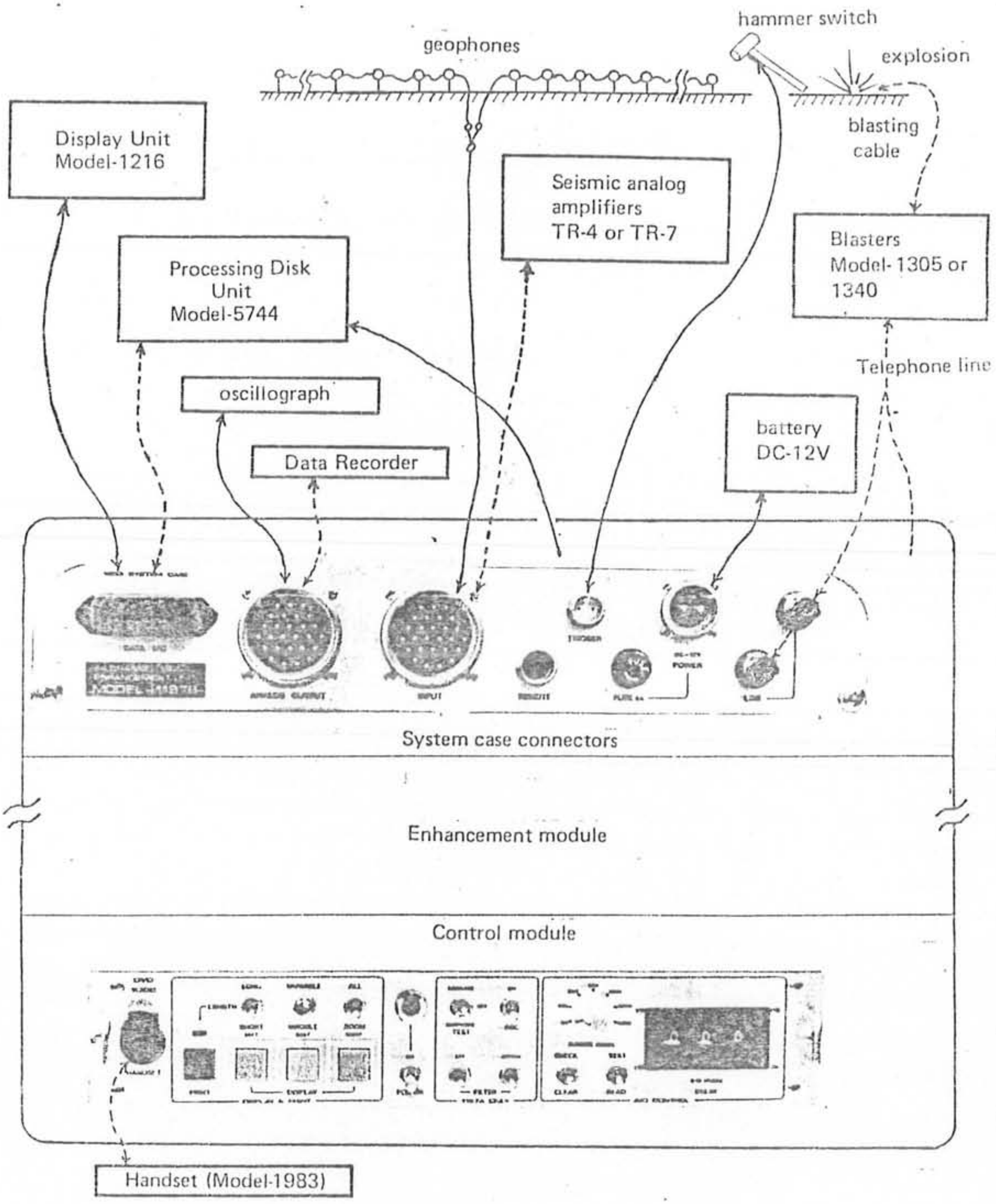
v) It is small, light and portable and easy to operate in the field.

4.1.4 PROCESSING DISK UNIT.

This unit is a digital unit used to write and
data
process the recorded field/option programmes soft- ware for data processing, stocking and filtering are



① POWER CONNECTOR
② FUSE
③ POWER MONITOR
④ POWER SWITCH
⑤ DATA I/O
⑥ FLOPPY DISK DRIVER
⑦ LCD MONITOR
⑧ PROGRAM KEY BOARD
⑨ RESET SWITCH
⑩ IPL SWITCH
⑪ CRT SWITCH
⑫ PRINT SWITCH
⑬ EXEC SWITCH
⑭ INTERFACE MODULE


hammer switch
geophones
explosion
blasting cable
Display Unit Model-1216
Seismic analog amplifiers TR-4 or TR-7
Blasters Model-1305 or 1340
Processing Disk Unit Model-5744
Telephone line
oscillograph
battery DC-12V
Data Recorder
System case connectors
Enhancement module
Control module
Handset (Model-1983)

available for this unit. Thus in conjunction with signal enhance unit and display unit not only can undertake digital recording, but also a variety of other data processing operations at the field shooting site can be performed permitting evaluation of the recorded field data immediately at the site.

FEATURES OF DISK UNIT.

i) Data is recorded on easy to use 5.25" data can be instantly recalled at the shooting field site using the display unit and enhance unit.

ii) An eighty character LCD (Monitor) provides message at every step of operations that gives clear directions for the next step.

iii) Standard interface (GP-IB) connector permits later readout of data recorded on floppy disk by external computer and thus computer data processing after the field work can be undertaken.

iv) Its small size and light weight ensure easy handling and portability in the field.

4.2 GEOPHONE.

It is an electromechanical device which converts mechanical energy into electrical current. Thus a geophone converts the vertical ground vibrations (incoming refraction signals) to electrical signals. Geophones, however, are characterized by their frequency responses. In general the natural frequency of various geophones are usually in the range from 1 to 45 Hz. For seismic refraction prospecting geophone, however, this frequency response should be from 1 to 10 Hz. Hence a refraction geophone and a reflection geophones distribution is made on the basis of its frequency response characteristics Modern geophones have high sensitivity, yielding an out put of 0.5 to 0.7 volts per 10 m/sec velocity of the ground motion.

Nearly all the geophones used for the present refraction work were of the "Moving-Coil Electromagnetic" type. In this type there is a permanent magnet in the form of cylinder into which a circular slot has been cut in such a way that the slot separates the central south pole from the outer annular north pole.

Geophone is planted in vertical position on the ground so that when the ground moves vertically, the magnet moves with it in exact copy and the static coil interacts with the moving magnetic field to generate a voltage between the terminal of the coil. The out put voltage of geophone is then directly proportional to the strength of the input signal.

4.3 SEISMIC CABLE.

The input signal from a geophone is transmitted to the recording system by means of a specially designed seismic cable. Two sets of such cables Model-1417 manufactured by O Y O Corporation Japan were used during the present seismic field work. Each cable has 12 "take-outs" at 7 meter distance from each other. Each geophone enplaced on the seismic field profile is connected to one of these take-outs in a planned manner.

4.4. ENERGY SOURCE.

Because of the non-availability of a "geleginte - detonator" source, 10 Kgm. hammer was used as the energy source. This hammer has a sensor transducer connected to it so that when we strike the hammer vertically on a metalic plate placed horizontally at the shot point location on the ground the mechanical energy of the hammer impact is converted to an electric pulse, by this sensor transducer which is connected to the amplifier unit. Thus the shot instant is recorded by the refraction recording system as the hammer impact time.

CHAPTER 5

FIELD PROCEDURE AND DATA ACQUISITION

CHAPTER NO.5.

FIELD PROCEDURE.

5.1 FIELD PLANNING.

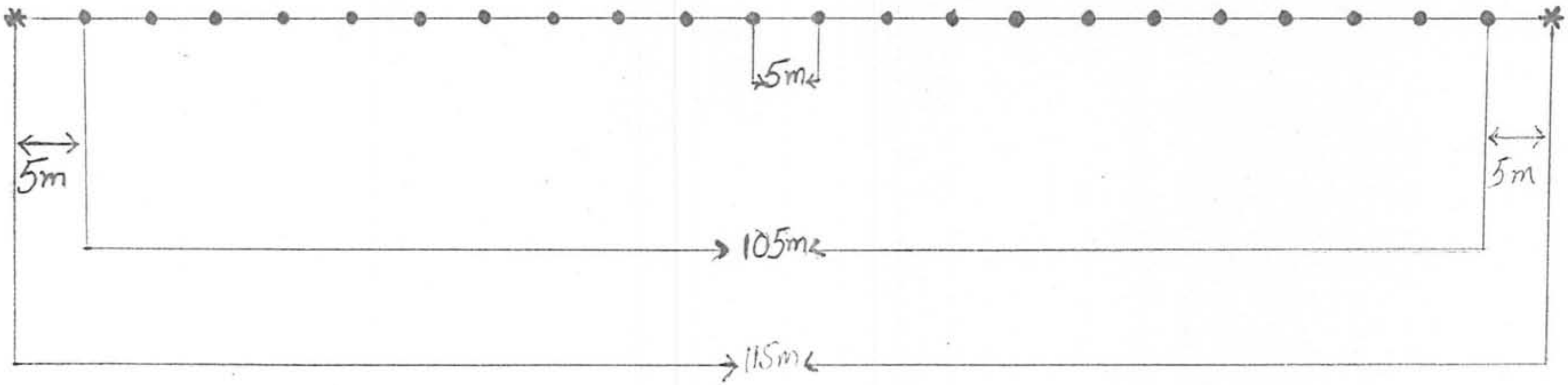
The object of the present survey being to map the velocity distribution in weathered and sub-weathered zones and correlate it with the subsurface lighology of the project area.

To achieve this objective of the survey six crossed refraction profiles were laid. Reversed refraction shooting at each of the six profiles was undertaken. Based on initial experimental work using varied shooting parameters such as off set distance and geophone to geophone distance. The following (5.1) refraction profile geometry was adopted to complete field work:-

5.1.2 REFRACTION SHOOTING PARAMETERS.

1) Project area	Tarlai Khurd
2) Location map used	Islamabad & surrounding
3) Scale of the map	1:50,000
4) Geological method used	Seismic Refraction method
5) Instrument used	Mc Seis - 1500
6) Shooting scheme	Reversed shooting
7) Spread length	110 m
8) Off-set distance.	5 m
9) No. of geophones used	22
10) Inter-geophone distance	5 m
11) Energy source	10 Kg Hammer impact through a steel plate placed horizantally at the shot Point.

Geophone Geometry



● $G_1, G_2, \ldots G_{22}$ = Geophones

* = Shot points

Fig. 5.2

5.2 REFRACTION SPREAD LAYOUT SCHEME.

To achieve the objectives as outlined above six cross refraction profiles (spreads) were laid. Out of these four were parallel to each other and two were perpendicular to them i.e. crossing them (fig 5.2) Relevant details of these profiles are as under:-

Profile No.	Orientation	Total spread length(m)
SP.1	N.S.	110
SP.2	N-S	105
SP.3	E-W	105
SP.4	N-S	105
SP.5	N-S	110
SP.6	E-W	105

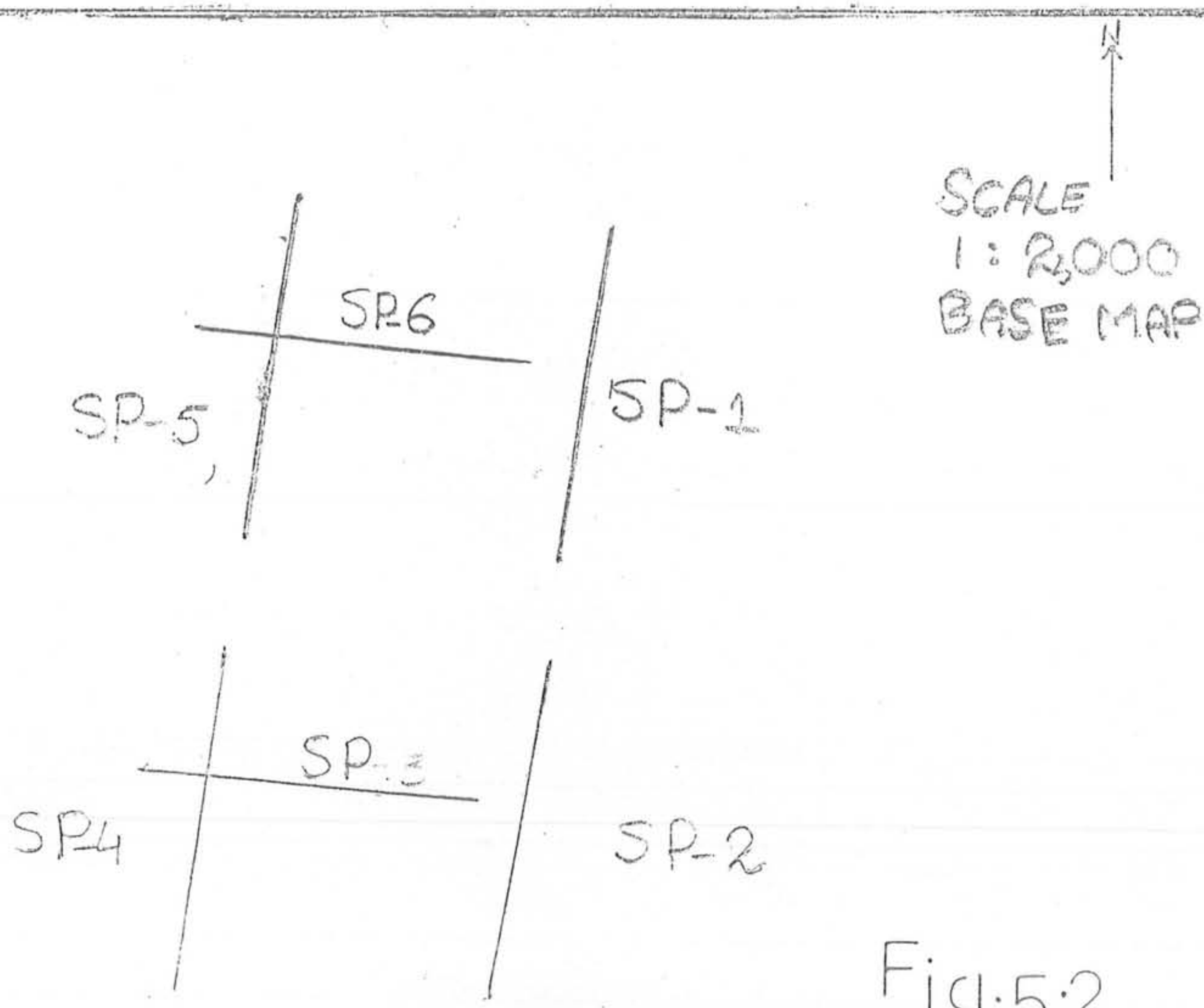
Total spread length is the distance between the shot point and last geophone on the spread line.

5.3 SEISMIC REFRACTION DATA RECORDING PROCEDURE.

Seismic refraction field data recording on Mc Seis-1500 seismic prospecting was conducted as follows:-

All the four units of Mc Seis - 1500 system were connected and all the initial controls were adjusted following the procedure described in the manufacturer's manual.

Thus on power to dispaly unit, enhance unit and seismic amplifier respectively and then on power to processing disk unit in the last. When the heavey hammer



Fig·5·2

stroke on the metal plate at a shot point position. The trigger signal was received from the hammer switch and deep tone sound was produced by the system.

The ground vibrations detected by the geophones were recorded in the memory of signal Enhance Unit and displayed on the CRT screen of display unit in wiggle form.

The quality of recorded data displayed on the CRT screen was checked, whether the first breaks are visible for each trace or not. If not then the shot was repeated for the same spread. The data displayed on the CRT screen was recorded on the floppy disk in the processing disk unit (The disk must be initialized in this unit before recording) for further analysis by a simple key board operation.

The hard copy of waveform data with parameters such as ID.NO., Range (m sec) Delay time and timing line may be printed out when we press the print out switch of the Signal Enhance Unit. Printing stops when the switch is pressed second time.

After recording data on disk, clear the memory of the unit by pressing test and clear switches simultaneously for next shot point.

5.4 PRECAUTIONS.

While recording a seismic data it is essential to observe certain field precautions to ensure maximum S/N ratio.

1) There must be no movement of persons, animals or vehicals in the vicinity while taking a seismic record.

2) Geophones must be planted vertically in the field and properly tamped.

3) Geophones must be located on compact ground to ensure scattering of the increasing signal, before reaching the geophone, in the loose ground.

4) Metal plate must be fully and horizontally in-contact with the carefully prepared at the shot point.

5) Sensor trigger switch must be properly attached to the hammer so that the shot instant is correctly picked by the sensor.

6) All the connections of the instruments and power supply unit must be tight and clear.

7) All the component units of the instrument must be properly connected using correct and designated cables as laid down in the manual.

8) In case of bushy or grassy field conditions of the shooting should be avoided on a windy day. As this would increase the noise component of the geophone pick up and its relative S/N ratio will deteriorate.

CHAPTER 6

REFRACTION FIELD DATA PROCESSING

CHAPTER NO.6.

REFRACTION FIELD DATA PROCESSING

6.1 INTRODUCTION.

Seismic Refraction data in the field was recorded in the form of Refraction "Seismograms". Seismograms are generally the wiggly traces lined parallel to each other on the recording paper(fig.6.1) Each trace represents the recorded arrival time for its respective refracted wave. To convert this travel time data in conjunction with the shot point & geophone spread geometry into the number of layers investigated and their characteristic velocities which in turn are correlated into their characteristic subsurface lithological set up is the main objective of seismic refraction data processing.

First the processing of field data was done manually and then on the Hewlett Packard (Model-216) personal computer of the Department of Earth Sciences, Quaid-i-Azam University, Islamabad, so as to achieve comparable maximum accuracy. The major steps involved in the processing of seismic refraction data are briefly described as below:-

i) Picking of 1st arrival from the "Seismograms".

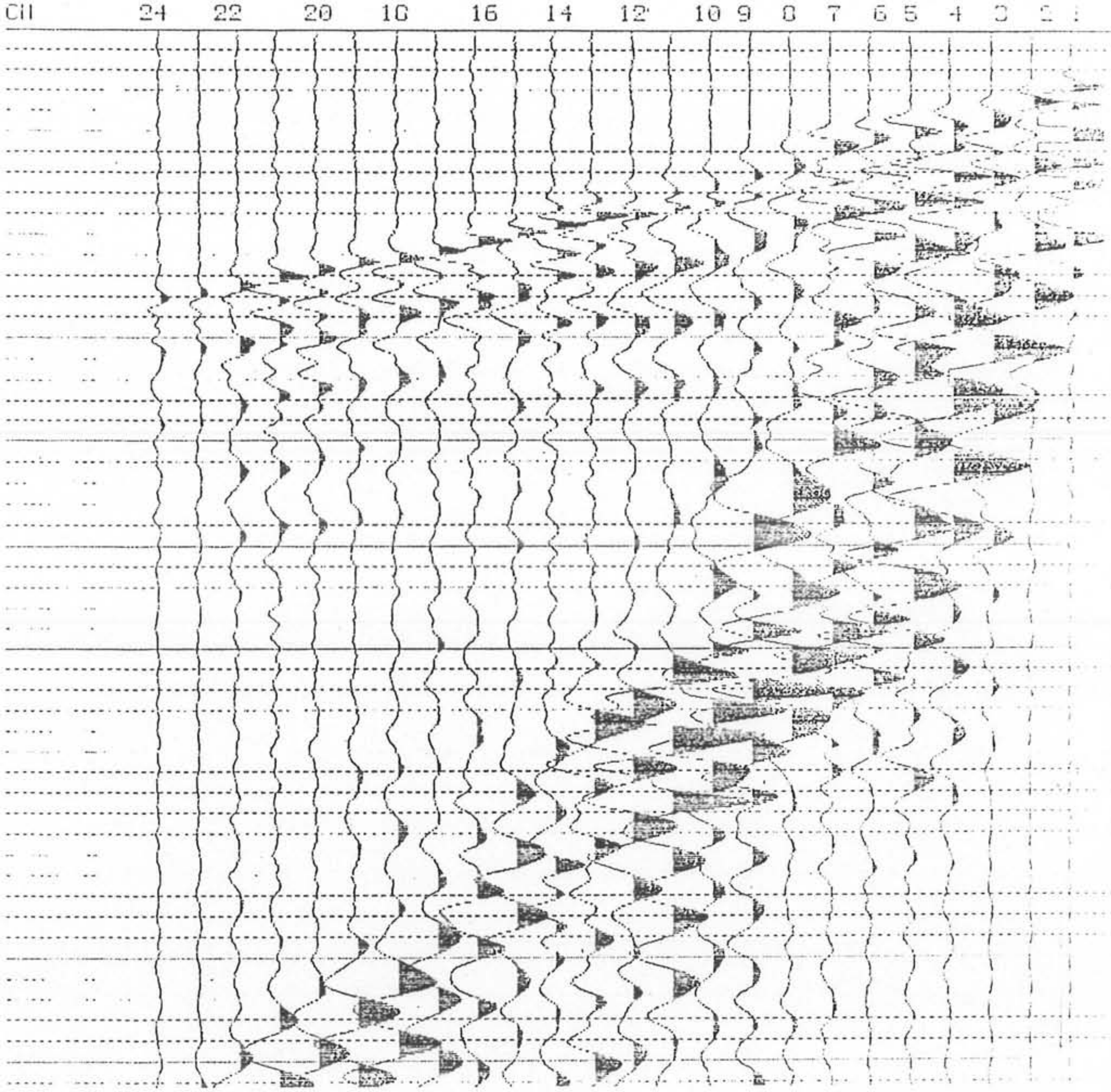
ii) Plotting of these picked refraction travel times versus the distance. from the shot point to respective geophones so as to obtain "Travel Time Curus" using least Square line fitting.

iii) Manual as well as computer processing of the travel time curves was meant to eventually yield (i) no of layers picked, (ii) updip and downdip velocities of each refractor from which (iii) to calculate depth below shot point and (iv) the dip angle of the refractor. This dual (Annual and Computer) processing, thus yielded the interpreted plot of the velocity model along with its travel time curve (T-X graph) which generated it. From these dually processed data results were tabulated for comparative study showing computer results besides the manual results (Table . 7.1). Also following maps were prepared (a) Iso-velocity map of Vo. (b) Iso-velocity map of V1. (c) Iso-Pach map of Ho (d) Iso-dip map of Θo.

6.2 PICKING OF FIRST ARRIVAL.

Refraction arrivals were identified as first breaks on the seismogram as illustrated in fig. 6.1. Seismic refraction record (seismogram) actually comprised of 24 wiggle traces. Each trace is scaled by a time line perpendicular to the trace at 10 milliseconds regular interval. Thus refraction first breaks were read at 23 traces corresponding to 23 geophones respectively. The first break at the 24th/11 trace located at the bottom of the seismogram shows the recorded the hammer instant as the shot instant. This was taken as zero time for reference in calliberating the time break read outs of the 23 refraction first breaks. (Fig 6.1). Thus all the refraction travel-times on the

ID.NO. 034
STACK COUNT 01
RANGE 500 msec
DELAY TIME 0000 msec
TIMING LINE 10 msec/line



OYO McSEIS 1500 Ver1.1

FIG: 64 SEISMOGRAM

seismogram were scaled for total travel times with respect to this time break.

6.3 PLOTTING OF REFRACTION TRAVEL TIME CURVES.

After having picked the 1st arrival time at each geophone on the refraction profile a plot of these (Travel times) versus distance from shot point to each corresponding geophone was drawn. For these T-X graphs travel times were respectively plotted along Y-axis and the distances of respective geophones from the shot point along X-axis. The plotted points clearly exhibited linear alignments each of differing slopes. The number of such linear alignments with differing slopes constituted the no. of layers mapped. Thus a T-X curve eventually slopes itself as comprising of a no. of straight line section with each straight line-representing a layer.

The T-X graphs for each refraction spread reversed shooting data were plotted manually as well as on the computer. The time scale was plotted in milliseconds on Y-axis whereas the distance scale was plotted in meters on X-axis.

6.4 CALCULATIONS OF REFRACTION VELOCITIES.

For each straight line section of the travel time curves the reciprocal of its slope gives the apparent velocity of the layer it represents:-

Thus the apparent velocity of a refractor =

1/slope of its T-X graph line.

As reverse refraction shooting technique was adopted in the field so for a single shot point geophone spread lay out two travel time curves(one for forward shooting and the other for reverse shooting) were obtained. Thus for each single layer updip and downdip velocities were obtained. Using these two velocities true velocity of the layer was computed using the following formula:-

$$\text{True velocity of nthlayer.} = Vn = \frac{2\ Vnu\ Vnd}{Vnu + Vnd}$$

Where Vnu = Updip velocity of nth layer

Vnd = Downdip velocity of nth layer.

From these velocities the dip angle of the first refractor was calculated:-

$$\text{Dip angle} = \Theta o = \tfrac{1}{2}\left(\sin^{-1}\frac{Vo}{V1u} - \sin^{-1}\frac{Vo}{V1d}\right)$$

Where Vo = True velocity of 1st layer

V1u & V1d are the updip and downdip velocity of the 2nd layer respectively. For preparation of Ido-velocity maps, true layer velocities were used.

6.5 CALCULATION OF REFRACTOR DEPTH.

Two types of refractor depths are computable viz. The depth from shot point to the refractor/in perpendicular direction Z1u & Z1d and the vertical depth from SP to refractor in vertical direction H1u & H1d. These depths were calculated wing the following formulae.

$$Zu = \frac{Vo\ Tu}{2\ Cos\,ic} \qquad Hu = \frac{Zu}{Cos\ \theta o}$$

$$Zd = \frac{Vo\ Td}{2\ Cos\,ic} \qquad Hd = \frac{Zd}{Cos\ \theta}$$

$$ic = \tfrac{1}{2} \quad Sin^{-1}\ \frac{Vo}{V1u} \quad + \quad Sin^{-1}\ \frac{Vo}{V1d}$$

Where Zu & Zd are P updip and downdip perpendicular depths respectively and Hu and Hd are vertical updip and downdip depths respectively. Tu & Td are updip and downdip intercept time respectively. Vo and V1 are velocities of 1st and 2nd layer respectively. A straight line of a travel time curve segment when projected backward so that it cut Y-axis then the intercept so made on Y-axis represents the "Intercept-time" value for that refractor.

6.6 DATA PROCESSING PROCEDURE BY HEWELT PACKARD MODEL-216P.C:

The refraction data was processed on Hewlett Packard model-216 personal computer using "Mc-seis soft ware" entitled "HPS-13, simple Refractor". This computer programme is designed to process the refraction seismogram travel time data and produce the reverse shot travel time curve. At the same time it eventually produces the velocity depth section.

This software works as under:-

After booting the system, the programme is inserted in the disk drive and is loaded into the main memory of the computer. After programme activation series of relevent informative question are serially asked viz:-

1) Curve type (one way OR reciprocal i.e reverse shot).
2) Maximum no of geophones used in the spread.
3) Off-set distance.
4) Is geophone spacing (Y/N).
5) Intergeophone distance.
6) Travel time (milliseconds) for each geophone.

Once all these questions are properly answered as input data, the computer then undertakes the plot of (distance, travel times) co-ordinates on theCRT in the shape of crosses. The computer then draws a "Best fit" straight line through these crosses. A similar procedure was adopted for the data of the reverse shooting. After completion of this stage the computer is instructed to run the programme and after compiling it provided the following results:-

1) Velocity of layers in Km/sec.
2) Depth to the refractor in meters.
3) Dip angle of the refractor, if any, If the above parameters and the plotted travel time graph are found satisfactory then the computer is commanded to plot the model alongwith the results on a plotter. connected to the computer.

6.7 ACCURACY OF THE RESULTS.

A number of errors may crop/up at both recording as well as the processing stage which may effect the overall occuracy of the computed results error discussed below.

6.7.1 Recording Errors.

During the field work the following errors may yield on erroneous seismic record:-

a) Location Error.

When geophones are not vertically planted and properly tamped, then the incoming signals energy in the vertical direction resolves itself in two directions, one along the inclined geophone axis & the other in a vertical direction to it and [illegible] lost. Thus the quality of acquired data is affected. Also improper tamping means loose ground and geophone contact and the scattering loss of the incoming signal. This error was minimized by carefully planting the geophones vertically and firmly into the ground and tamping it subsequently.

b) Traffic noise.

When the shooting points are located near the road or imhabited or industrially active areas then S/N ratio depletes considerably because of increase in input noise component. This can be avoided however by relocating Sp's to less or no noise areas or shooting at a time when Noise is the least.

6.7.2 Processing Errors.

During data processing also a number of errors can creep in the data which by careful handling can be avoided or may be eliminated.

a) Observational Error.

While picking the shot instant and the first arrivals from various traces of the "Seismogram" errors may creep in their wrong estimation, especially from traces where the preaks are not sharp. This causes serious errors in further computation of interface depths and layer velocities. To minimize these observational errors first of all proper gain control of amplifiers and proper impact energy of the source was ensured so result in sharp time breaks.

b) Errors due to wrong in put at the computer Key board.

During data processing by computer, it was noted that wrongly typed/input data figures causes a major error in the interpreted results. So before in the execution of of any section of the software programme all data stored in computer memory was doubly checked.

CHAPTER 7

INTERPRETATION

CHAPTER NO.7

INTERPRETATION, DISCUSSION OF RESULTS.

7.1 INTRODUCTION

Interpretation of the processed seismic refraction data is based on the individual and intergrated study of the following maps and illustrations:-

1) Iso-velocity contour map (Vo), showing distribution of velocity (Vo) map No.7.1
2) Iso-velocity contour map (V1), showing the velocity distribution of velocity (V1) (map 7.2).
3) Iso-Pach contour map (Ho), showing the distribution of Ho (map No.7.3).
4) Iso-dip contour map (Θo), showing the distribution of the dip (Θo), (map No.7.4).

The interpreted velocities of 1st, 2nd and 3rd refactors ranges from 320-540 m/sec. 1600-2270 m/sec and 2650-3740 m/sec. respectively. These ranges of velocities have been correlated with the existing subsurface lithological set up in the project area as under:-

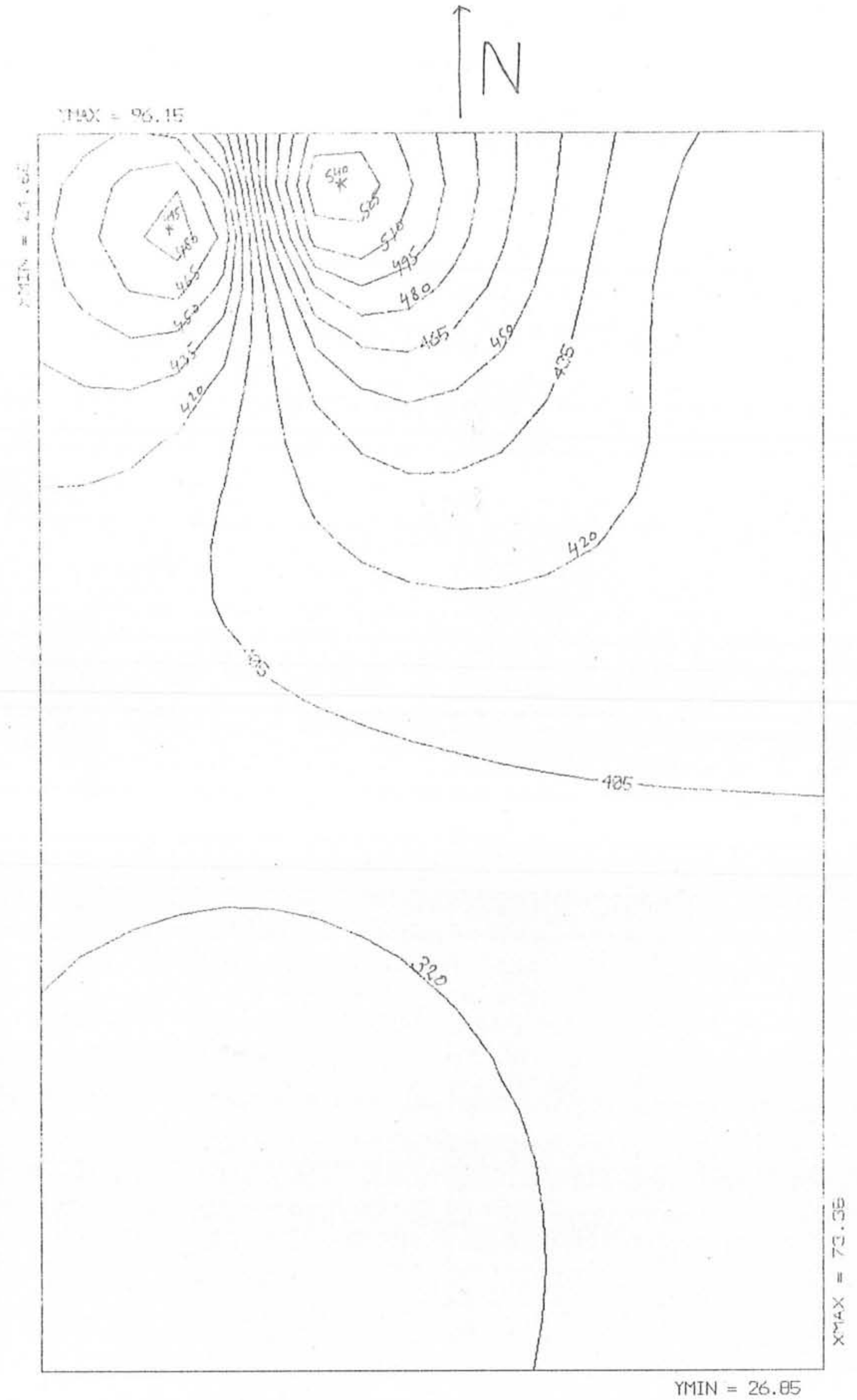
Velocity range (m/sec)	Correlated Lithology
320-540	Weathered layer/Quaternary clay, silt & shale.
1600-2270	Friable sandstones with clayey and shaley intercalation and moisture impregnation.
2650-3740	Differentially compacted sandstone.

7.2 INTERPRETATION OF ISO-VELOCITY MAP(Vo):

The velocity distribution in the first layer is mapped and illustrated in the form of Iso-Velocity(Vo) contour map with the contour interval of 15 m/sec. The velocity(Vo) in the first layer ranges from 320-540 m/sec. It increases steeply towards the northern portion of the map forming two dipolar peaks. Its lithological correlation thus yields dominance of sandy unconsolidated sediments in the north which changes to silty, shaly and eventually to clayey nature as we move towards the south. Thus whereas a dominent portion of the Southern half of the area is covered by clayey The northern portion has predominance of Sand.

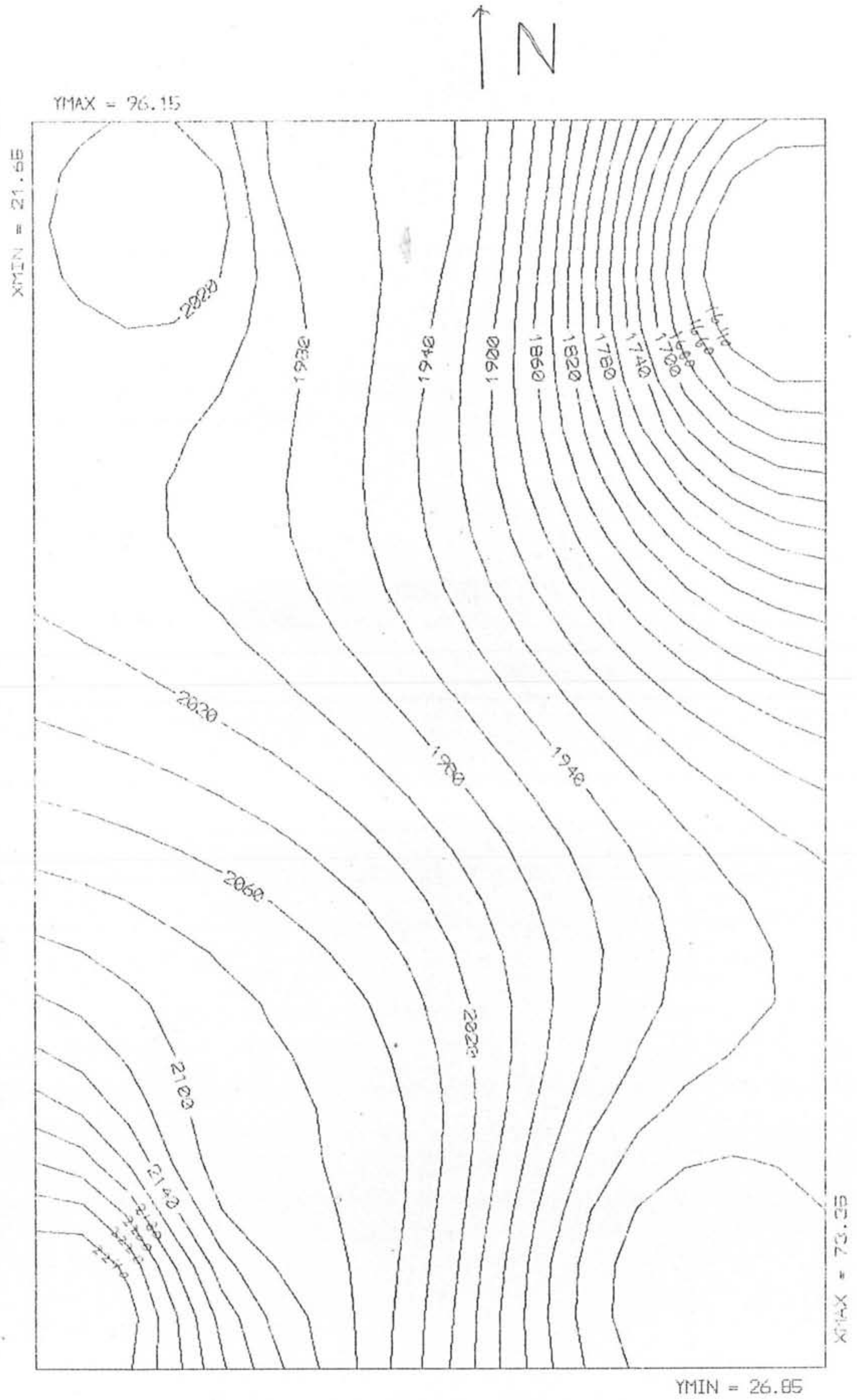
7.3 INTERPREATION OF ISO-VELOCITY (V1) MAP.

The Iso-velocity (V1) contour map shows the distribution of velocity in the 2nd layer which is the subweathered layer. The contour interval of this map is 20 m/sec. The velocity range is 1600-2270 m/sec. This is interpreted as characteristic of friable Sandshone with clayey and shaley intercalations in which at places moisture or water saturation may be present. The contour map shows distinctly higher velocity forming in the left half of the map which gradually tapers to the lower velocity zone in the right half. within the velocity range of 1600-2270 m/sec. in this subvreathed layer. Particularly we have velocity maximum (2260 m/sec)



ISO-VELOCITY CONTOUR MAP (V_0)

Fig. 7·1



ISO-VELOCITY CONTOUR MAP (V_1)

Fig. 7.2

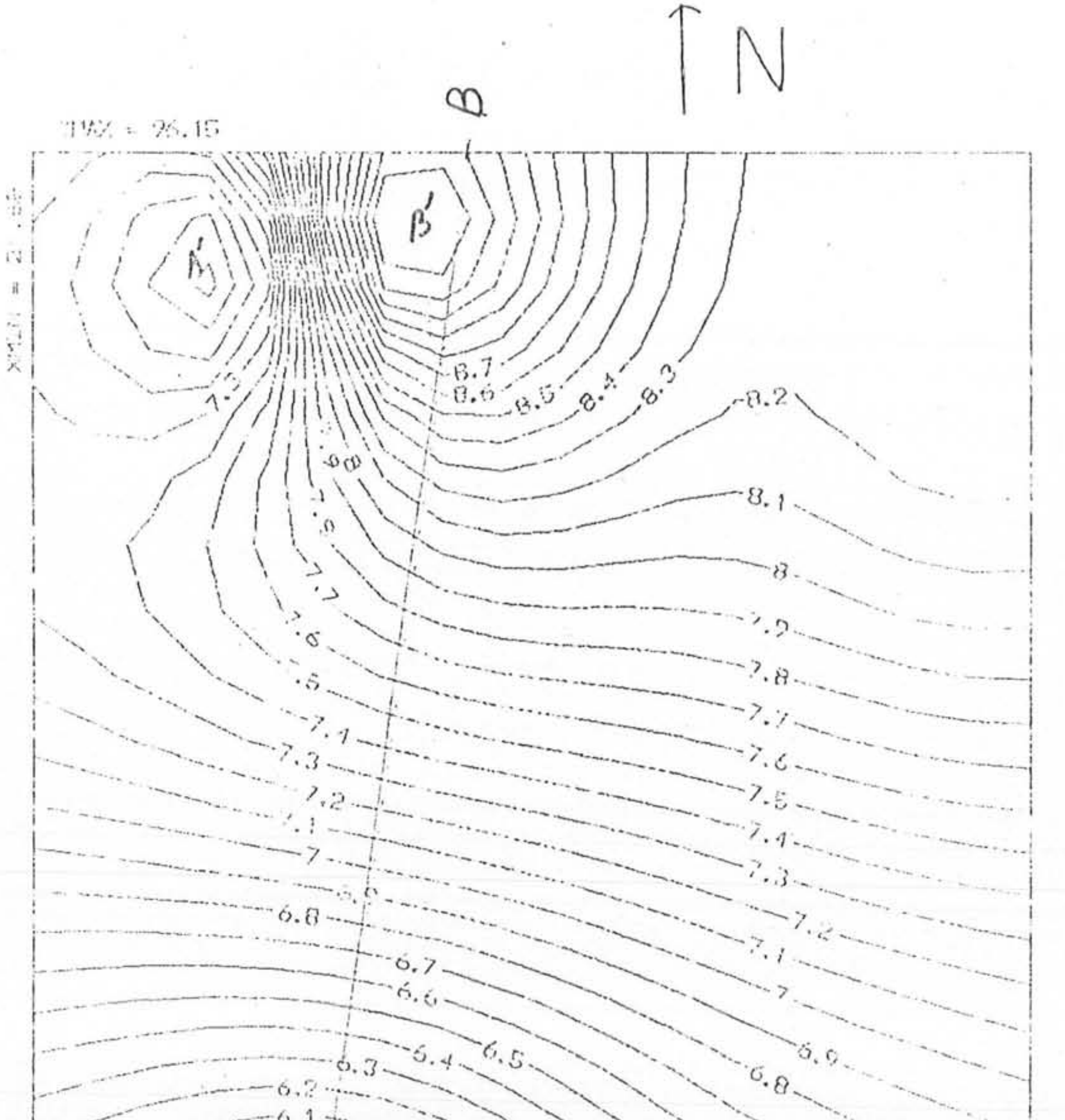
pitching in the South Western corner of the map and its minimum (1640 m/sec) pitching in the North Eastern corner. Thus generally the velocity in this 2nd layer varces from 2240 m/sec to 1640 m/sec along the NW-SE diagonal. Lithologically this may represent higher slayey and shaley in and ercalation within sandstone in the NE portion which becomes more cleaner as we reach its SW portion.

7.4 INTERPRETATION OF ISO-PACH CONTOUR MAP(Ho).

The Iso-Pach contour map for Ho (The vertical depth of the first layer) shows the variation in the thickness of the weathered first layer. The contour interval of this map is 0.1 m. This depth Ho varies from 5.4 to 10.4 m. The weathered layer thickness therefore is increasing towards the North and more prominently in the North-West portion of the map which is characterijed by two dipolar type maximum at A'&B'. In the southern portion of the areas the weathered layer is thinner which forms a circular peak with lowest value at pt. p.

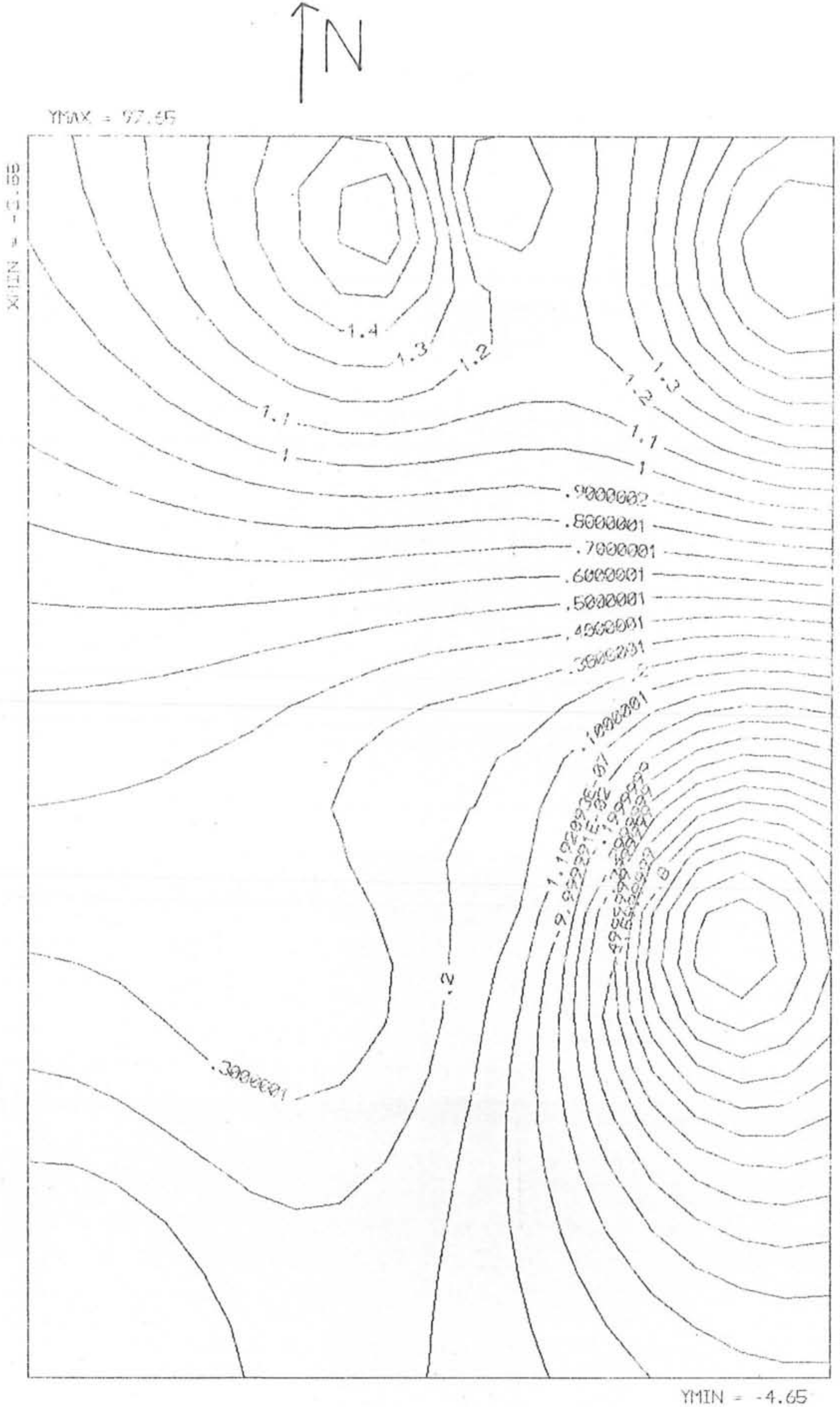
7.5 INTERPRETATION OF ISO-DIP CONTOUR MAP (Θo).

The map shows variations in dip of first and 2nd layer interface showing higher dip pattern in the northern and the central middle portion of th map, which means thickening of the weathered Layer in these portions. This conclusion conforms generally with the interpreted results of the first layer Iso-pach map as it should.



TSO-PACH CONTOUR MAP H.

Fig. 7.3



ISO-DIP MAP θ_0

Fig. 7.4

7.6 RESULTS.

The integrated study of the Iso-velocity, Isopach and Iso-dip maps in the context of velocity-cum-lithology correlation used for this interpretation, it is cancluded that:-

1) The restricted nature of energy generated by the seismic source (However weighting 10 Kgm) used only two layers could be generally mapped. Only at top places viz profiles SP1 & SP2 the third layer could be observed.

2) The general pattern of velocity and lithology interpreted for the project area is:-

320-540 m/sec	Weathered unconsolidated quatemery deposits of clay, silt, shale.
1600-2270 m/sec.	Friable sandstone with clayey intercalation
2650-3740 m/sec.	Differentially compacted sandstone

3) The first layer is the weathered layer with velocity ranging from 320-540 m/sec and thickness ranging from 5.4 to 10.4 m which generally attain higher values of both velocity and thickness in northern portion of the project area.

4) On the basis of only one 3 layer shot point data the thickness of the 2nd layer is estimated to be 21 meters, and velocity of the 3rd layer to be 4097 m/sec. This 3rd layer being high velocity layer is interpreted to represent compact clean sandstone.

5) In the 2nd layer the velocity ranges from 1600-2270 m/sec. which may represent friable sandstone with clayey intercelation in the lower velocity zone of this range of silty intercalation in their maximum velocity zone.

6) Although data processing has been done by hand as well as on the computer, however, only the computer processed results have been discussed.

COMPARISION OF MANUALLY AND COMPUTERIZED CALCULATIONS :-

Profile No.	Vo. (m/s)			VI(m/s)			V2 (m/s)		
	Computer ized	Manually	error	Computer ized	Manually	error	Comp uter ized	Manually	error
SP.I	410	410.0	-0.9	1600	1570.3	29.7	3740	4097.5	357.5
SP.2	400	405.3	-5.3	1690	1848.8	158.6	2650	2715.9	65.9
SP.3	380	377.4	2.6	2080	2189	109			
SP.4	390	393.5	3.5	2270	2372.7	102.7			
SP.5	320	317.4	3.6	2040	2038	2			
SP.6	540	582.3	42.3	1960	1909.7	50.3			

TABLE. 7.1

COMPARISON OF MANUALLY AND COMPUTERIZED CALCULATION

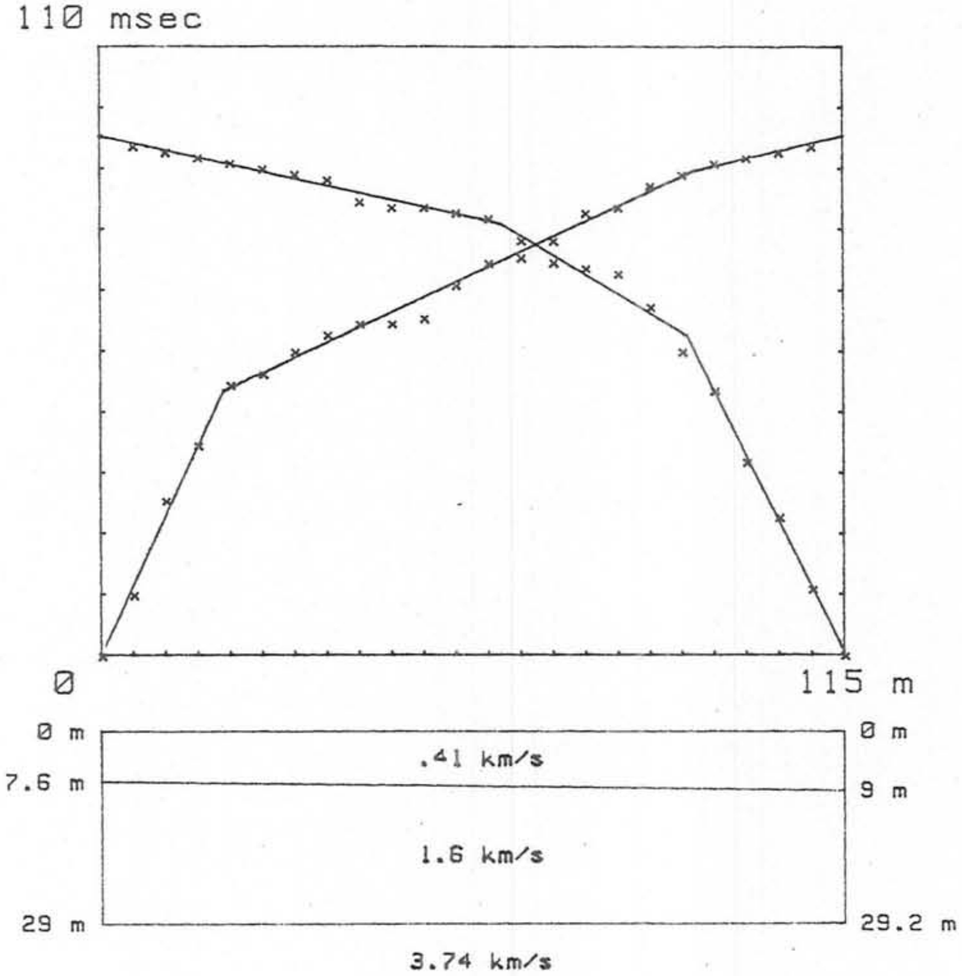
Profile No.	Ho(m)						H1(m)						Θo			Θ1		
	Computerized		Manually		Error		Computerized		Manually		Error		Compt.	Man.	Err	Compt	Man.	Error
	Hou	Hod	Hod	Hou	Hou	Hod	H1u	H1d	H1u	H1d	H1u	H1d						
SP.I.	9	7.6	7.87	8.9	0.1	0.27	20.2	21.4	19.8	23	.4	1.6	°54'	1°049'	5	-7° 18'	-6°	-1° 18'
SP.2	6.7	5.8	5.8	7.9	1.2	0	11.5	15.1	14.7	17.7	3.2	2.6	0°	58'	=58'	-5° 48'	6° 14'	26'
SP.3	5.4	5.3	5.6	5.9	0.5	0.3							12'	12'	0'			
SP.4	7.2	4.6	4.93	7.4	0.2	0.38							24'	16'	-42'			
SP.5	9.5	4.2	5.1	7.7	1.8	0.9							1°	1° 14'	-14'			
SP.6	10.4	8.4	7.42	11	0.6	0.98							1° 42'	1° 57'	-15'			

TABLE 7.2

APPENDEX-A

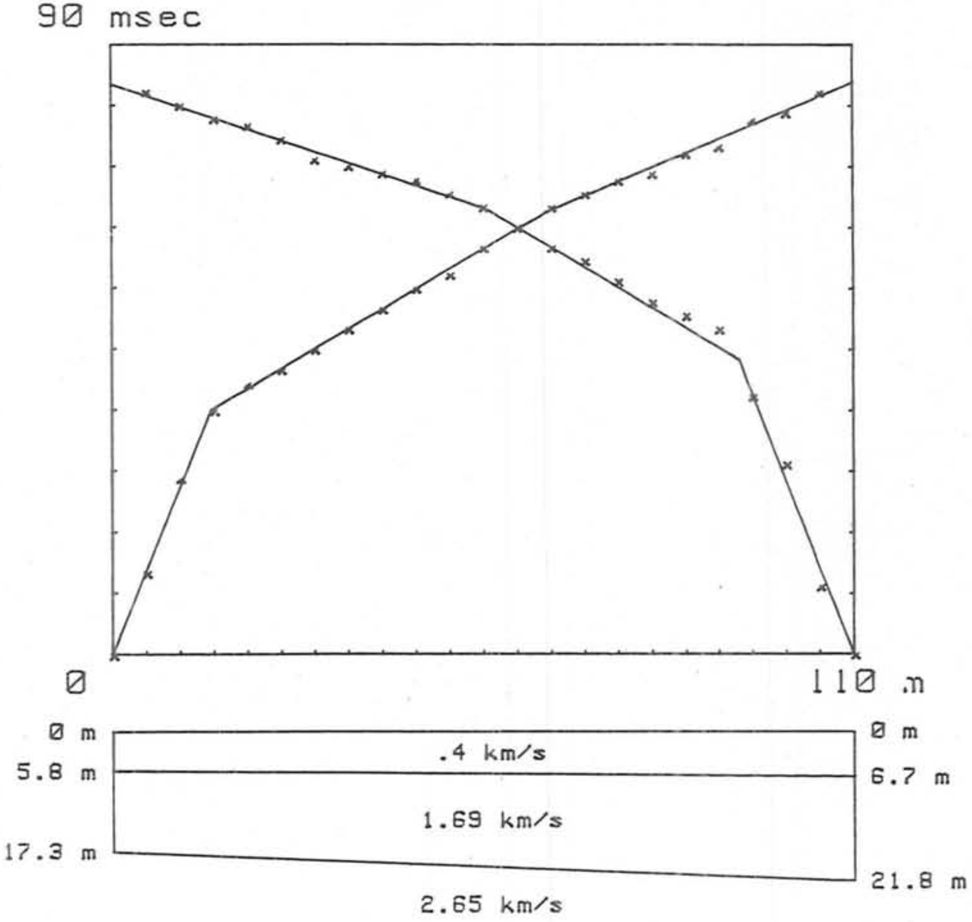
PLOTTING BY
HEWLETT PACKARD

SP-1



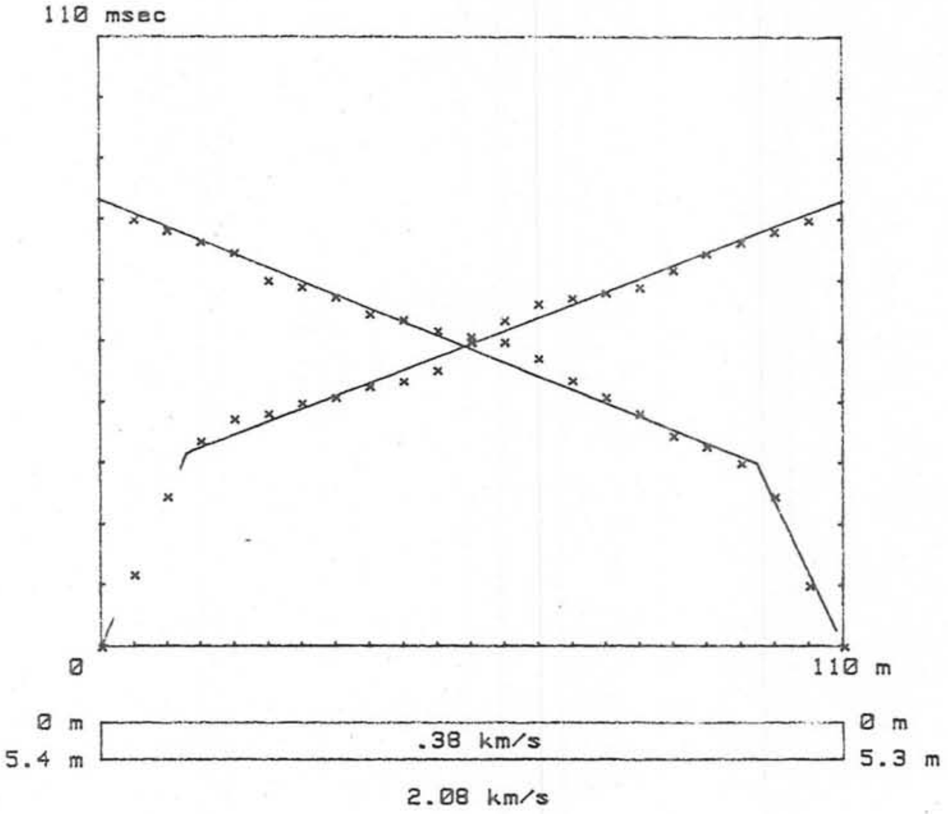
```
1st Layer
  V= .41 Km/s
  Zl= 7.6 m Zr= 9 m
  Dip12= 1.9
2nd Layer
  V= 1.6 Km/s
  Vl= 1.83 Km/s
  Vr= 1.43 Km/s
  Zl= 21.4 m Zr= 20.2 m
  Dip23=-7.3
3rd Layer
  V= 3.74 Km/s
  Vl= 3.65 Km/s
  Vr= 3.93 Km/s
```

SP-2



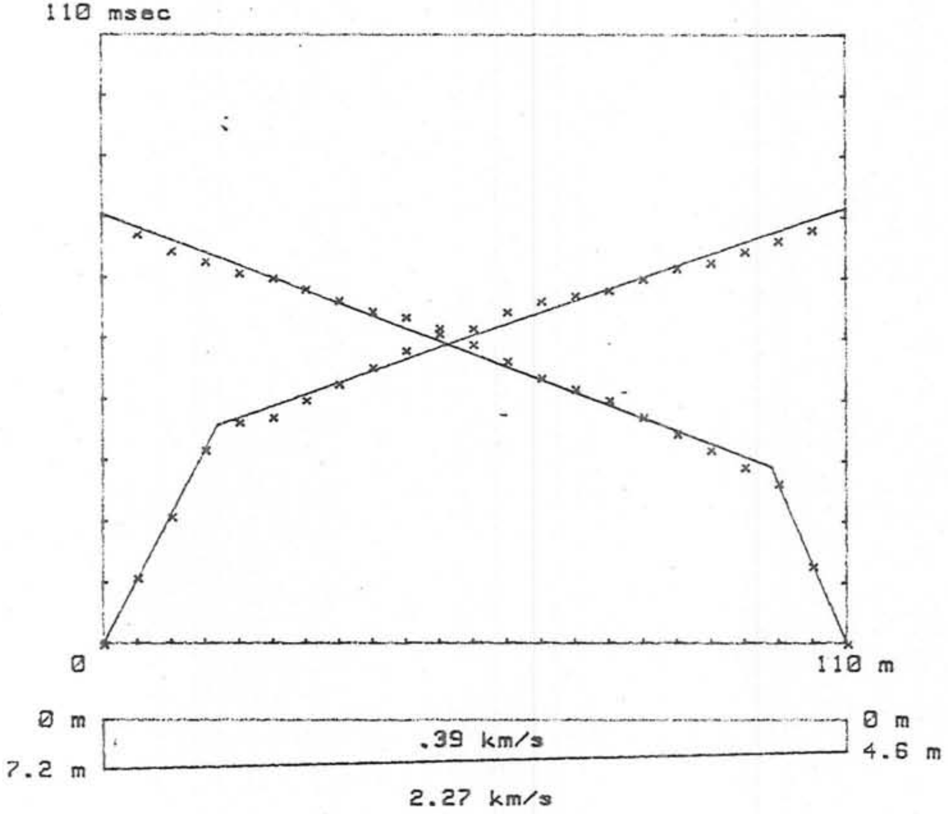
```
1st Layer
   V= .4 Km/s
   Zl= 5.8 m Zr= 6.7 m
   Dip12= 0
2nd Layer
   V= 1.69 Km/s
   Vl= 1.7 Km/s
   Vr= 1.69 Km/s
   Zl= 11.5 m Zr= 15.1 m
   Dip23=-5.8
3rd Layer
   V= 2.65 Km/s
   Vl= 2.38 Km/s
   Vr= 3.02 Km/s
```

SP-3



1st Layer
V= .38 Km/s
Z1= 5.4 m Zr= 5.3 m
Dip12= .2
2nd Layer
V= 2.08 Km/s
V1= 2.12 Km/s
Vr= 2.05 Km/s

SP-4



1st Layer

V= .39 Km/s

Zl= 7.2 m Zr= 4.6 m

Dip12= .4

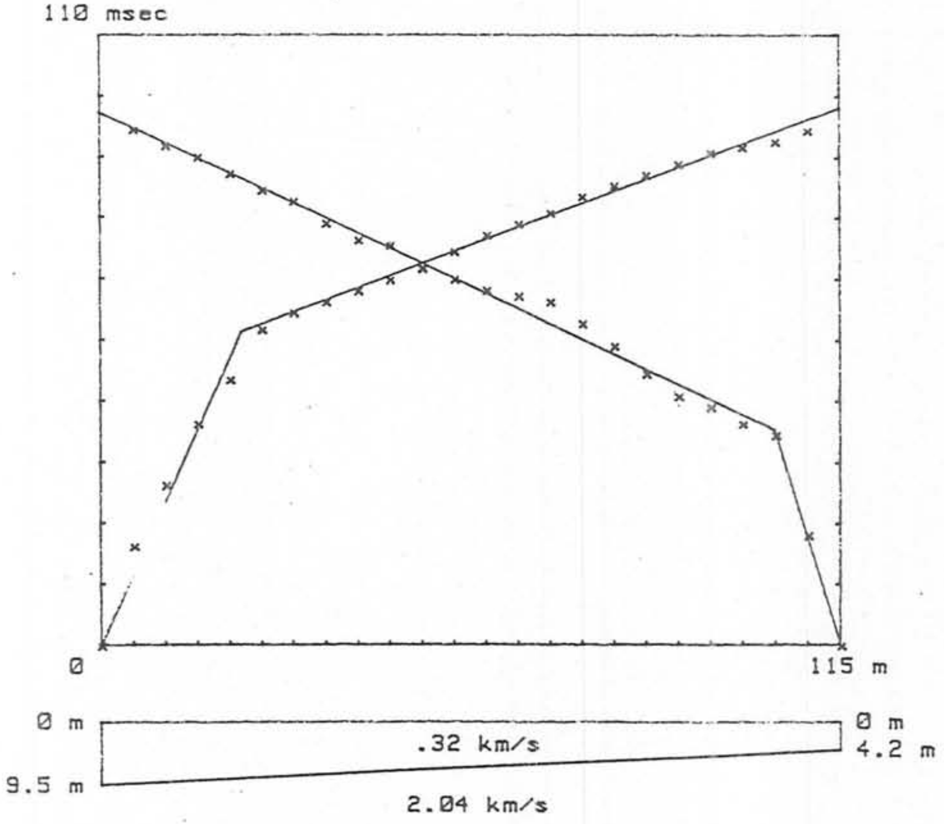
2nd Layer

V= 2.27 Km/s

Vl= 2.37 Km/s

Vr= 2.17 Km/s

SP-5



1st Layer

V= .32 Km/s

Z1= 9.5 m Zr= 4.2 m

Dip12= 1

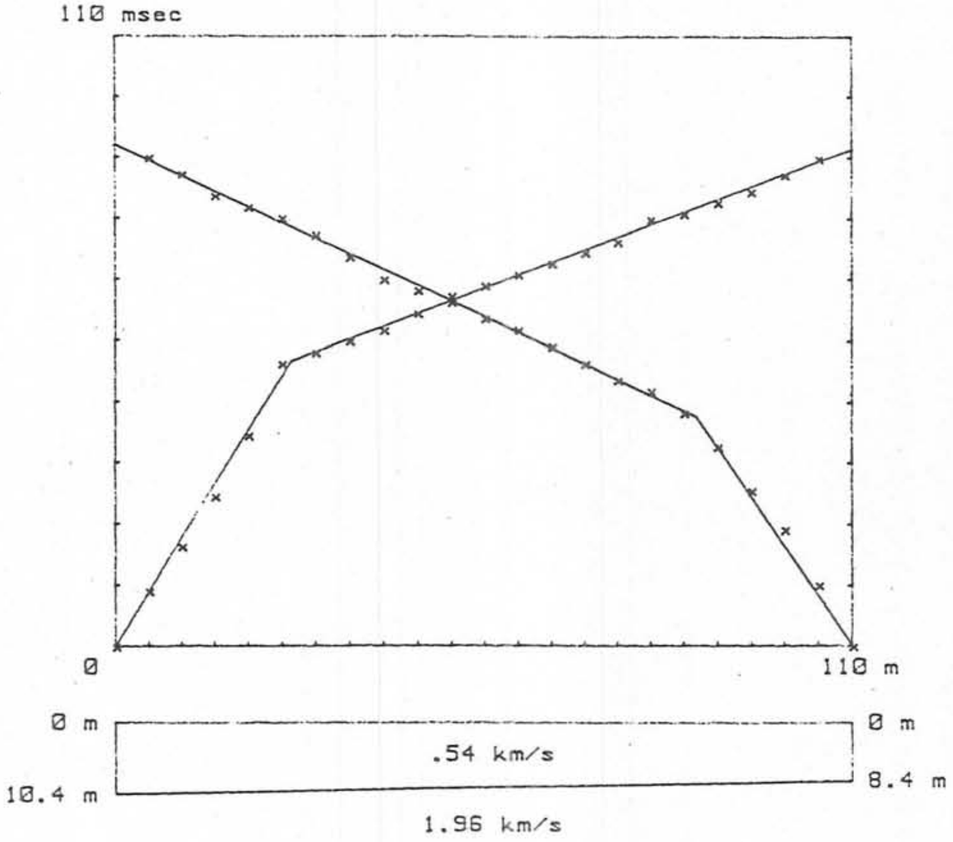
2nd Layer

V= 2.04 Km/s

V1= 2.3 Km/s

Vr= 1.84 Km/s

SP-6



1st Layer

V= .54 Km/s

Zl= 10.4 m Zr= 8.4 m

Dip12= 1.7

2nd Layer

V= 1.96 Km/s

Vl= 2.18 Km/s

Vr= 1.78 Km/s

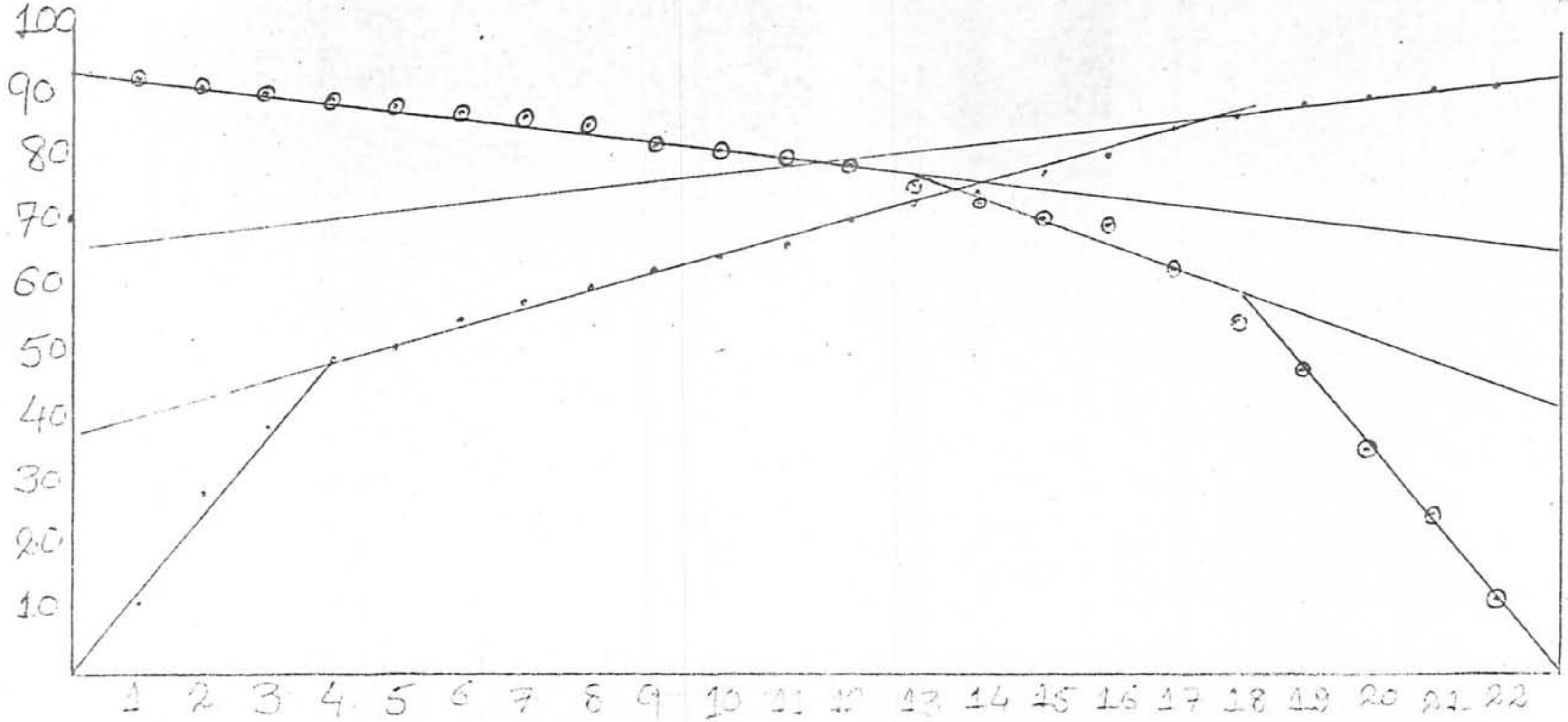
PLOTTING BY HAND

SP1

V_0d = 405.4 m/sec
V_1d = 1777.7 m/sec
V_2d = 4000 m/s
T_1d = 0.037 sec
T_2d = 0.065 sec
H_0d = 7.87 m
H_1d = 23 m

V_0True = 410.9 m/sec
V_1True = 1570.3
V_2True = 4097.5 m/sec
$\theta_0 = 4° 49'$
$\theta_1 = -6°$

V_0U = 416.6 m/sec
V_1U = 1406.3 m/sec
V_2U = 4200 m/sec
T_1U = 0.042 sec
T_2U = 0.066 sec
H_0U = 8.9 m
H_1U = 19.8 m

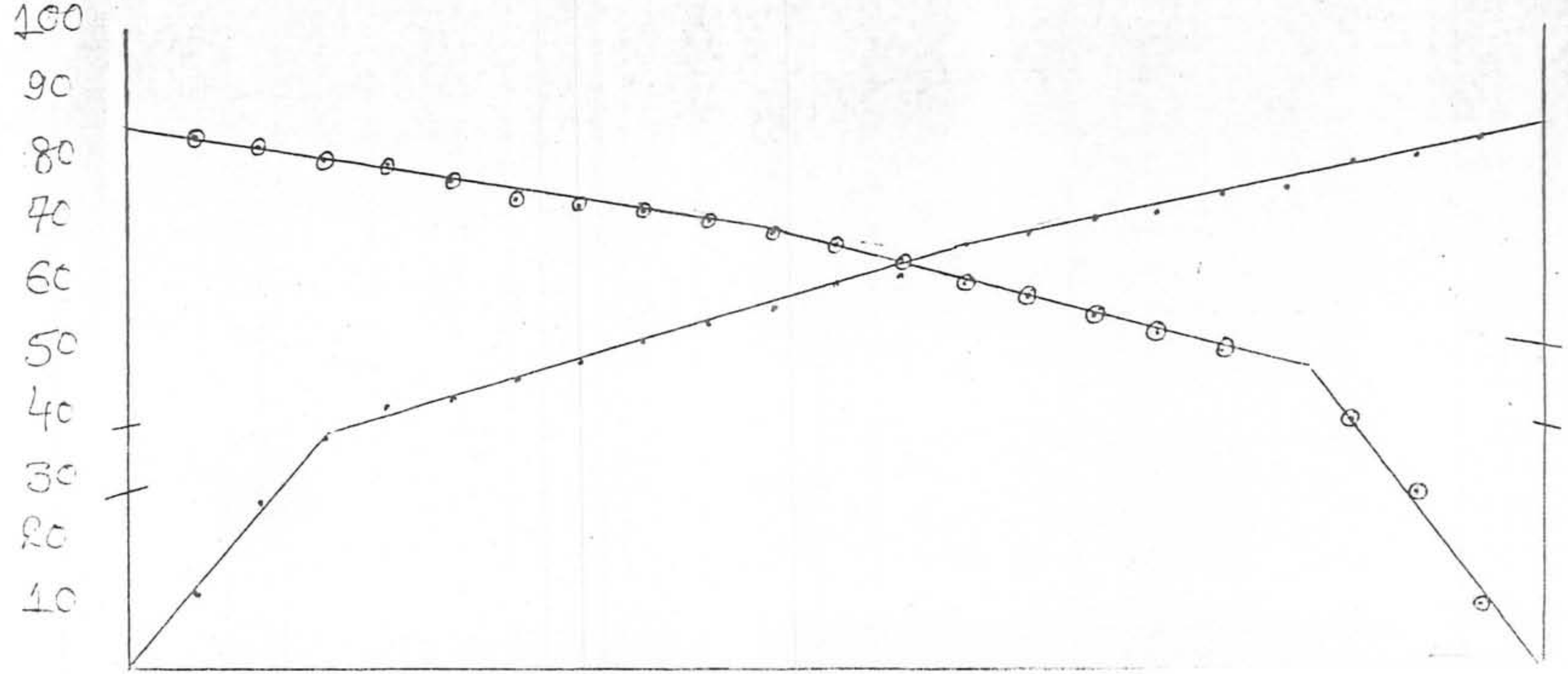


SP-2

V_{0d} = 416.6 m/sec
V_{1d} = 1718.5 m/sec
V_{2d} = 2340.4 m/sec
T_{1d} = 0.028 sec
T_{2d} = 0.038 sec
5.82 m
14.7 m

V_0 True = 405.3 m/sec
V_1 True = 1848.6 m/sec
V_2 True = 2715.9 m/sec
$\theta_0 = -58'$
$\theta_1 = 6^\circ 14'$

V_{0u} = 394.7 m/sec
V_{1u} = 2000 m/sec
V_{2u} = 3235.2 m/sec
T_{1u} = 0.038 sec
T_2 = 0.051 sec
H_{0u} = 7.89 m
H_{1u} = 17.7 m

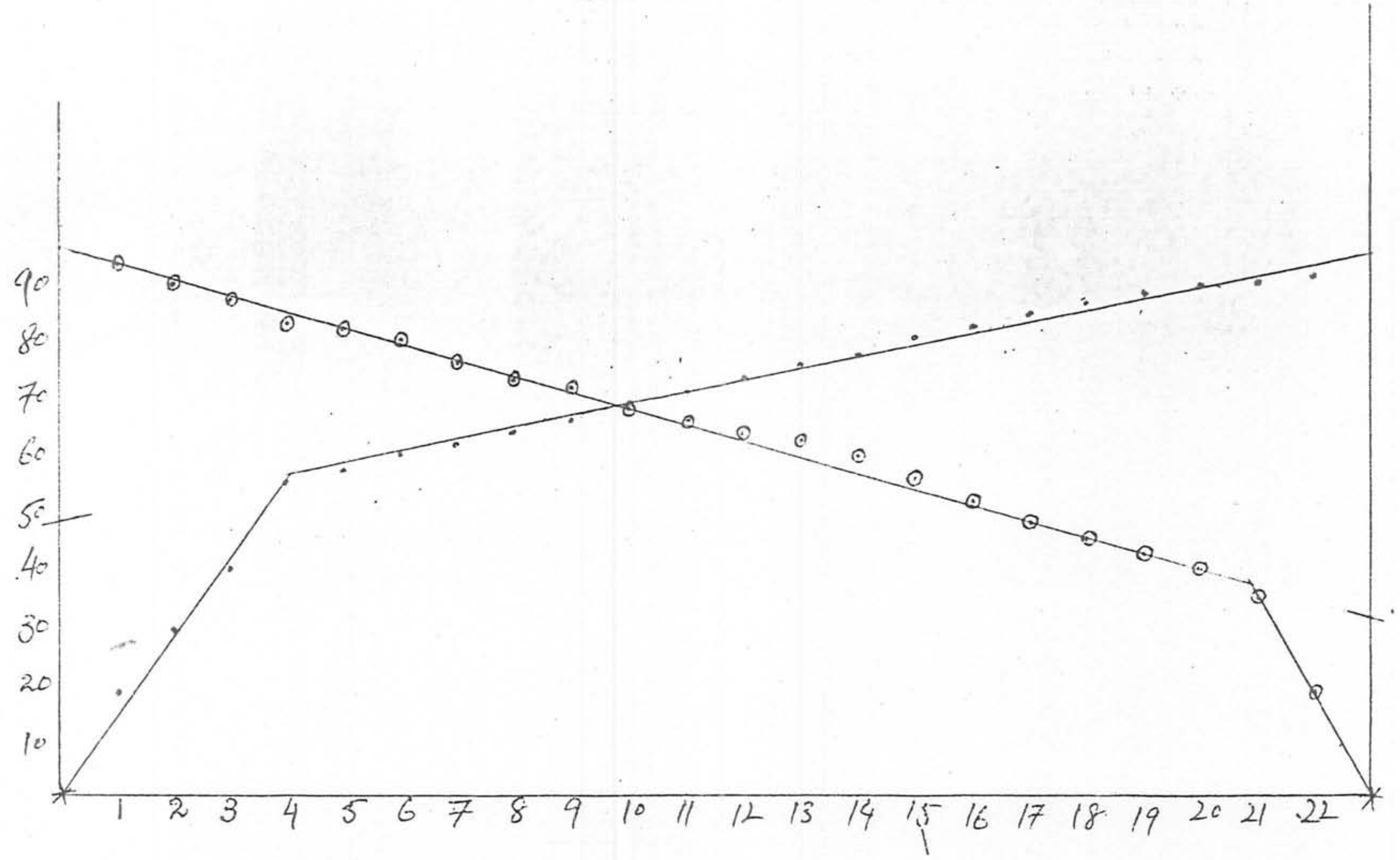


SF-5

$V_0u = 357.1$ m/sec
$V_1u = 2361.1$ m/sec
$T_1u = 0.048$ sec
$H_0u = 7.71$ m

$V_0True = 317.4$ m/sec
$V_1True = 2038$ m/sec
$\theta_0 = 1° 14$

$V_0d = 285.7$ m/sec
$V_1d = 1793.4$ m/sec
$T_1d = 0.032$ Sec
$H_0d = 5.14$ m.

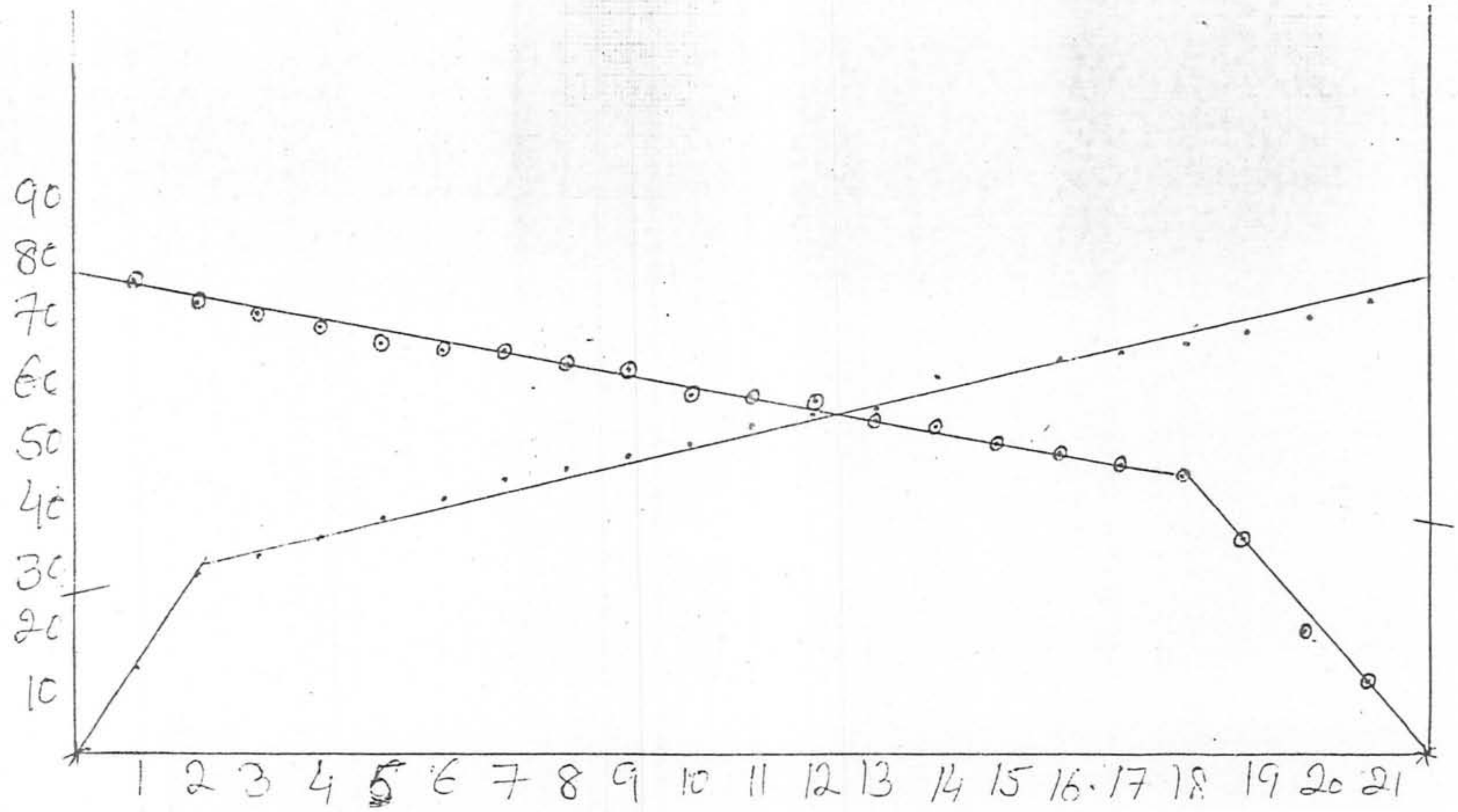


SP-4

$V_{od} = 357.5$ m/sec
$V_{1d} = 2129.6$ m/sec
$T_{1d} = 0.025$ sec
$H_{od} = 4.98$ m

$V_{0\,True} = 393.47$ m/sec
$V_{1\,True} = 2372.7$ m/sec
$\theta_0 = 4°6'$

$V_{ou} = 437.5$ m/sec
$V_{1u} = 2678.57$ m/sec
$T_{1u} = 0.037$ sec
$H_{ou} = 7.38$ m

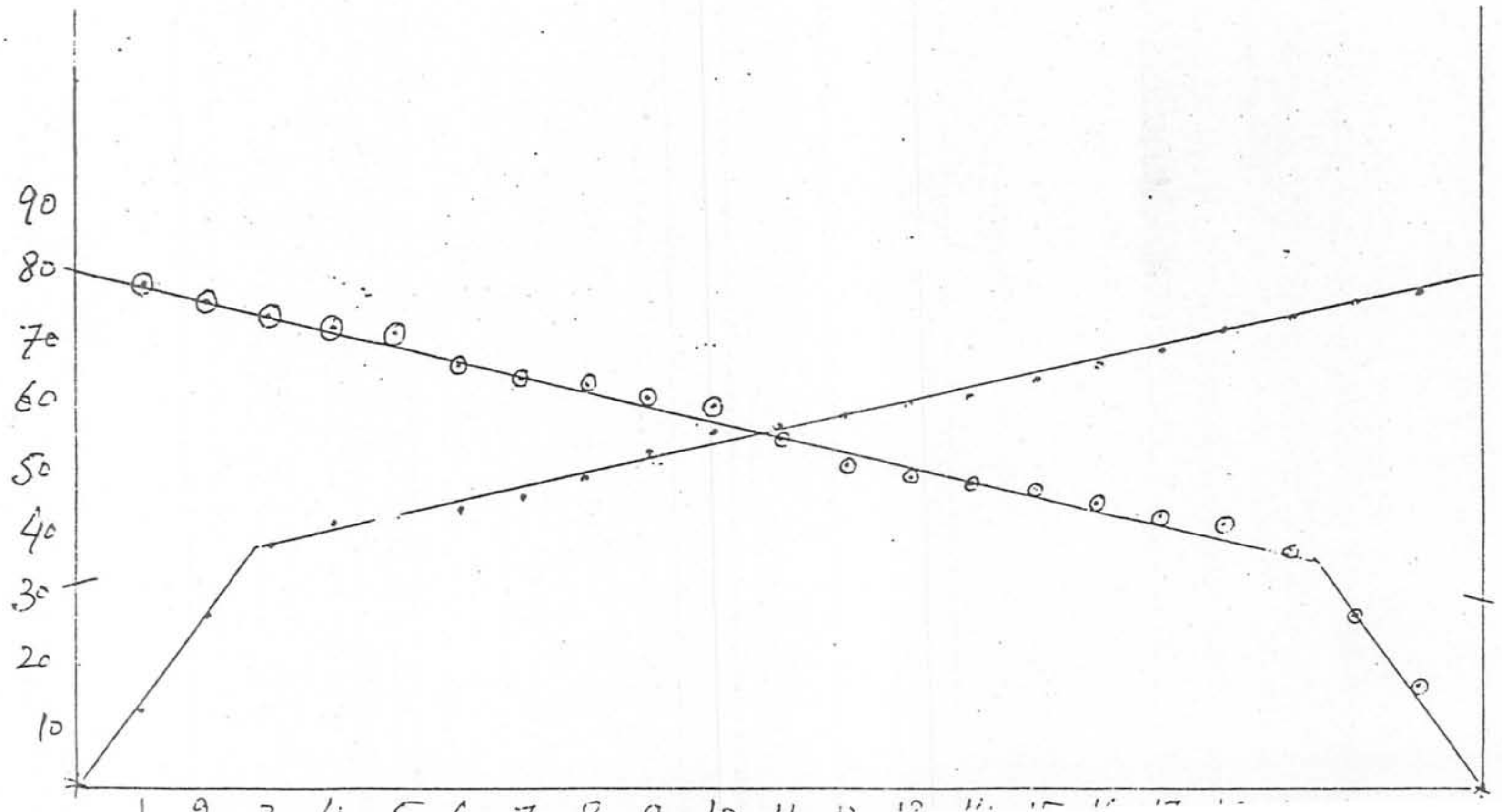


SP5

Vou = 384.6 m/sec
V1u = 2083.3 m/sec
T1u = 0.031 sec
Hou = 5.9 m

VoTrue = 377.4 m/sec
V1True = 2189 m/sec
θo = 12′

Vod = 370.4 m/sec.
V1d = 2162.2 m/sec
T1d = 0.029 sec
Hod = 5.6 m.

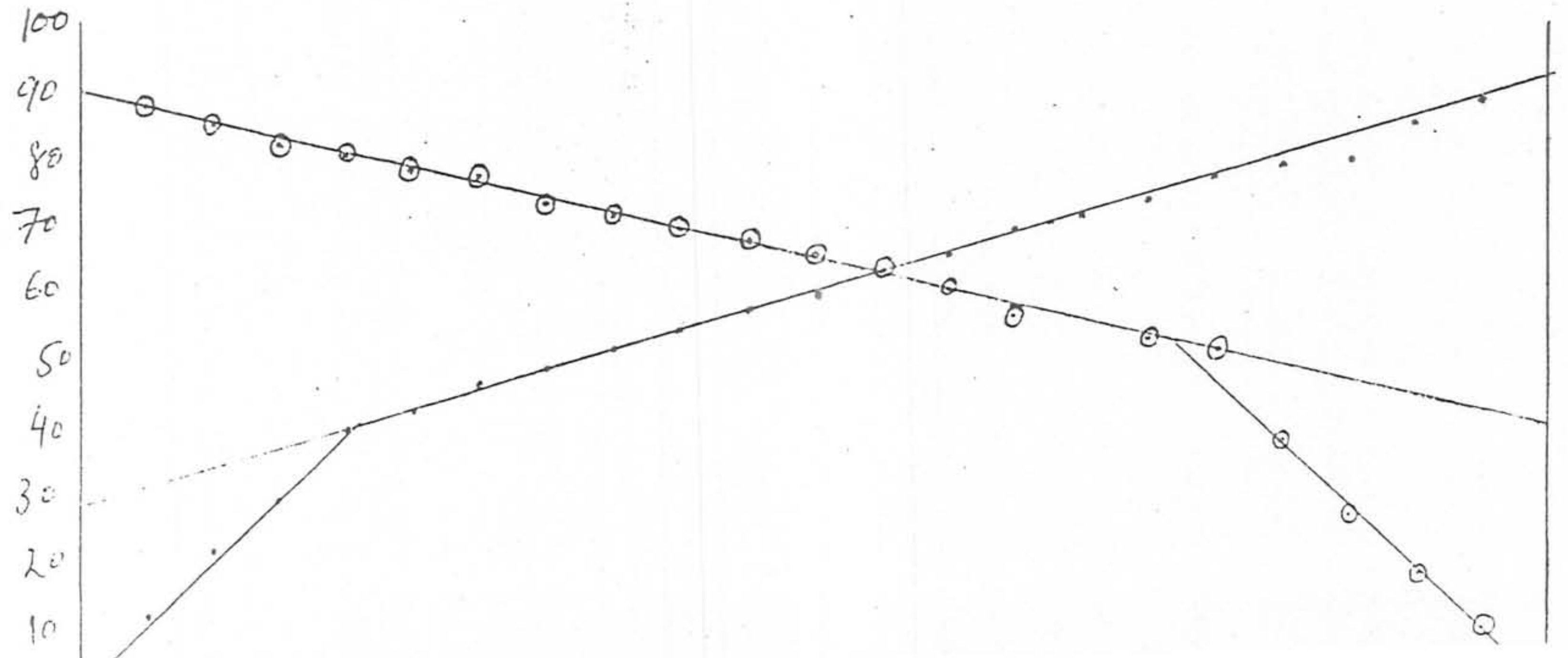


SP-26

$V_{od} = 519.4$ m/sec
$V_{1d} = 1707.3$ m/sec
$T_{id} = 0.027$ Sec
$H_{od} = 7.42$ m

V_0 True = 582.3 m/sec
V_1 True = 1909.7 m/sec
$\theta_0 = 1^\circ 57'$

$V_{0u} = 537.6$ m/sec
$V_{1u} = 2166.6$ m/sec
$T_{1u} = 0.040$ Sec
= 11 m



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